Small and Mighty: Why forage fisheries management could benefit from an ecosystem based framework.
A case study of the Southwest Nova Scotia/Bay of Fundy Atlantic herring stock component.

By

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

at

Dalhousie University
Halifax, Nova Scotia

December 2016

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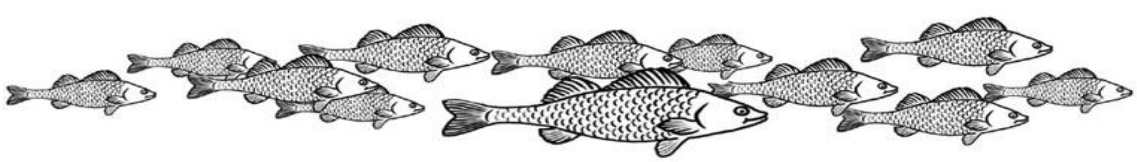

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Abbreviations

BoF: Bay of Fundy

CPUE: Catch Per Unit Effort

DFO: Fisheries and Oceans Canada

EAFM: Ecosystem Approach to Fisheries Management

EBFM: Ecosystem Based Fisheries Management

EBM: Ecosystem Based Management

EBSA: Ecologically and Biologically Significant Areas

ICES: International Council for the Exploration of the Seas

IFMP: Integrated Fisheries Management Plan

ITQ: Individual Transferable Quota

LRP: Limit Reference Point

MPA: Marine Protected Areas

MSY: Maximum Sustainable Yield

NAFO: North Atlantic Fisheries Organization

SWNS/BoF: Southwest Nova Scotia/Bay of Fundy

TAC: Total Allowable Catch

URP: Upper Reference Point

Acknowledgements

I would like to firstly thank my supervisors Ramon Filgueira and Laura Hussey-Bondt. Ramon thank you for agreeing to take me on despite your lack of intensive knowledge on forage fish and herring. Your guidance and enthusiasm in conducting and writing a graduate research paper have been a huge help. Laura Hussey-Bondt, thank you for agreeing to take me on despite your busy demanding schedule at DFO. This paper would never have been possible without your insight and extensive knowledge on the herring fishery. Thank you to both of you for working with me to make this project the best it can be. Similarly, I would like to thanks Dr. Robert Stephenson for accepting to be my second reader on the paper. Your insight and knowledge of herring will be greatly appreciated.

Secondly, thank you to my second reader Dr. Robert Stephenson for agreeing to read this manuscript and provide feedback. Your expertise on these small and mighty fish were greatly appreciated.

I would like to thank the MAP 2015/2016 class. Misery loves company and without being surrounded by all of the misery in writing our individual graduate projects, I would not have made it. It truly does help having 18 other people around who can completely understand the agony and frustrations of the writing process. You have all helped to expand my mind and world view. Where ever the ocean takes us all, I'm glad it also connects us.

To the MAP faculty, thank you for all of your encouragement and resources throughout the program. We would have never been able to do this without you.

Liz Wilson, thank you for your words of encouragement and guidance over numerous dinners and meetings.

I would also like to thank my internship host WWF-Canada and Sobey Fund for Oceans for allowing me the opportunity to use my research in a meaningful way towards your Food for All initiative. Special thanks to my internship supervisor Aurelie C. Godin for her assistance and encouragement throughout the internship. Your knowledge and expertise were greatly appreciated. Likewise, I'd like to thank the whole Oceans team at WWF-Canada for making me feel like part of the team. Continue to fight for the oceans and especially the little fish!

Finally, thank you to my friends and family for allowing me to talk your ear off about a small fish. Although none of you knew what a forage fish was before I started, thank you for taking this journey with me and helping me think things through aloud. To all of you, your love and support mean the world to me.

Gardiner, J. 2016. Small and Mighty: Why forage fisheries management could benefit from an ecosystem based framework. A case study on Bay of Fundy/Southwest Nova Scotia herring stock component [graduate project]. Halifax, NS: Dalhousie University.

Abstract

Forage fish are defined as low to mid-trophic level species that are preyed upon by many top predators within their respective ecosystems. The dependence on these forage fish from top predators makes them a crucial link between autotrophs and predators within an ecosystem. It has been suggested that forage fish species are more valuable in the water, acting as support for these top predators, than being directly fished for other uses such as human consumption, bait or fish meal/oil. In Nova Scotia (Canada), many lobster fishers rely heavily on forage fish species as bait within lobster traps. Forage fisheries within Atlantic Canada include Atlantic herring (*Clupea harengus*), mackerel (*Scomber scombrus*), and capelin (*Mallotus villosus*). The current management of these fish in Canada is based on single species assessments. However, due to forage fish's unique interactions with both their ecosystems and other fisheries, a management plan that focuses on these interactions is crucial for ecosystem sustainability. Accordingly, this project assessed the current single species management of these forage fisheries using a holistic analysis on a case study of the Southwest Nova Scotia/Bay of Fundy herring stock component. This holistic analysis assessed factors within a political, economic, socio-cultural, technological and environmental framework through a PESTE analysis. From this analysis, the strengths, weaknesses, opportunities and threats within the current management regime were determined. Using these opportunities and threats, a gap analysis was conducted to identify the feasibility of alternative ecosystem based management frameworks for forage fisheries.

Keywords: forage fish; ecosystem based fisheries management; Canada; Nova Scotia; herring; fisheries management; sustainability; PESTE analysis; SWOT analysis.

1.0 Introduction

The term forage fish is an umbrella term used to describe low to mid-trophic level, small schooling fish species (Pikitch et al., 2012). These species of fish are critical links in the marine ecosystems they inhabit as they act as the main link between autotrophic plankton and large predators. Many of these larger predators are dependent on these forage fish for food (Guenette, Melvin & Bundy, 2014). In addition to the high importance to upper trophic level species, in some ecosystems, forage species have a "wasp-waist" effect (Cury et al., 2000). This effect occurs when a large amount of species within the top and lower trophic levels are linked by a single or few mid-trophic level species. In addition, "wasp-waist" species are usually not only the major link but also have both a bottom up and top down control on their preys and predators, respectively (Cury et al., 2000; Guenette et al., 2014). As the preferred prey of many larger marine animals such as predatory fish, marine mammals and seabirds, as well as their unique wasp-waist control, forage fish species are crucial for ecosystem functioning. Forage fish species that are of relative importance in Canada include mackerel (*Scomber scombrus)*, capelin (*Mallotus villosus)*, and Atlantic herring (*Clupea harengus)*.

Forage fish are also commonly referred to as 'bait fish' (Pikitch et al., 2012) due to their large role as bait for many commercial fisheries, such as lobster and snow crab (Harnish & Willison, 2008). Many forage fish species have large oil and fat contents within their meat, making them highly attractive for use as bait. This high fat content also makes them a great candidate for use in fish meal and fish oil for aquaculture and farm feed purposes (Alder & Pauly, 2006). Finally, these forage fish are also sold for direct human consumption as a variety of products (Cashion, 2016). Many communities within developing countries rely on these products of forage fish for their main source of animal protein (Alder & Pauly, 2006). Therefore, forage fish are crucial for food security in a variety of outlets.

Forage fish's schooling behavior makes their catchability high and makes them easy to target, so that operational costs of the fishery are relatively cheap compared to other commercial fisheries (Alder & Pauly, 2006). In addition, the global trade of forage fish products puts a high amount of pressure on these fisheries (Alder & Pauly, 2006). Forage fish stock abundance seem to fluctuate mostly because of environmental factors (Alder & Pauly, 2006; DFO, 2015; Rountos, Frisk & Pikitch, 2015), but recent studies have started to show concern regarding the impacts fishing efforts have on these stocks (Pikitch et al., 2012; Guenette et al., 2014). Due to their crucial links in both food security and ecosystem functioning, it is important that the fishing of these species is done sustainably.

1.1 The Management Problem

Most fisheries in Canada, including the herring fishery, are managed on a single species basis through Integrated Fisheries Management Plans (IFMPs) (DFO, 2013b). These IFMPs outline the management approach for each individual fishery, including information on quotas, seasons, and fishing gear. Many IFMPs are set as 'evergreen' plans that remains in place until a change is required. These IFMPs should be updated annually, in relation to science, traditional ecological knowledge, and industry data for appropriateness and potential changes (DFO, 2013b). The IFMP is a tool to help DFO achieve its management objectives for a fishery by documenting the best approaches and considerations to be taken. These IFMPs consider different ecological, economic and social aspects, as well as stakeholders of the fishery from consultations held by DFO regarding the ecological and socioeconomic factors.

Within these IFMPs, Canadian fisheries follow a precautionary approach that was developed by DFO according to the United Nations Fish Stock Agreement (United Nations, 1995) that Canada ratified in 1999. This agreement has been in effect since 2001 although the current precautionary approach framework for Canadian fisheries was developed in 2005 (DFO, 2006). The precautionary approach can be defined as managing resources in a way that prevents serious harm and irreversible damage and uses caution when there is scientific uncertainty (DFO, 2006). For DFO fisheries management, this approach has been applied by creating three stock zones: critical, cautious and healthy (Figure 1).

The healthy zone is defined as when the stock status is above the upper reference point (URP) and is thus considered sustainable (DFO, 2006). When a stock is within this healthy zone, no major fisheries management adjustments need to be made. The cautious zone is defined as when the stock falls between the URP and the limit reference point (LRP). When a stock is in this cautious zone, rebuilding actions should be considered to help increase the stock back to the URP. Finally, the critical zone within this framework is defined when the stock has gone below the LRP. At this point, management must promote stock rebuilding by keeping the removals low. The objectives of this framework are to keep fishery management in Canada in line with international agreements and fishery stocks sustainable (DFO, 2006).

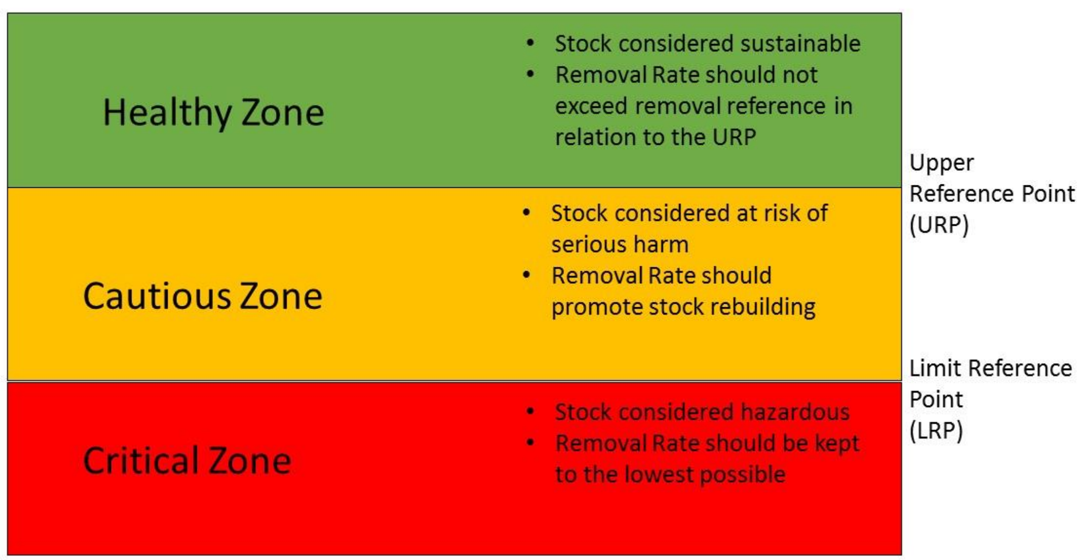


Figure 1. Harvest strategy zones for DFO's fisheries management. Adapted from DFO 2006.

Although the above-mentioned stock zones have been applied to the fishery though a precautionary approach, the reference points and assessments are based strictly on the herring and do not take into consideration ecosystem implications given the single-species approach. In a study conducted by Pikitch et. al. (2012), it was estimated that forage fisheries management globally is not conservative enough in regards to their respective ecosystem services for other species. Therefore, the purpose of this project is to assess the current forage fisheries management in Canada to find areas where it can improve. To accomplish this, a case study of the Southwest Nova Scotia/Bay of Fundy (SWNS/BoF) spawning stock of the Atlantic Herring fishery in North Atlantic Fisheries Organization (NAFO) divisions 4VWX was chosen. This spawning stock was chosen due to its high economic importance, as well as its long history in Canada (Stephenson, Lane, Aldous, & Nowak, 1993).

This research project thus sets out (1) to assess the weaknesses and strengths within Canada's current management plan for forage fisheries using the SWNS/BoF herring fishery as a case study, and (2) to explore alternative management frameworks that could address these weaknesses and fill gaps within the current management framework.

1.2 Research Question and Project Purpose

Forage fish are highly interconnected within their ecosystems. They have a large role in the dynamics of many trophic levels and fisheries in their regions. Accordingly, forage fish sustainability is crucial to the overall sustainability of the ecosystem. Within the past few years, there have been many suggestions for a more holistic approach to management of forage fish due to these reasons (Bakun, Babcock & Santora, 2009; Cury et al., 2011; Guenette & Stephenson, 2012; Pikitch et al., 2012). The purpose of this study is thus to answer the following research question: Using SWNS/BoF herring stock as a case study, **What is an appropriate framework for management of forage fish within Canada?**

2.0 Methodology

Fisheries management is known as a wicked problem (Jentoft & Chuenpagdee, 2009). A wicked problem is one that is not easily defined and/or solved and has no definite origin of conflict. These problems can arise from both social and ecological aspects and thus need to be approached with a variety of solutions. As such, it is important to understand the full socio-ecological environment within which a management plan is working. In a study conducted by Levin, Francis, and Taylor (2016), a participatory process was used to create a conceptual model for herring fisheries in the Pacific to determine the socio-ecological environment within which these fisheries were working. The model combined both herring sustainability and human well-being as the focus. From this process, 32 questions were created that need answering in order to fully understand a fisheries system (Appendix I). From these questions, there are five different components found to play a role in the herring fishery: 1) climate and oceanographic components, 2) socioeconomic components, 3) institutional structure and governance 4) human activities and 5) habitat and biological components. This process emphasized that the fishery is an integrated body that cannot just be addressed from a strict fisheries science approach but should include multiple disciplines within natural and social sciences. Thus for this research on the management for the Atlantic herring fishery in Southwest Nova Scotia/Bay of Fundy (SWNS/BoF) region, a PESTE/SWOT analysis was conducted. This method for analysis will allow for political (P), economic (E), social (S), technological (T) and environmental (E) factors (PESTE) of the fishery to be analyzed, giving the analysis a holistic approach. These factors were then categorized as either a strength (S), weakness (W), opportunity (O) or threat (T) (SWOT).

2.1 Case Study: Southwest Nova Scotia/Bay of Fundy Herring Fishery

For this study, the Southwest Nova Scotia/Bay of Fundy (SWNS/BoF) stock component of the NAFO divisions 4VWX herring fishery was assessed as a case study. The SWNS/BoF component is one of the larger stock components of the fishery with the area spanning waters off southwestern Nova Scotia (west of Baccaro Point) and the Bay of Fundy. Herring have unique and complex population dynamics and thus each managed stock complex, in this case the 4VWX, is comprised of stock components (Stephenson, Melvin & Power, 2009). This stock component is comprised of three main spawning grounds: German Bank, Scots Bay and Trinity Ledge (Figure 2). Although the herring from each stock component are known to mix in the same area, there is a homing mechanism that brings them back to discrete spawning areas to spawn every year (Stephenson et al., 2009).

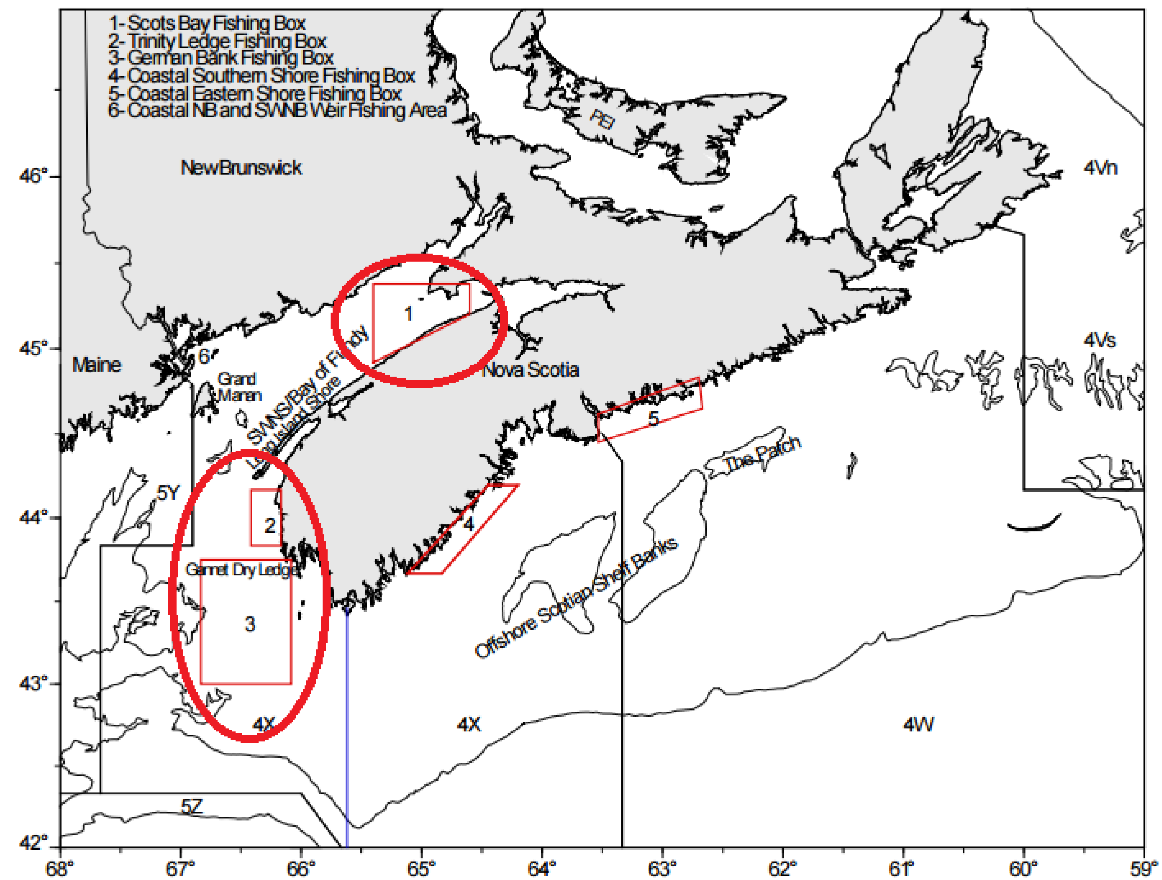


Figure 2. Spawning grounds for fishery outlined in red. Adapted from DFO 2016.

2.1.1 The Fishery

The herring fishery is one of the oldest fisheries in this area (Stephenson et al., 1993). Believed to have begun before the landing of European settlers, the fishery mainly used fixed fishing gear in the form of inshore weirs. Today, the fishery has two categories of fishing gear: mobile and fixed. The mobile gear sector is much more prominent in the area than the fixed gear, and is allocated about 80% of the quota each year (DFO, 2016).

In addition to the herring fishery, the SWNS/BoF area is also a host to many other sectors including lobster fishing, scallop fishing, transportation, tidal energy exploration, aquaculture and ecotourism. Many of these sectors interact directly with the herring fishery. For example, the lobster fishery uses herring as bait within their traps (Harish & Willison, 2008), and the ecotourism industry relies on the Bay of Fundy as a feeding ground for many migratory marine mammals and seabirds, many of which consume large amounts of herring (Bakun et al., 2009). Thus, it is important for not only the herring fishery and the ecosystem, but also for the other sectors within the Bay of Fundy, to manage the herring conservatively.

2.1.2 Herring Biology

Herring are small schooling forage fish that create dense aggregations within various places of the Gulf of Maine (Bigelow & Schroeder, 1953). Although there is evidence of populations mixing among each other during migrations between spawning and overwintering grounds, there are clear spawning grounds for different spawning stock components, as herring are known to have a homing mechanism (Stephenson et al., 2009). In SWNS/BoF region, these spawning grounds include: German Bank, Scots Bay, and Trinity Ledge (Figure 2).

Herring become sexually mature around 4 years of age (Bigelow & Schroeder, 1953). Classified as iteroparous, they can spawn multiple times over the course of their lifetime. Most herring spawn annually, releasing 40,000 eggs on average (Bigelow &Schroeder, 1953). It is estimated that the timing of herring spawning events is related to plankton blooms in the area (Sinclair & Tremblay, 1984). For SWNS/BoF there are two distinct spawning seasons: fall and spring, with the majority of herring spawning in the fall (Kornfield, Sidell & Gagnon, 1982). The eggs that are secreted by herring create a large mat like structure that sinks and sticks to the pebble, rock or gravel type substrate (Bigelow &

Schroeder, 1953). These structures have been found between depths of 5 meters to 55 meters (Bigelow & Schroeder, 1953). Within 7-10 days of spawning, eggs begin to hatch into larvae. Herring larvae contain a yolk sac until they are about 10 mm in length. (Bigelow & Schroeder, 1953). Once the yolk sac is diminished, the larvae preys on plankton species within the water column. At the length of about 40 mm, the larvae begins to take on a more adult herring shape and appearance and becomes a juvenile herring.

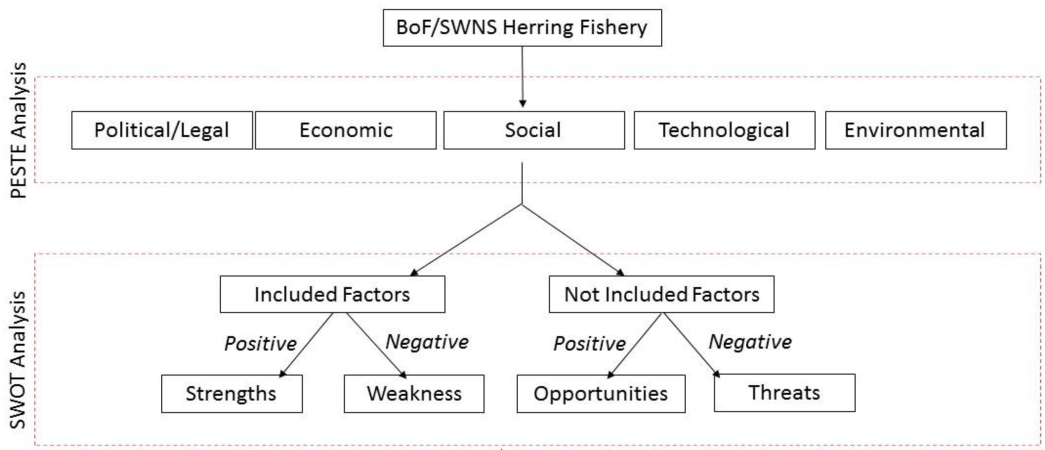
2.2 PESTE/SWOT Analysis

A PESTE analysis is a tool that can be used for multi-criteria decision making, such as decisions pertaining to fisheries management (Srdjevic, Bajcetic, & Srdjevic, 2012). It identifies factors of a particular system and how these factors have, can and will impact it (Srdjevic et al., 2012). For this study there are five different categories for factors that were assessed: Political/Legal (P), Economic (E), Socio-cultural (S), Technological (T) and Environmental (E). These factors were chosen based on the 32 questions created from Levin et al. 2016 (Appendix I).

After the factors for each component were defined for the PESTE analysis, a SWOT analysis (strengths, weaknesses, opportunities and threats) was conducted to help determine if the factor was included or not included within the current management plan, and whether it had a positive or negative impact on the management of the fishery (Figure 3). Accordingly, each factor was assigned to one of the following four categories:

- I+ (included already within management, positive influence; strength)
- NI+ (not yet included within management, positive influence; opportunity)
- I- (included within management, negative influence; weakness)
- NI- (not included in management, negative influence; threat).

The results from this analysis were then used to indicate what is missing or should be removed within the current fisheries management plan to help improve the management of herring fisheries in this area, and more broadly forage fish fisheries in Canada. To conduct the PESTE/SWOT analysis, a literature review was completed to help give insight on the chosen factors in table 1. These influences, which were chosen based on the 32 questions created by Levin et al. (2016), surrounded the subjects of broad social, political and economic forces, human activities, climate, habitat, institutional and governance factors, herring and the herring food web, and human well-being (Appendix I).



SWOT Analysis Classification	Included Factors	Not Included Factors
Positive	I+	NI+
Negative	I-	NI-

Figure 3. Scoring the results of the PESTE/SWOT analysis. Adapted from Srdjevic et al. (2012).

2.2.1 Political/Legal Factors

Factors considered in this scope were those concerning the management framework applied to the herring fishery, relevant Acts and Regulations, as well as umbrella policies put forth by the DFO for fisheries in Canada. By assessing the political and legal factors of the fishery, the root cause of decision making within the fishery could be addressed. It can also assess how the political and legal system can hinder or enhance fishery management.

2.2.2 Economic Factors

Factors considered within this component revolved around the economic value of the fishery. Examples of influences considered were the amount of herring landed for the SWNS/BoF stock each year, the various uses of herring products, how much herring was exported and the cost per kilogram of herring in Nova Scotia. By assessing these economic factors of the fishery, it can be determined whether the use of a dollar value in decision making will help strengthen or weaken the management decisions.

2.2.3 Socio-cultural Factors

Factors considered in this category are to assess the human component of the fishery system. Examples of influences are the number of fishing licenses and people involved in the fishery, the allocation of quota to different fishing methods, and the culture behind the fishery. Due to fisheries being an industry that involves people and their livelihoods, the human components should not be ignored within management decisions.

2.2.4 Technological Factors

Technological factors are considered to assess how technology has changed and can change the fishery and thus management decisions. This assessment will address how the fishery has changed over time with new technological advances, how these technologies have changed the catch per unit effort (CPUE), and how survey methods and assessments have changed.

2.2.5 Environmental Factors

A large amount of the PESTE analysis will be assessing the natural environment. As fishing extracts fish from the natural ecosystem, it is important that our management of these activities understands and takes into consideration all of the ecosystem factors associated with this removal. These influences include: physical oceanographic conditions such as temperature, biological components such as life history traits of herring, and ecosystem components such as predator abundance and foraging. Due to herring's large influence on the local ecosystem and food web, it is important to take into consideration the environmental factors that impact the fishery to ensure the fishery is managed from a holistic approach.

2.3 Gap Analysis of Alternative Management Frameworks

The PESTE/SWOT analysis was designed to identify relevant factors that could be either included or removed within the current fisheries management approach for the SWNS/BoF herring fishery. The PESTE/SWOT was followed by a gap analysis to assess whether the gaps in the current management plan for the SWNS/BoF herring fishery (scores of NI+) could be filled by using alternative ecosystem based management frameworks. The gap analysis was summarized in a matrix in which the gap factors (NI+) and other included strengthening factors (I+) were coded using a stop light approach ranking management frameworks as green, yellow, red or black for feasibility of implementation. Green ranked factors are those that are included within the management framework already and would be easy to implement. Yellow ranked factors are those that are not included within the management framework but would be simple to implement given the current governance structures, policies and available information. Red ranked factors are those that are not included within the management framework and would be difficult to implement within it given the current governance structures, policies and available information. Finally, black ranked factors are those that cannot be fully included within the definition of the framework. The purpose of the gap analysis is to determine the most feasible ecosystem approach framework for forage fisheries in Canada.

There were three ecosystem management frameworks assessed: ecosystem based management, ecosystem based fisheries management and ecosystem approach to fisheries management as defined by Patrick and Link (2015) (Table 2).

Table 2. Definitions of each ecosystem management framework as defined by Patrick & Link (2015).

Management Type	Current Fisheries Management	Ecosystem Based Management	Ecosystem Based Fisheries Management	Ecosystem Approach to Fisheries Management
Definition	Takes into consideration one specific fisheries stock.	Takes into consideration multiple fish stocks, other industries, and environments they interact with.	Takes into consideration multiple fish stocks in one region and the physical environment it interacts with.	Takes into consideration one specific fisheries stock and the physical environment it interacts with.
Considered in Stock Assessment	Assesses only the health and abundance of defined stock	Assesses physical, social and economic environments of each sector.	Assesses physical environmental factors such as climate, habitat and predators.	Assesses physical environmental factors such as climate, habitat, and predators.

3.0 Results

A total of 24 factors were reviewed in the context of the PESTE/SWOT analysis (Table 1). 15 of these factors were already considered within the current management plan for the SWNS/BoF herring stock, including, eight political/legal factors, four economic factors, three sociocultural factors, three technological factors and six environmental factors.

3.1 PESTE/SWOT Analysis Results

Table 1. Results of the PESTE/SWOT analysis for the Bay of Fundy/Southwest Nova Scotia herring stock. NI (not included), I (included), + (strength/opportunity), - (weakness/threat).

Political/Legal	Effect	**Economic**	Effect
1. Fisheries Act	1. I+	1. Landings of SWNS/BoF Stock	1. I+/NI+
2. Oceans Act	2. I+	2. Uses and Markets for Herring	2. NI+
3. Atlantic Fishery Regulations	3. I+	3. Exports of Herring	3. NI+
4. Fishery (General) Regulation	4. I+	4. Price Per Kilogram of Herring (Province)	4. I-/I+
5. Structure of DFO	5. I+		
6. Herring Advisory Committee Meeting	6. I+		
7. DFO's Precautionary Approach Framework	7. I+/NI+		
8. Policy on New Fisheries for Forage Species	8. NI+		
Sociocultural	Effect	**Technological**	Effect
1. Number of licensed fishers that are active	1. NI+	1. Changes in fishing technology over time	1. I+
2. Types of fishing	2. I+	2. Catch per unit effort changes	2. NI-
3. Culture of fishery	3. I+	3. Survey and assessment methods	3. I+
Environmental	Effect		
1. Temperature changes	1. NI+		
2. Prey abundance	2. NI+		
3. Dependence of top predators	3. NI+		
4. Spawning Grounds	4. I+/NI+		
5. Ecologically Important Areas in BoF	5. NI+		
6. Life History Traits	6. I+		

3.1.1 Political/Legal Component

There were eight factors analyzed within the political/legal component of the PESTE analysis. In total, four different legislative factors were considered: the *Fisheries Act,* the *Oceans Act,* the *Atlantic Fishery Regulations,* and the *Fishery (General) Regulations.* Once the legal factors of fisheries management in Canada were assessed, the structure of Canada's authoritative body for fisheries management, DFO, and the Herring Advisory Committee Meeting for the fishery was considered for analysis. Finally, two DFO policies were analyzed in relation to the herring fishery: *A Fishery Decision-*

Making Framework Incorporating the Precautionary Approach (DFO's Precautionary Approach Framework) and *The Policy on New Fisheries for Forage Species.*

Before an analysis of the management of a fishery can be conducted, it is important to understand the legal premise a management plan is created from. *The Constitution Act* is the overarching legal document that all laws in Canada are based under. *The Constitution Act* was established in 1867 and allowed the provinces to be governed under one governing body, with jurisdictional power defined for different sectors within Canada. In section 91 of the Act, it is stated that the Federal government has jurisdictional power over "Sea Coast and Inland Fisheries" (The Constitution Act, 1867, S. 91). This allows the Federal government to create and regulate fisheries across the country. To further facilitate this process, the *Fisheries Act* was created. This is one of the oldest pieces of legislation in Canada regarding conservation, dating back to 1868 (Bailey et al., 2016). The purpose of this Act is to help ensure that fisheries across the country are managed with the same intent. The various sections within the *Fisheries Act* describe general laws of fisheries including authority, licensing needs, sales, pollution of fish habitats, blocking of waterways, and how fishing limits and allocations are created, among other components. Pertaining to forage fisheries, and the herring in particular, there is one noteworthy section:

S. 31 – This section of the Act, forbids the creation of a reduction fishery. A reduction fishery, is a fishery that targeted fish specifically to reduce it to fish meal, fish oil and fertilizer. Prior to this section of the act in 1985, there was a prominent reduction fishery for herring (Cashion, 2016). This amendment of the *Fisheries Act*, thus changed the market for herring in this area and the fishery's catch and processing methods.

Another piece of legislation that impacts Canada's oceans is the *Oceans Act*. Similar to the *Fisheries Act,* this act allows the federal government to govern and regulate the actions within Canada's oceans. Throughout the Act it is stated that there is a need for integrated sustainable development in regards to Canada's oceans and that the precautionary principle should be practiced when applicable

(*Ocean's Act,* 1996). In relation to herring fishery management, there are two sections that should be noted:

S. 30 – This section lays out principles of a strategy for development within Canada's oceans. There are three key principles that should be abided when using Canada's oceans: sustainable development, integrated management of activities and the precautionary approach. These principles are partly considered within management decisions of the herring fishery.

S. 31 – This section calls for integrated management plans to be created for activities that affect the "estuaries, coastal waters and marine waters that form part of Canada." Following this Act, DFO began to create IFMPs in 2002 for its fisheries, including the Atlantic herring.

From the *Fisheries Act's* legislative authority, there are two regulations that were established that should also be considered when analyzing the political and legal components of herring fishery management: the *Fishery (General) Regulation,* and the *Atlantic Fishery Regulations, 1985.* These regulations expand on the *Fisheries Act* to directly guide and manage specific fisheries. For example the *Fishery (General) Regulations* provides specifics for fisheries in Canada in general such as defining procedures for weighing fish, defining the ability to set conditions of licenses and observer requirements. This regulation is more nationally focused than the *Atlantic Fishery Regulations, 1985*. The *Atlantic Fishery Regulations, 1985,* provides specifics on how to obtain a license, what gear can be used at different times, and other specifics of the herring fishery. Through these regulations, the *Fisheries Act* is supported in more fishery specific details.

Overall, the Acts and Regulations pertaining to the herring fishery are included within the fishery management plan and help strengthen the management of the fishery (I+, Table 1). It is in relation to these acts that management decisions are made. These acts and regulations are required to be followed by DFO when managing fisheries.

DFO is the overall governing body of Canada's fisheries (Fisheries and Oceans Canada, 2016). This department of the federal government is responsible for fisheries as well as other ocean activities within Canada. To help further analyze the political factors of the herring fishery's management, it is important to consider the organizational structure of DFO and how decisions are made within this organization. From a historical perspective, the DFO has been shaped and changed many times (VanderZwaag, 1983). Since 1930, there has been a Department of Fisheries within the Canadian government. Between 1930 and 1971 this department changed to include marine and fisheries, and fisheries and forestry. In 1971 the Department joined the Department of the Environment, having one minister overlooking both fisheries and the environment. This quickly changed again in 1979, to two departments: The Department of the Environment and The Department of Fisheries and Oceans (VanderZwaag, 1983), allowing the departments to focus more closely on specific environmental issues.

Today, the Minister of Fisheries and Oceans is the person in power over DFO (Fisheries and Oceans Canada, 2016). The Minister of Fisheries and Oceans has the final say in all decisions made in relation to fisheries as stated in the *Fisheries Act.* However, due to the large amount of fisheries within Canadian waters, DFO has created an organizational structure (Figure 4) that divides the oceans into different regions: Pacific, Central and Arctic, Quebec, Gulf, Newfoundland and Labrador, and Maritimes. For each region there is a Regional Director General (RDG) that is allowed to make decisions and provide guidance on region specific changes in management. For the purpose of the case study, the region that is of interest is the Maritimes region. Each region can be further divided into sectors with specific Regional Directors for each sector. For the case of fisheries management, the sector is Fisheries Management. Under this Regional Director in the Maritimes Region, there is a Director, then a Manager, and then a Senior Advisor. Each Senior Advisor is responsible for a number of fisheries within their region. This is the person who generally develops the first advice on changes to management based on stakeholder, scientific and industry input (Personal Communications, Laura Hussey-Bondt, November 1 2016), as well as working with DFO fisheries management staff in local Area Offices. For the SWNS/BoF herring stock, the Senior Advisor would report (via the Manager and Director) to the RDG for most decisions in the management of this fishery (Personal Communications, Laura Hussey-Bondt, November 1 2016). Allowing decisions in regards to the management of the fishery to be approved by the RDG allows for decisions to be made in a timelier manner, thereby strengthening the management of the fishery (I+, Table 1).

Figure 4. Flow Chart of DFO Organizational Structure. Labels in red represent applicable to herring fishery

As mentioned above, the Senior Advisor of the fishery suggests management changes, taking into account stakeholder input. For the case of the herring fishery, there is an annual meeting of the Scotia- Fundy Herring Advisory Committee. This committee has been around in different forms since 1972 (Stephenson et al., 1993). This meeting brings stakeholders for this fishery together to discuss how to proceed in the next year in regards to management decisions. Stakeholders at the meeting can include DFO scientists, mobile and fixed gear fishers, fishery councils, non-governmental organizations, Aboriginal groups, and tourism representatives. The meetings normally include a presentation from DFO scientists regarding the science behind the fisheries biomass and stock assessment. From these presentations, the stakeholders are allowed to raise any concerns they have with the fishery and propose changes they would like to see to the management plan. This process allows for solutions to fishery based problems to be created and the stock to be assessed annually. During 2016’s meeting, for example, it was proposed that the Total Allowable Catch (TAC) would remain at 50,000 tons but the effort by the mobile fleet would decrease in one area where surveys showed decreases in spawning biomass (Personal Communications, Laura Hussey-Bondt, November 2 2016). The mobile fleet agreed that instead of decreasing the TAC, the fleet would only fish a maximum of four days a week and put a limit on the overall landings for the German Bank fishing area (Figure 2) during the spawning period. This would decrease the overall effort of the fishery in this area and provide a chance for the stock to continue rebuilding. This decision making process is included within the current management framework and is considered a strength as it allows every stakeholder's voice to be heard and a joint solution to be found for present problems within the fishery (I+, Table 1).

Finally, there are two policies that should be considered within this political/legal component: *A Fishery Decision-Making Framework Incorporating the Precautionary Approach* (DFO's Precautionary Approach Framework) and the *Policy on New Fisheries for Forage Species*. These policies are not within Acts nor Regulations and thus there are no legal requirements to follow them within management plans. However, DFO's objective has been to integrate the policies into as many fisheries as possible – the herring fishery being one of them. DFO's Precautionary Approach Framework was introduced to the herring fishery in 2012 (Clark et al., 2012).

DFO's Precautionary Approach Framework is an approach to fisheries management that will apply precautionary action to fisheries when there is scientific uncertainty or unreliability regarding the stock, in order to prevent serious harm to that fishery (Fisheries and Oceans Canada, 2009). There are three key objectives from this framework to help fisheries achieve this approach: control fishing mortality (i.e. TAC), consider all removals from the stock within stock assessments, and define the limit reference point (LRP) and upper reference point (URP) based on relevant stock assessment and ecosystem indicators (Figure 1). Within the SWNS/BoF herring fishery's management these objectives have been slowly introduced into the management regime, with a LRP having been established in 2012.

The TAC for the SWNS/BoF herring fishery has been set on an annual basis since the TAC began in the fishery in the 1970s, and is used as a way of limiting the amount of herring taken from the fishery each year. However, to date, the inclusion of commercial fisheries are the only removals considered for making recommendations for the TAC (DFO, 2016). Two other removals that should be considered in the management plan for the SWNS/BoF herring fishery are the predatory removals of the stock and bait removals. Currently, predatory removals are not explicitly included in setting the TAC but are considered within natural mortality rates of the fishery (Guenette & Stephenson, 2012). It has been argued that the natural mortality estimate for forage fisheries is underestimated in relation to predatory needs (Guenette & Stephenson, 2012). Likewise, bait removals are regulated under an umbrella license for mackerel and herring (Harnish & Willison, 2008) and not currently accounted for against the SWNS/BoF TAC. This creates inaccurate numbers for removal estimates against the TAC. This could cause the TAC to be higher than the stock can maintain as herring are a main food source for many predators in the area (Baukan, et al., 2009). This will be discussed further in the environmental assessment (Section 3.1.5).

Finally, in 2012 the LRP was created for this stock (Clark et al., 2012). The LRP is a tool within DFO's Precautionary Approach Framework to help identify when a stock is so low that serious harm to the stock and/or the ecosystem could occur (Figure 1). This LRP was determined by DFO through a peer-reviewed science process, and then applied to the fishery as part of a rebuilding plan for the fishery. A URP still has to be created for the stock to help determine when the stock is within "healthy status". Due to the low stock levels over the past 10 years, the need for this reference point is a lower priority.

Overall, DFO's Precautionary Approach Framework has progressively been introduced into the fisheries management of the SWNS/BoF herring stock since 2012, but still has components missing from the management plan. To help strengthen it further, a URP should be created and stock assessments should put more emphasis on both bait and predatory removals from the stock (I+/NI+, Table 1).

The second policy for consideration for the herring fishery is the *Policy on New Fisheries for Forage Species*. This policy was created in 2009 as a framework for new forage fisheries. There are five objectives within the policy with a conservation-basis. These objectives include maintaining species, relationships, and commercial opportunities within a healthy zone (Fisheries and Oceans Canada, 2009b). This policy explains different biological and management prerequisites that are needed in order to open a new fishery on forage species. The biological prerequisites are heavily concerned with forage fisheries status in relation to the effects on predatory species. This is a link that the current management plan for herring is missing. The management prerequisites require the definition of lower and upper stock reference points and appropriate harvest control rules for when these stocks fall below these reference points. Due to the creation of the LRP in 2012, many of these management prerequisites are already integrated into the management plan for the herring fishery. However, predators are not specifically included within the current stock assessments and creation of this LRP.

Overall, the Policy for *New Fisheries for Forage Species* is a factor that is not included within the management plan. The policy was developed for the creation of new forage fisheries and thus the prerequisites are not required within established fisheries such as the SWNS/BoF herring fishery. However, the emphasis on ecosystem indicators and relationships between forage fish and predatory species within the policy would greatly benefit the herring fisheries management and the ecosystem in general. Therefore, DFO should consider starting to meet these prerequisites for the fishery and applying this policy to all of its forage fisheries already in place (NI+, Table 1).

3.1.2 Economic Component

In order to understand the decision-making process for the management of the fishery, it is important to understand the main economic factors that play a role within the business of the fishery. Namely, landings of herring for the stock, uses and markets for herring, exports of herring and price per kilogram of herring.

The annual landings for the herring fishery are recorded in metric tonnes within the stock assessments each year. These landings are based on logbook entries from fishers and dockside monitoring of the fishery by DFO as stated within the stock assessments. The landings from the stock each year are representative of the TAC that was set by DFO (Figure 5). The creation of this TAC each year allows for the removal of herring from the fishery to be kept to an appropriate level, while the monitoring ensures that this TAC is enforced. This quota and monitoring system ensures the stock remains at a sustainable state. Currently the SWNS/BoF herring stock is in the cautious zone of fishery and a TAC is set at 50,000 tonnes (DFO, 2016). A consideration of landings is therefore included within the herring fishery management. However, the plan does not consider landings from non-commercial fisheries. For example, landings from the bait and recreational fishers of herring are not adequately recorded (Fisheries Resource Conservation Council, 2009). This can cause an underestimate of landings/total fishing mortality, and a higher TAC than is sustainable. Therefore, accurate recording of these recreational and bait landings are an opportunity to strengthen the management of the fishery (I+/NI+, Table 1).

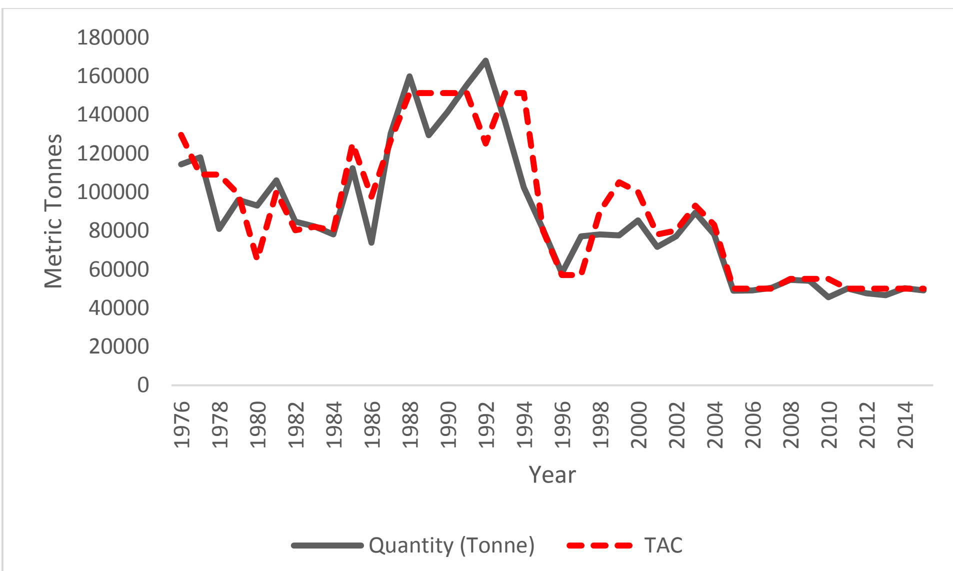


Figure 5 Herring landings and TAC for the SWNS/BoF stock in Nova Scotia for years 1976-2015. Note: Raw data table can be found in Appendix.

A second economic factor that was assessed was the use and market of herring products. Traditionally, herring in Canada were used mainly for direct human consumption such as pickled and canned herring (DFO, 1981). More recently, many herring in the world go toward uses such as fish meal and fish oil (Alder & Pauly, 2006). Although reduction fisheries were banned in 1976 in the *Fisheries Act*, many by-products and by-catch of herring in Canada are reduced to fish meal and oil (Cashion, 2016; Alder & Pauly, 2006). Fish meal and oil are used for a variety of sectors, including use as animal feed for both agriculture and aquaculture. It is estimated that as the aquaculture industry continues to grow, the demand for fish meal will also grow. Forage fish are expected to meet this demand due to their high oil content (Alder & Pauly, 2006). Similarly, much of the herring caught in the Maritime region is thought to be sold as bait to the lobster and crab fisheries (Harnish & Willison, 2008). However, due to inadequate recording of herring sold, it is difficult to accurately estimate how many different herring products are sold each season. The recording of these end uses of herring could help determine if the products being sold are efficient for both the fishery and the ecosystem and could help to strengthen the fishery (NI+, Table 1).

Likewise, many herring products in Canada are exported to other markets internationally. In a report by Govender, Hayne, Fuller and Wallace (2016), it was estimated that 54% of Canada's seafood is exported. However, due to mislabeling and inadequate recording, it is impossible to quantify how much of specific stocks are exported. It is known that most of the West Coast herring are sent to Japan for use as roe (Fisheries and Oceans Canada, 2014). For East coast herring, the sale of roe is less common. The Canadian International Merchandise Trade Database (Statistics Canada) identifies four different herring products (Appendix). Using the data from this database, it is estimated that roughly 6% of Nova Scotia's Atlantic herring are exported as "herring products." In addition, Govender et al. (2016), report that many forage species are in products labelled "NES" (not elsewhere specified). This makes it impossible to estimate how much herring, and more specifically SWNS/BoF herring, is exported every year. If this data was better managed and recorded, patterns and trends in markets and uses could be determined.

These patterns could help pinpoint where the majority of herring is going and whether these markets are sustainable. Similar to the uses of herring, a more accurate recording of these export transactions can strengthen the fisheries management to ensure the fishery is conducted within a sustainable fashion (NI+, Table 1).

The final factor considered in this analysis was the price per kilogram of herring. This was calculated using the landings data available on DFO's website and dividing the landing value by the landing quantity. It should be noted that the price per kilogram of herring is based on provincial herring landings and is not stock specific. Data was only available from 1990-2014. The price per kilogram of herring has increased since 1990 (Figure 6). The reasons behind this price increase are difficult to conclude as there may be many factors involved. Currently, the price per kilogram of herring is considered within the management plan as economic prosperity is an objective of the 2013 rebuilding plan (DFO, 2013). The inclusion of this factor in the management plan could be considered negative as viewing the fish simply as valuable in a monetary sense could put more emphasis on sales rather than conservation of the stock. On the contrary, the inclusion of this factor helps to better understand the driving factors of the fishing industry and its possible strategies. Therefore, the inclusion of price per kilogram of herring should be interpreted as a tool for predicting the economic pressures and should not overshadow the herring's ecological importance (I-/I+, Table 1).

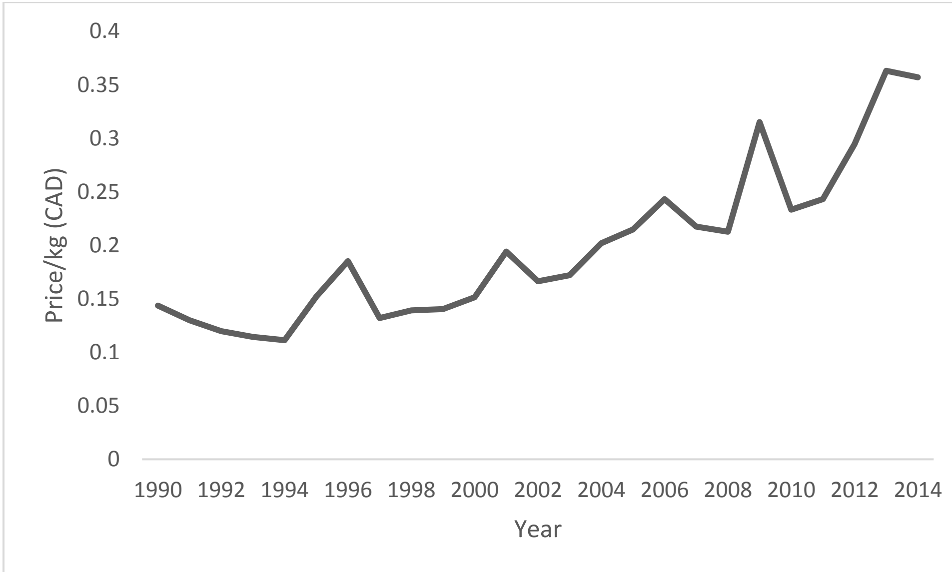


Figure 6. Price (CAD) per kilogram of herring in Nova Scotia for the years 1990-2014.

3.1.3 Socio-cultural Components

As previously mentioned, fisheries management is a wicked problem that should be addressed from a variety of lenses (Jentoft & Chuenpagdee, 2009). Consequently, it is important to take into account sociocultural components of the fishery such as licensed fishers, types of fishing and fishing gear, and the culture of the fishery.

The SWNS/BoF stock component of the 4VWX herring fishery is a diverse fishery that includes many types of licenses (Table 3). The majority of the catches within this component are landed from the commercial fishery. The number of fishering licenses for herring in the Maritime Region is a total of 3671 (Table 3), however, not all of these licenses are fishing from the SWNS/BoF stock component. The licenses issued for herring are not divided into different stock components but are given broad areas in which they can fish. This can cause difficulty in management decisions regarding active fishers, when the total number of fishers for the stock can fluctuate year-to-year. Therefore, issuing licensees by each stock component rather than by region could improve the management decisions of the fishery (NI+, Table 1).

In the herring fishery, there are two main categories of fishing gear: mobile and fixed. The mobile gear includes purse seines and a limited use of midwater trawls. The fixed gear fishery includes gillnets, coastal weirs, trap nets, and beach, drag and bar seine fisheries. Within the fisheries management plan for the herring fishery, the types of fishing are acknowledged. Furthermore, the TAC for the fishery is divided by fishing category: fixed or mobile gear (DFO, 2013). Due to the high volumes of the catch from the purse seine fishery, the mobile gear category is allocated roughly 80% of the TAC each season. This leaves 20% for the fixed gear fisheries. This division of the TAC allows for more herring to be allocated to where higher catches of herring are. This socio-cultural factor is included within the management plan and helps strengthen the management objectives (I+, Table 1).

Table 3. Types of fishing licenses for herring in the Maritime Region for 2015. (Personal Communication, Laura Hussey-Bondt, October 24 2016).

Type of Fishing License	Gear Used	Number of Licenses Issued
Commercial Fishing	Purse Seine	33
Commercial Fishing	Gillnet	2002 (24 commercial communal licenses for Aboriginal and First Nation groups).
Commercial Fishing	Trap Net	19
Commercial Fishing	Weir	216 (5 commercial communal licenses for Aboriginal and First Nation groups).
Commercial Fishing	Beach/drag/bar seine	43 (1 commercial communal license for Aboriginal and First Nation groups)
Commercial Fishing	Midwater trawl	1
Personal use (bait – mackerel and herring)	Gillnet	1278 (43 of these are for communal Aboriginal licenses)
Food, Social, and Ceremonial (FSC) fisheries by Aboriginal and First Nations groups	Various fixed gear including angling, jigging, spearing, hand line, dip netting, weir and gillnet	10
Recreational	Gillnet	69
Total		**3671**

Finally, herring fishing has been prominent in the SWNS/BoF waters for decades (Stephenson et al., 1993). The long history of fishing in the area undoubtedly creates a unique culture surrounding the herring fishery. It is estimated that the herring fishery was active prior to European colonization in the form of weir fishing (Stephenson et al., 1993). First Nation and Aboriginal groups have been fishing herring with both fixed and mobile gear since then. As such, DFO allocates licenses every year for all commercial communal and FSC fisheries as to respect treaty rights of these groups. Likewise, the Rebuilding Plan states that the management will “respect Aboriginal and treaty rights to fish” (DFO, 2013) emphasizing the importance of the herring fishery amongst the Aboriginal and First Nation groups.

Today, the commercial fishery is dominated by purse seine commercial fishing. This has created a different culture associated with the fishery. It was not until 1934 that purse seiners were introduced into the fishery in the form of oar-powered dories (Stephenson et al., 1993). The use of purse seines allowed for fishers to catch more fish in a shorter amount of time which increased the CPUE. Once diesel power was introduced, purse seiners increased and today dominate the fishery. This change in fishing behaviour was noted in the management of the fishery and led to the creation of a TAC quota system in the 1970s and the expansion of processing capacity for herring products in Nova Scotia (Stephenson et al., 1993). This shift allowed fisheries managers to better allocate and distribute the quota amongst fishers, indicating that the management of the herring stock does include cultural changes within its plan by adapting to fit the culture. This adaptation of the management plan with the culture of the fishery helps to strengthen the management (I+, Table 1).

3.1.4 Technological Component

Three factors were considered: changes in fishing technology over time, catch per unit effort (CPUE) changes, and survey and assessment methods.

The herring fishery in SWNS/BoF region is an old fishery that is estimated to have begun before European settlers came to Canada (Stephenson et al., 1993). This earlier fishery is believed to have been a subsistence fishery that used similar gear to weir fishers today. Since this time, the fishery has expanded into a commercial fishery, using an array of gear types, namely weirs, gillnets and purse seines. Weirs are a fixed gear that operate close to shore that catch mainly juvenile fish (Stephenson et al., 1993). Likewise, gillnets are also a fixed gear used in the area. The catch from gillnets has decreased over time due to processors favouring high catch volumes and lower costs from the purse seine industry (Stephenson et al., 1993). The catches from these types of fisheries are used for a variety of products. Purse seines are a mobile gear that catch the majority of the TAC each year (Personal Communications, Laura Hussey-Bondt, Nov 2 2016). This type of gear was first used to remove fish from within the weir traps close to shore (Stephenson et al., 1993). Since the introduction of technology and diesel powered boats, the use of purse seine moved further off shore and has dominated the fishery since the 1960s (Stephenson et al., 1993). With the increase of these purse seine boats, several management changes were implemented including the creation of a TAC , the implementation of an individual transferable quota (ITQ) system, and limiting the entry into the fishery.

The TAC is the quota that can be divided amongst the fishers each season. For the SWNS/BoF fishery, this quota is divided amongst both the mobile and fixed gear, as previously mentioned. The introduction of the ITQ was to further divide the allocated TAC to individual license holders in the mobile gear fleet. The implementation of this ITQ was to help decrease the effect of fishers trying to fill the quota as fast as possible (Stephenson et al., 1993). Furthermore, limited entry into the fishery was established so that only a discrete number of licenses could be assigned every year to maintain the share of the TAC. Therefore gear changes within the fishery are included within the management plan and help to strengthen the fishery (I+, table 1).

A common tool used to determine fish abundance within fisheries is the CPUE. The CPUE of a fishery is defined as how much a fishery is able to catch within a given measure of effort. Over the years DFO has recorded the CPUE for the 4VWX herring fishery within its stock assessments. The recording of this CPUE has changed in format from catch per hour searching to the more recent catch per day and catch per boat (DFO Stock Assessments from 1976-2016). However, for forage fisheries, like the herring fishery, the CPUE is not an adequate tool for determining population estimates. This is due to the natural schooling behaviour of herring that make them easy to catch despite small stock levels (Power, Knox, Macintyre, Melvin & Singh, 2012). Therefore the CPUE is calculated for the fishery to determine the effort of the fleet but is not used for decisions within the management framework, as it does not strengthen the decision making process (NI-, Table 1).

Finally, the methodology for stock surveys and assessments in the fishery were considered. To date, the fishery is surveyed every year and a full assessment is normally done every 2 years. The last full assessment for the 4VWX herring fishery was in 2015 (DFO, 2015). These assessments are completed using both industry and scientific information. The industry information includes logbooks, dock side monitoring and recording of biological characteristics by fishers. The scientific information includes tagging studies and acoustic surveys of spawning grounds from industry vessels (DFO, 2015). From the 2015 assessment it was concluded that due to the stock remaining within the cautious zone for the fishery, harvesting strategies should exercise caution. This year, following the surveys, the update report concluded that Scots Bay (Figure 2) biomass continues to increase while the German Bank (Figure 2) spawning stock biomass had the lowest estimate recorded (DFO, 2016). This biennial assessment and yearly survey of the fishing stock allows for trends in biomass to be acknowledged and accounted for within management in a timely manner. For example, based on the decline observed within German Bank, industry has decided to reduce its fishing to four days a week (Personal Communications, Laura Hussey-Bondt, Nov 2 2016). This inclusion of yearly surveys and biennial assessments is therefore a strength of the herring fishery management that allows for timely adaptive management decisions (I+, Table 1).

3.1.5 Environmental Component

Due to forage fish's prominent connection and interactions with their environments and ecosystems, there were 6 factors analyzed within both their abiotic and biotic environments. Namely, temperature changes, prey abundance, dependence of top predators, spawning grounds, ecologically and biologically significant areas (EBSAs), and life history traits of herring.

With the ever-present threat of climate change and associated warming oceans (Mills et al., 2013; Pershing et al., 2015), it is important to consider the impacts these temperature changes have on the herring stock. Brunel and Dickey-Collas (2010) conducted a study on how temperature changes impacted multiple herring populations within the North Sea. With the use of multiple populations in their assessment, a general pattern observed was faster growth rates and a shorter life span. Similarly, in another study performed by Akimova, Nunez-Riboni, Kempf and Taylor (2016), warmer waters had a positive correlation with the spawning stock biomass of herring. Although there is not a consensus on the exact relationship between herring biology and rising temperatures, it is evident that changes will occur as oceans warm. Currently temperature is not considered within the management plan, but its inclusion could help to strengthen the management of the fishery (NI+, Table 1).

Herring play a role within their ecosystem as both predator and prey. These roles allow for herring to have both a bottom-up and a top-down effect on their ecosystem (Figure 7). Currently, the management of this fishery is single species based. This management framework only considers herring within its management plan and does not consider the influence by prey and predators. This could be problematic due to herring's unique wasp-waist effect on this ecosystem.

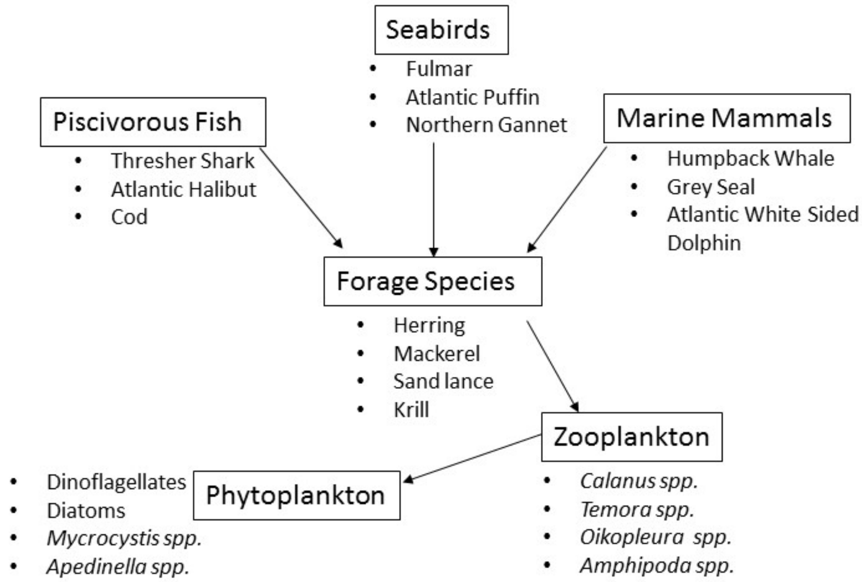


Figure 7. Herring trophic relationships for the SWNS/BoF region. Species represent examples of common predators obtained from Bakun et al. (2009) and common prey species obtained from Akimova et al. (2016) and Martin and LeGresley (2008).

Herring prey mainly on zooplankton species such as *Calanus spp., Temora spp., Oikopleura spp.* and *Amphipoda spp.* (Akimova et al., 2016). In order to ensure that the herring stock is healthy, it is important to consider the amount of food herring are receiving in their environments. Similar to temperature changes, food abundance was found to have an impact on herring populations, by impacting their condition (Mollmann, Kornilovs, Fetter & Koster, 2005). In the Baltic Sea, temperature changes had an impact on the dominance of zooplankton in the area, impacting the condition of herring (Mollmann et al., 2005). This impact on herring condition is a clear example of how both the abiotic and biotic factors can impact herring directly and non-directly. This is an ecosystem relationship that is currently not included within the single species management framework, but could help strengthen the management of herring (NI+, Table 1).

Likewise, herring are also preyed upon by many top predators (Table 4). Of these predators, many species are dependent upon herring, both adult and juvenile, for the majority of their food. Harbour porpoise, a common cetacean in the Bay of Fundy, consumes 50% of its diet from herring alone

(Bakun et al., 2009). It is also estimated that at least one third of the long term biomass of forage fish should remain in the ocean solely to feed seabirds (Cury et al., 2011). Thus, a large portion of herring are consumed every year by predators. The current single species management framework does not consider this removal within its management plan. For stock estimates, the general rule of natural mortality is 20% (Guenette et al., 2014). For other trophic level species, this natural mortality rule may be viable, but considering the amount of predators that rely on and consume herring in this area, it is recommended that this estimate be increased (Guenette et al., 2014). By underestimating the natural mortality, the associated recommended fishing mortality could be unsustainable for the whole ecosystem. For example, if herring, are heavily fished, the top predators that rely on this species for the majority of its food will experience detrimental impacts (Pikitch et al., 2014; Cury et al., 2011). Therefore, the dependence on herring by predators should be included within the management plan. This will ensure stock estimates and removals are representative of both fishing and natural mortality to ensure the removal rate is set at a level that is sustainable for both herring and the ecosystem (NI+, Table 1).

Table 4. Predators that feed on herring within the Bay of Fundy. Adapted from Bakun et al. (2009).

Species	**Adult or Larvae/Egg Diet**
Marine Mammals	
Fin Whale	Adult
Humpback Whale	Adult
Minke Whale	Adult
Pilot Whale	Adult
Harbour Porpoise	Adult
Atlantic White-Sided Dolphin	Adult
Harbour Seal	Adult
Grey Seal	Adult
Seabirds	
Greater Shearwater	Adult
Sooty Shearwater	Adult
Cory's Shearwater	Adult
Northern Gannet	Adult
Great Black-Backed Gull	Adult

Herring Gull	Adult
Northern Fulmar	Adult
Fish	
Spiny Dogfish	Adult
Silver Hake	Adult
Atlantic Cod	Both
Pollock	Both
Summer Flounder	Adult
Winter Skate	Adult
Thorny Skate	Adult
Sea Raven	Adult
Bluefin Tuna	Adult
Shortfin Mako Shark	Adult
Blue Shark	Adult
Haddock	Larvae/Egg
Sand Lance	Larvae/Egg
Winter Flounder	Larvae/Egg
Smelt	Larvae/Egg
Sculpins	Larvae/Egg
Atlantic Mackerel	Larvae/Egg
Atlantic Herring	Larvae/Egg

Another factor considered in the environmental component was the spawning grounds of herring within the fishing area. For the SWNS/BoF stock there are three principal spawning regions: German Bank, Trinity Ledge and Scot's Bay (Figure 2). Herring create discrete populations based on specific spawning grounds, such as the SWNS/BoF herring fishery component (Stephenson et al., 2009). This allows for site specific surveys to be completed on spawning fish, thus allowing DFO to estimate a relative index of abundance for specific spawning components. Currently, within the SWNS/BoF herring fishery component, fishing within Trinity Ledge spawning ground during the spawning period, has been prohibited. This is due to the stock abundance being within levels of concern (DFO, 2013). This fishing area has been closed for two years (2015 and 2016) while Scots Bay and German Bank have remained open for the SWNS/BoF fishery (DFO, 2013). Although the overarching SWNS/BoF fishery includes many spawning components and is managed as one stock due to intermixing of spawning populations, the estimate of stock abundance by spawning grounds, allows for specific management decisions to be made on a place-by-place basis. This allows for adaptive management that is relevant to a specific area rather than an overarching zone (i.e. NAFO 4VWX). However, this consideration of spawning grounds is still within the single species management framework and it does not consider the environmental conditions. If there were detrimental impacts to these spawning grounds from other abiotic influences, herring could experience harmful effects in relation to their spawning. This could lead to lower stock abundances in the following years. Therefore, the spawning grounds are a factor considered in the management plan that helps strengthen its decision making process, but could be improved on by integrating other environmental factors in relation to these spawning grounds (I+/NI+, Table 1).

Herring spawning grounds are not the only biologically important areas within the BoF region. In 2013, DFO identified 16 Ecologically and Biologically Significant Areas (EBSAs) within the BoF region (Buzeta, 2014). These EBSAs were created to assist in the creation of meaningful Marine Protected Areas (MPAs) (Buzeta, 2014). These EBSAs are defined by areas that are of importance to species through habitat, feeding grounds, spawning grounds or overall vulnerability. Six of the 16 EBSAs in the BoF are identified due to their relationship with marine mammal or seabird habitats, which are predators of herring. The connection between these habitats and the amount of available food, in the form of herring, could be considered within the management plan to help sustain not only herring, but also herring's predators (NI+, Table 1).

The final environmental factor to be analyzed is the life history traits of herring. As described above, herring are iteroparous species that spawn annually and reach sexual maturity around age 4 (Bigelow & Schroeder, 1953). There are four life stages for herring: egg, larvae, juvenile and adult, each stage ranging in length. These traits are important to consider when managing a species, as spawning needs to remain at a sustainable level to ensure replenishment of the stock each year. Currently, the management plan does take into consideration life history traits such as growth, life span, and the annual reproductive components of herring. The stock assessment records and estimates catch-at-age of the herring catches, mean length and weight, and the general condition of herring. These traits are used to create restrictions on both minimum size and fishing seasons (DFO, 2013). These considerations allow for the fish to be caught in a manner that allows for the prevention of a decline to the spawning component. Thus, the inclusion of life history traits within the current management plan strengthens the management of the fishery to help sustain the fish stock (I+, Table 1).

3.2 Gap Analysis for Alternative Management Frameworks

The PESTE/SWOT analysis of the SWNS/BoF herring fishery identified factors that were not currently included within the management framework but could be potential positive influences in fulfilling the management objectives (NI+, Table 1). Due to the majority of the “gap” factors falling under the environmental component, three ecosystem management frameworks were assessed: ecosystem based management (EBM), ecosystem based fisheries management (EBFM), and ecosystems approach to fisheries management (EAFM), as defined by Patrick and Link (2015). The single species approach is considered to be the current management framework (Table 2).

Ecosystem based management (EBM) is a growing concept among many resource managers and conservationists. The idea behind EBM is that management of natural resources can no longer be single sector based but must recognize the interactions these sectors have within their social, economic and ecological environments, creating a holistic approach to management (Pikitch et al., 2004). The concept of EBM has been around for years but has recently grown in popularity due to changing climates and environments, and overall exploitation of many natural resources that have led to regime shifts (Patrick & Link, 2015). For the purpose of this paper, EBM is defined as a holistic management framework that addresses multiple fish stocks, industries, and their environments within a specific region (Table 2).

Through the gap analysis, an EBM framework had a total of 17 green factors (NI+/I+ factors that are already included in this framework), 2 yellow (NI+/I+ factors not included in the framework but easy to implement within this framework) and 3 red (NI+/I+ factors not included in this framework and that would be difficult to implement within this framework) (Table 5). The political factors surrounding acts and regulations would have to be integrated into any framework implemented as they are required by Canadian law (Constitution Act 1867). The other political factor that scored green was the P*olicy on New Fisheries of Forage Species*, as many of the objectives within this policy align with EBM's objectives of a holistic approach to natural resource management (Fisheries and Oceans Canada, 2009b). The herring advisory committee meeting scored yellow, as EBM takes a multi-industry perspective on natural resource management, and thus a broader or multiple advisory committees would have to be created in order to be effective. Finally, the Precautionary Approach Framework would be difficult to implement within EBM as multiple stocks, species and industries would have to be considered when creating LRP and URP for harvest control rules.

The economic factors that scored green for EBM are landings of the SWNS/BoF stock and uses and markets of herring. These two factors are considered within EBM, as this holistic approach would be concerned about all of the landings for herring (i.e. commercial, recreational, bait) as well as the socio-cultural environments these fish products interact with (i.e. direct human consumption, bait, animal feed, etc.). In order to effectively consider exports of herring, a better recording system and better traceability of fish products needs to be implemented nationally.

The holistic approach to natural resource management of EBM would consider the socio-cultural factors within its framework. Accordingly, these factors score green for EBM. The technology factor that scored green was changes in fishing technology. This factor would be considered in an EBM approach due to its temporal scope of past, present and future changes to systems. The survey assessment and methods scored red as an EBM approach would call for a survey and assessment method for multiple fisheries and sectors. This could be difficult as there needs to be common indicators and objectives for these different sectors.

Finally, with a large emphasis on the ecosystem, EBM heavily considers the environmental factors with the exception of herring specific life history traits. EBM considers all species and industries within an area, and thus the life history traits of all species would need to be incorporated in this framework. This would take time to gather data and find linkages between them, hence a score of yellow.

Ecosystem based fisheries management (EBFM) is similar to EBM in considering the social, economic, political and ecological environments a system works within, but focuses only on the fisheries sector (Patrick & Link, 2015). EBFM goes beyond single species management, and includes multiple fisheries within its management regime. This allows for decisions on fisheries within a specific area to be made with each fishery in mind, considering the way these fisheries operate and affect each other. There are four main objectives for EBFM: 1) Minimize ecosystem degradation, 2) Minimize irreversible changes to ecological interactions, 3) Maintain the socioeconomic benefits of the target fisheries, and, 4) Educate the public on ecosystem processes and minimize anthropogenic risks (Pikitch et al., 2004). These four objectives are holistic for both the natural ecosystem and the social ecosystem, recognizing the importance of the resource of fish to society and economy (Table 2).

This management framework scored 16 green, 4 yellow, 1 red and 1 black (cannot be captured within this framework) factor in the gap analysis (Table 5). Many of these scores are similar to EBM because EBFM is also a holistic approach to resource management. The four differences between these two frameworks lie in the fact that EBM considers various sectors within an area, while EBFM is only concerned with the fisheries sector. As such, the precautionary approach framework scored red for EBM but yellow for EBFM as it would be easier to create harvest control rules based only on fisheries and their interactions, rather than on a variety of sectors (Table 5). Likewise, survey and assessment models also scored yellow, as they would have to be created in a uniform fashion across multiple fisheries, but are easier to implement than in EBM, due to the single sector bases of EBFM. Regarding environmental factors, the inclusion of EBSAs scored black, as EBFM would only be concerned with those that pertained to fisheries and thus is not completely included within EBFM, while EBM would be concerned about all

EBSAs. Finally, regarding life-history traits, due to the multispecies focus of EBFM, these would be included within this framework. This factor scored green in EBFM, but only red in EBM due to the fact that EBFM is only concerned with fish species. Currently, most fisheries management plans already consider these species life history traits. Thus, it would simply be an easy combination of all fisheries data. For EBM however, there would be species considered in which life history traits have yet to be defined making its implementation more difficult (yellow).

An ecosystem approach to fisheries management (EAFM) is an ecosystem management framework that has a single stock focus but also considers the interactions the stock has within its ecological environment. Many current ecosystem management tools have been implemented with this type of management framework in mind.

This EAFM framework scored 19 green, 1 yellow, 1 red and 1 black factors in the gap analysis. Due to the single species focus of this framework, all of the political factors would be included. The economic factors scored similarly to a single species framework, as it is still only concerned with the commercial fishing sector and does not consider how these products interact with the socio-cultural environments. The major difference here between the current single species management and EAFM, is that the bait and recreation landings would be included within the management framework as they are part of the greater ecosystem this management framework would consider. The major difference between this framework and the current single species framework lies within the environmental factors. All of these environmental factors would be considered within an EAFM framework with the exception of EBSAs, as only the ones that pertain to the specific target fishery would be considered.

Overall, the current management regime for the SWNS/BoF herring fishery, which based on a single species based framework, had 12 green factors, 5 yellow factors, 1 red, and 4 black factors. The best ranking regime appeared to be the ecosystem approach to fisheries management as it ranked 19 green factors, 1 yellow, 1 red and 1 black factor. The next best fit for management would be an ecosystem based fisheries management regime that was specific to the area (Table 5).

Table 5. Gap Analysis of Management Frameworks

NI+/I+ Factors	Current Management	Ecosystem Based Management	Ecosystem Based Fisheries Management	Ecosystem Approach to Fisheries Management
Political/Legal				
Fisheries Act				
Oceans Act				
Atlantic Fishery Regulations				
Fishery (General) Regulation				
Structure of DFO				
Herring Advisory Committee Meeting		Would be a broader advisory committee for all sectors in the region	Would be a broader advisory committee for all fisheries in region	
DFO's Precautionary Approach Framework		Would need to make harvest control rules from all sectors	Harvest control rules would be made based on all fisheries	
Policy on New Fisheries of Forage Species				
Economic				
Landings of SWNS/BoF Stock	Only concerned with commercial fishery			
Exports of Herring	Need to improve traceability of fishing products to make this easier to implement			

Uses and Markets of Herring			Would not be concerned with how products interact with socio-cultural environments but would be easy to track	Would not be concerned with how products interact with socio-cultural environments but would be easy to track
Socio-cultural				
Number of active licensed Fishers				
Types of Fishing				
Culture of Fishery		Would care about multiple fishing cultures		
Technological				
Changes in fishing technology				
Survey and Assessment Methods		Would have to find ways to broadly survey different sectors in an efficient way	Would have to find ways to broadly survey all fisheries in an efficient way	
Environmental				
Temp Changes				
Prey Abundance				
Dependence of Top Predators				
Spawning Grounds				
EBSAs in the BoF			Only concerned with grounds that are relevant to fisheries	Only concerned with grounds that are relevant to specific fishery stock
Life History Traits		Would have to incorporate life history traits of many species and resources		

4.0 **Discussion**

Forage fish are an important part of the ecosystems in which they live. The reliance on these small schooling fish by many other animals as their main food source, makes them a key component to healthy ecosystems. Due to this unique reliance from other trophic level animals, the management of these forage fisheries should be highly environmentally inclusive and holistic. This project analyzed the management framework of forage fisheries in Canada with a case study of the SWNS/BoF herring fishery to determine strengths and weaknesses for forage fisheries.

The PESTE/SWOT analysis conducted on Canada's SWNS/BoF herring fishery emphasized the need for a more holistic approach to fisheries management by determining specific factors that could help strengthen the current fisheries management regime for ecosystem sustainability (Table 1). A gap analysis of these indicators analyzed three different ecosystem based frameworks for ways to help incorporate these factors into the management of forage fisheries. Through this analysis, it was determined that an ecosystem approach to fisheries management would be the easiest first step in creating a more holistic framework for forage fisheries management in Canada.

Traditionally, fisheries management in Canada has been single species based. Management systems have focused on one species at a time and have set maximum sustainable yields (MSY) and quotas based on these individual species data. This single species strategy for fisheries management has become the benchmark for most fisheries (DFO, 2006; Rice & Duplisea, 2013) and is the recommended management by the International Council for the Exploration of the Seas (ICES) (Rice & Duplisea, 2013). This type of management has a dominant position in policies such as the United Nations Fish Stock Agreement and the World Summit for Sustainable Development (Rice & Duplisea, 2013; DFO, 2006). However, there has been debate about the appropriateness of this benchmark with upcoming changes and regime shifts within the marine environment (Levin & Mollmann, 2015). With the oceans and its ecosystems in constant change, it is becoming increasingly more apparent that a more holistic approach to resource management is needed (Levin & Mollmann, 2015).

As previously mentioned, forage species have unique and diverse relationships with the many environments in which they interact with. These environments include political, economic, socio-cultural, technological and ecological environments. Canada's current fisheries management framework could improve on the inclusion of these environments and their interconnections with fish species, specifically, economic and ecological environmental factors (Table 5).

Globally, forage fish landings make up about 37% of the wild marine fish catch (Alder, Campbell, Karpouzi, Kaschenr, & Pauly, 2008). Of this roughly 31.5 million tonne catch, 90% of it is reduced to fish meal and fish oil, to feed other carnivorous species of animals through agriculture and aquaculture (Alder et al., 2008). Therefore, the sustainability of forage fish is important not only for the natural predators of their ecosystem, but for the farmed animal species that humans consume. Furthermore, in Canada, it is estimated that a large portion of both mackerel and herring are targeted for use as bait in the lobster fishery (Harnish & Willson, 2008). This consideration of how much of Canada's forage fish species is directed to these uses is not considered within the current management plan (Table 1). With the use of a more EBFM framework or EBM framework, these markets and uses of forage fish could be considered in management decisions. This factor could help drive more sustainable decisions, so that the sustainability of both the ecosystem and food processes can be accomplished. Likewise, if the majority of forage fish are going towards fish meals and bait, perhaps a more sustainable alternative can be suggested to help alter the impact this demand has on the natural stock (Wietecha, 2016).

Another area of improvement for Canada's current forage fisheries management is the inclusion of factors within the ecological environment. Through the PESTE analysis of Canada's SWNS/BoF herring fishery, it was suggested that herring can be greatly impacted by temperature, prey abundance and predator dependence (Table 1). Within the SWNS/BoF region, herring are explained to have a "wasp-waist" effect on their ecosystem (Guenette et al. 2014). This effect suggests that the sustainability of herring is important not only for herring themselves, but for the sustainability of the whole food web. The current adapted single species management framework fails to incorporate these relationships within its targets and objectives for herring. Through a gap analysis, all three ecosystem based frameworks improved on the incorporation of these ecological environment factors, suggesting that these frameworks would aid in making fishery decisions based on the interactions between forage fish and other species to ensure ecosystem sustainability (Table 5).

Over the past few years, DFO has been incorporating a more holistic approach into its current fisheries management framework with the use of the precautionary approach framework, harvest control rules and integrated fisheries management plans (IFMPs) (DFO 2006, 2013b, 2014). These changes have helped DFO to broaden its vision and focus of the fishery and begin integrating many of the factors identified within the PESTE analysis (Table 1). Although many of these factors are still target species based and can be improved upon, the use of an annual herring advisory committee meeting is a factor that has been implemented since 1981 (Stephenson et al., 1993). These advisory committee meetings allow for different stakeholders from the fishery to voice their concern and views to DFO. DFO then uses the opinions of these stakeholders in recommending changes to the fishery each year.

There have been many attempts at trying to integrate ecosystem based frameworks into fisheries management regimes (Rice & Duplisea, 2013). One such attempt was done by ICES by trying to incorporate this holistic approach with the traditional MSY standards. ICES created a multispecies assessment working group that used a multispecies virtual population analysis to address factors such as predation, catch size, and MSY for multiple species (Rice & Duplisea, 2013). This analysis established that there were major concerns in keeping all species within their current specific MSY targets concurrently. This has led to a recommendation of an EBFM framework that would integrate these targets to include the influence from other MSYs, making them easier to attain. However, despite the numerous papers on

EBM and fisheries, there has been little action in the way of implementation. Rice and Duplisea (2013) suggested that forage fish may be a perfect test bed for this style of management due to their unique trophic level relationships.

For proper implementation of any new management regime, it is important to incorporate stakeholder voices. One belief in why ecosystem based frameworks have not been more dominantly implemented into fisheries management is due to a mismatch of priorities between fishers and decision makers (Long, Charles, & Stephenson, 2016). Surveys by Long et al. (2016), asked 23 fishers what they thought should be the main ecosystem based priorities for fisheries management. These surveys concluded that for fishers, the top priorities for ecosystem based framework were sustainability, development of long-term objectives, and stakeholder involvement. Meanwhile, the literature assessed by Long et al. (2015) put priority on more ecosystem connections for ecosystem based frameworks. This mismatch of priorities between decision makers and stakeholders, such as fishers, show that in order to implement an ecosystem based framework appropriately, stakeholders need to be involved from the beginning. Due to SWNS/BoF's herring advisory committee, ensuring that DFO's definition and priorities of an ecosystem based framework, and the various stakeholder's definition and priorities of an ecosystem based framework align will be easier when moving towards implementation.

Through the gap analysis of this paper, three ecosystem based frameworks were assessed to determine the best possible fit for an ecosystem based framework within Canada's forage fisheries. These frameworks were: ecosystem based management (EBM), ecosystem based fisheries management (EBFM), and ecosystem approach to fisheries management (EAFM). These frameworks range in complexity and scope of integration and as such, some indicators would be more difficult to implement than others (Table 5). However, all of the frameworks improved upon the current single species fisheries management of forage fisheries in integrating factors that will help strengthen management decisions for whole ecosystem sustainability.

The first ecosystem based framework assessed was EBM. This type of management can be difficult to implement due to its complexity of integration among various sectors. There have been very few case studies on successful implementation of a full EBM framework, despite the copious amounts of literature on how implementation can be successful (Levin & Mollmann, 2014; Stelzenmuller, Breen, Thomsen & Hofstede, 2013; Levin, Fogartym, Murawski, & Fluharty, 2009; Pikitch et. al. 2004; Slocombe, 1993). For the case of the SWNS/BoF region, this type of management regime would be a hefty goal. The amount of data required for full implementation of EBM in this area would take many years to collect as there were found to be 5 factors that needed more information (Table 5). These factors were: a broad advisory committee, exports of resources in the area, integrated harvest control rules, integrated survey and assessment methods of various fish stocks, and integrating life history traits of many species within an ecosystem.

A step down in complexity from EBM would be ecosystem based fisheries management (EBFM). This type of management framework is defined as an ecosystem approach that deals with only the fisheries sector (Table 2). This management framework would be slightly easier to implement into Canada's current fisheries management regime (Table 5). There are still specific factors that would need more data and information to be adequately implemented, namely, a broad fisheries advisory committee, harvest control rules for fisheries that are based on the integration of all fisheries, exports of seafood products in the area, survey and assessment methods that integrate all fisheries, and the inclusion of EBSAs that are outside of the scope of fisheries specific grounds within management decisions.

The final ecosystem management framework is an ecosystem approach to fisheries management (EAFM). This framework is single species based in nature, but applies more emphasis on the ecological environment and its interactions with the target species, a large component currently missing from Canada's forage fisheries management (Table 5). Due to this emphasis on more environmental factors, this framework scored the best for ease of implementation against the factors chosen for analysis in this project (Table 5). The biggest setbacks of this framework are that it remains single species based and puts little to no emphasis on integration of the socio-cultural environments nor other fisheries within the area.

Globally, forage fisheries have begun to see impacts that reductions in these species can have on the ecosystem as a whole. In the Antarctic, there is a strict limit on the amount of estimated biomass of krill that can be caught within the fishery. This limit of 75% is to ensure that there is enough krill for the dependent predators within the water as managers have recognized that a decrease in krill could have negative impacts on other Antarctic species (Pikitch et al., 2012). Likewise, other areas such as the Barents Sea, the Benguela Current, the California Current and the Humboldt Current have all had different target catch limits implemented by their respective authorities based on the potential negative impacts that could occur to the ecosystem if these forage species decrease (Pikitch et al., 2012). These types of reference points and conservation limits that take into consideration the whole ecological environment would be a good first step in implementing an ecosystem approach within Canada's forage fisheries.

5.0 Conclusions and Recommendations

In conclusion, the current management regime of forage fisheries in Canada is missing many ecological interactions between forage fish and their ecosystems. Due to the large impact these forage fish species can have on their environments, it is important to address the ecological environment within their fisheries management framework. Accordingly, the adoption of an ecosystem based framework would strengthen the management by considering factors within the political, economic, socio-cultural, technological and physical environments in which they interact. Through an analysis of three separate ecosystem based frameworks, it was concluded that the easiest way to move towards a holistic ecosystem based framework would be to first implement an EAFM framework. This type of framework would require DFO to find baseline data for the target species and its interactions with other species, habitats, and sectors within a specific area. If DFO implements this type of framework across multiple fisheries, they can then be integrated into an EBFM framework. Following this integration of fisheries management plans, the integration of various sectors within a specific area could be implemented to help reach full EBM framework for specific regions. This would help to ensure that not only forage fisheries were sustainable but that natural resource management of areas were sustainable to ensure sustainability for the whole region, as everything is interconnected.

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Appendix I

32 Questions in Levin et al. (2016).

Questions about broad social, political, and economic forces

1. How have global market forces influenced the commercial Herring fishery? How have the markets changed over time?
2. What are the social, cultural, and political motivations for Herring fisheries, and how have they changed over time?
3. What is the relationship between Herring fisheries and broader issues of indigenous rights?

Questions about human activities (and their effects on Herring)

4. What is the relative influence of fishing, other human activities and climate on Herring population dynamics, and how can the impacts be differentiated?
5. What are the cumulative effects of human activities (fishing, coastal development, toxins, etc.), predators and climate on Herring populations?
6. What are causes of historical disappearance of Herring, and is the current status of Herring a lingering consequence of historical impacts?
7. How does fishing affect spawn timing, and what impact does this have on population dynamics?
8. What are the ecological, economic, and cultural costs and benefits of alternative fisheries management strategies?

Climate questions

9. How does global-scale climate variability related to El Niño and the Pacific Decadal Oscillation influence Herring behavior and population dynamics?
10. How is changing climate affecting Herring populations?

Habitat questions

11. Does the quantity and/or quality of spawning habitat determine Herring productivity and population size?
12. Does the artificial supplementation of spawning habitat (i.e., by trees or boughs) result in increases in the long-term median Herring population size?
13. Are Herring using deeper spawning habitat? If so, why, and how does that affect their vulnerability to predation?

Institutional and governance questions

14. How do policies and management strategies that address the spatial distribution of fishing effort and the temporal order of fisheries better account for aboriginal rights as codified by court decisions and law?
15. What are the pros and cons of different temporal and spatial scales for adaptive Herring decision making?
16. How would different forms of knowledge alter definitions of overfishing thresholds and sustainable levels of fishing?
17. What role can institutional processes play in better facilitating the rebuilding of Herring populations?
18. How can we allocate harvest in such a way that supports ecological, economic, and cultural resilience?

Questions about Herring and the Herring food web

19. Are Herring vital rates (e.g., recruitment, mortality) or behavior positively or negatively density dependent? How has the nature of density dependence changed over time?

20. How do the processes that determine or limit Herring population size vary across spatial and temporal scales?
21. What factors affect survival of Herring eggs, larvae and young-of-the-year?
22. How has size structure changed over decadal to millennial time scales, and what are the causes and consequences of such changes?
23. What is the spatial structure of Herring populations, and what factors influence the degree of connectivity among sub-populations? Has this changed over time?
24. What factors influence interannual and interdecadal movement of spawning Herring stocks?
25. What is the role of genetic and life-history diversity in maintaining Herring populations? How has this changed over time?
26. What is the relative importance of bottom-up versus top-down processes for Herring behavior and population dynamics, and how has this varied over time?
27. What are the cross-ecosystem linkages that influence Herring, and how have they changed over time?
28. How have changes in ocean productivity, predator abundance or other factors affected the long-term median biomass of Herring?

Questions about human wellbeing

29. What thresholds of Herring abundance and distribution exist for meeting cultural objectives?
30. How do the economic and cultural benefits associated with the harvest of sac-roe, spawn-on-kelp, adult fish for bait, and adult fish for food propagate through local and regional social systems? What are the consequences of this for equity and food security?
31. What nonfishing human activities are supported by Herring, that is, what is the value of the supportive ecosystem services provided by Herring?
32. What is the trade-off between economics and human wellbeing if Herring remain in the ecosystem versus if they are harvested and removed from the system? How does this vary over the range of Pacific Herring?

Appendix II

HS Trade Codes and Products used for Herring

Herring
030241 - Herring, fresh or chilled, excl fish of heading 03.04, excl livers and roes **030351** - Herrings, Frozen, Excluding heading 03.04, livers and roes **030486** - Herring fillets, frozen **030542** - Smoked herrings, including fillets, other than edible fish offal

Appendix III

Raw data of Landings and TACs from yearly assessments

Year	Quantity	TAC
2015	49024	50000
2014	50250	50000
2013	46554	50000
2012	47614	50000
2011	50100	50000
2010	45534	55000
2009	54113	55000
2008	54500	55000
2007	50360	50000
2006	49160	50000
2005	48900	50000
2004	78000	83000
2003	89360	93000
2002	77054	80000
2001	71570	78000
2000	85284	100000
1999	77552	105000
1998	78139	90000
1997	77027	57000
1996	58068	57000
1995	80747	80000
1994	102340	151200
1993	136662	151200
1992	167967	125000
1991	155376	151200
1990	141400	151200
1989	129400	151200
1988	159900	151200
1987	130200	126500
1986	73733	97600
1985	112400	125000
1984	78100	80000
1983	82227	82000
1982	84733	80200
1981	106000	100000
1980	93000	65000
1979	96000	99000
1978	80876	109000
1977	117980	109000
1976	114342	129600