A SCOPING LITERATURE REVIEW OF EUROPEAN AND ATLANTIC CANADIAN GREEN CRAB (*CARCINUS MAENAS*) FISHERIES LITERATURE TO IDENTIFY KNOWLEDGE GAPS FOR FISHERIES-BASED INVASIVE SPECIES MANAGEMENT

by

Brianna Crosby

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Dalhousie University is located in Mi'kma'ki, the
ancestral and unceded territory of the Mi'kmaq.
We are all Treaty People.

Table Of Contents

Tables

Figures

Crosby, B. 2023. A scoping literature review of European and Atlantic Canadian green crab (*Carcinus maenas*) fisheries literature to identify knowledge gaps for fisheries-based invasive species management [graduate project]. Halifax, NS: Dalhousie University.

Abstract

Aquatic invasive species are considered economic and environmental threats to Canada's aquatic ecosystems. In Atlantic Canada, the European green crab (*Carcinus maenas*) is a management concern due to its destructive nature. The green crab is an aggressive predator that disrupts ecosystems by outcompeting native decapods, destroying critical habitat, and causing a loss of biodiversity. Additionally, green crabs affect Atlantic Canadian fisheries by preying upon commercially important bivalve species. A potential management solution is the implementation of green crab fisheries to control the invasive populations in Atlantic Canada. Green crab fisheries in the species' native European range have been reported as successful and as such, small trial fisheries have been established in Atlantic Canada.

This study conducted a scoping literature review of European and Atlantic Canadian green crab fisheries literature using a fisheries performance indicator framework developed by Anderson et al. (2015) modified for qualitative analysis to determine what is currently known about each fishery and where knowledge gaps lie. It was determined that Economic indicators were the most common performance indicators in fisheries literature, followed by Ecology and Community. Knowledge gaps were identified for harvest data, product market, stock health, and multiple community metrics. Additionally, there was a lack of Indigenous knowledge in the literature. Management recommendations suggested ways that fisheries managers can address these gaps through day-to-day reporting, interactions with fishers, collaboration with scientific communities, and outreach to Indigenous communities.

Keywords: Green crab; *Carcinus maenas*; invasive species; Atlantic Canada; Europe; fishery; management.

Abbreviations

AIS	Aquatic invasive species
CA	Canada/Atlantic Canada
CCFAM	Canadian Council of Fisheries and Aquaculture Ministers
CFP	Common Fisheries Policy
DFO	Fisheries and Oceans Canada
EU	Europe/European
FSLN	Federal Science Library Network
IUCN	International Union for the Conservation of Nature
IUU	Illegal, unregulated, or unreported
NB	New Brunswick
NL/NFLD	Newfoundland
NS	Nova Scotia
PEI	Prince Edward Island
UK	United Kingdom
US	United States

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1. CHAPTER ONE: INTRODUCTION

Aquatic invasive species (AIS) are harmful, non-native species found in marine, estuarine, and freshwater environments (Therriault et al., 2008). There are many ways an AIS can invade waterways including shipping, ballast water discharge, recreational boating, aquarium trade, live products, and illegal introductions (Government of Canada, 2004). After introduction, AIS populations grow rapidly in part due to a lack of natural predators to keep populations in check (Government of Canada, 2019c). While AIS are a danger to human health and the economy, it is their threat to native ecosystems and biodiversity that is of great concern to environmental managers (Therriault et al., 2008). AIS disrupt ecosystems by reducing biodiversity, degrading habitats, and outcompeting native species (Government of Canada, 2019c). Canada is at high risk from AIS as it has the world's longest coastline, 20% of global freshwater stocks, and prominent fisheries (Government of Canada, 2004).

The Government of Canada introduced action plans and regulations that outline the country's goals for AIS mitigation. In 2001, Canada officially recognized AIS threat mitigation as a priority (Government of Canada, 2004). This led to the creation of the Canadian Council of Fisheries and Aquaculture Ministers (CCFAM) – Aquatic Invasive Species Task Group in 2002 and the release of *A Canadian Action Plan to Address the Threat of Aquatic Invasive Species* in 2004 (Government of Canada, 2004). The plan outlined the challenges associated with AIS and future AIS management objectives (Government of Canada, 2004). It was recognized that AIS could have negative environmental, economic, and socio-cultural consequences so the action plan recommended that future AIS mitigation was guided by an inter-jurisdictional, inter-departmental, and international management framework (Government of Canada, 2004). Suggested application of this framework included introducing new AIS legislation and regulations, risk assessments, early detection activities, monitoring, eradication, stewardship, and education (Government of Canada, 2004). Later, in 2015, the Government of Canada introduced the Aquatic Invasive Species Regulations (SOR/2015-121) under the Fisheries Act (Legislative Services Branch, 2021). The Regulations listed known AIS in Canada, prohibitions and exemptions for possessing, transporting, or releasing AIS, and regulations for AIS control and eradication (Legislative Services

Branch, 2021). Listed under Part 3 of the Aquatic Invasive Species Regulations was an AIS of particular concern for the Atlantic Provinces – the European green crab.

1.1 The Green Crab

The Canadian Atlantic provinces – Nova Scotia (NS), New Brunswick (NB), Prince Edward Island (PEI), and Newfoundland (NL) – have been invaded by an AIS known as the European green crab. *Carcinus maenas* (L.) (Figure 1), more commonly known as the green crab, or the shore crab (hereafter: green crab) is a medium sized crab from the Portunidae family (Klassen & Locke, 2007) that can grow up to 9 cm in width and lives for 5 to 7 years (Therriault et al., 2008). Paradoxically, the green crab is not always green and can sometimes be red or yellow which causes it to be mistaken for native Atlantic Canadian crabs such as the Jonah crab (*Cancer borealis*), the lady crab (*Ovalipes ocellatus*), the mud crab (*Neopanope sayi* and *Rhithropanopeus harrisii*), and the rock crab (*Cancer irroratus*) (Government of Canada, 2019a; Klassen & Locke, 2007). The best way to identify the green crab is by the five prominent spines on either side of its eyes (Figure 1) (Government of Canada, 2019a).

Figure 1: The European green crab, *Carcinus maenas (James, 2017)*.

As its common name suggests, the green crab is native to Europe and North Africa but has spread to all continents except for Antarctica (Figure 2) (Klassen & Locke, 2007; Young & Elliott, 2020). The green crab was named one of the 100 worst invasive species in the world by the International Union for the Conservation of Nature (IUCN) because it has serious impacts on biological diversity and human activities (Lowe et al., 2000). It has successfully invaded both the eastern and western shores of North America (Figure 2) including all four Atlantic provinces, New England, British Columbia, Washington, Oregon, and California (Young & Elliott, 2020). It has also successfully colonized the coasts of South America (Argentina), Africa (South Africa), and Australia (Victoria, New South Wales, and Tasmania) (Figure 2) (Klassen & Locke, 2007; Young & Elliott, 2020). Green crabs have also been identified in Brazil, Panama, Madagascar, Sri Lanka, Hawaii, Pakistan, and India but they failed to establish invasive populations due to inhospitable habitat (Klassen & Locke, 2007; Young & Elliott, 2020).

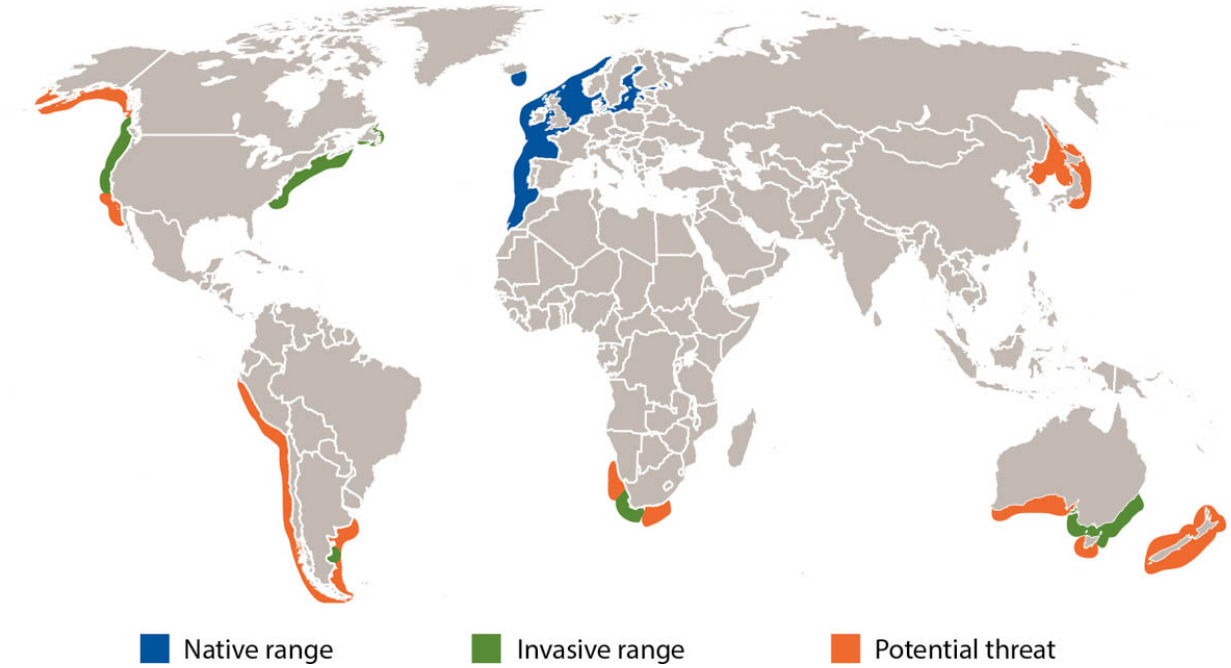

Figure 2: Global distribution of the European green crab, *Carcinus maenas.* (Figure 1 from (Grosholz et al., 2021)).

It is the green crab's biology and behaviour that makes it such a successful invader. The green crab is eurythermal and euryhaline meaning that they can conform to a

wide range of temperatures and salinity (Klassen & Locke, 2007). They can survive in temperatures from 0°C to 35°C and in salinities from 4 to 52 ‰ (Therriault et al., 2008; Young & Elliott, 2020). Additionally, through a process called 'bubbling' the green crab can breathe air and survive out of water for up to 10 days (Young & Elliott, 2020). These wide tolerances and resistance to desiccation have likely aided the green crab in travelling to and colonizing new environments. The green crab can live in a variety of environments including rocky and unvegetated intertidal, mudflats, sandy beaches, saltmarshes, seagrass beds, and in sublittoral zones up to 10 m in depth (Bernier et al., 2020; Klassen & Locke, 2007; Young & Elliott, 2020). Once settled, the green crab reproduces with females potentially laying up to 370,000 eggs per year (Klassen & Locke, 2007).

1.2 The Green Crab in Atlantic Canada

The green crab's invasion of the Atlantic provinces began in 1817 when it arrived on the east coast of the United States (US) (Young & Elliott, 2020). It is unconfirmed how green crabs travelled from Europe, but ballast water discharge or ship biofouling are the prevailing theories (Young & Elliott, 2020). The 1817 green crabs were thought to have originated from Southern Europe (DFO, 2022) and were the first of three genetically distinct populations that have invaded the Atlantic Provinces. (Young & Elliott, 2020). Once established in the US, the green crab moved up the coast and was found in New Brunswick's Passamaquoddy Bay in 1951 (Point 1, Figure 3) (Klassen & Locke, 2007). In 1954 and 1960 the green crab was detected along the southern tip of Nova Scotia (Points 2 and 3, Figure 3), likely having dispersed from Passamaquoddy Bay, and by 1964 they were seen in Peggy's Cove (Point 4, Figure 3) (Klassen & Locke, 2007). The spread of green crabs in Nova Scotia is unclear for the mid-1960s to the 1990s due to poor documentation and conflicting information. For reasons unknown, green crab dispersal stalled after the 1960s Peggy's Cove detections and intertidal monitoring during 1965 to 1973 did not detect the crabs along the eastern shore of Nova Scotia (Klassen & Locke, 2007). The green crab made a reappearance sometime in the late 1970s to early 1990s, though the literature has confounding information on this timeline; Klassen & Locke (2007) state that the green crab was detected in Whitehead, NS, in 1978 (pg. 10)

(Point 5, Figure 3) but they also state that the Whitehead observation occurred in late 1980s (pg. 9). However, Fisheries and Oceans Canada (DFO) states that green crab reappearance occurred in the late 1980s to early 1990s (DFO, 2022). Regardless of when the detection occurred, both Klassen & Locke and DFO agree that the detection in Whitehead, NS, was likely a secondary introduction of a more cold tolerant green crab (compared to the Southern European lineage) from Northern Europe (DFO, 2022; Klassen & Locke, 2007). The original population of green crabs spread from the Peggy's Cove area to the eastern shore of Nova Scotia in the early 1980s (Point 6, Figure 3) while the second population moved northward into Cape Breton and the Gulf of St. Lawrence in the mid-1980s to late 1990s (Points 7 – 18, Figure 3) (DFO, 2022; Klassen & Locke, 2007). The green crabs reached PEI in 1996 when they were discovered in Georgetown (Point 19, Figure 3) and by 2001 the species had spread to Charlottetown Harbour, Savage Harbour, and Victoria, PEI (Points 20 – 22, Figure 3) (Klassen & Locke, 2007). Finally, green crabs were detected in Placentia Bay, NL, in 2007 (Point 23, Figure 3). The green crabs found in Newfoundland were hardier and more aggressive than the first two green crab populations and were in fact a third, hybridized population of the first and second green crab populations (DFO, 2022). As of 2020, the green crab is found on the Bay of Fundy, Atlantic, and Gulf of St. Lawrence coasts, from Cascumpec Bay and Miminegash Harbour in PEI, as far north as Pokemouche Bay in New Brunswick, and eastward to Fortune Bay in Newfoundland (Figure 3) (Bernier et al., 2020; Klassen & Locke, 2007; Young & Elliott, 2020). In only 70 years, green crab have become nearly ubiquitous in Atlantic Canada.

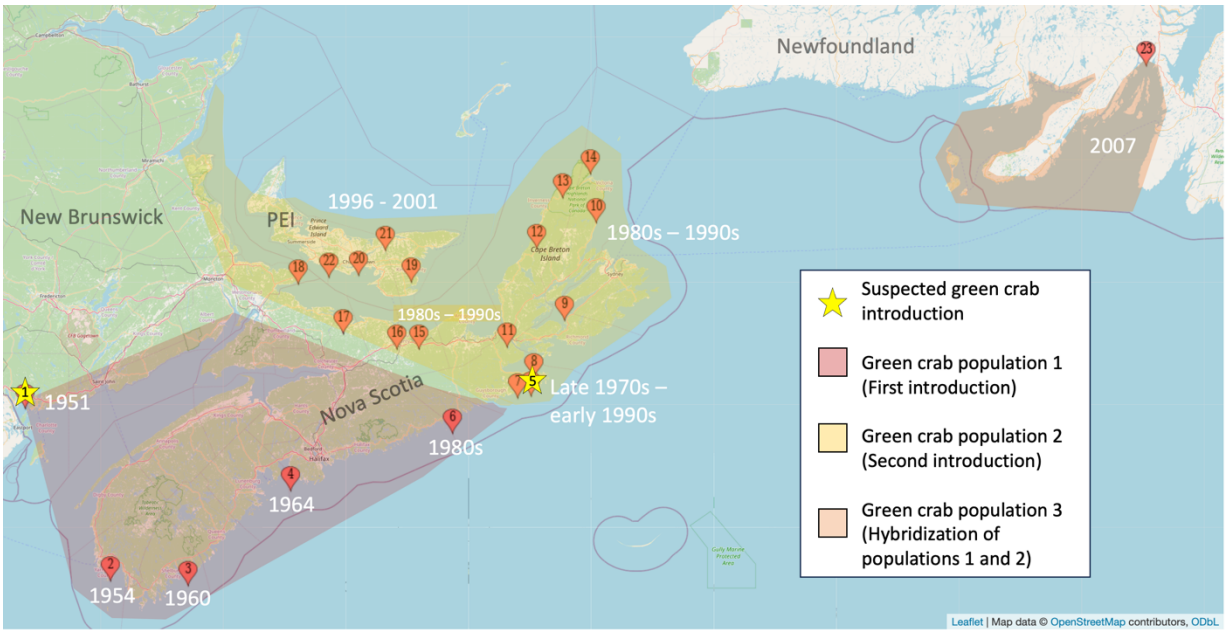

Figure 3: A map of the green crab invasion pathway in Atlantic Canada. Coordinates from Klassen & Locke (2007).

Many authors refer to the green crab as an ecosystem engineer for its ability to negatively affect an entire ecosystem (Klassen & Locke, 2007; Young & Elliott, 2020). In their native range, the green crabs do not exhibit the same negative effects on ecosystems as the crabs are kept in check by predators such as the European sea bass (*Dicentrarchus labrax*), velvet swimming crab (*Liocarcinus puber*), and seabirds (Klassen & Locke, 2007). However, in Atlantic Canada they do not have as many natural predators and they establish themselves as aggressive predators (Young & Elliott, 2020). They eat native molluscs, polychaetes, and other crustaceans but have a preference for bivalves such as clams and mussels (Klassen & Locke, 2007; Young & Elliott, 2020). Green crabs can harm ecosystem biodiversity by causing trophic cascades (Klassen & Locke, 2007; Vercaemer et al., 2016); Predation pressure caused by green crabs indirectly increases infaunal populations, triggers protection strategies in prey (such as thicker shells and relocation), and removes lower trophic filter feeders (Bernier et al., 2020; Klassen & Locke, 2007). Additionally, when foraging in eelgrass beds, green crabs shred the plants and destroy a critical ecosystem component that provides food and shelter (Howard et al.,

2019; Zhou et al., 2015). Eelgrass also helps regulate nutrient cycling so a loss in eelgrass correlates with a decline in ecosystem health (Zhou et al., 2015).

Green crabs are also of great concern to commercial aquaculture and fisheries interests (DFO, 2011). Due to the green crab's affinity for bivalves, there is concern about how blue mussel (*Mytilus edulis*), eastern oyster (*Crassostrea virginica*), bay scallop (*Argopecten irradians irradians*), and soft-shell clam (*Mya arenaria*) culture and fishing will be affected (Bernier et al., 2020; Klassen & Locke, 2007). The concern is warranted; It is believed that green crabs were responsible for the 1940s collapse of the New England soft-shell clam industry where soft-shell clam production decreased from 8.5 million pounds to 0.6 million pounds over 8 years (Klassen & Locke, 2007; Young & Elliott, 2020). Now, green crabs are estimated to cost $22.6 million annually in damages to New England shellfish fisheries (Vercaemer et al., 2016). Atlantic Canada's highly lucrative American lobster (*Homarus americanus*) fishery is being monitored by DFO for green crab impacts. Green crab and American lobster habitat and food sources overlap and it is possible that competition for resources or predation of juvenile lobsters will affect the lobster fishery (Government of Canada, 2019b; Klassen & Locke, 2007; Young & Elliott, 2020). The lobster fishery is also affected when green crabs enter lobster traps and eat either the bait or trapped lobster (DFO, 2011).

1.3 Green Crab Control

Green crabs are well-established in all four Atlantic Provinces, so prevention and early detection are no longer viable management strategies. Management efforts must focus instead on monitoring, control, and eradication. To monitor populations, the provinces encourage citizens to call or email local government or DFO when they see green crab, including details such as date, location, or a photo (Government of Newfoundland and Labrador, n.d.; Government of Prince Edward Island & Fisheries, Aquaculture, and Rural Development, n.d.; New Brunswick Invasive Species Council, n.d.; Province of Nova Scotia, 2014). The provinces also focus on controlling spread from recreational boating. They have developed educational webpages, posters, and brochures to promote awareness of AIS, green crab spread, and ways they can prevent it by cleaning, draining, and drying boats, trailers, and gear after use (Government of Prince

Edward Island & Fisheries, Aquaculture, and Rural Development, n.d.; New Brunswick Invasive Species Council, n.d.; Province of Nova Scotia, 2014). Lastly, trapping is used to detect, monitor, or eradicate (where possible) AIS populations (DFO, 2022). Trapping for green crab has occurred in Canada since 2006 and all four Atlantic Provinces use trapping as a management approach (Mckenzie et al., 2022). There are multiple kinds of traps used, including collapsible crab traps (Fukui traps), eel traps, minnow traps, and crayfish traps, which are baited with herring, mackerel, squid, or cod (Mckenzie et al., 2022). The Fukui trap is the most popular trap for green crab management due to its lightweight and collapsible design (Mckenzie et al., 2022).

Overall, physical removal has been effective at reducing green crab populations (DFO, 2022). The green crab trapping program at Seaside Kejimkujik National Park in Nova Scotia is one example of successful trapping efforts. From 2008 to 2009, staff at Seaside Kejimkujik National Park noticed that eelgrass beds had declined by 43% in the presence of green crabs so they began trapping them using modified eel and shrimp traps baited with herring (Bernier et al., 2020; DFO, 2011; Mckenzie et al., 2022). This was a resounding success; By trapping green crab, eelgrass beds began to recover by 10% each year, native species presence increased, and as of 2020, 2 million green crabs were caught and removed from Seaside Kejimkujik National Park (Mckenzie et al., 2022; Parks Canada Agency, 2020).

Trapping and physical removal efforts have demonstrated that they reduce green crab populations and allows ecosystems to recover (DFO, 2022). However, if the management goal is to reduce invasive green crab populations to non-destructive levels, sustained trapping will be necessary (DFO, 2022). Sustained trapping and eradication could be more difficult to manage and more expensive than other management options such as monitoring and mitigation (Fisheries and Oceans Canada Government of Canada, 2019). However, there is a possible management tool that would enable long-term trapping while simultaneously offsetting costs: green crab commercial fisheries.

1.4 Green Crab Commercial Fisheries – A Management Tool?

In the late 2000s, DFO began establishing commercial green crab fisheries as a long-term management solution. Such fisheries are comparable to the well-established

fisheries in the green crab's native European range, including fisheries in the United Kingdom (UK), France, Spain, and Portugal (Klassen & Locke, 2007). While the literature confirms that the European fisheries have been in operation for many years, precise dates are difficult to find. The UK fishery began in the 1980s (Morris et al., 2007) and Portuguese fishery records date back as far as 1938 (Leitão et al., 2014), so it can be assumed that European green crab fisheries have been evolving since the early 1900s.

Another fishery from which green crab fishery inspiration may be drawn is the moleche (also known as molecche or moeche) and masanette fishery in Italy (Varagnolo, 1968). The traditional moleche fishery dates back to the 18th century and focuses on the capture and cultivation of soft-shell crab (moleche) or hard-shell female crabs (masanette) (Cataudella et al., 2015; Varagnolo, 1968). They are considered local delicacies and can fetch high prices (Cataudella et al., 2015; Glamuzina et al., 2017). For a long time, *C. maenas* was thought to be the green moleche crab (Varagnolo, 1968), but it is actually *Carcinus aestuarii* (formerly *Carcinus mediterraneus*) which is also called a green crab and was thought to be a *C. maenas* subspecies until 2004 (Cataudella et al., 2015; Glamuzina et al., 2017). While not the same species, literature on the moleche fishery (especially prior to 2004) is still relevant to understanding the European green crab fisheries.

Atlantic Canada began introducing pilot or experimental green crab fisheries in the late 2000s. In 2009, DFO gave Newfoundland fishers experimental green crab licenses as part of a stewardship and population control program (McKenzie et al., 2011). In the first year of the experimental fishery, two fishers used 30 traps each, twice a day, for 9 days and they harvested 6,000 pounds of green crab (DFO, 2011; McKenzie et al., 2011). There appeared to be local interest in Newfoundland's green crab fishery upon its opening (DFO, 2011) but it is unclear if this fishery is still operational.

Next, Nova Scotia launched an experimental green crab fishery in the southwest of the province in 2011 which evolved into a commercial fishery that expanded to the eastern shore in 2014 (Mckenzie et al., 2022; Vercaemer et al., 2016). From 2011 to 2015, 19 green crab licenses were distributed and 3 million crabs (weighing 157 tonnes) were removed from Nova Scotian waters (Vercaemer et al., 2016). It was noted that these fishing efforts resulted in reduced green crab catch rates (Vercaemer et al., 2016).

Lastly, a trial PEI/Gulf of St. Lawrence region fishery began in 2011 (Mckenzie et al., 2022, L. Poirier, personal communication, December 6, 2023). Fishers could either sell by-catch green crabs while fishing under another license or an eel licence could be exchanged for a green crab license (St-Hilaire et al., 2016). Unfortunately, the fishery was short-lived as it closed in 2018 due to a lack of fisher interest and market value (Mckenzie et al., 2022).

1.5 Study Scope

The green crab is a management issue as it is a highly destructive invasive species in the Atlantic Provinces. Preventative measures are no longer effective because the green crab has firmly established itself on Atlantic Canada's coasts, leaving population management as an option. However, long-term control programs can be costly and difficult to maintain. A potential management tool that could offset costs is mitigation through a commercial green crab fishery. While Atlantic Canada is experimenting with green crab fisheries as an invasive species control method, the fisheries are still in their infancy. As there are green crab fisheries in the crab's native European range, there is a unique opportunity to study an established fishery for comparison against an emerging fishery. By comparing European and Atlantic Canadian green crab fisheries, opportunities for growth and research gaps could be identified for the Atlantic Canadian fishery. The problem is that literature about either European or Atlantic Canadian fisheries is difficult to find and when it is identified, it is not highly detailed. Ultimately, synthesis of European and Atlantic Canadian green crab fisheries knowledge should occur prior to making green crab management decisions to ensure that all who are involved are aware of knowledge gaps and opportunities and can make well-informed decisions.

This study asks the question: "What is known about European and Atlantic Canadian green crab fisheries (within peer-reviewed and grey literature) and how can this information be used to inform fisheries managers of gaps and opportunities in fisheries-based invasive species management?" This study will address this question through a set of goals, 1) determine what is known about the European and Atlantic Canadian fisheries through a fishery performance framework lens; 2) compare the European fisheries and the Atlantic Canadian fisheries (using what was determined in Goal 1) to identify gaps in

the literature; and 3) suggest areas for future green crab fisheries research, practices, and growth with a focus on invasive population management. Goal 1 will be addressed by a scoping literature review and analysis using a fishery performance framework developed by Anderson et al. (2015) (Methods and Results), whereas Goals 2 and 3 will be addressed post-framework analysis (Discussion). Comparison (Goal 2) will be made between European and Atlantic Canadian literature but not of the fisheries themselves. It is outside of the scope of this study to determine the effectiveness of the Atlantic Canadian green crab fisheries as invasive species management.

2. CHAPTER TWO: METHODS

A scoping literature review design was used to evaluate the size and scope of European and Atlantic Canadian green crab fisheries literature. Studies pulled from two databases underwent screening for eligibility and were analysed using a fishery performance framework.

2.1 Sourcing Literature

Two databases were used to source the literature for the review; the databases were ScienceDirect and the Federal Science Library Network (FSLN). The ScienceDirect database was selected as its scope was broad, was not limited to one geographical area, and returned more than 1000 search results during preliminary searches (key search term: “green crab”). In contrast, the FSLN database was chosen for its focus on Canadian government literature, both peer-reviewed and grey. Two databases were used to extend the reach of the search and the databases were not compared against one another.

The search strings used to search the databases were built in a “(Species) AND (Location) AND (Keyword)” format. It was important to define the species and location within the search strings as the scope of the study focused on literature for a single species in specific geographic locations. Searching by only species and location would result in a high volume of studies so the search was further refined for fisheries literature using the keyword section.

The search strings were formed by scanning key green crab literature and were refined by conducting trial-and-error searches in each database. In the finalized strings, the species section remained unchanged for both databases and included the scientific name and common names (i.e., "*Carcinus maenas*" OR "European green crab" OR "green crab"). The location section encompassed province, region, and country names. All four Atlantic Canadian provinces and their abbreviations (e.g., "Nova Scotia" OR "NS") were included, and region names were used as the Atlantic provinces are also grouped under various names, including "Maritimes", "Maritimes region", "Atlantic Canada", and "Gulf region". Both "Maritimes" and "Maritimes region" were included despite their similarity because trial searches indicated the terms generated different results and so they were both included for expanded search potential. For the strings targeting European fisheries, the terms were "Europe", "Italy", and "Spain". Additional countries such as France, Portugal, and the United Kingdom were considered but were cut due to difficulty integrating the terms within ScienceDirect's search parameters. Spain was chosen to represent the Atlantic coast European fisheries because Spanish green crab fisheries were frequently mentioned in key literature. Italy was chosen to capture literature about the moleche industry which may have included *Carcinus maenas* until 2004 (Glamuzina et al., 2017). Keywords were used to search for studies focused on fisheries and related topics. Keywords were determined using titles, abstracts, and keywords from key green crab reference papers (such as Klassen & Locke, 2007; St-Hilaire et al., 2016; Therriault et al., 2008). This process resulted in 8 preliminary keywords (Table 1) that were used in trial searches to determine how suitable the keyword was. The titles and abstracts from the trial search were skimmed for frequently appearing words or concepts, which informed the second and final set of keywords (Table 1). Final keywords were sometimes different elaborations on a root word to capture all uses of a word in a string (e.g., "Fishery", "Fisheries" and "Fishing"). Word variation was not needed for FSLN searches as they had a 'wild card' search function where an asterisk could be used to search for multiple terms (e.g., "Fish*" would return studies including the words "Fishery", "Fisheries", and "Fishing").

Table 1: Terms used in the database search strings.

Species	Location	Keyword	
		Preliminary	Final
Carcinus maenas	Nova Scotia	Fish	Fishery
European green crab	NS		Fisheries
Green crab	New Brunswick		Fishing
	NB	Harvest	Harvest
	Prince Edward Island		Harvesting
	PEI		Harvester
	Newfoundland	Manage	Manage
	NL		Management
	NFLD		Managing
	Atlantic Canada	Control	Control
	Maritimes		Controlling
	Maritimes region	Invasive species	Invasive
	Gulf region		Invasive species
	Europe		Aquatic invasive species
	Spain	Soft shell crab	Soft shell
	Italy		Moeche
			Moleche
		Economics	Economic
			Economic analysis
			Performance
			Employment
			Income
			Cost benefit
			Profit
			Profitability

Species	Location	Keyword	
		Preliminary	Final
			Capital
			Value
			Input output
			Break even
		Seafood	Food fishery
			Recreational fishery
			Local market

Due to differing Boolean operator rules, the search strings for each database were not structured the same though they used the same search terms (Table 2). The ScienceDirect database restricted the length of the search string and therefore many more strings were used than the FSLN database. Overall, the ScienceDirect database used 75 strings and the FSLN database used 6 strings (Tables 11 and 12, Appendix). The literature search process took place from July 17th, 2023, and July 21st, 2023. The strings were copied (from a master excel sheet containing all the strings) into the search function of the respective database and the resultant citations were downloaded as .ris files. All the results were downloaded to include as many studies as possible in the literature review. Each .ris file was named using a database abbreviation, string number and part (if the download was too large for one file), the search date, and the initials of the researcher (e.g., "SD_string4pt3_Jul172023_BC.ris"). The FSLN and ScienceDirect .ris files were separated into two folders and stored using cloud storage. ScienceDirect string 60 was removed during searching due to being irrelevant as the green crab is native to Europe and strings 71 and 76 did not return any results (Table 11, Appendix).

Table 2: Examples of the ScienceDirect and Federal Science Library Network search strings used to create the body of literature for the literature review. A full list of the search strings can be found in the Appendix (Tables 11 and 12).

Database	Search String
ScienceDirect	("carcinus maenas" OR "european green crab" OR "green crab") AND (Maritimes OR "Atlantic canada" OR "gulf region") AND (Fishery OR Fisheries OR fishing)
Federal Science Library Network (FSLN)	("carcinus maenas" OR "european green crab" OR "green crab") AND (maritimes OR "maritimes region" OR "atlantic canada" OR "gulf region") AND (fish* OR harvest* OR manag* OR control* OR invasive OR ("soft shell" OR "moeche" OR "moleche") OR (economic OR "economic analysis" OR performance OR employment OR income OR "cost benefit" OR profit OR capital OR profitability OR value OR "input output" OR "break even") OR ("food fishery" OR "recreational fishery" OR "local market"))

2.2 Screening

Literature screening was completed using Covidence, a literature review management software (Veritas Health Innovation, 2023). To screen the search strings results, the stored .ris files were uploaded into Covidence's reference import tool which converted them into a readable format (Veritas Health Innovation, 2023). 16,015 .ris file results were imported into Covidence for screening, with 15,880 .ris files resulting from ScienceDirect searches and 135 from FSLN searches. On importing, Covidence scanned for duplicate studies by comparing the title, year, volume, and author(s) of the first unique occurrence of a reference with those from newly imported references (Veritas Health Innovation, 2023). 12,836 duplicates were automatically removed, leaving 3,179 unique studies. As this is an automated process, there was a small chance that relevant studies were misidentified as duplicates and were not included in the review.

Next, these studies were screened by title and abstract according to a pre-determined set of inclusion and exclusion criteria (Table 3). Covidence structured screening around a 'Yes', 'No', or 'Maybe' system (Veritas Health Innovation, 2023).

The screener could screen a study's title and abstract and choose 'Yes' or 'Maybe' to move a relevant study to the full text review stage, or they could choose 'No' and the study would be classified as irrelevant and removed from the review. Screening was primarily done by the author with a screening reliability test conducted by a second screener. The second screener reviewed 10% of the studies and the screeners agreed on screening choices 90% of the time.

Table 3: Final inclusion and exclusion criteria for literature review screening. *North Africa was removed as a target location at the full text screening phase as the study narrowed to focus on two places only (Atlantic Canada and Europe).

Inclusion Criteria	Exclusion Criteria
• Included target species (*Carcinus maenas*, European green crab, green crab, shore crab) • Included target geographical area (Atlantic Canada, Nova Scotia, Prince Edward Island, New Brunswick, Newfoundland, Europe, Spain, France, Italy, United Kingdom, Portugal, any unlisted but relevant European countries, North Africa*) • Correct date range for Atlantic Canadian literature (2000-2022) • Correct date range for European literature (1990-2022) • Focus or mention of green crab fishery or harvesting (including fishery management, gear, markets, economics, productivity, value, employment, profitability,	• Wrong species/not green crab related • Wrong geographical area (not Atlantic Canada, Europe or North Africa*) • Wrong date for Atlantic Canadian literature (pre 2000) • Wrong date for European literature (pre 1990) • No mention of green crab fishery or harvesting • Is about green crab physiology (not relevant to study) • Green crabs are used as a study/test species for manipulative or observational experiments (not relevant to study) • Is not written in English • Is an encyclopedia article, book review, website, or news article

Inclusion Criteria	Exclusion Criteria
recreational and commercial fisheries, etc.) • Focus or mention of soft shell crab/moeche/moleche industries • Includes mention of green crabs as commercial or commercially important species, and seafood species. Include unnamed crustaceans described as commercially important species • Includes mention of invasive green crabs, management, trapping, etc. • Includes mention of socio-ecological or -economic aspects, social sciences, etc. regarding green crab (or unnamed but commercially important crab) management, fisheries, harvesting, seafood, etc. • Is written in English • Include if it meets above requirements and is from a relevant and reliable journal, peer-reviewed article, book chapter, report, or review	

The inclusion and exclusion criteria were also evaluated after 10% of the studies were screened. The first set of inclusion and exclusion criteria were formed around the terms used in the search strings (Table 1). The inclusion criteria stated that studies had to include the target species (green crab and synonymous names), target locations (Atlantic Canada, Europe, and places within), should directly refer to a green crab fishery or mention one or more of the search string keywords, should be in the correct date range

(2012-2022 for Atlantic Canadian literature, 2002-2022 for European literature), and should be from a reputable source. The exclusion criteria mirrored the inclusion criteria (i.e., exclude the study if the target species was not mentioned, if it was not in the correct location, etc.). The exclusion criteria also specified that studies about green crab physiology (not included in the scope of the review) and non-English studies were excluded.

The first 10% of studies were reviewed by both screeners using these criteria. The inclusion and exclusion criteria were then refined based on repeated themes noticed during the prior screening. Under the inclusion criteria, the term “shore crab” was added to reflect a name commonly used for *C. maenas* in Europe, additional descriptors and keywords were added to the harvesting and management sections, and new sections were added to reflect commercial importance and socio-ecological or -economic aspects of a fishery. Under the exclusion category, sections were added to exclude studies focused on the use of green crabs as an experimental or manipulative test species as laboratory experiments were not the focus of this study. Additionally, the date ranges for relevant studies were changed. Date ranges were a part of the screening criteria instead of the search strings to keep the original search as wide as possible. Originally, it was decided that a date range of 10 years (2012-2022) for Atlantic Canada and 20 years (2000-2022) for Europe was appropriate. However, while screening the first 10% of studies, the author noticed that studies from the early 2000s mentioned Atlantic Canada’s green crab fisheries, and that studies focusing on the European fisheries were sparce after the 1990s. Therefore, it was determined that a date range of 22 years (2000-2022) for Atlantic Canada and 32 years (1990-2022) for Europe were more appropriate for the review. Finally, North Africa was added as a target location in the inclusion criteria but was ultimately cut at the full text screening phase. The study was narrowed to only two areas for easier comparison between green crab fisheries and most of the green crab’s native range is in Europe (Figure 2). The remaining 90% of studies were screened using the revised inclusion and exclusion criteria.

A total of 3,032 studies were excluded in the screening of title and abstracts, leaving 147 studies for review in the full text screening phase where each study was read and reassessed using the same inclusion and exclusion criteria (Table 3). Of the 147

studies, 117 were excluded leaving 30 relevant studies to include in the final data extraction phase. The studies were excluded because they did not focus on the green crab (50 studies), contained irrelevant information (36 studies), did not have copies available online (17 studies), were outside the date range (7 studies), were from the wrong location (e.g., the United States, western Canada) (6 studies), or were not in English (1 study).

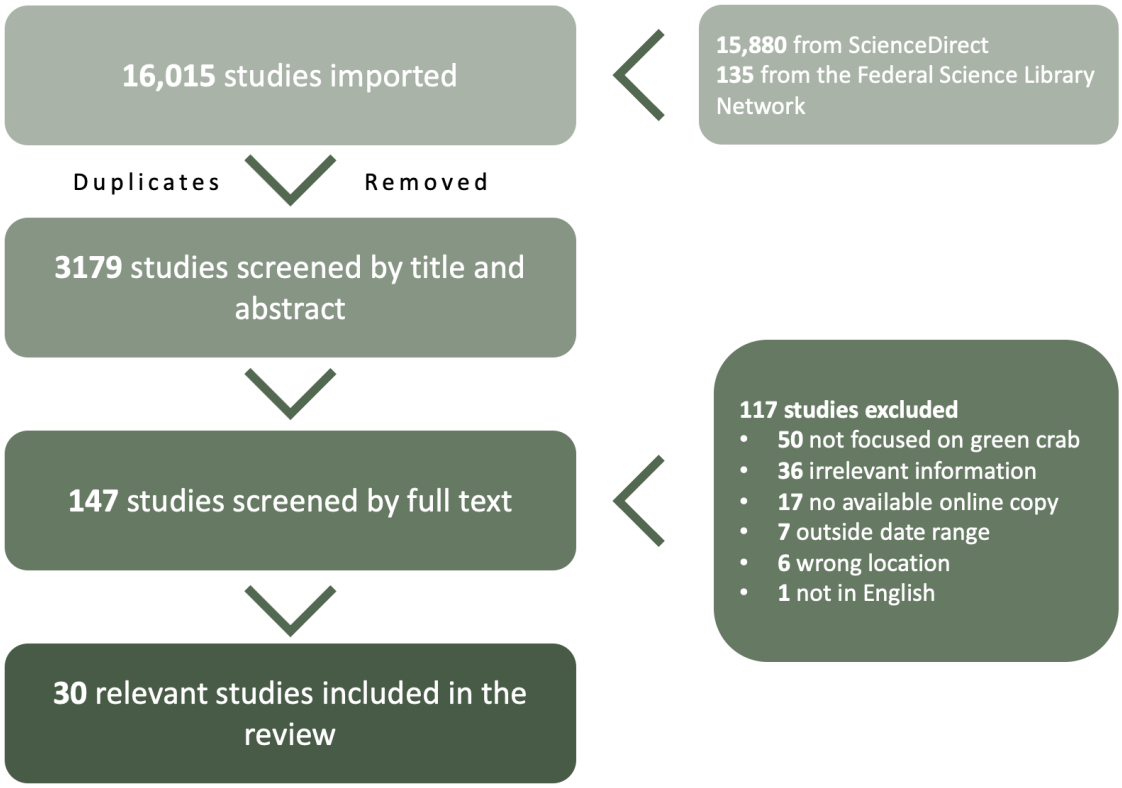

Figure 4: PRISMA flowchart of the literature screening process. Adapted from a PRISMA flowchart generated by Covidence (Veritas Health Innovation, 2023).

2.3 Data Extraction

The data extraction phase reviewed studies and extracted specific information about green crab fishery performance. Covidence was not used for data extraction because the software's provided templates were designed for human experimental or trial studies (i.e., templates included sections to analyse a study's design, population, participant recruitment, etc.) and did not fit this study's parameters for data extraction.

Instead, a Microsoft Excel spreadsheet was used to design and organize the data extraction process (Table 4).

Table 4: The terms used in the data extraction spreadsheet.

	Metric	Description
General/Technical Information	*Title*	The title of the study.
	Author(s)	The study's author(s).
	Year	The year the study was published.
	Publication type	The type or style of literature that the study was written in. Each study was classified as either scientific journal/peer-reviewed paper or grey literature.
	Perspective	The perspective that a study was written in, classified as either European or Atlantic Canadian. The perspective was determined by combination of direct mention of where a study took place or where a review focused on, where a publishing organization was based, author affiliations, and context from the study itself.
	Fishery place	The province or country mentioned in relation to a green crab fishery.
Fishery Performance Information	*Fishery information*	Information about a green crab fishery. The information was directly copied from a study and pasted into the Excel sheet. Applicable information ranged from explicit mention of green crab fishery data to acknowledgement of the fishery's existence.
	Applying the framework	After the initial quote selection, a quote was reread to better understand the content and to determine if aspects of fishery performance, determined by the framework, were identifiable.

To extract data, each study was read in detail and all relevant information (represented by the term in Table 4) was recorded. Study characteristics such as publication year, publication type, perspective, and fishery location (Table 4) were recorded in the spreadsheet to determine the technical scope of a study. Next, direct quotes relating to green crab fisheries (at the researcher's discretion) were copied and pasted into their own cells in the spreadsheet. Quotes were used to break up relevant information from the study into more manageable pieces for framework analysis. The number of quotes varied and ranged from 1 to 12 relevant quotes per study. The criteria for what was considered information about a green crab fishery was very broad; information about a fishery could include explicit mention a green crab fishery, mention of directed green crab fishing, harvest, or capture, mention of the green crab as a commercial species, and figures, tables, or numerical data about green crabs. Once the study was read through and all relevant information was copied into the spreadsheet, each quote was read again with a fishery performance framework lens.

The framework used for data extraction was a fishery performance framework developed by Anderson et al. (2015) (Figure 5). This framework was found early in the study's planning stage (prior to search string development) while searching fisheries literature for ideas on how to analyse green crab fisheries. It was chosen for use in this study because it provided a comprehensive framework of fishery performance metrics and a system for quantitatively comparing fisheries. The framework consisted of three indicators – Ecology, Economics, and Community – broken down into 14 dimensions and further into 68 metrics (Figure 5). The metrics could be coded in levels of 1 to 5, where 5 reflects better metric performance and thus allow for quantitative scoring of fishery performance (Anderson et al., 2015). The original intent was to score European and Atlantic Canadian green crab fishery performance using the system proposed by Anderson et al. and suggest management recommendations for the areas where the newer Atlantic Canadian fisheries scored lower than the established European fisheries. However, it was found that the information identified in relevant studies was not detailed enough for meaningful scoring and so use of the framework was adapted by disregarding the quantitative scoring system and instead focusing on analysing using the qualitative Indicator, Dimension, and Metrics.

Indicator	Dimension	Metric
Ecology	Fish Stock Health & Environmental Performance	Percentage of Stocks Overfished
		Degree of Overfishing
		Stock Declining, Stable or Rebuilding
		Regulatory Mortality
		Selectivity
		Illegal, Unregulated or Unreported Landings
		Status of Critical Habitat
		Proportion of Harvest with a 3rd Party Certification
Economics	Harvest	Landings Level
		Excess Capacity
		Season Length
		Ex-Vessel Price cf. Historic High
	Harvest Assets	Ratio of Asset Value to Gross Earnings
		Total Revenue cf. Historic High
		Asset Value cf. Historic High
		Borrowing Rate cf. Risk-free Rate
		Source of Capital
		Functionality of Harvest Capital
	Risk	Annual Total Revenue Volatility
		Annual Landings Volatility
		Intra-annual Landings Volatility
		Annual Price Volatility
		Intra-annual Price Volatility
		Spatial Price Volatility
	Trade	International Trade
		Final Market Wealth
		Wholesale Price cf. Similar Products
		Capacity of Firms to Export to the US & EU
	Product Form	Processing Yield
		Shrink
		Capacity Utilization Rate
		Product Improvement
		Final Market Use
		Ex-Vessel to Wholesale Marketing Margins
	Post-Harvest Asset Performance	Borrowing Rate cf. Risk-free Rate
		Source of Capital
		Age of Facilities
Community	Managerial Returns	Captains Earnings cf. Regional Average Earnings
		Captains Wages cf. Non-fishery Wages
		Captains Social Standing
		Processing Owners Earnings cf. Regional Average Earnings
		Processing Owners Wages cf. Non-fishery Wages
		Processing Owners Social Standing
	Labor Returns	Crew Earnings cf. Regional Average Earnings
		Crew Wages cf. Non-fishery Wages
		Crew Social Standing
		Processing Workers Earnings cf. Regional Average Earnings
		Processing Workers Wages cf. Non-fishery Wages
		Processing Workers Social Standing
	Health & Sanitation	Harvest Safety
		Access to Health Care for Captains
		Access to Health Care for Crew
		Access to Health Care for Processing Owners
		Access to Health Care for Processing Workers
		Sanitation
	Community Services	Regional Support Businesses
		Contestability & Legal Challenges
		Education Access for Harvest Captains
		Education Access for Crew
		Education Access for Processing Owners
		Education Access for Processing Workers
	Local Ownership	Nonresident Employment as Captains
		Nonresident Ownership of Processing Capacity
	Local Labor	Nonresident Employment as Crew
		Nonresident Employment as Processing Workers
	Career	Crew Experience
		Age Structure of Harvesters
		Worker Experience

Figure 5: Fishery performance framework used to analyse European and Atlantic Canadian green crab fisheries literature. Adapted from Figure 1 from Anderson et al. (2015).

The analysis began at the broadest level of the framework and narrowed down to the most specific level (Indicator → Dimension → Metric). Analysis was subject to the researcher's discretion. First, the quote was assessed at the Indicator level wherein the quote was read for themes of Ecology, Economics, or Community (Step 1, Figure 6). If the quote demonstrated one of these themes at the Indicator level, then it was analysed at the Dimensions level (within the identified Indicator) (Step 2, Figure 6). For example, if the Indicator was Economy, the analysis would only look at Dimensions under Economy and Dimensions under Ecology and Community would not be considered. If the quote did not match with any Dimensions, then analysis stopped here and the quote could only be analysed to the Indicator level (Step 1, Figure 6). If the quote had information relevant at the Dimensions level, then it was analysed at the Metric level (within the identified Dimension) (Step 3, Figure 6). For example, if the identified Dimension was Harvest Assets, only the Metrics under Harvest Assets (such as Functionality of Harvest Capital) would be considered. If the quote did not match any Metrics, then the quote could only be analysed to the Dimension level (Step 2, Figure 6). This analysis process resulted in 'framework combinations' which described how much detail a quote referenced in certain aspect of fisheries performance. The combinations resulting from the analysis included: 'Indicator Only', 'Indicator + Dimension', and 'Indicator + Dimension + Metric' combinations (Examples of each combination in Table 5). If the quote represented multiple Indicators, Dimensions, or Metrics, then the analysis would be repeated until all combinations were identified. Finally, the number of unique combinations per study and number of times a combination occurred per fishery (European or Atlantic Canadian) were totaled.

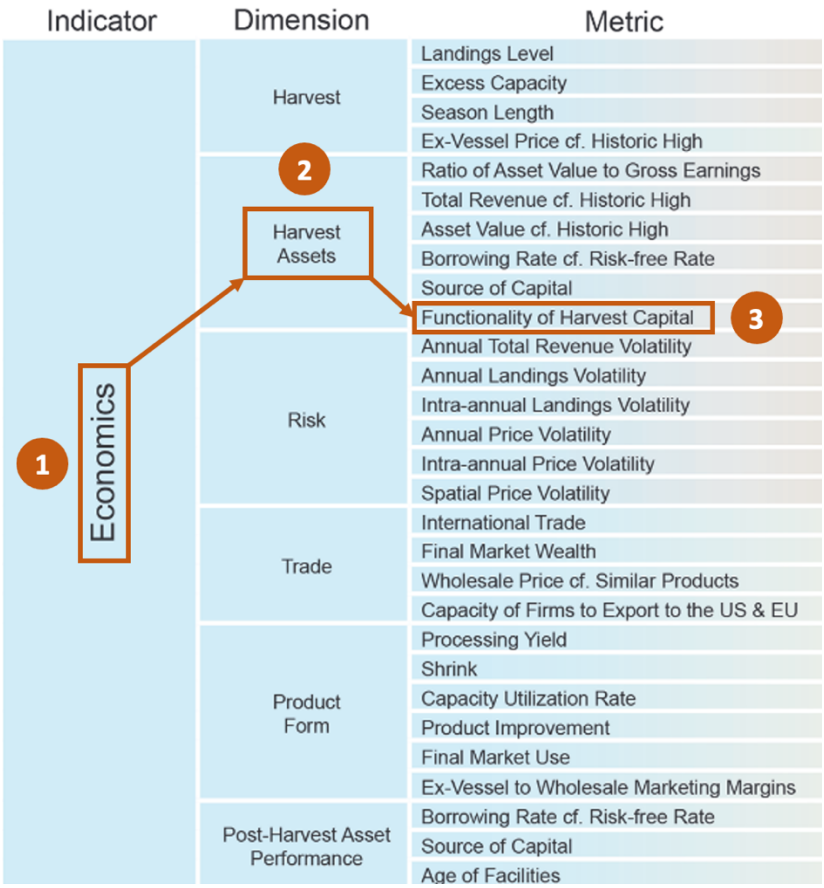

Figure 6: Steps used to analyse information about green crab fisheries using a fisheries performance framework. Analysis resulted in a framework combination. The combination in this figure is 'Economics + Harvest Assets + Functionality of Harvest Capital'. Adapted from Figure 1 from Anderson et al. (2015).

Table 5: Examples of framework combinations.

	Indicator Only	**Indicator + Dimension**	**Indicator + Dimension + Metric**
Quote	"Fyke nets do not require bait and are **widely available from their use in the local American eel (Anguilla rostrata) inshore soft-bottom fishery** (Cairns et al. 2007, 2013), providing **start-up cost reductions** that are desirable from a fishery sustainability perspective." (Poirier et al., 2020)	"In this review, we critically assess microplastics research with relevance to fishing and aquaculture, the **health of commercially exploited organisms**, and food security; to understand the current state of microplastics research and evaluate whether microplastics pose a risk to food security." (Walkinshaw et al., 2020)	"Besides their **economic importance** in the **food flavoring industry**, green crabs are often harvested for recreational purposes." (Vale & Sampayo, 2002)
Indicator	Community	Ecology	Economics
Dimension	N/A	Fish Stock Health & Environmental Performance	Product Form
Metric	N/A	N/A	Final Market Use
Final Combination	**Community**	**Ecology + Fish Stock Health & Environmental Performance**	**Economics + Product Form + Final Market Use**

3. CHAPTER THREE: RESULTS

The scoping literature review resulted in a limited body of literature with 30 relevant studies identified. There was an even distribution of European literature and Atlantic Canadian literature with 15 studies each (Table 6). The European studies spanned from 1994 to 2021 and consisted of only peer-reviewed journal articles and no grey literature. Portugal was mentioned the most (7 studies) followed by the UK (5 studies combining mentions of the UK, England, and Scotland), Spain (3 studies), and France (1 study). The Atlantic Canadian studies spanned from 2004 to 2022 and included 6 peer-reviewed journal articles and 9 grey literature reports. Nova Scotia and Newfoundland were mentioned the most often (6 studies) followed closely by Prince Edward Island (4 studies). New Brunswick was only mentioned in one study.

Table 6: Summary of literature characteristics.

	Europe	**Atlantic Canada**
Literature type	15 peer-reviewed 0 grey **15 total**	6 peer-reviewed 9 grey **15 total**
Date range	1994 – 2021	2004 – 2022
Fishery place	Portugal (7 studies) United Kingdom (5 studies) Spain (3 studies) France (1 study)	Nova Scotia (6 studies) Newfoundland (6 studies) Prince Edward Island (4 studies) New Brunswick (1 study)

Through the application of the modified Anderson et al. (2015) framework, 16 unique framework combinations were identified across the 30 studies (Figure 7). All three of the framework's Indicators (Ecology, Economics, and Community) were identified as 'Indicator Only' combinations (Figure 7). The 'Indicator Only' combinations were present only in Atlantic Canadian literature; The Ecology and Economic Indicators

were identified in 1 study each and the Community Indicator was identified in 3 studies (Table 7).

There were 3 ‘Indicator + Dimension’ combinations identified (Figure 7). The ‘Fish Stock Health & Environmental Performance’ Dimension was found in 2 European and 1 Atlantic Canadian studies, the ‘Harvest’ Dimension was found in 1 European study but not in Atlantic Canadian studies, and the ‘Product Form’ Dimension was found in 2 Atlantic Canadian studies but no European studies (Table 7).

Lastly, there were 10 ‘Indicator + Dimension + Metric’ combinations identified in the literature (Figure 7). There were 3 metrics under Ecology, including ‘Degree of Overfishing’ (2 European studies (EU), no Atlantic Canadian studies (CA)), 'Stock Declining, Stable, or Rebuilding’ (2 EU, 1 CA), and ‘Illegal, Unregulated or Unreported Landings’ (1 EU, 0 CA) (Table 7). There were 7 metrics under Economy, including ‘Landings Level’ (2 EU, 6 CA), ‘Asset Value cf. Historic High’ (1 EU, 0 CA), ‘Annual Landings Volatility’ (1 EU, 0 CA), ‘Annual Price Volatility’ (1 EU, 0 CA), ‘Processing Yield’ (0 EU, 3 CA), ‘Product Improvement’ (1 EU, 4 CA), and ‘Final Market Use’ (3 EU, 1 CA) (Table 7).

All three Indicators, 3 of 14 Dimensions, and 10 of 68 Metrics were identified in the literature (Figure 7). Economic fishery performance was the best represented in the literature with 10 combinations, followed by Ecology with 5 combinations, and Community was the least represented with only 1 combination (Table 7).

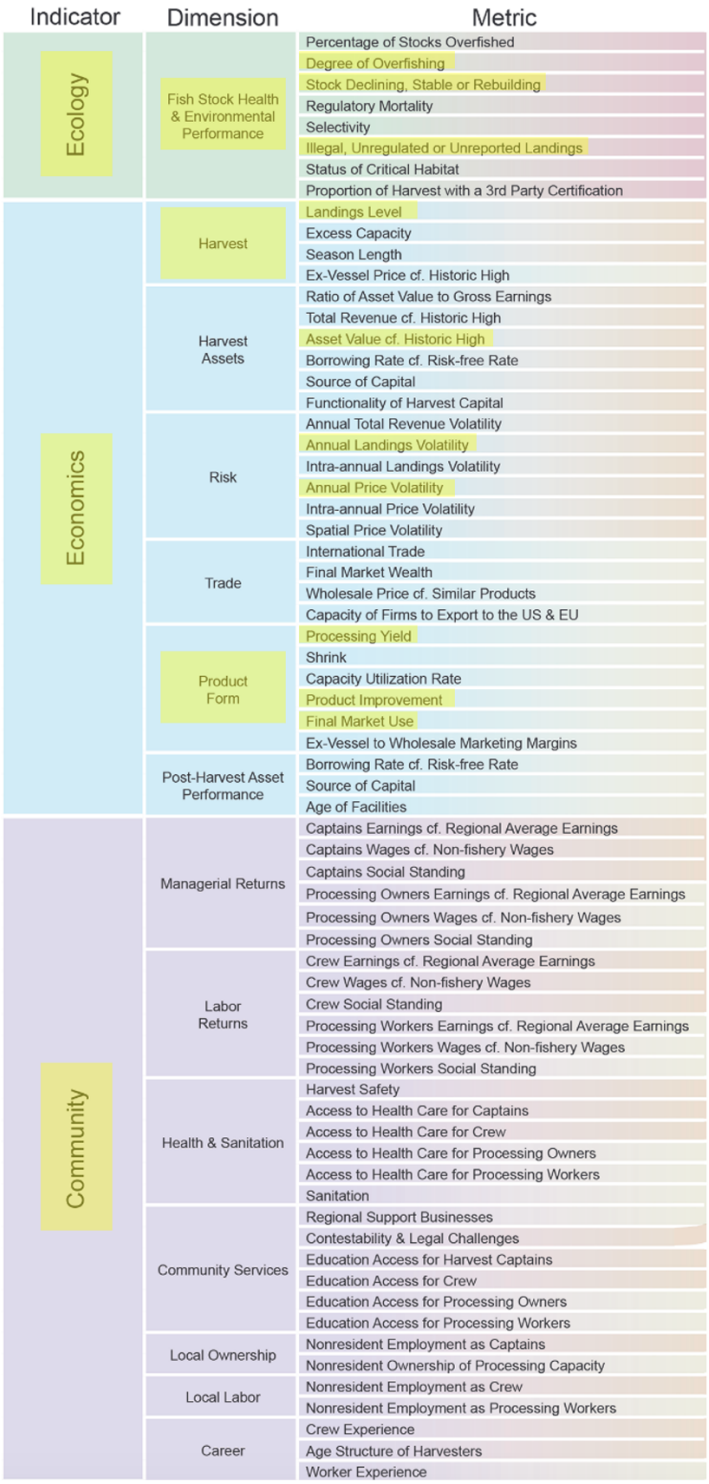

Figure 7: The 16 combinations (highlighted in yellow) identified in fisheries literature through framework analysis. Each yellow highlight represents one combination (e.g., the highlighted 'Annual Price Volatility' represents the 'Economics + Risk + Annual Price Volatility' combination). Adapted from Figure 1 from Anderson et al. (2015).

Table 7: The combinations identified within the literature and the number of studies per combination. EU = European fishery, CA = Atlantic Canadian fishery.

Combination	Number of studies	
	EU	CA
Ecology	0	1
Ecology + Fish Stock Health & Environmental Performance	2	1
Ecology + Fish Stock Health & Environmental Performance + Degree of Overfishing	2	0
Ecology + Fish Stock Health & Environmental Performance + Stock Declining, Stable or Rebuilding	2	1
Ecology + Fish Stock Health & Environmental Performance + Illegal, Unregulated or Unreported Landings	1	0
Economics	0	1
Economics + Harvest	1	0
Economics + Product Form	0	2
Economics + Harvest + Landings Level	2	6
Economics + Harvest Assets + Asset Value cf. Historic High	1	0
Economics + Risk + Annual Landings Volatility	1	0
Economics + Risk + Annual Price Volatility	1	0
Economics + Product Form + Processing Yield	0	3
Economics + Product Form + Product Improvement	1	4
Economics + Product Form + Final Market Use	3	1
Community	0	3

3.1 Economics

The Economics indicator was identified most frequently in the literature. It had 7 'Indicator + Dimension + Metric' combinations, 2 'Indicator + Dimension' combinations, and 1 'Indicator Only' combination (Table 8). There were more studies that mentioned Atlantic Canadian fisheries (17 studies) than European fisheries (10 studies) (Table 8).

Table 8: The Economic combinations identified within the literature and the number of studies per combination. EU = European fishery, CA = Atlantic Canadian fishery.

Combination	Number of studies	
	EU	**CA**
Economics	0	1
Economics + Harvest	1	0
Economics + Product Form	0	2
Economics + Harvest + Landings Level	2	6
Economics + Harvest Assets + Asset Value cf. Historic High	1	0
Economics + Risk + Annual Landings Volatility	1	0
Economics + Risk + Annual Price Volatility	1	0
Economics + Product Form + Processing Yield	0	3
Economics + Product Form + Product Improvement	1	4
Economics + Product Form + Final Market Use	3	1
TOTAL	**10**	**17**

3.1.1 European Fisheries

The European fisheries were represented by 7 framework combinations and the most common one was the 'Economics + Product Form + Final Market Use' combination with 3 studies (Table 8). To be identified under 'Final Market Use', studies had to mention the specific form a green crab is sold as. Relevant studies identified green crab market uses as whole, unprocessed crabs – live or dead – for human consumption (Robson et al., 2007) or bait (Sheehan et al., 2008), fresh cooked crabmeat, canned crabmeat (Robson et al., 2007) and food flavoring (Vale & Sampayo, 2002). Under the same Dimension as 'Final Market Use' was the 'Product Improvement' metric. To be identified as 'Product Improvement', studies had to consider new green crab products or ways current green crab products could improve. The 'Product Improvement' metric was represented by Robson et al. as this study acknowledged the risks with shipping, storing, and selling whole, unprocessed green crabs and they investigated how crab shelf life

could be improved (2007). They found that green crab shelf life can be extended when chilled at 41°C (Robson et al., 2007), thus improving the final market product.

The next most common combination was the 'Landings Level' metric, represented by 2 studies. To be identified under 'Landings Level' a study had to quantitatively describe fishery landings. For landings, Klassen & Locke stated that green crab fisheries in Portugal, Spain, France, and England averaged 200 tonnes per year from 1982-1987 and that the fisheries in France, Portugal, and Spain averaged 900 tonnes per year as of 1997 (2007). This indicated that within 10 years the fisheries in France, Portugal, and Spain must have seen a substantial increase in green crab landing levels for the average catch to change so drastically. Klassen & Locke briefly commented on the landing levels in Scotland by saying that catches are small and irregular (2007). As this was a qualitative observation on landings it could not be identified to the 'Landings Level' metric but because it still recognized green crab landings it was instead identified at the less specific 'Harvest' dimension. Pita et al. also provided quantitative representations of green crab landings in Europe, stating that from 2003-2015, 77.27 tonnes of green crab were caught in Galicia, Spain with a decreasing annual catch variation of -0.65 kg (representing the 'Annual Landings Volatility' metric by providing a quantitative description of catch variation) (2019). Overall, these studies provided both broad and highly specific examples of European green crab fishery landings with contrasting views on landing growth.

Lastly, the study by Pita et al. was the only study with information identifiable as 'Asset Value cf. Historic High' and 'Annual Price Volatility' metrics. To be classified under these metrics, studies had to provide quantitative evidence of asset value or price volatility, respectively. Pita et al. stated that the green crab catch in Galicia (from 2003-2015) was evaluated at 0.07 M€ or 0.74 € per kg with positive annual variation of 9.18 € or 0.08 € per kg (2019).

3.1.2 Atlantic Canadian Fisheries

The Atlantic Canadian fisheries were represented by 6 framework combinations and the 'Economics + Harvest + Landings Level' combination was identified most frequently with 6 studies (Table 8). Mentions of landings levels for Atlantic Canadian

green crab fisheries were in association with trial fisheries, trial harvests, or experimental licenses. Klassen & Locke reported that a harvesting trial in 2002 in PEI caught 15,000 green crabs in 14 days with catch rates of >100 crabs per trap which weighed >7 kg per trap (2007). Additionally, in 2009, experimental trapping in Basin Head, PEI, resulted in a total catch of 12,500 crabs (DFO, 2011). In Newfoundland, collaboration between DFO and Fish Food and Allied Workers caught approximately 14,500 kg (2008-2009), 24,000 kg (2014-2016), and 400,000 kg (2017-2021) of green crab in Placentia Bay (DFO, 2011, 2022; McKenzie et al., 2011). In southern Nova Scotia, an experimental fishery from 2011-2015 averaged 50 crabs per trap per day and caught 157 tonnes of green crab (Vercaemer et al., 2016). The only mention of green crab landings in New Brunswick reported that less than 5 crabs/trap/day were caught along the province's southwest shore (Vercaemer et al., 2016). The last study to mention landing levels in Atlantic Canada was by Dave & Routray wherein they stated that commercial green crab catches in Nova Scotia, PEI, and Newfoundland increased from 27,042 tonnes to 101,382 tonnes from 1990-2014 (2018).

The second most frequent combination was 'Economics + Product Form + Product Improvement' with 4 studies, followed by 'Economics + Product Form + Processing Yield' (3 studies), 'Economics + Product Form' (2 studies), and then 'Economics + Product Form + Final Market Use' (1 study). These combinations related to green crab products and how they are sold. To be identified as 'Product Improvement', a study had to mention green crab product development or novel uses for green crabs. Currently, the final market use for green crabs in Atlantic Canada is bait (Mckenzie et al., 2022) but multiple Canadian studies looked into ways to improve the marketability of green crabs by reimagining their end use (i.e., they identified 'Product Improvement'). Aside from marketing the green crabs as soft-shell crabs or crab pastes (as in Europe), studies also suggested improving the green crab product by using green crab in compost, fertilizer (Mckenzie et al., 2022), pet and aquaculture food, nutraceuticals (Locke & Klassen, 2008; Vercaemer et al., 2016), and bioplastics (Bernier et al., 2020). Green crab nutraceuticals were of particular interest in Canadian literature and it was in these studies that the 'Processing Yield' metric was identified. 'Processing Yield' was identified when studies spoke of green crab products and attempts to refine or increase the product yield.

Relevant ‘Processing Yield’ studies focused on green crab nutraceutical oils and bioproducts (such as chitin, carotenoproteins, or omega-3 fatty acids) and experimental chemical processes designed to refine nutraceutical output (Dave & Routray, 2018; Naczk et al., 2004; Zhang et al., 2022). Lastly, if the study did not directly mention green crab products, product improvement, or product yield but still discussed the sale of green crab, then it was identified as ‘Product Form’. Studies by Klassen & Locke and Bernier et al. represented ‘Product Form’ as they discussed how the marketability of green crab must be considered while developing the Atlantic Canadian green crab fisheries (2007; 2020).

Lastly, there was 1 study with an ‘Economics’ (‘Indicator Only’) combination because the study’s information was not specific enough to identify it to a Dimension or Metric level, but it still had an economic focus. The relevant study was by Poirier et al., (2018) where they advocate for bycatch reduction devices on fyke nets used for green crabs in order to “minimize […] economic impacts of [the] new fishery.” (pg 166) (2018).

In general, European and Atlantic Canadian green crab fisheries literature focused on harvest and marketing. The literature provided quantitative descriptions of landings but the data from Atlantic Canada was more spatially and temporally specific than European literature. However, European literature included asset value and volatility information that Atlantic Canadian studies lacked. European literature identified the final market use of green crabs more often than Atlantic Canadian literature, but Atlantic Canadian studies expanded on final market use by exploring product improvement and yield. Finally, trade and post-harvest performance information was not identified in any of the literature.

3.2 Ecology

The Ecology indicator was the second-most represented in the literature. It had 5 combinations with 3 ‘Indicator + Dimension + Metric’ combinations, 1 ‘Indicator + Dimension’ combination, and 1 ‘Indicator Only’ (Table 9). There were more studies that

mentioned European fisheries (7 studies) than Atlantic Canadian fisheries (3 studies) (Table 9).

Table 9: The Ecology combinations identified within the literature and the number of studies per combination. EU = European fishery, CA = Atlantic Canadian fishery.

Combination	Number of studies	
	EU	**CA**
Ecology	0	1
Ecology + Fish Stock Health & Environmental Performance	2	1
Ecology + Fish Stock Health & Environmental Performance + Degree of Overfishing	2	0
Ecology + Fish Stock Health & Environmental Performance + Stock Declining, Stable or Rebuilding	2	1
Ecology + Fish Stock Health & Environmental Performance + Illegal, Unregulated or Unreported Landings	1	0
TOTAL	**7**	**3**

3.2.1 European Fisheries

The European fisheries were represented by 4 framework combinations and the most frequent combinations were the 'Ecology + Fish Stock Health & Environmental Performance', 'Ecology + Fish Stock Health & Environmental Performance + Degree of Overfishing', and 'Ecology + Fish Stock Health & Environmental Performance + Stock Declining, Stable or Rebuilding' combinations with 2 studies each (Table 9). To be identified under the 'Degree of Overfishing' or 'Stock Declining, Stable or Rebuilding' metrics, the study had to directly reference overfishing or stock dynamics, respectively. In the case of the 'Stock Declining, Stable or Rebuilding' metric, the European green crab stocks were found to be declining. A study on the green crab tilling fishery in the UK by Sheehan et al. noted that the expanding, "highly lucrative" (pg. 308) fishery may be reducing the population's reproductive output (2008). The other study that mentioned

declining European green crab stocks was an Atlantic Canadian-based report by Klassen & Locke (2007). They reference a 1991 study that states overfishing in commercial green crab fisheries in the native European range – specifically in Portugal – have reduced green crab populations (Klassen & Locke, 2007). This observation also applied to the 'Degree of Overfishing' metric. The same 1991 study and its overfishing claim is brought up in another study by Locke & Klassen (2008).

If a study spoke of fish stock dynamics or stock health in ways that did not match with framework metrics, then it was identified to the "Fish Stock Health & Environmental Performance" dimension. This combination was identified in studies from Walkinshaw et al. (2020) and Vital et al. (2021) which both concerned microplastics. Here, the focus was on if and how ingested microplastics affected green crab health and edibility. Walkinshaw et al. conducted a literature review to assess current microplastic research and the risk to commercial aquatic species and reported that green crabs had been found to retain microplastics (2020). Vital et al. determined that green crabs do ingest microplastics but focused more on human ingestion and human health aspects of microplastics (2021). Ultimately, these two studies demonstrated at least a partial awareness in European literature as to how green crab stocks interact with microplastic pollution.

The last combination was 'Ecology + Fish Stock Health & Environmental Performance + Illegal, Unregulated or Unreported Landings' and to be considered under this metric, the study had to directly reference illegal, unregulated, or unreported (IUU) landings. This combination was identified in a study of Portugal fisheries catches by Leitão et al. (2014). They reported that between 1938 and 2009 green crab contributed 0.02 tonnes (SD = +/- 0.01) or 0.00001 to 0.00007% of the unreported catch in Portugal (Leitão et al., 2014), but did not elaborate further.

3.2.2 Atlantic Canadian Fisheries

The Atlantic Canadian Fisheries were represented by 3 framework combinations with each combination identified in 1 study (Table 9). The 'Stock Declining, Stable or Rebuilding' combination was identified in a study by Bernier et al. as they suggested that a green crab fishery for invasive species management in the Gulf of St. Lawrence should

be cautious and take care to consider fluctuations in green crab abundance (2020). The 'Fish Stock Health & Environmental Performance' combination was identified in a study by Klassen & Locke where they proposed some "stumbling blocks" (pg. 40) that a future green crab fishery may face, including green crab stock health and adjacent environmental effects (2007). Klassen and Locke warned that green crab stocks may not be able to support a commercial fishery, and further discussed how a green crab fishery could negatively affect the environment if they are intentionally introduced to uninvaded areas to establish a fishery (2007). The study also highlighted that other fishery and aquaculture representatives hold reservations about the fishery in fear that fishery management (and by extension, stock management) will outweigh invasive species management and a fishery would spread the green crab population (Klassen & Locke, 2007).

Finally, the 'Ecology' combination was identified in Poirier et al. (2018). The 'Ecology' combination was used if a study identified ecological aspects of green crab fisheries that did not match the Dimensions or Metrics. Poirier et al. focused on developing a bycatch reduction device for use in a green crab fishery, emphasizing that a green crab fishery should attempt to limit the amount of bycatch (particularly for other commercially valuable species) (2018). Due to the scope of the study (bycatch reduction device development), there was little information directly pertaining to green crab ecology. However, this study was assigned the 'Ecology' combination because it considered the ecological effects that a green crab fishery could have on other marine life.

European literature spoke more often and in higher detail about ecological performance indicators than Atlantic Canadian studies. The content of European literature suggests that Europe is aware of green crab stock health and possible reasons why (e.g., overfishing, IUU landings, interactions with microplastics). Conversely, Atlantic Canadian literature suggests there is concern about commercial green crab stocks and how green crabs will affect other commercial fishery stock health. In general, European literature focused on impacts *on* green crab fisheries while Atlantic Canadian literature focused on impacts *of* green crab fisheries. However, across the literature there is an overall low amount of detail about any ecological performance indicator.

3.3 Community

The least represented framework category was Community with only 3 Atlantic Canadian studies assigned to this Indicator. There were no applicable dimensions or metrics and thus community impacts of green crab fisheries were only discernable at a high level for Atlantic Canada. There were no European studies aligned with the Community indicator.

The 3 studies identified as having a loose idea of community impact (according to the framework) were Favaro et al. (2020), Poirier et al. (2018), and Poirier et al. (2020). Favaro et al. conducted a study on the effectiveness of different kinds of bait for green crab capture in Newfoundland. When they chose their bait types (herring, mussels, squid, and cod), it was with consideration for what was readily available for local fishers and what was produced through local fisheries and aquaculture (Favaro et al., 2020). This study demonstrated community aspects because it focused on local bait that could be cost-effective or easy to procure for Newfoundland fishers, which could potentially lower operating costs in green crab fisheries. In the Poirier et al. (2018) study, the goal was to build a bycatch reduction device for fyke nets for use in a PEI green crab fishery. Here, the fyke net improvement was more important than inventing a new, green crab specific trap because the fyke net is already used in PEI eel fisheries (Poirier et al., 2018). The community aspect in this study was apparent as Poirier et al. (2018) took care to consider existing equipment that would reduce green crab fishery start-up costs, fashioned the bycatch reduction device out of easily accessible and inexpensive materials, and made it reversable so fishers could participate in eel and green crab fisheries. In 2020, Poirier et al. revisited the fyke net in a study comparing fyke nets and Fukui traps for green crab capture. Again, communities were taken into consideration as fyke nets were recommended due to prior usage in local PEI fisheries and their ability to function without bait which could reduce start-up and operational costs (Poirier et al., 2020).

The literature above does suggest some thought is being put into how a green crab fishery can affect local communities, but ultimately it appears that community aspects are not evaluated or documented to the extent that economic or ecological aspects are. This represents a significant gap in the literature. Even when community aspects were present, the literature was not specific enough to evaluate the Community dimensions and metrics

proposed by Anderson et al. (2015). Additionally, the literature does not identify how European or Atlantic Canadian green crab fisheries approach health and safety, education, or employee benefits.

3.4 Acknowledging Fisheries

Of the 30 relevant studies, 9 did not meet any of the framework's metrics, dimensions, or indicators (Table 10). Instead, they only acknowledged the existence of a fishery but did not elaborate further, preventing the application the framework.

Seven of these nine studies acknowledged European fisheries. The studies said that the green crab was a popular consumed crab, that it was fished, that it was purchased, and that it was a species of commercial value (Table 10). While it could be argued that these descriptions could fall under the Economic indicator, it was ultimately decided that the lack of supporting details in the studies made it difficult to meaningfully assess economic aspects, and thus these studies were considered as just acknowledging a fishery. While some studies stated that the green crab was a commercial fishery product, two studies indicated otherwise (Table 10). Batista et al. (2015) stated that green crab was of "no or few commercial value" (pg. 171) while Maulvault et al. (2016) still acknowledged that green crabs were consumed but considered them "less important" (pg. 774) than other consumed seafood.

Typically, the European studies focused on European fisheries but there was one European study by Mancinelli et al. (2017) which mentioned the Atlantic Canadian green crab fishery. This study focused on invasive blue crab (*Callinectes sapidus*) in Europe, but touched on the experimental green crab fishery implemented by DFO as an example of an invasive crab fishery. The only other study to acknowledge the Atlantic Canadian green crab fisheries was a Canadian-based study by Tremblay et al. (2006) wherein it was stated that "at the time of writing there is a proposed experimental [green crab] fishery" (pg. 6).

Table 10: Acknowledgment of European and Atlantic Canadian green crab fisheries. EU = Europe, CA = Atlantic Canada.

Study Perspective	Acknowledged fishery	Quote	Reference
EU	EU	"Carrasqueira fishermen trawl the area for estuarine species that […] are important natural resources for human food intake, such as […] the crab *Carcinus maenas* […]"	(Machado et al., 2017)
EU	EU	Green crab "were purchased from local fishermen in four fishing ports along the Tarragona coast"	(Schuhmacher et al., 1994)
EU	EU	Green crab described as a "target species" under the "main fisheries prosecuted by the Scottish under 15 m fleet"	(Kafas et al., 2017)
EU	EU	"[…] this species [green crab] is one of the most important and exploited natural resources in temperate estuarine systems […]"	(Pereira et al., 2006)
EU	EU	"The most relevant crabs consumed in Europe are the brown crab (*Cancer pagurus*), velvet crab (*Necora puber*), spider crab (*Maja squinado* or *Maja brachydactyla*), and green crab (*Carcinus maenas*)."	(Anacleto et al., 2016)
EU	EU	Green crab considered of "no or few commercial value"	(Batista et al., 2015)
EU	EU	"The less important species [consumed] are lobsters, spider	(Maulvault et al., 2016)

Study Perspective	Acknowledged fishery	Quote	Reference
		crabs, Norway lobster, velvet crabs, European lobsters, and green crabs, contributing with 36% of crustaceans' consumption […]"	
EU	CA	"[…] the Department of Fisheries and Oceans in Canada has begun experimenting with a commercial green crab fishery."	(Mancinelli et al., 2017)
CA	CA	"At the time of writing there is a proposed experimental fishery for green crab that may help to keep green crab in check."	(Tremblay et al., 2006)

4. CHAPTER FOUR: DISCUSSION AND RECOMMENDATIONS

This study asked, "What is known about European and Atlantic Canadian green crab fisheries (within peer-reviewed and grey literature) and how can this information be used to inform fisheries managers of gaps and opportunities in fisheries-based invasive species management?". The question was explored through three goals; 1) determine what is known about the European and Atlantic Canadian fisheries through a fishery performance framework lens; 2) compare the European fisheries and the Atlantic Canadian fisheries (using what was determined in Goal 1) to identify gaps in the literature; and 3) suggest areas for future green crab fisheries research with a focus on invasive population management. Goal 1 was addressed in the Methods and Results sections, and Goals 2 and 3 will be addressed in this discussion.

The results from the scoping literature review identified both technical characteristics of the literature and more specific, framework-contextualized information about the fisheries. For the technical literature characteristics, it was found that the body of literature on green crab fisheries was limited, both in number of studies and details about the fisheries. European and Atlantic Canadian literature were represented equally

when the studies were categorized by location. However, when the European and Atlantic Canadian studies were further analysed to determine which countries or provinces were mentioned regarding fisheries, certain locations were mentioned more frequently than others.

For the framework-contextualized information, it was found that Economic fishery performance Indicators were discussed most frequently in green crab fisheries literature, followed by Ecology Indicators, and then Community Indicators which were severely underrepresented in the literature. Under the Economic Indicator, it was found that European literature discussed green crab final market use more than any other Dimension whereas Atlantic Canadian literature discussed harvest landing Metrics most frequently. Under the Ecology Indicator, there were no dominant Metrics represented in either European or Atlantic Canadian studies. Lastly, the Community Indicator had results that significantly differed from the Economic and Ecology Indicators. Only Atlantic Canadian studies explored community aspects of fisheries performance and the community aspects were not identified past the Indicator level.

The following section will compare the European and Atlantic Canadian literature (Goal 2) and discuss possibilities for why certain performance metrics appeared more frequently than others. The discussion will also address the limitations of this study's design, the framework, and study content. Finally, the discussion will conclude by suggesting areas for future green crab fisheries research and recommending actions for green crab fisheries managers (Goal 3).

4.1 Overview of Identified Literature

The body of relevant literature identified in this study included 30 studies, with 21 from the primarily scientific (peer-reviewed) literature and 9 from the grey literature. This body of literature was limited as fisheries literature only represented 20% of green crab literature identified during the title and abstract screening stage (30 relevant studies out of 147 potential studies).

The literature was also limited in study detail. Of the 30 studies, many only gave high-level observations about green crab fisheries but did not include more specific or fishery-level information, and 30% of the relevant studies (9 studies) had such high-level

observations that they only acknowledged a green crab fishery's existence. For example, Sheehan et al. identified green crab fisheries in the title, but the study only made brief observations on green crab final market use and stock health and instead focused on how reduced populations of green crab affect mudflat ecology (2008). This study was captured during the search as the title contained the keywords 'fishery' and 'green crab' and the abstract stated that the green crab was a target species for the title fishery. Despite the matching keywords, the study placed more emphasis on other species' health than the focal fishery. Ultimately, the studies that only provided high level observations, such as the study by Sheehan et al. (2008), were still included in the review as they directly mentioned green crab fisheries and it was decided that more information was better than less.

The overall lack of in-depth information on green crab fisheries made it challenging to identify fishery performance indicators from the framework; Only 10 of 68 metrics and 3 of 14 dimensions were applicable to the literature. Less than 15% of the metrics were identifiable in the green crab fishery literature. Despite challenges in identifying literature with robust and detailed descriptions of green crab fisheries, comparisons between the European and Atlantic fisheries were still possible with those studies that met the inclusion criteria of this review.

The size and level of detail of the relevant European and Atlantic Canadian green crab fisheries literature suggests that the fisheries are not well represented in both peer-reviewed and grey literature. Green crab research may be focused on other topics; During screening it was noted that many of the rejected studies focused on green crab physiology, so perhaps green crab research from the past 20 to 30 years has focused on biological sciences rather than fisheries management.

The relevant literature was also categorized by location to determine the geographic characteristics of the 30 relevant studies. It was found that European and Atlantic Canadian studies were equally represented as there were 15 studies for both locations. However, when the studies were further analysed by country or province, there were locations that were mentioned more frequently than others.

For European green crab fisheries, Portugal's (7 studies) and the UK's (5 studies) fisheries were mentioned most frequently. One could theorize that there is a correlation

between the number of times a fishery was mentioned and a country's fishery output (i.e., the more fish a country captures, the more likely a green crab fishery will be mentioned), however, this is not the case. Spanish fisheries produce 5 times more than Portuguese fisheries and 1.3 times more than UK fisheries (as of 2020) (Ritchie & Roser, 2021), but both Portugal and UK were mentioned more frequently than Spain (3 studies). Therefore, it is unlikely that there is a correlation between the number of studies a green crab fishery was mentioned in and the country's total fishery production. Other possible explanations as to why the Portuguese and the UK fisheries were mentioned most frequently in the literature could be green crab landings, fleet size, or cultural importance of green crab.

For Atlantic Canadian fisheries, the Nova Scotia, Newfoundland, and PEI fisheries were represented almost equally (NS and NL = 6 studies, PEI = 4 studies) and green crab trapping in New Brunswick was only mentioned once. This disparity is interesting as green crabs are well established in the Atlantic provinces and New Brunswick is no exception, as the crabs are found in both the Bay of Fundy and Gulf of Saint Laurence (Figure 8). Therefore, the apparent lack of New Brunswick green crab fisheries is likely not due to crab distribution. Instead, the province appears to be focusing on alternative forms of green crab management that involves trapping green crabs (as mentioned in Bernier et al. (2020)) but a commercial fishery is not yet being considered. Additionally, it is possible that the literature failed to attribute a fishery to New Brunswick specifically (unlike the directly mentioned Nova Scotia, PEI, and Newfoundland fisheries) but instead called it a Gulf Region fishery. For example, a 2015 – 2017 pilot green crab fishery Gulf Region fishery was mentioned by Bernier et al. (2020) but could not be definitively counted as a New Brunswick fishery.

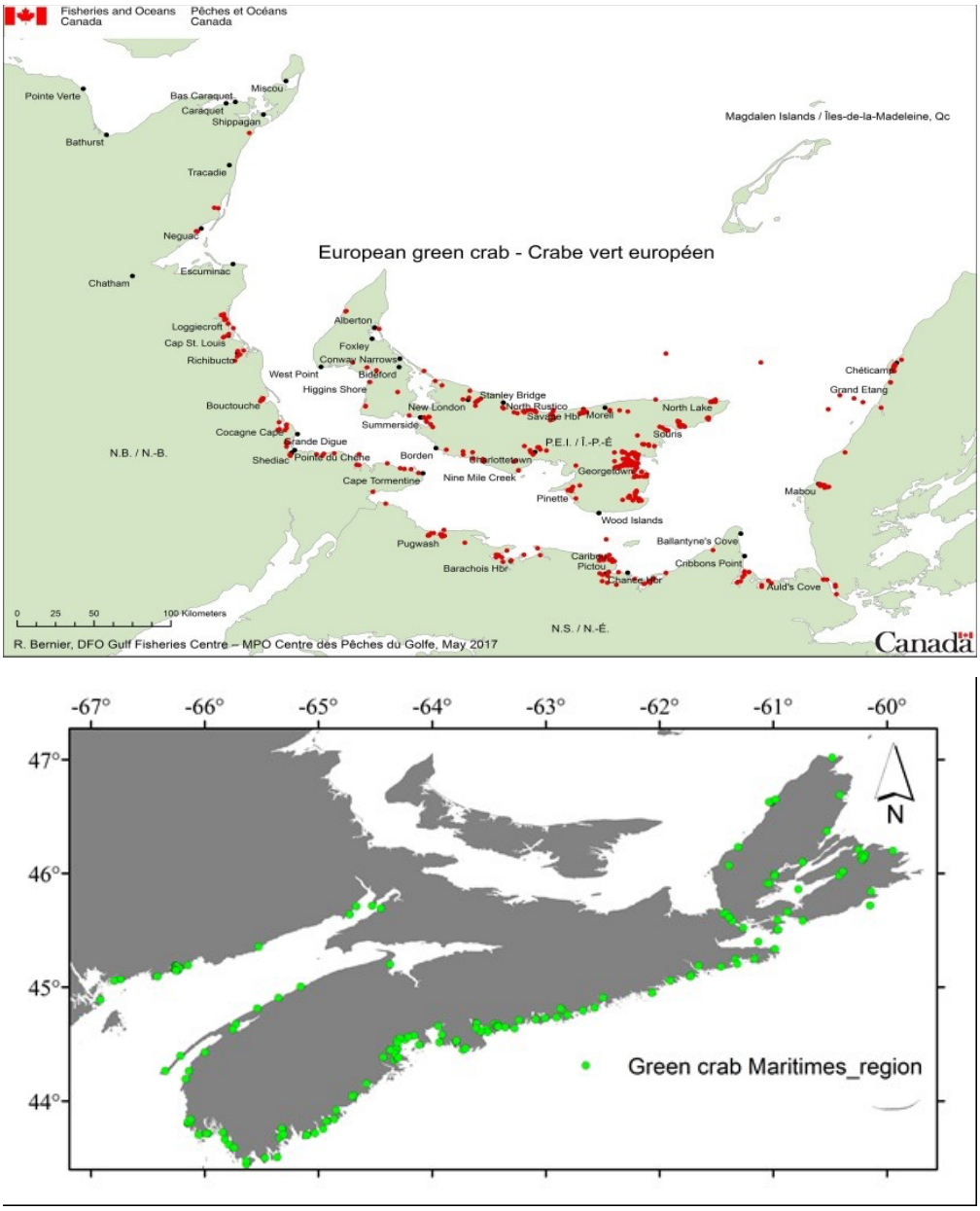

Figure 8: Maps showing green crab distribution in New Brunswick (represented by red dots on top map and green dots on bottom map) (Government of Canada, 2019b).

4.2 Comparison of European and Atlantic Canadian Fisheries Literature

This study sought to determine what was known about European and Atlantic Canadian green crab fisheries (Goal 1) and compare the literature to identify gaps (Goal 2). Under the Economic Indicator, it was found that European literature discussed green

crab final market use more than any other economic dimension whereas Atlantic Canadian literature discussed harvest landing metrics most frequently. Under the Ecology Indicator, there were no dominant metrics represented in either European or Atlantic Canadian studies. Lastly, only Atlantic Canadian studies explored Community aspects of fisheries performance and the Community aspects were not identified past the Indicator level.

4.2.1 Economics

The Economics indicator was identified most frequently in the literature through themes of green crab market use and harvest data. Studies on Europe's green crab fishery gave the impression of a long-time fishery that had found its niche and perhaps novel product development was not of high importance. In the literature, discussion of final market use simply noted the popular value-added formats of green crab sale (e.g., whole crab, canned meat, flavorings, etc.). Only one study mentioned product improvement where the study focused on improving whole crab transportation (Robson et al., 2007), but did not suggest new or novel uses for the green crab. Conversely, Atlantic Canadian fisheries literature was quite different and painted a picture of a burgeoning fishery with ideas on how to improve the product. There were 4 times as many Atlantic Canadian studies on green crab product improvement than European studies. The current market use for green crabs in Atlantic Canada is bait (Mckenzie et al., 2022) but studies indicated that market research and development was occurring. Departing from the current final market use, studies suggested novel green crab products such as animal foods, fertilizers, and nutraceuticals. The literature also moved beyond just suggesting new products as 3 studies focused on refining methodology for green crab nutraceuticals, representing the 'Processing Yield' metric that was missing in European literature. There is currently little or no food market for green crab in Atlantic Canada (Klassen & Locke, 2007) and if these fisheries are to be successful and long-running like the European fisheries, then innovation must occur. These Atlantic Canadian studies suggested that the need for innovation is understood and as green crab fisheries develop, so do green crab products.

Additionally, the Atlantic Canadian fisheries literature contained more thorough harvest data than European literature. All four of the Atlantic Provinces had harvest data

represented in the literature and landings were generally reported annually or in <5-year increments. Harvest data was reported differently in European literature. In some studies, harvest data combined data from multiple countries and averaged landings across multiple years, and in others, harvest data was narrowed down to a community level. Differences in governmental landing reporting systems may explain why European catch data shows up less often in the literature than Atlantic Canadian data. The experimental green crab fisheries in Atlantic Canada were established by DFO, which is also the governing body that collects fisheries landings in Canada (Government of Canada, 2016). As DFO would have had been very involved in experimental fishery set up and monitoring, it could have been simple for DFO to collect landings from the experimental fisheries either from fishers they had been working with or by reporting landings themselves. This easy reporting opportunity may explain why Atlantic Canadian literature had thorough harvest data. Reporting landings may not be as easy in Europe where fishery governance is driven by the Common Fisheries Policy (CFP) (Pita et al., 2012). The CFP was considered to be a failing policy as its use across multiple countries created unique management challenges and there was weak policy enforcement (Da Rocha et al., 2012; Pita et al., 2012). It is possible that under the CFP, green crab landings were not reliably recorded which resulted in less specific harvest data in fisheries literature. However, in 2012 there was a reform of the CFP which introduced landing obligations (Catchpole et al., 2017), so stricter landing data collection could potentially make its way into future European green crab fisheries literature.

4.2.2 Ecology

The Ecology indicator was the second most identified in the literature. European literature included a variety of ecological information about green crab stock health, including overfishing, stock stability, and illegal, unregulated, and unreported landings. Studies also investigated how microplastic pollution affected green crab health and edibility, which was not identified in Atlantic Canadian studies. Atlantic Canadian literature focused less on the health of the green crab stock and rather on how a green crab fishery might affect native or commercial species. Studies highlighted concerns from fishery and aquaculture representatives who worried that green crab stock health would

overshadow the original invasive species management intent of fisheries and that green crabs could be introduced to uninvaded areas to establish a fishery. Additionally, there was concern about bycatch of native, at risk, or commercial species in green crab traps. Overall, the literature portrayed two very different perspectives on green crab fishery ecology. These perspectives may be based on the concept of indigeneity or invasiveness. For Europe, the green crab fishery is a native species fishery. Some European literature almost lovingly describes the green crab, stating that it is a charismatic coastal species that people form memories around (Morris et al., 2007). Therefore, it is understandable why European ecological literature focused on aspects of green crab stock health as it is both an economically and culturally important species that needs to be kept healthy. Conversely, in Atlantic Canadian literature green crab ecological impacts focus on the crab's invasive status and how it as an invasive predator threatens native species. For example, there are studies that examine the effects of green crabs on American lobster (Lynch & Rochette, 2009; Rayner & McGaw, 2019), which is a native and commercial species in Atlantic Canada, but there are no studies that examine the inverse. Additionally, because the Atlantic Canadian fisheries focuses on invasive population control, poor stock health could even be considered a good outcome toward population control objectives. Poor health would, however, be counterproductive to the goals of a long-term green crab commercial fishery. Ultimately, it is plausible that Atlantic Canadian studies focus on ecological impacts *of* green crabs rather than *on* green crabs because the crabs are a threat to native biodiversity and they need to be removed from the environment.

4.2.3 Community

Comparison between the European and Atlantic Canadian fisheries for the community metric was not possible as there were no Community metrics identified for European fisheries. The lack of considerations of community aspects for the European fishery may be due to the distribution of the fishery. It spans multiple countries in which there are likely many small and distinct green crab fisheries per country. It would be much easier to determine community aspects for Atlantic Canada due to the smaller fishery area and the comparatively smaller number of distinct fisheries. It is also possible

that community impacts are not widely available for specific fisheries, such as green crab, and instead European literature examines community impacts on broader scales. For example, Natale et al. identified fishery dependent communities across Europe but did not focus on a particular fishery (2013). Finally, the lack of community impacts in European green crab literature might be reflective of a Europe-wide knowledge gap, as suggested by Urquhart et al. (2011).

The Community aspects identified in the Atlantic Canadian literature could only be identified to the Indicator level because the studies considered how green crab fisheries could be made more accessible for local fishers and communities, but these aspects did not match framework Dimensions or Metrics. The 3 relevant studies focused on ways to tailor green crab fisheries for local fishing communities by reducing start-up costs or by using materials that fishers already have access to. The studies were place specific (e.g., modifying fyke nets in PEI makes sense because they have an established fyke net eel fishery (Poirier et al., 2018)) but this is not a bad thing. Considering place-specific, local needs and building a fishery around them may be a way for managers to effectively address community fishery performance indicators from the beginning. Ultimately, there were only high-level community concepts identified in Atlantic Canadian studies which is likely reflective of a knowledge gap.

4.3 Limitations

4.3.1 Study Design

This study's design was limiting in certain ways. First, the study was limited to English literature only. Europe is made of many countries with different official languages, so it is possible that a portion of literature was inadvertently missed when studies were screened in English. The study was also limited to European and Atlantic Canadian green crab literature. This was due to time constraints on the researcher. It would be interesting to see how geographically and oceanographically similar places, such as New England, or the opposite coast of North America, such as British Columbia or California, are managing invasive green crab. For example, Grosholz et al. (2021) and McKenzie et al. (2011) (a study already included in the review) talk about the successes and failures of California's green crab eradication program.

The most limiting aspect of this study was the use of only two databases. This was also due to time constraints. ScienceDirect was chosen as it was a broad database but it only searches for peer-reviewed literature. Therefore, the searches would have not returned relevant grey literature such as European reports on the status of the UK (Morris et al., 2007) and Portuguese green crab fisheries (Gomes, 1991). There was also relevant scientific literature (identified from the author's past research) that were not included in the two databases used in this study. These studies focused on Atlantic Canadian research supporting a soft-shell green crab fishery modeled after Italy's moleche fishery (Poirier et al., 2016; St-Hilaire et al., 2016). The body of literature for this review was limited with 30 relevant studies but this suggests that if future reviews included additional databases and locations, the number of relevant studies could increase. An expanded search could aid in identifying what is known about European and Atlantic Canadian green crab fisheries and provide more comparison between fisheries in various geographic and governance contexts.

4.3.2 Framework Limitations and Critique

The framework by Anderson et al. (2015) represented a wide view of fishery performance and management. It included 68 Metrics which meant that there were many ways in which a study could be assessed. However, there were also places in which the framework could use improvement.

The framework's most detailed Indicator was Economics, which included Metrics pertaining to the actual harvest of the product, possible risk associated with sale and stocking, how and where products sold, and post-harvest considerations. The Economy section was structured like a progression through a fishing season and aided in analysing the literature.

The Ecology Indicator had only 1 Dimension with 8 Metrics that were helpful when assessing stock dynamics but none of the metrics assessed species health. Species health could perhaps be implied within the "Fish Stock Health & Environmental Performance" Dimension, but to not have a more specific metric seems like a missed opportunity. This metric would have been useful when the literature investigated how microplastics affected green crab health (Vital et al., 2021; Walkinshaw et al., 2020). A

metric on how the fishery addressed bycatch would be another improvement. During the data extraction phase, it was noted that studies considered the effect of a green crab fishery on the health of non-target species but this was not identifiable at the Metric level. A bycatch Metric would have been useful when analyzing Atlantic Canadian green crab literature as native species bycatch was of concern (Poirier et al., 2018).

The Community Indicator had the highest number of Metrics but analysis of the literature under this Indicator was difficult. The Dimensions represented broad and identifiable ideas on how fisheries interacted with community including community services, local ownership, and local labour, but the Metrics became repetitive or unrelated to its parent Dimension. For example, under the 'Health & Sanitation' and 'Community Service' Dimensions, 4 of 6 Metrics are the same save for slight modifications (Figure 9). Under the 'Local Ownership' Dimension, the two metrics only consider non-resident aspects and do not consider local aspect as the Dimension suggests (Figure 9). Ultimately, this Indicator started off strong with relevant Dimensions but would benefit if the Metrics were reworked to avoid repetition and disconnect.

Figure 9: Examples of Community Metric repetition and disconnect from the parent Dimension. Adapted from Figure 1 from Anderson et al. (2015).

A final suggestion for the framework would be to include a Policy indicator. Policy and governance play large roles in fishery management yet there was no mention of these concepts in the framework. The framework could benefit from an Indicator, Dimensions, and Metrics that reflect these roles.

4.3.3 Study Content Limitations – Indigenous Inclusion

While the relevant studies touched on aspects of ecology, economics, and community, there was one aspect that was missing in the literature: Indigenous knowledge. The Atlantic Provinces are located on the unceded ancestral territory of the Mi'kmaq, also known as Mi'kma'ki. As part of the path towards reconciliation and recognition of the treaty right to hunt, fish, and gather in pursuit of a moderate livelihood, DFO has committed to a reconciliation strategy that prioritizes engagement and collaboration with Indigenous communities (Government of Canada, 2019d, 2021). However, where does an invasive species eradication fishery fit into this?

A study by Wehi et al. (2023) explored the relationships between invasive species and Indigenous peoples in the context of species management. The study first established how Indigenous peoples have unique, biocultural relationships with the world in which humans are not in a place of privilege over other species (Wehi et al., 2023). Then, Wehi et al. discussed how labeling species as 'native' or 'invasive' inherently places positive or negative connotations on a species and disregards any meaningful relationships a species had in its original habitat. In predesignating a species as 'bad', it makes it difficult to determine how human – species relationships will develop (Wehi et al., 2023). Wehi et al. then described an Anishinaabe invasive species framework that explores these relationships ("'Where are you from? How did you get here? What are your intentions? How are you behaving while in our territories? and What gifts or contributions do you offer this community?'" (pg. 1408)). This framework looks at forming positive and reciprocal relationships with invasive species rather than demonizing them, which is often not seen in other forms of invasive species management. Finally, Wehi et al. recognized that eradication of an invasive species is not the only approach for invasive species management and perhaps social/cultural/economic impact-based management

plans may allow for nuanced invasive species management that maintains important Indigenous human – species relationships.

In the green crab context, the study by Wehi et al. offers some interesting roads for discussion between fisheries managers and Indigenous communities. It is true that the green crab is described as an aggressive and destructive invasive species, but realistically the green crab is simply a newcomer to Atlantic Canada and it is trying to survive in an environment it did not ask to be placed in. Are eradication or population depletion the correct management tools for green crab management? Are there ways to manage green crab while respecting human – green crab relationships? Could a fishery provide a respectful and reciprocal relationship with green crabs while also managing the harm caused by green crabs? The gap in Indigenous knowledge in green crab fisheries literature represents an opportunity to explore these questions and open the floor to conversations about the future of green crab fisheries between Indigenous communities, fishery managers, and other stakeholders.

4.4 Management Recommendations

Under the Economics Indicator, it was determined that the Atlantic Canadian fisheries had detailed literature on final market use and harvest data. As both a fishery in its infancy and an invasive species control fishery, it is important that harvest data is collected to monitor population control efforts and economic output. It is therefore recommended that green crab fisheries managers continue to keep detailed records of landings. In conjunction with this recommendation, a research gap was identified as it is currently unknown (or unavailable in the literature) how many green crabs need to be caught to reduce populations to non-destructive levels but also be profitable. This is likely out of the scope of a manager's duties, so it is recommended that the scientific community address this knowledge gap while collaborating with fisheries managers for details on day-to-day landings, trends in catch effort, or population dynamics of note.

Another challenge for the Atlantic Canadian fisheries is that it lacks a market (other than bait) on which to sell the green crabs. To be a successful fishery, people must buy green crab products. Again, this may be outside the managerial scope. Therefore, it is recommended that market researchers determine the interest in, palatability, and

profitability of green crab products in Atlantic Canada. Fisheries managers could aid with this research by monitoring the current green crab markets for fluctuations in price or interest.

Next are the research gaps identified under the Ecology Indicator. First, to address the gaps in knowledge about Atlantic Canadian green crab stock health (such as population fluctuation, physical health of green crabs, and overfishing) further research into how green crab fisheries will maintain stock health while reaching invasive species control goals is recommended. This is complementary with the recommendation that managers and the scientific community determine how many green crabs need to be caught to reduce populations to non-destructive levels but also be profitable (as mentioned in the above Economics suggestion). Stock health is important because even though the fishery is being used to reduce green crab populations (and therefore poor stock health may seem desirable), it is also a commercial fishery and stock health must be maintained so fishers can rely on the fishery. Additionally, it is recommended that as green crab fisheries develop, research into native species bycatch occurs. This gap is important to acknowledge as there could be ways to mitigate bycatch and create a more ecologically sustainable green crab fishery. This could be a collaborative effort between the scientific community and fisheries managers involving research and design of new or modified traps and monitoring bycatch along with green crab landings.

There were large research gaps identified under the Community Indicator as the literature only identified high-level observations of community. Community dynamics are important to understand in fisheries management as fishers form the foundation of any fleet. It is recommended that managers and social scientists conduct more research on community impacts, starting with the metrics identified in the framework by Anderson et al. (2015). This provides the opportunity to assess community needs and incorporate them into the growing green crab fisheries. Managers could conduct research on community aspects through day-to-day interactions with green crab fishers, as even anecdotal conversations with green crab fishers could reveal opportunities for study and community improvement.

Lastly, there is a gap in Indigenous knowledge about green crab fisheries. This is an opportunity wherein managers, scientists, policy makers, and other green crab fishery

stakeholders could collaborate with Indigenous communities to have conversations about the future of green crab fisheries. It is recommended that this collaborative process begins with fisheries representatives reaching out and establishing relationships with Indigenous communities who are interested in green crab harvest.

4.5 Final Remarks

Ultimately, this study and these recommendations are important because green crabs are a management concern for Atlantic Canada. There is an opportunity to develop commercial fisheries as a population control tool, but for that effort to be successful, fisheries managers must first be aware of what is *known* about the green crab fisheries, what is *not known* about the fisheries, and how the fisheries can grow and improve for better green crab management. Through a scoping literature review of two databases, this study addressed these statements by determining what is available in the literature concerning European and Atlantic Canadian green crab fishery economics, ecology, and community, comparing the aspects to identify knowledge gaps, and suggested opportunities for research and collaboration. Invasive species management is a complex issue but by better understanding the green crab problems and opportunities, managers can make well-informed management decisions.

REFERENCES

Anacleto, P., Maulvault, A. L., Barbosa, V., Nunes, M. L., & Marques, A. (2016). *Shellfish: Characteristics of Crustaceans and Mollusks* (pp. 764–771). Academic Press. https://doi.org/10.1016/B978-0-12-384947-2.00623-1

Anderson, J. L., Anderson, C. M., Chu, J., Meredith, J., Asche, F., Sylvia, G., Smith, M. D., Anggraeni, D., Arthur, R., Guttormsen, A., McCluney, J. K., Ward, T., Akpalu, W., Eggert, H., Flores, J., Freeman, M. A., Holland, D. S., Knapp, G., Kobayashi, M., … Valderrama, D. (2015). The Fishery Performance Indicators: A Management Tool for Triple Bottom Line Outcomes. *PLoS ONE*, *10*(5), e0122809. https://doi.org/10.1371/journal.pone.0122809

Batista, M. I., Horta e Costa, B., Gonçalves, L., Henriques, M., Erzini, K., Caselle, J. E., Gonçalves, E. J., & Cabral, H. N. (2015). Assessment of catches, landings and fishing effort as useful tools for MPA management. *Fisheries Research*, *172*, 197–208. https://doi.org/10.1016/j.fishres.2015.07.020

Bernier, R. Y., Poirier, L. A., Ramsay, A., & LeBlanc, A. (2020). *European green crab (Carcinus maenas) population monitoring surveys (2000-2016) and efficacy of traps used for their capture in the southern Gulf of St. Lawrence*.

Cataudella, S., Crosetti, D., Ciccotti, E., & Massa, F. (2015). Sustainable management in Mediterranean coastal lagoons: Interactions among capture fisheries, aquaculture and the environment. *GFCM Studies and Reviews*, *95*, 7–49.

Catchpole, T. L., Ribeiro-Santos, A., Mangi, S. C., Hedley, C., & Gray, T. S. (2017). The challenges of the landing obligation in EU fisheries. *Marine Policy*, *82*, 76–86. https://doi.org/10.1016/j.marpol.2017.05.001

Da Rocha, J.-M., Cerviño, S., & Villasante, S. (2012). The Common Fisheries Policy: An enforcement problem. *Marine Policy*, *36*(6), 1309–1314. https://doi.org/10.1016/j.marpol.2012.02.025

Dave, D., & Routray, W. (2018). Current scenario of Canadian fishery and corresponding underutilized species and fishery byproducts: A potential source of omega-3 fatty acids. *Journal of Cleaner Production*, *180*, 617–641. https://doi.org/10.1016/j.jclepro.2018.01.091

DFO. (2011). *Regional Advisory Process on European Green Crab, (Carcinus maenas), Populations and Mitigations in the Newfoundland and Labrador Region* [DFO Can. Sci. Advis. Sec. Proceed. Ser. 2011/020.]. https://waves-vagues.dfo-mpo.gc.ca/library-bibliotheque/344322.pdf

DFO. (2022). *Comparison of trapping methods for invasive European Green Crab*.

Favaro, B., Butt, M. A., & Bergshoeff, J. A. (2020). Comparison of catch per unit effort of invasive European green crab (Carcinus maenas) across four bait types. *Fisheries Research*, *225*, 105484. https://doi.org/10.1016/j.fishres.2020.105484

Fisheries and Oceans Canada Government of Canada. (2019, May 3). *Control and management of aquatic invasive species*. https://www.dfo-mpo.gc.ca/species-especes/ais-eae/control-management-controle-gestion/index-eng.html

Glamuzina, L., Conides, A., Mancinelli, G., Dobroslavić, T., Bartulović, V., Matić-Skoko, S., & Glamuzina, B. (2017). Population Dynamics and Reproduction of Mediterranean Green Crab Carcinus aestuarii in Parila Lagoon (Neretva Estuary, Adriatic Sea, Croatia) as Fishery Management Tools. *Marine and Coastal Fisheries*, *9*(1), 260–270. https://doi.org/10.1080/19425120.2017.1310155

Gomes, V. (1991). FIRST RESULTS OF TAGGING EXPERIMENTS ON CRAB CARCINUS MAENAS (L.) IN THE RIA DE AVEIRO LAGOON, PORTUGAL. *Ciência Biológica. B, Ecologia e Sistemática*, *11*(1–2), 21–29.

Government of Canada. (2004). *A Canadian Action Plan to Address the Threat of Aquatic Invasive Species*. https://waves-vagues.dfo-mpo.gc.ca/library-bibliotheque/365581.pdf

Government of Canada, F. and O. C. (2016, October 6). *Seafisheries Landings*. https://www.dfo-mpo.gc.ca/stats/commercial/sea-maritimes-eng.htm

Government of Canada, F. and O. C. (2019a, April 9). *European Green Crab*. https://www.dfo-mpo.gc.ca/species-especes/profiles-profils/europeangreencrab-crabevert-eng.html#_Features

Government of Canada, F. and O. C. (2019b, April 9). *European Green Crab*. Fisheries and Oceans Canada. https://www.dfo-mpo.gc.ca/species-especes/profiles-profils/europeangreencrab-crabevert-eng.html#_Distribution

Government of Canada, F. and O. C. (2019c, May 3). *About aquatic invasive species*. https://www.dfo-mpo.gc.ca/species-especes/ais-eae/about-sur/index-eng.html

Government of Canada, F. and O. C. (2019d, September 6). *Reconciliation strategy*. https://www.dfo-mpo.gc.ca/fisheries-peches/aboriginal-autochtones/reconciliation-eng.html

Government of Canada, F. and O. C. (2021, January 12). *Study on the Implementation of Mi'kmaq Treaty Fishing Rights to Support a Moderate Livelihood*. https://www.dfo-mpo.gc.ca/transparency-transparence/briefing-breffage/2021/livelihood-subsistance-eng.htm

Government of Newfoundland and Labrador. (n.d.). *The Invasion…European Green Crab*. Retrieved November 23, 2023, from https://www.gov.nl.ca/ffa/files/education-pdf-the-invasion...european-green-crab.pdf

Government of Prince Edward Island & Fisheries, Aquaculture, and Rural Development. (n.d.). *Stop the spread of aquatic invasive species*. Retrieved November 23, 2023, from https://www.princeedwardisland.ca/sites/default/files/publications/af_invasivespeciesbro.pdf

Grosholz, E., Drill, S., McCann, L., & Bimrose, K. (2021). Engaging the importance of community scientists in the management of an invasive marine pest. *California Agriculture*, *75*(1), 40–45. https://doi.org/10.3733/ca.2021a0006

Howard, B. R., Francis, F. T., Côté, I. M., & Therriault, T. W. (2019). Habitat alteration by invasive European green crab (Carcinus maenas) causes eelgrass loss in British Columbia, Canada. *Biological Invasions*, *21*(12), 3607–3618. https://doi.org/10.1007/s10530-019-02072-z

James, A. (2017, February 28). European Green Crab. *Vic High*. https://www.vichighmarine.ca/european-green-crab/

Kafas, A., McLay, A., Chimienti, M., Scott, B. E., Davies, I., & Gubbins, M. (2017). ScotMap: Participatory mapping of inshore fishing activity to inform marine spatial planning in Scotland. *Marine Policy*, *79*, 8–18. https://doi.org/10.1016/j.marpol.2017.01.009

Klassen, G., & Locke, A. (2007). *A Biological Synopsis of the European Green Crab, Carcinus maenas*.

Legislative Services Branch. (2021, June 4). *Consolidated federal laws of Canada, Aquatic Invasive Species Regulations*. https://laws-lois.justice.gc.ca/eng/regulations/SOR-2015-121/FullText.html

Leitão, F., Baptista, V., Zeller, D., & Erzini, K. (2014). Reconstructed catches and trends for mainland Portugal fisheries between 1938 and 2009: Implications for sustainability, domestic fish supply and imports. *Fisheries Research*, *155*, 33–50. https://doi.org/10.1016/j.fishres.2014.02.012

Locke, A., & Klassen, G. J. (2008). *Using the Quantitative Biological Risk Assessment Tool (QBRAT) to predict effects of the European green crab, Carcinus maenas, in Atlantic Canada*.

Lowe, S., Browne, M., Boudjelas, S., & De Poorter, M. (2000). *100 of the World's Worst Invasive Alien Species: A Selection From The Global Invasive Species Database* (p. 12). The Invasive Species Specialist Group (ISSG) a specialist group of the Species Survival Commission (SSC) of the World Conservation Union (IUCN). https://doi.org/10.1525/9780520948433-159

Lynch, B. R., & Rochette, R. (2009). Spatial overlap and interaction between sub-adult American lobsters, Homarus americanus, and the invasive European green crab Carcinus maenas. *Journal of Experimental Marine Biology and Ecology*, *369*(2), 127–135. https://doi.org/10.1016/j.jembe.2008.11.002

Machado, A., Fernandes, A. P., Paixão, E., Caeiro, S., & Matias-Dias, C. (2017). An epidemiological approach to characterise the human exposure pathways in a

contaminated estuarine environment. *Science of The Total Environment*, *601–602*, 1753–1761. https://doi.org/10.1016/j.scitotenv.2017.05.108

Mancinelli, G., Chainho, P., Cilenti, L., Falco, S., Kapiris, K., Katselis, G., & Ribeiro, F. (2017). The Atlantic blue crab Callinectes sapidus in southern European coastal waters: Distribution, impact and prospective invasion management strategies. *Marine Pollution Bulletin*, *119*(1), 5–11. https://doi.org/10.1016/j.marpolbul.2017.02.050

Maulvault, A. L., Anacleto, P., Barbosa, V., Nunes, M. L., & Marques, A. (2016). *Shellfish: Role in the diet* (pp. 772–778). Academic Press. https://doi.org/10.1016/B978-0-12-384947-2.00625-5

McKenzie, C., Canada. Department of Fisheries and Oceans, & Canadian Science Advisory Secretariat. (2011). *Ecological assessment of the invasive European green crab (Carcinus maenas) in Newfoundland 2007-2009: Vol. 2010/033.* Centre for Science Advice (CSA), Newfoundland and Labrador Region, Fisheries and Oceans Canada. https://science-catalogue.canada.ca/record=4046189~S6http://waves-vagues.dfo-mpo.gc.ca/Library/343554.pdf

Mckenzie, C., Matheson, K., Sargent, P., Piersiak, M., Bernier, R., Simard, N., & Therriault, T. (2022). *Trapping Methods for the Invasive European Green Crab in Canada*.

Morris, E., Goudge, H., & Duce, C. (2007). *An introductory review of the biology and population dynamics of the green shore crab, Carcinus maenas (L.), in the UK, with specific reference to the Menai Strait.*

https://www.researchgate.net/publication/309674545_An_introductory_review_of_the_biology_and_population_dynamics_of_the_green_shore_crab_Carcinus_maenas_L_in_the_UK_with_specific_reference_to_the_Menai_Strait

Naczk, M., Williams, J., Brennan, K., Liyanapathirana, C., & Shahidi, F. (2004). Compositional characteristics of green crab (Carcinus maenas). *Food Chemistry*, *88*(3), 429–434. https://doi.org/10.1016/j.foodchem.2004.01.056

Natale, F., Carvalho, N., Harrop, M., Guillen, J., & Frangoudes, K. (2013). Identifying fisheries dependent communities in EU coastal areas. *Marine Policy*, *42*, 245–252. https://doi.org/10.1016/j.marpol.2013.03.018

New Brunswick Invasive Species Council. (n.d.). *Clean Drain Dry*. New Brunswick Invasive Species Council. Retrieved November 23, 2023, from https://www.nbinvasives.ca/clean-drain-dry

Parks Canada Agency, G. of C. (2020, July 16). *Coastal estuary restoration*. https://parks.canada.ca/pn-np/ns/kejimkujik/nature/conservation/ecosystem-cotier-coastal

Pereira, E., Abreu, S. N., Coelho, J. P., Lopes, C. B., Pardal, M. A., Vale, C., & Duarte, A. C. (2006). Seasonal fluctuations of tissue mercury contents in the European shore crab Carcinus maenas from low and high contamination areas (Ria de Aveiro, Portugal). *Marine Pollution Bulletin*, *52*(11), 1450–1457. https://doi.org/10.1016/j.marpolbul.2006.05.006

Pita, C., Chuenpagdee, R., & Pierce, G. J. (2012). Participatory issues in fisheries governance in Europe. *Management of Environmental Quality: An International Journal*, *23*(4), 347–361. https://doi.org/10.1108/14777831211232209

Pita, P., Fernández-Márquez, D., Antelo, M., Macho, G., & Villasante, S. (2019). Socioecological changes in data-poor S-fisheries: A hidden shellfisheries crisis in Galicia (NW Spain). *Marine Policy*, *101*, 208–224. https://doi.org/10.1016/j.marpol.2018.09.018

Poirier, L. A., Mohan, J., Speare, R., Davidson, J., Quijón, P. A., & St-Hilaire, S. (2016). Moulting synchrony in green crabs (*Carcinus maenas*) from Prince Edward Island, Canada. *Marine Biology Research*, *12*(9), 969–977. https://doi.org/10.1080/17451000.2016.1210810

Poirier, L. A., Tang, S., Mohan, J., O'Connor, E., Dennis, E., Abdullah, M., Zhou, D., Stryhn, H., St-Hilaire, S., & Quijón, P. A. (2018). A novel bycatch reduction device (BRD) and its use in a directed fishery for non-indigenous green crabs (C. maenas) in Atlantic Canada. *Fisheries Research*, *204*, 165–171. https://doi.org/10.1016/j.fishres.2018.02.018

Poirier, L. A., Tummon Flynn, P., Gehrels, H., & Quijón, P. A. (2020). Fukui foldable traps versus fyke nets as options for fishing European green crabs (Carcinus maenas) in soft-bottom habitats: Exploring efficiency and limiting bycatch. *Fisheries Research*, *230*, 105637. https://doi.org/10.1016/j.fishres.2020.105637

Province of Nova Scotia. (2014, October 20). *Aquatic Invasive Species*. https://novascotia.ca/fish/sportfishing/resource-management/ais/

Rayner, G., & McGaw, I. J. (2019). Effects of the invasive green crab (Carcinus maenas) on American lobster (Homarus americanus): Food acquisition and trapping behaviour. *Journal of Sea Research*, *144*, 95–104. https://doi.org/10.1016/j.seares.2018.10.004

Ritchie, H., & Roser, M. (2021). *Fish and Overfishing*. Our World in Data. https://ourworldindata.org/fish-and-overfishing

Robson, A. A., Kelly, M. S., & Latchford, J. W. (2007). Effect of temperature on the spoilage rate of whole, unprocessed crabs: Carcinus maenas, Necora puber and Cancer pagurus. *Food Microbiology*, *24*(4), 419–424. https://doi.org/10.1016/j.fm.2006.07.016

Schuhmacher, M., Batiste, J., Bosque, M. A., Domingo, J. L., & Corbella, J. (1994). Mercury concentrations in marine species from the coastal area of Tarragona Province, Spain. Dietary intake of mercury through fish and seafood consumption. *Science of The Total Environment*, *156*(3), 269–273. https://doi.org/10.1016/0048-9697(94)90193-7

Sheehan, E. V., Thompson, R. C., Coleman, R. A., & Attrill, M. J. (2008). Positive feedback fishery: Population consequences of 'crab-tiling' on the green crab Carcinus maenas. *Journal of Sea Research*, *60*(4), 303–309. https://doi.org/10.1016/j.seares.2008.09.002

St-Hilaire, S., Krause, J., Wight, K., Poirier, L., & Singh, K. (2016). Break-even analysis for a green crab fishery in PEI, Canada. *Management of Biological Invasions*, *7*(3), 297–303. https://doi.org/10.3391/mbi.2016.7.3.09

Therriault, T. W., Herborg, L. M., Locke, A., & McKindsey, C. W. (2008). *Risk Assessment for European green crab (Carcinus maenas) in Canadian Waters*. 44.

Tremblay, M. J., Paul, K., & Thompson, A. (2006). *Recent trends in the abundance of the invasive green crab (Carcinus maenas) in Bras d'Or Lakes and eastern Nova Scotia based on trap surveys: Vol. 2673.* Fisheries and Oceans Canada, Bedford

Institute of Oceanography. https://science-catalogue.canada.ca/record=4013674~S6https://waves-vagues.dfo-mpo.gc.ca/library-bibliotheque/325747.pdf

Urquhart, J., Acott, T., Reed, M., & Courtney, P. (2011). Setting an agenda for social science research in fisheries policy in Northern Europe. *Fisheries Research*, *108*(2), 240–247. https://doi.org/10.1016/j.fishres.2010.12.026

Vale, P., & Sampayo, M. A. de M. (2002). First confirmation of human diarrhoeic poisonings by okadaic acid esters after ingestion of razor clams (Solen marginatus) and green crabs (Carcinus maenas) in Aveiro lagoon, Portugal and detection of okadaic acid esters in phytoplankton. *Toxicon*, *40*(7), 989–996. https://doi.org/10.1016/S0041-0101(02)00095-8

Varagnolo, S. (1968). *Fishery of the green crab (Carcinus maenas L.) and soft crab cultivation in the lagoon of Venice: Vol. 37.* General Fisheries Council for the Mediterranean, Food and Agriculture Organization of the United Nations. https://science-catalogue.canada.ca/record=3847097~S6

Vercaemer, B., Sephton, D., Canada. Dept. of Fisheries and Oceans. Maritimes Region. Science Branch, Canada. Dept. of Fisheries and Oceans. Maritimes Region. Coastal Ecosystem Sciences Division, & Canada. Department of Fisheries and Oceans. Bedford Institute of Oceanography. (2016). *European green crab (Carcinus maenas) monitoring in the Maritimes Region 2008-2015: Vol. 3147.* Bedford Institute of Oceanography. https://science-catalogue.canada.ca/record=4043217~S6http://waves-vagues.dfo-mpo.gc.ca/Library/365160.pdf

Veritas Health Innovation. (2023). *Covidence systematic review software* [Computer software]. www.covidence.org

Vital, S. A., Cardoso, C., Avio, C., Pittura, L., Regoli, F., & Bebianno, M. J. (2021). Do microplastic contaminated seafood consumption pose a potential risk to human health? *Marine Pollution Bulletin*, *171*, 112769. https://doi.org/10.1016/j.marpolbul.2021.112769

Walkinshaw, C., Lindeque, P. K., Thompson, R., Tolhurst, T., & Cole, M. (2020). Microplastics and seafood: Lower trophic organisms at highest risk of contamination. *Ecotoxicology and Environmental Safety*, *190*, 110066. https://doi.org/10.1016/j.ecoenv.2019.110066

Wehi, P. M., Kamelamela, K. L., Whyte, K., Watene, K., & Reo, N. (2023). Contribution of Indigenous Peoples' understandings and relational frameworks to invasive alien species management. *People and Nature*, *5*(5), 1403–1414. https://doi.org/10.1002/pan3.10508

Young, A. M., & Elliott, J. A. (2020). Life History and Population Dynamics of Green Crabs (Carcinus maenas). *Fishes*, *5*(1), Article 1. https://doi.org/10.3390/fishes5010004

Zhang, Y., Sully, P., Spitzer, L., Dutilleul, P., & Simpson, B. K. (2022). Comprehensive biorefinery of invasive European green crab (Carcinus maenas) into multiple high-value biomolecules. *Journal of Cleaner Production*, *374*, 134052. https://doi.org/10.1016/j.jclepro.2022.134052

Zhou, Y., Liu, X., Liu, B., Liu, P., Wang, F., Zhang, X., & Yang, H. (2015). Unusual pattern in characteristics of the eelgrass Zostera marina L. in a shallow lagoon

(Swan Lake), north China: Implications on the importance of seagrass conservation. *Aquatic Botany*, *120*, 178–184. https://doi.org/10.1016/j.aquabot.2014.05.014

APPENDIX

Table 11: Search strings for the ScienceDirect database.

Number	String
1	("carcinus maenas" OR "european green crab" OR "green crab") AND (Maritimes OR "Atlantic canada" OR "gulf region") AND (Fishery OR Fisheries OR fishing)
2	("carcinus maenas" OR "european green crab" OR "green crab") AND (Maritimes OR "Atlantic canada" OR "gulf region") AND (Harvest OR harvesting OR Harvester)
3	("carcinus maenas" OR "european green crab" OR "green crab") AND (Maritimes OR "Atlantic canada" OR "gulf region") AND (manage OR Management OR managing)
4	("carcinus maenas" OR "european green crab" OR "green crab") AND (Maritimes OR "Maritimes region" OR "Atlantic canada" OR "gulf region") AND (Control OR controlling)
5	("carcinus maenas" OR "european green crab" OR "green crab") AND (Maritimes OR "Atlantic canada" OR "gulf region") AND (Invasive OR "Invasive species" OR "aquatic invasive species")
6	("carcinus maenas" OR "european green crab" OR "green crab") AND (Maritimes OR "Atlantic canada" OR "gulf region") AND ("soft shell" OR "moeche" OR "moleche")
7	("carcinus maenas" OR "european green crab" OR "green crab") AND (Maritimes OR "Atlantic canada" OR "gulf region") AND (economic OR "economic analysis" OR performance)
8	("carcinus maenas" OR "european green crab" OR "green crab") AND (Maritimes OR "Atlantic canada" OR "gulf region") AND (employment OR income OR "cost benefit")
9	("carcinus maenas" OR "european green crab" OR "green crab") AND (Maritimes OR "Atlantic canada" OR "gulf region") AND (profit OR capital OR profitability)
10	("carcinus maenas" OR "european green crab" OR "green crab") AND (Maritimes OR "Atlantic canada" OR "gulf region") AND (value OR "input output" OR "break even")
11	("carcinus maenas" OR "european green crab" OR "green crab") AND (Maritimes OR "Atlantic canada" OR "gulf region") AND ("food fishery" OR "recreational fishery" OR "local market")

Number	String
12	("carcinus maenas" OR "european green crab" OR "green crab") AND ("Nova Scotia" OR NS) AND (Fishery OR Fisheries OR fishing)
13	("carcinus maenas" OR "european green crab" OR "green crab") AND ("Nova Scotia" OR NS) AND (Harvest OR harvesting OR Harvester)
14	("carcinus maenas" OR "european green crab" OR "green crab") AND ("Nova Scotia" OR NS) AND (manage OR Management OR managing)
15	("carcinus maenas" OR "european green crab" OR "green crab") AND ("Nova Scotia" OR NS) AND (Control OR controlling)
16	("carcinus maenas" OR "european green crab" OR "green crab") AND ("Nova Scotia" OR NS) AND (Invasive OR "Invasive species" OR "aquatic invasive species")
17	("carcinus maenas" OR "european green crab" OR "green crab") AND ("Nova Scotia" OR NS) AND ("soft shell" OR "moeche" OR "moleche")
18	("carcinus maenas" OR "european green crab" OR "green crab") AND ("Nova Scotia" OR NS) AND (economic OR "economic analysis" OR performance)
19	("carcinus maenas" OR "european green crab" OR "green crab") AND ("Nova Scotia" OR NS) AND (employment OR income OR "cost benefit")
20	("carcinus maenas" OR "european green crab" OR "green crab") AND ("Nova Scotia" OR NS) AND (profit OR capital OR profitability)
21	("carcinus maenas" OR "european green crab" OR "green crab") AND ("Nova Scotia" OR NS) AND (value OR "input output" OR "break even")
22	("carcinus maenas" OR "european green crab" OR "green crab") AND ("Nova Scotia" OR NS) AND ("food fishery" OR "recreational fishery" OR "local market")
23	("carcinus maenas" OR "european green crab" OR "green crab") AND ("New Brunswick" OR NB) AND (Fishery OR Fisheries OR fishing)
24	("carcinus maenas" OR "european green crab" OR "green crab") AND ("New Brunswick" OR NB) AND (Harvest OR harvesting OR Harvester)

Number	String
25	("carcinus maenas" OR "european green crab" OR "green crab") AND ("New Brunswick" OR NB) AND (manage OR Management OR managing)
26	("carcinus maenas" OR "european green crab" OR "green crab") AND ("New Brunswick" OR NB) AND (Control OR controlling)
27	("carcinus maenas" OR "european green crab" OR "green crab") AND ("New Brunswick" OR NB) AND (Invasive OR "Invasive species" OR "aquatic invasive species")
28	("carcinus maenas" OR "european green crab" OR "green crab") AND ("New Brunswick" OR NB) AND ("soft shell" OR "moeche" OR "moleche")
29	("carcinus maenas" OR "european green crab" OR "green crab") AND ("New Brunswick" OR NB) AND (economic OR "economic analysis" OR performance)
30	("carcinus maenas" OR "european green crab" OR "green crab") AND ("New Brunswick" OR NB) AND (employment OR income OR "cost benefit")
31	("carcinus maenas" OR "european green crab" OR "green crab") AND ("New Brunswick" OR NB) AND (profit OR capital OR profitability)
32	("carcinus maenas" OR "european green crab" OR "green crab") AND ("New Brunswick" OR NB) AND (value OR "input output" OR "break even")
33	("carcinus maenas" OR "european green crab" OR "green crab") AND ("New Brunswick" OR NB) AND ("food fishery" OR "recreational fishery" OR "local market")
34	("carcinus maenas" OR "european green crab" OR "green crab") AND ("Prince Edward Island" OR PEI) AND (Fishery OR Fisheries OR fishing)
35	("carcinus maenas" OR "european green crab" OR "green crab") AND ("Prince Edward Island" OR PEI) AND (Harvest OR harvesting OR Harvester)
36	("carcinus maenas" OR "european green crab" OR "green crab") AND ("Prince Edward Island" OR PEI) AND (manage OR Management OR managing)
37	("carcinus maenas" OR "european green crab" OR "green crab") AND ("Prince Edward Island" OR PEI) AND (Control OR controlling)

Number	String
38	("carcinus maenas" OR "european green crab" OR "green crab") AND ("Prince Edward Island" OR PEI) AND (Invasive OR "Invasive species" OR "aquatic invasive species")
39	("carcinus maenas" OR "european green crab" OR "green crab") AND ("Prince Edward Island" OR PEI) AND ("soft shell" OR "moeche" OR "moleche")
40	("carcinus maenas" OR "european green crab" OR "green crab") AND ("Prince Edward Island" OR PEI) AND (economic OR "economic analysis" OR performance)
41	("carcinus maenas" OR "european green crab" OR "green crab") AND ("Prince Edward Island" OR PEI) AND (employment OR income OR "cost benefit")
42	("carcinus maenas" OR "european green crab" OR "green crab") AND ("Prince Edward Island" OR PEI) AND (profit OR capital OR profitability)
43	("carcinus maenas" OR "european green crab" OR "green crab") AND ("Prince Edward Island" OR PEI) AND (value OR "input output" OR "break even")
44	("carcinus maenas" OR "european green crab" OR "green crab") AND ("Prince Edward Island" OR PEI) AND ("food fishery" OR "recreational fishery" OR "local market")
45	("carcinus maenas" OR "european green crab" OR "green crab") AND (Newfoundland OR NL OR NLFD) AND (Fishery OR Fisheries OR fishing)
46	("carcinus maenas" OR "european green crab" OR "green crab") AND (Newfoundland OR NL OR NLFD) AND (Harvest OR harvesting OR Harvester)
47	("carcinus maenas" OR "european green crab" OR "green crab") AND (Newfoundland OR NL OR NLFD) AND (manage OR Management OR managing)
48	("carcinus maenas" OR "european green crab" OR "green crab") AND (Newfoundland OR NL OR NLFD) AND (Control OR controlling)
49	("carcinus maenas" OR "european green crab" OR "green crab") AND (Newfoundland OR NL OR NLFD) AND (Invasive OR "Invasive species" OR "aquatic invasive species")

Number	String
50	("carcinus maenas" OR "european green crab" OR "green crab") AND (Newfoundland OR NL OR NLFD) AND ("soft shell" OR "moeche" OR "moleche")
51	("carcinus maenas" OR "european green crab" OR "green crab") AND (Newfoundland OR NL OR NLFD) AND (economic OR "economic analysis" OR performance)
52	("carcinus maenas" OR "european green crab" OR "green crab") AND (Newfoundland OR NL OR NLFD) AND (employment OR income OR "cost benefit")
53	("carcinus maenas" OR "european green crab" OR "green crab") AND (Newfoundland OR NL OR NLFD) AND (profit OR capital OR profitability)
54	("carcinus maenas" OR "european green crab" OR "green crab") AND (Newfoundland OR NL OR NLFD) AND (value OR "input output" OR "break even")
55	("carcinus maenas" OR "european green crab" OR "green crab") AND (Newfoundland OR NL OR NLFD) AND ("food fishery" OR "recreational fishery" OR "local market")
56	("carcinus maenas" OR "european green crab" OR "green crab") AND (Europe OR Italy OR Spain) AND (Fishery OR Fisheries OR fishing)
57	("carcinus maenas" OR "european green crab" OR "green crab") AND (Europe OR Italy OR Spain) AND (Harvest OR harvesting OR Harvester)
58	("carcinus maenas" OR "european green crab" OR "green crab") AND (Europe OR Italy OR Spain) AND (manage OR Management OR managing)
59	("carcinus maenas" OR "european green crab" OR "green crab") AND (Europe OR Italy OR Spain) AND (Control OR controlling)
60	("carcinus maenas" OR "european green crab" OR "green crab") AND (Europe OR Italy OR Spain) AND (Invasive OR "Invasive species" OR "aquatic invasive species")
61	("carcinus maenas" OR "european green crab" OR "green crab") AND (Europe OR Italy OR Spain) AND ("soft shell" OR "moeche" OR "moleche")

Number	String
62	("carcinus maenas" OR "european green crab" OR "green crab") AND (Europe OR Italy OR Spain) AND (economic OR "economic analysis" OR performance)
63	("carcinus maenas" OR "european green crab" OR "green crab") AND (Europe OR Italy OR Spain) AND (employment OR income OR "cost benefit")
64	("carcinus maenas" OR "european green crab" OR "green crab") AND (Europe OR Italy OR Spain) AND (profit OR capital OR profitability)
65	("carcinus maenas" OR "european green crab" OR "green crab") AND (Europe OR Italy OR Spain) AND (value OR "input output" OR "break even")
66	("carcinus maenas" OR "european green crab" OR "green crab") AND (Europe OR Italy OR Spain) AND ("food fishery" OR "recreational fishery" OR "local market")
67	("carcinus maenas" OR "european green crab" OR "green crab") AND ("Maritimes region") AND (Fishery OR Fisheries OR fishing)
68	("carcinus maenas" OR "european green crab" OR "green crab") AND ("Maritimes region) AND (Harvest OR harvesting OR Harvester)
69	("carcinus maenas" OR "european green crab" OR "green crab") AND ("Maritimes region") AND (manage OR Management OR managing)
70	("carcinus maenas" OR "european green crab" OR "green crab") AND ("Maritimes region") AND (Invasive OR "Invasive species" OR "aquatic invasive species")
71	("carcinus maenas" OR "european green crab" OR "green crab") AND ("Maritimes region") AND ("soft shell" OR "moeche" OR "moleche")
72	("carcinus maenas" OR "european green crab" OR "green crab") AND ("Maritimes region") AND (economic OR "economic analysis" OR performance)
73	("carcinus maenas" OR "european green crab" OR "green crab") AND ("Maritimes region") AND (employment OR income OR "cost benefit")

Number	String
74	("carcinus maenas" OR "european green crab" OR "green crab") AND ("Maritimes region") AND (profit OR capital OR profitability)
75	("carcinus maenas" OR "european green crab" OR "green crab") AND ("Maritimes region") AND (value OR "input output" OR "break even")
76	("carcinus maenas" OR "european green crab" OR "green crab") AND ("Maritimes region") AND ("food fishery" OR "recreational fishery" OR "local market")

Table 12: Search strings used for the Federal Science Library Database.

Number	String
1	("carcinus maenas" OR "european green crab" OR "green crab") AND (maritimes OR "maritimes region" OR "atlantic canada" OR "gulf region") AND (fish* OR harvest* OR manag* OR control* OR invasive OR ("soft shell" OR "moeche" OR "moleche") OR (economic OR "economic analysis" OR performance OR employment OR income OR "cost benefit" OR profit OR capital OR profitability OR value OR "input output" OR "break even") OR ("food fishery" OR "recreational fishery" OR "local market"))
2	("carcinus maenas" OR "european green crab" OR "green crab") AND ("Nova Scotia" OR NS) AND (Fish* OR Harvest* OR Manag* OR Control* OR Invasive OR ("soft shell" OR "moeche" OR "moleche") OR (economic OR "economic analysis" OR performance OR employment OR income OR "cost benefit" OR profit OR capital OR profitability OR value OR "input output" OR "break even") OR ("food fishery" OR "recreational fishery" OR "local market"))
3	("carcinus maenas" OR "european green crab" OR "green crab") AND ("New Brunswick" OR NB) AND (Fish* OR Harvest* OR Manag* OR Control* OR Invasive OR ("soft shell" OR "moeche" OR "moleche") OR (economic OR "economic analysis" OR performance OR employment OR income OR "cost benefit" OR profit OR capital OR profitability OR value OR "input output" OR "break even") OR ("food fishery" OR "recreational fishery" OR "local market"))
4	("carcinus maenas" OR "european green crab" OR "green crab") AND ("Prince Edward Island" OR PEI) AND (Fish* OR Harvest* OR Manag* OR Control* OR Invasive OR ("soft shell" OR "moeche" OR "moleche") OR (economic OR "economic analysis" OR performance OR employment OR income OR "cost benefit" OR profit OR capital OR profitability OR value OR "input output" OR "break even") OR ("food fishery" OR "recreational fishery" OR "local market"))

Number	String
5	("carcinus maenas" OR "european green crab" OR "green crab") AND (Newfoundland OR NL OR NLFD) AND (Fish* OR Harvest* OR Manag* OR Control* OR Invasive OR ("soft shell" OR "moeche" OR "moleche") OR (economic OR "economic analysis" OR performance OR employment OR income OR "cost benefit" OR profit OR capital OR profitability OR value OR "input output" OR "break even") OR ("food fishery" OR "recreational fishery" OR "local market"))
6	("carcinus maenas" OR "european green crab" OR "green crab") AND (Europe OR Italy OR Spain) AND (Fish* OR Harvest* OR Manag* OR Control* OR Invasive OR ("soft shell" OR "moeche" OR "moleche") OR (economic OR "economic analysis" OR performance OR employment OR income OR "cost benefit" OR profit OR capital OR profitability OR value OR "input output" OR "break even") OR ("food fishery" OR "recreational fishery" OR "local market"))