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National Risk Assessment of Recreational Boating as a Vector for Marine Non-indigenous Species

N. Simard[1], M. Pelletier-Rousseau[1], C. Clarke Murray[2], C.W. McKindsey[1], T.W. Therriault[3], A. Lacoursière-Roussel[4], R. Bernier[5], D. Sephton[6], D. Drolet[1], A. Locke[5], J.L. Martin[7], D.A.R. Drake[8] and C.H. McKenzie[9]

[1]Maurice Lamontagne Institute,Fisheries and Oceans Canada,
850 route de la Mer, Mont-Joli, QC,G5H 3Z4

[2]North Pacific Marine Science Organization (PICES),
P.O. Box 6000, Sidney, BC,V8L 4B2

[3]Pacific Biological Station, Fisheries and Oceans Canada,
3190 Hammond Bay Road, Nanaimo, BC, V9T 6N7

[4]Laval University,
1030 avenue de la Médecine, Quebec, QC, G1V 0A6

[5]Gulf Fisheries Centre, Fisheries and Oceans Canada,
343 University Avenue, P.O. Box 5030, Moncton, NB, E1C 9B6

[6] Bedford Institute of Oceanography, Fisheries and Oceans Canada,
1 Challenger Drive, Dartmouth, NS, Canada, B2Y 4A2

[7] St. Andrews Biological Station, Fisheries and Oceans Canada,
531 Brandy Cove Road, St. Andrews, NB, E5B 2L9

[8] Department of Biological Sciences, University of Toronto Scarborough,
1265 Military Trail, Toronto, ON, M1C 1A4

[9] Northwest Atlantic Fisheries Centre, Fisheries and Oceans Canada,
P.O., Box 5667, St. John’s, NL A1C 5X1

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Foreword

This series documents the scientific basis for the evaluation of aquatic resources and ecosystems in Canada. As such, it addresses the issues of the day in the time frames required and the documents it contains are not intended as definitive statements on the subjects addressed but rather as progress reports on ongoing investigations.

Research documents are produced in the official language in which they are provided to the Secretariat.

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ABSTRACT

The National Aquatic Invasive Species Committee (NAISC), a federal-provincial-territorial committee that reports to the Canadian Council of Fisheries and Aquaculture Ministers (CCFAM), submitted a request to DFO Science for science advice related to the potential risk that the recreational boating vector poses to freshwater and marine systems in Canada with respect to the introduction and spread of non-indigenous species (NIS).

This research document assesses the relative risk posed by recreational boating as a vector for NIS in marine systems on both the East and West coasts of Canada. It includes information on the level of infestation of NIS (**Regional NIS Background**) in different Canadian and international ecoregions serving as a source for Canadian waters, the probability that boats will be fouled by NIS (**Boat Infestation Probability**), information on boat movements (**Arrival Probability**), and environmental similarity between source and receiving ecoregions (**Survival Probability)**. This information was combined with estimates of annual boat traffic to evaluate the relative risk of boating in different Canadian marine ecoregions for the introduction and spread of NIS (**Final Ecoregion Invasion Risk**).

This assessment provides evidence that primary introduction and secondary spread of NIS may occur via recreational boating in all temperate Canadian marine ecoregions. There was a high degree of connectivity within and between ecoregions on both coasts due to an estimated 4.02 M annual trips per year, while the probability of NIS being transported within and among ecoregions, and of NIS surviving in receiving environments, was relatively high. There was a general trend of greater NIS richness (mainly invasive tunicates) in southern areas relative to northern areas, greater NIS richness on the West coast compared to the East coast, and greater concentrations of NIS richness around high-volume ports/marinas on both coasts. As the majority of transient traffic was intra-ecoregional, the probability of boater-mediated secondary spread of NIS within ecoregions was high. Although, long distance spread of NIS via international and inter-ecoregional recreational boating was less common, it is still a possibility. The Final Ecoregion Invasion Risk score was ‘Highest’ for the Puget Trough/Georgia Basin ecoregion on the Pacific coast and ‘Lowest’ for all other marine ecoregions. This contrast in relative risk was due to seasonal differences in boating activities on each coast and by substantially higher annual traffic in the Georgia Basin relative to other ecoregions in Canada. Special attention should be placed on high risk vessel types in all ecoregions even when they represent a small subset of recreational boats. Specifically, boats with poor maintenance practices, that have spent extended periods in water and are travelling extensively from invaded locations, pose the greatest risk of transporting NIS. Further studies are needed to improve risk estimates for ecoregions where few boats or boaters were surveyed, such as the Labrador Shelf and the Arctic. No measure of impacts has been included in this risk assessment. However, invasive tunicates are well known to be introduced and spread via recreational boat fouling, and for their substantial ecological and economic impacts.

Évaluation nationale des risques associés à la navigation de plaisance comme vecteur de propagation des espèces aquatiques envahissantes

RÉSUMÉ

Le comité national sur les espèces aquatiques envahissantes (CNEAE), un comité fédéral-provincial-territorial qui relève du conseil Canadien des ministres des pêches et de l'aquaculture (CCFAM), a soumis une demande d'avis scientifique à la direction des Sciences du Ministère des Pêches et des Océans du Canada concernant le risque potentiel que représente la navigation de plaisance à titre de vecteur d'introduction et de dispersion d'espèces non-indigènes (ENI) dans les écosystèmes d'eau douce et marin au Canada.

Ce document de recherche évalue le risque relatif que représente la navigation de plaisance comme vecteur d'ENI dans les écosystèmes marins sur les côtes est et ouest du Canada. Ce document contient des informations sur les niveaux d'infestation d'ENI (**Niveaux de fond régionaux d'ENI**) dans les différentes écorégions canadiennes et internationales pouvant servir de sources d'ENI pour les eaux canadiennes, des informations sur la probabilité que les bateaux soient encrassés par des biosalissures contenant des ENI (**Probabilité d'infestation du bateau**), des informations sur le mouvement des bateaux (**Probabilité d'arrivée**) ainsi que sur la similarité environnementale entre les écorégions sources des bateaux et les écorégions qui les reçoivent (**Probabilité de survie**). Ces informations ont été combinées avec des estimés du trafic annuel de plaisance afin d'évaluer le risque relatif d'introduction et de dispersion d'ENI associé à la navigation de plaisance dans les différentes écorégions marines du Canada (**Risque d'invasion écorégional final**).

Cette évaluation suggère que l'introduction primaire et la dispersion secondaire d'ENI peut survenir par le biais de la navigation de plaisance dans toutes les écorégions marines tempérées du Canada. Il existe un niveau élevé de connectivité à l'intérieur et entre les écorégions des deux côtes qui est expliqué par un estimé de 4.02 millions de voyages par année. De plus, la probabilité que des ENI soient transportées à l'intérieur et entre les écorégions et qu'elles survivent dans les environnements récepteurs était relativement grande. Certaines tendances générales ont été observées : la richesse d'ENI (principalement des tuniciers envahissants) était généralement plus grande dans les régions situées plus au sud par rapport à celles plus nordiques; la richesse d'ENI était plus élevée sur la côte ouest relativement à la côte est et; la richesse d'ENI était plus élevée à proximité des ports et des marinas recevant un grand volume de trafic sur les deux côtes. Puisque la majorité du trafic des visiteurs était intra-écorégional, la probabilité de dispersion secondaire des ENI par ces bateaux à l'intérieur même d'une écorégion était élevée. Bien que la dispersion d'ENI sur de longues distances due au trafic international et inter-écorégional soit peu commune, elle demeure une possibilité. Le risque d'invasion écorégional final était 'Très élevé' pour l'écorégion *Puget Trough/Georgia Basin* sur la côte ouest et 'Très faible' pour toutes les autres écorégions marines. Ce contraste est expliqué par les différences saisonnières des activités de plaisance sur chaque côte et par le trafic annuel plus élevé dans le Bassin de Georgia relativement aux autres écorégions du Canada. Une attention particulière devrait être portée sur les types de bateaux à risque élevé dans toutes les écorégions, malgré qu'ils représentent une petite proportion de la population de plaisanciers. Plus spécifiquement, les bateaux qui voyagent fréquemment dans des régions infestées, qui ont des mauvaises pratiques d'entretien et qui passent de longues périodes dans l'eau posent un risque plus élevé de transporter des ENI. Des études supplémentaires seront nécessaires afin d'améliorer l'estimé des risques dans les écorégions où peu de bateaux ont été échantillonnés et questionnés, telles que l'écorégion *Labrador Shelf* et l'Arctique. Dans cette étude, aucune mesure d'impact n'a été incorporée, mais les tuniciers sont des espèces pouvant être introduites et dispersées via l'encrassement sur les coques des plaisanciers, et sont bien connues pour leur impacts, autant écologiques qu'économiques.

INTRODUCTION

Non-indigenous species (NIS) pose significant ecological and economic threats to Canadian freshwater, estuarine, and marine waters. Colautti et al. (2006) estimated the cost of three marine NIS (oyster thief, *Codium fragile*, European green crab, *Carcinus maenas*, and clubbed tunicate, *Styela clava*) to the Canadian economy at about $100 million annually. Although eradication of aquatic NIS may be possible following establishment (Thresher and Kuris 2004; Drolet et al. 2014), eradication is generally rare and most NIS persist in their introduced range following establishment (Mack et al. 2000). Therefore, preventing the influx of NIS to uninvaded areas is critical to addressing this threat to Canadian marine ecosystems.

Marine species may be transported by many vectors beyond their native range. Prominent vectors include commercial shipping (ballast water and biofouling), recreational boating (biofouling), aquaculture and fishing activities, and the live animal and aquarium trades (Carlton 1985; Gollasch 2002; Floerl and Inglis 2003a; Semmens et al. 2004). Most invasions of marine NIS in coastal areas have resulted from international shipping, through ballast water and hull fouling, or the introduction of bivalves for aquaculture (Ruiz et al. 2000; Wonham and Carlton 2005; Williams et al. 2013). However, a recent analysis of NIS in California (Williams et al. 2013) suggests that vessel biofouling accounted for as many NIS introductions as ballast water and aquaculture combined. Recent work has focused on better understanding the factors involved in the spread of NIS from areas of primary introduction (i.e., where an NIS is first established in a new region) and several studies have implicated recreational boating as a mechanism for secondary spread (i.e., spread from areas of primary introduction) of NIS along coasts (Ashton et al. 2014; Wasson et al. 2001, but see Blakeslee et al. 2010). Smaller private and commercial boats are often moored within or near commercial ports (Minchin et al. 2006). Smaller boats may also access bays and environments that are not accessible to commercial boats (Wasson et al. 2001). Non-indigenous species spread via recreational boats may occur from locations of primary introduction (Floerl et al. 2009; Lacoursière-Roussel et al. 2012a; Zabin 2014), indicating that recreational boats interact with primary pathways of NIS introductions. Therefore, connectivity of the recreational boating network within and among ecoregions, and in particular with key NIS hubs, are important considerations when assessing invasion risk (Forrest et al. 2009; Davidson et al. 2015). Despite the overall role of recreational boating in the introduction and spread of NIS, management action in coastal areas often focuses exclusively on the role of large ships as vectors (Minchin et al. 2006).

Transfer of NIS between freshwater locations via boating is often due to NIS becoming fouled in trailers, propellers, anchor chains, or fishing gear, and bait buckets, which may persist when trailering between waterbodies (e.g. Johnson and Padilla 1996; Johnson et al. 2001; Rothlisberger et al. 2010; Drake and Mandrak 2014). While trailering may also be of some importance in marine systems (Schaffelke and Deane 2005; Darbyson et al. 2009a), transfer among marine locations is thought to result primarily from hull fouling and the movement of fouled boats between locations. Fouling surveys of recreational boats in marinas typically find that greater than 50% of boats are fouled (see review in Minchin et al. 2006, Ashton et al. 2012) and Floerl and Inglis (2003b) suggest that marina design may exacerbate the degree of hull fouling.

Although the risk of recreational boating to the introduction and spread of NIS is well recognized, few studies have attempted to quantify the risk associated with this vector relative to other vectors within marine ecosystems (but see Williams et al. 2013; Anderson et al. 2014, 2015). It is becoming clear that the importance of vectors must be compared within and among regions as well as among vectors (Williams et al. 2013; Anderson et al. 2015; Ruiz et al. 2015). A vector approach focuses on the processes by which most NIS arrive in new locations, rather than on a species-by-species basis allowing vectors to be managed more efficiently through policy and management frameworks.

Transport of marine organisms by recreational boat hull fouling may be the largest unregulated vector for NIS and is poorly studied and understood (Clarke Murray et al. 2011; Ashton et al. 2012). In Canada, research on NIS on recreational boats has focused on a few specific areas including British Columbia (Clarke Murray et al. 2011, 2012, 2013, 2014), Prince Edward Island (Darbyson et al. 2009b, 2009c), and Nova Scotia (Lacoursière-Roussel et al. 2012a,b). In British Columbia, SCUBA surveys showed the high prevalence of NIS on the submerged surfaces of recreational boats (Clarke Murray et al. 2011). Boater questionnaire data further showed that fouling was related to travel and maintenance behaviours (Clarke Murray et al. 2013*)*. NIS associated with recreational boats have been shown to survive transport in water (*Styela Clava*, *Botrylloides violaceus* and *Didemnum vexillum*; Clarke Murray et al. 2012) and even extended period of atmosphere exposure similar to those faced by boats trailered between locations, during summer months (48 hours, *Styela Clava*, Darbyson et al. 2009c). Genetic analyses have also shown the importance of recreational boating to the spread of NIS in eastern Canada (Lacoursière-Roussel et al. 2012a). However, there has been no national synthesis of recreational boating as a vector for marine NIS in Canada.

Given this gap, the National Aquatic Invasive Species Committee (NAISC), a federal-provincial-territorial committee that reports to the Canadian Council of Fisheries and Aquaculture Ministers (CCFAM), requested scientific advice to assess the risk due to recreational boating and the introduction and spread of NIS to aquatic freshwater and marine systems in Canada.

The marine portion of this risk assessment evaluates the relative risk of recreational boats as a vector for NIS in Canadian marine waters (Atlantic and Pacific coasts). The relative risk posed by recreational boating to marine ecosystems in the Arctic was not addressed in this document and remains a knowledge gap. Fisheries and Oceans Canada (DFO) has conducted many species-based risk assessments and a few pathway-based risk assessments for NIS (DFO 2012a, DFO 2012b, DFO 2014). The present research document assesses, for the first time, the risk posed by recreational boating as a vector for NIS in marine systems in Canada and will contribute to the overall body of knowledge of NIS pathways and vectors in Canada. This document may be used to generate advice to inform targeted research, the locations and methodology for boater-specific monitoring activities, management effort directed towards high-risk boating activities, potential policy/regulatory changes, and the overall management of this vector.

This study was undertaken to address the request for science advice regarding:

The risk posed by recreational boating in Canadian marine waters on both the east and west coasts, including:

- Characterizing the movement patterns of recreational boats in marine waters within and between ecoregions.
- Estimating the potential risk to marine ecoregions based on vessel characteristics, their movements, environmental similarity, and NIS sources.

To provide context for this risk assessment, background information is provided on the biological invasion process, recreational boating as a vector, species likely to be transported by boating, and related aspects of NIS impacts, regulation, and management. The risk assessment was completed for ecoregions on both the East and West coasts of Canada and includes information on the level of infestation of NIS in the different Canadian and international ecoregions, the probability that boats will be fouled by NIS – based on extensive surveys and statistical models, information on boat movements and environmental similarity between source and receiving ecoregions. This is combined with information on annual boat traffic to estimate the relative risk of recreational boating to the introduction and spread of NIS in Canadian marine ecoregions. This analysis is based on extensive data and represents the best information available to address the questions posed by NAISC.

THE BIOLOGICAL INVASION PROCESS

The invasion process can be conceptualized as a series of successive stages: initial dispersal of NIS (uptake, transport, and release), establishment (survival and reproduction), and spread (Carlton 1985; Puth and Post 2005). Invasion success is believed to be influenced by colonization pressure (i.e., total number of species released in a single receiving region, Lockwood et al. 2009) and propagule pressure (i.e., propagule number – number of discrete introduction events; and propagule size – number of individuals released in an introduction event; Lockwood et al. 2005, 2009), while establishment is influenced by the environmental similarity between source and receiving areas (Barry et al. 2008; de Rivera et al. 2011). Thereafter, spread may be influenced by the species' ecology and influence of additional vectors. Sudden and strong dominance by a species may result from Allee effects, biotic interactions, spatial and temporal environmental heterogeneity (e.g. warming trends; Stachowicz et al. 2002), adaptation (Sax and Brown 2000), and/or multiple introductions (Lee 2002; Roman and Darling 2007; Roman 2011).

THE RECREATIONAL BOATING VECTOR

Boater behaviour, in terms of antifouling practice and voyage history, varies at global, regional, and local scales. A number of factors influence the probability of boats being fouled. This includes background levels of fouling (Floerl and Inglis 2005), boat type (e.g., sail boats vs power boats) and boat maintenance history (e.g., application of anti-fouling paint, cleaning of underwater structures, including hulls, propellers, trim tabs, etc.) (Clarke Murray et al. 2011; Lacoursière-Roussel et al. 2012b). Floerl et al. (2005) and Floerl and Inglis (2005) suggested that antifouling paints (depending on the antifouling used) may prevent hull fouling for 9-18 months when boats are used regularly. Once NIS become attached to hull surfaces, it is often necessary to remove them manually either by in-water cleaning or by removing the boat from the water and scraping and/or pressure washing. If an antifouling paint is not applied after cleaning, which happens often due to the cost of application, the benefits from cleaning are only short-term. Fragments of organisms may remain attached to the hull, which may be transported or promote further fouling (Floerl et al. 2005). In Canada, boat maintenance differs markedly between the Atlantic and Pacific coasts as boats in the Atlantic are typically removed annually to avoid winter freeze-up or otherwise inclement conditions; whereas, boats on the Pacific coast may stay in-water for extended periods – up to several years, with limited or no hull maintenance.

In general, the faster a boat travels, the more likely fouling will be sloughed off. However, there is some evidence that invasive species may be more resistant to dislodgement than native ones (Clarke Murray et al. 2012) and niche areas that are protected from hydrodynamic forces during travel may offer refuge for NIS (Davidson et al. 2010). In addition, variation in boat travel habits influences maintenance behaviours (e.g. recreational boaters that travel frequently by boat may be more inclined to keep their boat hull clean), both of which affect the extent of hull fouling and thus the probability of NIS transport.

Boats in any given marina can be divided into two categories: resident and transient. Resident boats are those that have a permanent moorage at a marina for at least part of the year. Resident boats remain in home marinas or only undertake short day trips within the local area without visiting other marinas. In contrast, transient boats undertake lengthier voyages by visiting non-home marinas, sometimes many and sometimes for extended periods. There are important differences between resident and transient boats (Floerl and Inglis 2005; Darbyson et al. 2009b). Resident boats may have the greatest hull fouling but may pose smaller risk of secondary dispersal as they do not travel to other locations (Darbyson et al. 2009b). Transient boats likely have greater potential to spread organisms to other sites (marinas) by virtue of their travel history, despite being fouled to a lesser degree than resident boats (Davidson et al. 2012).

MARINAS AND BOAT TRAFFIC

High connectivity between uninvaded and invaded locations enhances invasion risk (Floerl et al. 2009) by heightening potential propagule pressure to uninvaded sites. Coastal ports and marinas are connected to varying degrees by commercial and recreational boat traffic among other vectors. In general, most primary invasions of coastal areas are thought to be due to commercial shipping while other vectors, including recreational boating, disperse NIS further afield leading to secondary introductions or spread. This pattern of movement is supported by studies showing a loss of genetic diversity of various NIS from port to marina populations (Dupont et al. 2010; Goldstien et al. 2010; Bock et al. 2011; Lacoursière-Roussel et al. 2012a), consistent with the hypothesis of ports being the sites of primary introductions and recreational boats being the vectors of spread. The frequency of boater movements also influences and may be used to predict NIS spread, as has been noted in Australia (Floerl and Inglis 2005), New Zealand (James and Hayden 2000, cited in Dodgshun et al. 2007; Floerl et al. 2005) and both coasts of Canada (Clarke Murray et al. 2011; Lacoursiere-Roussel et al. 2012a and 2012b; Darbyson et al. 2009b, 2009c).

Marinas, ports, and fishing harbors are ideal entry points for NIS. The same characteristics that make these areas safe for boats facilitate NIS settlement and establishment. This, combined with increased propagule pressure in these areas, makes them among the most invaded marine habitats around the world (Lambert and Lambert 1998), while altered hydrological and environmental conditions can create favourable conditions for arriving NIS (Floerl and Inglis 2003b). These areas are characterised by a diverse abundance of artificial vertical and horizontal substrates, including pilings, floating docks, and breakwater walls, as well as boat hulls with various levels of antifouling protection (Glasby et al. 2007). Much of the artificial habitat is floating and thus protected from aerial exposure that affects species in rocky intertidal habitats or predators common in benthic ones (Glasby et al. 2007; Dafforn et al. 2009).

Fouling species growing on marina structures and resident boats have the potential to transfer propagules to visiting boats for subsequent spread to other locations (Floerl and Inglis 2001). In northern Australia, Floerl and Inglis (2005) found a relationship between the structure of fouling communities in marinas and the boats in them but this varied with antifouling paint age and the length of time boats were in marinas.

ASSOCIATED SPECIES

Species introduced and spread by recreational boating include diverse taxonomic groups, such as bivalves, algae, bryozoans, and ascidians. Non-indigenous bivalve introductions are notoriously harmful outside of their native range. Two well-documented examples include the black-striped mussel, *Mytilopsis sallei* Récluz, 1849 (Field 1999; Willan et al. 2000), and the green mussel, *Perna viridis* Linnaeus, 1758 (Power et al. 2004). Marine macroalgae likely introduced by recreational vessels include *Undaria pinnatifida* Suringar, 1873 (Hay 1990; Farrell and Fletcher 2006) and *Codium fragile* spp. *fragile* Hariot, 1889 (Bird et al. 1993).

The bryozoans *Watersipora subtorquata* d'Orbigny, 1852 and *Bugula neritina* (Linnaeus, 1758) are cosmopolitan invaders and well-known hull fouling species (Floerl and Inglis 2005). Both are tolerant of chemicals in antifouling paint, allowing them to facilitate the transport of other invasive species that may settle and grow on them (Floerl et al. 2004). A number of invasive ascidian introductions have been linked to recreational hull fouling (Lambert and Lambert 1998; Lutzen 1999). In Canada, aquaculture products, equipment transfers, or hull fouling are the most probable vectors of both primary introduction and secondary spread of these tunicates. In Prince Edward Island (PEI), the primary introduction of the solitary ascidian *Styela clava* was likely a slow moving barge but secondary spread has been linked to aquaculture transfers and hull fouling (Locke et al. 2007).

REGULATIONS AND MANAGEMENT

Managing or eliminating NIS, once introduced, is costly and challenging (Ashton et al. 2012), so preventing the introduction of NIS via vector regulation or management is an effective management strategy (Floerl et al. 2005). Quantifying the mechanisms of NIS introduction and spread may assist in “prioritizing specific pathways and vectors for enhanced surveillance or development of new policies and regulations to thwart further invasion” (Darling 2014).

At the international level, the International Maritime Organization has developed voluntary guidelines for the control and management of ship biofouling to minimize the transfer of aquatic invasive species (AIS) (IMO 2011). Although intended for commercial ships these also provide targeted guidance to minimize transfers of AIS via hull fouling of recreational craft. Currently, biofouling management for foreign recreational boats is voluntary in Australia, but is anticipated to become mandatory for all foreign boats (Commonwealth of Australia 2009). Current voluntary guidelines include application of antifouling coatings, regular in-water inspection, and cleaning of vessels and gear just prior to arrival, direct travel to Australia to prevent re-contamination, and maintaining a log book detailing voyage and biofouling maintenance. Inglis et al. (2012) conducted an extensive review of scenarios for biofouling of several types of vessels for New Zealand, including various management options being considered in Canada.

The Aquatic Invasive Species regulation in the Canadian *Fisheries Act* provides authority for the control of listed marine biofouling species. The movement of a vessel known to pose a risk of spreading or releasing listed AIS into the marine environment can be stopped until the risk is assessed and/or mitigated. This regulation was recently tested in Placentia Bay, Newfoundland and Labrador (NL), where a fishing boat that had been part of a mitigation experiment in May 2015 to remove *Ciona intestinalis* (500 kg of tunicate and mussels removed) was sold and scheduled to travel to another NL harbour where no *C. intestinalis* had been found. When alerted, Fisheries Officers contacted the owner and informed him that, under the new AIS regulation, he could not move his boat until it was determined to be *C. intestinalis*-free. A dive survey was conducted and no regulated AIS were found on the boat’s hull. The owner was notified of the ship’s AIS status and was permitted to continue vessel movement.

METHODS

STUDY AREA

The study area includes the marine portions of the Pacific and Atlantic coasts of Canada; there was no available information regarding recreational boating activity for the Arctic. The Atlantic coast of Canada constitutes the coastline and waters of the Estuary and Gulf of St. Lawrence, the Bay of Fundy, and the outer Canadian Atlantic coast, encompassing the marine portions of the provinces of Quebec, New Brunswick, Nova Scotia, Prince Edward Island, and

Newfoundland and Labrador (Figure 1). The Pacific coast of Canada constitutes the coastline and waters along the province of British Columbia (Figure 2).

Given significant differences in environmental conditions and boating patterns on both coasts, the relative risk of boating was compared at an ecoregion level. This decision was made following the review of several options for dividing each coast into spatial units (O'Boyle 2009). These included marine ecoregions defined by Spalding *et al.* (Marine Ecosystems of the World – MEOW, 2007), DFO (Powles et al. 2004), the Commission for Environmental Cooperation (CEC, Wilkinson et al. 2009), and Parks Canada (Harper et al. 1993). The MEOW ecoregions, defined on a biogeographical basis, can be quite large and did not capture the spatial variation in ecological conditions and boating patterns necessary for the Atlantic analyses. However, when subdivided into Canadian and American portions of each MEOW ecoregion, this classification scheme reflected the variation in ecological/environmental and boating patterns for the Pacific coast. Given that the proposed DFO marine ecoregions poorly reflect patterns in "coastal" communities and boating activity, this classification was not appropriate for the current exercise. The CEC defines Coastal Regions (Level III) based on local characteristics of water masses, regional landforms, and biological communities (Wilkinson et al. 2009). However, CEC classifications, if incorporated into the assessment, would have yielded too fine a gradation in environmental/ecological conditions. Parks Canada identified marine regions to define marine conservation areas that, by design, would include coastal areas and is based on variation in oceanographic, coastal environment, and physiographic conditions, and marine mammal, bird, fish, and invertebrate communities. This classification yielded an appropriate level of division that corresponded to variation in biological communities and boating patterns for the Atlantic coast.

Therefore, for the purpose of this study, the Atlantic coast of Canada was divided into nine ecoregions (hereafter called Atlantic ecoregions) using the Parks Canada biogeographic classification (Harper et al. 1993) (Figure 1). The St. Lawrence Estuary ecoregion was restricted to the eastern tip of Île d'Orléans to include the Upper Estuary but not the freshwater portion (El-Sabh and Murty 1990; Gagnon 1998) (Figure 1). Based on the same rationale, this ecoregion was also restricted to areas downstream of Saint Fulgence in the Saguenay River (Gagnon 1995). The Pacific coast was divided into three marine ecoregions (hereafter called Pacific ecoregions) using the Marine Ecoregion of the World (MEOW) classification outlined by Spalding et al. (2007) with a further subdivision of the Pacific North Coast Integrated Management Area (PNCIMA ecoregion) (Figure 2) since there are no marinas located in the remaining offshore portion of the MEOW ecoregion. The northern limit of the Puget Trough/Georgia Basin ecoregion was set at Lund, which includes Campbell River in the PNCIMA ecoregion. Following the same rationale used for the Atlantic coast, the Puget Trough/Georgia Basin ecoregion was restricted to areas downstream of Burnaby to exclude the freshwater part of the river. As a national risk assessment, the recreational boat traffic was analyzed only for the Canadian portion of these ecoregions. Therefore, US/Canada Maritime limits were used to separate the Puget Trough/Georgia Basin into two ecoregions: "Puget Trough/Georgia Basin" and "Puget Trough/Georgia Basin (USA)" ecoregions. The Oregon/Washington/Vancouver Coast and Shelf ecoregion was likewise separated into two ecoregions: "Oregon/Washington/Vancouver Coast and Shelf" (hereafter, "Vancouver coast and Shelf") and "Oregon/Washington/Vancouver Coast and Shelf (USA)". The three Pacific coast ecoregions (hereafter, "Pacific ecoregions") in Canadian waters are considered to be equivalent to the nine Atlantic Canada (Parks Canada) ecoregions, as both classifications are based on various species distributions and oceanographic features (O'Boyle 2009).

MARINA MANAGER AND BOATER QUESTIONNAIRES

General information on marinas and their boating communities was obtained using questionnaires. A total of 298 and 198 marina manager questionnaires were completed on the Pacific (2007-2008) and Atlantic (2009-2014) coasts, respectively (Table 1). Questionnaires sought information on marina characteristics (number of berths), resident boats (number of resident boats of each boat type, e.g. sailboat/powerboat), and transient boats (number of transient boats per year). Questionnaire data were from Lacoursière-Roussel et al. (2012a, 2012b, mostly Scotian Shelf and Magdalen Shallows ecoregions), DFO-led work in the Atlantic Region (McKenzie et al. 2014; Simard et al. 2015) and from Clarke Murray et al. (2011) for the Pacific coast. Details of the full questionnaires are presented in Appendix 1.

Boater questionnaires were used to evaluate boating movement patterns and maintenance history. Recreational boats included in this risk assessment were small boats, generally smaller than 15 meters (only 2.7% >15 meters), used for recreational purposes (sailboat, power boat), small fishing boats, converted fishing boats, and combined fishing and recreational boats. Commercial ships such as bulk carriers, tankers, container ships, barges, and ferries were not included in this study. For the Atlantic coast, a total of 1307 boater questionnaires were completed by boaters from 2009 to 2014 (in 2009 by Lacoursière-Roussel et al. 2012a and 2012b, mostly Scotian Shelf and Magdalen Shallows ecoregions, and by DFO-led efforts from 2011-2014, McKenzie et al. 2014; Simard et al. 2015) (Table 1). On the Pacific coast, 616 boater questionnaires were completed in 2008-2009 as outlined by Clarke-Murray et al. (2012). The boater questionnaires solicited information about boats (home marina, boat type, boat size, hull type, where it is stored or trailered), antifouling practices (type and time since last antifouling paint application, time since last cleaning) and travel history (marinas visited and types of trips undertaken). Trip types included local day trips (departure and return to marina in the same day), weekend trips (trips of a few days), tours (multiple destinations in one trip) and long trips (long haul travel to destinations further away).

For the Atlantic coast, boaters completed questionnaires in marinas and were asked to report the number of nights spent in each marina visited in the previous season. For the Pacific coast, boaters completed questionnaires online, by mail or in marinas (Clarke-Murray et al. 2011). Surveys were similar between coasts with one difference: number of nights spent in visited marinas was collected on the Atlantic coast while identity of marinas visited (one night or more) was collected on the Pacific coast. However, for the purpose of this study, “transient boats” are boats that have spent a minimum of one night in a non-home marina of the Atlantic or Pacific ecoregions: data available for both coasts. Details of the full questionnaires are presented in Appendix 2.

Each home or visited marina/port/mooring (hereafter called “marinas”) mentioned in boat surveys was assigned to an ecoregion. For the Atlantic coast, transient boats were from marinas classified as being within one of the nine Parks Canada ecoregions (Figure 1). Marinas situated outside the boundaries of Park Canada ecoregions were assigned to one of the MEOW ecoregions or some higher-order biogeographic classification (Figure 3 and 4). MEOW classification is based on a nested biogeographical system composed of 12 realms, 62 provinces, and 232 ecoregions. Marinas south of the Bay of Fundy ecoregion were classified as being in The Gulf of Maine/Bay of Fundy (USA) or Virginian MEOW ecoregions (Figure 3) or, south of this and elsewhere in the world, as being from MEOW Provinces as information on marina locations were often less precise (e.g., state) and data were limited (i.e., small number of boaters) (Figure 4). Canadian and foreign marinas located in freshwater (in this study <5psu during summer months) were assigned to ecoregions as following the Freshwater Ecoregions of the World (FEOW – Abell et al. 2008) classification (Figure 5). For the Pacific coast, marinas mentioned in Pacific boater questionnaires were classified as being in the relevant Pacific/MEOW ecoregions as outlined above or in FEOW ecoregions (Figure 2 and 5).

TRANSIENT TRAFFIC IN MARINE ECOREGIONS

Annual traffic

The number of transient boats that an ecoregion receives on an annual basis is one of the most important factor to consider in the final risk calculations; the more transient boats traveling to and within a given ecoregion, the greater the potential invasion risk. To estimate the total number of transient boats per year in a given ecoregion, we multiplied the average number of transient boats in a given ecoregion by the total number of marinas in that ecoregion. The average number of transient boats per ecoregion was calculated using the estimated number of visitors per marina per year, which was extracted from marina manager questionnaires (Appendix 1). The number of marinas in each ecoregion was compiled using the list of marinas in our recreational boating database that was supplemented with the DFO small craft list of ports and information from the British Columbia Marine Conservation Analysis database for the Pacific Region and Marina.com for the Atlantic Region. Marinas, yacht clubs, fishing harbors, wharfs, and ports that may be used by recreational boaters are considered as "marinas" but large commercial ports were excluded (although individual marinas associated with these ports were included).

Absolute annual number of transient marine recreational boating trips

In order to estimate the absolute annual number of transient marine recreational boating trips in Canada, a Monte Carlo simulation was used to relate the annual number of transient boaters in each ecoregion with a frequency distribution describing the number of destinations (marinas) visited by an individual transient boater, thereby providing the total number of trips taken annually in each ecoregion. Implicit in this approach is an assumption that a destination equals a single trip. This assumption provides an underestimate of the number of trips because a destination can be visited multiple times.

To conduct the simulation, probability distributions were fit to the empirical distribution describing the number of trips taken by individual transient boaters in each ecoregion (e.g., number of trips taken per year by an individual boater on the *x*-axis, number of boaters belonging to each yearly trip number on the *y*-axis). The appropriate discrete probability distribution (i.e. geometric vs. negative binomial vs. Poisson) for each ecoregion was selected based on an Akaike's information criterion, which measures the relative quality of a statistical model for a data set. A geometric distribution provided superior fit for the overall data and zero-truncated geometric distributions were chosen for each ecoregion, which forces each boater to take at least 1 trip/yr. Once the parameters of each zero-truncated distribution were determined for each ecoregion, the re-sampling process occurred as follows: n random values were selected from the fitted distribution, where n is the number of boaters in the ecoregion, and the sum of n values represented the total number of trips taken per year by all boaters in the ecoregion. This process was repeated 1000 times, providing a probability distribution of the number of yearly trips taken in each ecoregion. See Appendix 3 for the resulting yearly trip distributions and Casas-Monroy et al. (2014) for similar methods.

DETERMINING RECREATIONAL BOATING INVASION RISK

This risk assessment uses a four-step process broadly consistent with CEARA National Detailed-Level Risk Assessment Guidelines (Mandrak et al. 2012) and the National Code on

Introductions and Transfers of Aquatic Organisms (DFO 2013). The relative invasion risk posed by recreational boats was a function of the probability that a boat that visits a marina is fouled by NIS (**Boat Fouling Probability**) and the probability that NIS arrive, survive, and establish (**Introduction Probability**) (Figure 6). Transit survival and release probability were assumed to be constant since this vector-based assessment considers fouling communities composed of multiple species. Although risk assessments typically include independent estimates of impact, this assessment calculates the relative likelihood that a boat will transport and establish NIS weighted across multiple fouling species and standardized within each ecoregion. Potential ecological impacts of recreational boating as it relates to marine NIS are considered in the discussion.

The steps used to calculate risk are outlined in Figure 6. **Boat Fouling Probability** (Step 1) was estimated by combining information on regional NIS infestation levels (regional background of NIS in marinas – **Regional NIS Background**) (Step 1a; the potential of NIS colonization on boats, which is a function of exposure to propagule pools in source ecoregions) and the probability that a given boat will be fouled (Step 1b; boat and boater characteristics - **Boat Infestation Probability)**. **Introduction Probability** was estimated by combining the probabilities of boats arriving (transient boat traffic data – **Arrival Probability**) (Step 2a) and survival/establishment of NIS fouling species (climate and salinity match between source and recipient marinas – **Survival Probability**) (Step 2b). **Boat Fouling Probability** was combined with **Introduction Probability** to determine the relative invasion risk of transient boats for each ecoregion – **Relative Invasion Risk** (Step 3a). **Relative Invasion Risk** was combined with estimates of the annual transient boat traffic (**Annual Traffic**) in the visited ecoregion to determine the **Final Relative Invasion Risk** per transient boat (Step 3b). Finally, **Mean Ecoregion Invasion Risk** was calculated using the percentages of transient boats in each risk category to obtain the **Final Ecoregion Invasion Risk** for each ecoregion (Step 4). The following equations were used:

$$Boat\ Fouling\ Probability = (Regional\ NIS) \times\ (Boat\ Infestation\ Probability)$$

$$Introduction\ Probability\ = (Arrival\ Probability)\ \times\ (Survival\ Probability)$$

$$Relative\ Invasion\ Risk = (Boat\ Fouling\ Probability)\ \times (Introduction\ Probability)$$

$$Final\ Relative\ Invasion\ Risk_i = (Relative\ Invasion\ Risk) \times (Annual\ Traffic)$$

Each boat in a given ecoregion was then classified into risk categories as modified from Mandrak et al. (2012) (Table 2).

$$Final\ Ecoregion\ Invasion\ Risk_j = ((\%\ Lowest\ Risk \times 1) + (\%\ Low\ Risk\ \times 2) + (\%\ Intermediate\ Risk\ \times 3) + (\%\ High\ Risk\ \times 4) + (\%\ Highest\ Risk\ \times 5))/100$$

where, “i” represents a boat and “j” represents an ecoregion.

We did not consider resident boats (i.e., those boats that do not visit other marinas) in this risk assessment given their assumed limited ability to transport NIS to other marinas. We concentrated our analyses on transient boats – those that visit marinas other than their own home marina within a given boating season. We assumed that the fouling on each transient boat is associated with the biota (fouling NIS) present in their home ecoregion, and not from all the ecoregions they may have visited before arriving at a marina in a Canadian ecoregion. We made this assumption in part because detailed boat voyage histories (order of visited marinas, timing of visits, and so on) were not available. Considering the high number of boater questionnaires completed and the quality of those data, we assume that completed questionnaires provide an accurate and representative subsample of the recreational boater population for each of the ecoregions assessed.

Data sources and methods used to calculate each of the variables and the combined estimates of risk are provided for each step of the risk assessment. Data on NIS background in marinas, boat infestation probability, boat traffic, and environmental conditions in both source and recipient marinas were compiled separately for each transient boat in each visited ecoregion.

BOAT FOULING PROBABILITY (STEP 1)

We assume that the organisms observed on fouling plates deployed within annual marina monitoring studies reflect the species most likely to be transported by the recreational boat vector. Fouling plates are commonly deployed within NIS monitoring programs and provide a substrate that is similar to marina structures and submerged boat surfaces. Floerl and Inglis (2005) showed that the communities on boats generally reflect those in the marinas in which they are moored (Floerl and Inglis 2005).

The probability of a boat being fouled by NIS is a function of the Regional NIS Background (Step 1a) and the Boat Infestation Probability (Step 1b) (Figure 6). The use of 'Regional NIS Background' assumes that a boat that spent most of the boating season in its home marina should have fouling that scales linearly with what is in the background (home ecoregion of the boater). However, this is clearly a simplification of the fouling process and fouling communities on boats may result from different sources (e.g. visited marinas, transient boats). However, as our database does not include travel histories, we could only associate fouling with home marinas (home ecoregions). For Boat Infestation Probability, behavioral and cleaning practices are assumed to affect boat fouling; the presence of any macrofouling on boats was assumed to indicate potential for carrying NIS. For a given boat, the product of Regional NIS Background and Boat Infestation Probability gives the overall probability of a boat being fouled by NIS.

Step 1a: Regional NIS Background

Data Sources

Regional infestation levels were estimated using the results of a standardized regional Aquatic Invasive Species (AIS) monitoring program (Sephton et al. 2011; Simard et al. 2013; McKenzie et al. 2016) and previous studies (Clarke Murray et al. 2014; Gartner et al. unpublished data) on the Atlantic and Pacific coasts, respectively. For the Atlantic coast, collectors consisted of rope strung through 3 PVC settlement plates that were equally spaced vertically and deployed randomly within monitoring sites approximately one meter below the water surface. For the purpose of this study, only monitoring sites located in marinas or ports were used to determine Regional NIS Backgrounds (a total of 172 sites were surveyed between 2006 and 2014, most across multiple years). Most of the collectors considered in this study were immersed for one full season (spring to fall). Sites from Newfoundland were sampled following a different monitoring schedule due to the distances travelled and low concentration of AIS in most marinas. There, collectors were immersed from spring to summer, from summer to fall, or for an entire year. This included 8 sites in the Laurentian Channel ecoregion, 1 in the Newfoundland Shelf ecoregion, and 6 in The Grand Banks ecoregion. For 2 sites in the Scotian Shelf ecoregion, we used data from plates deployed from summer to fall because NIS were only observed at those times in those sites. NIS cover (mostly tunicates) on each PVC plate was determined semi-quantitatively for each species by visual examination. Categories for cover were 0% / absent; 0-25% cover; >25-50%; >50-75%; and >75% cover. The median of each category (e.g. >25-50%=37.5) was used to calculate the total NIS cover on each plate to a maximum of 87.5% total cover (which corresponds to the median of the highest category). Although these data were not used in the calculations, they provide additional information on the nature of NIS fouling on the East coast.

For the Pacific coast, existing AIS monitoring programs using two settlement plate sampling designs were used to gather data on diversity of NIS (NIS richness). Data collected in previous studies (Clarke Murray et al. 2014; Gartner et al. unpublished data) at 106 sites along the British Columbia coast between 2006 and 2012 were used to get information on NIS richness. Settlement plate designs were either the same PVC settlement plates used in the Atlantic program or a plastic circular base, with four plastic, circular Petri dishes (9 cm) attached to each base, with two circular bases at two depths (15 cm and 1 m below the surface). Plates were immersed from spring through fall (or for an entire year in a subset) and processed to determine species occurrences. Only the NIS richness variable was used to calculate Regional NIS Background.

Risk Variable Calculation

Overall NIS richness (hereafter, NIS richness) in each site was defined as the total number of NIS observed on all survey plates in that location over the history of the AIS monitoring program. For risk calculations, a value of “1” was added to NIS richness of all monitored sites to eliminate the possibility to obtaining zero risk values and to capture the possibility that survey plates may not have detected all NIS. For each monitored site, NIS richness was normalized by dividing the observed NIS richness at that site by the maximum NIS richness observed at any monitored site [$(NIS_{site}+1)/(NIS_{max}+1)$]. Regional NIS Background in a given ecoregion was calculated as the median of standardized NIS richness values obtained from all monitored sites in that ecoregion. We used the median Regional NIS Background score recorded in each ecoregion as the score for all boats from that ecoregion as the monitoring database did not include all home marinas of transient boats.

For non-Canadian ecoregions, the highest (1) and lowest (0.0833) Regional NIS Background scores were attributed to foreign marine and freshwater ecoregions, respectively. Although no standardized sampling in these ecoregions exists, there is considerable literature to support the assumption that NIS loads in adjacent foreign marine ecoregions are, on average, greater than those observed in Canadian marine ecoregions (e.g. Pederson et al. 2006). We assumed that the situation was similar for foreign ecoregions situated further away from Canadian marine ecoregions. With respect to freshwater ecoregions, it was assumed that they would have few NIS that would be of concern for marine ecoregions.

Step 1b: Boat Infestation Probability

We used boater behaviour data from questionnaires and macrofouling data (both native and non-indigenous species) from boat surveys as a proxy for Boat Infestation Probability, assuming that transient boats with macrofouling have the potential to carry NIS if they were present in an ecoregion.

Boat sampling

The occurrence of macrofouling species (i.e., excluding biofilm) was noted for each boat surveyed. For the Atlantic coast, 467 boats of the 1307 boaters questioned were examined for macrofouling. Boat sampling was conducted using an underwater video camera mounted on a frame (Atlantic coast), a combination of mounted video and SCUBA diver video surveys (NL), a visual inspection by snorkeling (2 marinas in Magdalen Shallows ecoregion, n=72 boats), or in dry-dock (1 marina in the St. Lawrence Estuary ecoregion, n=20 boats). When using a video system, hull and niche areas (e.g., propellers, rudders, trim tabs) were examined by manoeuvring the camera with an adjustable telescopic arm. Videos were later analyzed in the laboratory and the presence of macrofouling species on different boat parts (hull, propeller, etc.) noted for each boat surveyed.

For the Pacific coast, boats in 24 marinas were surveyed during two consecutive summers (2008-2009) (see Clarke Murray et al. 2011 for details). In the second year of sampling, busy marinas with high levels of transient boater traffic were targeted to obtain a more balanced sample of both resident and transient boats. In total, 163 boats were examined for macrofouling by SCUBA divers (see details in Clarke Murray et al. 2011). The submerged surfaces of each boat were photographed, including six replicate randomly selected hull areas and one of each niche area (non-hull area), including the propeller, shaft, keel, vents, and water intakes. The photographs were then subjected to image analysis and the presence of any macrofouling noted.

Fouling model

We used the predictive fouling model developed by Clarke Murray et al. (2013) to predict the presence of macrofouling on individual boats. Surveyed boats were classified as being “fouled” or “clean”. Fouled boats were those that had any macrofouling (excluding biofilm) on underwater surfaces (hulls or niche areas). Boats with no visible macrofouling were assumed to be clean. Discriminant function analysis (DFA) was used to find a combination of variables that collectively discriminate between the two groups (i.e., fouled vs clean boats).

For the Atlantic coast, boater questionnaire results were converted into several continuous (e.g., age of antifouling paint) and discrete (e.g., sailboat vs. powerboat) variables. After exploratory analysis, eight variables were used in DFA to determine the variables that best explained differences between the two boat groups. The eight variables used in the analysis included boat type, hull type, storage type, trip types, time in water, use of antifouling paint, time since manual cleaning, and time since antifouling paint application. For consistency between coasts, all types of fishing boats (fishing boat, converted fishing boat, and combined fishing and recreational boat) were grouped as a single category, “fishing boat”. Note that many of the boater questionnaires had missing information and therefore the analysis used data from only 254 of the 467 video/visual inspection surveys (54%).

For the Pacific coast predictive model, questionnaire results were converted into discrete and continuous variables and were used in DFA (Clarke Murray et al. 2013). Once again, many of the boater questionnaires had missing information such that the analysis could only use data from 163 of the 616 SCUBA surveys (26%).

Covariance matrices were used in model development as Box’s M statistic showed unequal variances, thus violating one of the assumptions of DFA (Francis 2001). To address the possibility of multicollinearity, cross-correlations between variables in the predictive model were evaluated using Pearson’s correlation. Highly correlated (i.e., largely redundant; $p<0.05$) variables were removed from the model such that the variable that had the lowest correlation with the dependent variable was removed from the analysis, and the analysis repeated. Model validation was performed using leave-one-out cross-validation analysis and an overall error rate calculated. Fisher’s discriminant function describes differences between groups using retained variables and these were used in the predictive equations. The most accurate model was applied to the remainder of the questionnaire dataset (questionnaires without accompanying video surveys) and used to calculate a probability of being fouled for those boats with complete information for the model variables. Probability of being fouled was thus calculated for 776 and 478 boats on the Atlantic and Pacific coasts, respectively. Model construction and validation was done using IBM SPSS Statistics 22 (SPSS Inc.).

Risk variable calculation

Boat Infestation Probability was assigned using biofouling survey results (0.001 = clean; 1= fouled), when available. A probability of 0.001 was assigned for boats classified as 'clean' boats in order to capture the possibility of missing macrofouling when boats were surveyed (e.g. video quality, hidden NIS in niche areas). For transient boats that were not examined visually but for which boater survey information was available, the probability of being fouled was calculated based on the relevant fouling model, when possible. For transient boats that were not examined visually and for which fouling probabilities could not be estimated by the fouling model (i.e., missing information of one or more variables in the predictive equation), average (mean for continuous variable or mode for discrete variable) values for missing variables based on the data from the other boats from a given home ecoregion were assigned to that boat and the fouling probability was calculated using the appropriate fouling model. This approach allowed a Boat Infestation Probability to be assigned to every transient boat in the database for subsequent steps in the risk assessment.

Boat Fouling Probability

Regional NIS Background (Step 1a) and Boat Infestation Probability (Step 1b) scores for each transient boat were multiplied together to yield boat fouling probabilities (Boat Fouling Probability = Regional NIS Background x Boat Infestation Probability).

INTRODUCTION PROBABILITY (STEP 2)

Introduction Probability was estimated using information on transient boat arrivals (number of destinations – Arrival Probability) and environmental similarity (climate and salinity match – Survival Probability) between source (i.e., home) and recipient marinas. We assumed that the greater the number of destinations visited, the greater the Arrival Probability in a given ecoregion. Again, we assumed that boats spent most time in home marinas such that NIS fouling communities on boat hulls most resembled those in home marinas (i.e. that boat NIS fouling communities correspond NIS Background). Environmental similarity was assessed by comparing conditions between home and visited marinas for a given boat.

Step 2a: Arrival Probability

Arrival Probability was defined as the relative (to the maximum observed in any ecoregion, $NoDestinations_{max}$) total number of destinations (overnight non-home marina visits, $NoDestinations_{boat}$) visited by a boat in a given ecoregion: $NoDestinations_{boat}/NoDestinations_{max}$.

Step 2b: Survival Probability

Because salinity and temperature are fundamental physical factors that determine survival and reproduction of most aquatic organisms, Survival Probability was estimated as the environmental (salinity and climate) similarity between source (home) and recipient marinas.

Salinity Similarity

Each marina was classified into a salinity category (freshwater, brackish and marine). Marinas with salinities <5 psu were classified as freshwater; those with salinities >5-20 psu as brackish; and those with salinities >20 psu as marine (Wolff 1999). For Canadian marinas, a list of the marinas in the recreational boating database was evaluated by one or two experts in each relevant DFO region (Pacific, Maritimes, Gulf, Newfoundland and Labrador, and Quebec). Experts attributed a salinity category to each marina based on available monitoring data and their knowledge of the region. For potential brackish or freshwater marinas, we used mean salinity surface values (June-October) calculated from data extracted from the Atlantic Zone AIS monitoring database, the St. Lawrence Global Observatory, and relevant publications (Metcalfe et al. 1976; Drinkwater 1987; El Sabh and Murty 1990; Lafleur et al. 1995; Gagnon 1995, 1998; Strain et al. 2001; Hughes Clarke and Haigh 2005; NOAAChesapeake Bay Program 2008; Loomer et al. 2008; NOAA Database Explorer 2015; NOAA Tides and Current 2015).

A matrix approach was used to attribute salinity match scores for source-recipient marina pairs (Table 3). The score had three possible values ranging from “Lowest” (1– very dissimilar salinity for a marina pair, such as between a freshwater and marine water marinas pair) to “Highest” (5 – same salinity classification for marina pair, such as between two marine marinas). Data were normalized between 0 and 1 by dividing each salinity score by the maximum salinity similarity score obtained (5), which led to 0.2 (lowest), 0.6 (Intermediate) and 1 (Highest) scores. If a given boat visited multiple marinas with different salinities (marine and brackish marinas) in a given ecoregion, it was given the highest salinity match score obtained. This was the case for 82 transient boats of 1129 transient boats in the boating traffic dataset; all other boats that visited multiple marinas in a given ecoregion obtained the same salinity match score for all of their visits.

Climate Similarity

Climate similarity of paired source and recipient marinas was estimated based on their geographic locations. All marinas were classified by latitude into one of four climate zones: Tropical (20°S-20°N), Warm-Temperate (20°-40°), Cold-Temperate (40°-60°) and Polar (>60°) following Spalding et al. (2007) and Gollasch and Leppäkoski (2007).

A matrix approach was used to attribute climate match scores for all source-recipient marina-pairs (Gollasch 2007). Climate match scores (3 possible values) ranged from “Lowest” (1– for marina-pairs with highly divergent climates, such as between a Tropical and Cold-Temperate marinas pair) to “Highest” (5– if marina pairs were classified as being from the same climate category, such as between two Cold-Temperate marinas). Data were normalized between 0 and 1 by dividing each climate score by the maximum climate similarity score obtained (5), giving score values ranging from 0.2 (lowest), 0.6 (Intermediate) and 1 (Highest) (Table 4).

Survival Probability

Survival Probability for a given transient boat was estimated by combining salinity and climate match scores into a single environmental similarity measure using a matrix approach (Table 5). Since both salinity and climate must be suitable for NIS to survive, a lowest probability approach was used to determine the Survival Probability to reflect the influence of the most limiting environmental variable. For example, for a given source-recipient marina-pair with a lowest climate similarity and a highest salinity similarity, the Survival Probability would be lowest (0.2).

RELATIVE INVASION RISK (STEP 3)

Step 3a: Relative Invasion Risk

The risk associated with a given boat in a given ecoregion was calculated as the product of Boat Fouling Probability (Step 1) and Introduction Probability (Step 2) scores (Relative Invasion Risk = Boat Fouling Probability × Introduction Probability). Each boat in a given ecoregion was classified into risk categories as modified from Mandrak et al. (2012) (Table 2). These risk rankings were based on the distributions of risk of all transient boats in ecoregions and were used to compare boats in a given ecoregion to those in other ecoregions prior to incorporating annual traffic into the Relative Invasion Risk scores.

Step 3b: Final Relative Invasion Risk

The **Final Relative Invasion Risk** was estimated by combining **Annual Traffic** and **Relative Invasion Risk** scores for each boat in a visited ecoregion. Raw data on annual traffic was standardized by dividing ecoregional scores by the maximal annual traffic observed in any ecoregion ($Traffic_{ecoregion}/Traffic_{max}$). The same traffic score was assigned to each boat visiting a given ecoregion. For example, all transient boats visiting the Bay of Fundy ecoregion were given the same traffic score. We assumed that our data on transient boats is a representative subsample of the transient boat population.

FINAL ECOREGION RELATIVE INVASION RISK (STEP 4)

The Final Ecoregion Invasion Risk was calculated for each ecoregion by the weighted proportion of boats in each risk category. The same risk categories used in Step 3a were applied (Table 2).

$$Final\ Ecoregion\ Relative\ Invasion\ Risk_j = ((\%\ Lowest\ Risk \times 1) + (\%\ Low\ Risk\ \times 2) + (\%\ Intermediate\ Risk\ \times 3) + (\%\ High\ Risk\ \times 4) + (\%\ Highest\ Risk\ \times 5))/100$$

The highest mean value was divided into 5 equal bins to classify each Final Ecoregion Invasion risk (from Lowest to Highest).

EXPECTED DISTRIBUTIONS OF RELATIVE INVASION RISKS

To calculate an estimate of rare boats having very high relative risk scores in each ecoregion, we used a combination of distribution fitting and bootstrap procedures to generate expected distributions of Relative Invasion Risk scores for transient boats visiting each ecoregion over a ten year period. Examination of the distribution of Relative Invasion Risk scores (log-transformed) from all ecoregions showed that a generalized Pareto distribution with two parameters (no tail-boundary parameter) best approximated the data (Figure 7). This distribution was fitted to the measured risk-score distribution for each ecoregion; goodness of fit was evaluated visually and by using χ^2 tests (Table 6). We then generated random numbers from the estimated distributions; the number of values drawn corresponded to 10 times the estimated annual traffic for each ecoregion. Note that the outcome of this procedure is sensitive to the quality of Relative Invasion Risk scores available in each ecoregion. Some ecoregions, where many boats were surveyed, had very well estimated tails (low uncertainty) resulting in tight clustering of generated values whereas ecoregions where lower numbers of boats were sampled (greater uncertainty) yielded more scattered scores. We then ranked the data into risk categories (Table 2).

A similar procedure was used to evaluate the range of possible annual mean risk scores for each ecoregion. Distributions were fit as described earlier, but we accounted for the precision of parameter estimates in the bootstrapped data. To this end, we generated a range of possible distributions of risk scores by assuming a normal distribution for each Pareto parameter, drew a random value for each, and computed the distribution of risk scores. A number of values equal to annual traffic for a given ecoregion were generated for each risk score distribution and mean scores calculated. This was repeated 1000 times. Again, ecoregions with high uncertainty (unprecise parameter estimates) yielded more scattered results.

UNCERTAINTIES

Based on a combination of the quantity and quality of the data available and the suitability of the selected measure as a proxy for the variable of interest, levels of uncertainty (very high to very low) were assigned to each parameter of the risk assessment (Table 7). The highest level of uncertainty assigned to any of the steps of the assessment was retained as the uncertainty associated with the Relative Invasion Risk and the Final Ecoregion Invasion Risk. A Final Ecoregion Invasion Risk score was not provided for ecoregions represented by <10 transient boats as there was not enough data to provide informed advice in these situations.

RESULTS

BOATER BEHAVIOUR

The number of completed manager (1-200) and boater (0-589) questionnaires varied greatly among ecoregions (Table 1). Sailboats and power boats were the most abundant boat types in most ecoregions. The exceptions were the Bay of Fundy, Laurentian Channel, and Newfoundland Shelf ecoregions, where fishing boats were the most abundant boat type (Table 1). Of the 1907 boaters questioned, 79% (1507) had their home marinas in one of the Canadian marine ecoregions targeted by this risk assessment (Figures 1 and 2). The other boats were from international (4%) and freshwater (7%) ecoregions (Figures 3, 4, and 5) or else information about home marinas was not provided (11% of boaters – mostly those that completed the survey online on the Pacific coast). International boaters surveyed were principally from the United States (92%) and their home marinas were close to Canadian ecoregions.

Boater behaviours differed between the Atlantic and Pacific coasts (Figure 8). Most boats on the Pacific coast were kept in water year-round whereas most boats on the Atlantic coast spent only part of the year in water because of harsh winter conditions (Figure 8a-b). “Local trips” was the most common trip type undertaken by boaters in both regions (79% and 69%, for the Atlantic and Pacific coasts, respectively, Figures 8c-d). A greater proportion of Pacific boaters undertook “weekenders” (trips of a few days duration) and “tours” (long trips with multiple destinations along the way), than did Atlantic boaters (Figures 8c-d). Most Atlantic boats had antifouling paint < 4 months of age (applied during the current boating season), whereas boats on the Pacific coast generally had antifouling paint > 4 months of age (Figures 8e-f) likely due to lengthier time spent in-water.

Transient boaters

Risk scores were calculated for 1129 transient boats (Atlantic: 727; Pacific: 402) for which boaters provided information on home and visited marinas (Table 8). The number of transient boaters questioned that visited a given ecoregion ranged from 3 to 385 but was typically >20. Most transient boats (82.9%) had their home marina in a Canadian marine ecoregion; 10.5% and 6.6% were from freshwater ecoregions or from foreign marine ecoregions, respectively (Table 9).

TRANSIENT TRAFFIC IN MARINE ECOREGIONS

Annual inter-regional traffic varied greatly among ecoregions, ranging from a low of 754 boats to a high of 371,843 transient boats (i.e., estimated number of transient boats) per ecoregion (Table 10). The highest estimated numbers of transient boats were in the three Pacific ecoregions (Puget Trough/Georgia Basin > PNCIMA > Vancouver Coast and Shelf), which experienced orders of magnitude greater levels of transient boating than that observed in most Atlantic ecoregions. For the Atlantic coast, the Scotian Shelf and Magdalen Shallows ecoregions had the highest estimated number of transient boats whereas the Labrador Shelf, North Gulf Shelf, Newfoundland Shelf, and The Grand Banks ecoregions had the smallest estimated number of transient boats.

The absolute number of trips estimated per year by recreational boaters in marine Canadian water was 4.02 Million and ranged from a high of 3,242,406 trips in the Puget/Georgia Basin ecoregion, to a low of 1569 trips in the North Gulf Shelf ecoregion (Appendix 3).

BOAT FOULING PROBABILITY

Regional NIS Background

NIS observed in Atlantic and Pacific ecoregions that were included in NIS Background score calculations are presented in Tables 11 and 12, respectively. NIS richness varied among monitoring sites, ranging from 0 (no NIS detected) to 11 NIS in a given site (Figures 9 and 10). The highest NIS richness was observed in the Puget Trough/Georgia Basin (1 monitoring site had 11 NIS; 1 site had 9 NIS; and 3 sites had 8 NIS), Scotian Shelf (10 sites with 5 NIS, 3 sites with 6 NIS; 1 site with 7 NIS) and Bay of Fundy (12 sites with 5 NIS) ecoregions. On average, most sites in the Bay of Fundy and along the Scotian Shelf had 3 or more NIS (80.3% of all sites in the regions). In contrast, although the highest NIS richness was observed in the Puget Trough/Georgia Basin ecoregion, a large proportion of the sites were characterized by low richness (i.e., 47.6 % of all sites in this region had 2 or less NIS). The greatest maximum NIS cover (>75%) was only observed in the Scotian Shelf (24 sites), Magdalen Shallows (15 sites), Bay of Fundy (14 sites) and Laurentian Channel (1 site) ecoregions (Figure 11).

Regional NIS Background scores based on NIS richness are presented in Tables 11 (Atlantic) and 12 (Pacific). Bay of Fundy, Scotian Shelf and Puget Trough/Georgia Basin ecoregions had the highest scores (0.5, 0.417, and 0.333, respectively). All other Canadian ecoregions had scores of 0.167 (Magdalen Shallows, The Grand Banks, Vancouver Coast and Shelf, PNCIMA), 0.125 (North Gulf Shelf) and 0.083 (Laurentian Channel and Newfoundland Shelf). Because no monitoring sites were located in Labrador Shelf and St. Lawrence Estuary ecoregions, the lowest Background score (0.083) was assigned to these ecoregions based on expert knowledge. As stated previously, Regional NIS Background was set at lowest score (0.083) and highest score (1) possible for freshwater and foreign marine ecoregions, respectively.

Table 13 shows percentages of transient boats per ecoregion for each NIS Background score. Among all Canadian ecoregions, Bay of Fundy received the highest percentage of transient boats (18.9%) from ecoregions with the highest (1) NIS Background score. Labrador Shelf received 33.3% of transient boats with the highest NIS Background Score of 1, but the number of transient boats was very low (n = 3). Bay of Fundy and Scotian Shelf ecoregions received the highest percentage (35.1% and 56.7%, respectively) of transient boats with a NIS Background score of 0.417. Laurentian Channel, North Gulf Shelf and St. Lawrence Estuary ecoregions received the highest percentage of transient boats (62.2%, 77.8% and 83.4%, respectively) from ecoregions with the lowest NIS Background score (0.083). Transient boats visiting Newfoundland Shelf (60%), Magdalen Shallows (70.6%), and The Grand Banks (90.5%) ecoregions mainly originated from ecoregions having a NIS Background score of 0.167. The three Pacific ecoregions (Vancouver Coast and Shelf, PNCIMA, and Puget Trough/Georgia Basin) received the majority of their traffic from ecoregions with NIS Background scores of 0.333 (71.4%, 78.7% and 88.8%, respectively).

Uncertainty

Considering the quality and quantity of the data, the uncertainty surrounding the Regional NIS Background was considered to be “Very low” for most Canadian ecoregions because we used extensive scientific information from standardized multi-year and ongoing AIS monitoring programs to estimate this parameter (Table 14). NIS richness based on recruitment plate data seems to well represent the fouling NIS known to be present in ecoregions. However, two ecoregions had no standardized data (Labrador Shelf, St. Lawrence Estuary) and two had only 1 (Newfoundland Shelf) and 2 (North Gulf Shelf) monitoring sites. For these ecoregions (except Newfoundland Shelf), as well as freshwater and foreign marine ecoregions, the uncertainty is greater and considered to be "Moderate" (Table 14) as reasoned in the Methods. Based on additional information from other studies (McKenzie et al. 2016), we attributed a score of "Low" for the Newfoundland Shelf ecoregion.

Boat Infestation Probability

For the Atlantic coast, 467 boats of the 1307 boaters questioned were surveyed for biofouling (Table 15). Of these, 80 (17.2%) had no evidence of macrofouling while 387 (82.8%) had some macrofouling present.

The best fouling model for the Atlantic coast was DFA using the presence of macrofouling on boats (Fouled/Clean) with the predictor variables tours, days in water, and boat type, in decreasing order of explanatory value (Figure 12). This model predicted that powerboats that undertook tours and were in the water on average 86.9 (+/- 21.8 SE) days or less were more likely to be clean of macrofouling. Fouled boats were more likely to be sailboats or fishing boats that did not undertake tours, and that were in the water more than 110.9 (+/- 6.9 SE) days during a boating season. The best model explained 20.6% of the variation (Canonical correlation =0.206, p=0.013). Cross-validation showed that the model successfully predicted boat fouling status in 62.6% of the cases (false positives: 47.5%; false negatives: 35.5%).

The equation to predict group membership on the Atlantic coast was

$$F = 1.111 + 1.754T - 0.001D - 0.860B$$

where *F* is the fouling discriminant function score, *T* is the incidence of touring trip (0/1), *D* is the number of days in water (continuous) and *B* is the boat type (1= powerboat, 2= sailboat, 3=fishing boat, 4= other). The closer the discriminant function score is to the group centroid, the higher the probability of group membership (Group centroid Clean = 0.485, Fouled = -0.091).

We then used the equation to predict group membership for boats with questionnaire answers but without accompanying video surveys. Of the 776 boats with completed information for all three variables, 41.2% (N=320) were predicted to be clean and 58.8% (N=456) to be fouled. This differs from results from video/snorkeling survey results, where 82.8% of boats surveyed had macrofouling.

For the Pacific coast, 163 boats of the 616 boaters questioned were surveyed for macrofouling (Table 15). Of these, 52 (31.9%) had no evidence of fouling while 111 (68.1%) had at least some macrofouling present (Clarke Murray et al. 2011). The best predictive fouling model retained four variables (Canonical Correlation=0.348, Wilks Lambda = 0.879, p<0.001) (Clarke Murray et al. 2013). In order of importance, the significant predictor variables were: storage location, antifouling paint age, boat type, and incidence of long trips taken (Figure 13). Essentially, this fouling model predicted that boats stored in water year round, which do not undertake "long trips" and have antifouling paint older than 13.2 (+/- 1.3 SE) months would be more likely to have macrofouling present. Both sailboats and powerboats with these characteristics would be likely to have macrofouling, but sailboats had a higher probability of being fouled than did powerboats (73% versus 60%). Model cross-validation showed that the fouling model correctly predicted fouling status 71.2% of the time (false positives: 23.4%; false negatives: 40.4%).

The equation to predict group membership on the Pacific coast was

$$F = -0.382 + 1.433S - 0.040A - 0.593B + 2.427L$$

where *F* is the fouling discriminant function score, *S* is the storage type (1=year round, 2=part time, 3=trailered), *A* is the age of antifouling paint (continuous), *B* is the boat type (1=powerboat, 2=sailboat, 3=fishing boat, 4=other) and *L* is the incidence of long trips taken (0/1) (Group centroid Clean = 0.461, Fouled = -0.212).

Applying the fouling model to the remainder of the questionnaire data set with complete information (n=329) predicted that 61.7% of surveyed boats were fouled which roughly corresponds to dive survey results (Clarke Murray et al. 2011).

Boat Infestation Probability was based on biofouling survey results for 405 (36%) of the 1129 transient boats which were examined visually (0.001 = clean; 1 = fouled). For 581 boats without video surveys (51%), Boat Infestation Probability was based on Fouling Probability estimated by the DFA models. For the 143 (13%) remaining transient boats without video and missing information on certain variables, the mean or mode of the missing variable was used as described previously and Boat Infestation Probability was likewise calculated for these boats using the derived DFA model.

Individual Boat Infestation Probability scores (raw data) were used in risk calculations and were grouped into categories for each ecoregion for summary (Table 16). Transient boats in the Bay of Fundy (54.1%), Magdalen Shallows (63.2%), Scotian Shelf (56.1%), and Vancouver Coast and Shelf (57.1%) ecoregions were characterized as mostly having Boat Infestation Probability Scores greater than 0.6 (Table 16). Transient boats in other ecoregions had Boat Infestation Probabilities mostly in the range of 0.4-0.8 (Newfoundland Shelf, The Grand Banks, PNCIMA, and Puget Trough/Georgia Basin), 0.2-0.4 (Laurentian Channel, North Gulf Shelf, and St. Lawrence Estuary) and 0.001 (Labrador Shelf).

Uncertainty

Based on the relatively low percentage of the variance explained by the fouling models (20.6% and 34.8% for the Atlantic and Pacific coasts, respectively), uncertainty levels were considered to be “Moderate” for all ecoregions because Boat Infestation Probability was attributed to 64% of the transient boats using fouling models.

INTRODUCTION PROBABILITY

Arrival Probability

Detailed information on boating traffic patterns is shown in Figures 14, 15 and 16 and Table 17. Most transient boating activity on the Atlantic coast was intra-ecoregional for the Bay of Fundy, Magdalen Shallows, Scotian Shelf, and The Grand Banks ecoregions (48.8-92.8%), while it was inter-ecoregional for the Labrador Shelf, Laurentian Channel, Newfoundland Shelf, and North Gulf Shelf ecoregions (57.1-64.3%) (Figure 14, Table 17). The number of destinations on the Atlantic coast showed similar patterns as number of nights for intra- and inter-ecoregion traffic (with the exception of Bay of Fundy, which had the highest percentage of inter-ecoregion travel) (Figure 15). Patterns for the Laurentian Channel and the St. Lawrence Estuary ecoregions are somewhat different from the other Atlantic ecoregions as both are characterized by transient boating being from freshwater ecoregions; 54.2% of the total number of nights spent in the St. Lawrence Estuary were boats from freshwater marinas (mostly the St. Lawrence (FW) and Laurentian Great Lakes ecoregions) and 47% and 61.6% of the total destinations in the Laurentian Channel and St. Lawrence Estuary ecoregions, respectively, were also from freshwater ecosystems. International traffic was generally low in all Atlantic ecoregions. Bay of Fundy and Labrador Shelf ecoregions received the highest percentage of transient boats from foreign countries in terms of number of nights (24.4 and 28.6%, respectively; note that n=3 for the Labrador Shelf ecoregion) and number of destinations (17.1 and 33.3%, respectively).

International traffic in the Bay of Fundy ecoregion included boats from the Gulf of Maine/Bay of Fundy, Northern European Seas, Tropical Northwestern Atlantic, and Virginian MEOW ecoregions.

On the Pacific coast, most inter-ecoregional traffic on the Vancouver Coast and Shelf and the PNCIMA ecoregions was due to boats originating from the Puget Trough/Georgia Basin ecoregion (Figure 16). International traffic accounted for 7 to 10% of all traffic in all Pacific ecoregions, mostly due to boats from the Puget Trough/Georgia Basin (USA) ecoregion.

Transient boats visiting most Canadian ecoregions were mainly represented by sailboats (Figures 17-19), with the exception of the Newfoundland Shelf, The Grand Banks, and PNCIMA ecoregions, where powerboats were the dominant boat type in terms of number of destinations.

Percentages of transient boats with different Arrival Probability scores (based on number of destinations) are shown in Table 18 (Arrival Probability scores were grouped into categories for display purposes but raw data were used for risk calculations). The Puget Trough/Georgia Basin ecoregion was the only ecoregion that received transient boats with an Arrival Probability >0.51; most transient boats (70.6%) visiting that ecoregion had Arrival Probability scores >0.11. Most (63.2-100%) transient boats in other ecoregions had Arrival Probability scores <0.10. The three Pacific ecoregions (Vancouver Coast and Shelf, PNCIMA, and Puget Trough/Georgia Basin) had greater percentages of transient boats with Arrival Probability scores >0.11 (22.9, 36.38 and 70.6%, respectively) than did Atlantic ecoregions.

Uncertainty

As no boater questionnaires were completed for the Labrador Shelf ecoregion and there were only 3 transient boats to visit this ecoregion, we considered the uncertainty for Arrival Probability as “Highest” for this ecoregion. Based on the number of boats that visited the other ecoregions (>10 boats) and the suitability of the number of destinations used as a proxy for Arrival Probability, the level of uncertainty was considered ‘Low’ for other ecoregions (Table 14).

Survival Probability

Most transient boats (52.2-100%) visiting most Canadian ecoregions obtained the highest Survival Probability score (1), with the exception of the St. Lawrence Estuary ecoregion, which received mainly transient boats (44%) that had a Survival Probability score of 0.6 (Table 19).

Uncertainty

Considering the data sources used for environmental similarity measurements and the suitability of salinity and climate matches as a proxy of Survival Probability, a “Low” uncertainty value was assigned for this variable (Table 14).

RELATIVE INVASION RISK

Most transient boats visiting Canadian ecoregions had “lowest” and “low” Relative Invasion Risk scores; boats rarely obtained “very high” risk scores (Figure 7). The greatest proportion of transient boats visiting the Puget Trough/Georgia Basin ecoregion had a “Low” Relative Invasion Risk score (Table 20). This ecoregion also received some transient boats with “Intermediate”, “High” and “Highest” scores (2.9% combined). The PNCIMA ecoregion was the only other ecoregion that received traffic that obtained “Intermediate” and “High” scores (1.2% combined). The highest proportion of transient boats visiting all other Canadian ecoregions had a “Lowest” Relative Invasion Risk (69.1-100%). The Scotian Shelf, Vancouver Coast and Shelf, and PNCIMA ecoregions received 20.3, 28.6 and 29.7%, respectively, of transient boats with a “Low” Relative Invasion Risk score (Table 20).

FINAL RELATIVE INVASION RISK

Weighting the Relative Invasion Risk scores by Annual Traffic values for each ecoregion resulted in all transient boats obtaining a “Lowest” Final Relative Invasion Risk score, except for those in the PNCIMA and the Puget Trough/Georgia Basin ecoregions (Table 21). For the Puget Trough/Georgia Basin ecoregion, 63% of transient boats had a “Low” score, 34% had a “Lowest” score, and 2.9%, together, obtained “Intermediate”, “High” and ”Highest” scores. A small proportion (5.8%) of transient boats visiting the PNCIMA ecoregion obtained a “Low” score and the rest (94.2%) had a score of “Lowest”.

FINAL ECOREGION INVASION RISK

The Puget Trough/Georgia Basin obtained a ‘Highest’ mean Final Ecoregion Invasion Risk score, while all other ecoregions obtained a ‘Lowest’ score (Table 21).

Uncertainty regarding Final Ecoregion Invasion Risk scores was set at “Moderate” for all ecoregions (Table 14). Again, because of insufficient data, it was not possible to assign a level of risk for the Labrador Shelf ecoregion.

EXPECTED RELATIVE INVASION RISK SCORES

In general, the Pareto distribution described the distribution of risk scores of transient boats in most ecoregions (i.e., there was no significant deviation between observed and derived distributions). However, the Pareto distribution poorly described the distribution of risk scores for the Magdalen Shallows, North Gulf Shelf, and St. Lawrence Estuary ecoregions (Table 6). Predicted Relative Invasion Risk scores per ecoregion, over a ten-year period, are presented as risk categories (Table 22). The greater number of boats over a larger time-scale allows for a better overall estimate of rare boats having highest relative risk scores within each ecoregion. Several boats were classified in the “High” (up to 0.06%) and “Highest” (up to 0.03%) risk categories in the Laurentian Channel and the three Pacific ecoregions (Vancouver Coast and Shelf, PNCIMA and Puget Trough/Georgia Basin). Using the predictive relative invasion risk scores, we can estimate a total of nine “High” risk boats and nine “Highest” risk boats visiting the Laurentian Channel ecoregion over a ten year period. Labrador Shelf had insufficient data to be incorporated in Bootstrap analysis.

The estimated annual mean Relative Invasion Risk scores obtained with bootstrapped data for each ecoregion are presented in Figure 20. The three Pacific ecoregions had the greatest ranges with higher (than Atlantic ecoregions) mean Relative Invasion Risk scores.

SENSITIVITY ANALYSES

Sensitivity analyses were performed by excluding one variable at a time from the Risk score calculations to observe the effect on results. Excluding NIS Background, Boat Fouling Probability, Arrival Probability and Survival Probability from the calculations had only minor effects on proportions of transient boats in each risk category and no effect on the distribution of Final Ecoregion Invasion Risk scores, except for one ecoregion when Arrival Probability was excluded (PNCIMA; from Lowest to Intermediate, Figure 21). Traffic score had the greatest effect on proportions of transient boats in each risk category and the Final Ecoregion Invasion risk score changed for three ecoregions (Scotian Shelf – from Lowest to Low; Vancouver Coast and Shelf – from Lowest to Intermediate; and PNCIMA – from Lowest to Intermediate). Removal of Traffic scores from the Final Ecoregion Invasion Risk scores (equivalent to the Final Relative Invasion Risk scores) allowed the importance of the other factors to the calculation to be more evident. This step showed that the Final Relative Invasion Risk score was most sensitive to Arrival Probability (scores changed for 6 ecoregions: Bay of Fundy – from Lowest to Highest;

Magdalen Shallows – from Lowest to Intermediate, Newfoundland Shelf – from Lowest to High, Scotian Shelf – from Low to Highest; Vancouver Coast and Shelf – from Intermediate to Highest; and PNCIMA – from Intermediate to Highest, Figure 21).

DISCUSSION

The purpose of this assessment was to characterize the risk posed by recreational boating as a vector for NIS in Canadian marine waters on both the East and West coasts, following a formal science advice request. Specifically, we were tasked to address the following objectives:

- Characterize movement patterns of recreational boats in marine waters within and between ecoregions; and
- Estimate the potential risks posed by recreational boating to marine ecoregions considering vessel characteristics, their movements, environmental similarity, and NIS sources.

To address these objectives, we developed a relative risk assessment model for recreational boats on the Atlantic and Pacific coasts of Canada. We used boater and manager questionnaires to describe the movement patterns of boats on each coast. Each of the parameters we were asked to consider in the analyses (vessel characteristics, their movements, and environmental similarity) were incorporated in the calculation of risk, as was a measure of NIS loading in source marinas (Figure 6). We characterized the invasion risk posed by recreational boats as a function of the probability that transient boats are fouled by NIS (Boat Fouling Probability) and the probability that NIS arrive, survive, and establish (Introduction Probability).

Data for all variables were standardized to calculate the relative risk associated with recreational boats in each ecoregion. Thus, the attribution of an overall 'Low' risk score to a given ecoregion (Final Ecoregion Relative Invasion Risk) does not indicate that recreational boating poses a low absolute risk for this ecoregion, but rather that the risk in that ecoregion is low compared to others. Results from this study reflect samples of the current boating population and risk assessment results should be updated as variables evolve (e.g. changes to recreational boating traffic, different NIS loads, etc.). For example, sensitivity analyses showed that changes in the annual traffic will have the greatest effect on final outcomes. In addition, the Final Ecoregion Relative Invasion Risk scores are overall scores and do not consider the risk associated with specific types of boating activities; some activities (e.g. international traffic) may represent considerable risk in most ecoregions but these were uncommon events. This information is provided through finer examination of the data for the different variables.

GENERAL MOVEMENT PATTERNS OF RECREATIONAL BOATS

Analysis of recreational boating movement patterns provides evidence that primary introduction and secondary spread of NIS may occur via recreational boating in all temperate Canadian marine ecoregions. High connectivity between non-invaded and invaded locations can enhance risk and influence the establishment of NIS populations (Floerl et al. 2009). Marinas in ecoregions on both coasts are highly connected to marinas within the same ecoregion as well as to other ecoregions on the same coast. While marinas in some Atlantic ecoregions are also well connected to freshwater marinas and some international marinas, survey results did not show the same degree of international connectivity found on the Pacific coast where international traffic was largely restricted to nearby USA marinas. NIS present in a given ecoregion may be transported by recreational boats to marinas within the same or to other ecoregions.

It is well known that international shipping and historical aquaculture imports are the most likely pathways of NIS primary introductions in coastal areas (Carlton 1985; Hewitt et al. 2009; Williams et al. 2013). This assessment confirms that recreational boating may provide a vector for secondary spread (Clarke Murray et al. 2011; Lacoursière-Roussel et al. 2012a and 2012b). The spatial pattern of NIS presence in British Columbia was related to recreational boating activity as well as commercial shipping activity (Clarke Murray et al. 2014). Spread of NIS on the Pacific coast may be largely due to boats from the Puget Trough/Georgia Basin ecoregion as most boating activity in that ecoregion and in the other west coast ecoregions is by boats originating from there. Analysis of the connectivity between the Canadian Pacific coast and more invaded southern regions of the USA has not been done but even the small degree of connectivity (in fact, "small" in terms of proportion of boats but "large" in terms of absolute numbers) with US marinas introduces the risk of "stepping–stone" introductions (Floerl et al. 2009). In contrast, ecoregions on the Atlantic coast received traffic from multiple ecoregions and thus spread along that coast is likely due to both intra- and inter-ecoregion boating.

In general, the greatest absolute NIS richness was observed on the Pacific coast, but higher median NIS richness was observed in some Atlantic Canada ecoregions (Bay of Fundy and Scotian Shelf) suggesting the dominance of a few NIS on the East coast relative to the West coast and a higher variability between monitoring sites on the West coast than on the East coast. There was a general trend for greater NIS richness in southern areas relative to northern areas and greater concentrations of NIS richness around important ports/marinas. The high connectivity among marinas inside an ecoregion and between ecoregions via recreational boating could increase the rate of NIS introduction and spread in northern ecoregions through "stepping-stone" processes (Floerl et al. 2009).

Boating traffic in all Pacific ecoregions was an order of magnitude greater than that on the Atlantic coast. Likewise, the level of boating within both regions varied considerably among ecoregions such that risk in regions such as The Grand Banks ecoregion was much less than that in the Scotian Shelf ecoregion and risk in the Puget Trough/Georgia Basin was much higher than that in the PNCIMA ecoregion.

Given the large sample size and representative distribution of marinas that were sampled along Canadian eastern and western coastlines (i.e., a similar proportion of marinas and boats was usually sampled in the different areas in each ecoregion), we are confident that the data provide a representative view of boating patterns to, from, and among Canadian temperate marine marinas.

POTENTIAL RISKS OF RECREATIONAL BOATING TO MARINE ECOREGIONS

The Final Ecoregion Invasion Risk score was greatest for the Puget Trough/Georgia Basin ecoregion ("Highest") in comparison to all other Pacific and Atlantic ecoregions which scored "Lowest". This was largely due to differences in boating activities between the two coasts (i.e., year-round boating and a greater level of traffic on the Pacific coast). The Puget Trough/Georgia ecoregion has, by far, the highest level of annual recreational traffic, thereby increasing the probability that rare, high risk boats will navigate there even when all other variables remain the same.

Year-round boating on the Pacific coast results in higher traffic, with boats visiting more destinations and spending a greater length of time in the water than boats on the Atlantic coast (Clarke Murray et al. 2011). Models showed that the best predictors of fouling on Pacific boats involved the incidence of long trips taken and the age of antifouling paint on their hulls. Moreover, given that most boating activity on the Pacific coast was within the Puget Trough/Georgia Basin ecoregion or originated from there, Survival Probability scores were also typically greater in the Pacific than in the Atlantic. Likewise, very few boats arrived from freshwater marinas in the Pacific Region, which also increased overall Survival Potential.

In contrast, boating on the Atlantic coast was largely seasonal, given the risk of freeze-up of coastal waters and the generally inclement weather over the winter. Atlantic boats are typically removed from the water for the winter. Accordingly, the number of days spent in the water was a better predictor of fouling on the Atlantic coast than on the Pacific coast. This importance of soak time has also been observed in other studies (Lacoursière-Roussel et al. 2012b; Floerl et al. 2009).

Overall, Survival Probability was most often “highest” in most Canadian ecoregions, given the high proportion of traffic originating from nearby marine locations. However, a greater proportion of boats arrived from freshwater marinas on the Atlantic coast, which decreased overall Survival Probability for this region.

It is important to note that even for ecoregions with Final Ecoregion Invasion Risk scores of ‘Lowest’, the Relative Invasion Risk of some transient boats was categorized as having greater risks (Low, Intermediate, High and Highest risk scores) before weighting by traffic scores. These boats obtained a greater Invasion Risk score because they originated from foreign ecoregions (Tropical Northwestern Atlantic and Virginian ecoregions for the Atlantic coast and Puget Trough/Georgia Basin USA for the Pacific coast), were likely fouled, or visited many marinas in a given ecoregion. Boats from areas with greater NIS richness that travel more extensively, with poor maintenance, or extended in-water periods are of greatest risk. Predicted Relative Invasion Risk scores over ten years suggest that transient boats with greater risk scores are found in both the Pacific and Atlantic coasts and that, although uncommon, represent a considerable risk to all ecoregions.

CONSIDERATIONS

Many factors influence the outcome of relative boating risk. These include the data sources and methods used to calculate risks (i.e., formulas, assumptions, and derivations). Relevant issues are discussed below.

Non-fouling species

This risk assessment concentrates on fouling species. Notwithstanding the evidence that organisms such as crabs and other mobile species may be transferred via sea chests in larger vessels (e.g., Coutts et al. 2003; Frey et al. 2014), or in other locations on recreational boats, including refuge areas such as internal spaces, anchors and fishing/diving gear and live wells (Acosta and Forrest 2009), it was judged that the risk of transfer of NIS via these mechanisms was less than that of fouling of external under-water surfaces (although refuge areas are available to fouling organisms and thus likely also to more mobile organisms). Moreover, with the exception of a couple of mobile taxa on the Pacific coast, mobile taxa were not routinely surveyed in marina surveys for NIS and thus there was no logical way to include them in the assessment.

Role of standardized sampling programs

In the present study, Regional NIS Background was estimated by considering only data on specific NIS that were monitored in all ecoregions within standardized programs. Therefore, results for NIS richness should not be viewed as the overall number of NIS present in each ecoregion. NIS were observed in monitoring sites not included in our analysis (i.e. aquaculture sites, not included for the purpose of this analysis), were detected using methods other than recruitment plates (e.g., *Carcinus maenas* using traps on both coasts; *Botryllus schlosseri* with SCUBA surveys in the Laurentian Channel ecoregion; *Botrylloides violaceus* in the North Gulf Shelf and The Grand Banks ecoregions; *Didemnum vexillum* in the Bay of Fundy), or were not surveyed consistently in all ecoregions for a given coast (e.g. *Codium fragile* spp. *fragile* on the Atlantic coast).

Invasion model

Boat fouling communities likely represent a subset of the resident fouling community in a given marina. The longer a boat stays in a marina, the more its fouling community resembles the fouling community of the resident marina (Floerl and Inglis 2005). However, hull biofouling could also represent the accumulation of species from different visited locations. Therefore, our assumption that the fouling on each transient boat is associated with NIS in their home ecoregion instead of all ecoregions visited before arriving in a Canadian marina may have influenced the outcome of this assessment to some degree, particularly with respect to boats that spend several days outside of their home marina or ecoregion before arriving in a given location. The possibility of such a "stepping–stone" process occurring was not included in this study because of limited data (i.e., voyage histories were not obtained from the boater questionnaires).

Overall, boat fouling models were used to predict Boat Infestation Probability scores for 64% of transient boats. Models for both coasts explained a relatively low percentage of the variance and should be used with caution. We may have underestimated risk scores for this parameter, particularly for Atlantic ecoregions where 58.8% of boats were predicted to be fouled while 82.8% of boats surveyed had macrofouling. Although these differences may be due to differences between questionnaire responses from boaters whose boats were surveyed and those whose boats were not surveyed, additional research should be conducted to better understand the factors that predict macrofouling on boats on the Atlantic coast. It is also possible, given the stochastic nature of fouling on submerged surfaces (e.g. Agius 2007; Grey 2009) and the fact that data were collected over multiple years in different locations, that strong correlations between fouling and the predictor variables do not have time to develop, given that boating is done over such a short period on the Atlantic coast. Other variables and factors not included in the fouling model may also influence Boat Infestation Status, including degree of fouling on boats. However, the majority of the boats examined were surveyed directly in marinas (Atlantic coast), which could have led to an oversampling of the fouled boats since these boats are likely those that are left in the water longer. In future fouling model development, degree of fouling should be determined and included to evaluate variables explaining fouling.

As this risk assessment was done at a national scale, a similar study done for each coast would likely provide a better indication of risk due to recreational boating between ecoregions within a region (i.e., Atlantic or Pacific). Annual traffic on the Pacific coast is an order of magnitude greater than that on the Atlantic coast, diminishing the importance of other variables. Likewise, number of destinations visited by transient boaters is generally greater on the Pacific coast than on the Atlantic coast because of broad differences in boating patterns. Given that Traffic and Arrival Probability most influenced the outcome of this relative risk assessment, coast-specific relative risk assessments may better identify risks due to boating at the regional level. In addition, somewhat different suites of organisms were monitored on the two coasts (i.e., mostly tunicates and a bryozoan in the Atlantic Region but tunicates, bryozoans, barnacles and mobile amphipods in the Pacific Region). This difference may also have accounted for the absolute number of NIS being greater on the Pacific than the Atlantic coast.

Trailered Boats

Many of the boats used in coastal areas are easily transported by trailer and are not typically moored in marinas as they are removed from the water following use. This boating community was not well sampled in our survey. Some boaters in the Pacific Region were surveyed at boat shows or through on-line methods and thus trailered boats may have been better sampled in that region (13.8% on 616 boater questionnaires, Clarke Murray et al. 2011). It is unknown how effective this sampling was and to what extent the data obtained for these boaters is a representative sample of this population. Trailered boats pose different risks in terms of fouling, entanglement and contained spaces (Darbyson et al. 2009a), as well as differences in survival probability due to desiccation occurring during overland travel. Additional research is required to characterize the risk of this boating community in Canadian marine waters.

Boat Purchasing Activity

One potentially concerning aspect of recreational boating as it relates to NIS transport is the purchase and transportation of boats between ecoregions. This is a largely unmonitored pathway and, though poorly captured through the boater surveys, may be an important consideration that should be investigated further. The risk posed by boat sale and transport can be substantial because many sold boats have been poorly maintained for extended periods prior to being moved, leading to increased NIS colonization.

Survival Probability

As fundamental physical factors for survival and reproduction of most aquatic species, temperature and salinity were used to determine Survival Probability. However, environmental match is not always a good predictor of invasions. For example, the macroalga *Caulerpa taxifolia* inhabits tropical areas in its native distribution but is able to invade more temperate areas when provided the opportunity (Occhipinti-Ambrogi and Savini 2003).

Measure of impacts

No measure of impact has been used in this study. However, tunicates were found in most ecoregions on both coasts and are known to cause substantial ecological and economic impacts (Therriault and Herborg 2007). Other approaches could also have been used, such as considering the abundance of high-impact NIS in source locations as outlined in Molnar et al. (2008). However, the species listed in Molnar et al. (2008) are only those that are invasive in the different ecoregions. Many of these “invasive” species in source ecoregions are actually from the Canadian ecoregions considered in the present work and thus are not an issue. Moreover, “local” invasive species (i.e., species that are “local” to an area but are invasive elsewhere), such as *Sabella spallanzanii*, which is native to the Mediterranean and would not be considered as “invasive” for that region by Molnar et al. (2008), may be important invaders in other areas.

Data Quality

The quality of the information used in different steps of the calculations is generally quite high. Most data used was from standardized monitoring programs or surveys done over multiple years. Some of these (e.g., the Atlantic Zone AIS Monitoring Program, salinity monitoring) were done within the context of larger programs whereas others (e.g., boater surveys) were done within the context of graduate and other directed studies and specifically to gather information needed to complete the present risk assessment. Information on boat infestation probability was based on peer-reviewed statistical models (Clarke Murray et al. 2013) and biological information was from widely used classifications (e.g., Spalding et al. 2007). There were a few notable data gaps. For example, there were few NIS monitoring sites in the Newfoundland Shelf and the North Gulf Shelf ecoregions and few boaters completed all answers in questionnaires in both these and the Vancouver Coast and Shelf ecoregions. Thus, it was not possible to assign a level of risk for the Labrador Shelf ecoregion because of insufficient data. Additional efforts are needed to collect data and complete the analysis for this ecoregion and to improve estimates for others.

CONCLUSIONS

Primary introduction and secondary spread of NIS may result from recreational boating in all Canadian marine ecoregions. There is a high degree of connectivity within and between ecoregions on both marine coasts and thus the probability that NIS present in a given ecoregion may be transported by recreational boats to other marinas within the same or in other ecoregions is relatively high. As a consequence of this high connectivity between geographically close ecoregions, survival probability was generally high in most Canadian ecoregions. The high connectivity among marinas inside an ecoregion and between ecoregions via recreational boating could increase the rate of NIS introduction and spread in northern ecoregions through "stepping-stone" processes, as NIS richness in southern ecoregions were generally higher on both coasts.

The Final Ecoregion Invasion Risk was greater in the Puget Trough/Georgia Basin ecoregion, relative to other Pacific and Atlantic ecoregions, due to the substantial degree of boating activity. Sensitivity analyses have shown that annual traffic and arrival probabilities (i.e., number of destinations visited by boats) are the two main variables that influence the most our model outcomes. These regional differences are thus greatly influenced by seasonality of boating activities and annual traffic; with Pacific coast having year-round recreational traffic while the Atlantic coast has a generally restricted boating season. The Puget Trough/Georgia Basin ecoregion has the greatest annual traffic of all ecoregions and transient boats, within the latter ecoregion visit the greatest number of destinations during a boating season. The fouling model used in this risk assessment have highlighted the importance of antifouling paint age for Pacific boaters and time spends in water for Atlantic boaters (among others) to predict presence of hull macrofouling, once again resulting mainly from the difference in boating season length between the two coasts. Additional research should be conducted to better understand the factors that predict macrofouling on boats, particularly on the Atlantic coast. Other variables and factors not included in the fouling model may also influence Boat Infestation Status, including degree of fouling on boats. Special attention should be placed on high risk boat types in all ecoregions. Boats from areas with greater NIS richness that travel most extensively and with poor maintenance or extended in-water periods are of greatest risk. As tunicates were found in most ecoregions and may be introduced and spread in different locations via hull fouling of recreational boats, impacts of these NIS may be expected to be substantial, at ecological and economic levels.

Results of recreational Boating Risk Assessment conducted in both freshwater and marine systems show that high risk events are rare (this study, Drake et al. unpublished data), but may have high impacts. This risk assessment gives a relative risk of recreational boating for the introduction and spread of NIS for different Canadian marine ecoregions and is not directly comparable to other studies. Results from this study reflect samples of the current boating population and risk assessment results should be updated as variables included in this model evolve.

Further studies are needed, particularly for ecoregions for which we have limited (e.g. Labrador Shelf) or no information (e.g., the Arctic) to complete the analysis and improve risk estimates, especially in the context of global warming, leading to an increased accessibility to Arctic waters. In contrast to other historically important pathways, such as shipping and aquaculture, there are no specific management actions in place today to limit NIS introduction and spread by the recreational boating vector.

The predicted increase of global sea temperature may facilitate future introductions and spread of NIS, by leading to earlier timing of recruitment and increased magnitude of growth and recruitment of non-indigenous ascidians relatively to natives ones (Sorte et al. 2010). It is thus crucial to continue NIS monitoring activities; the degree at which NIS invade and progress in a system is important to evaluate not only changes related to global warming, but also effectiveness of management options that can be set to address hull fouling issues within the recreational boating vector. A national monitoring program could facilitate the assessment and comparison of NIS levels of invasion on both the Pacific and Atlantic coasts without bias.

RECOMMENDATIONS

Considering the risk posed by recreational boating in Canadian marine waters on both the East and West coasts, management of recreational boats as a vector for marine NIS should be strongly considered in Canada. New Zealand and Australia have made efforts to address this vector (Inglis et al. 2012; Commonwealth and Australia 2009). In particular, Inglis et al. (2012) has conducted an extensive review of scenarios for vessel biofouling for New Zealand which includes several types of vessels and management options (e.g., application of effective antifouling coatings, inspection, maintenance and documentation on maintenance) that may be considered in Canada. Further work on tracking of recreational boats would be useful to evaluate most common routes in order to target potential mitigation measures. Study of other particular characteristics within recreational population, such as trailered boats and boat purchasing activities could be important to understand and include in future risk assessments of recreational boating as vectors. Finally, more information on NIS survival and impacts of their introduction and spread at different geographical scales could be valuable to include in the evaluation of different management options.

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TABLES

Table 1. Number of manager and boater questionnaires completed and percentage of boat types surveyed in each ecoregion. Number of boats per boat type is indicated in brackets.

<table>
<tr><th>Ecoregion</th><th>Manager questionnaires</th><th>Boater questionnaires[1]</th><th>% Sailboats</th><th>% Powerboats</th><th>% Fishing boats</th></tr>
<tr><td>Bay of Fundy</td><td>10</td><td>67</td><td>36 (24)</td><td>18 (12)</td><td>40 (27)</td></tr>
<tr><td>Labrador Shelf</td><td>1</td><td>0</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td>Laurentian Channel</td><td>34</td><td>50</td><td>40 (20)</td><td>18 (9)</td><td>42 (21)</td></tr>
<tr><td>Magdalen Shallows</td><td>47</td><td>589</td><td>51 (299)</td><td>34 (203)</td><td>14 (83)</td></tr>
<tr><td>Newfoundland Shelf</td><td>17</td><td>8</td><td>-</td><td>-</td><td>100 (8)</td></tr>
<tr><td>North Gulf Shelf</td><td>6</td><td>19</td><td>58 (11)</td><td>42 (8)</td><td>-</td></tr>
<tr><td>Scotian Shelf</td><td>35</td><td>344</td><td>64 (221)</td><td>28 (97)</td><td>7 (24)</td></tr>
<tr><td>St. Lawrence Estuary</td><td>15</td><td>156</td><td>69 (108)</td><td>30 (47)</td><td>1 (1)</td></tr>
<tr><td>The Grand Banks</td><td>33</td><td>58</td><td>9 (5)</td><td>53 (31)</td><td>38 (22)</td></tr>
<tr><td>Vancouver Coast and Shelf</td><td>34</td><td rowspan="3">Online questionnaire (total 616)</td><td rowspan="3">43 (262)</td><td rowspan="3">52 (319)</td><td rowspan="3">2 (13)</td></tr>
<tr><td>PNCIMA</td><td>64</td></tr>
<tr><td>Puget Trough/Georgia Basin</td><td>200</td></tr>
</table>

[1] Note that some boater questionnaires had missing information on boat type

Table 2. Risk categories as Relative Invasion Risk or Final Relative Invasion Risk percentage ranges. Modified from Mandrak et al. 2012.

Risk Category	Probability Category
Lowest	0.0 – 0.05
Low	0.05 – 0.40
Intermediate	0.40 – 0.60
High	0.60 – 0.95
Highest	0.95 – 1.0

Table 3. Matrix used to determine climate similarity match scores for source-recipient marina pairs, after Gollasch and Leppäkoski (2007). Climate zones are identified as polar (+60ºN), cold-temperate (40-60ºN), warm-temperate (20-40ºN) and tropical (0-20ºN) (see Step 2b in Figure 6).

	SOURCE marina			
RECIPIENT marina	**Polar**	**Cold-temperate**	**Warm-temperate**	**Tropical**
Polar	Highest	Intermediate	Lowest	Lowest
Cold-temperate	Intermediate	Highest	Intermediate	Lowest
Warm-temperate	Lowest	Intermediate	Highest	Intermediate
Tropical	Lowest	Lowest	Intermediate	Highest

Table 4. Matrix used to combine salinity and climate scores to determine Survival Probability (see Step 2b in Figure 6) Modified from Casas-Monroy et al. 2015.

CLIMATE	**SALINITY**		
	Highest	**Intermediate**	**Lowest**
Highest (1)	Highest	Intermediate	Lowest
Intermediate (0.6)	Intermediate	Intermediate	Lowest
Lowest (0.2)	Lowest	Lowest	Lowest

Table 5. Matrix used to determine salinity similarity scores for source-recipient marina pairs (after Carlton 1985). Salinity zones are categorized as fresh water (<5 PSU), brackish water (>5-20 PSU) and marine water (>20 PSU) (see Step 2b in Figure 6).

	SOURCE marina		
RECIPIENT marina	**Fresh water**	**Brackish water**	**Marine water**
Fresh water	Highest	Intermediate	Lowest
Brackish water	Intermediate	Highest	Highest
Marine water	Lowest	Highest	Highest

*Table 6. Chi square tests (χ^2) results of data distributions and Pareto fitted distributions comparisons. Significant differences mean that the data does not fit the expected distribution and are indicated with * and ***, df = degree of freedom.*

Ecoregion	χ^2	df	p value
Bay of Fundy	1.9045	3	0.59
Labrador Shelf	NA	NA	NA
Laurentian Channel	4.6806	6	0.58
Magdalen Shallows	71.393	8	$2.59E^{-12}$***
Newfoundland Shelf	2.239	2	0.326
North Gulf Shelf	7.089	2	0.0288*
Scotian Shelf	15.165	8	0.056
St. Lawrence Estuary	16.675	7	0.0196*
The Grand Banks	0.2448	2	0.8898
Vancouver Coast and Shelf	0.6241	4	0.96
PNCIMA	7.9616	7	0.336
Puget Trough/Georgia Basin	12.569	8	0.1275

Table 7. Description of uncertainty based on quantity and quality of the data available, modified from Therriault and Herborg (2007) cited in Casas-Monroy et al. 2014.

Level of Uncertainty	Data quality and quantity	Data suitability
Very low uncertainty	Extensive scientific information; peer-reviewed information	Measure is known as most important variable(s) of interest
Low uncertainty	Substantial scientific information; non peer-reviewed information	Measure is a subset of known important variables
Moderate uncertainty	Moderate level of information; first hand, unsystematic observations, expert opinion	Measure is moderated associated with known important variable(s) of interest
High uncertainty	Limited information or circumstantial evidence	Measure has limited association with known important variables
Very high uncertainty	Little to no scientific information	Measure has little or no association with known important variable(s)

Table 8. Total number of transient boats and number of transient boats per boat type for which boater questionnaires were completed in each Canadian ecoregion. Note that a single transient boat may have visited more than one ecoregion.

Visited ecoregion	# Transient boats	# Sailboats	# Powerboats	# Fishing boats	# Others[1]
Bay of Fundy	37	28	7	2	-
Labrador Shelf	3	3	-	-	-
Laurentian Channel	90	72	14	4	-
Magdalen Shallows	374	243	111	20	-
Newfoundland Shelf	20	5	8	7	-
North Gulf Shelf	18	15	1	2	-
Scotian Shelf	305	205	80	20	-
St. Lawrence Estuary	168	125	42	1	-
The Grand Banks	21	5	12	4	-
Vancouver Coast and Shelf	35	23	9	3	-
PNCIMA	155	74	76	5	-
Puget Trough/Georgia Basin	385	210	162	11	2

[1]Personal water craft (e.g. jetski)

Table 9. Number and origin of transient boats for which boater surveys were completed.

	Home Ecoregion	**# Transient Boats**
Atlantic and Pacific Ecoregions	Bay of Fundy	4
	Labrador Shelf	3
	Laurentian Channel	15
	Magdalen Shallows	288
	Newfoundland Shelf	2
	North Gulf Shelf	8
	Scotian Shelf	178
	St. Lawrence Estuary	50
	The Grand Banks	23
	Vancouver Coast and Shelf	6
	PNCIMA	18
	Puget Trough/Georgia Basin	344
Freshwater (FW) Ecoregions	Columbia Unglaciated USA (FW)	1
	Chesapeake Bay (FW)	1
	Laurentian Great Lakes (FW)	19
	Northeast US & Southeast Canada Atlantic Drainages (FW)	2
	St. Lawrence (FW)	96
Foreign Marine Ecoregions	Gulf of Maine/Bay of Fundy	9
	Lusitian	2
	Northern European Seas	3
	Tropical Northwestern Atlantic	11
	Virginian	10
	Warm Temperate Northwest Atlantic	3
	Puget Trough/Georgia Basin USA	33

Table 10. Estimated numbers of transient and resident boats in each ecoregion.

Ecoregion	Transient Boats		Resident Boats		# marinas	# Annual transient boats	Annual Traffic score	# Resident boats
	# Manager questionnaires	Mean # Boats	# Manager questionnaires	Mean # Boats				
Bay of Fundy	10	36.2	3	117.7	97	3,511	0.0094	11,414
Labrador Shelf	1	63.0	1	54.0	17	1,063	0.0028	918
Laurentian Channel	32	21.9	30	14.4	124	2,713	0.0072	1,781
Magdalen Shallows	45	65.0	45	45.6	224	14,552	0.0391	10,209
Newfoundland Shelf	15	15.2	14	13.6	104	1,577	0.0042	1,411
North Gulf Shelf	5	38.5	4	82.0	25	962	0.0025	2,050
Scotian Shelf	34	118.7	31	54.9	250	29,669	0.0797	13,734
St. Lawrence Estuary	14	191.7	15	26.6	36	6,901	0.0185	959
The Grand Banks	33	9.9	32	23.2	76	754	0.0020	1,762
Vancouver Coast and Shelf	7	416.8	34	26.5	84	35,010	0.0941	2,229
PNCIMA	13	518.8	64	28.7	191	99,085	0.2664	5,487
Puget Trough/Georgia Basin	43	1071.6	200	84.3	347	371,843	1	29,258

Table 11. NIS observed (X) in DFO standardized monitoring sites of Atlantic ecoregions and NIS Background score assigned to each ecoregion. NFLD = Newfoundland.

	Ecoregion								
	Bay of Fundy	**Labrador Shelf**	**Laurentian Channel**	**Magdalen Shallows**	**NFLD Shelf**	**North Gulf Shelf**	**Scotian Shelf**	**St. Lawrence Estuary**	**The Grand Banks**
# Monitoring sites	22	-	15	82	1	2	44	-	6
NIS Background score	0.500	0.083	0.083	0.167	0.083	0.125	0.417	0.083	0.167
<u>NIS</u>									
Ascidiella aspersa	-	NA	-	-	-	-	X	NA	-
Botryllus schlosseri	X	NA	-	X	-	-	X	NA	X
Botrylloides violaceus	X	NA	X	X	-	-	X	NA	-
Caprella mutica	X	NA	-	X	-	-	X	NA	-
Ciona intestinalis	X	NA	-	X	-	-	X	NA	-
Diplosoma listerianum	-	NA	-	-	-	-	X	NA	-
Styela clava	-	NA	-	X	-	-	X	NA	-
Membranipora membranacea	X	NA	X	X	-	X	X	NA	X

Table 12. NIS observed (X) in DFO standardized monitoring sites of Pacific ecoregions and NIS Background scores assigned to each ecoregion. From Gartner et al. unpublished.

	Ecoregion		
	Vancouver Coast and Shelf	**PNCIMA**	**Puget Trough/ Georgia Basin**
# Monitoring sites	19	45	42
NIS Background score	0.167	0.167	0.333
NIS			
Amphibalanus improvisus	-	-	X
Ampithoe valida	-	-	X
Barentsia benedeni	-	X	X
Botrylloides violaceus	X	X	X
Botryllus schlosseri	X	X	X
Caprella drepanochir	-	-	X
Caprella mutica	X	X	X
Eulalia viridis	-	-	X
Eumida sanguinea	-	-	X
Incisocalliope derzhavini	-	-	X
Melita nitida	-	-	X
Membranipora membranacea	-	X	X
Molgula manhattensis	-	-	X
Monocorophium acherusicum	-	-	X
Monocorophium insidiosum	-	-	X
Parougia caeca	-	X	-
Polydora cornuta	-	X	X
Pseudostylochus ostreophagus	-	-	X

Table 13. Percentages of transient boats that obtained each NIS Background score in visited ecoregions.

Ecoregion	# Transient boats	NIS Background Scores						
		0.083 (%)	0.125 (%)	0.16 7 (%)	0.333 (%)	0.41 7 (%)	0.50 0 (%)	1.000 (%)
Bay of Fundy	37	16.2		18.9	-	35.1	10.8	18.9
Labrador Shelf	3	33.3		33.3	-		-	33.3
Laurentian Channel	90	62.2	5.6	16.7	-	6.7	-	8.9
Magdalen Shallows	374	18.7	1.9	70.6	-	4.8	-	4.0
Newfoundland Shelf	20	25	-	60	-	15	-	-
North Gulf Shelf	18	77.8	-	11.1	-	-	-	11.1
Scotian Shelf	305	8.2	-	25.6	-	56.7	0.3	9.9
St. Lawrence Estuary	168	83.9	1.2	7.1	-	2.4	-	5.4
The Grand Banks	21	4.8	-	90.5	-	-	-	4.8
Vancouver Coast and Shelf	35	-	-	20	71.4	-	-	8.6
PNCIMA	155	0.6	-	12.3	78.7	-	-	8.4
Puget Trough/Georgia Basin	385	0.3	-	2.1	88.8			8.8

Table 14. Level of uncertainty for each variable of the risk assessment per ecoregion, after Therriault and Herborg 2007.

Ecoregion	Level of Uncertainty				
	Regional NIS Background	Boat Infestation Probability	Arrival Probability	Survival Probability	Final Score
Bay of Fundy	Very low	Moderate	Low	Low	Moderate
Labrador Shelf	Moderate	Moderate	Highest	Low	Highest
Laurentian Channel	Very low	Moderate	Low	Low	Moderate
Magdalen Shallows	Very low	Moderate	Low	Low	Moderate
Newfoundland Shelf	Low	Moderate	Low	Low	Moderate
North Gulf Shelf	Moderate	Moderate	Low	Low	Moderate
Scotian Shelf	Moderate	Moderate	Low	Low	Moderate
St. Lawrence Estuary	Moderate	Moderate	Low	Low	Moderate
The Grand Banks	Very low	Moderate	Low	Low	Moderate
Vancouver Coast and Shelf	Very low	Moderate	Low	Low	Moderate
PNCIMA	Very low	Moderate	Low	Low	Moderate
Puget Trough/Georgia Basin	Very low	Moderate	Low	Low	Moderate

Table 15. Number of boat surveys for macrofouling from each home ecoregion.

	Home Ecoregion	# Boat Surveys for macrofouling
Atlantic and Pacific Ecoregions	Bay of Fundy	3
	Labrador Shelf	-
	Laurentian Channel	3
	Magdalen Shallows	242
	Newfoundland Shelf	1
	North Gulf Shelf	5
	Scotian Shelf	86
	St. Lawrence Estuary	65
	The Grand Banks	12
	Vancouver Coast and Shelf	7
	PNCIMA	11
	Puget Trough/Georgia Basin	96
Freshwater Ecoregions	Laurentian Great Lakes (FW)	3
	Northeast US & Southeast Canada Atlantic Drainages (FW)	-
	St. Lawrence (FW)	34
	Columbia Unglaciated USA (FW)	1
Foreign Marine Ecoregions	Gulf of Maine/Bay of Fundy	1
	Lusitian	2
	Northern European Seas	-
	Tropical Northwestern Atlantic	3
	Virginian	-
	Warm Temperate Northwest Atlantic	2
	Puget Trough/Georgia Basin USA	24

Note that 24 boats (Pacific Region) and 5 boats (Atlantic Region) surveyed had missing information for home ecoregion

Table 16. Distribution (% per range) of Boat Infestation Probability scores for transient boats in each ecoregion.

Ecoregion	# Transient boats	Boat Infestation Probability Score						
		0.001	[0.011-0.200]	[0.201-0.400]	[0.401-0.600]	[0.601-0.800]	[0.801-0.999]	1.000
Bay of Fundy	37	2.7	-	37.8	5.4	35.2	-	18.9
Labrador Shelf	3	66.7	-	-	-	-	-	33.3
Laurentian Channel	90	11.1	-	46.7	4.4	17.8	-	20
Magdalen Shallows	374	10.4	-	20.3	6.1	25.2	-	38
Newfoundland Shelf	20	5	-	15	35	35	-	10
North Gulf Shelf	18	11.1	-	55.6	-	11.1	-	22.2
Scotian Shelf	305	2.6	-	26.6	14.7	30.5	-	25.6
St. Lawrence Estuary	168	11.3	-	48.2	2.4	8.3	-	29.8
The Grand Banks	21	9.5	-	-	42.9	38.1	-	9.5
Vancouver Coast and Shelf	35	14.3	2.9	14.3	11.4	22.8	-	34.3
PNCIMA	155	8.4	5.7	11	25.2	25.2	4.5	20
Puget Trough/Georgia Basin	385	7.5	4.2	9.1	27.5	24.9	5.5	21.3

Table 17. Traffic patterns (percentage of nights spent and destinations visited) for transient boats in each ecoregion. Maximal percentages per ecoregion for number of nights and destinations are indicated in bold. Number of nights (%): number of nights spent by transient boats; Number of destinations (%): number of destinations visited by transient boats; Intra-ecoregion: transient boats from the same ecoregion; Inter-ecoregion: transient boats from other Canadian marine ecoregions; International (Int.): transient boats from marine foreign ecoregions; Freshwater (FW): transient boats from Canadian and foreign freshwater ecoregions

Visited Ecoregion	# Transient boats	Number of nights (%)				Number of destinations (%)			
		Intra-ecoregion	Inter-ecoregion	Int.	FW	Intra-ecoregion	Inter-ecoregion	Int.	FW
Bay of Fundy	37	**48.8**	22.4	24.4	4.4	19.5	**51.2**	17.1	12.2
Labrador Shelf	3	0.0	**57.1**	28.6	14.3	0.0	33.3	33.3	33.3
Laurentian Channel	90	3.5	**58.9**	6.8	30.8	4.2	36.7	12.0	**47.0**
Magdalen Shallows	374	**65.4**	12.6	3.2	18.8	**69.1**	11.2	3.8	16.0
Newfoundland Shelf	20	33.0	**64.1**	2.9	0.0	2.6	**82.1**	15.4	0.0
North Gulf Shelf	18	0.0	**64.3**	8.2	27.6	0.0	**52.4**	14.3	33.3
Scotian Shelf	305	**68.4**	17.0	7.8	6.8	**56.7**	26.3	8.8	8.3
St. Lawrence Estuary	168	23.6	14.4	7.8	**54.2**	23.3	9.6	5.5	**61.6**
The Grand Banks	21	**92.8**	0.7	1.5	5.0	**66.7**	7.7	2.6	23.1
Vancouver Coast and Shelf	35	-	-	-	-	10.9	**79.1**	10.0	0.0
PNCIMA	155	-	-	-	-	8.6	**83.2**	7.3	1.0
Puget Trough/Georgia Basin	385	-	-	-	-	**91.2**	1.4	7.0	0.4

Table 18. Distribution (% per range) of Arrival Probability scores for transient boats (%) in each ecoregion.

Ecoregion	# Transient boats	Arrival Probability Score					
		<0.10	[0.11-0.20]	[0.21-0.30]	[0.31-0.40]	[0.41-0.50]	>0.51
Bay of Fundy	37	97.3	2.7	-	-	-	-
Labrador Shelf	3	100	-	-	-	-	-
Laurentian Channel	90	97.8	2.2	-	-	-	-
Magdalen Shallows	374	82.1	16.3	1.6	-	-	-
Newfoundland Shelf	20	90	5	5	-	-	-
North Gulf Shelf	18	100	-	-	-	-	-
Scotian Shelf	305	85.9	12.1	1.6	0.4	-	-
St. Lawrence Estuary	168	84.5	14.9	0.6	-	-	-
The Grand Banks	21	95.2	4.8	-	-	-	-
Vancouver Coast and Shelf	35	77.1	22.9	-	-	-	-
PNCIMA	155	63.2	22.6	7.7	5.2	1.3	-
Puget Trough/Georgia Basin	385	29.4	35.8	15.1	13.5	2.9	3.3

Table 19. Survival Probability scores obtained by transient boats (%) per ecoregion.

Ecoregion	# Transient boats	Survival Probability Scores		
		0.2 Score (%)	0.6 Score (%)	1.0 Score (%)
Bay of Fundy	37	13.5	8.1	78.4
Labrador Shelf	3	33.3	-	66.7
Laurentian Channel	90	43.3	4.44	52.2
Magdalen Shallows	374	5.6	9.6	84.8
Newfoundland Shelf	20	10.0	-	90.0
North Gulf Shelf	18	38.9	-	61.1
Scotian Shelf	305	4.6	5.2	90.2
St. Lawrence Estuary	168	17.2	44.0	38.7
The Grand Banks	21		4.8	95.2
Vancouver Coast and Shelf	35	-	-	100
PNCIMA	155	-	0.6	99.4
Puget Trough/Georgia Basin	385	-	0.5	99.5

Table 20. Percentage (%) of transient boats that obtained each risk category in each ecoregion. I.D. = Insufficient data (see Step 3a in Figure 6).*

Visited ecoregion	# Transient boats	Lowest (%)	Low (%)	Intermediate (%)	High (%)	Highest (%)
Bay of Fundy	37	94.6	5.4	0	0	0
Labrador Shelf	3	I.D.	I.D.	I.D.	I.D.	I.D.
Laurentian Channel	90	96.7	3.33	0	0	0
Magdalen Shallows	374	94.7	5.3	0	0	0
Newfoundland Shelf	20	95	5	0	0	0
North Gulf Shelf	18	100	0	0	0	0
Scotian Shelf	305	79.7	20.3	0	0	0
St. Lawrence Estuary	168	98.2	1.8	0	0	0
The Grand Banks	21	100	0	0	0	0
Vancouver Coast and Shelf	35	71.4	28.6	0	0	0
PNCIMA	155	69.1	29.7	0.6	0.6	0
Puget Trough/Georgia Basin	385	34.3	62.9	1.8	0.8	0.2

*Risk categories correspond to percentage ranges presented in Table 2.

Table 21. Final Ecoregion Relative Invasion Risk and level of uncertainty per ecoregion, and percentage (%) of transient boats in each risk category. I.D. = Insufficient data (see Step 3b in Figure 6).*

Visited ecoregion	# Transient boats	Lowest (%)	Low (%)	Intermediate (%)	High (%)	Highest (%)	Mean Final Relative Invasion Risk	Level of Uncertainty
Bay of Fundy	37	100	0	0	0	0	Lowest	Moderate
Labrador Shelf	3	I.D.	I.D.	I.D.	I.D.	I.D.	I.D.	Highest
Laurentian Channel	90	100	0	0	0	0	Lowest	Moderate
Magdalen Shallows	374	100	0	0	0	0	Lowest	Moderate
Newfoundland Shelf	20	100	0	0	0	0	Lowest	Moderate
North Gulf Shelf	18	100	0	0	0	0	Lowest	Moderate
Scotian Shelf	305	100	0	0	0	0	Lowest	Moderate
St. Lawrence Estuary	168	100	0	0	0	0	Lowest	Moderate
The Grand Banks	21	100	0	0	0	0	Lowest	Moderate
Vancouver Coast and Shelf	35	100	0	0	0	0	Lowest	Moderate
PNCIMA	155	94.2	5.8	0	0	0	Lowest	Moderate
Puget Trough/Georgia Basin	385	34.3	62.9	1.8	0.8	0.3	Highest	Moderate

*Risk categories correspond to percentage ranges presented in Table 2.

Table 22. Predicted percentages of transient boats in each risk category per ecoregion using bootstrapped data over a period of ten years. I.D. = Insufficient data*

Visited ecoregion	# Transient boats	Lowest (%)	Low (%)	Intermediate (%)	High (%)	Highest (%)
Bay of Fundy	35,111	100	0	0	0	0
Labrador Shelf	I.D.	I.D.	I.D.	I.D.	I.D.	I.D.
Laurentian Channel	27,130	98.80	1.09	4.05E-02	3.32E-02	3.32E-02
Magdalen Shallows	145,520	99.62	37.93E-02	0	0	0
Newfoundland Shelf	15,770	99.94	5.71E-02	0	0	0
North Gulf Shelf	9,620	100	0	0	0	0
Scotian Shelf	296,690	98.11	1.89	0	0	0
St. Lawrence Estuary	69,010	99.74	25.36E-02	1.45E-03	0	0
The Grand Banks	7,540	100	0	0	0	0
Vancouver Coast and Shelf	350,100	93.02	6.93	3.77E-02	1.43E-02	3.71E-03
PNCIMA	990,850	89.11	10.67	12.68E-02	5.89E-02	3.05E-02
Puget Trough/Georgia Basin	3,718,843.	70.53	29.43	3.28E-02	2.04E-03	5.38E-05

*Risk categories correspond to percentage ranges presented in Table 2.

FIGURES

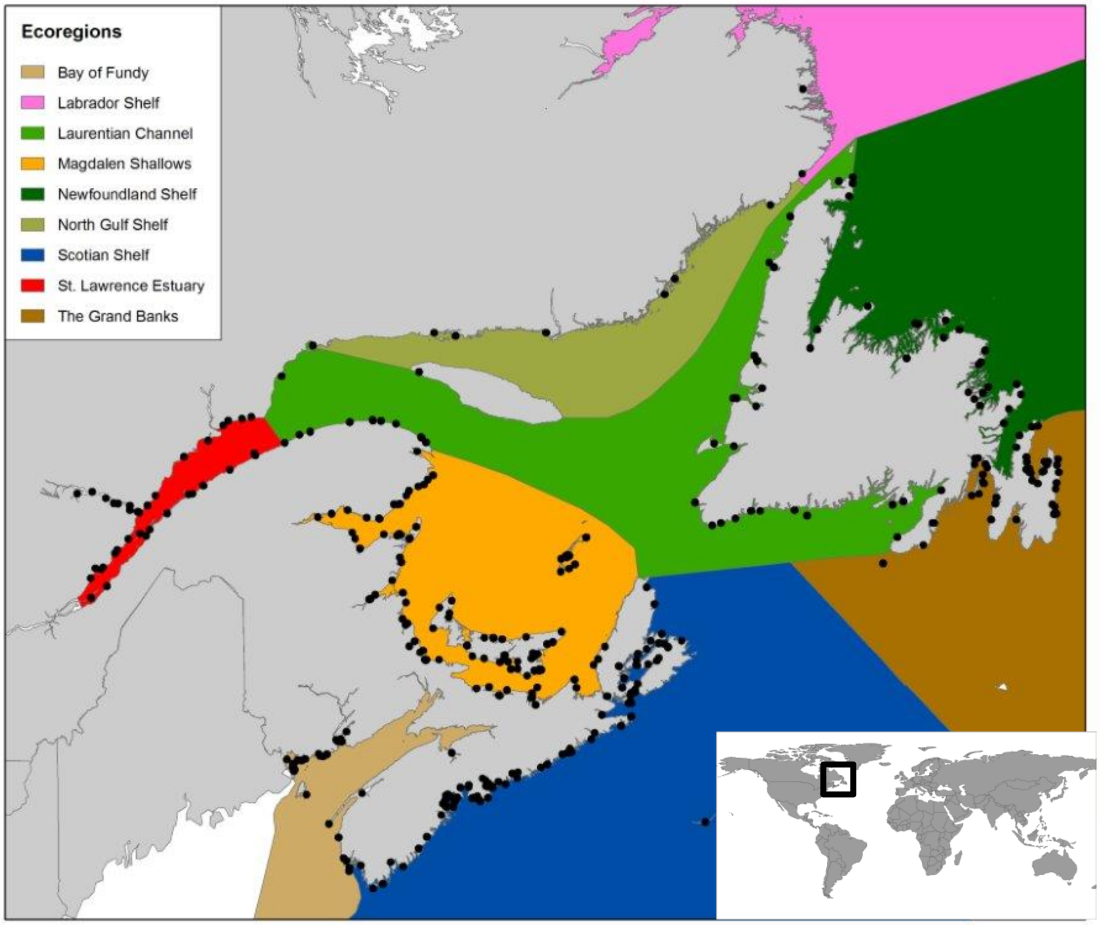


Figure 1. Atlantic ecoregions based on the Parks Canada biogeographic classification (Harper et al. 1993) and visited and home marinas of the Atlantic Region mentioned in boater questionnaires (black dots).

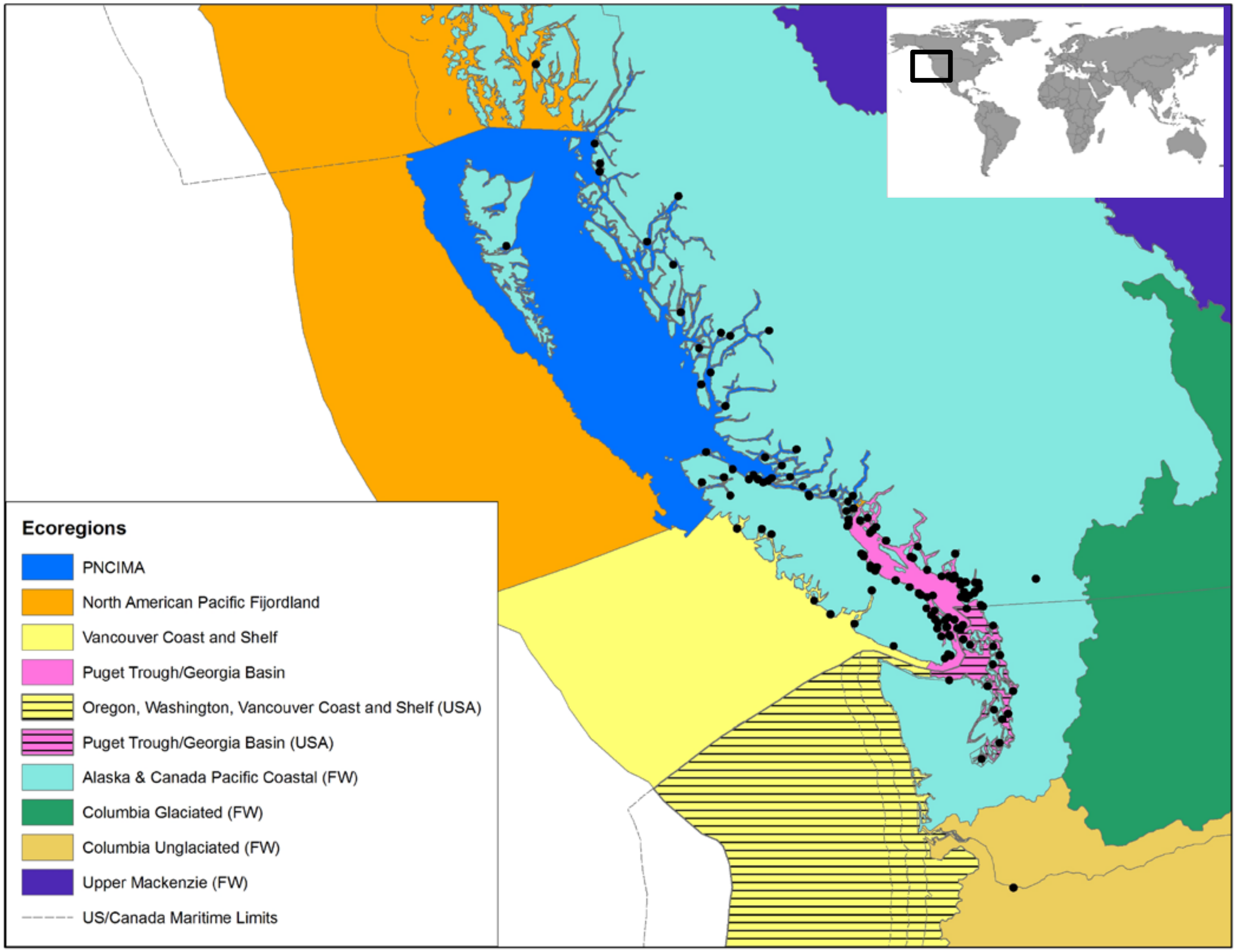


Figure 2. Pacific ecoregions based on the Marine Ecoregions of the World (MEOW) classification (Spalding et al. 2007) with further subdivision of the Pacific North Coast Integrated Management Area (PNCIMA ecoregion, PNCIMA initiative,) and Freshwater Ecoregions of the World (FEOW - Abel et al. 2008) classification. Visited and home marinas in the Pacific ecoregions mentioned in the Pacific boater questionnaires are indicated by black dots.

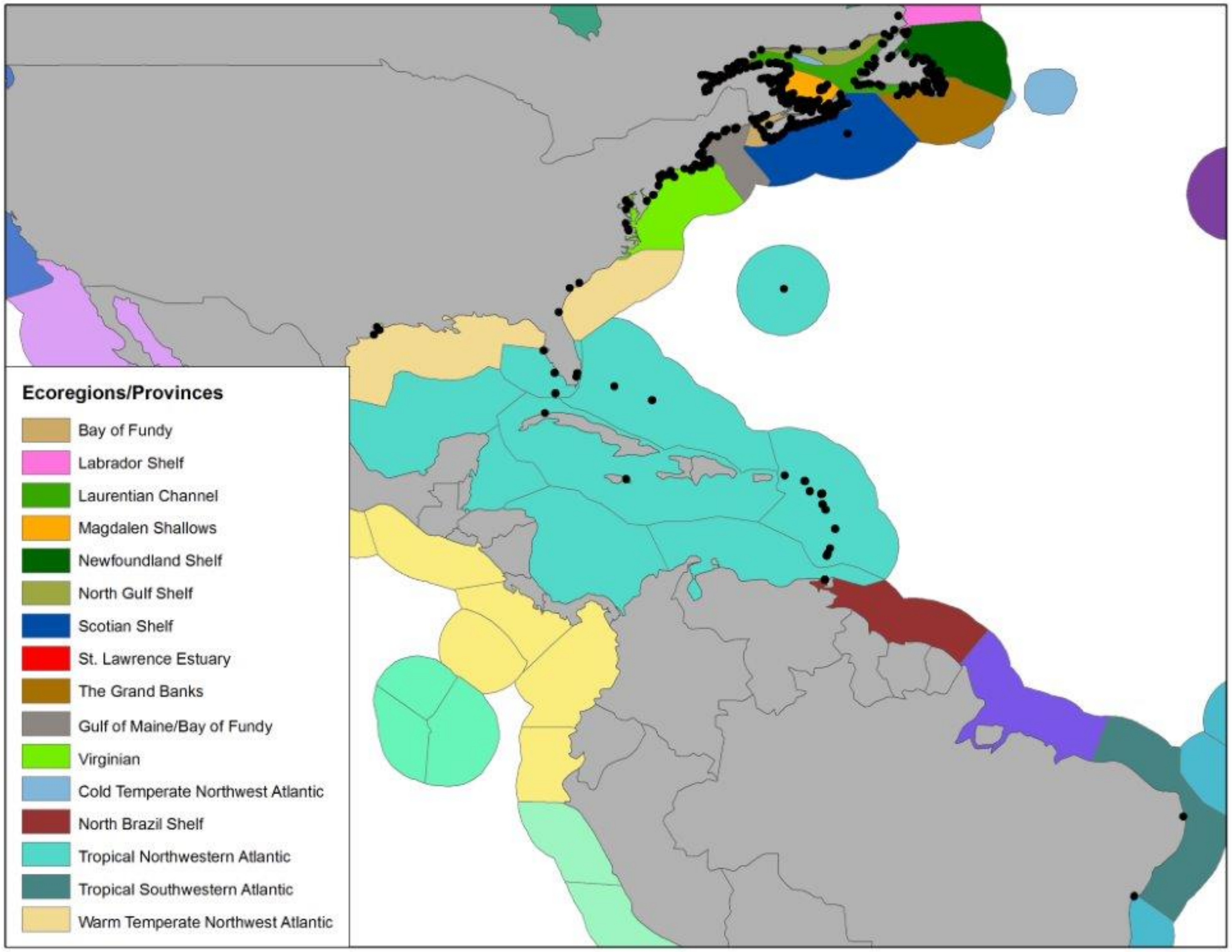


Figure 3. Visited and home marinas of the Americas Atlantic coast mentioned in Atlantic boater questionnaires and associated ecoregions/provinces using MEOW classification (Spalding et al. 2007) and Parks Canada classification (Harper et al. 1983) are indicated by black dots.

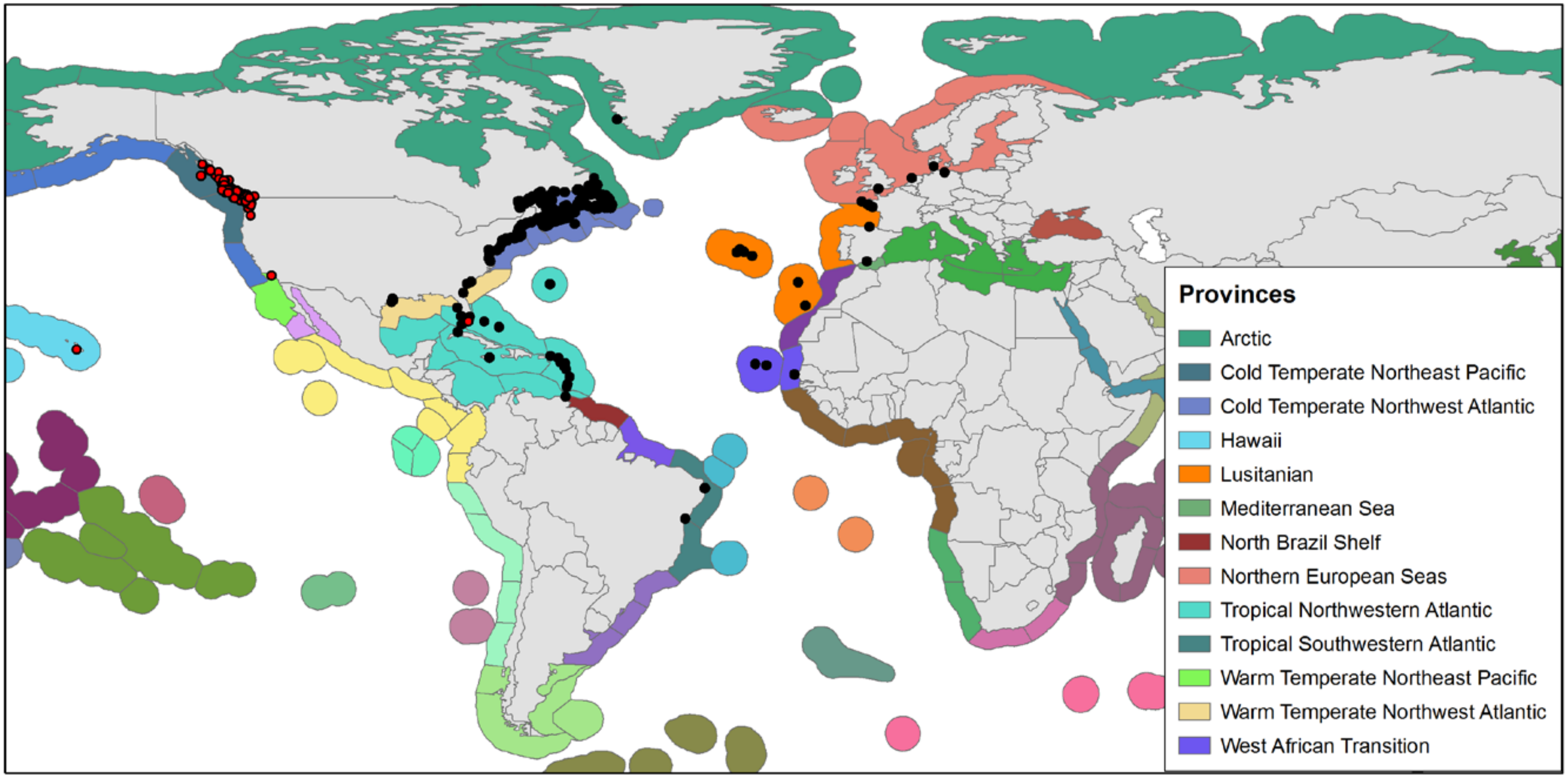


Figure 4. Visited and home marinas of the world mentioned in Atlantic (black dots) and Pacific (red dots) boater questionnaires and associated provinces using MEOW classification (Spalding et al. 2007).

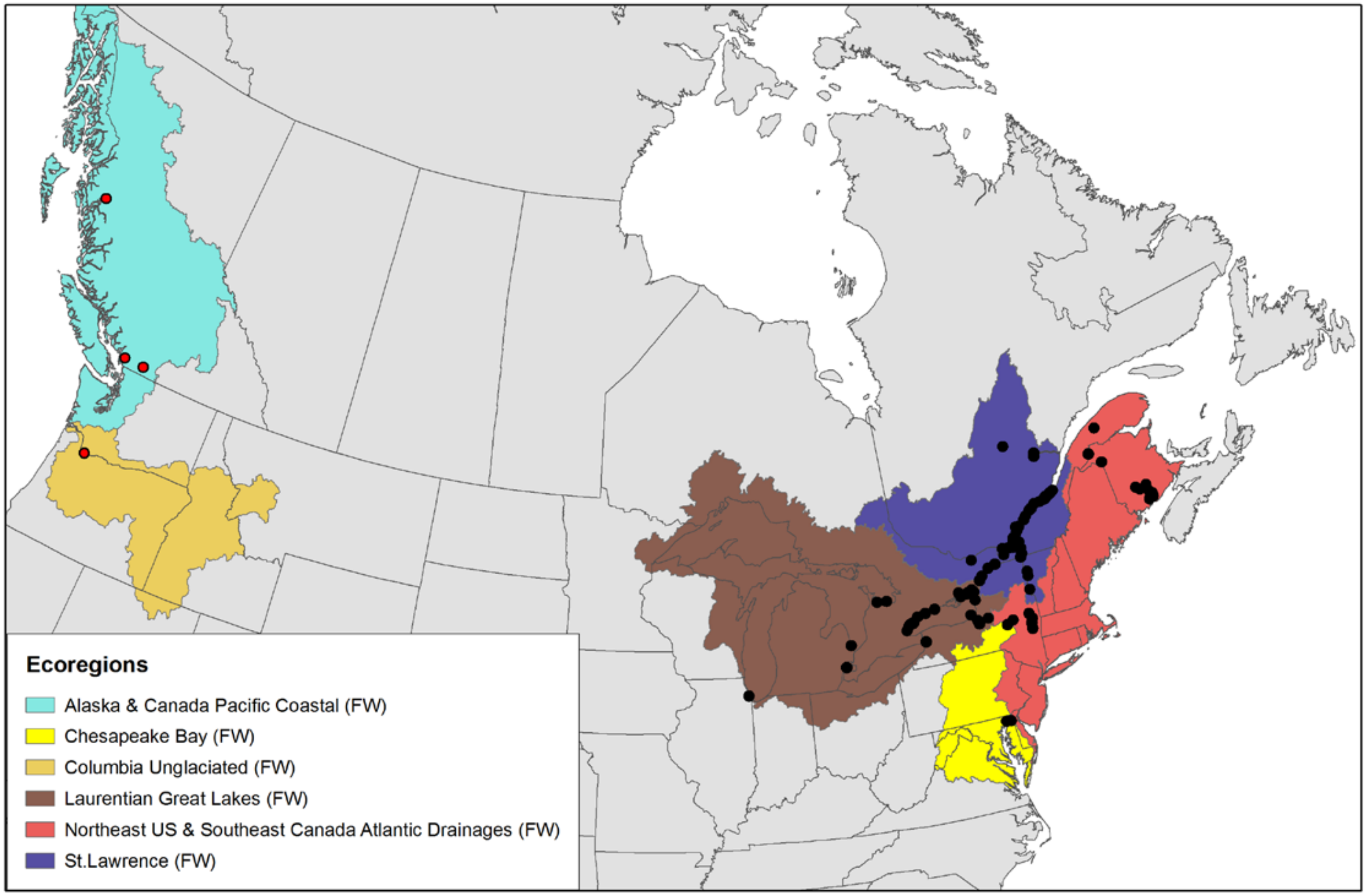


Figure 5. Visited and home freshwater marinas mentioned in the Atlantic (black dots) and Pacific (red dots) boater questionnaires and associated ecoregions using Freshwater Ecoregions of the World (FEOW - Abel et al. 2008) classification.

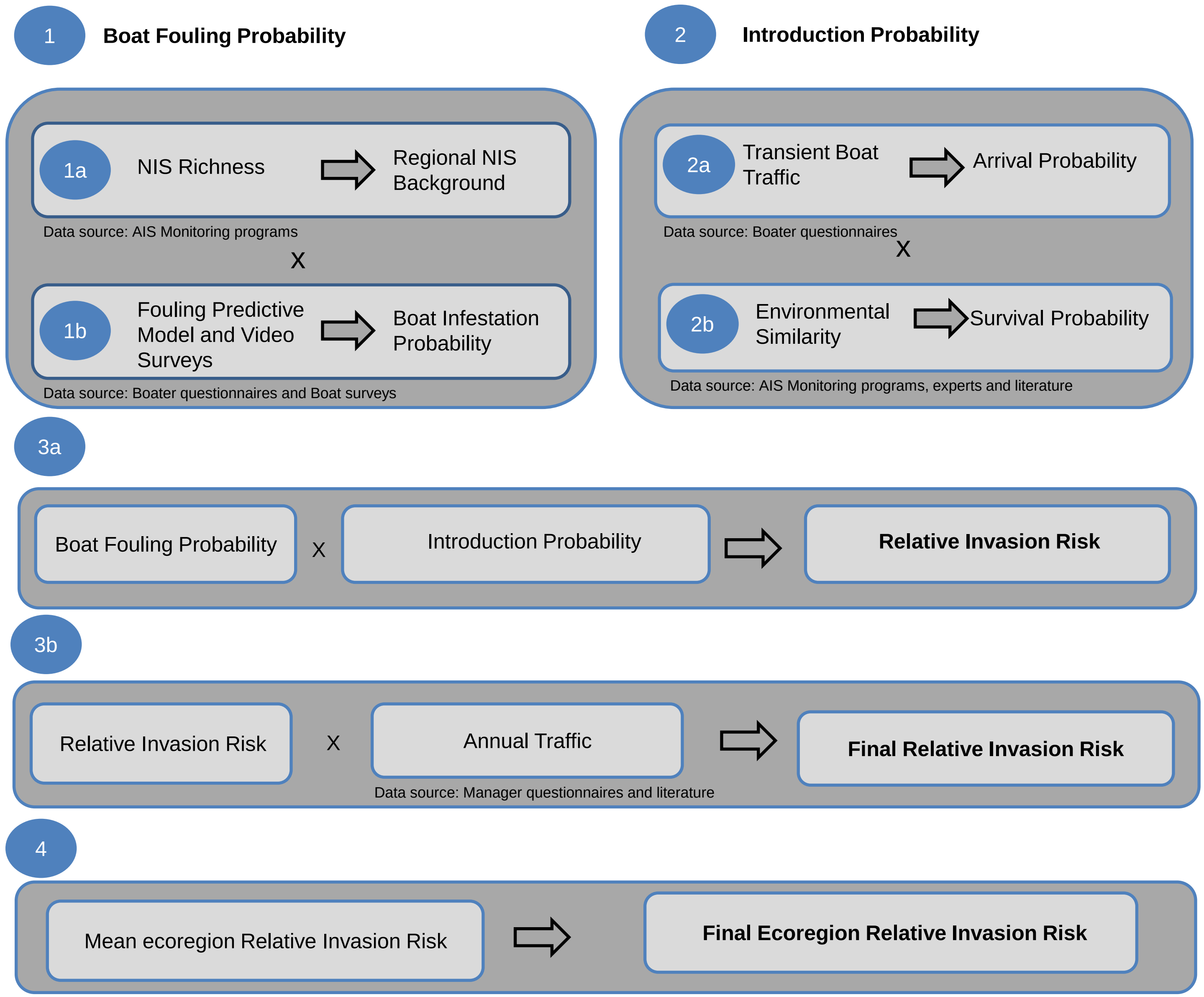


Figure 6. Flow chart illustrating steps for recreational boating invasion risk assessment for Canadian ecoregions. See text for details.

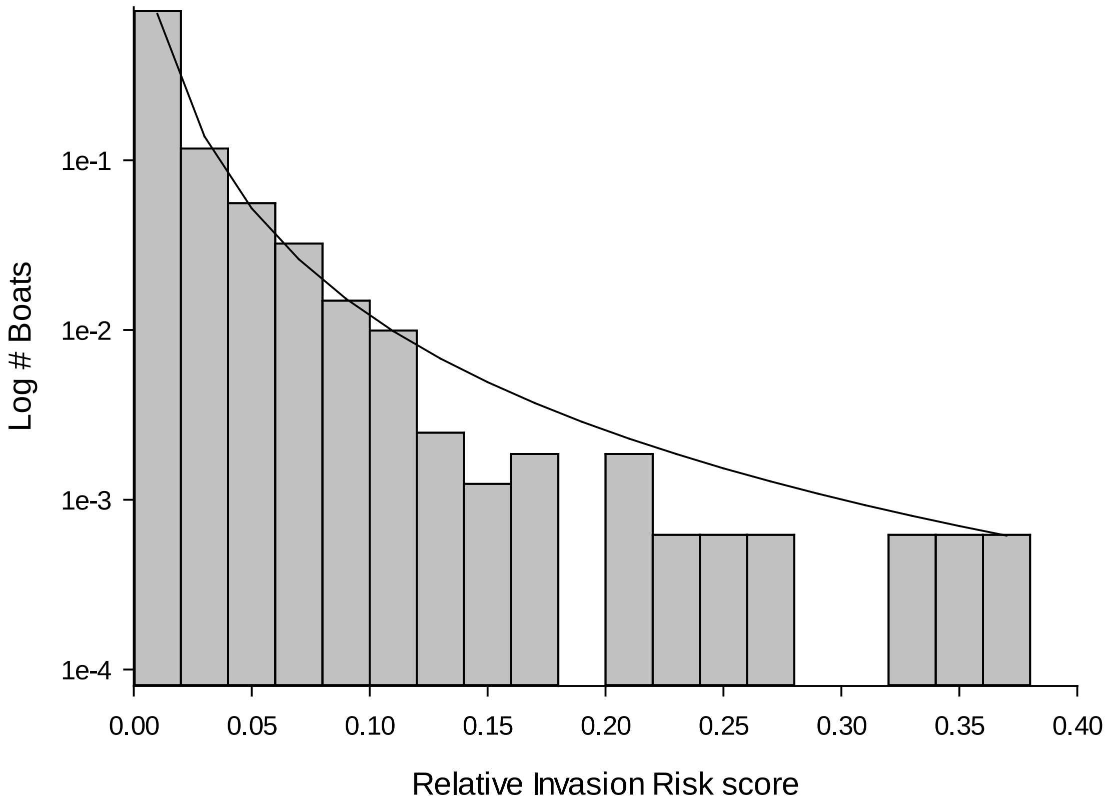


Figure 7. Distribution of Relative Invasion Risk scores obtained for all transient boats (1129) and Pareto distribution fitted on data (line). Because of large differences in number of boats among Relative Invasion Risk scores, y-axis was log-transformed.

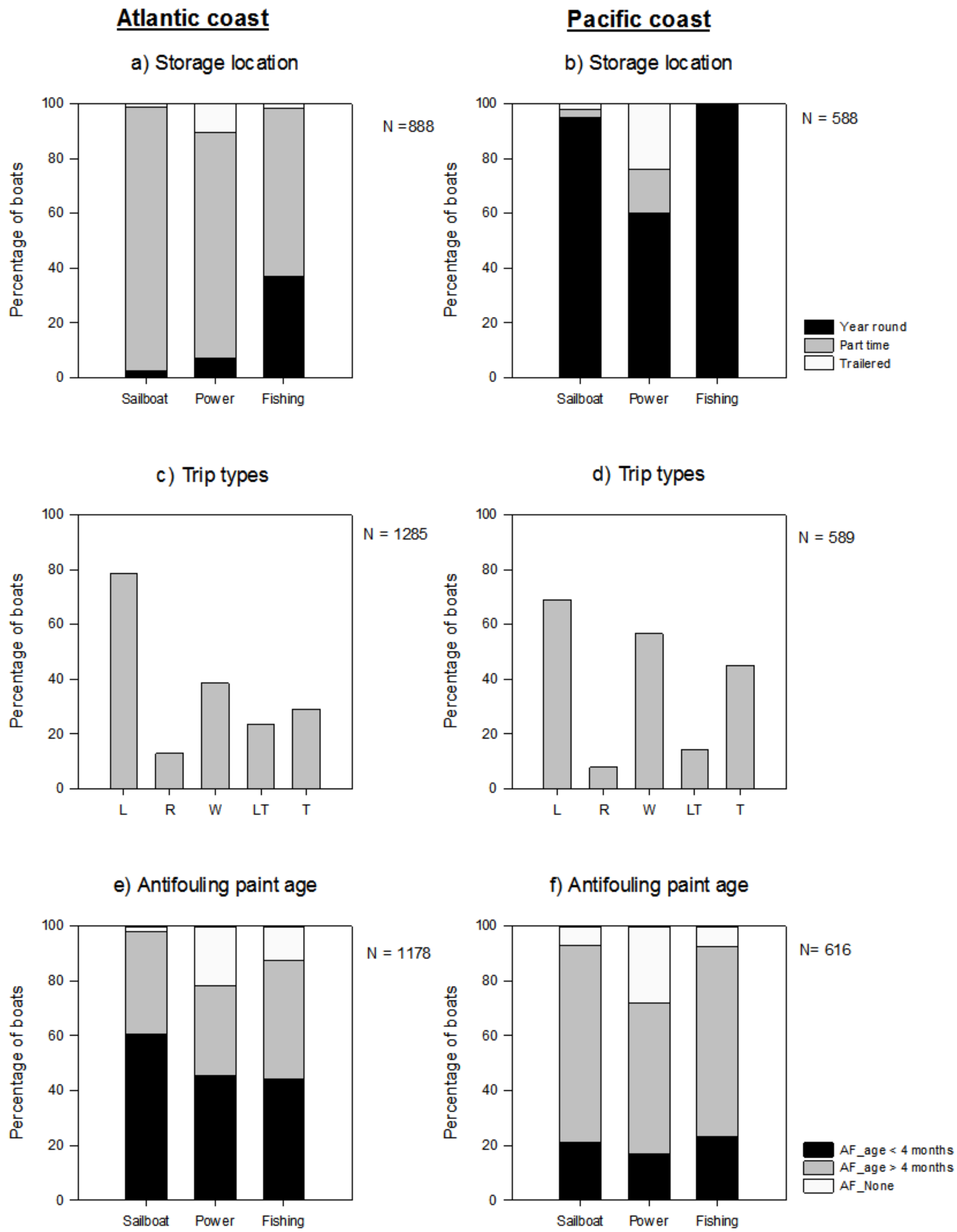


Figure 8. a-b) Storage location, c-d)Trip types undertaken, and e-f) Antifouling paint age for boats from Atlantic and Pacific coasts for which boaters have answered those behavioral questions (N = number of boats). Power = Power boat and Fishing = Fishing boat (a, b, e, f). Fishing boat type includes Fishing boat, Converted fishing boat and Combined recreational and fishing boat. Year round = Boats stored in water year round, Part time = boats stored in water part of the time, and Trailered = stored on land and trailered to boat launch (a, b). L = Local, R = Racing, W = Weekender, LT = Long, and T = Tours trips (c, d). AF_age < 4 months = Antifouling paint that was less than 4 months of age, AF_age > 4 months = Antifouling paint that was greater than 4 months of age and AF_None = no antifouling paint (e, f).

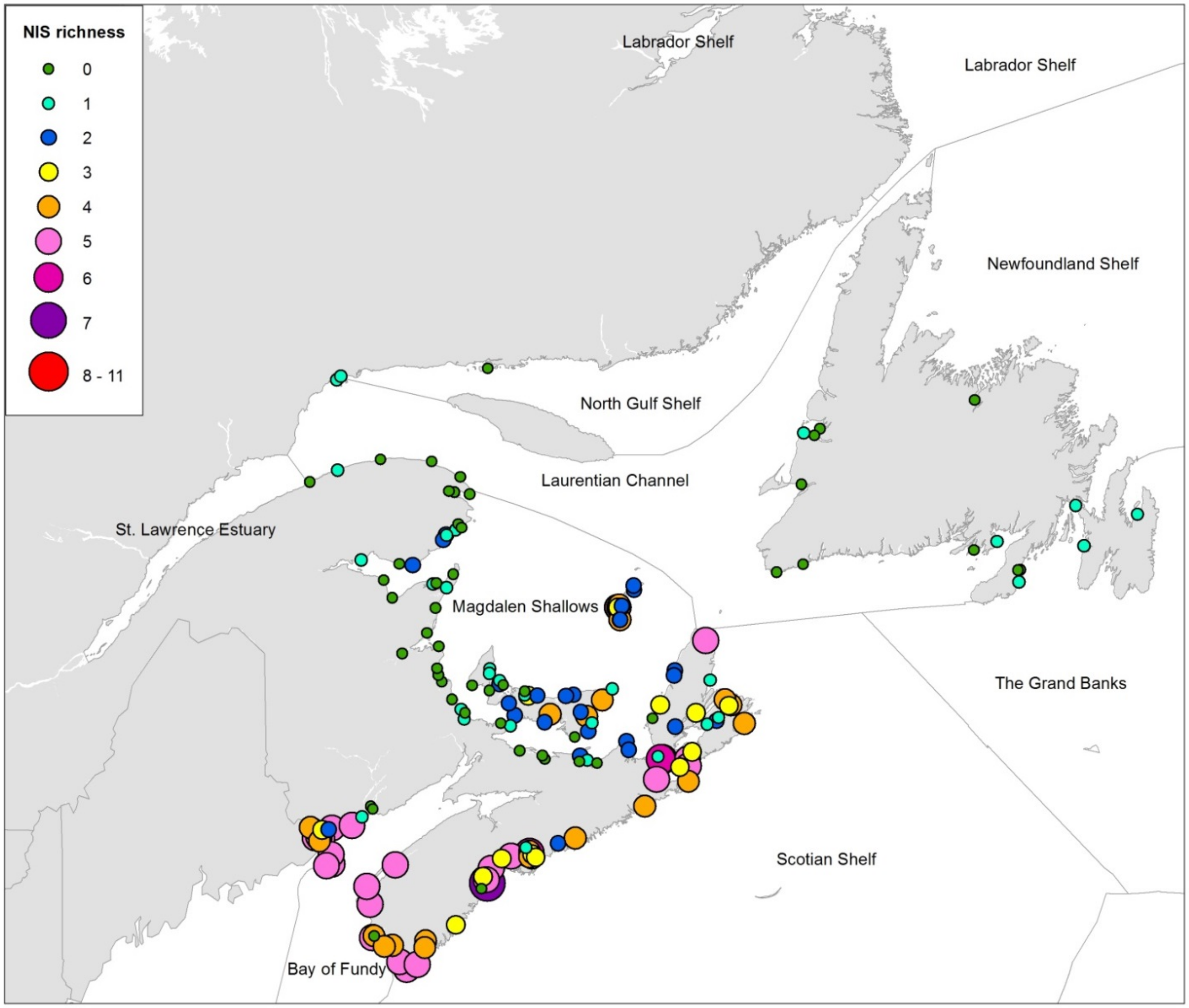


Figure 9. NIS richness measured in monitoring sites of the Atlantic coast (see Step 1a in Figure 6). See Table 7 for NIS Background score per ecoregion

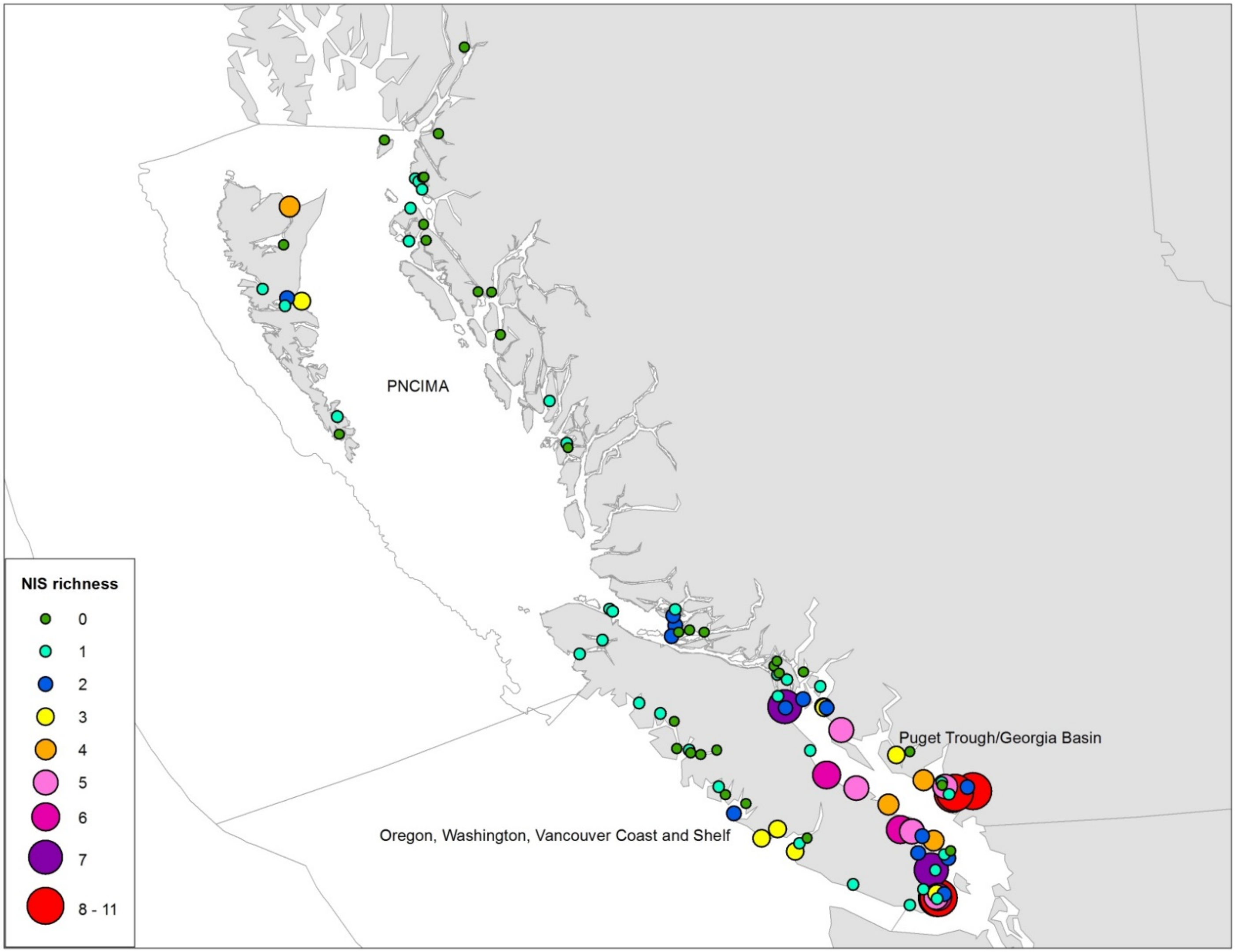


Figure 10. NIS richness measured in monitoring sites of the Pacific coast (see Step 1a in Figure 6). See Table 8 for NIS Background score per ecoregion.

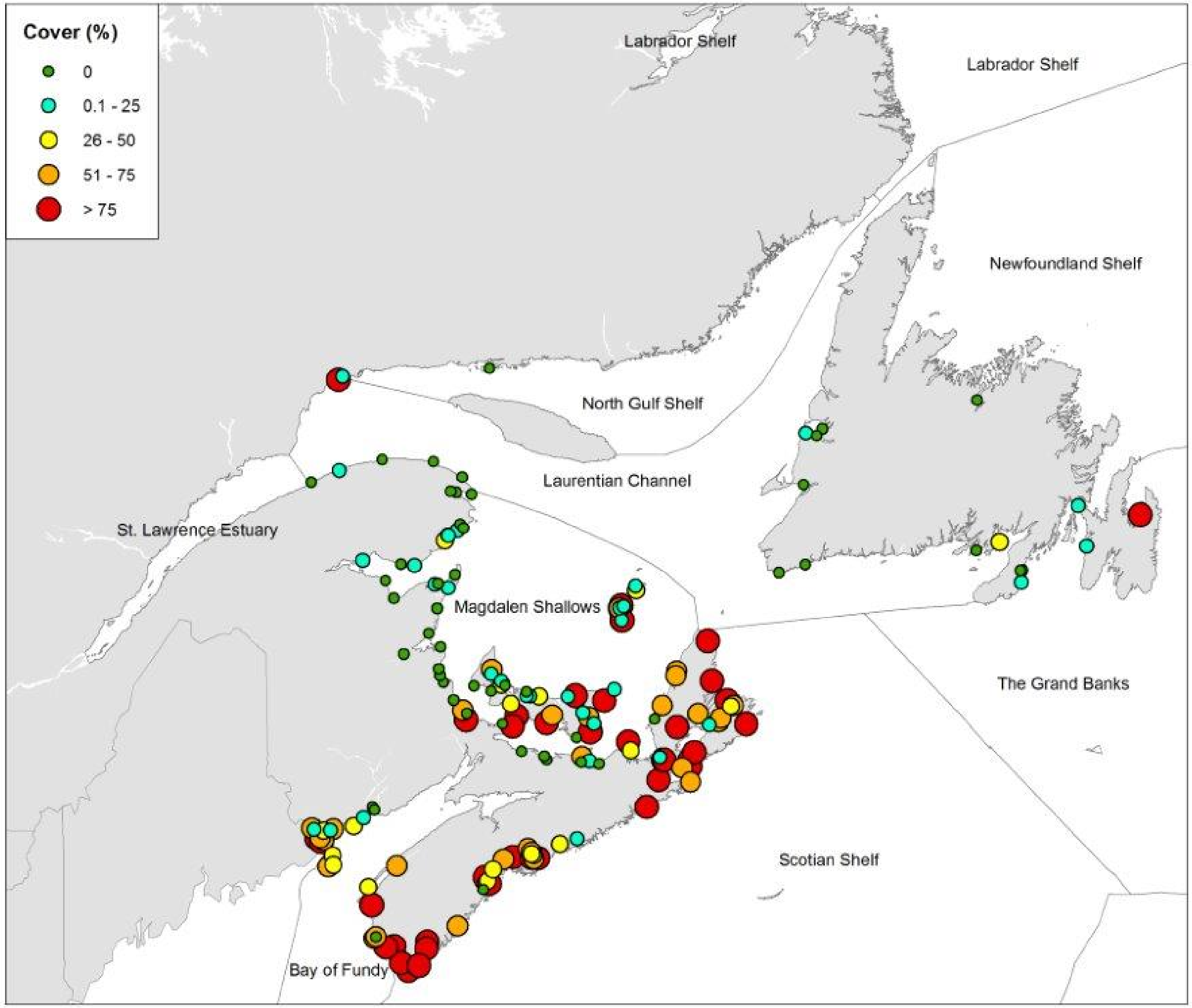


Figure 11. NIS cover (%) measured in monitoring sites of the Atlantic coast.

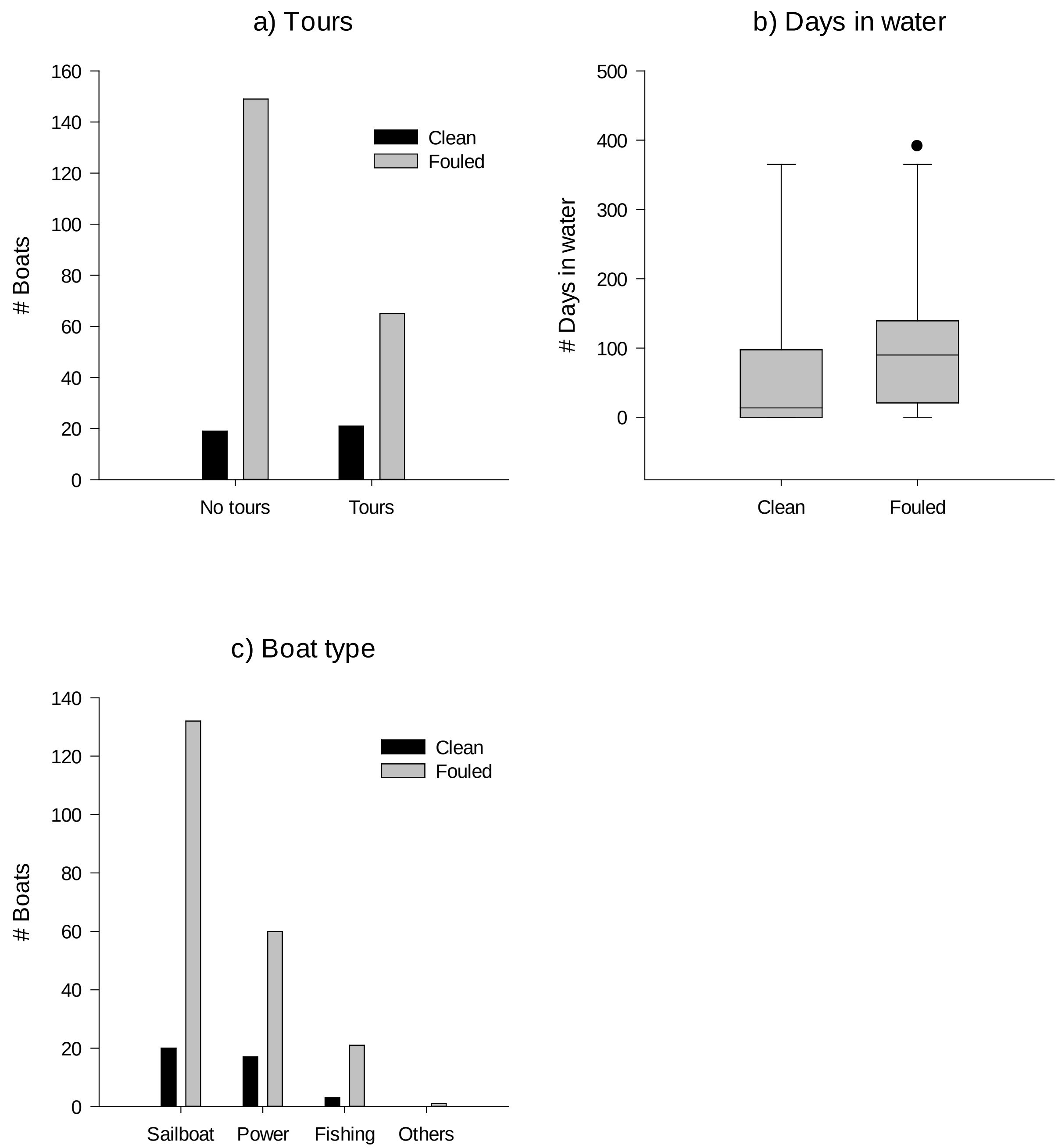


Figure 12. Variables used in the prediction fouling model (Clean/Fouled) for the Atlantic coast: a) Tours; b) Days in water and; c) Boat type for the 254 videos surveys included in the model. For days in water, the lower and upper boundary of the box plot graph indicates the 25th and 75th percentile respectively, the line within the box marks the median and the error bars below and above the box indicate the 10th and 90th percentiles. Power: Power boat and Fishing: Fishing boat. See Step 1a in Figure 6.

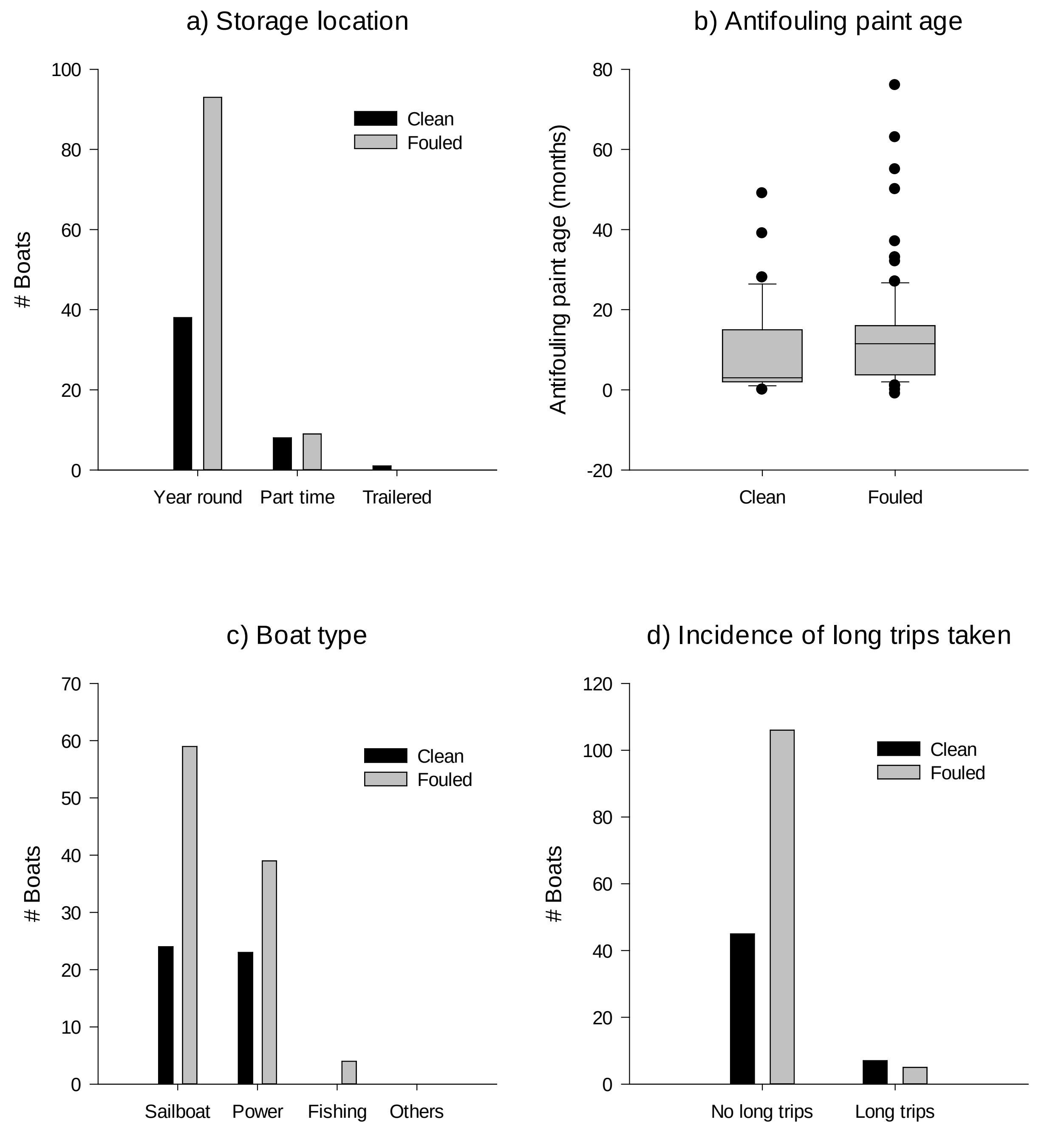


Figure 13. Variables used in the prediction fouling model (Clean/Fouled) for the Pacific coast: a) Storage location; b) Antifouling paint age; c) Boat type and; d) Incidence of long trips taken for the 149 videos surveys included in the model. Year round: Boats stored in water year round; Part time: boats stored in water part of the time and Trailered: stored on land and trailered to boat launch. The lower and upper boundary of the box plot graph for antifouling paint age indicates the 25th and 75th percentile respectively, the line within the box marks the median and the error bars below and above the box indicate the 10th and 90th percentile. Power: Power boat and Fishing: Fishing boat. See Step 1a in Figure 6.

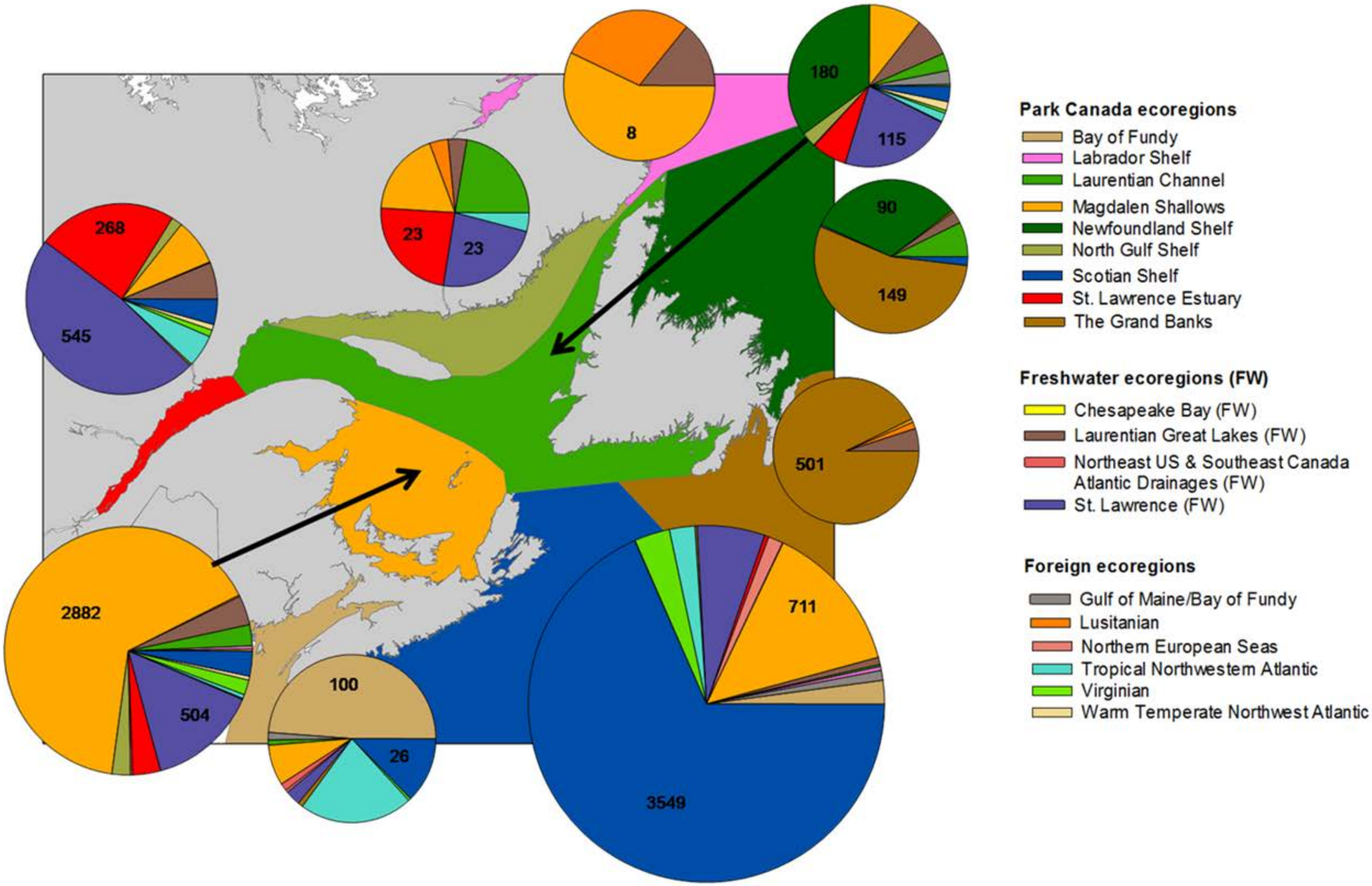


Figure 14.Total number of nights spent by transient boats in each ecoregion. The size of pie charts is relative to the estimated number of visitors in each ecoregion (see Table 13). See Step 2a in Figure 6.

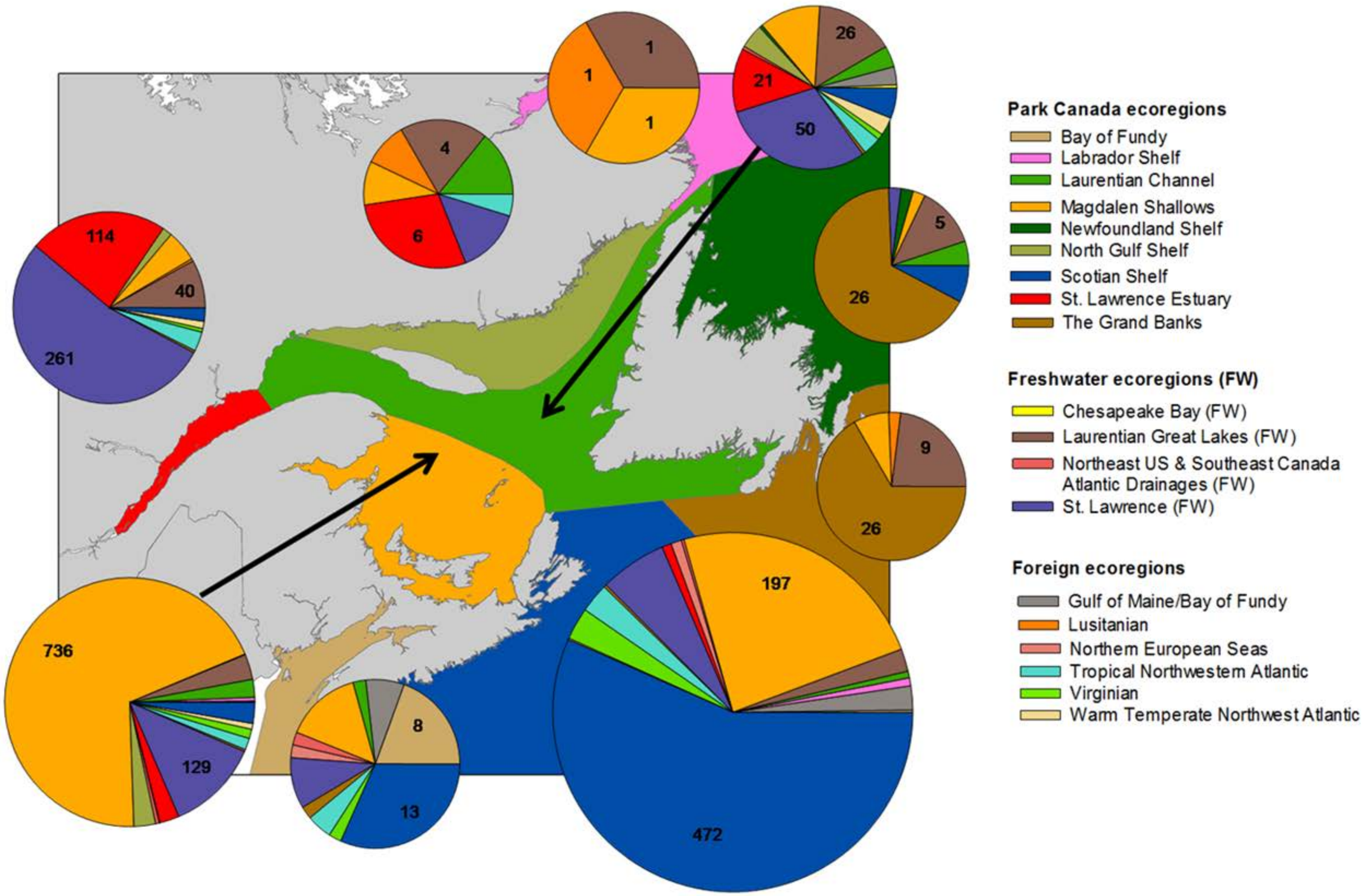


Figure 15. Total number of destinations visited by transient boats in Atlantic ecoregions. The size of pie charts is relative to the estimated number of visitors in each ecoregion. See Step 2a in Figure 6.

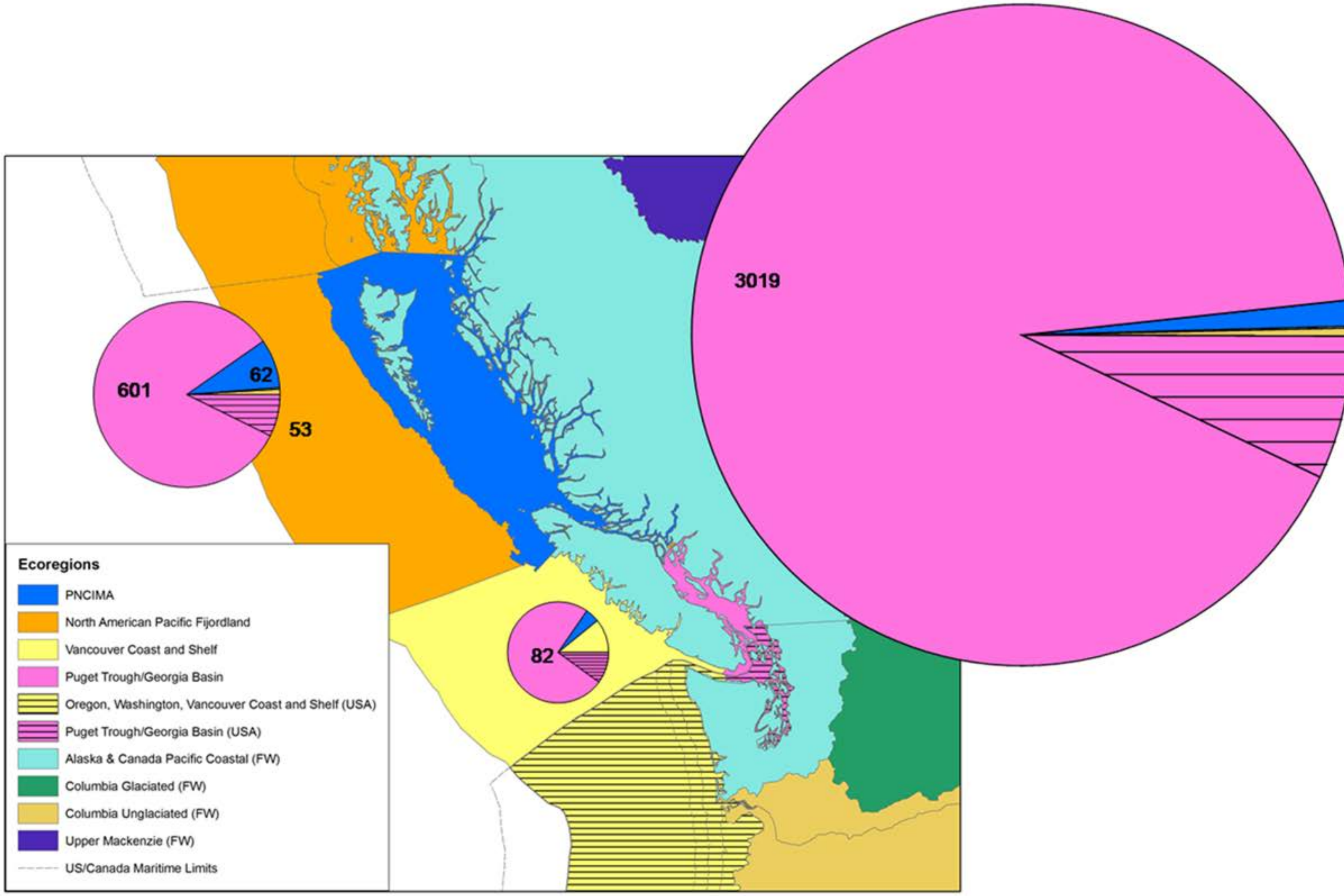


Figure 16. Total number of destinations visited by transient boats in Pacific ecoregions. The size of pie charts is relative to the estimated number of visitors in each ecoregion. For a visual comparison with Atlantic Region (Figures 13, 14, 17 and 19), pie chart sizes on the Pacific coast should appear 4.5 times larger. See Step 2a in Figure 6.

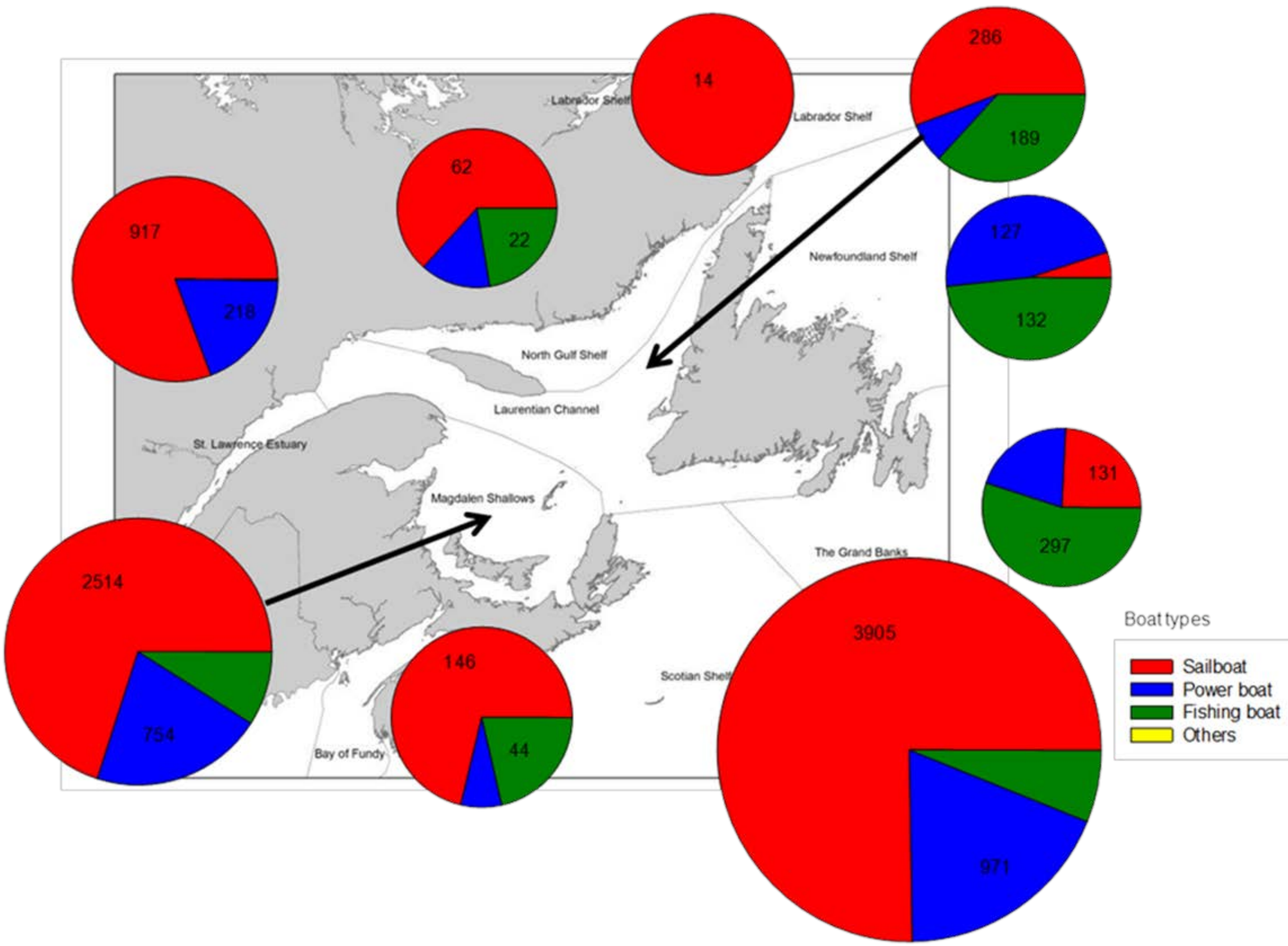


Figure 17. Total number of nights spent by transient boats per boat type in Atlantic ecoregions. The size of pie charts is relative to the estimated number of visitors in each ecoregion.

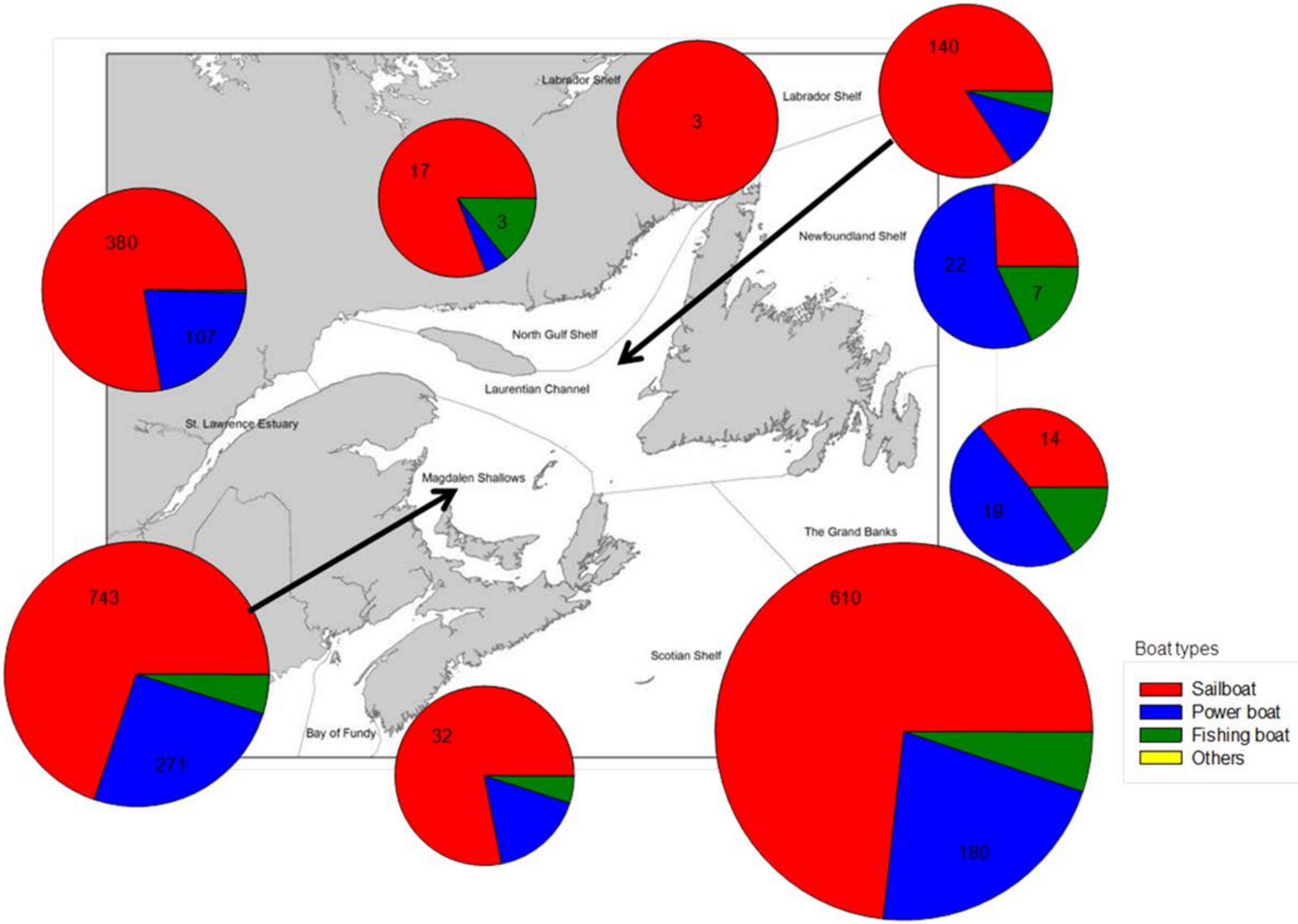


Figure 18. Total number of destinations visited by transient boats per boat type in Atlantic ecoregions. The size of pie charts is relative to the estimated number of visitors in each ecoregion.

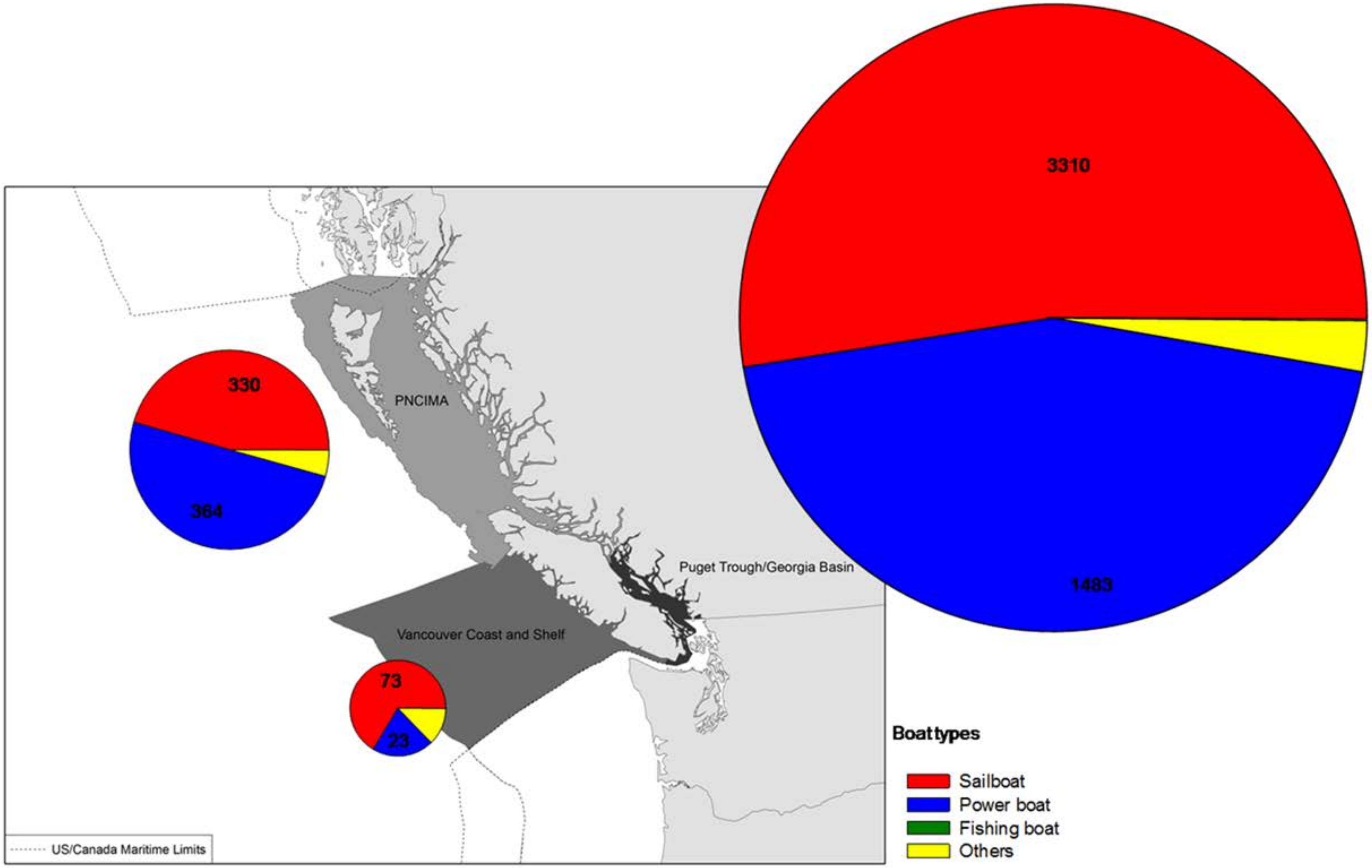


Figure 19. Total number of destinations visited by transient boats per boat type in Pacific ecoregions. The size of pie charts is relative to the estimated number of visitors in each ecoregion. For a visual comparison with Atlantic Region (Figures 13, 14, 17 and 19), pie chart sizes in the Pacific Region should appear 4.5 times larger.

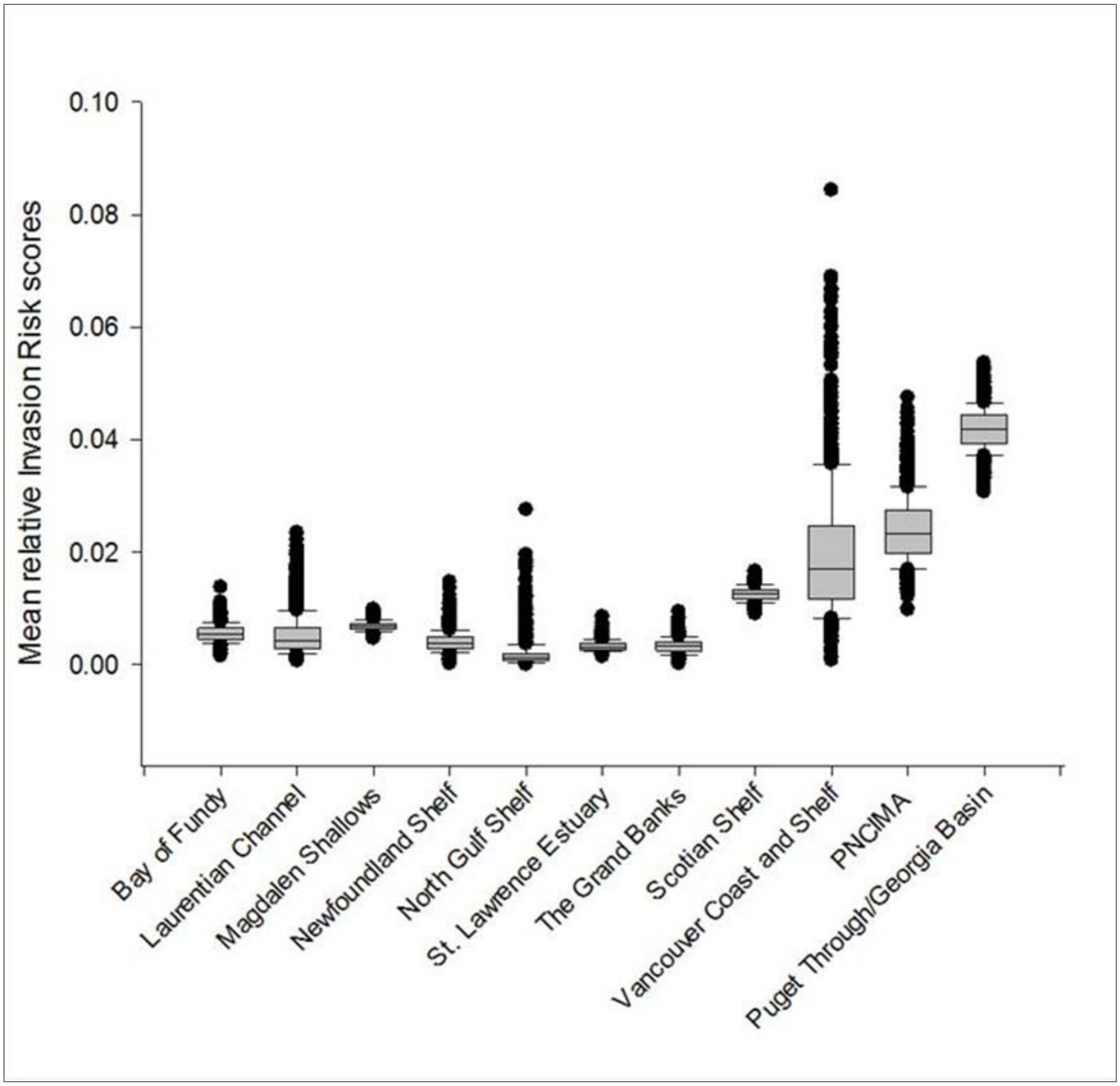


Figure 20. Range of possible annual mean Relative Invasion Risk scores for each ecoregion obtained with bootstrapped data. The lower and upper boundary of the box plot graph indicates the 25th and 75th percentile respectively, the line within the box marks the median and the error bars below and above the box indicate the 10th and 90th percentile.

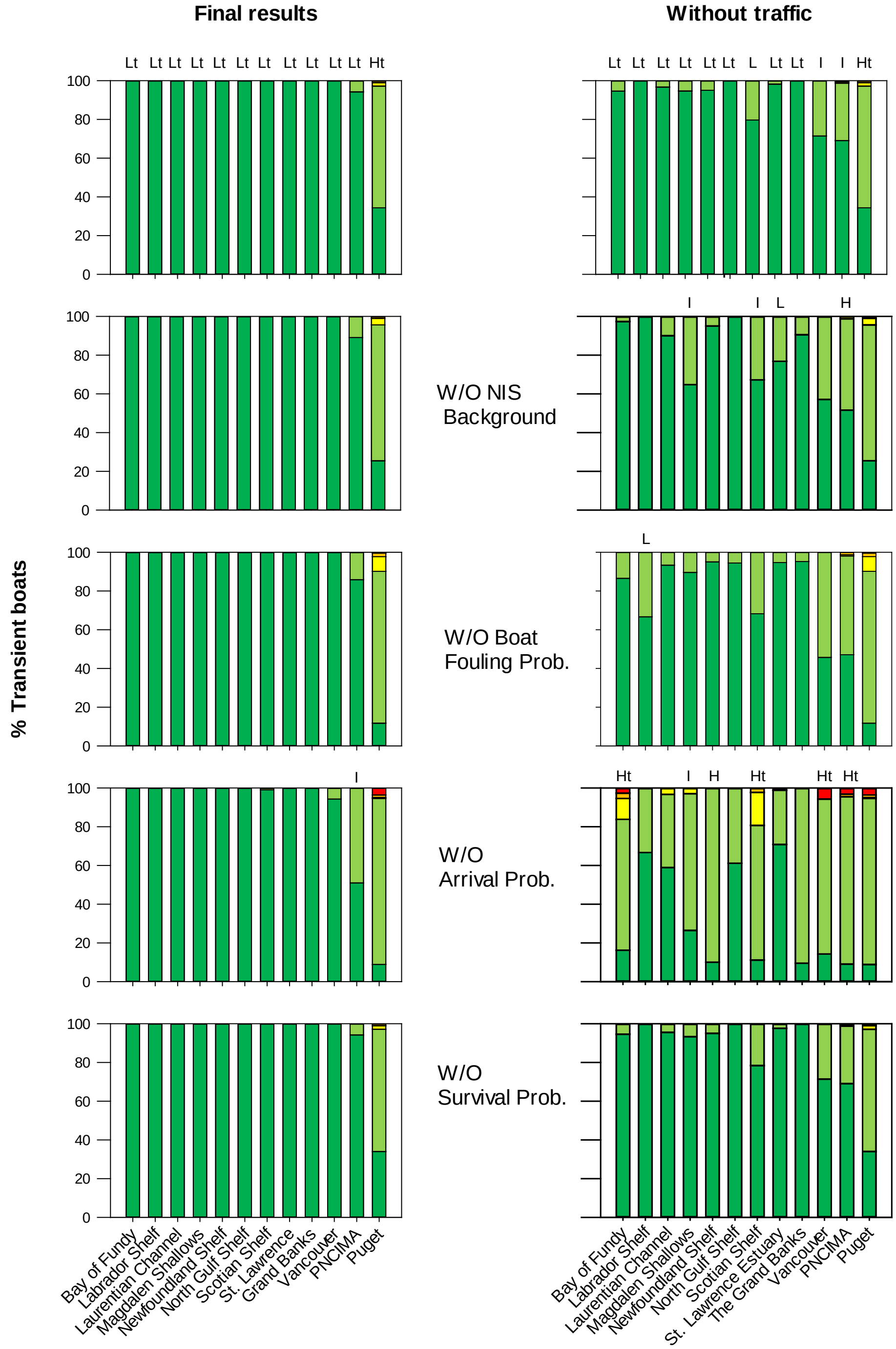


Figure 21. Percentages of transient boats in each risk category obtained with sensitivity analyses. The upper left figure represents the Final Relative Invasion Risk scores obtained for each ecoregion and the Final Ecoregion Relative Invasion Risk score is indicated above each bar (Lt = Lowest, L = Low, I = Intermediate, H = High and Ht = Highest); figures below in the left column represent the results obtained without inclusion of the variable indicated in the middle. Upper right figure represents final results without traffic score and figures below in the right column represent final results without traffic score included and without the variable indicated in the middle. Final Ecoregion Invasion Risk scores are indicated if they are different from the above figure for each given column. Puget = Puget Trough/Georgia Basin.

APPENDIX 1: MANAGER QUESTIONNNAIRES

Manager questionnaires were used to collect general information on marinas

Atlantic Coast (Lacoursière-Roussel et al. 2012b) Manager Questionnaire

CAISN CANADIAN AQUATIC INVASIVE SPECIES NETWORK — The BINNACLE

Marina/ Yacht Club Manager's Questionnaire

Part I: Contact information

Your name: ____________________

Name of the marina/yacht club: ____________________

Phone: (   ) ______-_______

Email: ____________________

Would you like your candidacy to be kept to win a **$100 gift certificate** at Binnacle?

☐ Yes ☐ No

Part II: Marina/ Yacht Club information

1. When was the marina built? _____ (year)

2. Do some vessels at your marina stay in the water year-round? ☐ Yes ☐ No

If yes, how many vessels? _____

3. What is the maximum size for a craft at your marina?

Length (in feet) ________ and/or Displacement (in tonnes)__________

4. How many sites within the marina? _____

5. How many sites are reserved for visitors? _____

6. How many sites are currently occupied by each type of craft? If unknown, approximate number.

Sailboat: _____ Power boat: _____ Fishing boat: _____

Converted fishing boat: _____ Other (specify)_______________ : _____

7. What type of trips do the local people take? Please write the number of boats for each type of trip. If unknown, approximate number.

____ Local trips – out and back to home marina in one day

____ Racing – trips made for the purpose of racing the boat

____ Weekenders – trips of a few days duration visiting 1-2 different moorages

____ Long trips – long haul travel to destinations further away, once there remain in a single moorage the entire time

____ Tours – long trips with multiple destinations along the way, staying in each moorage for only a few nights

☐ Other (please specify) ____________________

Part II: Boat Movement

8. Where do you expect local people mostly travel?

Name of the marina / Yacht Club ______________________________

City / Town ____

9. Where are visitors most commonly from?

Name of the marina / Yacht Club ______________________________

City / Town ____

10. What is the average time that tourists stay in your marina or yacht club? ____ days

11. How many visitors last summer? If unknown, approximate number. ____________

12. Was the number of visitors last year representative of the last 5 years? ☐ Yes ☐ No

If no, can you specify the number of visitors per year please? If unknown, approximate number.

2004: _____ 2005: _____ 2006: _____ 2007: _____ 2008: _____

13. Is the number of visitors mostly constant in all summer months? ☐ Yes ☐ No

If no, can you specify when and the number of vessels visiting during this short period of time? If unknown, approximate number.

From ______ to ______ Number of vessel expected during this period: _____

From ______ to ______ Number of vessel expected during this period: _____

From ______ to ______ Number of vessel expected during this period: _____

Thank you for your time and cooperation!

Anaïs Lacoursière-Roussel (PhD Student, McGill University)
Chris McKindsey (Research scientist, DFO)

* **Use of data collected:** All information collected is for research purposes only. Your contact information will remain confidential, and responses are not connected to your identity in any way. Your completion of the following questionnaire indicates that you consent to participate in this research.

Atlantic Coast (DFO work) Manager Questionnaire

Marina/ Yacht Club Manager's Questionnaire

Part I: Contact information

Name: ____

Marina/yacht club: ____

Phone: (   )______-_____________

Email:____

Part II: Marina/ Yacht Club information

1. When was the marina built? _____ (year)

2. What is the maximum boat size at your marina?
   Length (feet) ___________ and/or Displacement (tonnes) ___________

3. Number of dock sites at the marina: _____

4. Number of mooring sites: _____

5. Number of sites reserved for visitors: _____

6. Do some boats at your marina stay in the water year-round? O Yes O No
   - If yes, how many? _____

7. When are boats taken out of the water? ___________________

8. Do you remove docks from the water? O Yes O No
   - If yes, when do you remove them? ________________

9. Is there any event (or time) – when we can meet with a number of people (e.g., special event, boat show, etc)?
   - Date: From _________ to __________
   - Number of people expected for the event: ___________

Part III: Local boats

10. Number of sites usually occupied by each type of local craft.

Sailboat: _____ Power boat: _____ Fishing boat: ______

Converted fishing boat: _____ Other (specify)______________: ______

11. What type of trips do the local boating people take? Please, write the number of boats for each type of trip.

___ Day trips – Out and back to home marina in one day

___ Racing

___ Weekenders – Trip of 1-4 nights before coming back to your home marina

___ Long trips – Remain in a single destination more than 4 nights

___ Tours – Visit more than 2 destinations

___ Other (please specify) ____

12. What are the three most common destinations?

a) Town/ city: ______________Name of marina/ port: _____________

How many boats do you expect to visit this site each year ? _______

b) Town/ city: ______________Name of marina/ port: _____________

How many boats do you expect to visit this location each year ? _______

c) Town/ city: ______________Name of marina/ port: _____________

How many boats do you expect to visit this location each year ? _______

Part IV: Visiting boats

13. How many visiting boats did you have at your marina last summer? ____

14. Was the number of visiting boats last year similar for each of the 5 preceding years?
O Yes O No

- If you answered “no”, give the number of visiting boats for each year

2006: _____ 2007: _____ 2008: ______ 2009: _____ 2010: ______

15. What is the average number of nights that tourists/visiting boats stay at your marina or yacht club? ______

16. How many visiting boats do you have each year from outside your province? ____

17. How many boats are from international ports? ______

18. What would you consider to be the most common port/marina visited (by visiting boats) prior to arrival at your marina?

Pacific Coast (Clarke Murray et al. 2013) Manager Questionnaire

Part A – Contact information

Yacht Club/Marina Name: ____

Your Name: ____________________________ Your Position/Title: ____________

Facility Mailing Address: ____

Facility Coordinates: Latitude ________________Longitude: ___________________

Phone #: (   )_____________   Fax: (   )_____________

Email:_______________________   Website:_____________________________

Part B – General information

1. Year facility was built: ___________   2.Year facility began operation: _________

3.a) Age of floats or docks: _____________b) Last replaced (year): _______________

4. Rate of annual marina traffic (average number of visiting boats during peak season):

Low (<1 per day)   Moderate (1-10 oer day)   High (>10 per day)

5. Number of moorage slips: a) Resident ______b) Visitor ______   c) Total ______

6. Maximum length of slips (Ft): a) Resident _____ b) Visitor ______ c) Total ______

7. Total number of visiting boats (approximate):

a) 2007: Canadian _________ International __________

b) 2008: Canadian __________ International___________

8. What type of trips do resident boat owners typically take from your facility (Please indicate the %, or approximate number of boats for each type of trip):

- Local Trips – out and back within a day _____
- Weekenders – trips lasting a few days _____
- Local Racing – racing that takes place visiting facilities within 50km in the waters immediately off the facility _____
- Long Trips – travel beyond 50km from ____
- Long Distance Racing – racing that facility requires overnight outings ______
- Other (please specify): ______________

9. Do you have a tidal grid: O Yes O No

Depth range (below datum): _______________

10. Facility services (please check all that apply):

O	Customs	O	Garbage	O	Launch Ramp
O	Power (amp.___________)	O	Recycling	O	Rails
O	Pumpout	O	Fresh Water	O	Crane
O	Fuel Dock	O	Repairs / Mechanical	O	Travel Lift

Part C – Maintenance information

1. Do you move floats/docks from other locations to your facility: O Yes O No

a) Where from: ____

b) Approximate time of year they are moved: ___________________________________

2. Are the following cleaned at your facility:

a) Pilings: O Yes O No How often: ______________________________

b) Floats/Docks: O Yes O No How often: ______________________________

3. Do you use antifouling paint or other protective substances on facility structures:

O Yes O No

4. Do your members employ divers to clean hulls in-water: O Yes O No

APPENDIX 2 BOATER QUESTIONNAIRES

Boater questionnaires used to evaluate boating patterns and maintenance history.

Atlantic Coast (Lacoursière Roussel et al. 2012a) Boater Questionnaire

Date ____/ ____/ 2009 (dd/mm/yyyy)

Boat name ____

Name of the current mar ina/Yacht Club ________________________

If applicable, where is your home marina?

Name ________________________	Province/State ________________
City or Town ___________________	Country______________________

If you are currently outside of your home ma rina/yacht club, how long do you expect to stay? _____day

Part I: Your Boat

1.Type of craft:

O Sailboat   O Power boat   O Converted fishing boat   O Other (specify) ______________

2. Size of craft:

Length (in feet)____________   and/or   Displacement (in tonnes)_____________

3. Hull type:

o Wood   o Fibreglass   o Aluminum   o Other (specify) ______________

4. Where is your boat stored?

O In the water only part of the year.
When did you put your boat in the water this year ____/____/____ (dd/mm/yyyy)

O In the water year-round.

O Stored on land and trailered to launch site.
What is the boat launch you most commonly use? If unknown please write the closest city or town to the boat launch ________________________________

O Other (please specify) ____

5. What types of antifouling treatments do you use on your boat?

O None

O My boat is brand new and has not been cleaned yet

O do not know

O Antifouling paint:

a) When was the date of the last antifouling treatment? ____ / ____ (month/year)

b) What type of antifouling paint is presently on your boat?
O Ablative   O Hard   o Combination

O I do not know. Product brand name used (if known): ___________________

c) Who paints your boat?
O Myself   O Private   o Professional

6. What method of cleaning do you use?
O Scrubbing   o Scraping   o Power washing   o Other (specify) ________

7. Where do you do your boat's hull cleaning?

Part II: Boat Movement

9. What types of trips have you taken with your boat within the **last 6 months**?

O Local trips – out and back to home marina in one day

O Racing – trips made for the purpose of racing the boat

O Weekenders – trips of a few days duration visiting 1-2 different moorages

o Long trips – long haul travel to destinations further away, once there remain in a single moorage the entire time

O Tours – long trips with multiple destinations along the way, staying in each moorage for only a few nights

O Other (please specify) ________________________________

____

10. Before the current marina/yacht club, where was your **boat last moored (or stopped)**?

Marina / Yacht Club _________________ City / Town ____________________

Which date did you arrive in the current marina ____/ ____/ ____ (dd/mm/yyyy)

How long did you stay there? _____ days

During your last trip, what was your average speed? _____ knots

What was the elapsed time between your last moored area and your current marina/yacht club? (Time spent underway) _______________________________

11. Please indicate the number of **days** you spent moored at **all of the places** you visited **with your boat** within the **last 6** months:

Bay of Fundy- St. John River	# Day	Northumberland Strait – PEI	# Day	Coastal Nova Scotia	# Day	Coastal Nova Scotia	# Day
Bellisle Bay Marina		Hector Quay Marina		Alderney Marina Ltd.		Lunenburg Yacht Club	
Chipman Marine Wharf		Miramichi Yacht Club		Armdale Yacht Club		Mahone Bay Classic Boat Marina	
Digby Marina		Pointe de Chene		Bedford Yacht Club		Oak Island Marina	
Gagetown Marina		Richibucto		Brooklyn Marina		Petpeswick Yacht Club	
Mactaquac Marina		Sawmill Point, Boat Basin		Canso Marina		Royal Nova Scotia Yacht Squadron	
Oromocto Boat Club		Shediac Marina		Chester Yacht Club		Sea Rover Marine	
Regent Street Wharf		Station Wharf Marina Inc.		Darmouth Yacht Club		Shearwater Yacht Club	
Rothesay Yacht Club		Sunrise Shore Marina		Guysborough Marina		Shelburne Yacht Club	
Royal Kennebecassis Yacht Club		Bowdridge Landing		Gold River Marina		Shining Waters	
Saint John Marina Ltd.		Cardigan Marina		Lahave River Yacht Club		South Shore Marine	
Saint John Power Boat		Charlottetown Yacht Club		Liscombe Lodge Marina		St. Mary's Boat Club	
Cape Breton		Montague Marina		Lunenburg Marina		Yarmouth Marina	
Baddeck Marine		Northport Pier		Other			
Barra Strait Marina		Quartermaster Marine		Country	City / town	Marina/Yacht Club	# Day
Bras d'Ors Yacht Club		Silver Fox Marina					
Cape Breton Boat Yard		Souris Marina					
Dodson Yacht Club		Stanley Bridge Marina					
Dundee Marina		Victoria Harbour					
Isle Madame Boat Club		USA					
Northern Yacht Club		Agamenticus Yacht Club					
Petit de Grat Marina		Biddeford Pool Yacht Club					
Port Hawkesbury Marina		Boston					
Royal C.B. Yacht Club		Camden Yacht Club					
St. Peters Marina		Centerboard Yacht Club					
Northumberland Strait – PEI		Harraseeket Yacht Club					
Ballantyne's Cove		New York					
Bathurst Marina		Northeast Harbor Fleet					
Cocagne Cape Port		Portland					
Dalhousie Regional Marina		Rockland Yacht Club					
O Never moored outside my home marina						O Unknowm	

Atlantic Coast (DFO work) Boater Questionnaire (Data collected from 2011-2014)

Date: ____/____/2011 (dd/mm/yyyy)

Boat name: ____

Berth number:__________________

If applicable, where is your home marina?

Name: ______________________ Province/State: _______________

City /Town: _________________ Country: _____________________

If you are presently outside your home marina/yacht club, how long do you expect to stay? _____ night(s)

Part I: Your Boat

1.Type of craft:

O Sailboat O Power boat O Converted fishing boat

O Fishing boat (used solely for fishing) O Fishing boat (combined fishing and recreational) O Catamaran

2. Size of craft:

Length (feet) ________ and/or Displacement (tonnes)________

3. Hull type:

O Wood O Fibreglass O Aluminum O Other (specify) _______________

4. Do you use a tender? O Yes O No

- In total, how many days was it in the water last year? ______
- Did you take your tender to any other location besides your home marina?
  O Yes O No
- Do you clean it before taking it outside your home marina?
  O Yes O No
- While sailing, do you
  - O tow your tender?
  - Or
  - O transport it on deck or in davits?

5. Where do you keep your boat?

O In the water for a part of the year:

Part II: Boat Movement

9. Indicate what type of trips you have taken or plan to take with your boat this boating season.

___ Day trips – out and back same day (to home marina)

___ Long trips – remain at a single destination more than 4 nights

___ Racing

___ Tours – visit more than 2 destinations in 1 trip

___ Weekenders – trip of 1-4 nights before coming back to home marina

☐ Other (please specify) ____

10. How many boating trips (1 night or longer) did you take last summer (2010)?____________trips

11. How many days did you sail your boat last summer (2010)?_____

12. If you've sailed your boat this year, list the last 5 marinas/ports where your boat was moored/berthed.

City /Town	Marina/Yacht Club	What day did you leave that area? (dd/mm/yyyy)	How long were you there? (nights)

13. How did you get here?
    O Sea
    O Trailer/Over land

14. During the 2010 boating season, what was the longest time you spent moored, tied up, or anchored outside your home marina?

______months, ______days

Location: _______________

15. Did you travel outside Canada? If so, please indicate locations

16. Please indicate the number of nights you moored/berthed your boat at the following locations this season/year:

Quebec	# Nights	Cape Breton	# Nights	Nova Scotia	# Nights	Nova Scotia	# Nights
Port de Refuge de Cap-à-l'Aigle		Petit de Grat Marina		Alderney Marina Ltd.		Oak Island Marina	
Club Nautique de Tadoussac		Port Hawkesbury Marina		Armdale Yacht Club		Petpeswick Yacht Club	
Club Nautique de Baie-Comeau		Royal C.B. Yacht Club		Bedford Yacht Club		Royal Nova Scotia Yacht Squadron	
Club Nautique de Sept-Îles		St. Peters Marina		Brooklyn Marina		Sea Rover Marine	
Marina de Trois-Pistoles		PEI/NS/NB Northumberland Str.		Canso Marina		Shearwater Yacht Club	
Club Nautique de Rivière-du-Loup		Ballantyne's Cove		Chester Yacht Club		Shelburne Yacht Club	
Marina de Rimouski		Bathurst Marina		Darmouth Yacht Club		Shining Waters	
Club de Yacht de Matane		Cocagne Cape Port		Guysborough Marina		South Shore Marine	
Club Nautique de Cap-aux-Meules inc.		Dalhousie Regional Marina		Gold River Marina		St. Mary's Boat Club	
Club Nautique du Chenal inc. (Havre-aux-Maisons)		Hector Quay Marina		Lahave River Yacht Club		Yarmouth Marina	
Club Nautique les Plaisanciers du Havre		Miramichi Yacht Club		Liscombe Lodge Marina			
Club Nautique de Carleton		Pointe de Chene		Lunenburg Marina			
Marina de Bonaventure		Richibucto		Lunenburg Yacht Club			
Marina de Paspébiac		Sawmill Point, Boat Basin		Mahone Bay Classic Boat Marina			
Club Nautique de New Richmond		Shediac Marina		Others			
Club Nautique de Chandler		Station Wharf Marina Inc.		Country	City/Town	Marina/Yacht Club (if applicable)	# Nights
Club Nautique de Percé		Sunrise Shore Marina					
Québec (précisez)		Bowdridge Landing					
Montréal (précisez)		Cardigan Marina					
Cape Breton		Charlottetown Yacht Club					
Baddeck Marina		Montague Marina					
Barra Strait Marina		Northport Pier					
Bras d'Ors Yacht Club		Quartermaster Marine					
Cape Breton Boat Yard		Silver Fox Marina					
Dodson Yacht Club		Souris Marina					
Dundee Marina		Stanley Bridge Marina					
Isle Madame Boat Club		Victoria Harbour					
Northern Yacht Club							

Pacific Coast (Clarke Murray et al. 2013) boater questionnaire

Date survey completed: ____/____/________ (dd/mm/yyyy)

1. Permanent residence information
   Province/State ______________________________
   Country ___________________________________

<u>Part I: Your Boat</u>

2. Type of craft:
   - o Sailboat
   - o Power boat
   - o Converted fish boat
   - o Personal watercraft (e.g. Seadoo)
   - o Other (specify) ____________________
3. Hull type:
   - o Wood
   - o Aluminium
   - o Fibreglass
   - o Other (specify) ____________________
4. Size of craft: Length (in feet)_________________________________
   <u>and/or</u> Displacement (in tonnes) ___________________

5. Where is your boat stored? Please check one of the following four choices.
   - o In the water year-round.
     What is the name and location of your home marina?

     Name ________________________________

     City or Town __________________________

     Province/State _________________________

     Country ______________________________

   - o In the water only part of the year.
     Which marina do you use _____________________________

     How long was your boat stored in the water during the past 12 months?

     ____

   - o Stored on land and trailered to launch site.
     What is the boat launch you most commonly use? If unknown please write the closest city or town to the boat launch

     ____

   - o Other (please specify) ____

Part II: Antifouling

1. What types of antifouling practices do you employ on your boat? Please fill in all that apply.
   - o None
   - o My boat is brand new and has not been cleaned yet
   - o I recently bought my boat and do not know its antifouling history
   - o Antifouling paint:

     How often do you apply antifouling paint to your boat's hull (or have it applied?) eg. Once a year, Every two years, etc. __________________
     ____

     What was the date of the last antifouling treatment you applied or had applied to your boat:
     ____/________ (month/year)

     What type of antifouling paint did you apply during your last application treatment? If you can remember please enter the brand name of the paint in addition to the type. If you do not know the type of paint, you can enter the brand name only.

     - o Ablative
     - o Hard
     - o Combination
     - o I don't know

       Product brand name used (if known): _______________________

   - o Manual hull cleaning (brushing, scrubbing, pressure-wash, etc.):

     How often do you manually clean your boat's hull?
     ____

     What was the date of your last manual cleaning?

     ____/________ (month/year)

     What methods of manual cleaning do you employ? Check all that apply.

     - o Scrubbing
     - o Scraping
     - o Power washing
     - o Other (please specify) _______________________________________

     Where do you perform your boat's manual hull cleaning? Please select all that apply.

     - o In water
     - o On tidal grid
     - o In dry dock
     - o On land
     - o Other (please specify) _______________________________________

Part III: Boat Movement

Please provide information on the use and movement of your craft within the past 12 months:

1. What types of trips did you take on your boat within the last 12 months? Check all that apply.
   - o Locals – out and back to home marina in one day
   - o Racing – trips made for the purpose of racing the boat
   - o Weekenders – trips of a few days duration visiting 1-2 different moorages
   - o Long trips – long haul travel to destinations further away, once there remain in a single moorage the entire time
   - o Tours – long trips with multiple destinations along the way, staying in each moorage for only a few nights
   - o Other (please specify) ____

11. In the last 12 months, what was the maximum amount of time you spent moored, tied up, or anchored in any single place outside your home marina?

   - o Never moored outside my home marina
   - o Unknown – it is a charter boat
   - o 1 day
   - o 2 days
   - o 3 days
   - o 4 days
   - o 5 days
   - o 6 days
   - o 1 week
   - o 2 weeks
   - o 3 weeks
   - o 1 month
   - o 2 months
   - o 3 months
   - o 4 months
   - o 5 months
   - o 6 months
   - o 7 months
   - o 8 months
   - o 9 months
   - o 10 months
   - o 11 months

11. Please check the names of **all the places** you visited **on your boat** within the **last 12 months:**

√	**Lower Mainland**		**West Vancouver Island**		**North Coast & Queen Charlotte Islands**
	Vancouver		Tofino		Prince Rupert
	Horseshoe Bay		Ucluelet		Terrace
	Coal Harbour		Bamfield		Skidegate
	False Creek		Broken Islands Group		Masset
	Ladner		Port Alice		Queen Charlotte City
	Port Moody		Zeballos		Port Simpson
	Abbotsford		Winter Harbour		Kitimat
	Delta		Coal Harbour		Kemano
	Port Coquitlam		Tahsis		
	Richmond				
	South Vancouver Island		**Mid-North Vancouver Island**		**Central Coast**
	Berry Island		Nanaimo		Bella Coola
	Blind Channel		Protection Island		Bella Bella
	Pender Island		Nanoose Bay		Rivers Inlet
	Mayne Island		French Creek		Namu
	Galiano Island		Fanny Bay		Ocean Falls
	Thetis Island		Deep Bay		Klemtu
	Gabriola Island		Quadra Island		Kingcome
	Mudge Island		Cortes Island		Hartley Bay
	Saturna Island		Denman Island		Hakai Pass
	Saltspring Island		Hornby Island		Dawsons Landing
	Sidney		Comox		Dean River
	Saanich		Courtenay		Butedale
	Squamish		Campbell River		
	Sooke		Port McNeil		**Sunshine Coast**
	Victoria		Sayward		Gibson's
	Mill Bay		Alert Bay		Sewell
	Cowichan Bay		Telegraph Cove		Bowen Island
	Ladysmith		Port Alberni		Sechelt
	Crofton		Royston		Powell River
	Port Renfrew		Quathiaski Cove		Lund
			Port Hardy		Ladner
			Heriot Bay		Minstrel Island
			Kelsey Bay		North Broughton Island
			Hanson Island		Okeover Inlet
			Bull Harbour		Owen Bay
					Port Neville
					Refuge Cove
					Savary Island
					Simoon Bay
					Sointula
					Stuart Island
					Surge Narrows
					Passage Island
					Pender Harbour

10. Did you travel with your boat to any provinces outside of British Columbia within the last 12 months? Please check all provinces you visited.

- Alberta
- Manitoba
- New Brunswick
- Newfoundland
- Nova Scotia
- Ontario
- Prince Edward Island
- Quebec
- Saskatchewan
- Northwest Territories
- Nunavut
- Yukon

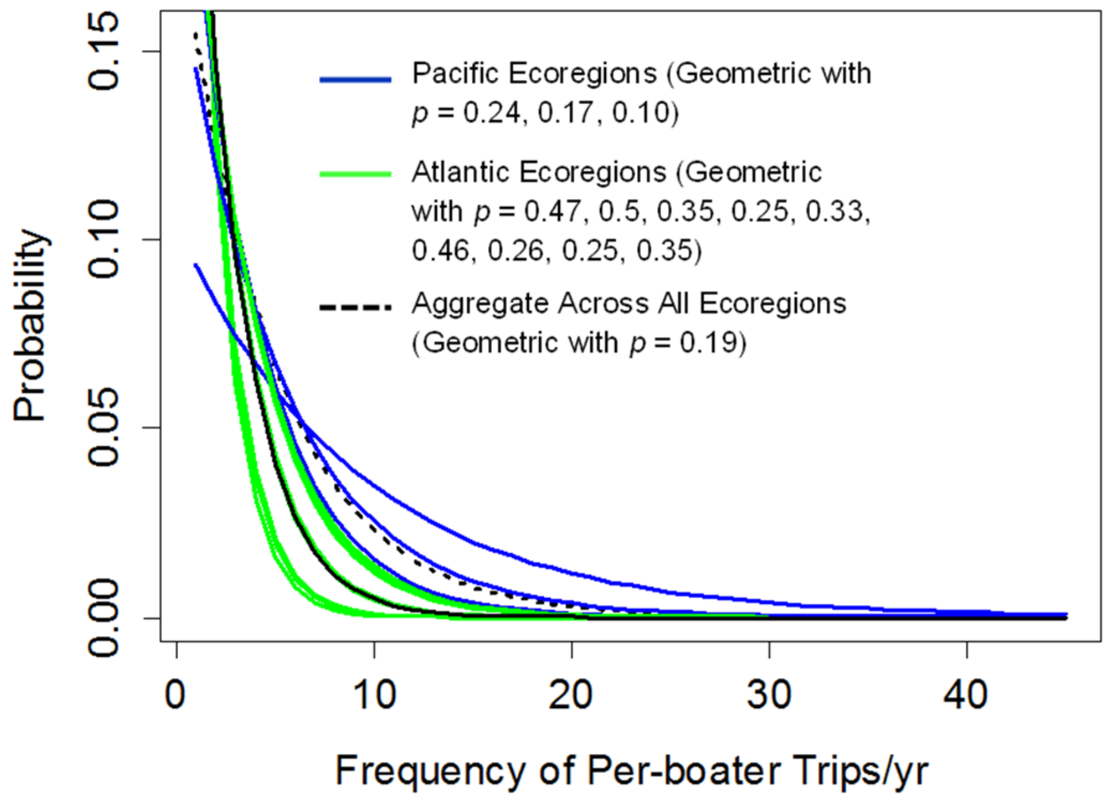
11. Did you travel to the US with your boat within the last 12 months? If yes, please check all states that you visited.

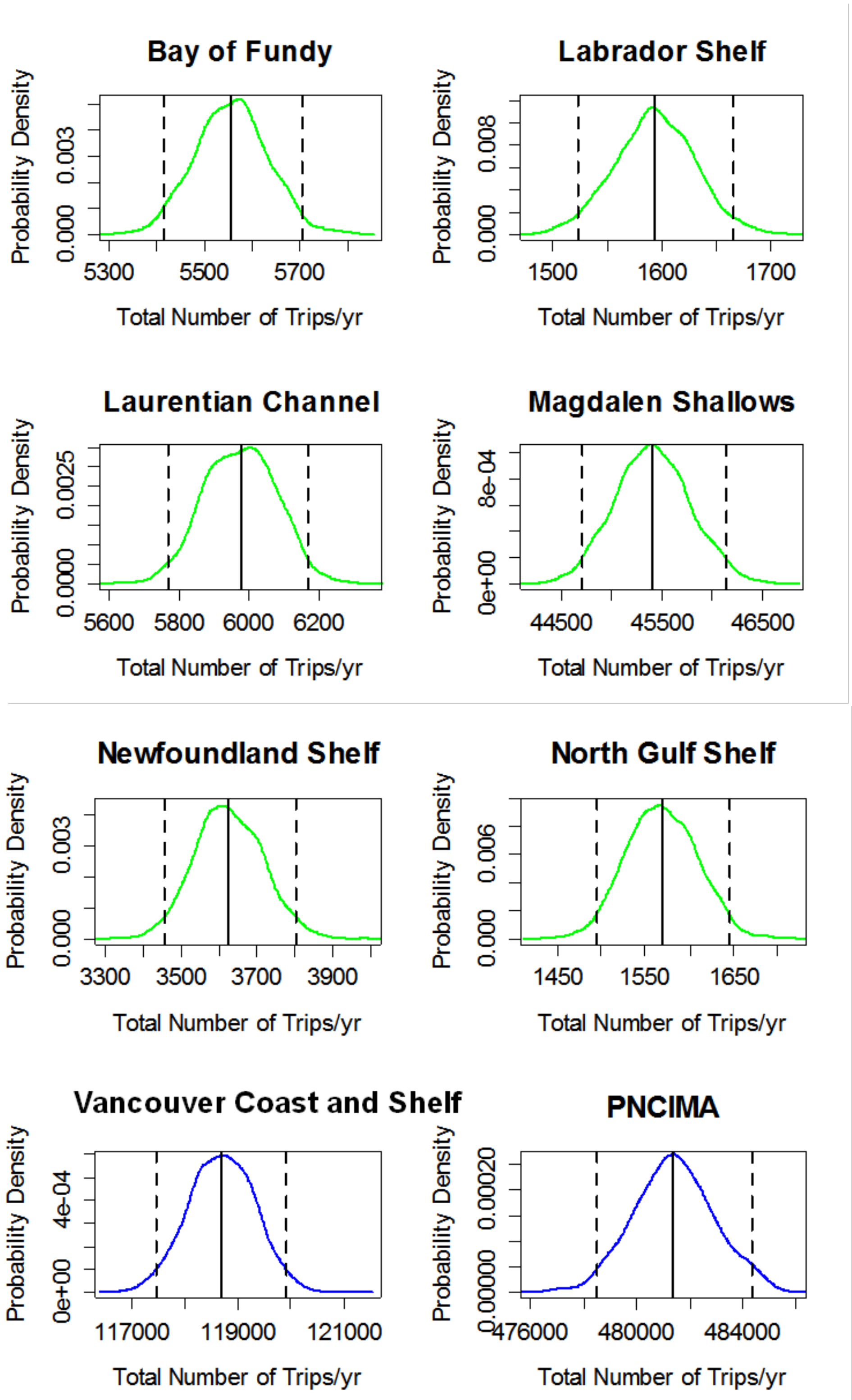
- Alabama
- Alaska
- Arizona
- Arkansas
- California
- Colorado
- Connecticut
- Delaware
- Florida
- Georgia
- Hawaii
- Idaho
- Illinois
- Indiana
- Iowa
- Kansas
- Kentucky
- Louisiana
- Maine
- Maryland
- Massachusetts
- Michigan
- Minnesota
- Mississippi
- Missouri
- Montana
- Nebraska
- Nevada
- New Hampshire
- New Jersey
- New Mexico
- New York
- North Carolina
- North Dakota
- Ohio
- Oklahoma
- Oregon
- Pennsylvania
- Rhode Island
- South Carolina
- South Dakota
- Tennessee
- Texas
- Utah
- Vermont
- Virginia
- Washington
- West Virginia
- Wisconsin
- Wyoming

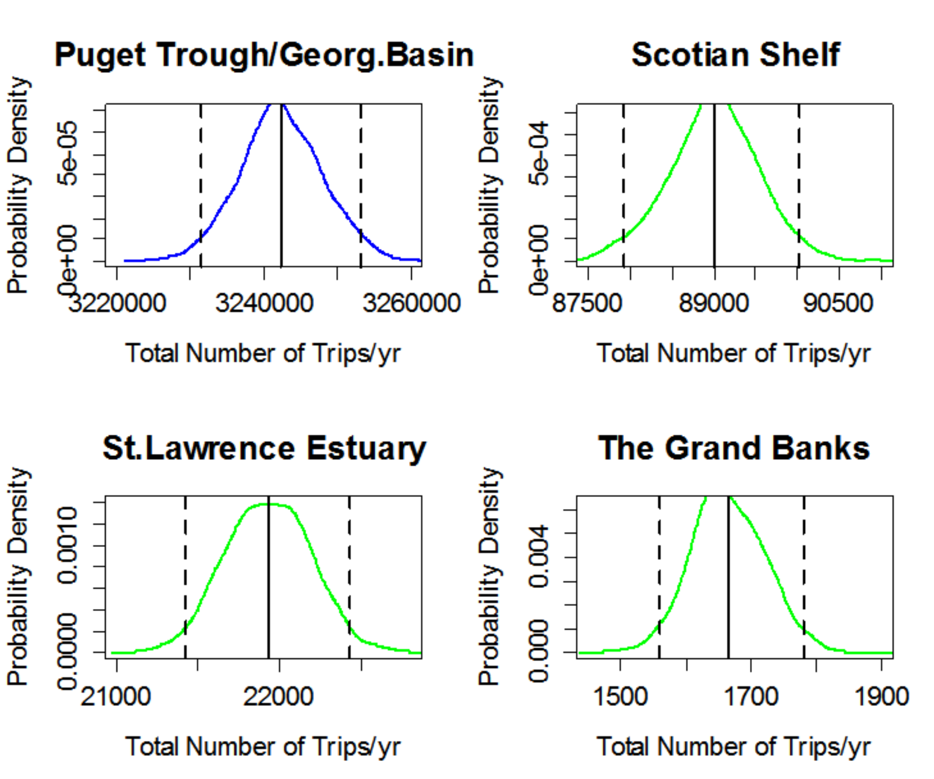
12. If applicable, please write all the countries outside of Canada and the US that you visited on your boat in the last 12 months.

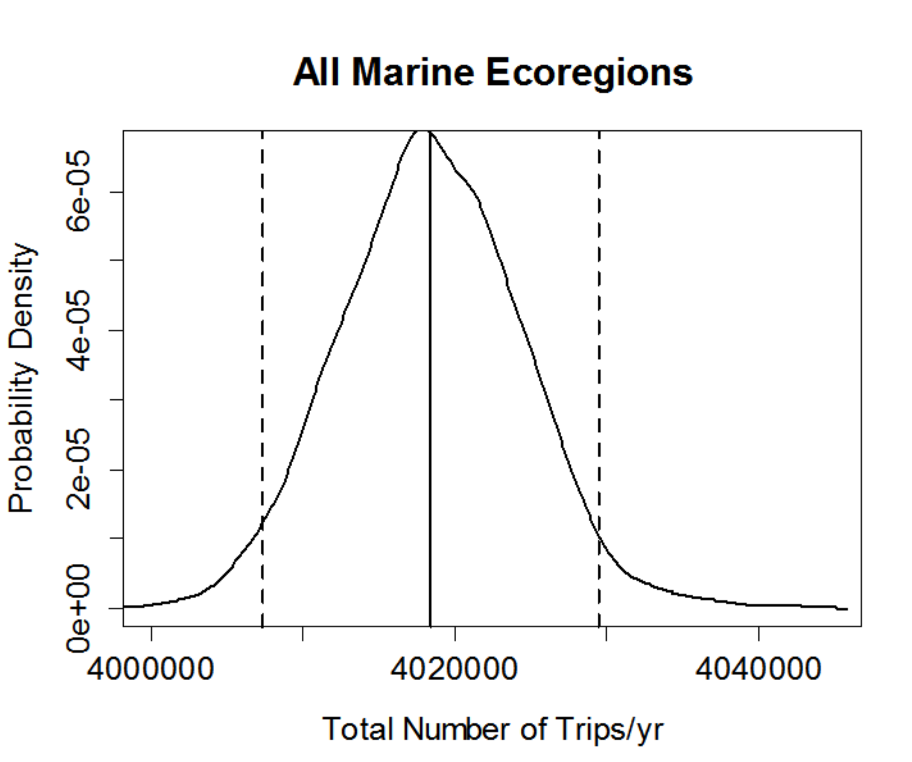
APPENDIX 3: ESTIMATION OF CANADIAN MARINE TRIPS

Estimation of the absolute annual number of transient marine recreational boating trips in Canada based on a Monte Carlo re-sampling process and zero-truncated geometric distributions. The upper panel illustrates the fitted frequency distributions describing the number of yearly trips taken by individual boaters within an ecoregion; whereas, lower panels describe the total number of yearly trips taken by all transient boaters in each ecoregion Results in the lower panel are reported as a 95% confidence interval (dashed vertical lines, i.e., true population estimate between upper and lower bound) and mean values (solid vertical lines).




Bay of Fundy
Probability Density
0.000 0.003
5300 5500 5700
Total Number of Trips/yr
Labrador Shelf
Probability Density
0.000 0.008
1500 1600 1700
Total Number of Trips/yr
Laurentian Channel
Probability Density
0.0000 0.0025
5600 5800 6000 6200
Total Number of Trips/yr
Magdalen Shallows
Probability Density
0e+00 8e-04
44500 45500 46500
Total Number of Trips/yr
Newfoundland Shelf
Probability Density
0.000 0.003
3300 3500 3700 3900
Total Number of Trips/yr
North Gulf Shelf
Probability Density
0.000 0.006
1450 1550 1650
Total Number of Trips/yr
Vancouver Coast and Shelf
Probability Density
0e+00 4e-04
117000 119000 121000
Total Number of Trips/yr
PNCIMA
Probability Density
0.00000 0.00020
476000 480000 484000
Total Number of Trips/yr


Puget Trough/Georg.Basin
Probability Density
0e+00
5e-05
3220000
3240000
3260000
Total Number of Trips/yr
Scotian Shelf
Probability Density
0e+00
5e-04
87500
89000
90500
Total Number of Trips/yr
St.Lawrence Estuary
Probability Density
0.0000
0.0010
21000
22000
Total Number of Trips/yr
The Grand Banks
Probability Density
0.000
0.004
1500
1700
1900
Total Number of Trips/yr


All Marine Ecoregions
Probability Density
0e+00
2e-05
4e-05
6e-05
4000000
4020000
4040000
Total Number of Trips/yr