Recommendations to improve Canada's marine biosecurity

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Table of Contents

List of Figures

List of Tables

Abstract

Alien species are species that have been introduced to areas outside of their native range, whether intentionally or unintentionally. A small proportion of alien species will become invasive, meaning they reproduce and spread long distances from where they were first introduced, with the potential to have significant socio-economic impacts, reduce biodiversity, and impact ecosystem services and processes. Globalization and increases in activities such as aquaculture, shipping, fisheries, and the aquarium trade has led to an increased number of alien species introductions in recent decades. While management strategies for invasive species have predominantly been developed for the terrestrial ecosystem, strategies in the marine environment are lacking. This project utilized a systematic literature review to examine how aquatic invasive species are introduced to and move around Canada, what management regulations are in place, and how Canada's approach differs to other countries. Canada's biosecurity measures are compared to those of New Zealand, Australia, and the United States. It is recommended that Canada improve intergovernmental cooperation and management, legislation and enforcement, ease of access, monitoring in high-risk areas, and ensure the use of the precautionary approach and adaptive management.

Keywords: Aquatic invasive species, biosecurity, biodiversity, Canadian biosecurity

List of Abbreviations

AAFC-Agriculture and Agri-Food Canada

ACEBO-Australian Chief Environmental Biosecurity Officer

AFS-Anti-Fouling System

AIS-Aquatic Invasive Species

ANSTF-Aquatic Nuisance Species Task Force

BWM-Ballast Water Management

CBD-Convention on Biological Diversity

CBSA-Canadian Border Services Agency

CFIA-Canadian Food Inspection Agency

COP15-15th meeting of the Conference of the Parties

DAFF-Department of Agriculture, Fisheries, and Forestry

DAWE-Department of Agriculture, Water, and the Environment

DFO-Fisheries and Oceans Canada

ECCC-Environment and Climate Change Canada

eDNA-Environmental DNA

EO-Executive Order

eRNA-Environmental RNA

FAO-Food and Agriculture Organization of the United Nations

IAS-Invasive Alien Species

IMO-International Maritime Organization

IPBES- Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services

IUCN- International Union for Conservation of Nature

MOE-Mid-Ocean Exchange

MPA-Marine Protected Area

MPI-Ministry for Primary Industries

MPSC-Marine Pest Sectoral Committee

NGO-Non-Governmental Organization

NISC-National Invasive Species Council

NOAA-National Oceanic and Atmospheric Administration

NRCan-Natural Resources Canada

TBT-Tributyl Tin

USCG-United States Coast Guard

USFWS-US Fish and Wildlife Service

US-United States of America

UV-Ultraviolet

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Chapter 1: Introduction

1.1 Invasive Species

For hundreds of years, species have moved via human activity to areas outside of their native regions for several reasons (Novoa et al., 2018). While some introductions are done purposefully for agriculture, aquaculture, forestry, ornamental horticulture, the pet trade, and recreation, introductions are not always intentional (Novoa et al., 2018). Other introductions are purely unintentional, and occur through ballast water, ship/hull fouling, or contamination of transported products (Novoa et al., 2018). Many consider several of these introductions desirable due to their benefits and low to no ecological and economic costs (Ewel et al., 1999; Novoa et al., 2018), while other introduced species provide little to no benefit but are also inconsequential to the environment, for example those that do not survive in the new environment (Novoa et al., 2018). Conflict species are those that provide both benefits and costs, resulting in conflict around their use and management as some stakeholders embrace them (Novoa et al., 2018). Approximately 0.1% of introduced species will become invasive, reproducing and spreading a significant distance from where they were first introduced, with the potential to have significant socio-economic impacts (International Union for Conservation of Nature [IUCN], 2017; Novoa et al., 2018; Smith et al., 1999). It is these species that have the most societal, cultural, and economic impacts. Therefore, the prevention of introducing these high-impact species is a management priority.

Invasive alien species (IAS) have been reported as the second most common cause of species extinctions (Giakoumi et al., 2019). They not only affect the functions of the ecosystems they are introduced to but can also have socio-economic and human health impacts in addition to negatively affecting ecosystem services (Giakoumi et al., 2019; Vilà & Hulme, 2017). Ecosystem functions are the biological processes that provide ecosystem services, which are the outputs from the ecosystem that benefit humans (Oliver et al., 2015). IAS cost economies billions annually through a variety of industries (Vilà & Hulme, 2017), and the annual cost globally has now exceeded US $423 billion (B) and has quadrupled every decade for the past 50 years (Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services [IPBES] Secretariat, 2023). Additionally, the negative impacts on ecosystem services and the costs associated with control and eradication of established IAS further contribute to this hefty price tag (Vilà & Hulme, 2017). As such, management of these species is necessary for both biodiversity conservation and human well-being (Giakoumi et al., 2019). Recently, cost-effective approaches have been developed for prioritizing management practices for control of terrestrial IAS (Giakoumi et al., 2019). Creation of similar approaches to prioritization methods for aquatic invasive species (AIS) in the marine environment are poorly developed (Giakoumi et al., 2019). Additionally, there are more studies for invasive freshwater fish than for invasive marine fish (Thomsen et al., 2014).

Introducing alien species to new areas is widely recognized as one of the top five threats to the function of marine ecosystems and biodiversity (Hewitt & Campbell, 2007). Connectivity within the marine environment results in even more difficulty controlling biological invasions (Giakoumi et al., 2019). The higher the ability of a species to disperse, and the larger the area it is introduced to, the more challenging it is to control the invasion (Giakoumi et al., 2019). Many recognized impacts of AIS focus on environmental values, though it is likely that there will be increasing impacts on maritime industries (Hewitt & Campbell, 2007). Those industries that rely on marine waters are likely to experience an increase in biofouling, which comes with higher costs for maintenance and replacement (Hewitt & Campbell, 2007). Additionally, high mortalities and decreased productivity have been observed in aquaculture industries due to competition and predation between aquaculture stocks and AIS (Hewitt & Campbell, 2007). One example found in Canada is the alga *Codium fragile*, which attaches to oysters and floats them away, earning it the moniker "the oyster thief" (Hewitt & Campbell, 2007). This removal of oysters by the alga results in a loss of productivity (Hewitt & Campbell, 2007).

Several pathways and vectors are involved in the movement of organisms outside of their native range (IUCN, 2017). A dispersal pathway is "the combination of processes and opportunities resulting in the movement of propagules from one area to another, including aspects of the vectors involved, features of the original and recipient environments, and the nature and timing of what exactly is moved" (Wilson et al., 2009, p.136). Vectors are the dispersal mechanisms that can be human or non-human mediated (Richardson et al., 2011). Specifically, vectors are the physical means in or on which species are able to travel beyond their native range (IUCN, 2017). Primary pathways and vectors result in a novel introduction, while secondary pathways and vectors are those that result in the dispersal of AIS that have been established (Mghili et al., 2023). Higher vector activity results in a higher frequency of potential introductions (Tidbury et al., 2021). The number (i.e., magnitude) and frequency of individuals released to a non-native region are key properties of pathways, as increases to these properties result in an increased likelihood of successful AIS establishment (Wilson et al., 2009).

The Convention on Biological Diversity lists main pathways with subsequent vectors acting within each pathway (IUCN, 2017). Not all AIS are active in every vector, as some may be introduced through a single pathway and single vector, but most AIS have multiple vectors contributing to primary and secondary introduction (IUCN, 2017; Pergl et al., 2017). The dispersal of AIS can often involve multiple pathways, both natural and human-mediated, and that can occur simultaneously (Bagnara et al., 2022).Within the marine realm, the most common vectors include biofouling of vessel hulls, ship and ballast water movements, and aquaculture (i.e., escape from confinement and contamination of transported goods) (IUCN, 2017; LeBlanc et al., 2020). Additionally, some other possible pathways and vectors for AIS in the Maritimes Region are discussed below, in alphabetical order. These include: hitchhiking through marine construction; marine debris; recreational activities; corridors; through interconnected waterways, and; unaided, through climate change.

1.2 Biosecurity

For the purpose of this study, “biosecurity” will be used in reference to environmental biosecurity. Environmental biosecurity focuses on actively preventing, mitigating, and eradicating AIS outbreaks in order to sustain the integrity of natural ecosystems, the relationship between humans and nature, relevant industries, and the health of the public (Reid et al., 2021).

Proactive management that focuses on pathways of invasion is needed to reduce the risk of AIS becoming established in novel areas (Cunningham, 2019). A vector for AIS is a specific route through a given pathway by which AIS are transferred (Reid et al., 2021). Managing AIS vectors, coupled with early detection and rapid response are important parts of biosecurity (Cunningham, 2019). Unfortunately, the tools for reducing the spread of AIS in a global context have shown only minor improvements (Cunningham, 2019).

As a signatory to the Convention on Biological Diversity (CBD), Canada has set targets to conserve and promote biodiversity (Reid et al., 2021). One such target, CBD Target 11 (which corresponds to Aichi Target 9), was to identify the pathways of AIS introductions, and have risk-based intervention or management plans in place for species or pathways that are considered a priority by 2020 (CBD, 2020). Differing reports make it unclear whether Canada has achieved this goal, as some report Canada has met this goal (CBD, n.d.), while others state Canada has failed in meeting its targets (Bernstien, 2022). This discrepancy may be due to differing views on what is considered successful.

Furthermore, Canada made commitments to maintain biodiversity at the 15th meeting of the Conference of the Parties (COP15) in late 2022 (CBD, 2022). COP15 Target 6 also specifically addresses AIS, aiming to identify and manage pathways for AIS introductions, prevent priority AIS introductions and establishments, and reduce the rate of introduction of other AIS by 50%, all by 2030 (CBD, 2022). This also includes the eradication or control of AIS in priority sites, such as islands (CBD, 2022). However, eradication of these AIS would be more difficult than earlier interventions.

Prevention of AIS is significantly less expensive than eradication (Figure 1), poses fewer logistical challenges (Reid et al., 2021), and is more efficient (Fisheries and Oceans Canada [DFO], 2023). A crucial component of prevention is the early detection of AIS populations to stop them from establishing in Canada (Reid et al., 2021). To help accomplish this, DFO works with partners across the country to prevent the introduction, establishment, and spread of AIS (DFO, 2023c).

Chapter 2: Approach

2.1 Overview

I conducted a systematic review of peer-reviewed literature, grey literature, policy, and legislation to summarize Canada's current biosecurity measures, and to identify knowledge and policy gaps relating to marine AIS and their management with English literature from targeted areas of Canada, the United States of America (US), New Zealand, and Australia. I used this review to make recommendations for improvement of biosecurity regulations relating to marine AIS in Canada. I conducted a further examination of pathways for AIS introduction and identification of active vectors in the DFO Maritimes Region of Canada, Nova Scotia and New Brunswick. I did this by using the literature to identify the dominant pathways and vectors for AIS transfer, and then grouped them based on the CBD's categorization of introduction pathways (IUCN, 2017). I examined policies in Nova Scotia and New Brunswick for regulations that are, or could be, used to prevent and manage marine AIS. Based on the literature review, the review of existing pathways and active vectors, and existing policies and legislation, I generated recommendations to improve marine biosecurity and prevent AIS introductions. Furthermore, I researched new and emerging technologies relating to AIS management and prevention in order to identify tools Canada may be able to utilize in AIS biosecurity.

2.2 Literature Sources and Search Terms:

I used scholarly search engines (Google Scholar and Novanet) and a non-scholarly search engine (Google) to locate multiple resources for this research including, but not limited to, peer-reviewed journal articles, government websites (from Canada, New Brunswick, Nova Scotia, Australia, New Zealand, and the US), government Acts, and news reports. Search terms included "biosecurity," "Canada's biosecurity," and "aquatic invasive species." Some literature sources were also provided by regional experts. The information included in this report includes open-access, public information and does not include internal processes, conversations, or data from governments. I used sources that were as recent as possible (ideally, 2017 and later) to aid in ensuring that the information was as current and relevant as possible. This information was used to build a background on AIS, legislation and regulations in the countries being examined, and to gain information on how Canada may proceed to improve biosecurity.

The literature and other sources were summarized into the following categories: AIS vectors, Canada's approach to biosecurity, the approaches to the biosecurity of Nova Scotia and New Brunswick, international approaches to biosecurity, new and emerging technologies in the field of AIS management and prevention, and which areas of the Maritimes Region provinces may be deemed higher priority for monitoring and management.

International Comparisons:

New Zealand and Australia are considered global leaders in biosecurity (Champion, 2018). Therefore, these two countries were used as the benchmark against which to compare Canada's approach to biosecurity. Search keywords included, but were not limited to, "New Zealand approach to biosecurity," "New Zealand ballast water regulations," "New Zealand Marine Biosecurity Act," "Australia Indigenous biosecurity," "Australia biosecurity," and "Australia biosecurity regulations."

Due to Canada's proximity to the US, this country was also included in the international comparison section. Canada and the US share a border (Reid et al., 2021), and as such it is important to determine how the US is also preventing AIS introductions and spread. Search terms included, but were not limited to, "United States aquatic biosecurity," "United States ballast water regulations," and "United States biofouling regulations." See Appendix 1 for a full list of search terms.

2.3 Identification of Locations for Monitoring and Management Prioritization

Upon request, DFO provided data on boat launches, wharves/slipways, small craft harbours, ferry terminals/cruise ship ports, large ferry terminals, marinas and yacht clubs, passenger vessel traffic, cargo vessel traffic, tanker vessel traffic, and shipping ports. This data was visualized through a series of maps provided by S. Butler (DFO, personal communication). I used these maps to provide further detail on active marine vectors in Nova Scotia and to provide insight into areas that may be a higher risk for AIS introductions and spread. However, these maps should be interpreted as a preliminary analysis of marine vector activities, as further detailed assessments are likely needed on a harbour-by-harbour basis.

Chapter 3: Findings and Discussion

A consolidated comparison of biosecurity in Canada, the US, New Zealand, and Australia is outlined below (Figure 2;Reid et al., 2021). Of the nine examples of how responsibility for biosecurity is divided and defined, Canada only has two (a federal government leading proactive management, and individual agencies responsible for biosecurity management that is relevant to their responsibilities) (Figure 2). Of the three challenges to biosecurity listed, Canada has two, a shared international border and climate change. This lack of division and defined responsibilities, coupled with two large challenges to biosecurity, illustrates Canada's need to drastically improve its biosecurity efforts. Notably, of the positive aspects of biosecurity approaches examined by Reid et al. (2021), such as education and outreach, Canada has none (Figure 2). Furthermore, there is not extensive involvement of Indigenous communities, rigorous enforcement of policies relating to international shipping and travel, or the use of a centralized authority for biosecurity.

3.1 Canada

3.1.1 General Background

Canadian marine biosecurity relies on a variety of partners, including government departments and agencies, port operators, facility operators, vessel operators, and international organizations (Transport Canada, 2020). Many Canadian organizations across all levels of government, academic institutions, non-governmental organizations (NGOs), businesses, and Indigenous communities have become stake- and rights-holders in biosecurity (Reid et al., 2021). These stake- and rights-holders identify vulnerabilities and formulate integrated solutions for Canada's marine biosecurity (Transport Canada, 2020).

Federal departments and agencies that are both involved in biosecurity and AIS management include DFO (including the Canadian Coast Guard), Canadian Food Inspection Agency (CFIA), Natural Resources Canada (NRCan), and Agriculture and Agri-Food Canada (AAFC), Environment and Climate Change Canada (ECCC), Parks Canada, Industry Canada, Health Canada's Pest Management Regulatory Agency, Department of National Defence, Transport Canada, and the Canadian Border Services Agency (CBSA) (DFO, 2018a; Office of the Auditor General of Canada, 2019; Reid et al., 2021). DFO is the primary authority for the management of AIS and coordinates efforts to meet Canada's international targets (DFO, 2018a; Office of the Auditor General of Canada, 2019). Species coming into Canada for ornamental purposes and aquaculture, among others, primarily fall under the responsibility of CFIA and

CBSA (Reid et al., 2021). CFIA has also compiled a list of regulated pests in Canada, including organisms such as viruses, nematodes, plants, fungi, molluscs, insects, and bacteria (CFIA, 2023a). While this list does identify pests from an invasive perspective, the main focus is on threats to plant and human health and not on the marine environment (CFIA, 2023a).

A subsection of the *Fisheries Act* (R.S.C., 1985, c. F-14), the *Aquatic Invasive Species Regulations* (SOR/2015-121), provides regulatory practices regarding AIS in Canada. These *Regulations* (SOR/2015-121) state that there are prohibitions against the importation, possession, transportation, and release of certain listed AIS, including any genetic material that would be able to propagate the species, as well as any activities that could lead to these. A list of AIS, as well as areas where importation, possession, transportation, and release are prohibited are also outlined in the *Regulations* (SOR/2015-121). Additionally, these prohibitions in the *Regulations* (SOR/2015-121) are not applicable if the member of the species is in a certain condition (for example, dead or eviscerated). As per the *Fishery (General) Regulations* (SOR/93-53), also under the *Fisheries Act* (R.S.C., 1985, c. F-14), people may apply for a permit to control or research AIS, for which there will be no charge. Notably, the majority of species listed in the *Aquatic Invasive Species Regulations* (SOR/2015-121) are freshwater species.

Most Canadian provinces also have regulations that could be applied to marine AIS, either directly or indirectly. Furthermore, some Provincial Ministers have delegated authority to enact the *Aquatic Invasive Species Regulations* (SOR/2015-121), or are lead regulators (especially, for freshwater species) based on Crown-Province Memorandums of Understanding or similar agreements (DFO, 2018a). For example, in response to zebra and quagga mussel introductions and spread, some provinces have set up inspection stations for watercraft moving across land (DFO, 2020).

Nova Scotia and New Brunswick both have legislation and regulations that can be applied to the prevention and management of AIS. Nova Scotian legislation that can be applied to marine AIS prevention and control includes the *Fisheries and Coastal Resources Act (*1996, c.25, s. 1), the *Wildlife Act* (R.S., c. 504, s. 2), and the *Fisheries Act (R.S.C., 1985, c F-14)* through the *Aquatic Invasive Species Regulations* (SOR/2015-121). There are regulations surrounding the unlawful possession of live fish, as well as the use of certain species as bait (Table 1;Nova Scotia Fisheries and Aquaculture, n.d.). The *Live Fish Possession Regulations*

(S.N.S. 1996, c.25), under the *Fisheries and Coastal Resources Act* (1996, c. 25, s. 1), also prevent the transportation of live fish without written permission. Under the *Wildlife Act* (R.S., c. 504, s. 2), exotic wildlife is any bird, mammal, or vertebrate that are not native to Nova Scotia and are wild when in their natural habitat. Exotic wildlife cannot be held in captivity or released from captivity, and cannot be imported without a permit issued under the *Wildlife Act* (R.S., c. 504, s. 2). Finally, the *Aquatic Invasive Species Regulations* (SOR/2015-121), as discussed above, are also applicable, particularly because the Nova Scotian Minister of Fisheries and Aquaculture is a prescribed person under the *Fisheries Act (*R.S.C., 1985, c. F-14), permitting them to take actions specifically outlined in this federal act, as opposed to just provincial regulations (SOR/2015-121). The relevant New Brunswick legislation comes from three *Acts*, the *Aquaculture Act* (S.N.B. 2019, c.40), the *Exotic Animals Act* (SNB 2017, c 52), and the *Fish and Wildlife Act*. It is illegal in New Brunswick to stock or transfer any fish without proper authorization, as well as to use live bait in most waters (Government of New Brunswick, n.d.). The *Aquaculture Act* (S.N.B. 2019, c.40) allows the Chief Veterinary Officer to take action for the control of an aquaculture site if there is, or is reason to believe, a hazard that is or will be present. Additionally, this *Act* prohibits the transfer of products between waterbodies, as well as the introduction of live goods to a water body. Finally, the *Exotic Animals Act* (SNB 2017, c 52) permits the Lieutenant-Governor in Council to make regulations for exotic animals, which includes exotic fish. Predominantly, policies within the provinces regulate the possession and movement of organisms, as well as the use of live bait for fishing.

3.1.2 Pathway: Transport-Stowaway

3.1.2.1 Ballast Water

Ballast water is considered to be the dominant vector for international introductions of AIS (Maréchal & Hellio, 2009). Ballasting is the process by which ships take on water and store it in onboard tanks to control trim and draft, improve stability, and improve safety (Firestone & Corbett, 2005). While any liquid or solid can be used, water is almost exclusively employed due to convenience (Firestone & Corbett, 2005). Organisms and pathogens from the area ballast water was taken are present in both the ballast water and the ballast sediment layer, which separates out from the liquid (Firestone & Corbett, 2005). The organisms are then transported between locations in the ballast (First et al., 2016). With a worldwide shipping network, thousands of species are being transported in ballast waters at any given time (Ricciardi &

MacIsaac, 2022). Some of these organisms, when introduced to new aquatic environments, will go on to reproduce, survive more than a single life cycle, and become established (Firestone & Corbett, 2005). Thus, ballast water has a high magnitude for AIS introductions with more species introductions concentrated in high traffic areas.

If a vessel that utilizes ballast water enters Canadian waters from an area other than the United States' waters of the Great Lakes Basin, the *Ballast Water Regulations* (SOR/2021-120) under the *Canada Shipping Act, 2001* and the *Fisheries Act* (R.S.C., 1985, c. F-14) outline how ballast water exchange must be approached (Table 2). Predominantly, the main factors of concern for ballast water exchange appear to be the distance from land and the depth of the receiving waters. For example, the first option outlined is to exchange ballast water at least 200 nautical miles from the nearest land and where the water is at least 200m in depth.

Canada's *Ballast Water Regulations* were updated in 2021 (SOR/2021-120) (Transport Canada, 2019b). These new regulations, unlike the previous ones, address not only the introduction of AIS from international sources, but also the spread within Canada and from Canada to the rest of the world (Transport Canada, 2019b). These regulations include a move away from conventional methods of ballast water management (BWM), such as mid-ocean exchange (MOE), to BWM systems that treat the water to minimize the number of viable organisms present (Transport Canada, 2019b). These include chemical treatments, filtration, and/or ultraviolet (UV) radiation treatment (Allard et al., 2015), or the use of potable water from the US or Canada as ballast water (Transport Canada, 2019b).

MOE is the most common method used for BWM to mitigate AIS introductions (Scriven et al., 2015). The purpose of this methodology is to expose freshwater organisms to the higher salinity levels of the ocean, which will decrease the chances of survival, and to exchange waters between areas of the ocean with significantly different ecological characteristics to help reduce the chances of invasion (Scriven et al., 2015). In 2006, Canada mandated saltwater flushing as part of MOE, and the US followed suit in 2008 (Ricciardi & MacIsaac, 2022). This resulted in an 87% decline in ballast water invasions in the Great Lakes (Ricciardi & MacIsaac, 2022). However, MOE and its associated assumptions are applicable to exchanges between freshwater and saltwater, as salinities in the marine environment do not differ drastically enough to be effective (Figure 4; Scriven et al., 2015). Additionally, MOE may promote survival of marine organisms in ballast water, as the organisms may benefit from the influx of oxygen and nutrients that enter ballast tanks with the new water (Rosenhaim et al., 2019). MOE is considered an interim method, to be used until humans have the ability to meet stricter standards (Simard et al., 2011). These stricter standards state that ships will discharge less than 10 viable organisms per cubic metre that are greater than or equal to 50 micrometres, and less than 10 viable organisms per millilitre (mL) that are less than 50 micrometres but greater than or equal to 10 micrometres (IMO, 2004). This underscores the need to develop and use effective chemical treatments for ballast.

Under proper conditions, the efficacy of chemical treatments can be quite high, with 100% removal efficiency for several species (Sayinli et al., 2022). Screen-type (tested at 50 microns) and disk-type (tested at 100 microns) automatic backwash filters have also been found to be very efficient, with removal ratings over 90% (Parsons & Harkins, 2002). The efficacy of UV treatments is dependent on the size and morphology of organisms (Tsolaki & Diamadopoulos, 2010), and the highest dose needs almost 24 hours to meet requirements (<10 cells/mL) (Lakshmi et al., 2021). Using a combination system, such as filtration and UV, as well as utilizing both ballast water exchange and treatment, can help improve treatment efficiency, reduce costs, and limit the danger posed to the environment and human health (Sayinli et al., 2022). Presumably, the ease of adopting these new standards is confounded by the effective duration of treatment or exposure (e.g., if a ship must remain in a containment zone while completing ballast water treatment, this could add to operating costs).

Under Transport Canada’s *Canada Shipping Act, 2001* , Canadian vessels or vessels entering Canadian waters must: develop and implement a BWM plan; follow standards designed to minimize the release of organisms; submit to surveys and inspections regularly by an organization authorized by the Minister of Transport; keep records; and possess a valid certificate confirming compliance with the convention (*Canada Shipping Act, 2001*; Transport Canada, 2019b). Renewal intervals for certificates shall not exceed five years, and the expiry of new certificates will not exceed five years from the date of expiry of the previous certificate, except under special circumstances (International Maritime Organization [IMO], 2023b). There are some exceptions and extensions that may be granted, such as for ships that are not in port when their certificate expires (IMO, 2023b). Within the Ballast Water Record Book, there must be documentation whenever ballast water has been taken in, circulated or treated, and discharged (IMO, 2019b). This includes the discharge of ballast water into a reception facility, or any accidental or exceptional discharge (IMO, 2019b). A completed Ballast Water Reporting Form must be submitted to the Minister of Transport, as must any changes to the BWM plan (SOR/2021-120).

3.1.2.2 Biofouling

Biofouling is the accumulation of unwanted marine organisms on submerged surfaces (Callow & Callow, 2011). Biofouling is not only responsible for the transport of sessile organisms, but also mobile species such as crabs and sea stars (Arndt et al., 2021). These mobile species typically occur last in the stages of biofouling and live within the third stage, which consists of sponges, sea squirts, mussels, oysters, and seaweeds (Arndt et al., 2021). In fact, the mobile species may need the already formed fouling matrix in order to continue to live in the biofouling community (Davidson et al., 2014).

The size of a vessel influences the size of its niche areas, and larger vessels have a larger amount of wetted surface area for invasive species to attach to (Arndt et al., 2021). As mentioned, there is a higher chance of AIS introductions in areas with high vector activity (Tidbury et al., 2021). Therefore, biofouling has the potential for high frequency and high magnitude, depending on the size of vessels and vessel activity. For example, a harbour with high traffic of large boats would be a higher invasion risk than a small harbour with a few small boats.

In addition to shipping vessels, recreational boats are subject to biofouling (DFO, 2023c; IUCN, 2017). Recreational boating activity contributes both to primary introduction (Pelletier-Rousseau et al., 2019) and the secondary spread of AIS (Clarke Murray et al., 2011), including through in-water movements (N. E. Kelly et al., 2013). The species, usually small, that attach to the boat are then transported (DFO, 2023c). This is how several AIS are introduced to new areas in Canada's waters (DFO, 2023c). Small recreational boats are capable of travelling long distances, and their comparatively slower travel speeds (versus commercial vessels) make them ideal for transporting fouling species (Clarke Murray et al., 2011). Research has shown the movements of boats indicate a high potential for recreational boats to act as vectors for AIS in North America, Australia, and New Zealand (Clarke Murray et al., 2011). However, despite its risks, hull fouling of small recreational watercraft is thought to be the largest unregulated vector for both introduction and spread of marine AIS (Clarke Murray et al., 2011).

Exemplifying the risk of AIS introductions, a study by Chan et al. (2015) found that several ships entering the Canadian Arctic had antifouling coatings that were at least 630 days old, while some had no coating at all. Moreover, self-reported estimates of biofouling coverage are unreliable as they are typically lower than would be expected from regression analysis (Chan et al., 2015).

Anti-fouling paints containing tributyl tin (TBT) are highly effective but also highly toxic (Clarke Murray et al., 2011). It has been found that they cause deformations in oysters, sex changes in whelks, accumulation in mammals, have negative impacts on the immune systems of fishes, and cause malformations in several other species (IMO, 2019a; Yebra et al., 2004). In October 2001, a conference was held to adopt the IMO's Anti-fouling Systems (AFS) Convention (Transport Canada, 2019a). The AFS Convention proposed to ensure that organotin compounds (i.e., TBT) cannot be applied or reapplied to ships as of January 1, 2003 (Transport Canada, 2019a). Any ships that bear non-compliant anti-fouling compounds must have a coating over them in order to prevent leaching (IMO, 2019a). The paint industry was therefore encouraged to develop products that do not contain TBT, while maintaining the same economic benefits associated with TBT products (Yebra et al., 2004). Additionally, the banning of TBT products is likely increasing the invasion rates via recreational boating, as the ban was followed by an increase in hull fouling and a resurgence of recreational boating as an important vector for AIS transport (Clarke Murray et al., 2011).

There are options and regulations to combat biofouling. The IMO's 2011 Guidelines for the Control and Management of Ships' Biofouling to Minimize the Transfer of Aquatic Invasive Species outline a consistent approach to manage biofouling around the world (Transport Canada, 2022a). The biofouling management plan should be specific to individual vessels and be included in operational documentation (IMO, 2011). According to these guidelines, vessel operators should select an appropriate method for anti-fouling, regulate growth in niche vessel areas, keep a record book for biofouling, and conduct regular maintenance, cleaning, and inspections of vessels (Transport Canada, 2022a). Management plans should be updated as needed, and the Biofouling Record Book should contain records of all inspections and biofouling management practices performed on the vessel (IMO, 2011). Transport Canada supports voluntary adherence to these guidelines by vessels in waters under Canadian jurisdiction (Transport Canada, 2022a).

While the AFS Convention has not yet come into force, Canada has implemented regulations for antifouling (Transport Canada, 2019a). The *Vessel Pollution and Dangerous Chemicals Regulations* (SOR/2012-69) state that ships must have on board either an anti-fouling certificate (if 400 gross tonnes or more) or a self-declaration (if less than 400 gross tonnes but at least 24m long)(Transport Canada, 2022a, 2019a). This declaration confirms that the vessel employs an AFS that meets the requirements of the AFS Convention and is to be signed by an authorized representative (if the vessel is Canadian) and the vessel owner (for any other vessel) (SOR/2012-69). As per the *Vessel Pollution and Dangerous Chemicals Regulations* (SOR/2012-69), should a vessel be from a state not part of the AFS, they must carry a certificate of compliance certifying that the vessel meets the applicable AFS requirements. The International Antifouling System Certificates cease to be valid if the AFS is changed or replaced and the Certificate is not endorsed by the Convention, or the ship is transferred to another State (IMO, 2023a). In the case of the latter, a new Certificate will only be granted when the issuing Party is satisfied that the ship complies with the Convention (IMO, 2023a). There is not, however, a timeframe outlined for validity of a certificate (i.e., no information on expiration after a certain number of years) (IMO, 2023a). This brings into question how effective the Certificate is if it may be valid for the full serviceable life of the vessel. This underscores the need to ensure that vessel hulls are clean from biofouling when in Canadian waters.

In-water cleanings can minimize the effects of biofouling, mainly the increased costs associated with frictional drag, which increases fuel consumption and operating costs (Pagoropoulos et al., 2018;Zhong et al., 2022). This method is not without its downsides, as it does not cause mortality of all organisms and can, in itself, be a mechanism through which AIS are introduced (Pagoropoulos et al., 2018). New technologies are emerging that can capture organisms as they are cleaned from the vessel, in order to mitigate introductions of AIS as a result of hull cleaning (Transport Canada, 2022a). It is recommended that cleaning be done early, before larger organisms are present and biofouling only consists of microorganisms (Pagoropoulos et al., 2018; Transport Canada, 2022a). Additionally, the Government of Canada conducted an online engagement to develop voluntary guidance on in-water cleaning of vessels (Transport Canada, 2022a). This guidance, however, only applies to vessels greater than 24 metres in length, though all vessels are encouraged to use best practices for managing biofouling (Transport Canada, 2022a). Feedback on the initial guidance revealed concern for introductions to the environment and impacts on water quality, as several participants believed the guidance did not do enough to prevent these outcomes (Transport Canada, 2022c). Some participants also believed that standards be achievable with current available technologies, while others supported stricter standards in order to encourage innovation and environmental protection by the cleaning industry (Transport Canada, 2022c). Finally, there were suggestions that Transport Canada develop more detailed testing, inspection, and approval procedures, and a suggestion that locations for testing be identified (Transport Canada, 2022c). It was also recommended that this be made into a national program by the federal government, rather than decisions being made by relevant authorities (i.e., port authorities) (Transport Canada, 2022c). Despite this, relevant authorities are responsible for handling cleaning request forms rather than the federal government (Transport Canada, 2022b). Cleaning can be done with or without capture, however only microfouling (a slime layer) and buildup from local waters can be cleaned without capture (Transport Canada, 2022b). What constitutes local waters is left to the discretion of the relevant authority, which is the authority or authorities that manage port operations (Transport Canada, 2022b).

3.1.3 Pathway: Transport-Contaminant

3.1.3.1 Contaminant on Animals (Excluding Parasites and Species Transported by Host and Vector)

Animals are shipped around the world for a multitude of reasons, including the pet trade, for food, research, display, sport, or farming (IUCN, 2017). Contaminants can be transported on both dead and living animals or animal products, as well as in or on material used for transport (IUCN, 2017). These materials include the water in which aquatic species are transported (IUCN, 2017). Species are then unintentionally introduced along with the transported animals (Katsanevakis et al., 2013). For example, in the ecoregions along the coasts of Oregon and Washington State, most invasive introductions likely happened accidentally through oyster farming, either through species hitchhiking on shells or equipment (Molnar et al., 2008). This is an important pathway in Canada, as millions of live aquatic organisms are transported into and around the country each year for purposes such as aquaculture, research, public display, and education (DFO, 2023d).

Contamination on animals is also a prevalent pathway in the Maritimes Region. While only a small percentage of approved transfer applications in New Brunswick were for marine finfish (8%) and marine molluscs (5%), more than half of Nova Scotia's approved applications were for marine finfish and 35% were for marine molluscs (DFO, 2023d). It is therefore important that potential introductions of AIS through contaminants on these animals be addressed and prevented.

As previously mentioned, the *Aquatic invasive Species Regulations* (SOR/2015-121) prohibit the transfer of listed species, which would help to prevent AIS transfer through this pathway by limiting what can be transferred in the country, and any contamination by other AIS. The Canadian provinces in the Maritimes Region have regulations surrounding aquaculture, as well as the possession and transport of live fish (Table 1). For example, New Brunswick's *Aquaculture Act* (S.N.B. 2019, c.40) would specifically relate to aquaculture contaminants. Additionally, the regulations in Nova Scotia surrounding possession and transport of live fish could be applied to aquaculture contaminants, however this would require ensuring the permitted live fish are not carrying invasive species (i.e., through testing and/or inspections).

3.1.4 Pathway: Release in Nature and Escape from Confinement

Organisms may be intentionally released, such as sport fishes and pets, while others may escape from captivity (Pyšek et al., 2020). Furthermore, organisms used as live bait can escape, be dumped, or be released and go on to become invasive (IUCN, 2017). Organisms from aquaculture farms may escape captivity and become established (DFO, 2023c). From the early 1980s, when Atlantic farming began, to the mid-1990s, over 250 000 Atlantic salmon were reported to have escaped from farms in Washington State and British Columbia (McKinnell & Thomson, 1997), indicating the potential for a high magnitude of AIS introductions. Also, infrastructure of aquaculture farms provides a surface for attachment and spread (DFO, 2023c). As aquaculture is one of the most common vectors for AIS introductions (LeBlanc et al., 2020), it frequently contributes to AIS introductions.

Social and legal frameworks exist to combat the release pathway. Canada has a "Don't Let it Loose" initiative to prevent the introduction of AIS to Canadian waters (DFO, 2023c).

Under the *Aquatic Invasive Species Regulations* (SOR/2015-121), introducing an alien aquatic species to a body of water is illegal, unless with authorization (Canadian Council on Invasive Species, 2023b; DFO, 2023c). Therefore, there are some initiatives to help prevent the release pathway, but many of these programs are more focused on freshwater species.

Several alternatives to releasing animals are available. For example, those interested in purchasing plants for aquariums and gardens can help by only purchasing native plants (Nova Scotia Invasive Species Council, 2021). Additionally, pets can be rehomed rather than released into the wild (Nova Scotia Invasive Species Council, 2021). In Nova Scotia, the Nova Scotia Invasive Species Council and the Canadian Council on Invasive Species have collaborated to recognize retailers through take-action initiatives (Nova Scotia Invasive Species Council, 2021). Retailers are provided with resources for preventing AIS introductions, to be given to customers and employees, and are also acknowledged for helping to protect Canada's ecosystems (Nova Scotia Invasive Species Council, 2021). The New Brunswick program works with many stakeholders across multiple groups and organizations (i.e., government, user-groups, etc.) to raise awareness about the detrimental impacts AIS can have (New Brunswick Invasive Species Council, n.d.). It is recommended that people purchasing pets and plants know which are legal to own, and purchase through reputable retailers (New Brunswick Invasive Species Council, n.d.). The New Brunswick regional program also encourages rehoming pets and plants, as well as contacting the retailer from which the pet or plant was initially purchased to see if they will accept it back (New Brunswick Invasive Species Council, n.d.). The regulations surrounding transport of live fish, as discussed above and in Table 1, may also help prevent AIS introductions through this pathway through the prohibition of transporting living fish as well as introducing them to bodies of water.

3.1.5 Pathway: Transport-Stowaway

3.1.5.1 Hitchhiking: Marine Construction

Construction itself can also result in AIS introductions, with the movement of sands and sediments and use of contaminated equipment (DFO, 2023c). Without proper cleaning, the heavy machinery becomes a vector of AIS spread (DFO, 2023c). Wind farms can contribute to the introduction of AIS, for example through the movement of vessels or equipment during construction (Bennun et al., 2021). The hard foundations provide habitat for AIS and allow them to establish or expand (Bennun et al., 2021). Research is also beginning to examine floating wind farms as a potential vector for AIS across the oceans (Institute of Marine Engineering, Science & Technology, 2017). While large construction projects may not be as frequent in a waterbody as some other vectors discussed here, there is the potential for high magnitude of AIS introductions. This would depend on the size of the project, as larger and more numerous machines required would result in higher surface area for AIS to hitchhike on.

Canada has regulations under the *Fisheries Act* (R.S.C., 1985, c. F-14) that are applied to marine construction. This *Act* states that the Minister of Fisheries and Oceans may make standards and codes of practice that aid in avoiding death to fish and harmful alteration, disruption or destruction of fish habitat, conserving and protecting fish or fish habitat, and prevent pollution. These standards and codes may specify procedures, practices and standards in relation to any works, undertakings and activities during any phase their construction, use, or decommissioning (R.S.C., 1985, c. F-14). No work, undertaking, or activity shall be carried out if it will result in harmful alteration, disruption, or destruction of fish habitat (R.S.C., 1985, c. F-14). Projects can be reviewed by DFO to identify any risks to fish and their habitat, as well as manage any risks posed by the project (DFO, 2022).

3.1.5.2 Hitchhiking: Marine Debris

Human-produced marine litter is one of the most ubiquitous environmental pollution challenges faced by the ocean, and amounts are expected to increase in coming years (Mghili et al., 2023). The addition of billions of tons of plastics around the world is exacerbating invasions in the marine environment (Pyšek et al., 2020). The frequency of potential introductions therefore could be quite high and increasing. Marine debris is typically relatively small pieces of plastic (Clarke Murray et al., 2018). The magnitude of this vector would therefore typically not be as high, however the example of a Japanese tsunami below illustrates that there is potential for high introduction magnitude.

Plastic debris floats and provides a stable surface which can be used for rafting, allowing for the introduction of invasive species to new areas (Thushari & Senevirathna, 2020). Bryozoans are the most dominant rafter, but plastics also provide substrate for organisms such as barnacles, mollusks, algae, and a variety of mobile organisms (Gregory, 2009; Sigler, 2014). Because these substances are capable of lasting for decades, they provide a method of transportation for species that allows them to travel for much longer and much further than they have in the past (Pyšek et al., 2020), providing an alternative to natural substrates, such as logs and pumice (Gregory, 2009). With the increase of plastics in the oceans, the number of AIS may grow at increasing speeds (Sigler, 2014). The impacts of AIS movement via ocean plastics in both the short- and long-term are not fully understood (Pyšek et al., 2020).

Rafting of AIS can be exacerbated by other factors, as natural disasters can contribute to introductions through marine debris. In 2011, an earthquake occurred off the coast of Honshu, Japan, in turn triggering an enormous tsunami (Clarke Murray et al., 2015; Therriault et al., 2018). This resulted in approximately 5 million tons of terrestrial and coastal debris being swept into the ocean (Clarke Murray et al., 2015). In June 2012, a large floating dock from Misawa, Japan was found on the coast of Oregon, covered in marine life (Carlton et al., 2018). Over 130 living species of invertebrates, protists and algae were collected from a small portion of the dock's more than $75m^2$ of biofouling (Carlton et al., 2018). Two pieces of the original dock in Misawa, Japan that washed up in Oregon and Washington were home to hundreds of species and tens of thousands of individuals that were alive and, for some, reproductively active (Clarke Murray et al., 2015).

The *Aquatic Invasive Species Regulations* (SOR/2015-121) allow fishery officers, fishery guardians, or someone acting under the direction of an officer or guardian, to undertake activities to address discovered AIS. There are not, however, policies related specifically to marine debris. The AIS Regulations could therefore be used to address AIS pathways and vectors on a case-by-case basis when needed, such as with marine debris. The responses to marine debris, however, would have to occur once something is already found in Canadian waters, emphasizing the need for early detection and rapid response to manage this pathway.

3.1.5.3 Hitchhiking: Recreational Activities

In addition to AIS introductions and spread through ship and boat movements, AIS can hitchhike on recreational equipment. Sports equipment, such as SCUBA tanks, canoes, and kayaks, to name a few, provide species a substrate onto which they can attach (DFO, 2023c). Recreational angling and commercial fishing can also move aquatic organisms, which can potentially survive for long periods of time on the equipment used in these fishing activities (IUCN, 2017). Frequency and magnitude of AIS introductions through recreational activities will likely depend on the activity, and how long equipment is in the water. For example, angling gear is unlikely to have the same number of AIS contaminants as the hull of a boat or kayak. Alternatively, areas where fishing is common, but kayaking is not would reflect the frequency with which each activity could introduce AIS. Additionally, equipment used throughout the day for fishing or kayaking would have a higher likelihood of becoming contaminated than equipment used for a short period of time.

An awareness campaign is used in Canada to help prevent the spread of AIS through recreational activities in all waterbodies (DFO, 2023b). Canadians are encouraged to clean, drain, dry, and decontaminate all equipment to prevent the spread of AIS (DFO, 2021, 2023a, 2023b). Clean, drain, dry should be done every time, everywhere (Canadian Council on Invasive Species, 2023a). This includes fishing gear and apparel, which should always be cleaned following use (DFO, 2023c). Cleaning of equipment should be done on dry land, draining the water from all watercraft, equipment, and trailers, and allowing all equipment and watercraft to dry completely (DFO, 2023b). Drying can be done through air drying for a minimum of 30 days, with towels, or using vacuums or pressurized air (DFO, 2023b). Decontamination can be done through one or multiple treatments with temperature, pressure, or chemicals (DFO, 2023b). However, for small vessels that travel and may remain in the water for long periods of time, this social campaign becomes harder to monitor and enforce.

3.1.6 Pathway: Corridors

3.1.6.1 Interconnected Waterways

Interconnected waterways as an AIS pathway are those that result from the creation of new canals or artificial waterways that connect bodies of water that were previously not connected (IUCN, 2017). Examples would include the Panama and Suez Canals as well as the Trans-European Inland Waterway network (IUCN, 2017). Many canals have also been expanded to allow larger vessels to utilize them, and more have been proposed (Pyšek et al., 2020). The Panama Canal, which connects the Atlantic and Pacific Oceans (IUCN, 2017; Thelma, 2019), and the Suez Canal are the two major canals for transfer of marine AIS (Thelma, 2019).

This pathway also includes interconnected waterways that are not man-made. The permanent opening of the Arctic Ocean is increasingly allowing species to move between the Atlantic Ocean and Pacific Ocean (Pyšek et al., 2020). Surface currents in the Arctic generally increased between 2003 and 2014, potentially due to decreased sea ice (Armitage et al., 2017; S.

J. Kelly et al., 2020), leading to increased connectivity between the Pacific and Atlantic oceans (S. J. Kelly et al., 2020). There is not yet a full understanding of the consequences resulting from the loss of an ice-restricted Arctic, both in the short-term and long-term (Pyšek et al., 2020). With Canadian Coast Guard ships traveling annually to the Arctic, including ships from Atlantic Canada (Canadian Coast Guard, 2022), organisms may be able to further travel from the Arctic to Atlantic Canadian waters.

Based on the geographic locations of not only Canada, but also the United States, New Zealand, and Australia in relation to the Suez and Panama Canals, direct marine impacts are unlikely as a result of current man-made canals and interconnected waterways. However, the northern regions of Canada could be impacted by waterways opened through more natural means, such as the Arctic. Atlantic Canada, specifically, as well as the US, New Zealand and Australia would be more likely to experience invasions because of secondary vectors (i.e., biofouling, ballast water, etc.) that occur following movement through interconnected waterways. As such, relevant regulations would be those associated with those secondary vectors. Frequency and magnitude would be heavily dependent on which secondary vectors are transporting AIS to each country.

3.1.7 Pathway: Unaided-Spread Due to Climate Change

Climate change will impact species distribution, demography, and life histories (Mainka & Howard, 2010). Climate change may speed up or aid in AIS establishment, offering new opportunities for animals to move past geographic barriers (Pyke et al., 2008). Trade patterns of plants and animals will change in response to new sources of demand, and previously uninhabitable environments may become more inhabitable for new, non-native species (Pyke et al., 2008). Under a changing climate, species are experiencing range shifts towards the poles (Parmesan & Yohe, 2003). The quick growth, ability to survive in difficult conditions, and wide dispersal ability of invasive species helps them to succeed when competing with native species under climate change (Mainka & Howard, 2010).

Climate change is an increasingly important challenge (Tittensor et al., 2019), and likely facilitates the movements of AIS to be introduced and establish (Pyke et al., 2008). The effects of climate change on AIS in Atlantic Canada have already begun. AIS, such as *Diplosoma listerianum*, can benefit from the warmer and more variable environments that result from climate change (Lowen & DiBacco, 2023). They are able to persist during colder periods due to small pockets where conditions remained favourable, called thermal refugia (Lowen & DiBacco, 2023). Another example species is the blue crab *Callinectes sapidus,* which is not native to Nova Scotia, which has been observed in the Gulf of Maine to Nova Scotia (D. S. Johnson, 2015). While it is unclear if this is the beginning of a permanent population, it is likely that these more recent observations come as a result of increasing water temperatures (D. S. Johnson, 2015). Thus, in the coming years, the frequency and magnitude of AIS introductions may both increase with increasing ocean temperatures

Climate change and AIS are often considered separately, though it is clear that their relationship is likely more complex and synergistic (Kernan, 2015). Climate change is likely to exacerbate the effects of AIS through multiple mechanisms, although it may, in some cases, make conditions less favourable for AIS, though this is more likely in freshwater habitats that marine (Kernan, 2015). Currently, unfavourable temperatures will result in the continued depletion of native species, or even drastic declines, thus lessening competition for alien species (Corrales et al., 2018). This illustrates that AIS are one stressor among many that may prove to be the final tipping point that destroys or severely alters an ecosystem. It is important to consider this factor in conjunction with other environmental stressors that affect the health and well-being of an ecosystem, and to prepare in advance to avoid negative impacts. Managing AIS could improve the resilience of ecosystems, possibly decreasing negative effects of climate change (Pyke et al., 2008).

3.2 New Zealand

3.2.1 General Background

New Zealand's *Biosecurity Act (1993)* provides the basis for the country's biosecurity, and responsibility for the biosecurity system lies with the Ministry for Primary Industries (MPI) (Champion, 2018). This department then coordinates other relevant federal agencies, specifically natural resource management and health, ensuring consistency in biosecurity management across the country (Champion, 2018). The MPI heads the biosecurity system of regulations, inspections, and surveillance (MPI, 2023b), and other agencies and departments lead initiatives when an AIS or disease will affect the responsibilities of that agency (Reid et al., 2021).

Moreover, the country's "Biosecurity 2025" initiative aims to share the ownership and management of biosecurity with citizens and businesses by 2025 (Le & Campbell, 2022). Everyone should play a role in the country's biosecurity, with end goals including participation in citizen science, businesses managing the biosecurity risks associated with their activities, ensuring people and businesses are aware of the importance of biosecurity, and groups feeling empowered to participate in biosecurity initiatives (MPI, 2016b). The initiative aims to connect and align actions and activities of all groups to help strengthen the country's biosecurity and encourage further action (This Is Us, 2023a). Biosecurity 2025 seeks to create a biosecurity of 4.7 million people (MPI, 2016b), or all of New Zealand (This Is Us, 2023a). To help support this initiative, an independent biosecurity brand called This Is Us was created, and aims to promote engagement (Reid et al., 2021; This Is Us, 2023a). This includes awards for citizens and organizations contributing to biosecurity initiatives, giving them recognition and a monetary reward (Reid et al., 2021; This Is Us, 2023b). Entries are submitted to and reviewed by a panel of representatives and professionals from different backgrounds, including government (Reid et al., 2021; This Is Us, 2023b). NGOs, scientists, landowners, community groups, Indigenous communities, and various other entities also contribute to AIS management in the country (MPI, 2016b; Reid et al., 2021). For example, NGOs and community groups work to protect the things they value, scientists develop knowledge and tools for biosecurity management, and landowners are responsible for managing AIS on their land (MPI, 2016b). Additionally, the New Zealand government hopes to obtain Social Licenses to Operate for those involved in the initiative (Le & Campbell, 2022). A social license to operate illustrates approval and acceptance of biosecurity initiatives by the community and stakeholders (Le & Campbell, 2022). This acceptance is extremely important for effective management of biological invasions (Le & Campbell, 2022).

Furthermore, management of invasions can occur prior to organisms entering the country. Protection (i.e., prevention) occurs pre-border, at the border, and post-border (MPI, 2023d). Pre-border and at-border protections would provide prevention of AIS, while post-border initiatives would be anything from eradication to management such as containment and control (Figure 1). Pre-border protection is achieved through banning certain items, requiring that certain items be treated prior to entering the country, and inspecting of overseas facilities and some cargo before it ships from other countries to New Zealand (performed by MPI) (MPI, 2023d). At the border, there is intensive monitoring for both travel (people and luggage) and cargo containers and packages (MPI, 2023d). MPI focuses primarily on preventing the entry of harmful organisms, intercepting their importation, and responding to newly established species (Champion, 2018). The Environmental Protection Authority is responsible for evaluating invasion risk and deciding whether entrance of new organisms into the country is allowable (Champion, 2018).

Finally, post-border protection is achieved through citizen reports of suspected AIS and diseases, formal investigations of many of those citizen reports, inspections, surveillance programs, and diagnostic testing (MPI, 2023d). Management of established AIS falls to territorial authorities, under regional plans (Champion, 2018) and each regional council has a plan for pest management (Bionet, n.d.). The National Policy Direction for Pest Management provides the framework and direction for not only regional pest management plans, but also national plans (MPI, 2023c). This helps to provide consistency in management plans across the country (MPI, 2023c). However, it is not always clear when pest management should be led by regional, national, or even small-scale management plans (MPI, 2020a). For this reason, the MPI also created the Biosecurity (Process for Assignment of Responsibility for Decision on Harmful Organism or Pathway) Regulations 2016, under the *Biosecurity Act 1993* to aid in assigning responsibility in the event of any ambiguity (Reid et al., 2021), such as when no plan is in place or an agreement cannot be reached on who should take responsibility (MPI, 2020a).

Currently, 6 000 sites located over the 12 most heavily used ports and marinas in New Zealand are checked bi-annually using trapping, and searches both underwater and on shore (MPI, 2023e). Anything that cannot be identified as local is sent for laboratory testing (MPI, 2023e). This has been a highly successful initiative and is funded through the central government (McDonald et al., 2020). Additionally, the New Zealand government outsources surveillance to teams that are highly trained, dedicated, and consistent (McDonald et al., 2020).

3.2.2 Pathway: Transport-Stowaway

3.2.2.1 Ballast Water

In 1998, working under a precautionary approach, New Zealand was one of the first countries to implement requirements for BWM (Hayes et al., 2019). These followed the IMO guidelines of the time (made in 1991), including MOE, onboard treatments, and discharge to a facility on shore (Hayes et al., 2019). New Zealand, like Canada, has implemented the International Convention for the Control and Management of Ships’ Ballast Water and

Sediments 2004 (Georgiades et al., 2020; Maritime New Zealand, 2018). These management practices are requirements in New Zealand (Maritime New Zealand, 2018)

3.2.2.2 Biofouling

In 2018, New Zealand implemented new regulations surrounding biofouling and required that all vessels must arrive with a clean hull (MPI, 2017). What constitutes a clean hull varies slightly, depending on the vessel's itinerary (MPI, 2017). Specifically, vessels that generally travel at moderate to high speeds and are staying for 20 days or less may have a slime layer, gooseneck barnacles, and slight fouling or early-stage fouling (barnacles, tubeworms or bryozoans) on both the hull and niche areas (MPI, 2017) (Figure 3). For vessels with a stay of 21 days or more, or entering an area not approved as a place of first arrival, only a slime layer and gooseneck barnacles are permitted (MPI, 2017) (Figure 3). If an unacceptable level of biofouling is found the vessel will need to be cleaned, either in or out of water, or told to leave the country within 24 hours if this cannot be done (MPI, 2017).

For the first two years after implementing these new regulations, New Zealand authorities focused primarily on education and assisting vessel operators in meeting the requirements (Zelinski, 2023). In early 2023, several cruise ships were denied entry to the country, due to biofouling (McGillivray, 2023; Zelinski, 2023). Some were allowed to continue with their itinerary following consultation with New Zealand officials, while some had to alter their itinerary and visit ports located in less sensitive areas of the country (Zelinski, 2023).

3.2.3 Pathway: Transport-Contaminant

3.2.3.1 Contaminant on Animals (Excluding Parasites and Species Transported by Host and Vector)

Quite recently, in December 2022, New Zealand has implemented standards to imported animal goods: The Import Health Standard: Aquatic Animal Products was implemented in the country (CFIA, 2023b; MPI, 2022). This document focuses on deceased animal products coming into the country (MPI, 2022), and helps to ensure that products are labelled correctly, are safe for consumption, and free from pests and harmful organisms (MPI, n.d.). These standards set in New Zealand also highlight the need for Canada to identify more potential marine AIS, ensuring that there is adequate knowledge on what organisms to look for and prohibit on incoming goods.

In addition to the standards surrounding deceased animal products, importing live animals is prohibited without meeting certain conditions, which may be dependent on the country from which the animals are coming (Food and Agriculture Organization of the United Nations [FAO], 2023). New Zealand's marine biosecurity focuses mainly on vessel movements, and aquaculture import, export, and movements (Campbell et al., 2017). Aquaculture biosecurity is primarily managing the threat to aquaculture production and facilities from AIS, rather than marine debris rafting, diseases, moving stock, managing potentially contaminated vessels and equipment, or the discharge of processing waste (Campbell et al., 2017).

3.2.4 Pathway: Release in Nature and Escape from Confinement

New Zealand also provides guidelines, outlined in the Aquaculture Biosecurity Handbook, which recommend that aquaculture practices, such as placing screens on discharge pipes, prevent stock escapes (MPI, 2016a). These guidelines, however, are not rules (MPI, 2016a). It is recommended that stock escapes be considered when designing and deciding on a location for a new farm so as to minimize the chances of escape (MPI, 2016a). It is also, in most cases, against the law to release animals from captivity to the wild (Tan, 2019). These types of guides are similar to what is offered in the Maritimes Region, Canada.

3.2.5 Pathway: Transport-Stowaway

3.2.5.1 Hitchhiking: Marine Construction

Similar to Canada's *Aquatic Invasive Species Regulations* (SOR/2015-121), New Zealand prohibits intentional introductions of alien species. New Zealand's *Biosecurity Act 1993* states that no one will knowingly transfer, release, or otherwise spread a pest or unwanted organism except in the process of a pest management plan, in an emergency, for scientific purposes, or if permitted by a chief technical officer. The *Biosecurity Act 1993* also outlines the duty of every person to report notifiable organisms suspected to be present and unestablished, and if its presence is unknown to the chief technical officer. Provisions under the *Biosecurity Act 1993* may therefore be applied to marine construction, as needed.

3.2.5.2 Hitchhiking: Marine Debris

The rafting of AIS on human-produced marine debris is currently under-represented as a threat to New Zealand's biosecurity and is unmanaged both at territorial and national levels (Campbell et al., 2017). In comparison, under the *Fisheries Act* (R.S.C., 1985, c. F-14), Canadian works, undertakings, and activities in and near water that receive a Letter of Advice or a

Fisheries Act (R.S.C., 1985, c. F-14) authorization have considerations for AIS dispersal or introductions, including via rafting on construction debris.

3.2.5.3 Hitchhiking: Recreational Activities

Similar to Canada, New Zealand has a "Check, Clean, and Dry" social campaign for AIS (MPI 2020b; MPI, 2021). Antifouling is also recommended for vessels that will be leaving for another part of New Zealand and will be gone for a while (duration not specified) (MPI, 2023a). These practices, however, do not appear to be legal requirements, but rather guidelines and tools for people to use (see MPI, 2023a).

3.3 Australia

3.3.1 General Background

The primary agency responsible for AIS management in Australia was the Department of Agriculture, Water, and the Environment (DAWE), now the Department of Agriculture, Fisheries and Forestry (DAFF), which implements the *Environment Protection and Biodiversity Conservation Act 1999*, and the regulations under the *Biosecurity Act* 2015 (Reid et al., 2021). However, members of government may not have enough funding to fill all roles and responsibilities for biosecurity, and they may not be the most qualified candidates for all roles (McAllister et al., 2020). Australia's *Biosecurity Act 2015* emphasizes shared responsibility in biosecurity, as State and Territory governments, industry, and the community have an important role to play in addition to the Australian government (DAFF, 2023f).

Formal responsibility for management of marine AIS falls to the federal government, which coordinates with state and territory governments through the Marine Pest Sectoral Committee (MPSC) (Stenekes et al., 2019). The Intergovernmental Agreement on Biosecurity provides all levels of government with their roles, responsibilities, and governance arrangements for biosecurity responses (Reid et al., 2021). State and territory governments are primarily responsible for marine biosecurity within their jurisdictions, in conjunction with relevant stakeholders (Stenekes et al., 2019). The MPSC is also responsible for emergency responses to invasions, which requires a rapid response to AIS incursions (Stenekes et al., 2019). The MPSC also provides leadership for research and development through the coordination of their counterparts at the state and territory level, and meet operational requirements for surveillance, response, and management (Stenekes et al., 2019).

Moreover, Australia's federal government works with Indigenous communities for biosecurity response, and benefits from their Traditional Knowledge in this partnership (Reid et al., 2021). The Indigenous Ranger Biosecurity Program provides Indigenous rangers with the skills and support to use their knowledge of the country and conservation to engage in several biosecurity activities (National Indigenous Australians Agency, 2020). These include animal, plant, and aquatic health surveillance, trapping and surveillance of insects, plant host mapping, reporting on animal health, and biosecurity awareness (National Indigenous Australians Agency, 2020). The role of Indigenous rangers increased in 2020, with $12.5 million having been invested since 2016 to support service activities, capability building initiatives, and traineeships (National Indigenous Australians Agency, 2020).

To increase coordination between groups, in late 2018, Australia appointed its first Chief Environmental Biosecurity Officer (ACEBO) (DAFF, 2023b). The ACEBO works extensively across and outside of government to strengthen biosecurity outcomes and raise awareness surrounding biosecurity issues, supported by the Environmental Biosecurity Office (DAFF, 2023b).

Similar to CFIA, DAFF has developed a priority list of pests, weeds, and diseases, which lists 168 species, including aquatic, that pose a significant threat to Australia (DAFF, 2023g; Reid et al., 2021). The list was determined based on pests, weeds, and diseases with potential or demonstrated negative impacts on the environment, ecotoxicity or are subject to nationally agreed eradication plans, have at least one potential or known pathway to Australia, have at least one potential or known pathway active in Australia, and have the potential to establish and spread if introduced (DAFF, 2023g). An implementation plan is being finalized to identify and prioritize actions to address these species and decrease the likelihood of their introduction, spread, and establishment (DAFF, 2023g). Like New Zealand, awards are also handed out each year to recognize significant contributions to the country's biosecurity (Reid et al., 2021).

3.3.2 Pathway: Transport-Stowaway

3.3.2.1 Ballast Water

Australia also utilizes the International Convention for the Control and Management of Ships' Ballast Water and Sediments 2004 for its ballast water regulations, like Canada and New Zealand (DAFF, 2020; Georgiades et al., 2020; Maritime New Zealand, 2018). As seen with

New Zealand, these regulations are also required in Australia (DAFF, 2020). Reporting obligations are different depending on if a vessel is trading domestically or internationally (DAFF, 2020). Vessels intending to discharge ballast water that was taken up in international waters must submit a Ballast Water Report through the Maritime Arrivals Reporting System 12 hours before they arrive (DAFF, 2020). However, even if vessel operators are not planning on discharging internationally sourced ballast water, they are still encouraged to manage their ballast water and submit a report (DAFF, 2020). Domestically sourced ballast water must also be managed or be deemed low risk and given an exemption from DAFF before discharge (DAFF, 2020). All vessels that carry ballast water must have a ballast water management plan, approved by the Director of Biosecurity or approved survey authority (DAFF, 2020). Non-commercial vessels less than 400 gross tonnes are exempt from having management plans and carrying International Ballast Water Certificates (DAFF, 2020), similar to Transport Canada's regulations also being applicable to larger vessels (Transport Canada, 2022a; see above discussion on Canada's regulations).

3.3.2.2 Biofouling

Australia enforces strict biofouling regulations to protect the country from introductions of new alien species, and biofouling management is standard for all vessels coming into the country (Humayun, 2023; Maishman & Murphy, 2023). As of June 15, 2022, Australia requires the operators of all vessels to provide information on biofouling management practices before they arrive in the country (DAFF, 2022). Pre-arrival questions about biofouling will include: if the vessel has an effective biofouling management plan or an alternative pre-approved by DAFF; if the vessel has been cleaned within 30 days of arrival; or if the vessel operator intends to do in-water cleaning while in Australia (DAFF, 2022). If proactive management cannot be demonstrated, additional pre-arrival questions will be asked, and DAFF may conduct inspections of hulls and niche areas (DAFF, 2022). This information helps the department assess biosecurity risk and target interventions of vessels (DAFF, 2022, 2023e).

The first step to enforcing these new biofouling requirements is education, and DAFF will be educating and advising ship managers between June 15, 2022, and December 15, 2023 (DAFF, 2022). These requirements are consistent with the IMO's Guidelines for the Control and Management of Ships' biofouling to Minimize the Transfer of Invasive Aquatic Species, and provide guidance in order to comply with the *Biosecurity Act 2015* (DAFF, 2023e).

3.3.3 Pathway: Transport-Contaminant

3.3.3.1 Contaminant on Animals (Excluding Parasites and Species Transported by Host and Vector)

Australia only permits the import of live fish for the aquarium trade, and only permitted species from approved countries may be imported (DAFF, 2023d). The country recognizes the animal health status and disease-free zones of trading partners, assessments for which are performed by the DAFF (DAFF, n.d.). An import proposal may be required as part of a biosecurity risk analysis, and may include information relating to plant pests, animal diseases, or treatments applied to the goods (DAFF, 2023c, 2023a). There are also guidelines around the translocation of fish in Australia (DAWE, 2020). These will be discussed below as part of the "Release in Nature and Escape from Confinement" pathway.

3.3.4 Pathway: Release in Nature and Escape from Confinement

Australia's guidelines for translocation of animals provide a framework for risk analyses on translocation proposals (DAWE, 2020). The different jurisdictions within the country also have their own policies and legislation to address escape from confinement (DAWE, 2020). For example, the *Fisheries Management Act 2007* in South Australia prohibits, except with a permit issued by the minister, a person to release or allow to escape any exotic fish, aquaculture fish, or fish kept from their natural habitat into any waters (DAWE, 2020). The *Fisheries Management Act* 2007 also prohibits, except by ministerial permit, depositing exotic aquatic plants. Also, when people are catching their own bait, it should only be used in the water that it originated from (Department of Primary Industries, n.d.-b). In addition, South Australia utilizes zone policies which specify the type of aquaculture, how much, and which species can be farmed in a certain area (Department of Primary Industries and Regions, the Government of South Australia, 2022). As per the *Fisheries Management Act 2007*, the Governor has authority to take action to control exotic organisms and respond to organisms that have been released or escaped.

3.3.5 Pathway: Transport-Stowaway

3.3.5.1 Hitchhiking: Marine Construction

Similarly to Canada's regulations surrounding works, undertakings, and activities, in Australia, under the *Environment Protection and Biodiversity Conservation Act 1999*, there are prohibitions against actions that significantly impact the environment. There are exceptions, such as (but not limited to) the actions being performed by the Commonwealth or a Commonwealth agency, or the person has approval within the confines of the *Act*. These provisions could be applied to marine construction, as needed.

3.3.5.2 Hitchhiking: Marine Debris

One example of Indigenous involvement in AIS management was when Indigenous Rangers in the north of Cape York, Australia, investigated a bamboo raft that washed on shore (National Indigenous Australians Agency, 2020). Samples were taken from the raft that revealed species on the raft were local (National Indigenous Australians Agency, 2020). The quick response of the Indigenous Rangers ensured that there was no threat to the country's biosecurity (National Indigenous Australians Agency, 2020). This example would indicate that monitoring and quick response are the main approach taken to AIS introductions through marine debris and highlights the value in engaging Indigenous peoples in AIS monitoring and response.

3.3.5.3 Hitchhiking: Recreational Activities

The government of New South Wales, Australia has recommendations for limiting the spread of AIS through recreational activities, similar to the social campaigns in New Zealand and North America. It is recommended that boats and gear are kept clean, and are checked before entering a waterway (Department of Primary Industries, n.d.-b). Activities should be avoided in areas with known populations of AIS (Department of Primary Industries, n.d.-b). In addition, it is recommended that recreational users maintain an anti-fouling coating on their vessels and maintain records of biofouling management (Department of Primary Industries, n.d.-a). The four countries examined here appear to employ similar suggestions around cleaning and drying of recreational equipment.

3.4 United States

3.4.1 General Background

In the US, AIS prevention efforts across the country are consistent, with federal laws given precedence over those of the states (Reid et al., 2021). In 1990, with the implementation of the Nonindigenous Aquatic Nuisance Prevention and Control Act, the Aquatic Nuisance Species Task Force (ANSTF) was created (ANSTF, n.d.-a). It was then reauthorized when the National Invasive Species Act was passed in 1996 (ANSTF, n.d.-a). Consisting of 26 members, 13 of which are Federal, this task force is co-chaired by the US Fish and Wildlife Service (USFWS) and the National Oceanic and Atmospheric Administration (NOAA) (ANSTF, n.d.-a). Half of the members of the ANSTF are Federal agency representatives, while the other half represent regional or national interest groups, such as the Native American Fish and Wildlife Society, the Great Lakes Commission, the American Water Works Association, and the Association of Fish and Wildlife Agencies, to name a few (ANSTF, n.d.-b). The ANSTF works to raise awareness and take action to prevent and manage AIS (ANSTF, n.d.-a).

The National Invasive Species Council (NISC) was created in 1999 with Executive Order (EO) 13112 (National Invasive Species Information Center, n.d.-b). The duty of the NISC is to provide leadership to maintain and grow Federal efforts to prevent, eradicate, and control AIS (NISC, n.d.-a). Inter-agency bodies, staff from Federal agencies, and stakeholders outside of the Federal government provide technical input to the NISC that benefits policy and planning (NISC, n.d.-a). Members of this council come from several US departments including, but not limited to, the Department of the Interior, the Department of Defense, the United States Department of Agriculture, the Department of Commerce, the Department of State, Homeland Security, Health and Human Services, the Department of Transportation, the Environmental Protection Agency, and the National Aeronautics and Space Administration (NISC, n.d.-a). Each federal agency that undertakes actions that affect the introduction, establishment, or spread of invasive species is responsible for identifying those actions, and for working to prevent and manage invasive species (Executive Office of the President, 2016). Indigenous communities have authority for management in their territories (Reid et al., 2021).

In the US, two EOs address invasive species, EO 13112 and EO 13751 (Executive Office of the President, 2016). EO 13112 was made in 1999, and called for executive departments and agencies to prevent the introduction and spread of invasive species while also supporting the eradication and removal of already established species (National Invasive Species Information Center, n.d.-c). This EO also stated that past efforts for prevention, eradication, and control demonstrated the necessity of collaboration across governments, stake- and rights-holders, and the private sector in protecting the US (Executive Office of the President, 2016). EO 13751 maintained the NISC as well as the Invasive Species Advisory Committee while expanding the membership and clarifying the operations of the NISC (Executive Office of the President, 2016). It also included both human and environmental health, climate change, innovations in technology, and other priorities into Federal efforts, as well as improving coordination and cost-effectiveness of actions (Executive Office of the President, 2016).

3.4.2 Pathway: Transport-Stowaway

3.4.2.1 Ballast Water

The United States Coast Guard (USCG), in addition to the regulations set forth by the IMO, requires that all vessels entering US ports clean ballast tanks of sediments regularly, maintain records of ballast management, and submit reports to a US port 24 hours before arrival (DNV, 2023). Additionally, periodic sampling of ballast water is performed (DNV, 2023). It is, however, worth noting that a ballast water management plan does not have to be approved (DNV, 2023). The specific treatment used on ballast water does, however, need to be one approved by the USCG (DNV, 2023). Alternatively, ship operators can opt to either not perform ballast exchange, or to use potable water from the United States (DNV, 2023).

Some US states have stricter regulations than others, for example, California's approach to ballast water regulations. The state's goal, through the Marine Invasive Species Act, was to implement treatments to reach a standard of no detectable living organisms in ballast water by 2020 (California Association of Port Authorities, 2023)**.** These standards, however, were not achievable from a technical standpoint (Gard, 2021a) and California had to delay implementation of this final goal until 2040 (Gard, 2021a; Legal Information Institute, n.d.; Wang et al., 2020). In the interim, stricter guidelines than the IMO's must be followed by January 1, 2030 (Gard, 2021a; Legal Information Institute, n.d.).

3.4.2.2 Biofouling

In addition to the IMO's guidelines, the US Federal government has regulations for biofouling management (Urdahl, 2017). The USCG, going beyond the IMO's regulations, requires that anchors and chains be rinsed when the anchor is retrieved, and fouling be regularly removed from a vessel's hull, piping and tanks (DNV, 2023). The Vessel General Permit program, through the Environmental Protection Agency, requires inspection of a vessel's hull for living organisms (Urdahl, 2017). Again, California has also implemented more strict regulations for biofouling within its jurisdiction (Urdahl, 2017). These regulations are under the California Code of Regulations, which are applicable to vessels with 300 gross registered tons or more, and that carry ballast water or have the ability to carry ballast water (Gard, 2021b). As an International AFS Certificate is not believed to be enough to document the effectiveness of a ship's antifouling coating with regard to marine AIS, California requires that each vessel has Biofouling Management Plans and Biofouling Record Books in line with the IMO's guidelines (Gard, 2021b). Additionally, strategies to manage fouling of both the hull and niche areas are required, as is management of fouling when the vessel has remained idle for extended periods of time (e.g., remaining in the same location for at least 45 days) (Gard, 2021b). Finally, ships must submit an Annual Vessel Reporting Form (Gard, 2021b). The California State Lands Commission has provided a document with guidance and information to aid in understanding and complying with these regulations (Urdahl, 2017). Therefore, somewhat similarly to New Zealand and Australia, California attempted to provide assistance in meeting these new regulations.

3.4.3 Pathway: Transport-Contaminant

3.4.3.1 Contaminant on Animals (Excluding Parasites and Species Transported by Host and Vector)

The USFWS uses Title 18 of the *Lacey Act* to prevent the introduction of invasive species through the trade of live organisms, among other pathways (Office of Congressional and Legislative Affairs, 2017). In 2016, a list of 11 alien aquatic species was created proactively to prevent those species from becoming invasive (Office of Congressional and Legislative Affairs, 2017).

Furthermore, the USFWS has worked to improve its listing process for injurious species in order to aid in the enhancement of decision-making tools, such as risk screening (Office of Congressional and Legislative Affairs, 2017). The relative abundance of data on invasive species distribution in the US, as well as their hosts, aids in surveillance and risk modelling (Reid et al., 2021). This allows for rapid evaluation of risk associated with particular species, as well as for prioritization of species to evaluate further (Office of Congressional and Legislative Affairs, 2017). These approaches can help identify organisms that may come into the country through shipments of aquatic animals.

In addition to the USFWS, there are other agencies that work to prevent AIS in the country. Customs and Border Protection determine whether plant and animal materials can enter the country, in an effort to prevent the introduction of new invasive species (NISC, n.d.-b). They also work alongside the Animal and Plant Health Inspection Service and USFWS to enforce the country's laws surrounding entry of invasive species (NISC, n.d.-b). These practices can aid in preventing contaminants on animals coming into the country.

3.4.4 Pathway: Release in Nature and Escape from Confinement

Like Canada, the US also has "Don't Let it Loose" initiatives, sponsored by the USFWS (Invasive Species Action Network, n.d.). The Aquatic Invasive Species branch of the USFWS funds and coordinates activities over the US, and reminds citizens to never release pets or aquarium contents (USFWS, 2021c). Additionally, they develop regulations prohibiting the importation of high-risk species, as well as some transportation of high-risk species (USFWS, 2021c). Also like Canada, Don't Let it Loose in the US is attempting to create strong industry partnerships in order to reach as many pet owners as possible through adding Don't Let it Loose resources onto pet care sheets, providing information for responsible pet ownership to those purchasing animals, and having rehoming information and resources as well as information on invasive species on their websites (Invasive Species Action Network, 2022).

3.4.5 Pathway: Transport-Stowaway

3.4.5.1 Hitchhiking: Marine Construction

Specific regulations to marine construction, as well as marine debris, were not found throughout the course of this study. While addressing these specific pathways is likely accomplished through government processes that are in line with the country's dedication to AIS prevention and management, the lack of clarity in this regard may result in misunderstanding for those outside of government.

3.4.5.2 Hitchhiking: Recreational Activities

The USFWS also has a "Clean, Drain, Dry" initiative, but with the added step of "Disposal" for anglers (USFWS, 2021a). Watercraft and outdoor recreational gear should be washed after every use, and after every waterbody (USFWS, 2021b). Hot water, when possible, should be used to clean all equipment and water should be drained from all relevant devices prior to leaving water access areas, and equipment should be allowed to dry for a minimum of five days or be towel dried (USFWS, 2021b).

3.5 New and Emerging Technologies for AIS Prevention, Monitoring, and Management

3.5.1 Anti-Fouling Paint

Currently, the alternatives to TBT are also toxic (Kyei et al., 2020). More eco-friendly, non-toxic alternatives are needed (Maréchal & Hellio, 2009; Park & Lee, 2018). One such option is provided by Graphite Innovation & Technologies, a company in Dartmouth, Nova Scotia (Withers, 2023). The anti-fouling coatings produced by this company not only reduce drag on ships and improve fuel efficiency, but they are also environmentally friendly (Withers, 2023). These paints are graphene-based, and help ship owners save time and money (Graphite Innovation & Technologies, 2022). Products such as these provide an opportunity for Canada, among other countries, to treat vessel hulls and niche areas to prevent AIS while also avoiding damage to the surrounding environment.

3.5.2 Genetic Analysis

Effective early detection of AIS requires the ability to detect these species even at very low population densities (Darling & Mahon, 2011). Identification may also have to be performed in difficult situations, such as through visual surveillance by divers or in low visibility or performed on organisms difficult to identify using traditional methods, such as morphological identification keys (Darling & Mahon, 2011). Molecular analysis of water samples for early detection of AIS is a promising approach for early detection (LeBlanc et al., 2020). Every organism will release genetic material into its environment through a variety of biological sources (LeBlanc et al., 2020). This is known as environmental DNA (eDNA) and can be used to indicate the presence of species within an ecosystem (LeBlanc et al., 2020). Techniques based on eDNA and environmental RNA (eRNA) capture, extract, and analyze traces of genetic material from environmental substances such as water, soil, and air (Cristescu & Hebert, 2018; De Brauwer et al., 2023). They are also typically more sensitive and cost-effective than traditional methods, while having higher specificity and the ability to process a greater quantity of samples (Darling & Mahon, 2011). eDNA has been used to detect non-indigenous tunicates in Eastern Canada from water samples (LeBlanc et al., 2020).

Delaying management practices until organisms can be found through nonmolecular methods can contribute to the negative impacts from AIS as well as increase expensive control measures (Sepulveda et al., 2020). Because monitoring using eDNA techniques focus on samples from the environment in which species live, rather than from the species themselves, they are being used in environmental research and monitoring programs globally (De Brauwer et al., 2023). Application of eDNA technology for AIS monitoring has predominantly been done, however, in freshwater environments (Sepulveda et al., 2020). In the DFO Maritimes Region, monitoring efforts utilize eDNA technology in addition to more conventional methods such as plate monitoring (Lowen & DiBacco, 2023). Generally, the variability in methods for eDNA use, as well as the diverse and unpredictable nature of eDNA underline the need for standardized laboratory protocols and analyses (De Brauwer et al., 2023). Continuing and expanding the use of eDNA, in addition to other detection methods, can aid in Canada's biosecurity efforts through more sensitive and early detection of species, aiding in the country's ability for rapid response. Refining processes and techniques would also be beneficial in order to ensure the accuracy of detections.

3.5.3 Hull Cleaning Technology

Rather than cleaning a hull following a biofouling outbreak, it may be more effective to disrupt the continuous development of a biofouling system (Hua et al., 2018), combined with anti-fouling paints and hull cleanings. Hua et al. (2018) demonstrated with a hydroblasting system, using water jets that are capable of removing biofilm from a hull to a certain degree, biofilm growth can be intermittently treated to interrupt biofouling species' growth. This delays the onset of biofouling while not significantly decreasing ship performance (Hua et al., 2018). This system is lightweight, low cost, and convenient to operate en route in water (Hua et al., 2018).

Another option is a submerged cavitation jet, which has both higher force and cleaning ability than conventional water jets (Zhong et al., 2022). Using a cavitation jet cleaning underwater can disrupt the development of biofouling at an early stage (Zhong et al., 2022). Depending on how frequently treatments need to be administered, however, service costs may end up exceeding fuel savings (Pagoropoulos et al., 2018; Zhong et al., 2022).

Furthermore, researchers are investigating the potential for ultrasonic technology to be used for cleaning and prevention of biofouling on ship hulls (Zhong et al., 2022). For example, Park and Lee (2018) applied ultrasonic projectors to the starboard shell plate of a class drill-ship. After four months, this side of the ship was relatively clean while the port side was heavily fouled (Park & Lee, 2018). The amount of fouling on the treatment side was heavily dependent on location, as the pressure from the sound decreased as distance from the source increased (Park & Lee, 2018). Notably, the noise from this ultrasonic antifouling technique is unlikely to affect marine life from far away, and the system can be adjusted to reduce impact if there are organisms close by (Park & Lee, 2018). This study does, however, provide a promising method for addressing fouling accumulation, even on large ships (Park & Lee, 2018).

A study performed by Zhong et al. (2022) illustrated that using an ultrasonic device in a ship's hull coupled with a submerged cavitation jet could feasibly be applied to ship hull cleaning. Ultrasonic and cavitation jet technologies are predominantly utilized independently in their application to underwater environments (Zhong et al., 2022). In some industries, such as wastewater treatment, the use of both hydrodynamic and acoustic cavitation can sometimes provide improved results (Zhong et al., 2022). The use of both can, in fact, provide better results than the two individual methods combined (Franke et al., 2011; Zhong et al., 2022). There is potential for this method to be applied to cleaning of ship fouling (Zhong et al., 2022). This work is, however, very preliminary and further investigation is needed (Zhong et al., 2022).

Robotics may also aid in managing biofouling. For example, Hullbot, made in Australia, provides cleaning of early stage biofouling on all underwater hull surfaces (Hullbot Pty Ltd, 2023b). The technology, in addition to cleaning, can provide reports on the status of the boat's hull, including invasive species identification, though this is still a pilot program (Hullbot Pty Ltd, 2023a). While this particular technology may still be relatively new, it provides insight into the initiatives being undertaken in Australia. It can be used to help inform Canada of potential avenues for innovation and new technologies to help in managing early-stage biofouling.

Chapter 4: Recommendations

4.1 Precautionary Approach and Adaptive Management

Management and prevention of AIS in Canada should be proactive and holistic, applying the precautionary principle whenever there is a lack of scientific evidence (Trouwborst, 2009). The precautionary principle aims to act against threats to the environment at an early stage, even in the face of scientific uncertainty, when there is reason to believe that serious and/or permanent harm may be done to the environment (DFO, 2018b; Trouwborst, 2009). Indeed, scientific uncertainty should not be used to justify delayed cost-effective prevention measures (Tang, 2013). Additionally, a precautionary approach taken must be regularly reviewed and adapted when needed and when new scientific evidence becomes available via adaptive management (Trouwborst, 2009).

As evident through the numerous continual AIS introductions and spread along Canada's Atlantic coast, an adaptive management strategy applying precautionary principles is greatly needed. Adaptive management involves implementing management strategies while simultaneously increasing relevant knowledge and setting routine 'check ups' on management strategies to revise approaches and decisions as needed (Williams, 2011).

Furthermore, both of these management strategies are guiding principles for DFO (DFO, 2018b), and the precautionary principle is listed as something that the Minister of Fisheries and Oceans may consider when making decisions (*Fisheries Act* R.S.C., 1985, c. F-14). An adaptive management strategy applying the precautionary approach could include:

1. establishing greater monitoring programs for new species introductions
2. utilizing a citizen science program and community environmental groups/NGOs to expand monitoring in Atlantic Canada
3. improving hull cleaning regulations and enforcement through collaboration between DFO (for vessels that the *Aquatic Invasive Species Regulations* apply to) and Transport Canada
4. implementation of new tools to monitor ship ballast water and enforce water treatment regulations from Transport Canada
5. ensuring all federal departments with sea-going vessels are compliant with hull cleaning and ballast water regulations and recommendations

6. implementing new tools for in-water cleaning of hulls and hull inspections to determine which vessels require immediate intervention to ensure compliance with regulations
7. adopting accessible wording to explain Acts and regulations applicable to hull fouling and ballast water
8. providing this information in easy to find locations (i.e., comprehensive web pages, pamphlets, etc.)

4.2 Intergovernmental Cooperation and Management

It is recommended that Atlantic Canada, like New Zealand and Australia, have one governing body responsible for marine AIS in order to streamline communication and provide a single point of contact for all regulations and initiatives (i.e., prevention, eradication, and control). This could be accomplished through the creation of a new department or agency that is responsible for coordinating marine biosecurity initiatives. Similar agencies could be applied to Canada's other coastlines along the Pacific and Arctic Oceans, allowing for collaboration among these bodies regarding national marine biosecurity as needed, and more efficient communication. A national agency could also be formed in order to coordinate initiatives across the country. This should also include the freedom to share information between and among governing bodies, so that all relevant authorities have the knowledge needed to combat AIS.

Additionally, government agencies should collaborate with the public and Indigenous Peoples, something also done in Australia and New Zealand, to ensure that as many people as possible are meaningfully involved in protecting the country from marine AIS. Canada should follow the example made by New Zealand, by creating a group that involves collaboration across many sectors, both private and government, like the This Is Us brand. Canada is committed to renewing relationships with Indigenous Peoples (Crown-Indigenous Relations and Northern Affairs Canada, 2022), and supports the United Nations Declaration on the Rights of Indigenous Peoples (Department of Economic and Social Affairs, n.d.). This underscores the need for Canadian policy-makers to collaborate with Indigenous Peoples, something that will be discussed further in the "Indigenous Collaboration" recommendation below.

4.2.1 Public Engagement, Education, and Citizen Science

The Canadian identity is closely linked with wilderness, helping to explain the support citizens show for the protection of nature and the use of protected areas (Reid et al., 2021;

Wright et al., 2019). This relationship may prove beneficial with quicker detection and prevention of AIS, provided public awareness campaigns are utilized and promoted (Reid et al., 2021). Education is an important tool for combating invasive species (Reo et al., 2017), and it is important that the public be educated about the threats posed by AIS and the impacts of management strategies, to increase the likelihood of support for these management strategies (Jacobson et al., 2006). Canada should therefore invest in federal education and outreach initiatives to ensure programs, and how they are presented, are consistent and effective across the country.

How these educational messages are presented is important, so Canada should utilize effective communication strategies. For example, it has been found that messages utilizing self-transcendent framing are more likely to evoke in-depth thinking, leading to stronger beliefs and support for prevention of AIS (Golebie & Van Riper, 2023). Self-transcendence refers to concern for entities outside of the self, including altruistic values (such as justice, peace, and equality) and biospheric values (such as environmental protection that helps in finding a connection and unity with nature) (Golebie & Van Riper, 2023). Hence, the recommendation to tie the biosecurity message to the Canadian identity, which elicits an emotional and value-based response from the public and will aid in acquiring public buy-in for new biosecurity initiatives.

As part of public engagement, it is also recommended that all relevant stake- and rights-holders be included in planning and decision making. Inclusion of these groups in decision-making ensures support and buy-in from those impacted by those decisions early-on in the process (Tompkins et al., 2008). Top-down deliberation and/or coproduction involves engagement initiated by an organization with the ability to make decisions, and involves two-way discussion and joint decisions by the decision-making entity, stake-holders, rights-holders, and the public (Reed et al., 2018). Bottom-up deliberation and/or coproduction involves engagement being initiated by stake-holders and/or members of the public, with decisions also being implemented by these groups (Reed et al., 2018). In the case of Canada's biosecurity, top-down deliberation and/or coproduction is recommended, with the possibility of bottom-up initiatives in future as more information is gained and interested parties can determine the outcomes of implemented regulations. This approach is recommended because, as discussed above, Canada has specifically made commitments to conserving biodiversity and preventing

AIS introductions. As such, it is important for Canadian policy-makers to take the initiative to begin these improvements to biosecurity.

Novoa et al. (2018) provides a framework for stakeholder engagement surrounding AIS (Figure 5). This 12-step process begins with identification of stakeholders, with the snowball technique identified as being quite effective (Novoa et al., 2018). This involves identifying an initial, small group of stakeholders through peer recommendation or literature review, and then asking this group to recommend additional stake- and rights-holders until no new suggestions are made (Novoa et al., 2018). When it is not possible to involve all identified stake- and rights-holders, key stake- and rights-holders are identified, typically through an impact-influence matrix, wherein only those who have the greatest likelihood of impacting the functioning of the management strategy are included (Novoa et al., 2018). Throughout the following stages, willingness to collaborate is examined, and there is co-designing of aims, objectives, and strategies (Novoa et al., 2018). Following monitoring of management practices, if there is still need for a management strategy, new stake- and rights-holders, benefits, and costs are determined (if any), and the strategy is revised (Novoa et al., 2018). This framework can be used to help provide the basis for engagement in management of AIS in Canada.

4.2.2 Indigenous Collaboration

There is increasing evidence that Indigenous estates, knowledge, and ethics of care provide significant insight for maintaining social-ecological systems (Austin et al., 2019). Indigenous Peoples in Canada are very aware of invasive species in their territories and are actively responding, however their work is often underreported in the literature (Reo et al., 2017). Conservation initiatives led by Indigenous Peoples involve managing, using, and rebuilding ecosystems while simultaneously renewing decision-making, rights, and leadership (Von Der Porten et al., 2019). Despite partnering with a variety of organizations, Indigenous Peoples can be left unaware or told too late about new AIS, negatively impacting early response (Reo et al., 2017). This gap in communication and reporting needs to be addressed not only to improve response times to, and management of, AIS but also to improve the relationship between Indigenous Peoples and the Canadian government.

The Canadian government is committed to renewing relationships with Indigenous Peoples through recognizing rights, respect, cooperation, and partnership (Crown-Indigenous

Relations and Northern Affairs Canada, 2022). Canada is on the traditional territories of several Indigenous Nations who are tightly linked with nature (Reid et al., 2021). Many Indigenous Peoples indicate their communities partnered with multiple levels of government, NGOs, and non-profit organizations to prevent new invasive species (Reo et al., 2017). As such, they may be open to further partnerships with stakeholders (Reid et al., 2021).Collaboration with Indigenous Peoples can range from co-management roles that are predominantly advisory, to co-governance where Indigenous Peoples have a large role in decisions affecting environmental management (Bowie, 2013). However, the inclusion of Indigenous voices in both academic and political spheres has and is typically conditional on adherence to scientific understanding of accuracy and methodology (J. T. Johnson et al., 2016)

Some Indigenous Peoples have maintained systematic, localized, and place-based environmental knowledge for long periods of time, providing significant information on how to maintain and steward biodiverse ecosystems (J. T. Johnson et al., 2016). However, Traditional Ecological Knowledge is often overlooked, poorly understood, or not incorporated into management and governance (Harrison & Loring, 2020), but multiple types of knowledge and ways of creating knowledge can address important knowledge gaps (Harrison & Loring, 2020). Therefore, Canadian policy makers shall ensure that all forms of knowledge, and those that possess them, are being included in decision-making processes.

It is important for scientists, policy makers, and Indigenous Peoples to learn to listen to each other's concerns and ideas with respect, while being open to change and to accept that there is more than one way of 'knowing' (J. T. Johnson et al., 2016). Indigenous groups should be included in all processes involved in decision-making and be partners in biosecurity initiatives. The relationship between non-Indigenous and Indigenous Peoples has not been mutually respectful, but it is believed that a mutually respectful relationship can be achieved and maintained (Commission de vérité et réconciliation du Canada, 2015). Marine AIS management should involve meaningful and respectful collaboration with Indigenous Peoples and provide an opportunity to re-establish a positive relationship between the Canadian government and Indigenous Peoples.

4.3 Improvements to Legislation and Enforcement

4.3.1 Improvements to Ballast Water and Biofouling Regulations

Due to the expected increase in movement of marine taxa, particularly through ballast water and biofouling (Bailey et al., 2020), monitoring and improved management of these vectors of AIS transfer should continue to be of utmost importance in the years to come. The assumptions made for MOE are mostly pertinent to vessels moving between freshwater and saltwater, as transfer between saltwater does not have enough change in salinity to effectively eradicate marine species (Scriven et al., 2015). Enforcing Transport Canada's ballast water treatments, and changing biofouling measures from recommendation to requirement, are the top two priorities likely to have the largest impact on protecting Canada's biosecurity. On a more local level, implementing and enforcing the *Aquatic Invasive Species Regulations* (to vessels less than 24 m in length) will limit secondary spread of AIS from southern to northern Nova Scotia. Implementing strategically placed in-water hull cleaning stations or ballast water testing stations within the Maritimes Regions will help protect other areas (e.g., the Arctic, sub-Arctic, and Gulf of St. Lawrence) from AIS introductions.

While the shipping industry may have financial motivations to control hull biofouling, there is less incentive to control fouling of niche areas, as most of these areas do not affect vessel performance (Arndt et al., 2021). Vessel operators should consider the various needs of the different areas of the ship (the hull and niche areas) and utilize multiple anti-fouling systems in order to minimize biofouling across all surfaces (Arndt et al., 2021; Georgiades et al., 2018). Factors such as niche areas, vessel size, time spent immobile, AIS assemblages at ports of origin and destination, frequency and type of anti-fouling paints used, and presence of one or more AFS on ships should be included in draft guidance of what is considered acceptably clean for vessels.

Education and support (i.e., awareness, discussions for how to best achieve standards) for vessel operators should be Canada's first step to make sure operators are equipped and prepared to meet clean hull standards. Moreover, guidelines on implementing hull-cleaning regulations to smaller vessels such as those covered under the *Aquatic Invasive Species Regulations* should be drafted to support regional AIS managers and enforcement. Furthermore, resources should be provided to regions for biofouling regulations.

Canada should provide more incentive to develop more desirable anti-fouling products. This can be done through adjustments to the Aquatic Invasive Species Prevention Fund, such as increased funding amount and funding duration. Currently, multi-year projects that receive this fund will only be funded for 3 years (DFO, 2023a). It is recommended that this be extended, in order to allow ample time for products to be researched and developed.

The Canadian government should provide support and financing for research to find new, effective technologies and treatments to prevent and manage biofouling, such as the cleaning jets and cleaning robots discussed earlier, as well as effective combinations of ballast water treatments. Moreover, Canada needs a standardized evaluation for treatments, as this is needed to develop novel treatments (Carrier et al., 2023). In addition, adequate educational opportunities should be provided in order to train citizens to move into these new and expanding industries.

4.3.2 Cost Mitigation of Compliance

Some states in the US require that an AIS decal be purchased prior to operating a boat in the state, and proceeds go to local outreach and prevention programs for AIS (National Invasive Species Information Center, n.d.-a). One example is Washington State, which requires that prevention permits ($24 each) be purchased by operators of watercraft not registered in the state, seaplanes, and certain commercial transporters (Washington Department of Fish & Wildlife, 2023). Funds are used for AIS prevention and management, contributing roughly $412 000 annually (Washington Department of Fish & Wildlife, 2023). For watercraft registered to Washington State residents, a $2 annual fee for boat registration also helps fund the AIS program (Washington Department of Fish & Wildlife, 2023). This approach of adding a cost to boating permits, watercraft registration, fishing permits, etc. is a recommended approach for Canadian federal and provincial authorities that would license each AIS vector active in their province, territory, or region. To get prevention systems in place (e.g., boat decontamination stations) in place, the Canadian government could make a one-time investment in busy ports to establish the infrastructure and then the boat/watercraft permit and registration fees could be used to continue to fund anti-biofouling programs (e.g., in-water cleaning services). Also, hull cleaning programs and harbour monitoring programs could be funded through offsetting projects from works, undertakings, and activities authorized under the *Fisheries Act* [R.S.C., 1985, c. F-14]) (e.g., harbour dredging).

4.4 Area Prioritization

4.4.1 Monitoring

To maximize resource use, monitoring needs to be prioritized based on vector activity and environmental conditions that are likely suitable for a large number of AIS. Marinas, aquaculture sites, and ports for fishing and commercial use are considered high-risk for AIS introduction (LeBlanc et al., 2020). Inspections of hulls, niche areas, and ballast water performed at harbours, marinas, ports, etc. that have high boat traffic, such as Halifax and Sydney (Figures 6-12), is recommended. Monitoring of smaller vessels would likely be higher on the Western coast of Nova Scotia due to a greater density of small craft harbours (Figure 11).

As suggested by Georgiades et al., (2018), viewing of vessels' hulls when anchored can be achieved by using remotely operated vehicles or pole-cameras. This same approach can be applied to boats when they are alongside a jetty. If necessary, cleaning could then be accomplished through methods like the cleaning robots mentioned above. These methods provide an opportunity for Canada to enforce inspections while minimizing the time in which vessels need to wait on results prior to transiting elsewhere, are low cost to taxpayers (especially relative to the cost of AIS management post establishment) and limit the need for additional personnel to complete dive inspections. Sample collection of organisms found on hulls, niche areas, and in ballast water will increase the geographic and, if performed over time, temporal monitoring of AIS entering Canadian ports, harbours, and marinas.

Additionally, increased monitoring efforts in key conservation areas (e.g., Marine Protected Areas [MPAs]) is recommended. Biological invasions may have significant impacts on MPAs, as they are often located close to ports and marinas or have frequent recreational boating and tourist activity (Mannino & Balistreri, 2018). Despite large amounts of information regarding MPAs, how they affect marine AIS is predominantly unknown (Giakoumi & Pey, 2017). MPAs may control the presence and reduce the impact of AIS within their boundaries, and vectors are expected to be less frequent due to restricted human activities (Giakoumi & Pey, 2017).

In order to increase the geographic scope of monitoring efforts, utilizing citizen science for data collection in these areas with NGO or community environmental groups could prove less costly, resource dependent, and time consuming than intensive monitoring programs completed by formally trained scientists (Mannino & Balistreri, 2018). The monitoring performed by scientists could be concentrated in priority areas and conservation areas. Therefore, it is recommended that Canada implement and utilize extensive citizen science campaigns to assist in monitoring AIS and invasions in MPAs, in areas with existing NGO or community interest, and in densely populated areas where citizen science is likely to occur regardless. Citizens should be equipped with equipment to photograph and document potential AIS, identification workshops, contact information for reporting AIS, and be given small containers in which to put specimens for preservation so they can be taken for identification. These programs could not only be used to help with public outreach and education through getting citizens more actively involved in biosecurity efforts, but also provides a way for the government to monitor areas where it may otherwise have been unable to delegate resources.

4.5 Ease of Access

Throughout the course of this study, determining current Canadian regulations relating to AIS proved, at times, difficult. Therefore, the final recommendation presented here is to ensure that information relating to AIS laws and regulations be made easily accessible to the public, as well as the relevant authorities for international vessels entering the country. When examining the *Ballast Water Regulations* under the *Fisheries Act (*R.S.C., 1985, c. F-14), references were made to sections of the Annex from the International Convention for the Control and Management of Ships' Ballast Water and Sediments, 2004. This added complexity to accessing information, as all relevant information was not consolidated in one place. Moreover, simply being able to access the relevant documents does not necessarily make the information accessible. Legalese, or legal language, is important to the functioning of the legal system but can be difficult to understand for those who are not trained in the law (Atim & Adah, 2023). Legalese is known for being obscure, ambiguous, and complex (Atim & Adah, 2023). In fact, plain language is a necessity to make the law more accessible to the public (Stephenson, 2017). It is therefore recommended that regulations are not only consolidated and presented in easy to find documents (such as pamphlets, flyers, infographics, interactive websites, etc.), but also in a language that the general public can easily understand and follow.

Chapter 5: Conclusion

This study sought to assess Canada's current biosecurity measures as they relate to marine AIS, with specific focus on the Maritimes Region of DFO. Through comparison with biosecurity measures in New Zealand, Australia, and the U.S., several areas for improvements in Canada were discovered. While there are regulations and legislation in place to address AIS prevention and management, focus on the marine environment is lacking. Furthermore, Canada would benefit from better cooperation and management (between governments, citizens, stake- and rights-holders, and Indigenous groups), stricter and more thorough regulations, consistent enforcement of these regulations, improved monitoring for AIS, and providing easier access to regulations. This will help to ensure Canada's adherence to the precautionary principle and adaptive management.

References

Allard, K., Cochrane, N., Curran, K., Fenton, D., Koropatnick, T., Gjerdrum, C., Greenan, B.J.W., Head, E., Macnab, P., Moors-Murphy, H., Serdynska, A., Trzcinski, M.K., Vaughan, M., and Whitehead, H. (2015). The Gully Marine Protected Area Data Assessment. DFO Can. Sci. Advis. Sec. Res. Doc. 2015/056. vi + 167 p.

ANSTF. (n.d.-a). *About Us*. U.S. Fish & Wildlife Service. https://www.fws.gov/program/aquatic-nuisance-species-task-force/about-us

ANSTF. (n.d.-b). *Membership*. U.S. Fish & Wildlife Service. https://www.fws.gov/program/aquatic-nuisance-species-task-force/membership

Armitage, T. W. K., Bacon, S., Ridout, A. L., Petty, A. A., Wolbach, S., & Tsamados, M. (2017). Arctic Ocean surface geostrophic circulation 2003–2014. *The Cryosphere*, *11*(4), Article 4. https://doi.org/10.5194/tc-11-1767-2017

Arndt, E., Robinson, A., & Hester, S. (2021). *Factors that influence vessel biofouling and its prevention and management* (CEBRA Project 190803, pp. 1–98). Centre of Excellence for Biosecurity Risk Analysis. https://cebra.unimelb.edu.au/__data/assets/pdf_file/0010/3822922/Endorsed-CEBRA-190803-Final-Report.pdf

Atim, Dekera Gerald, & Adah, Humphrey. (2023). A Pragmatic Analysis of Legalese: The Benue State University Experience. *International Conference on Research Identity, Value and Ethics*, 99–109. Retrieved from https://conferenceseries.info/index.php/ICRIVE/article/view/798

Austin, B. J., Robinson, C. J., Mathews, D., Oades, D., Wiggin, A., Dobbs, R. J., Lincoln, G., & Garnett, S. T. (2019). An Indigenous-Led Approach for Regional Knowledge Partnerships in the Kimberley Region of Australia. *Human Ecology*, *47*(4), Article 4. https://doi.org/10.1007/s10745-019-00085-9

Bagnara, M., Nowak, L., Boehmer, H. J., Schöll, F., Schurr, F. M., & Seebens, H. (2022). Simulating the spread and establishment of alien species along aquatic and terrestrial transport networks: A multi-pathway and high-resolution approach. *Journal of Applied Ecology*, *59*(7), Article 7. https://doi.org/10.1111/1365-2664.14184

Bailey, S. A., Brown, L., Campbell, M. L., Canning-Clode, J., Carlton, J. T., Castro, N., Chainho, P., Chan, F. T., Creed, J. C., Curd, A., Darling, J., Fofonoff, P., Galil, B. S., Hewitt, C. L., Inglis, G. J., Keith, I., Mandrak, N. E., Marchini, A., McKenzie, C. H., … Zhan, A. (2020). Trends in the detection of aquatic non-indigenous species across global marine, estuarine and freshwater ecosystems: A 50-year perspective. *Diversity and Distributions*, *26*(12), Article 12. https://doi.org/10.1111/ddi.13167

Bennun, L., van Bochove, J., Ng, C., Fletcher, C., Wilson, D., Phair, N., Carbone, G. (2021). Mitigating biodiversity impacts associated with solar and wind energy development. Guidelines for project developers. Gland, Switzerland: IUCN and Cambridge, UK: The Biodiversity Consultancy.

Bernstien, J. (2022, October 9). *Canada, host of the UN biodiversity summit, is struggling to meet its own targets*. CBC. https://www.cbc.ca/news/science/canada-failing-to-meet-biodiversity-targets-1.6610259

Bionet. (n.d.). *Pest managment plans*. New Zealand Government. https://www.bionet.nz/rules/pest-management-plans/

Bowie, R. (2013). Indigenous Self-Governance and the Deployment of Knowledge in Collaborative Environmental Management in Canada. *Journal of Canadian Studies*, *47*(1), Article 1. https://doi.org/10.3138/jcs.47.1.91

California Association of Port Authorities. (2023). *Ballast Water Management*. CAPA-California Ports. https://californiaports.org/ballast-water-management/

Callow, J. A., & Callow, M. E. (2011). Trends in the development of environmentally friendly fouling-resistant marine coatings. *Nature Communications*, *2*(1), Article 1. https://doi.org/10.1038/ncomms1251

Campbell, M. L., King, S., Heppenstall, L. D., Van Gool, E., Martin, R., & Hewitt, C. L. (2017). Aquaculture and urban marine structures facilitate native and non-indigenous species transfer through generation and accumulation of marine debris. *Marine Pollution Bulletin*, *123*(1–2), Article 1–2. https://doi.org/10.1016/j.marpolbul.2017.08.040

Canadian Coast Guard. (2022, June 30). *Canadian Coast Guard begins 2022 Arctic Season*. Government of Canada. https://www.canada.ca/en/canadian-coast-guard/news/2022/06/canadian-coast-guard-begins-2022-arctic-season.html

Canadian Council on Invasive Species. (2023a). *Clean Drain Dry*. Canadian Council on Invasive Species. https://canadainvasives.ca/programs/clean-drain-dry/

Canadian Council on Invasive Species. (2023b). *Don't Let It Loose*. Canadian Council on Invasive Species. https://canadainvasives.ca/programs/dont-let-it-loose/

Carlton, J., Chapman, J., Geller, J., Miller, J., Ruiz, G., Carlton, D., McCuller, M., Treneman, N., Steves, B., Breitenstein, R., Lewis, R., Bilderback, D., Bilderback, D., Haga, T., & Harris, L. (2018). Ecological and biological studies of ocean rafting: Japanese tsunami marine debris in North America and the Hawaiian Islands. *Aquatic Invasions*, *13*(1), Article 1. https://doi.org/10.3391/ai.2018.13.1.01

CBD. (n.d.). *Aichi Target Pages: Aichi Target 9*. Convention on Biological Diversity. https://www.cbd.int/aichi-targets/target/9

CBD. (2020, September 13). *Canada-National Targets*. Convention on Biological Diversity. https://www.cbd.int/countries/targets/?country=ca

CBD. (2022, December 22). *COP15: Final Text of Kunming-Montreal Gloval Biodiversity Framework*. Convention on Biological Diversity. https://www.cbd.int/article/cop15-final-text-kunming-montreal-gbf-221222

CFIA. (2023a). *List of pests regulated by Canada*. Government of Canada. https://inspection.canada.ca/plant-health/invasive-species/regulated-pests/eng/1363317115207/1363317187811

CFIA. (2023b). *New Zealad-Export requirements for fish and seafood*. Government of Canada. https://inspection.canada.ca/exporting-food-plants-or-animals/food-exports/requirements/new-zealand-fish-and-seafood/eng/1304244825182/1304244994271

Champion, P. (2018). Knowledge to action on aquatic invasive species: Island biosecurity – the New Zealand and South Pacific story. *Management of Biological Invasions*, *9*(4), 383–394. https://doi.org/10.3391/mbi.2018.9.4.02

Clarke Murray, C., Bychkov, A., Therriault, T., Maki, H., & Wallace, N. (2015). The impact of Japanese tsunami debris on North America. *PICES Press*, *23*(1), 28–30.

Clarke Murray, C., Maximenko, N., & Lippiatt, S. (2018). The influx of marine debris from the Great Japan Tsunami of 2011 to North American shorelines. *Marine Pollution Bulletin*, *132*, 26–32. https://doi.org/10.1016/j.marpolbul.2018.01.004

Clarke Murray, C., Pakhomov, E. A., & Therriault, T. W. (2011). Recreational boating: A large unregulated vector transporting marine invasive species: Transport of NIS by recreational boats. *Diversity and Distributions*, *17*(6), 1161–1172. https://doi.org/10.1111/j.1472-4642.2011.00798.x

Commission de vérité et réconciliation du Canada. (2015). *Canada's Residential Schools: Reconciliation : The Final Report of the Truth and Reconciliation Commission of Canada, Volume 6*. McGill-Queen's University Press.

Corrales, X., Coll, M., Ofir, E., Heymans, J. J., Steenbeek, J., Goren, M., Edelist, D., & Gal, G. (2018). Future scenarios of marine resources and ecosystem conditions in the Eastern Mediterranean under the impacts of fishing, alien species and sea warming. *Scientific Reports*, *8*(1), Article 1. https://doi.org/10.1038/s41598-018-32666-x

Cristescu, M. E., & Hebert, P. D. N. (2018). Uses and Misuses of Environmental DNA in Biodiversity Science and Conservation. *Annual Review of Ecology, Evolution, and Systematics*, *49*(1), Article 1. https://doi.org/10.1146/annurev-ecolsys-110617-062306

Crown-Indigenous Relations and Northern Affairs Canada. (2022, September 29). *Truth and Reconciliation Commission of Canada*. Government of Canada. https://www.rcaanc-cirnac.gc.ca/eng/1450124405592/1529106060525

Cunningham, S. (2019). Mitigating the threat of invasive marine species to Fiordland: New Zealand's first pathway management plan. *Management of Biological Invasions*, *10*(4), 690–708. https://doi.org/10.3391/mbi.2019.10.4.07

DAFF. (n.d.). *Evaluation of animal health status of countries, zones and compartments for imports of animals and products of animal origin*. Australian Government: Department of Agriculture, Fisheries and Forestry. https://www.agriculture.gov.au/sites/default/files/documents/evaluation-animal-health-status.pdf

DAFF. (2020). *Australian Ballast Water Management Requirements-Version 8*. DAFF. https://www.agriculture.gov.au/sites/default/files/documents/australian-ballast-water-management-requirements.pdf

DAFF. (2022). *80-2022: Australian biofouling management requirements*. Australian Government: Department of Agriculture, Fisheries and Forestry. https://www.agriculture.gov.au/biosecurity-trade/import/industry-advice/2022/80-2022

DAFF. (2023a). *Biosecurity risk analysis*. Australian Government: Department of Agriculture, Fisheries and Forestry. https://www.agriculture.gov.au/biosecurity-trade/policy/risk-analysis

DAFF. (2023b). *Environmental biosecurity*. Australian Government: Department of Agriculture, Fisheries and Forestry. https://www.agriculture.gov.au/biosecurity-trade/policy/environmental

DAFF. (2023c). *Import proposals*. Australian Government: Department of Agriculture, Fisheries and Forestry. https://www.agriculture.gov.au/biosecurity-trade/policy/risk-analysis/import-proposals

DAFF. (2023d). *Importing live fish to Australia*. Australian Government: Department of Agriculture, Fisheries and Forestry. https://www.agriculture.gov.au/biosecurity-trade/import/goods/live-animals/importing-live-fish-aus#can-i-import-fish-that-are-not-on-the-permitted-species-list

DAFF. (2023e). *Managing biofouling in Australia*. Australian Government: Department of Agriculture, Fisheries and Forestry. https://www.agriculture.gov.au/biosecurity-trade/aircraft-vessels-military/vessels/marine-pest-biosecurity/biofouling

DAFF. (2023f). *The Biosecurity Act 2015*. Australian Government: Department of Agriculture, Fisheries and Forestry. https://www.agriculture.gov.au/biosecurity-trade/policy/legislation/biosecurity-legislation

DAFF. (2023g). *The National Priority List of Exotic Environmental Pests, Weeds and Diseases*. Australian Government: Department of Agriculture, Fisheries and Forestry. https://www.agriculture.gov.au/biosecurity-trade/policy/environmental/priority-list

Darling, J. A., & Mahon, A. R. (2011). From molecules to management: Adopting DNA-based methods for monitoring biological invasions in aquatic environments. *Environmental Research*, *111*(7), Article 7. https://doi.org/10.1016/j.envres.2011.02.001

Davidson I, Scianni C, Ceballos L, Zabin C, Ashton G, Ruiz G (2014) Evaluating ship biofouling and emerging management tools for reducing biofouling-mediated species incursions. Report to the Marine Invasive Species Program of the California State Lands Commission, Sacramento, California. 36pp.

DAWE. 2020. *National policy guidelines for the translocation of live aquatic animals*, Canberra, March 2020. CC BY 4.0.

De Brauwer, M., Clarke, L. J., Chariton, A., Cooper, M. K., de Bruyn, M., Furlan, E., MacDonald, A. J., Rourke, M. L., Sherman, C. D. H., Suter, L., Villacorta-Rath, C., Zaiko, A., & Trujillo-González, A. (2023). Best practice guidelines for environmental DNA biomonitoring in Australia and New Zealand. *Environmental DNA*, edn3.395. https://doi.org/10.1002/edn3.395

Department of Economic and Social Affairs. (n.d.). *United Nations Declaration On The Rights of Indigenous Peoples*. United Nations. https://social.desa.un.org/issues/indigenous-peoples/united-nations-declaration-on-the-rights-of-indigenous-peoples

Department of Primary Industries. (n.d.-a). *Marine pests*. NSW Government. https://www.dpi.nsw.gov.au/fishing/aquatic-biosecurity/pests-diseases/marine-pests

Department of Primary Industries. (n.d.-b). *Recreational waterway users*. NSW Government. https://www.dpi.nsw.gov.au/fishing/aquatic-biosecurity/recreational-waterway-users

Department of Primary Industries and Regions, the Government of South Australia. 2022. Policy and legislation for aquaculture, Sourced on June 29, 2023, https://www.pir.sa.gov.au/primary_industry/aquaculture/policy_and_legislation_for_aquaculture.

DFO. (2018a). *A Canadian Action Plan to Address the Threat of Aquatic Invasive Species: Canadian Council of Fisheries and Aquaculture Ministers Aquatic Invasive Species Task Group*. Government of Canada. https://www.dfo-mpo.gc.ca/species-especes/publications/ais-eae/plan/index-eng.html

DFO. (2018b). *Guiding Principles*. Government of Canada. https://www.dfo-mpo.gc.ca/oceans/networks-reseaux/principles-principes-eng.html

DFO. (2020). *Early detection and monitoring for aquatic invasive species*. Government of Canada. https://www.dfo-mpo.gc.ca/species-especes/ais-eae/early-detection-precoce/index-eng.html

DFO. (2021). Science Advice on “Clean, Drain, Dry and Decontaminate” treatments and protocols to prevent the introduction and spread of aquatic invasive species. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2021/043. (Erratum : July 2022).D

DFO. (2022). *Request a review of your project near water: Step 1. What this service offers*. Government of Canada. https://www.dfo-mpo.gc.ca/pnw-ppe/reviews-revues/request-review-demande-d-examen-001-eng.html

DFO. (2023a). *Aquatic Invasive Species Prevention Fund*. Government of Canada. https://www.dfo-mpo.gc.ca/species-especes/ais-eae/funding-financement/index-eng.html

DFO. (2023b). *Clean, drain, dry and decontaminate*. Government of Canada. https://www.dfo-mpo.gc.ca/species-especes/ais-eae/prevention/clean-drain-dry-decontaminate-lavez-videz-sechez-decontaminez-eng.html

DFO. (2023c). *Preventing aquatic invasive species*. Government of Canada. https://www.dfo-mpo.gc.ca/species-especes/ais-eae/prevention/index-eng.html

DFO. (2023d). *Reporting on Introductions and Transfers*. Government of Canada. https://www.dfo-mpo.gc.ca/aquaculture/management-gestion/rep-rap-eng.htm

DNV. (2023). *Ballast Water Management*. DNV. https://www.dnv.com/maritime/ballast-water-management/uscg.html#:~:text=All%20ships%20calling%20at%20US,employ%20treatment%20instead%20of%20exchange

Ewel, J., O'Dowd, D., Bergelson, J., Daehler, C., & D'Antonio, C. (1999). *DeliberatIe ntroductions of Species: Research Needs* (8). *49*(8), Article 8.

Executive Office of the President. (2016, December 8). *Safeguarding the Nation From the Impacts of Invasive Species*. National Archives: Federal Register-The Daily Journal of the United States Government. https://www.federalregister.gov/documents/2016/12/08/2016-29519/safeguarding-the-nation-from-the-impacts-of-invasive-species

FAO 2023. New Zealand. Text by Skonhoft, A.. Fisheries and Aquaculture Division [online]. Rome. [Cited Thursday, June 29th 2023]. https://www.fao.org/fishery/en/legalframework/nz/en?lang=en).

Firestone, J., & Corbett, J. J. (2005). Coastal and Port Environments: International Legal and Policy Responses to Reduce Ballast Water Introductions of Potentially Invasive Species. *Ocean Development & International Law*, *36*(3), Article 3. https://doi.org/10.1080/00908320591004469

First, M. R., Robbins-Wamsley, S. H., Riley, S. C., & Drake, L. A. (2016). Towards minimizing transport of aquatic nuisance species in ballast water: Do organisms in different size classes respond uniformly to biocidal treatment? *Biological Invasions*, *18*(3), Article 3. https://doi.org/10.1007/s10530-015-1036-7

Gard. (2021a). *California adopts federal ballast water discharge standards*. Gard. https://www.gard.no/web/updates/content/32627750/california-adopts-federal-ballast-water-discharge-standards

Gard. (2021b). *California provides clarity on its biofouling regulations*. Gard. https://www.gard.no/web/updates/content/26585587/california-provides-clarity-on-its-biofouling-regulations

Georgiades, E., Kluza, D., Bates, T., Lubarsky, K., Brunton, J., Growcott, A., Smith, T., McDonald, S., Gould, B., Parker, N., & Bell, A. (2020). Regulating Vessel Biofouling to Support New Zealand's Marine Biosecurity System – A Blue Print for Evidence-Based Decision Making. *Frontiers in Marine Science*, *7*, 390. https://doi.org/10.3389/fmars.2020.00390

Giakoumi, S., Katsanevakis, S., Albano, P. G., Azzurro, E., Cardoso, A. C., Cebrian, E., Deidun, A., Edelist, D., Francour, P., Jimenez, C., Mačić, V., Occhipinti-Ambrogi, A., Rilov, G., & Sghaier, Y. R. (2019). Management priorities for marine invasive species. *Science of The Total Environment*, *688*, 976–982. https://doi.org/10.1016/j.scitotenv.2019.06.282

Giakoumi, S., & Pey, A. (2017). Assessing the Effects of Marine Protected Areas on Biological Invasions: A Global Review. *Frontiers in Marine Science*, *4*. https://doi.org/10.3389/fmars.2017.00049

Golebie, E. J., & Van Riper, C. J. (2023). Enhancing Aquatic Invasive Species Outreach Through Values-framed Messages. *Environmental Communication*, *17*(1), Article 1. https://doi.org/10.1080/17524032.2022.2156574

Government of New Brunswick. (n.d.). *Illegal Stocking*. https://www2.gnb.ca/content/dam/gnb/Departments/nr-rn/pdf/en/Fish/IllegalStocking-IntroducedFishSpecies.pdf

Graphite Innovation & Technologies. (2022). *Company Overview*. Graphite Innovation & Technologies. https://grapheneenterprise.ca/about/

Gregory, M. R. (2009). Environmental implications of plastic debris in marine settings—Entanglement, ingestion, smothering, hangers-on, hitch-hiking and alien invasions.

Philosophical Transactions of the Royal Society B: Biological Sciences, *364*(1526), Article 1526. https://doi.org/10.1098/rstb.2008.0265

Harrison, H. L., & Loring, P. A. (2020). Seeing beneath disputes: A transdisciplinary framework for diagnosing complex conservation conflicts. *Biological Conservation*, *248*, 108670. https://doi.org/10.1016/j.biocon.2020.108670

Hayes, K. R., Inglis, G. J., & Barry, S. C. (2019). The Assessment and Management of Marine Pest Risks Posed by Shipping: The Australian and New Zealand Experience. *Frontiers in Marine Science*, *6*, 489. https://doi.org/10.3389/fmars.2019.00489

Hewitt, C. L., & Campbell, M. L. (2007). Mechanisms for the prevention of marine bioinvasions for better biosecurity. *Marine Pollution Bulletin*, *55*(7–9), 395–401. https://doi.org/10.1016/j.marpolbul.2007.01.005

Hua, J., Chiu, Y.-S., & Tsai, C.-Y. (2018). En-route operated hydroblasting system for counteracting biofouling on ship hull. *Ocean Engineering*, *152*, 249–256. https://doi.org/10.1016/j.oceaneng.2018.01.050

Hullbot Pty Ltd. (2023a). *Private hull cleaning*. Hullbot. https://hullbot.com/programs/private-hull-cleaning

Hullbot Pty Ltd. (2023b). *Robot*. Hullbot. https://hullbot.com/robot

IMO. 2004. International Convention for the Control and Management of Ships' Ballast Water and Sediments, 2004. Retrieved from https://ceaa-acee.gc.ca/050/documents_staticpost/cearref_21799/86129/International_Convention.pdf

IMO. 2011. 2011 Guidelines for the Control and Management of Ships' Biofouling to Minimize the Transfer of Invasive Aquatic Species. *Resolution MEPC* 207(62): 1-25.

IMO. (2019a). *Anti-Fouling Systems*. International Maritime Organization. https://www.imo.org/en/OurWork/Environment/Pages/Anti-fouling.aspx

IMO. (2019b). *International Convention for the Control and Management of Ships' Ballast Water and Sediments (BWM)*. International Maritime Organization. https://www.imo.org/en/About/Conventions/Pages/International-Convention-for-the-Control-and-Management-of-Ships%27-Ballast-Water-and-Sediments-(BWM).aspx#:~:text=Under%20the%20Convention%2C%20all%20ships,international%20ballast%20water%20management%20certificate

IMO. (2023a). *Regulation 4- Validity of an International Anti-fouling System Certificate*. IMO Rules. https://www.imorules.com/GUID-97807A53-89B9-4862-94C6-7DBDE0275A08.html

IMO. (2023b). *Regulation E-1-Surveys*. IMO Rules. https://imorules.com/GUID-7F55E881-0AB8-42A3-8675-790CC8EFD13F.html

Institute of Marine Engineering, Science & Technology. (2017, January 16). *Floating wind farms as vectors for the spread of invasive species*. Institute of Marine Engineering, Science & Technology. imarest.org/funding/3055-research-into-floating-wind-farms-as-vectors-to-spread-invasive-species-wins-stanley-gray-fellowship

Invasive Species Action Network. (n.d.). *Don't Let It Loose: Promoting Responsible Pet Ownership*. Don't Let It Loose! Be a Responsible Pet Owner. https://www.dontletitloose.com/

Invasive Species Action Network. (2022, November 14). *Don't Let it Loose Newsletter November 2022*. https://mailchi.mp/b95e9913fbb2/dont-let-it-loose-newsletter-october-14456253?e=%5BUNIQID%5D

IPBES Secretariat. (2023, September 4). *Media Release: IPBES Invasive Alien Species Assessment*. IPBES. https://www.ipbes.net/IASmediarelease

Jacobson, S. K., McDu, M. D., & Monroe, M. C. (2006). *Conservation Education and Outreach Techniques* (1st ed.). Oxford University Press.

Johnson, D. S. (2015). The savory swimmer swims north: A northern range extension of the blue crab Callinectes sapidus? *Journal of Crustacean Biology*, *35*(1), Article 1. https://doi.org/10.1163/1937240X-00002293

Johnson, J. T., Howitt, R., Cajete, G., Berkes, F., Louis, R. P., & Kliskey, A. (2016). Weaving Indigenous and sustainability sciences to diversify our methods. *Sustainability Science*, *11*(1), Article 1. https://doi.org/10.1007/s11625-015-0349-x

Katsanevakis, S., Zenetos, A., Belchior, C., & Cardoso, A. C. (2013). Invading European Seas: Assessing pathways of introduction of marine aliens. *Ocean & Coastal Management*, *76*, 64–74. https://doi.org/10.1016/j.ocecoaman.2013.02.024

Kelly, N. E., Wantola, K., Weisz, E., & Yan, N. D. (2013). Recreational boats as a vector of secondary spread for aquatic invasive species and native crustacean zooplankton. *Biological Invasions*, *15*(3), Article 3. https://doi.org/10.1007/s10530-012-0303-0

Kelly, S. J., Popova, E., Aksenov, Y., Marsh, R., & Yool, A. (2020). They Came From the Pacific: How Changing Arctic Currents Could Contribute to an Ecological Regime Shift in the Atlantic Ocean. *Earth's Future*, *8*(4), Article 4. https://doi.org/10.1029/2019EF001394

Kernan, M. (2015). Climate change and the impact of invasive species on aquatic ecosystems. *Aquatic Ecosystem Health & Management*, *18*(3), Article 3. https://doi.org/10.1080/14634988.2015.1027636

Kyei, S. K., Darko, G., & Akaranta, O. (2020). Chemistry and application of emerging ecofriendly antifouling paints: A review. *Journal of Coatings Technology and Research*, *17*(2), Article 2. https://doi.org/10.1007/s11998-019-00294-3

Lakshmi, E., Priya, M., & Achari, V. S. (2021). An overview on the treatment of ballast water in ships. *Ocean & Coastal Management*, *199*, 105296. https://doi.org/10.1016/j.ocecoaman.2020.105296

Le, C. T. U., & Campbell, M. L. (2022). Public's perceptions of marine bioinvasive risks and responsible parties – Implications for social acceptability and better-informed communication in the marine biosecurity context. *Marine Pollution Bulletin*, *185*, 114283. https://doi.org/10.1016/j.marpolbul.2022.114283

LeBlanc, F., Belliveau, V., Watson, E., Coomber, C., Simard, N., DiBacco, C., Bernier, R., & Gagné, N. (2020). Environmental DNA (eDNA) detection of marine aquatic invasive species (AIS) in Eastern Canada using a targeted species-specific qPCR approach. *Management of Biological Invasions*, *11*(2), 201–217. https://doi.org/10.3391/mbi.2020.11.2.03

Legal Information Institute. (n.d.). *Cal. Code Regs. Tit. 2, § 2293—Performance Standards for Ballast Water Discharges*. Cornell Law School. https://www.law.cornell.edu/regulations/california/2-CCR-2293

Lowen, J. B., & DiBacco, C. (2023). Range expansion and establishment of a non-indigenous tunicate (*Diplosoma listerianum)* in thermal refugia is mediated by environmental variability in changing coastal environments. *Canadian Journal of Fisheries and Aquatic Sciences*, *80*(2), Article 2. https://doi.org/10.1139/cjfas-2022-0082

Mainka, S. A., & Howard, G. W. (2010). Climate change and invasive species: Double jeopardy. *Integrative Zoology*, *5*(2), Article 2. https://doi.org/10.1111/j.1749-4877.2010.00193.x

Mannino, A. M., & Balistreri, P. (2018). Citizen science: A successful tool for monitoring invasive alien species (IAS) in Marine Protected Areas. The case study of the Egadi Islands MPA (Tyrrhenian Sea, Italy). *Biodiversity*, 1–7. https://doi.org/10.1080/14888386.2018.1468280

Maréchal, J.-P., & Hellio, C. (2009). Challenges for the Development of New Non-Toxic Antifouling Solutions. *International Journal of Molecular Sciences*, *10*(11), Article 11. https://doi.org/10.3390/ijms10114623

Maritime New Zealand. (2018). *Ballast Water Management: Guidance for operators, masters and officers, and surveyors of New Zealand ships on the implementation of the International Convention for the Control and Management of Ships' Ballast Water and Sediments, 2004 in New Zealand*. Maritime New Zealand. https://www.maritimenz.govt.nz/content/commercial/environment/operators/documents/Ballast-water-management-guidelines.pdf

McAllister, R. R. J., Kruger, H., Stenekes, N., & Garrard, R. (2020). Multilevel stakeholder networks for Australian marine biosecurity: Well-structured for top-down information provision, requires better two-way communication. *Ecology and Society*, *25*(3), art18. https://doi.org/10.5751/ES-11583-250318

McDonald, J. I., Wellington, C. M., Coupland, G. T., Pedersen, D., Kitchen, B., Bridgwood, S. D., Hewitt, M., Duggan, R., & Abdo, D. A. (2020). A united front against marine invaders: Developing a cost-effective marine biosecurity surveillance partnership between government and industry. *Journal of Applied Ecology*, *57*(1), Article 1. https://doi.org/10.1111/1365-2664.13557

McGillivray, R. (2023, January 9). *Another Cruise Ship Refused Entry Due to Hull Issues*. Cruise Hive. https://www.cruisehive.com/another-cruise-ship-refused-entry-due-to-hull-issues/92087

McKinnell, S., & Thomson, A. J. (1997). Recent events concerning Atlantic salmon escapees in the Pacific. *ICES Journal of Marine Science*, *54*(6), Article 6. https://doi.org/10.1016/S1054-3139(97)80029-X

Mghili, B., De-la-Torre, G. E., & Aksissou, M. (2023). Assessing the potential for the introduction and spread of alien species with marine litter. *Marine Pollution Bulletin*, *191*, 114913. https://doi.org/10.1016/j.marpolbul.2023.114913

Molnar, J. L., Gamboa, R. L., Revenga, C., & Spalding, M. D. (2008). Assessing the global threat of invasive species to marine biodiversity. *Frontiers in Ecology and the Environment*, *6*(9), Article 9. https://doi.org/10.1890/070064

MPI. (n.d.). *Importing Seafood*. Ministry for Primary Industries. https://www.mpi.govt.nz/import/food/seafood/

MPI. (2017). *Guidance for commercial vessels-New Zealand's new biofouling requirements: The Craft Risk Management Standard*. Ministry for Primary Industries. https://www.mpi.govt.nz/dmsdocument/19403-New-Zealands-new-biofouling-requirements-The-Craft-Risk-Management-Standard-guidance-for-commercial-vessels

MPI. (2022). *Import Health Standard: Aquatic Animal Products* (AQUAPROD.GEN; Issue AQUAPROD.GEN, pp. 1–37). Ministry for Primary Industries. https://www.mpi.govt.nz/dmsdocument/51229-Aquatic-Animal-Products-Import-health-standard

MPI. (2021, November 12). *Check, Clean, Dry: Preventing didymo and other pests*. Ministry for Primary Industries. https://www.mpi.govt.nz/outdoor-activities/boating-and-watersports-tips-to-prevent-spread-of-pests/check-clean-dry/

MPI. (2020a). *Assigning responsibility for pest management*. Ministry for Primary Industries. https://www.mpi.govt.nz/legal/legislation-standards-and-reviews/biosecurity-legislation/assigning-responsibility-for-pest-management/

MPI. (2016b). *Biosecurity 2025 Direction Statement for New Zealand's biosecurity system*. Ministry for Primary Industries. https://www.mpi.govt.nz/dmsdocument/14857-Biosecurity-2025-Direction-Statement-for-New-Zealands-biosecurity-system

MPI. (2023a). *Cleaning boats: Removing pests and water plants*. Ministry for Primary Industries. https://www.mpi.govt.nz/outdoor-activities/boating-and-watersports-tips-to-prevent-spread-of-pests/cleaning-boats/

MPI. (2023b). *MPI's Role in Biosecurity*. Ministry for Primary Industries. https://www.mpi.govt.nz/biosecurity/about-biosecurity-in-new-zealand/mpis-role-in-biosecurity/

MPI. (2023c). *National Policy Direction for Pest Management*. Ministry for Primary Industries. https://www.mpi.govt.nz/biosecurity/about-biosecurity-in-new-zealand/national-policy-direction-for-pest-management/

MPI. (2023d). *Our work to keep pests and diseases out of NZ*. Ministry for Primary Industries. https://www.mpi.govt.nz/biosecurity/about-biosecurity-in-new-zealand/our-work-to-keep-pests-and-diseases-out-of-nz/

MPI. (2023e). *Surveillance programmes for pests and diseases*. Ministry for Primary Industries. https://www.mpi.govt.nz/biosecurity/exotic-pests-and-diseases-in-new-zealand/surveillance-programmes/

National Indigenous Australians Agency. (2020, July 31). *Indigenous Rangers on the biosecurity frontline*. Australian Government: National Indigenous Australians Agency. https://www.niaa.gov.au/news-centre/indigenous-affairs/indigenous-rangers-biosecurity-frontline

National Invasive Species Information Center. (n.d.-a). *Aquatic Invasive Species Decals*. U.S. Department of Agriculture. https://www.invasivespeciesinfo.gov/subject/aquatic-invasive-species-decals

National Invasive Species Information Center. (n.d.-b). *Executive Order 13112-Invasive Species*. U.S. Department of Agriculture. https://www.invasivespeciesinfo.gov/executive-order-13112

National Invasive Species Information Center. (n.d.-c). *Executive Order 13751*. U.S. Department of Agriculture. https://www.invasivespeciesinfo.gov/executive-order-13751

New Brunswick Invasive Species Council. (n.d.). *Don't Let It Loose*. New Brunswick Invasive Species Council. https://www.nbinvasives.ca/dont-let-it-loose

NISC. (n.d.-a). *About the Council*. U.S. Department of the Interior. https://www.doi.gov/invasivespecies/about-nisc

NISC. (n.d.-b). *U.S. Department of Homeland Security (DHS)*. U.S. Department of the Interior. https://www.doi.gov/invasivespecies/dhs

Nova Scotia Fisheries and Aquaculture. (n.d.). *Live Fish Possession Regulations*. https://novascotia.ca/fish/documents/regulations/FCRA-QandA.pdf

Nova Scotia Invasive Species Council. (2021). *Don't Let It Loose*. Nova Scotia Invasive Species Council. https://nsinvasives.ca/dont-let-it-loose/

Novoa, A., Shackleton, R., Canavan, S., Cybèle, C., Davies, S. J., Dehnen-Schmutz, K., Fried, J., Gaertner, M., Geerts, S., Griffiths, C. L., Kaplan, H., Kumschick, S., Le Maitre, D. C., Measey, G. J., Nunes, A. L., Richardson, D. M., Robinson, T. B., Touza, J., & Wilson, J.

R. U. (2018). A framework for engaging stakeholders on the management of alien species. *Journal of Environmental Management*, *205*, 286–297. https://doi.org/10.1016/j.jenvman.2017.09.059

Office of Congressional and Legislative Affairs. (2017, March 15). *Invasive Species Control*. U.S. Department of the Interior. https://www.doi.gov/ocl/invasive-species-control

Office of the Auditor General of Canada. (2019). *2019 Spring Reports of the Commissioner of the Environment and Sustainable Development to the Parliament of Canada: Report 1-Aquatic Invasive Species*. Office of the Auditor General of Canada. https://www.oag-bvg.gc.ca/internet/English/parl_cesd_201904_01_e_43307.html#hd2a

Oliver, T. H., Heard, M. S., Isaac, N. J. B., Roy, D. B., Procter, D., Eigenbrod, F., Freckleton, R., Hector, A., Orme, C. D. L., Petchey, O. L., Proença, V., Raffaelli, D., Suttle, K. B., Mace, G. M., Martín-López, B., Woodcock, B. A., & Bullock, J. M. (2015). Biodiversity and Resilience of Ecosystem Functions. *Trends in Ecology & Evolution*, *30*(11), 673–684. https://doi.org/10.1016/j.tree.2015.08.009

Pagoropoulos, A., Kjaer, L. L., Dong, Y., Birkved, M., & McAloone, T. C. (2018). Economic an dEnvironmental Impact Trade-Offs Related to In-Water Hull Cleanings of Merchant Vessels. *Journal of Industrial Ecology*, *22*(4), Article 4. https://doi.org/10.1111/jiec.12627

Park, J.-S., & Lee, J.-H. (2018). Sea-trial verification of ultrasonic antifouling control. *Biofouling*, *34*(1), Article 1. https://doi.org/10.1080/08927014.2017.1409347

Parmesan, C., & Yohe, G. (2003). A globally coherent fingerprint of climate change impacts across natural systems. *Nature*, *421*(6918), Article 6918. https://doi.org/10.1038/nature01286

Parsons, M. G., & Harkins, R. W. (2002). Full-Scale Particle Removal Performance of Three Types of Mechanical Separation Devices for the Primary Treatment of Ballast Water. *Marine Technology*, *39*(4), Article 4. https://doi.org/10.5957/mt1.2002.39.4.211

Pelletier-Rousseau, M., Bernier, R., Clarke Murray, C., Drolet, D., Lacoursière-Roussel, A., Locke, A., Martin, J. L., McKenzie, C. H., McKindsey, C. W., Therriault, T. W., & Simard, N. (2019). Assessment of recreational boating as a vector for marine non-indigenous species on the Atlantic coast of Canada. *Biological Invasions*, *21*(7), Article 7. https://doi.org/10.1007/s10530-019-01991-1

Pergl, J., Pyšek, P., Bacher, S., Essl, F., Genovesi, P., Harrower, C. A., Hulme, P. E., Jeschke, J. E., Kenis, M., Kühn, I., Perglová, I., Rabitsch, W., Roques, A., Roy, D. B., Roy, H. E., Vilà, M., Winter, M., & Nentwig, W. (2017). Troubling travellers: Are ecologically harmful alien species associated with particular introduction pathways? *NeoBiota*, *32*, 1–20. https://doi.org/10.3897/neobiota.32.10199

Pyke, C. R., Thomas, R., Porter, R. D., Hellmann, J. J., Dukes, J. S., Lodge, D. M., & Chavarria, G. (2008). Current Practices and Future Opportunities for Policy on Climate Change and Invasive Species. *Conservation Biology*, *22*(3), Article 3. https://doi.org/10.1111/j.1523-1739.2008.00956.x

Pyšek, P., Hulme, P. E., Simberloff, D., Bacher, S., Blackburn, T. M., Carlton, J. T., Dawson, W., Essl, F., Foxcroft, L. C., Genovesi, P., Jeschke, J. M., Kühn, I., Liebhold, A. M., Mandrak, N. E., Meyerson, L. A., Pauchard, A., Pergl, J., Roy, H. E., Seebens, H., … Richardson, D. M. (2020). Scientists' warning on invasive alien species. *Biological Reviews*, *95*(6), 1511–1534. https://doi.org/10.1111/brv.12627

Reed, M. S., Vella, S., Challies, E., De Vente, J., Frewer, L., Hohenwallner-Ries, D., Huber, T., Neumann, R. K., Oughton, E. A., Sidoli Del Ceno, J., & Van Delden, H. (2018). A theory of participation: What makes stakeholder and public engagement in environmental management work?: A theory of participation. *Restoration Ecology*, *26*, S7–S17. https://doi.org/10.1111/rec.12541

Reid, C. H., Hudgins, E. J., Guay, J. D., Patterson, S., Medd, A. M., Cooke, S. J., & Bennett, J. R. (2021). The state of Canada's biosecurity efforts to protect biodiversity from species invasions. *FACETS*, *6*, 1922–1954. https://doi.org/10.1139/facets-2021-0012

Reo, N. J., Whyte, K., Ranco, D., Brandt, J., Blackmer, E., & Elliott, B. (2017). Invasive Species, Indigenous Stewards, and Vulnerability Discourse. *American Indian Quarterly*, *41*(3), Article 3. https://doi.org/10.5250/amerindiquar.41.3.0201

Ricciardi, A., & MacIsaac, H. J. (2022). Vector control reduces the rate of species invasion in the world's largest freshwater ecosystem. *Conservation Letters*, *15*(2), Article 2. https://doi.org/10.1111/conl.12866

Richardson, D. M., Pyšek, P., Carlton, J.T. (2011). A compendium of essential concepts and terminology in invasion ecology. In D. M. Richardson (Ed.), *Fifty Years of Invasion Ecology: The Legacy of Charles Elton* (pp. 409-420). Blackwell Publishing Ltd.

Rosenhaim, I. L., Riemann-Campe, K., Sumata, H., Koeberle, C., Brauner, R., Herber, A., & Gerdes, R. (2019). Simulated ballast water accumulation along Arctic shipping routes. *Marine Policy*, *103*, 9–18. https://doi.org/10.1016/j.marpol.2019.02.013

Sayinli, B., Dong, Y., Park, Y., Bhatnagar, A., & Sillanpää, M. (2022). Recent progress and challenges facing ballast water treatment – A review. *Chemosphere*, *291*, 132776. https://doi.org/10.1016/j.chemosphere.2021.132776

Scriven, D. R., DiBacco, C., Locke, A., & Therriault, T. W. (2015). Ballast water management in Canada: A historical perspective and implications for the future. *Marine Policy*, *59*, 121–133. https://doi.org/10.1016/j.marpol.2015.05.014

Sepulveda, A. J., Nelson, N. M., Jerde, C. L., & Luikart, G. (2020). Are Environmental DNA Methods Ready for Aquatic Invasive Species Management? *Trends in Ecology & Evolution*, *35*(8), 668–678. https://doi.org/10.1016/j.tree.2020.03.011

Sigler, M. (2014). The Effects of Plastic Pollution on Aquatic Wildlife: Current Situations and Future Solutions. *Water, Air, & Soil Pollution*, *225*(11), Article 11. https://doi.org/10.1007/s11270-014-2184-6

Simard, N., Plourde, S., Gilbert, M., & Gollasch, S. (2011). Net efficacy of open ocean ballast water exchange on plankton communities. *Journal of Plankton Research*, *33*(9), Article 9. https://doi.org/10.1093/plankt/fbr038

Smith, C. S., Lonsdale, W. M., & Fortune, J. (1999). When to Ignore Advice: Invasion Predictions and Decision Theory. *Biological Invasions*, *1*, 89–96.

Stenekes, N, Kruger, H, McAllister, R.R.J & Garrard, R, 2019, *Who talks to whom about marine pest biosecurity? An analysis of the Australian marine pest network,* ABARES technical report 19.5 prepared for the Department of Agriculture, Canberra, August. CC BY 4.0. https://doi.org/10.25814/5d5370192d17e

Stephenson, M. (2017). "Harry Potter language?" The plain language movement and the case against abandoning 'legalese'. *Northern Ireland Legal Quarterly*, *68*(1), Article 1.

Tan, L. (2019, January 12). *Buddhist animal release practice: Saving lives or contributing to an ecological disaster?* NZ Herald. https://www.nzherald.co.nz/nz/buddhist-animal-release-practice-saving-lives-or-contributing-to-an-ecological-disaster/WOMMCGC3RXK6FLZGBO3M3LFSWU/

Tang, Y. (2013). Applying the Precautionary Principle in the Risk Management of Invasive Species via Ballast Water. *Applied Mechanics and Materials*, *295–298*, 2167–2171. https://doi.org/10.4028/www.scientific.net/AMM.295-298.2167

Thelma, J. (2019). Problems of invasive species. In. D. Pei & M. Junaid (Eds.), *Marine Ecology: Current and Future Developments (Volume 1)-Marine Pollution: Current Status, Impacts and Remedies* (pp.344-365). Bentham Science Publishers Pte. Ltd.

Therriault, T. W., Nelson, J. C., Carlton, J. T., Liggan, L., Otani, M., Kawai, H., Scriven, D., Ruiz, G. M., & Clarke Murray, C. (2018). The invasion risk of species associated with Japanese Tsunami Marine Debris in Pacific North America and Hawaii. *Marine Pollution Bulletin*, *132*, 82–89. https://doi.org/10.1016/j.marpolbul.2017.12.063

This Is Us. (2023a). *Biosecurity 2025*. Ko Tātou This Is Us. https://www.thisisus.nz/biosecurity-2025/

This Is Us. (2023b). *Biosecurity Awards*. Ko Tātou This Is Us. https://www.thisisus.nz/news-events/biosecurity-awards/

Thushari, G. G. N., & Senevirathna, J. D. M. (2020). Plastic pollution in the marine environment. *Heliyon*, *6*(8), Article 8. https://doi.org/10.1016/j.heliyon.2020.e04709

Tidbury, H. J., Copp, G. H., Davison, P. I., Olsson, K., Graham, J. A., Hill, T. W., Vilizzi, L., & Stebbing, P. D. (2021). Non-native marine species risk screening and vector analysis to inform conservation management in the southern Caribbean. *Aquatic Conservation: Marine and Freshwater Ecosystems*, *31*(12), 3564–3579. https://doi.org/10.1002/aqc.3712

Tittensor, D. P., Beger, M., Boerder, K., Boyce, D. G., Cavanagh, R. D., Cosandey-Godin, A., Crespo, G. O., Dunn, D. C., Ghiffary, W., Grant, S. M., Hannah, L., Halpin, P. N., Harfoot, M., Heaslip, S. G., Jeffery, N. W., Kingston, N., Lotze, H. K., McGowan, J., McLeod, E., … Worm, B. (2019). Integrating climate adaptation and biodiversity conservation in the global ocean. *Science Advances*, *5*(11), Article 11. https://doi.org/10.1126/sciadv.aay9969

Tompkins, E. L., Few, R., & Brown, K. (2008). Scenario-based stakeholder engagement: Incorporating stakeholders preferences into coastal planning for climate change. *Journal of Environmental Management*, *88*(4), 1580–1592. https://doi.org/10.1016/j.jenvman.2007.07.025

Transport Canada. (2021). *List of Canada's Designated Alternate Ballast Water Exchange Areas and Fresh Waters* (TP 13617E; Issue 13617E, pp. 1–8). https://tc.canada.ca/sites/default/files/2021-06/tp13617e.pdf

Transport Canada. (2020). *Partnerships and Stakeholders*. Government of Canada. https://tc.canada.ca/en/marine-transportation/marine-security/partnerships-stakeholders

Transport Canada. (2019a). *Anti-fouling Systems*. Government of Canada. https://tc.canada.ca/en/marine-transportation/marine-safety/anti-fouling-systems

Transport Canada. (2019b). *Managing ballast water*. Government of Canada. https://tc.canada.ca/en/marine-transportation/marine-pollution-environmental-response/preventing-aquatic-invasive-species-marine-transportation/managing-ballast-water

Transport Canada. (2022a). *Managing biofouling*. Government of Canada. https://tc.canada.ca/en/marine-transportation/marine-pollution-environmental-response/preventing-aquatic-invasive-species-marine-transportation/managing-biofouling

Transport Canada. (2022b). *Voluntary Guidance for Relevant Authorities on In-Water Cleaning of Vessels*. Government of Canada. https://tc.canada.ca/en/marine-transportation/marine-pollution-environmental-response/preventing-aquatic-invasive-species-marine-transportation/managing-biofouling/voluntary-guidance-relevant-authorities-water-cleaning-vessels#toc-9-2

Transport Canada. (2022c). *What We Heard: Voluntary guidance on cleaning vessels in-water*. Government of Canada. https://tc.canada.ca/en/corporate-services/consultations/what-we-heard-voluntary-guidance-cleaning-vessels-water#toc-4

Trouwborst, A. (2009). The Precautionary Principle and the Ecosystem Approach in International Law: Differences, Similarities and Linkages. *Review of European Community & International Environmental Law*, *18*(1), 26–37. https://doi.org/10.1111/j.1467-9388.2009.00622.x

Tsolaki, E., & Diamadopoulos, E. (2010). Technologies for ballast water treatment: A review. *Journal of Chemical Technology & Biotechnology*, *85*(1), Article 1. https://doi.org/10.1002/jctb.2276

Urdahl, K. (2017, October 25). *Biofouling Moves Up the Regulatory Agenda*. The Maritime Executive. https://maritime-executive.com/blog/biofouling-moves-up-the-regulatory-agenda

USFWS. (2021a). *Clean, Drain, Dry*. U.S. Fish & Wildlife Service. https://www.fws.gov/story/clean-drain-dry

USFWS. (2021b). *Five Ways to Protect Our Waters*. U.S. Fish & Wildlife Service. https://www.fws.gov/story/five-ways-protect-our-waters

USFWS. (2021c). *What is an aquatic invasive species?* U.S. Fish & Wildlife Service. https://www.fws.gov/story/what-aquatic-invasive-species

Vilà, M., & Hulme, P. E. (Eds.). (2017). *Impact of Biological Invasions on Ecosystem Services*. Springer International Publishing. https://doi.org/10.1007/978-3-319-45121-3

Von Der Porten, S., Ota, Y., Cisneros-Montemayor, A., & Pictou, S. (2019). The Role of Indigenous Resurgence in Marine Conservation. *Coastal Management*, *47*(6), Article 6. https://doi.org/10.1080/08920753.2019.1669099

Wang, Z., Nong, D., Countryman, A. M., Corbett, J. J., & Warziniack, T. (2020). Potential impacts of ballast water regulations on international trade, shipping patterns, and the global economy: An integrated transportation and economic modeling assessment. *Journal of Environmental Management*, *275*, 110892. https://doi.org/10.1016/j.jenvman.2020.110892

Washington Department of Fish & Wildlife. (2023). *Aquatic invasive species prevention permits*. Washington Department of Fish & Wildlife. https://wdfw.wa.gov/species-habitats/invasive/permits

Williams, B. K. (2011). Adaptive management of natural resources—Framework and issues. *Journal of Environmental Management*, *92*(5), 1346–1353. https://doi.org/10.1016/j.jenvman.2010.10.041

Wilson, J. R. U., Dormontt, E. E., Prentis, P. J., Lowe, A. J., & Richardson, D. M. (2009). Something in the way you move: Dispersal pathways affect invasion success. *Trends in Ecology & Evolution*, *24*(3), Article 3. https://doi.org/10.1016/j.tree.2008.10.007

Withers, P. (2023, April 13). *Dartmouth startup raises $10M to take its marine paint global*. CBC. https://www.cbc.ca/news/canada/nova-scotia/graphite-innovation-marine-paint-1.6808969

Wright, P. A., Moghimehfar, F., & Woodley, A. (2019). Canadians' perspectives on how much space nature needs. *FACETS*, *4*(1), Article 1. https://doi.org/10.1139/facets-2018-0030

Yebra, D. M., Kiil, S., & Dam-Johansen, K. (2004). Antifouling technology—Past, present and future steps towards efficient and environmentally friendly antifouling coatings. *Progress in Organic Coatings*, *50*(2), Article 2. https://doi.org/10.1016/j.porgcoat.2003.06.001

Zelinski, A. (2023, February 5). *New Zealand's hull law halts voyages, and cruisers learn a new term: Biofoul*. Travel Weekly. https://www.travelweekly.com/Cruise-Travel/New-Zealand-hull-law-halts-voyages

Zhong, X., Dong, J., Liu, M., Meng, R., Li, S., & Pan, X. (2022). Experimental study on ship fouling cleaning by ultrasonic-enhanced submerged cavitation jet: A preliminary study. *Ocean Engineering*, *258*, 111844. https://doi.org/10.1016/j.oceaneng.2022.111844

Figures

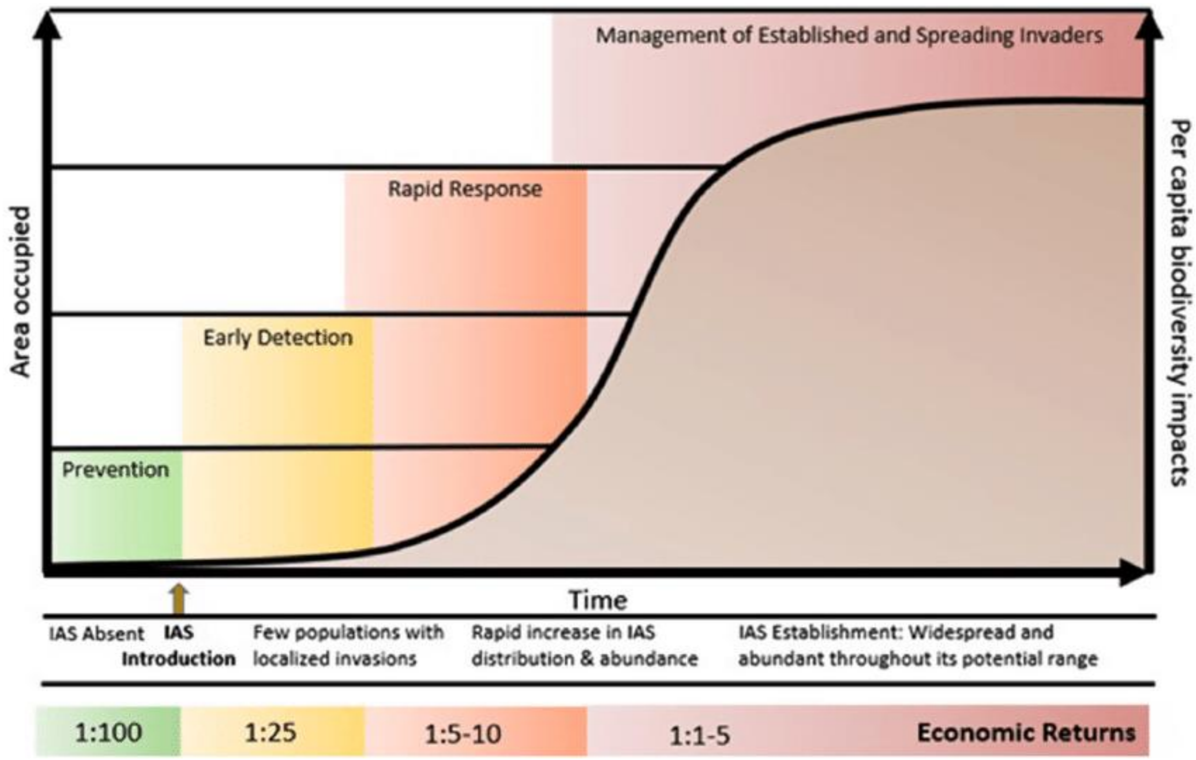
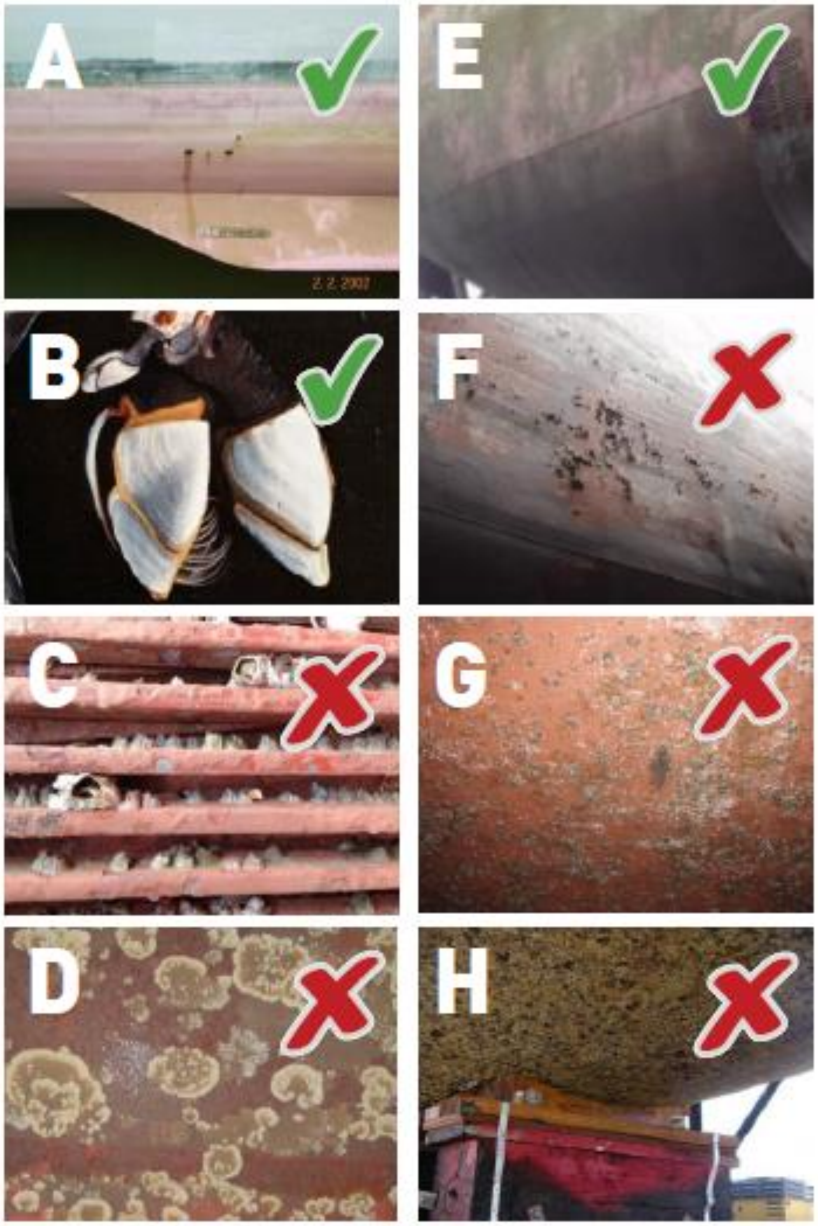


Figure 1 Species invasion curve from Reid et al. (2021), illustrating the areas occupied by IAS and the per capita biodiversity impacts over time. The economic returns of taking actions at each stage are shown below the graph.

	Canada	United States	Australia	New Zealand
Responsibilities				
Federal government primarily responsible for proactive management	✓	✓	✓	✓
Centralised biosecurity authority			✓	✓
Interagency body that leads and coordinates biosecurity initiatives		✓		
Government representative(s) for biosecurity			✓	✓
Individual federal agencies responsible for biosecurity initiatives relevant to their agency responsibilities	✓	✓	✓	✓
Rigorously and consistently enforced biosecurity controls for international shipping and travel			✓	✓
Regular federal reviews/updates on proactive biosecurity efforts		✓	✓	✓
Indigenous Peoples/communities appear to be involved to a large extent in all aspects of biosecurity				✓
Citizen scientists have clear, incentivised roles in IAS identification and proactive management			✓	✓
Challenges				
Shared international border(s)	✓	✓		
Past extinctions and present threats to endemic species from IAS			✓	✓
Climate change exacerbating biosecurity challenges	✓	✓	✓	✓
Bright spots				
Extensive public education on biosecurity			✓	✓
Extensive promotion and recognition of public engagement in biosecurity			✓	✓
Protection of biodiversity as a main goal of biosecurity initiatives			✓	✓

Note: IAS, invasive alien species.

Figure 2 Table comparing aspects of biosecurity between Canada, the United States, Australia, and New Zealand (from C. H. Reid et al. [2021]).



The only fouling a long-stay vessel may have is a slime layer (A) and gooseneck barnacles (B). Any other species, such as the acorn barnacle (C), or bryozoans (D), are not allowed. The images on the right show a slime layer (E) which would meet the new requirements, and moderate (F) extensive (G) and very heavy (H) levels of fouling which would not meet the new requirements.

(Images: John A Lewis, ES Link Services Pty Ltd).

Figure 3 Acceptable biofouling for long-stay vessels in New Zealand. Image from MPI (2017).

	DISCHARGED BALLAST		
RECEIVING WATERS	FW	BW	SW
FW	High	Medium	Low
BW	Medium	High	High
SW	Low	High	High

Figure 4 Likelihood of survival and reproduction of organisms, where FW=freshwater, BW=brackish water, and SW=saline water. From Scriven et al. (2015).

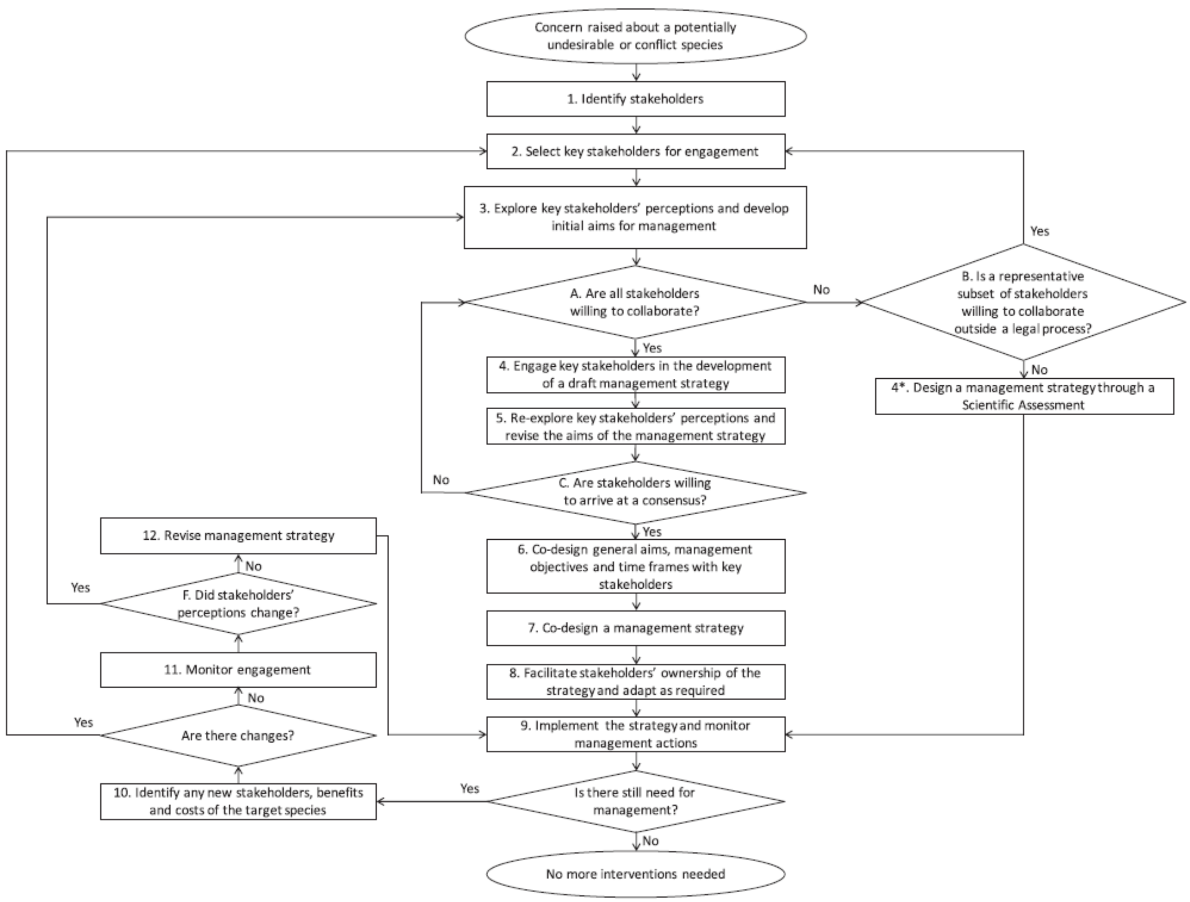


Figure 5: The 12-step framework for stakeholder engagement in management practices for alien species from Novoa et al. (2018).

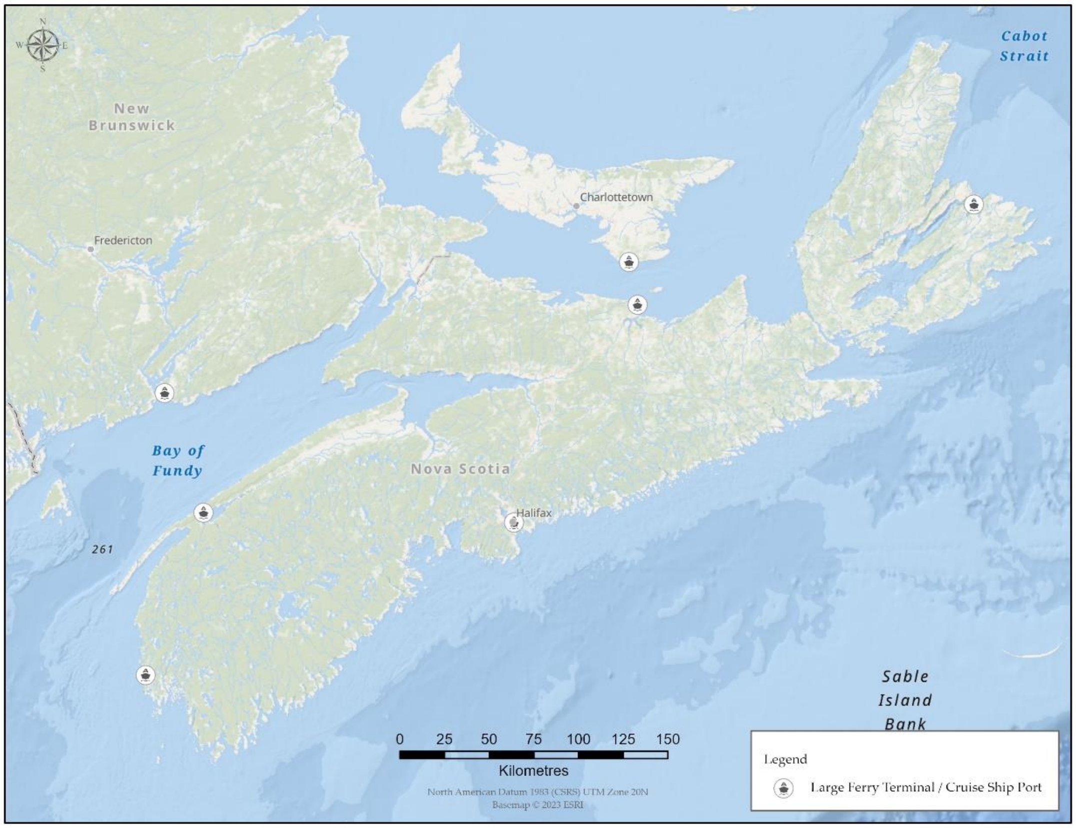


Figure 6 Large ferry terminal and cruise ship port locations in Nova Scotia, Canada. Map courtesy of S. Butler (DFO).

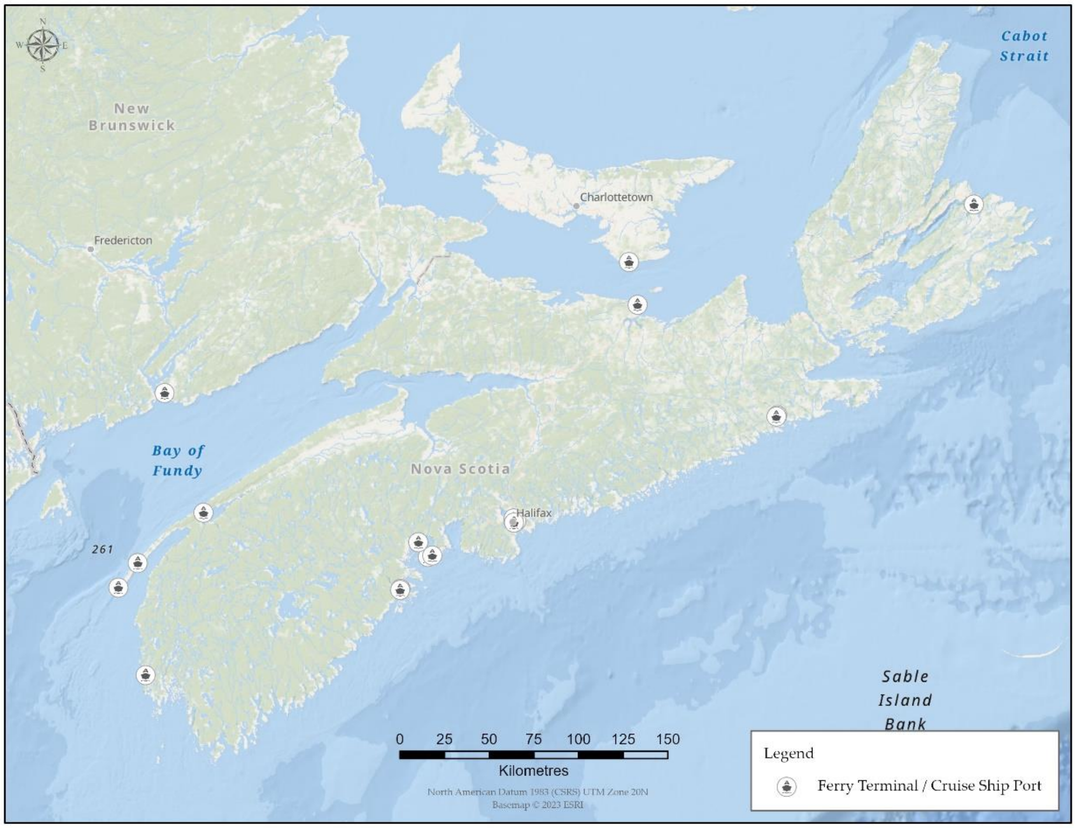


Figure 713 All ferry terminals and cruise ship ports in Nova Scotia. Map courtesy of S. Butler (DFO).

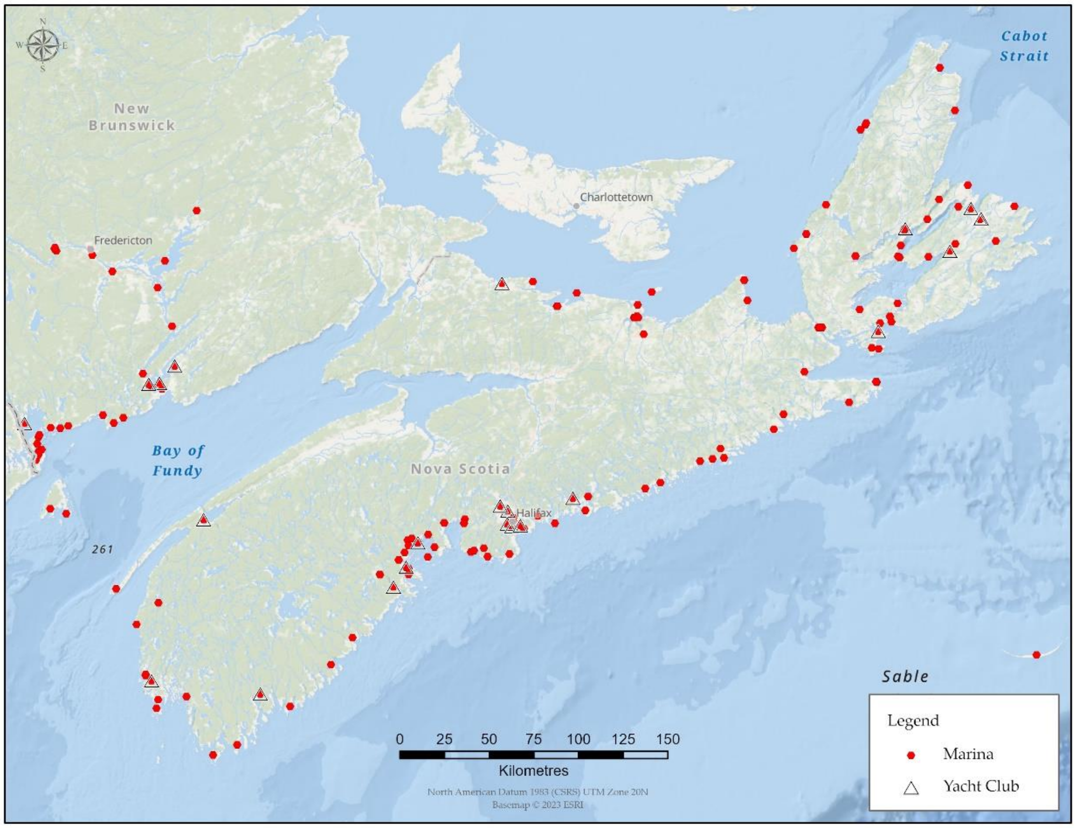


Figure 814 Marina and yacht clubs in Nova Scotia, Canada. Map courtesy of S. Butler (DFO).

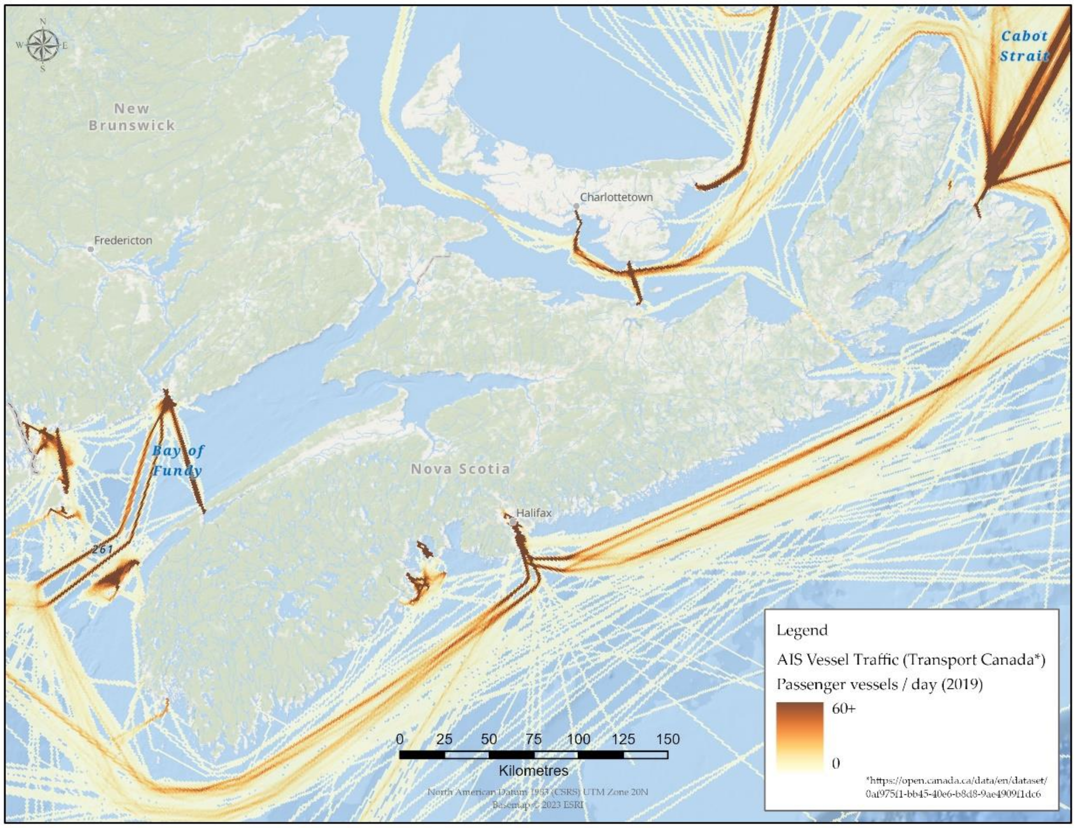


Figure 9 Passenger vessel traffic per day in Nova Scotia, Canada. Map courtesy of S. Butler (DFO).

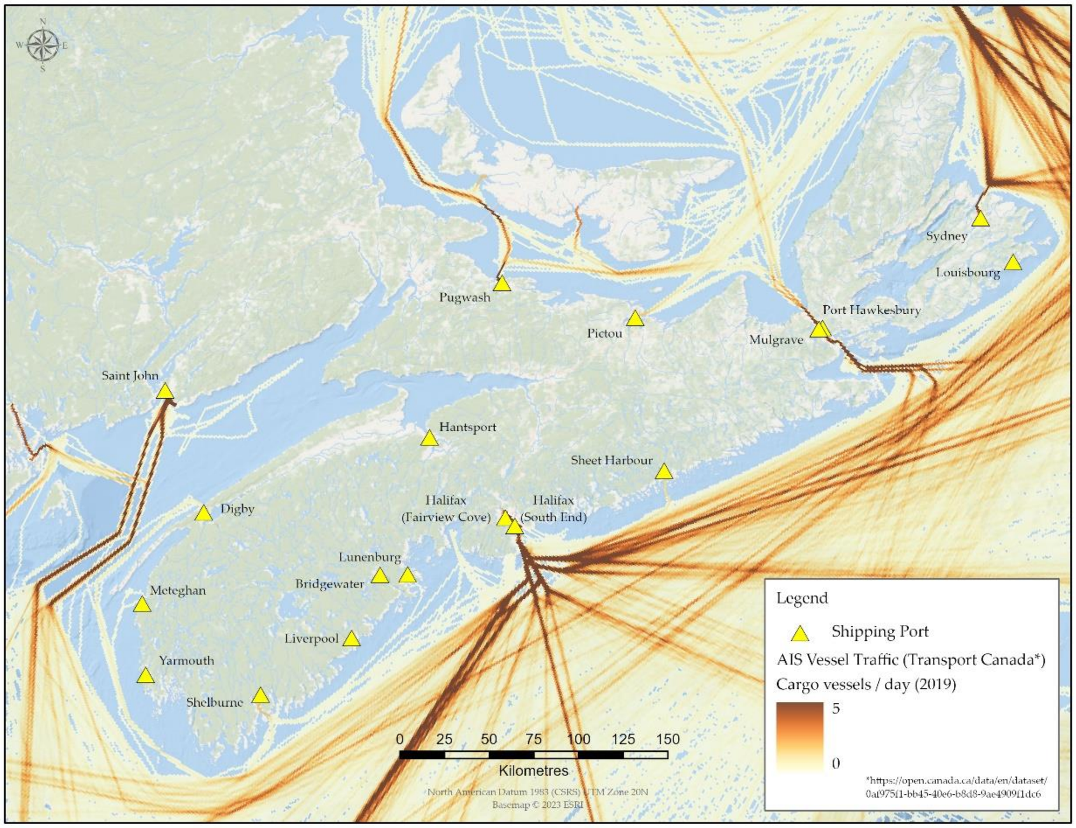


Figure 10 Cargo vessel traffic per day in Nova Scotia, Canada. Map courtesy of S. Butler (DFO).

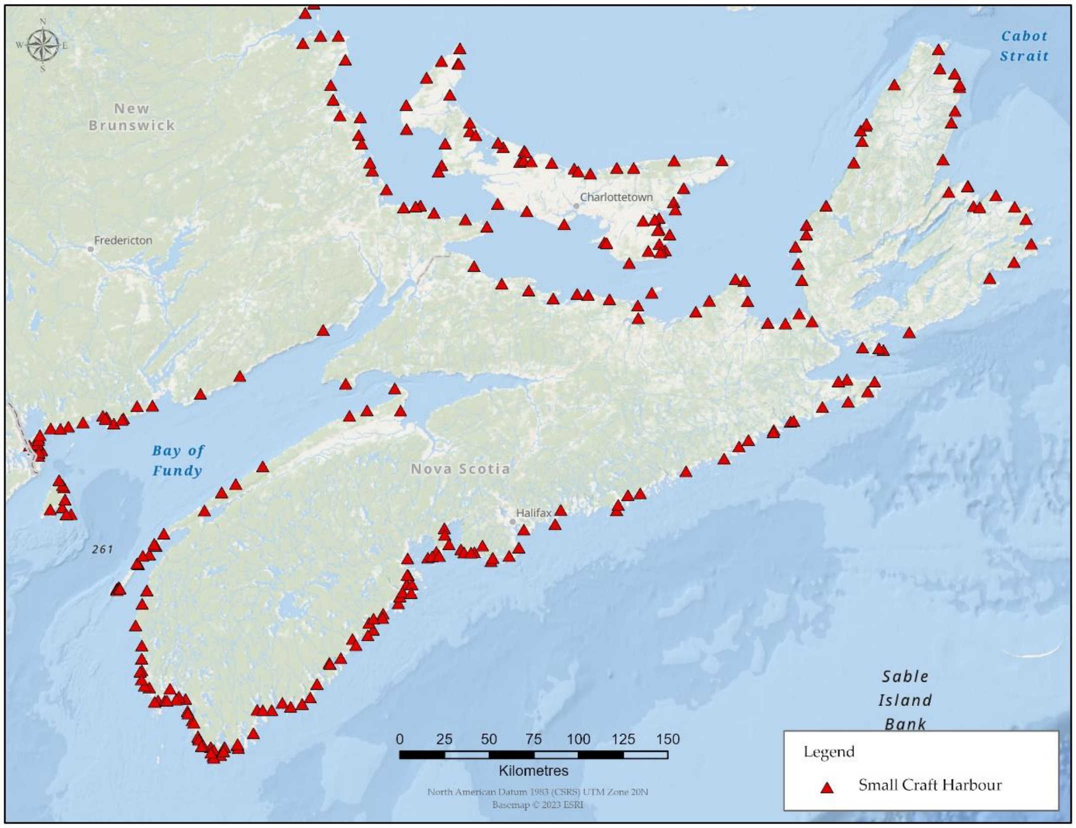


Figure 11 Small craft harbours in Nova Scotia, Canada. Map courtesy of S. Butler (DFO).

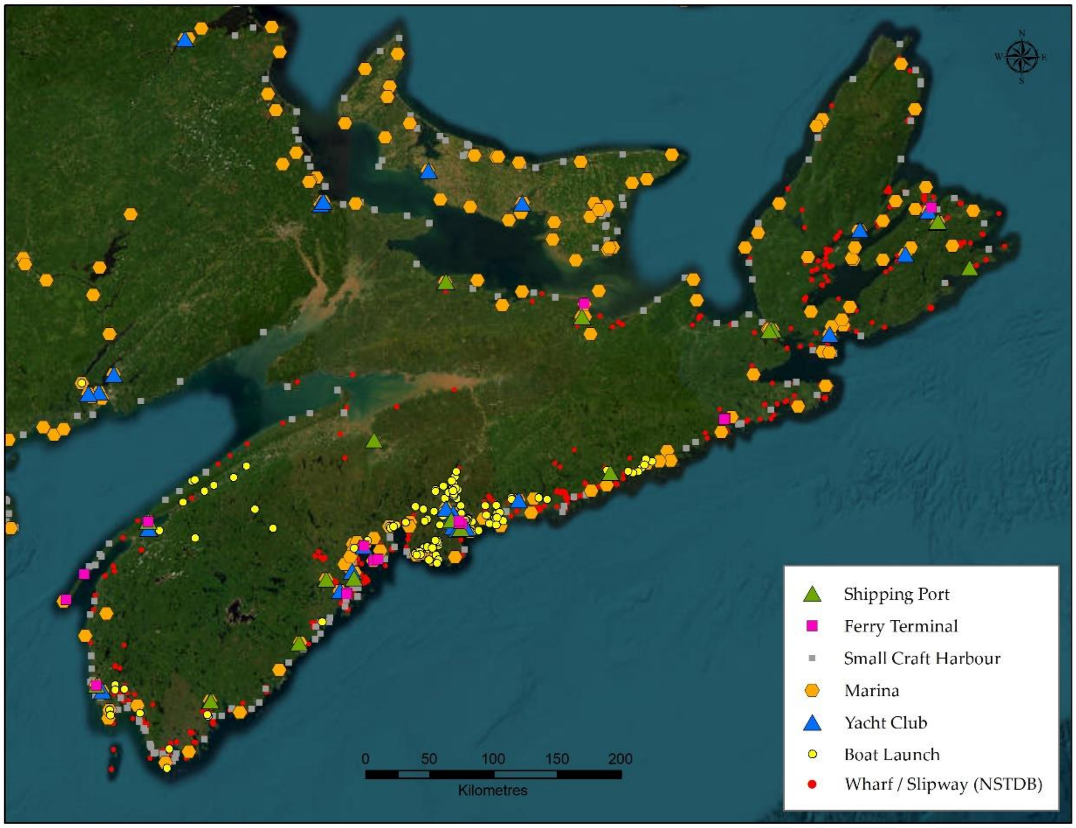


Figure 12 Shipping ports, ferry terminals, small craft harbours, marinas, yacht clubs, boat launches, and wharfs/slipways in Nova Scotia, Canada. Map courtesy of S. Butler (DFO).

Tables

Table 1 Regulations addressing AIS in Nova Scotia and New Brunswick.

Province	**Regulations**	**Relevant *Acts***
New Brunswick	-Minister can designate an aquaculture management area, where standards, procedures, or guidelines specific to methods, hazards, or containment of aquatic organisms are established (*Aquaculture Act* [S.N.B. 2019, c.40]). -Cannot transfer products between bodies of water, or introduce live products to a water body (except in accordance with regulations) (*Aquaculture Act* [S.N.B. 2019, c.40]). -A controlled aquaculture area may be designated if the Chief Veterinary Officer has reason to believe a hazard is, or may be, present at the site (*Aquaculture Act* [S.N.B. 2019, c.40]). -License holder may be ordered to take any necessary measures to prevent spread of hazards. -Illegal to transfer or stock any fish without proper authorization (Government of New Brunswick, n.d.). -Illegal to use live fish as bait in most waters (Government of New Brunswick, n.d.) -Lieutenant-Governor in Council may make regulations relating to exotic animals, including exotic fish (*Exotic Animals Act* [SNB 2017, c 52]).	*Aquaculture Act* (S.N.B. 2019, c.40) *Exotic Animals Act* (SNB 2017, c 52) *Fish and Wildlife Act*
Nova Scotia	-Cannot use as bait, dead or alive, smallmouth bass, chain pickerel, brown bullhead, white perch, yellow perch,	*Fisheries and Coastal*

	goldfish, or any fish that is not taken from the province's waters (Nova Scotia Fisheries and Aquaculture, n.d.) -Prohibitions around the unlawful possession of live fish (Nova Scotia Fisheries and Aquaculture, n.d.) -cannot transport live fish without written permission under the Live Fish Possession Regulations (S.N.S. 1996, c. 25) (under the *Fisheries and Coastal Resources Act*) -cannot keep exotic wildlife in captivity or release them from captivity (R.S., c. 504, s. 2) -cannot import exotic wildlife without an import permit issued under the *Wildlife Act* (R.S., c. 504, s. 2) -prohibited to possess/release/import/transport species listed under the Aquatic Invasive Species Regulations (SOR/2015-121)(under the *Fisheries Act)*	*Resources Act* (1996, c. 25, s. 1) *Nova Scotia Wildlife Act* (R.S., c. 504, s. 2) *Fisheries Act* (R.S.C., 1985, c. F-14)

Table 2 Canadian ballast water exchange regulations

Option	Outlines
1	In an area that is, at minimum, 200 nautical miles from the nearest land and where the water is, at minimum, 200m in depth.
2	Exchange must occur in an area as far from the nearest land as possible, to a minimum of 50 nautical miles, and in water, at minimum, 200 m in depth (IMO, 2019b)
3	Areas designated by the Minister are to be used for ballast water exchange. Under certain conditions, such as time of year (between

	December 1 and May 1) and water depth (300m), ballast water may also be exchanged in the Laurentian Channel Marine Protected Area (MPA) and the St. Ann's Bank MPA in areas that overlap with the Laurentian Channel (Transport Canada, 2021)

APPENDIX 1: Search Terms

- Aboriginal people invasive species
- Abundance of invasive species and introduction potential
- Adaptive management
- Aichi Target 9
- Annex B-4.1 ballast water
- Anthony Ricciardi invasive species ballast water
- Anti-fouling paint how often to reapply
- Anti-fouling paint reapplication
- Anti-fouling systems convention
- Aquaculture aquatic invasive species pathway
- Aquaculture escapees invasive
- Aquaculture Reform (Repeals and Transitional Provisions) Act 2004
- Aquaculture regulations canada
- Aquatic ecosystem flows invasive species
- Aquatic invasions
- Aquatic invasions marine habitat
- Aquatic invasive species and fish passage
- Aquatic invasive species and water flow
- Aquatic invasive species biogenic habitats
- Aquatic invasive species calcareous shells
- Aquatic invasive species carbon sequestration
- Aquatic invasive species carbon sequestration calcareous shells
- Aquatic invasive species ecosystem productivity
- Aquatic invasive species ecosystem-based management
- Aquatic invasive species food web
- Aquatic invasive species impact climate refugia
- Aquatic invasive species impact native foraging species
- Aquatic invasive species impact on habitat complexity
- Aquatic invasive species maritime industry equipment repair and replacement
- Aquatic invasive species native genetic diversity
- Aquatic invasive species nutrient flow
- Aquatic invasive species over multiple pathways
- Aquatic invasive species vector magnitude
- Article 4.7 ballast water California
- Ascidiella aspersa Atlantic Canada
- Ascidiella aspersa Atlantic Canada climate change
- Asian Shore Crab Atlantic Canada
- Asian Shore Crab Atlantic Canada climate change
- Asian Shore Crab climate change
- Atlantic salmon invasive species
- Atlantic whitefish aquatic invasive species
- Australia aquaculture aquatic invasive species
- Australia aquaculture biosecurity
- Australia aquaculture import regulations
- Australia aquaculture regulations
- Australia aquaculture regulations invasive species
- Australia ballast water regulations
- Australia biofouling regulations
- Australia biosecurity regulations
- Australia canals invasive species
- Australia construction marine aquatic invasive species
- Australia cruise ship denied entry
- Australia Indigenous biosecurity
- Australia invasive species council
- Australia marine debris aquatic invasive species
- Australia marine debris regulations aquatic invasive species
- Australia recreational activity regulations aquatic invasive species
- Australia recreational fishing aquatic invasive species
- Australia water canals invasive species
- Ballast water aquatic invasive species
- Ballast water exchange nutrients
- Ballast water exchange nutrients replenished
- Ballast water filtration efficacy
- Ballast water regulations
- Ballast water treatment methods
- Ballast water UV treatment
- Bequest value economics
- Blue Crab Atlantic Canada
- Blue Crab climate change Atlantic Canada

- Boat inspection stations Canada
- California ballast water regulations
- California biofouling regulations
- California Code of Regulations
- Canada action plan aquatic invasive species
- Canada Aichi Target 9
- Canada Aichi Targets
- Canada antifouling
- Canada aquaculture
- Canada aquatic invasive species
- Canada Convention on Biological Diversity Target 11
- Canada Don't Let it Loose
- Canada economic impact green crab
- Canada European green crab
- Canada marine biosecurity
- Canada marine conservation education
- Canada Reconciliation
- Canada Shipping Act
- Canada stakeholders marine biosecurity
- Canada tributyl tin
- Canadian Coast Guard Arctic
- Canadian endemic species aquatic invasive species
- Canadian stakeholders in marine biosecurity
- Canals as aquatic invasive species pathway
- CFIA Pest List
- Charlevoix Blueprint for Healthy Oceans, Seas and Resilient Coastal Communities
- Citizen science aquatic invasive species
- Climate change and aquatic invasive species
- Climate change aquatic invasive species
- Climate change Arctic ice
- Climate change creates niches for invasive species
- Climate change invasive species
- Climate change opening Arctic Ocean
- Climate change opening Arctic Ocean invasive species
- Climate change species range shifts
- Clubbed Tunicate Atlantic Canada
- Conflict resolution stakeholders rightsholders
- Convention on Biological Diversity
- Cultural value
- Cultural value economics
- Cumulative stressors climate change marine aquatic invasive species
- Department of Agriculture, Water, and the Environment Australia
- Department of Agriculture, Water, and the Environment list of pests, weeds
- DFO fleet separation
- DFO habitat protection policies
- Ease of access public laws
- Ease of access to information by general public
- Ease of access to legal regulations by general public
- Eco friendly antifouling marine coatings
- Ecosystem functions and services
- Effect of vessel size on biofouling
- Effective conservation education
- Effective Indigenous collaboration
- Effective marine conservation education
- Environmental stewardship impact relationship with nature
- Exotic Animals Act
- Federal Sustainable Development Strategy Canada
- Fish for invasive species license
- Fisheries Act
- Fisheries and Coastal Resources Act
- Fisheries and Oceans Canada anti-fouling
- Food and Agriculture Association of the United Nations (UNFAO) Code of Conduct for Responsible Fisheries
- Global Ghost Gear Initiative (2015)
- Global Ocean Alliance (2020)
- Government of Australia
- Government of Canada Reconciliation
- Graphite marine environment
- Graphite paint antifouling Nova Scotia
- Guidelines for inspection of anti-fouling systems on ships
- Has Canada reached Aichi Target 9?
- Hemigrapsus sanguineus Atlantic Canada
- Hemigrapsus sanguineus climate change
- Ian Campbell
- Ian Campbell floating wind farm
- Ian Campbell invasive
- Ian Campbell wind
- Ian Campbell wind farm

- Impact of aquatic invasive species on marine industries
- Improving policy maker accountability
- Indigenous collaboration aquatic invasive species
- Indigenous collaboration environmental conservation
- Indigenous knowledge aquatic invasive species
- Indigenous self-governance
- Indigenous Traditional Ecological Knowledge invasive species
- Intergenerational economics aquatic invasive species
- Intergenerational equity aquatic invasive species
- Intergenerational equity economics
- Intergenerational equity economics environmental conservation
- International Antifouling Certificate
- International Convention for the Control and Management of Ships' Ballast Water and Sediments, 2004
- International Convention for the Control and Management of Ships' Ballast Water and Sediments, 2004 Regulation B-1
- Invasive species Canada before and after ballast water regulations
- Invasive species council Australia
- Invasive species impact on functional biodiversity groups
- Invasive species impact on life history stages
- Irish moss Canada
- Irish moss Nova Scotia Canada
- Japanese tsunami marine debris Canada
- Legalese and the general public
- Live fish possession regulations Nova Scotia
- Magnitude invasive species
- Marine Debris Stakeholder Action Committee
- Marine Debris Stakeholder Action Committee Canada
- Marine industries invasive species
- Maritime industry aquatic invasive species
- Mid-ocean ballast exchange marine species nutrients
- Naval Sea Systems Command antifouling program
- New Brunswick Aquaculture Act
- New Brunswick Exotic Animals Act
- New Brunswick Fish and Wildlife Act
- New Brunswick illegal stocking
- New Brunswick Lieutenant-Governor in Council exotic fish
- New Zealand 2018 biofouling regulations
- New Zealand approach to biosecurity
- New Zealand aquaculture biosecurity
- New Zealand aquaculture escapes
- New Zealand aquaculture import regulations
- New Zealand aquaculture regulations
- New Zealand aquaculture regulations invasive species
- New Zealand ballast water regulations
- New Zealand canals invasive species
- New Zealand cruise ship hull cleaning
- New Zealand Cruise ships
- New Zealand cuise ship prevent entry
- New zealand GDP biosecurity
- New zealand GDP dedicated to biosecurity
- New Zealand Import Health Standard: Aquatic Animal Products
- New Zealand marine biosecurity act
- New Zealand marine construction aquatic invasive species
- New Zealand recreation aquatic invasive species
- New Zealand recreational activities aquatic invasive species
- New Zealand recreational fishing aquatic invasive species
- New Zealand regional pest managment plans
- North America canal aquatic invasive species
- North America canal marine aquatic invasive species
- Nova Scotia aquaculture sites
- Nova Scotia bait restrictions
- Nova Scotia biogenic habitat invasive species
- Nova Scotia Fisheries and Aquaculture
- Nova Scotia Fisheries and Coastal Resources Act
- Nova Scotia Wildlife Act

- Ocean acidification aquatic invasive species
- Oceans Act
- Office of Auditor General report on AIS
- Open ocean ballast water exchange
- Open ocean ballast water exchange marine organisms
- Open ocean ballast water exchange nutrients
- Opening of Arctic connects Atlantic and Pacific
- Panama Canal marine aquatic invasive species
- Percentage of aquatic species that become invasive
- Percentage of species that become invasive
- Plastics aquatic invasive species
- Precautionary approach aquatic invasive species
- Primary vs secondary spread invasive species
- Principle of adjacency Canada
- Quarantine Management System Barrow Island
- Recreational boating as primary invasion vector
- Regulations for the Prevention of Pollution from Ships and for Dangerous Chemicals
- Rockweed Nova Scotia Canada
- Section E Survey and Certification Requirements for Ballast Water Management
- Ship cleaning robot
- Ship cleaning robot Canada
- Social license to operate New Zealand
- Species at Risk Act
- Stakeholder and policy maker accountability
- Stakeholder and rightsholder analysis
- Stakeholders and rightsholders accountability
- Stakeholders and rightsholders identification methods
- Stewardship and human-nature relationship
- Suez Canal aquatic invasive species
- Sustainable Fisheries Framework Canada
- This Is Us brand New Zealand
- This Is Us New Zealand
- Traditional Ecological Knowledge
- Traditional Ecological Knowledge environmental conservation
- Traditional Ecological Knowledge invasive species
- Transport Canada biofouling
- United Nations Agreement on Straddling and Highly Migratory Fish Stocks
- United Nations Declaration on the Rights of Indigenous Peoples
- United States aquaculture regulations
- United States aquatic biosecurity
- United States ballast water regulations
- United States biofouling regulations
- United States canals aquatic invasive species
- United States fishing licence aquatic invasive species
- United States marine construction invasive species regulations
- United States marine debris regulations
- United States of America biofouling regulations
- United States recreational activities aquatic invasive species
- Vessel size biofouling
- Voluntary Guidance for Relevant Authorities on In-Water Vessel Cleaning final version
- What is biosecurity
- What makes invasive species so successful