Aquatic Invasive Species research funded by Fisheries and Oceans Canada 2005-2010

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TABLE OF CONTENTS

LIST OF TABLES iv
LIST OF FIGURES iv
LIST OF APPENDICES iv
ABSTRACT v
RÉSUMÉ vi
INTRODUCTION 1
LINK TO THE DFO MANDATE 1
THE AQUATIC INVASIVE SPECIES PROGRAM 3
METHODS 4
SUMMARY OF THE RESEARCH PROJECTS 4
RISK ASSESSMENT FRAMEWORK 5
SHIPPING AS A PATHWAY 6
Ballast water 6
Sea-chests 8
Ballast sediments 9
Identification of source regions of AIS 9
AQUACULTURE 10
Vectors of spread 10
AIS tolerance to environmental factors 11
Control and adaptive management 12
Impact of invasive tunicates on the aquaculture industry 14
OTHER STUDIES 15
Recreational fishery 15
Biodiversity 15
Habitat association 18
Management options 19
DISCUSSION AND CONCLUSIONS 20
LITERATURE CITED 23
APPENDICES 29

LIST OF TABLES

Table 1. AIS spending from 2005-2010. 3
Table 2. AIS Risk assessments published by DFO. 6
Table 3. Species of elevated concern as listed by the provinces and regions in 2009-2010 that were targeted by DFO AIS research funds, DFO/ CEARA, and CAISN. 22
Table 4. The amount of funding allocated to research per year during the period 2005-2010 through the AIS Program. 29

LIST OF FIGURES

Figure 1. Approach to respond to invasive alien species at different stages of an invasion. 2
Figure 2. Funding allocation from 2005-2010 according to major research themes (amounts in $1000). 5
Figure 3. Funding allocation according to activity or species (amounts in $1000). 23
Figure 4. Funding allocation according to region (amounts in $1000). The national projects are projects not linked to a specific region, or involve several regions. 29

LIST OF APPENDICES

Appendix A. Allocation of research funding per year and region 29
Appendix B. Summary information by individual research projects 30
Appendix C. Objectives and outcomes of individual research projects 33
Appendix D. Questionnaire to compile information 38

ABSTRACT

Kestrup, Å.M., and Foster, S.E. 2012. Aquatic Invasive Species research funded by Fisheries and Oceans Canada 2005-2010 Can. Manuscr. Rep. Fish. Aquat. Sci. 2998E: vi + 38 p.

The AIS Program was initiated in 2005 to assist Fisheries and Oceans Canada (DFO) respond to the invasive species challenge. From 2005-2010 $3 million was spent on research, covering a wide range of issues, including research linked to the prevention of new invasions and the management of established and spreading invaders (containment, eradication, and control). Much of the funded research targeted the shipping pathway and invasive tunicates in the aquaculture industry. The DFO AIS research projects supplemented other AIS activities in Canada such as the Canadian Aquatic Invasive Species Network research and DFO's risk assessments. Together these activities targeted most of the species listed by the provinces and regions as being of elevated concern. The results from the research projects have been used to provide scientific advice in support of regulations, policy and management strategies, and have been communicated to a wide range of stakeholders.

RÉSUMÉ

Kestrup, Å.M. et S.E. Foster. 2012. Recherche sur les espèces aquatiques envahissantes financée par Pêches et Océans Canada, 2005 - 2010. Rapp. man. can. sci. halieut. aquat. 2998E : vi + 38 p.

Le Programme sur les espèces aquatiques envahissantes (PEAE) a été lancé en 2005 pour aider Pêches et Océans Canada (MPO) à régler le problème que posent les espèces envahissantes. Entre 2005 et 2010, trois millions de dollars ont été investis dans des projets de recherche couvrant un large éventail de sujets, y compris la recherche liée à la prévention de nouvelles introductions et à la gestion des espèces envahissantes déjà établies et dont l'aire de répartition est en progression (confinement, éradication et contrôle). La plus grande partie de la recherche financée visait le transport maritime et les tuniciers envahissants présents dans l'industrie de l'aquaculture. Les projets de recherche sur les espèces aquatiques envahissantes (EAE) du MPO se sont ajoutés aux autres activités portant sur les EAE au Canada, telles celles effectuées par le Réseau national de recherche sur les espèces aquatiques envahissantes (CAISN) et les évaluations des risques du MPO. Toutes ces activités visaient la plupart des espèces considérées comme étant très préoccupantes par les provinces et les régions. Les résultats des projets de recherche ont permis la formulation d'avis scientifiques en appui à des règlements, des politiques et des stratégies de gestion, et ont été transmis à un large éventail d'intervenants.

INTRODUCTION

The following document provides an overview of the accomplishments of the research projects that received funding from the Aquatic Invasive Species Program (AIS Program) and were carried out across Canada by the regional research laboratories of the Department of Fisheries and Oceans Canada (DFO) during the first five years (2005-2010) of the AIS Program. During this period, DFO also contributed to the funding of the Canadian Aquatic Invasive Species Network (CAISN) which allowed DFO to establish partnerships with Canadian Universities.

Science is the foundation of DFO's strategic outcomes that are vital to Canada's economy and environment: Sustainable Fisheries and Aquaculture, Healthy and Productive Aquatic Ecosystems, and Safe and Accessible Waterways. The different science activities performed at DFO, including research, monitoring, advice, products and services, data management, and science management, serve these strategic outcomes. From 2005-2010, a total of $3 M was spent on various AIS targeted research projects across Canada (Table 1). Objectives of the AIS research program include: providing advice on the relative risk of an aquatic invasive species, to inform rapid response plans (the capacity to respond quickly to an invasion where prevention of the invasion fails) and to develop monitoring programs of high risk species, pathways and locations.

In this document, we will review the research component of the AIS program and discuss how results were used to inform other science and management activities. We will also discuss how this work was supplemented by CAISN. Where possible, this report will also give an account of how the results from the research projects have been used to test and inform regulations, and to inform management practices to control the invader and reduce the risk of secondary spread. Many of the funded research projects contributed to the development of risk assessments in order to determine the risk of AIS to Canada's aquatic ecosystems, including the development of a risk assessment framework and the production of risk assessments for a range of invaders and pathways. Results informed risk assessments, or addressed gaps of knowledge identified in completed risk assessments. Results from the other science activities have also contributed to the research program, for example, information from the monitoring activities have fed into several research projects, while results from the research projects have been used to develop monitoring programs. In addition, results from the research projects have also been used to inform rapid response planning.

LINK TO THE DFO MANDATE

Aquatic Invasive Species (AIS) are one of the leading threats to aquatic biodiversity and ecosystem health. They have the potential to displace domestic species that support traditional fisheries, and have a significant negative impact on industry, such as the aquaculture industry. Research is required to identify high-impact species and activities, guide management measures, support decision making, and support the development of

policies and regulations. These activities will support DFO delivery of its strategic outcome "Sustainable Fisheries and Aquaculture"[1].

The "Invasive Alien Species Strategy for Canada" (IAS Strategy) was developed in 2004 and proposes to respond to the invasive alien species challenge at the different stages of invasion with an approach that prioritizes the following activities (Fig. 1):

1) prevention of new invasions;
2) early detection of new invaders;
3) rapid response to new invaders; and
4) management of established and spreading invaders (containment, eradication, and control)

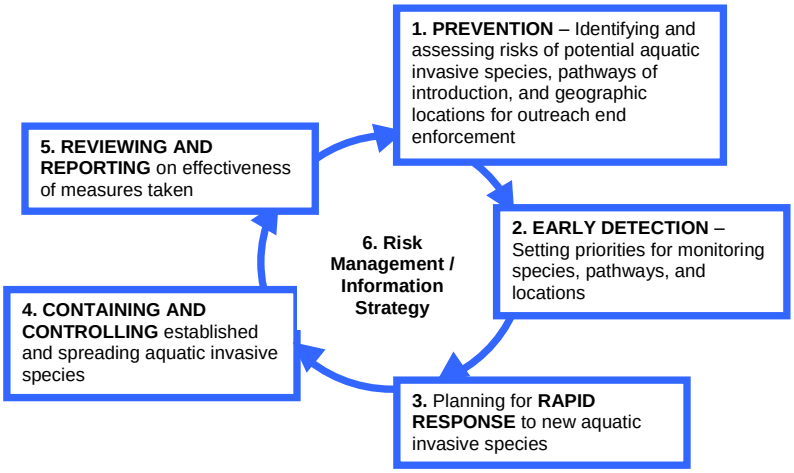

Figure 1. Approach to respond to invasive alien species at different stages of an invasion.

The "Canadian Action Plan to Address the Threat of Aquatic Invasive Species" (Canadian Action Plan) was developed in 2004 to implement the IAS Strategy. The Canadian Action Plan identified a number of key areas where action may prove effective in limiting the introduction and spread of alien species, including; *Identification* of the specific pathways by which organisms enter and spread through Canadian waters, and *prevention* of their entry into Canadian waters. For species that have already been introduced, the focus turns to; *early detection, rapid response, eradication, control of their spread,* or *adaptive management*.

AIS was identified as one of the research priority areas on DFO's 5-year research agenda (2007-2012), whose research is considered essential to address federal and departmental

[1] In 2011-2012 and onwards, due to an evolution of DFO Strategic Outcomes, the AIS Program will support delivery of the "Healthy Ecosystems" strategic outcome.

priorities and public good needs over a five year period. One of the key outcomes of the research program is to create new knowledge and methods that will support the development of better advice required for policy and decision making and in particular, ecosystem-based management.

THE AQUATIC INVASIVE SPECIES PROGRAM

In 2005, the Government of Canada provided $4 million in funding per year over five years to DFO to initiate the development of an aquatic invasive species program and to increase its contribution to the Great Lakes Fisheries Commission for the management of the sea lamprey in the Great Lakes through the Sea Lamprey Control Program consistent with the Canadian Action Plan. The long-term objectives of the AIS Program are to control the pathways by which AIS enter into Canadian waters in order to prevent future invasions and to control the spread of existing AIS. The funding was directed to scientific research and monitoring of AIS activities, as well as the development of risk assessments and a regulatory framework (Table 1).

Table 1. AIS spending from 2005-2010.

Theme	Funding ($1 M)
Sea Lamprey Program	10.0
Policy	1.0
Monitoring	3.0
Research	3.0
Risk Assessment (incl. CEARA)	2.0
Other (rapid response, database, coordination, networking)	0.5
CAISN	0.5

Within the Oceans and Science sector, the funding was allocated to the following envelopes/themes:

- *Research* - DFO has undertaken research related to pathways of introduction, factors affecting species' establishment, ecosystem impacts and mitigation methods. Research activities have been carried out within DFO and through a collaboration arrangement with CAISN. CAISN's focus was research on pathways of introduction and factors affecting species establishment. The funding for AIS research was sometimes supplemented by Strategic funds.

- *Monitoring* - DFO has funded regional surveillance and monitoring networks for high risk pathways of introduction, species, and geographic locations.

- *Rapid Response* - Rapid response is the capacity to respond quickly to an invasion where prevention of the invasion fails. While eradication is the primary goal, other management options include containment of the population, suppression of the population to slow its spread, or adaptation. Funding was allocated to the development of a science based rapid response framework. Future activities will focus on

developing legal and regulatory authorities, including the supporting policy framework, for the management of aquatic invasive species in cooperation with the provinces and territories.

- *Risk Analysis* - Risk assessment activities include the development of a science-based risk assessment model and the completion of risk assessments for priority pathways and species in order to facilitate policy and regulatory-based pathway management. In 2006, DFO established the Centre of Expertise for Aquatic Risk Assessment (CEARA) to develop the necessary expertise in risk assessment across the country and to develop national standards for, and to provide guidance on, scientifically defensible biological risk assessment tools and methods needed to identify key points in the invasion pathway and maximize the efficient use of limited resources to achieve the greatest potential for the prevention, eradication or control of AIS. CEARA is also responsible for identifying risk assessment priorities and tracking national risk assessments to provide science advice related to healthy and productive aquatic ecosystems and sustainable fisheries and aquaculture.

For information on the amount of funding allocated to research per year, see Table 4 in Appendix A.

METHODS

The information in this report was assembled in 2010-2011 by contacting the lead scientists that received funding from the AIS program during the period 2005-2010 for AIS research projects. The lead scientists were asked to answer the questions listed in Appendix D. Where the lead scientist no longer worked at DFO, the information was provided by the relevant manager.

SUMMARY OF THE RESEARCH PROJECTS

The majority of the research projects that received funding from the AIS Program were directly linked to the priorities identified in the IAS Strategy for Canada and the Canadian Action Plan, in particular they are linked to the following: prevention of new invasions and management of established and spreading invaders (containment, eradication, and control). Several projects were not directly linked to any of the four priorities, such as projects studying the biology, impact, and habitat association of a species, but have created new knowledge in order to identify high priority risks and set priorities and inform decision makers. Many projects covered more than one research theme (Fig. 2). Most research projects were specific to a region, but several projects were national in scope (Appendix A; Fig. 4).

Of the funding spent on research, 20% was spent on projects that fed directly into a risk assessment, 27 % was spent on projects that addressed gaps identified in a previous risk assessment, and 4% was spent on projects that did both. Fifty percent of the funding was spent on projects that were not directly linked to a risk assessment, although several projects focused on species and themes addressed in risk assessments.

In this report, projects have been grouped according to their linkage to shipping, aquaculture, biodiversity and recreational fishery for clarity of presentation, rather than according to their linkage to the above-mentioned priorities. All projects are listed in Appendices B and C. Appendix B provides an overview for each individual project, by the year funding was received, the amount of funding received, region, species, research theme and link to risk assessment. Appendix C provides an overview of the objectives of each project, if the results were used by management, legislation, or policy, and the publications produced.

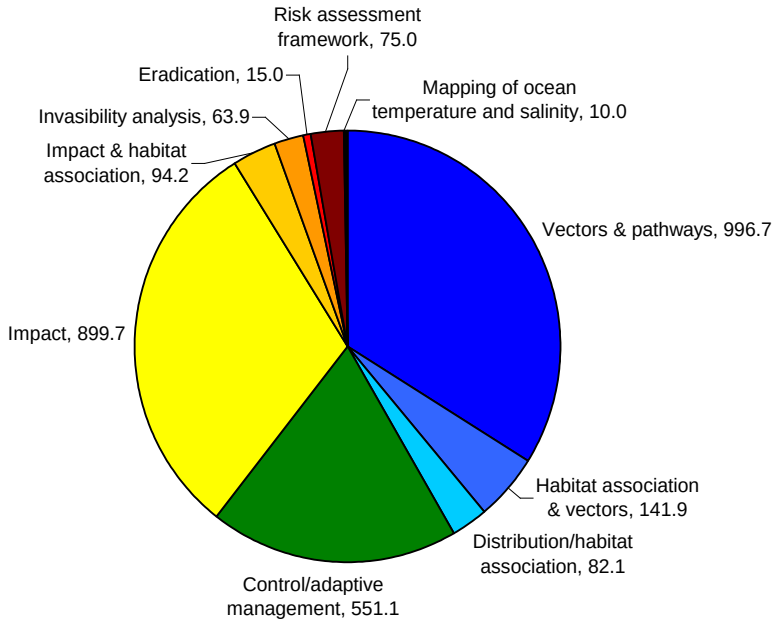

Figure 2. Funding allocation from 2005-2010 according to major research themes (amounts in $1000).

RISK ASSESSMENT FRAMEWORK

When making decisions on AIS, knowledge gaps, the uncertainties of current scientific knowledge, and the risks associated with not taking action must be balanced while ensuring the sustainability of Canada's aquatic ecosystems. Risk assessment is the process of estimating the risk presented by AIS to aquatic ecosystems, fisheries resources, fish habitat, and aquaculture, and has been identified as one of the implementation strategies to deal with the threat of AIS.

Research funding was used to develop and evaluate a quantitative biological risk assessment framework which can be applied to risk assessments of any AIS, and has been applied in risk assessments and in the evaluation of risk assessment guidelines (Cudmore *et al.* 2007, Cudmore and Koops 2007, Drouin and McKindsey 2007, Herborg and Therriault 2007, Johannsson 2007, Locke and Klassen 2007, Moore *et al.* 2007). However, while research funding was provided to develop the risk assessment

framework, the completion of the risk assessments was funded through CEARA at DFO. As of March 2011, 15 risk assessments have been published (Table 2).

Table 2. AIS Risk assessments published by DFO.

Species and province/region	Publication number in the CSAS* Res. Doc. series
Asian carps	2004/103
Northern snakehead *Channa argus*	2005/075
Dead man's hand *Codum fragile*	2007/007
Round goby *Neogobius melanostomus*	2007/038
Tunicates (only *Didemnum* sp.) in BC	2007/056
Spiny water flea *Bythotrephes longimanus*	2007/059
Tunicates, Atlantic and Pacific coasts, 5 species	2007/063
Green crab *Carcinus maenas*, Atlantic Canada	2007/077
Green crab, Atlantic and Pacific coasts	2008/042
Yellow perch *Perca flavescens*, BC	2008/073
Northern pike *Esox lucius*, pumpkinseed *Lepomis gibbosus*, and walleye *Sander vitreus*, BC	2008/074
Chinese mitten crab *Eriocheir sinensis*, Atlantic and Pacific coasts	2008/041
Largemouth *Micropterus salmoides* and smallmouth bass *M. dolomieu*, BC	2008/075
Bloody red shrimp *Hemimysis anomala*	2009/107
Largemouth bass and smallmouth bass, Gulf region	2010/065
Alternate Ballast Water Exchange Zones, Newfoundland and Labrador Region	2010/087
New Zealand mud snail *Potamopyrgus antipodarum*	2010/108

* Canadian Science Advisory Secretariat

SHIPPING AS A PATHWAY

Commercial shipping, including transoceanic ships, coastal vessels, and lakers, has been identified as an important pathway for both initial introductions of AIS to Canadian waters and secondary spread within Canadian waters of already established invaders. Live organisms picked up at previously visited ports are released when ballast water and ballast sediments are discharged at the destination. Ships cannot completely empty their tanks when discharging the ballast water, and carry a mixture of ballast water and sediment (i.e. particle-rich liquid ballast residual) in the tanks. However, the risk of transferring AIS when discharging this ballast residual and sediment had not previously been assessed. Shipping may also be introducing or facilitating the dispersal of fouling organisms (that attach to and grow upon hard objects below water) attached to sea-chests and hulls. Several research projects funded by the AIS Program have addressed the risk of introducing and spreading AIS through this pathway, many of which will feed into the national shipping risk assessment.

Ballast water

In 2005, a bibliography on Canadian ballast water research and management was developed and shared with Transport Canada (TC). It was made available to the public via the ballast water website of TC in order to increase the access to existing information on ballast water.

The Quebec region led the development of a ballast water database which was jointly funded by DFO, TC and CAISN. The database includes information on ballast water of foreign vessels coming from outside the exclusive economic zone (200 nautical miles from the coast) with the intent to discharge ballast water in Canadian ports, including the quantity of ballast water, the location of the exchange and the volume exchanged. This information is collected as ships must report to TC before entering Canadian waters using a ballast reporting form. The information in this database will further inform research and management activities related to ballast water.

Two projects examined efficacy of regulations proposed by the International Maritime Organisation (IMO) aimed at reducing the risk of ballast water mediated introductions (i.e. the International Convention for the Control and Management of Ships' Ballast Water and Sediments). One of the projects carried out by the Maritimes region assessed the risk of introduction of generic planktonic species contained in ballast water following the practice of mid-ocean exchange of ballast water (Regulation B-4 Ballast Water Exchange) (Brickman 2006, Brickman and Smith 2007). The objective was to develop a real-time risk assessment model for vessel ballast water exchange. Transoceanic vessels are required to flush their tanks at least 200 nautical miles from the nearest land, where the water is at least 200m deep, to reduce or eliminate the transfer of harmful organisms, and exchange at least 95% of the volume of ballast water with ocean water. The model simulates ballast water exchanges in shelf areas, and computes the relative overall risk of invasion for exchange segments along vessel tracks, as the organisms released are transported with currents towards the coast. The model can also be used to assess the variation in risk along a given vessel track, and provides quantitative guidance to regulators regarding what is an acceptable trip diversion. The model will be made available to vessel operators in Maritime Canada during the first half of 2011.

The objective of the second project was to evaluate if the proposed IMO minimum discharge regulations (Regulation D-2 Ballast Water Performance Standard) are reducing the densities of planktonic AIS (i.e. that float or drift) enough to prevent their establishment once the ballast water is released at the port of destination. The evaluation was based on a worst-case scenario focusing on the establishment of 6 species of parthenogenetic cladocerans, small zooplankton that reproduce asexually and are able to rapidly increase in numbers under favourable conditions, even when arriving at low densities. When reaching a critical threshold density, these organisms can produce diapausing eggs (highly resistant resting stages) which largely increases their chances of long term survival and thus increases the risk of establishment. The current standards stipulate that the concentration of viable organisms larger than or equal to 50 µm in their smallest dimension should be lower than 10 per cubic metre, while the concentration of viable organisms smaller than 50 µm but larger than or equal to 10 µm should be lower than 10 individuals per ml. The results showed that the proposed regulations will reduce the probability of establishment of some taxa substantially, while some taxa may still be able to establish. The study was carried out by the Central and Arctic (C&A) region. The results have been published (Bailey *et al.* 2009) and referred to by TC, who is currently revising the ballast water regulations, as well as the US Coast Guard, the US

Environmental Protection Agency, the 8 American states bordering the Great Lakes, and California. The project is also feeding into the national shipping risk assessment.

Ballast water transfer over short distances by domestic ships in the Great Lakes – St. Lawrence River, which is currently unregulated, may be an important vector of primary introductions of AIS from the St. Lawrence River into the Great Lakes and secondary introductions within the Great Lakes. A project carried out by the C&A region provided scientific evidence to TC whether Great Lakes' vessels are inadvertently responsible for the movement of AIS within the basin, and whether or not regulation of domestic ballast is warranted. In the study, ports were assigned to one of six regions within the system: Lakes Superior, Michigan, Huron, Erie, and Ontario, and the St. Lawrence River. The results showed that 71% of ballast water transfers were interregional, with a net movement of ballast water from the lower to the upper lakes. A small proportion of the ballast water discharged in the Great Lakes (<1%) originated from ports in the St. Lawrence River that may serve as sources for new AIS. The results have been referred to by TC who is currently revising the ballast water regulations, as well as federal and provincial/state authorities in the US and Canada. The results will feed into the national shipping risk assessment and have been presented in one publication so far (Rup *et al.* 2010), and another publication is underway.

Ships traveling outside Canada's Exclusive Economic Zone, i.e. more than 200 nautical miles (270km) from its coast, whether coastal or oceanic, are required to exchange their ballast water with saltwater before entering Canadian waters. Where vessels have been unable to flush their tanks in the open ocean due to unfavourable weather conditions or high seas, they may be allowed to exchange ballast in an Alternate Ballast Water Exchange Zone (ABWEZ) upon the Minister for Transport Canada's approval. The objective of one project was to identify ABWEZ in the Northeastern Newfoundland Shelf region that would minimize the risk of introduction of AIS into ecologically and biologically significant areas (EBSAs) in the Newfoundland and Labrador Region. The scientific advice was based on individual vessel routes approaching the Newfoundland and Labrador region and areas of the northwest Atlantic Ocean and oceanographic modeling (dispersion as a result of ocean currents, mixing and wind patterns). The project identified areas that were recommended for ABWEZ, areas that were of seasonal or moderate concern, and areas that were strongly discouraged due to the probable impact on EBSAs and sustainable fisheries and aquaculture in the Region. The results will be communicated to TC. The project addressed gaps in previous oceanographic models by focusing on ballast movement in Placentia Bay, and expanded the models to include physical data (Han *et al.* 2008, Ma *et al.* 2010), and fed into a risk assessment (DFO 2010ab, McKenzie *et al.* 2010). The model was also used to provide information on the possible route of introduction and potential spread of the European green crab that was discovered in Newfoundland in 2007 (McKenzie *et al.* 2007, Blakeslee *et al.* 2010, DFO 2010c). Two additional documents are in preparation and will be published by the Canadian Science Advisory Secretariat.

Sea-chests

Sea-chests and hulls may be vectors for the introduction or dispersal of fouling organisms in Canadian waters. A national project lead by the Quebec region will provide a better understanding of the types and abundances of fouling organisms on commercial vessels arriving on the east and west coasts of Canada, and the relationship between the fouling communities and vessel specifications, voyage histories, and maintenance records. The findings from the study will help establish guidelines for policy, and are expected to focus future monitoring and management of AIS in Canadian waters and abroad (Frey *et al.* in prep). The results from the study are not currently part of the national shipping risk assessment. Preliminary results were presented at the 2010 DFO Regional Science Forum in Victoria.

Ballast sediments

Although ballast sediments have been recognized as vectors of AIS, little is known about the risk of transferring AIS associated with ballast sediments. In order to improve the estimates of propagule pressure (the number of individuals, the number of species, and the number of introduction events) associated with ballast sediments, a project currently underway in the Quebec region is evaluating the proportion of ballast sediments released during deballasting procedures. Another objective is to examine which portion (i.e., strata) of the sediments is released, as well as the viability of the resting stages of organisms (such as cysts and diapausing eggs that can survive unfavourable conditions) in different layers. Sediment cores from ships with thick layers of sediment showed that the sediment at the bottom of one tank was >10 years old. These findings draw attention to the cumulative propagule pressure on the receiving environment (current vessel transit *vs*. previous years of traveling in other regions of the World). The project is done in collaboration with the University of Windsor and Université du Québec à Rimouski. Another project lead by the Pacific region assessed the potential for ships traveling between ports in the APEC region (Asia-Pacific Economic Cooperation) to transfer AIS into marine and coastal areas when discharging particle-rich ballast residual, and also provided recommendations of areas where flushing/exchange activities (i.e. Mid Ocean Exchange activities) should be avoided to reduce the uptake and/or discharge of potential AIS (Sutherland *et al.* 2009). The results will feed into the national shipping risk assessment.

Identification of source regions of AIS

In order to identify the species that may potentially arrive and establish in Canadian waters, and develop measures to prevent their introduction, it is necessary to identify the source regions of potential invaders. One project underway in the C&A region identified the ports that serve as the dominant sources of ship traffic and ballast water by completing a vector analysis of ship transits for select regions in Canada (East Coast, St. Lawrence Estuary, Gulf of St. Lawrence and the West Coast, not including the Arctic and the Great Lakes region). This was done by assembling port-specific ship transit information for these regions including the number of ships arriving to each port, the date of arrival and the type of vessel. For each ship arrival, the history of the vessel was researched to determine port of origin for the transit, as well as for any ballast water carried on board. In addition, species lists for these ports have been researched to identify the potential impacts of species in these ports if they were to establish in Canadian

waters. The results will support the national shipping risk assessment. Another project in the C&A region examined the risk of introducing AIS into Hudson Bay through the release of ballast water from ships traveling from ports in Europe and North America (North/South Consultants Inc. 2006).

AQUACULTURE

Vectors of spread

Projects on the east and west coasts of Canada examined the role of ocean currents as vectors of secondary spread of AIS that have a planktonic stage (i.e. float or drift) in order to predict future spread, and to assess if other vectors associated with human activities, in particular boating activities linked to the aquaculture industry, contribute to the spread. This research will help to identify the most important vectors for the spread of AIS, which will be useful when developing new management practices to reduce the risk of further spread. Understanding the role of ocean currents in spreading AIS will also be used to guide monitoring projects.

In the Gulf region, commercial activities (boating-vector transport conditions and the equipment used in the catch and processing of lobsters) and ocean currents were identified as the two most important vectors of spread of AIS, while the spread of invasive tunicates caused by natural movements of lobsters, rock crabs and lady crabs was negligible (Bernier *et al.* 2009, Darbyson *et al.* 2009 abc). This indicated that the efforts to limit/reduce spread should be put on recreational and industrial boating. It also lead to the development of models to predict the spread of AIS with a planktonic stage. The data generated by the project has been used by a PhD student to evaluate the effectiveness of search methods to monitor AIS (Kanary *et al.* 2010). A project on the Pacific west coast also examined the dispersal dynamics of the larval green crab in order to forecast its spread through natural dispersal, which helped focus management and monitoring efforts. The results were included in the national green crab risk assessment (Therriault *et al.* 2008) and publications are underway.

In PEI, the work on the relative risk of spread of invasive tunicates by commercial activities and ocean currents has been useful to limit the spread of solitary tunicates to new areas. Every time an application for Introductions and Transfers (I&T) comes in regarding the transport of mussels from one bay to another, an informal risk assessment is carried out. If the request is asking for permission to transfer mussels from a bay infested by the colonial violet tunicate (*Botrylloides violaceus*) to a neighbouring bay not yet infested by violet tunicates, the transfer is approved (under the condition that the mussels are treated), as the violet tunicate probably will spread to that bay sooner or later. However, if a request is done to transfer mussels from a bay infested by the solitary vase tunicate (*Ciona intestinalis*) to a bay on the northern side of PEI not infested by the vase tunicate, the transfer is not approved.

The Japanese skeleton shrimp (*Caprella mutica*) has had a negative impact on aquaculture activities, in particular the collection and growth of juvenile mussels (so called “mussel spat”). This AIS is adapted to filter-feeding and is found almost

exclusively on artificial structures such as nets, ropes and buoys. The species is widespread on both the east and west coasts of Canada. A project in the Quebec region contributed to the development of a strategy to control the spread of the shrimp to new sectors of the Canadian coast. The study, which focused on the mechanisms of the impact of the shrimp on mussel farming, revealed that the establishment and proliferation of the shrimp is facilitated by the presence of collecting plates for juvenile mussels. Furthermore, the shrimp maintains a relationship of facultative kleptoparasitism with the mussel (i.e. it steals food the mussel has caught, but can survive without doing so). The project has resulted in a biological synopsis (Turcotte and Sainte-Marie 2009) and a Master's thesis (Turcotte 2010), while two scientific publications are underway. The project helped develop an ongoing project by the Aquaculture Collaborative Research and Development Program (ACRDP), with the objective to evaluate the efficiency of the measures to reduce the risk of transferring the shrimp in shipments with scallop spat. The ACRDP is a DFO initiative to increase the level of collaborative research and development activity between the aquaculture industry and DFO.

AIS tolerance to environmental factors

Knowledge about the tolerance of AIS to variations in temperature and salinity is useful to predict their potential distribution and subsequently identify areas that are at risk of being invaded. This information can also be used to identify the time of the year when the risk of spreading the invader to new areas through commercial activities is minimal. Two different projects, one on the Pacific coast and one in Atlantic Canada, examined the effect of temperature and salinity on the survival of two species of colonial tunicates that have established on both coasts, the golden star and violet tunicates. The project in the Pacific region examined if temperature and salinity might be controlling their spread in BC. The results on the impact of temperature and salinity on their growth and reproduction were used to model the potential distribution of the tunicates in BC (Epelbaum *et al.* 2009a) and resulted in two other publications (Epelbaum *et al.* 2008, Epelbaum *et al.* 2009b).The study addressed gaps identified in the national tunicate risk assessment (Therriault and Herborg 2007) and by CAISN, and also addressed concerns raised by the aquaculture industry. In PEI, the information on the tolerance of tunicate larvae and buds to temperature and salinity were communicated to the aquaculture industry and regional authorities and helped to set guidelines to minimize the risk of spread through activities such as shellfish processing. Transport of mussels is now authorized to occur only in winter. The results fed into the national tunicate risk assessment (Therriault and Herborg 2007).

Similarly, a study of green crabs on the Canadian west coast showed that the distribution of adult crabs on a local scale is also regulated by environmental factors. Adult green crabs are taking advantage of lower salinity waters in the intertidal zone, a zone seldom occupied by adult native graceful crabs (*Cancer gracilis*) that require fully saline waters. The results were included in the national green crab risk assessment (Therriault *et al.* 2008) and publications are underway.

An understanding of when and how environmental parameters influence recruitment, growth and survival of *Ciona* is critical when developing cost-effective mitigation

strategies to reduce the impact of tunicates on the mussel production. In PEI, the timing of recruitment and the patterns of biomass accumulation of the vase tunicate were examined in order to assess the best time of the year for treatment (Ramsay *et al.* 2009). A similar project carried out at two separate locations (Montague River, PEI and in Mahone Bay, NS) examined the environmental cues associated with aspects of the basic life cycle and population dynamics of *Ciona.* In the field study conducted on the south shore of Nova Scotia, low winter and high summer temperatures were shown to be strong factors associated with intra- and inter- annual variation in larval recruitment (Vercaemer *et al.* 2011). In the laboratory, survival and growth of young *Ciona* recruits were affected by salinity and by temperature, suggesting that temperature and salinity are factors which will subsequently influence distribution, persistence and potential for spread of adult *Ciona* populations. Unfavourable sustained temperature and salinity conditions (e.g. re-locating leases or fouled shellfish and thereby taking advantage of local brackish salinities that *Ciona* does not tolerate) could be included in infestation management techniques. This research addressed gaps identified in an earlier review on the species (Carver al. 2006). The results have been communicated to the industry.

Control and adaptive management

The establishment of AIS is a threat to the aquaculture industry, and it is therefore crucial for the survival of the industry to develop methods to mitigate the impact of AIS that do not have adverse effects on the aquaculture products and on non-target species, and to identify the best timing for treatment. Research groups on the west and east coasts have been working independently with different methods to reduce the intensity of tunicate fouling on cultured bivalves. While the research group on the west coast has been evaluating both the use of biological control and chemical treatment options, the research group on the east coast has focused more on chemical treatment options. Biological treatments have been tested also on the east coast but appeared not to be working, and were therefore not investigated further.

In the Pacific region, the goal of one research project has been to identify potential invertebrate predators that could be co-cultured with oysters/clams/scallops as a biological means of tunicate control in shellfish aquaculture, and that could potentially control the geographic spread of the tunicates. The susceptibility of four species of invasive tunicates (the clubbed tunicate *Styela clava*, the golden star tunicate *Botryllus schlosseri*, the violet tunicate, and *Didemnum vexillum*) to predation by various species of benthic invertebrates (molluscs, echinoderms, and arthropods) was examined. Sea urchins, *Strongylocentrotus droebachiensis*, were found to be efficient grazers of all four species of tunicates (Epelbaum *et al.* 2009c). Results from this study were used to choose a potential predator for aquaculture field trials in a subsequent AIS project. This research addressed gaps identified in the tunicate risk assessment (Therriault and Herborg 2007), raised by industry, and identified by CAISN.

The work to examine the efficacy of various methods for controlling invasive tunicates in shellfish aquaculture (mechanical, biological, chemical) was continued in the project "Invasive Tunicates and Shellfish Aquaculture: Assessing Impacts and Testing Solutions". It was intended as a national project, but became two separate projects on the

Pacific and Atlantic coasts. On the Pacific coast, the effects of mechanical cleaning, biological control (sea urchins), and various chemicals (hydrated lime, brine, freshwater, vinegar) on growth and survival of the tunicates and the mottled sea star were examined. Focus was put on *Didemnum*, which was ranked as the highest risk species based on the tunicate risk assessment. The project has not yet been completed, but preliminary results show that hydrated lime is the most effective control option. The results have been shared with east-coast DFO managers and scientists/managers on the west coast. In the Gulf Region, the chemical treatment methods that had been tested at the beginning of the tunicate infestation in order to provide treatment recommendations to the aquaculture industry (such as lime, NaOH, citric acid, vemcon, and acetic acid), were validated and standardized to facilitate their application and knowledge transfer between regions. The current recommendations are: 100% brine or freshwater to control colonial tunicates, and 4% hydrated lime to control solitary tunicates. The experiments have been completed and a scientific publication is underway.

Another management option that has been tested includes the fallowing of a mussel lease (i.e. complete removing of artificial substrate and aquaculture products). Results demonstrated a lower infestation (up to 50%) of *Ciona* on a mussel lease near Mahone Bay, NS, for at least two subsequent years after implemention (Vercaemer *et al.* 2011). However, this method, derived from terrestrial pest management control was used during low infestation years and its validity has yet to be tested with high level of infestation and in locations where individuals could find refuge on other surrounding substrates.

A major concern with the different measures to control AIS, are the potential adverse effects on non-target organisms. The use of hydrated lime to control invasive tunicates, may have a negative impact on larvae of the American lobster (Locke 2008, Locke *et al.* 2009), but only if the larvae settle into areas with lime. A project carried out in the Gulf region used oceanographic models developed in a previous project to predict where larvae and lime go, and how long they coexist. The project has been completed. The results will be used to improve the current practices to control invasive tunicates.

If current standard practices of the aquaculture industry increase its vulnerability to AIS, new methods should be developed and considered. In the Gulf region, the methods used by the industry to clean mussel socks of epifauna were examined to evaluate if they actually made the socks more vulnerable to tunicate settlement. Another objective was to figure out how often farmers should be treating the mussel socks with lime. The results from the study fed into the national tunicate risk assessment (Therriault and Herborg 2007) and were communicated to the aquaculture industry.

The relationship between tunicate fouling intensity and mussel size/density in socks was examined in the Gulf region. The objective was to develop a method to reduce tunicate fouling and the associated risk of mussels falling off (caused by the weight of the tunicates) by manipulating the mussel density. The study revealed that fouling density is lower when mussel density is high (Ramsay *et al.* 2008). The results from the study also fed into the national tunicate risk assessment (Therriault and Herborg 2007).

The native rock crab (*Cancer irroratus*) has a positive impact on the mussel production by removing epifauna and waste on mussel socks. There was a concern in Atlantic Canada that the replacement of the rock crab by the green crab may have potential negative impacts on the mussel production, if the two species of crabs differ in their ability to clean mussel socks. However, a study led by the Quebec region showed that there is no significant difference between the species regarding their ability to remove epifauna. The replacement of rock crab by green crab is not likely to have an impact on the ability of crabs to clean mussel socks. The study also showed that it is beneficial for the mussel production to let crabs colonize the mussel socks (Mallet *et al.* 2009).

Impact of invasive tunicates on the aquaculture industry

Identifying high-impact invaders that will replace other AIS over time is important in order to allocate resources to develop methods to mitigate the impact of those species. A study of spatial competition between invasive tunicates was carried out during the invasion of *Ciona* in PEI (Ramsay *et al.* 2008). Subsequent to the invasion by *Ciona*, recruitment of the other three species of invasive tunicates was minimal, and the invasion led to the replacement of *Styela* by *Ciona* as the dominant tunicate. This study was partially funded by the AIS Program.

In addition to the negative impact of tunicate fouling on mussel productivity, caused by the sheer weight of the tunicates and the associated increased risk of the mussels falling off the socks, the tunicates may also compete with the mussels for food. The filtering activities of invasive tunicates were the focus of a series of projects carried out in the Gulf region with the objectives to compare the food uptake by invasive tunicates and native mussels and their impact on the availability of food particles, which would enable an assessment of the intensity of competition. A field approach for measuring food uptake was developed by the Gulf region to measure the consumption of planktonic larvae (bivalves, copepods, gastropods and polychaetes) by the blue mussel (*Mytilus edulis*) and *Styela* (LeBlanc *et al.* 2007). The results fed into the tunicate risk assessment (Therriault and Herborg 2007) and other projects that were refining the methods used to examine predation on and competition for zooplankton by mussels and tunicates.

In order to determine if invasive tunicates and native shellfish are competing for food, it is necessary to assess how they share the resource. This was a knowledge gap identified in the national tunicate risk assessment. The objective of an ongoing project by the Maritimes and Newfoundland regions is to document inter-specific differences in the capacity of two species of invasive tunicates (*Styela* and *Ciona*) and mussels to partition food by particle size. This project builds on a previous study in Atlantic Canada which showed that the phytoplankton community is dominated by picoplankton (0.2 to 2µm) in bays with aquaculture where mussels control phytoplankton biomass (Cranford *et al.* 2008). Preliminary studies showed that *Styela*, unlike mussels, were able to retain a large fraction of picoplankton owing to differences in their water filtration mechanisms. Another objective of the current project is to document spatial and temporal variations in the size-structure of the phytoplankton in coastal waters, which will help to determine the degree of competition between the mussels and tunicates for ambient food resources. However, it is also necessary to assess how much of the available resources the invasive

tunicates and the mussels are extracting from the water column. A project in the Gulf region indicated that vase tunicates consumed approximately 6% of the phytoplankton present in the water column in mussel farms, which was viewed as being low from an ecological perspective. These results will be incorporated in a future publication linked to the AIS project: "Characterizing the role of feeding efficiencies of native vs. non-native filter feeders in facilitating the establishment and spread of aquatic invasive species" (which received funding 2010/11). The effect of *Ciona* on the biodiversity and productivity of marine ecosystems, especially the productivity of blue mussels, was further examined in another project in the Gulf region. Comparisons were made of the composition of planktonic biota and the growth rate of caged mussels in estuaries with and without *Ciona*. The filtration rate of the vase tunicate was compared with that of other filtering organisms.

OTHER STUDIES

Recreational fishery

The use of live bait in the recreational fishery is an important pathway for the introduction of AIS to inland waters in Canada. A well-publicized study in the Kenora/Lake of the Woods area, carried out by the C&A region, assessed the potential for AIS to enter Lake of the Woods (in ON, MB, US) through the baitfish trade and increased the awareness of the risk associated with baitfish dumping. In the survey of baitfish suppliers and anglers, no AIS were present in the examination of angler bait buckets, although some fishing parties (<3%) had illegally brought live bait into Ontario, and 8% of the anglers dumped their live bait into the lake upon completion of fishing.

Rainbow trout (*Oncorhynchus mykiss*) has been widely introduced to many regions in the world, often with negative consequences for local fish populations. The objectives of a project in the region of Newfoundland were to investigate the potential impacts the introduced rainbow trout on native salmonid populations, and to assess the potential for physical removal of rainbow trout as a potential control measure. The second objective was abandoned as it was deemed ineffective as a control measure due to 1) the amount of effort involved and 2) populations did not decline through time after removal indicating that the population was being seeded from somewhere else (most likely anadromous individuals). The results were presented at a scientific conference (Clarke *et al.* 2006).

Crayfish are frequently used as live bait, and several species have been widely introduced to inland lakes, often with negative impacts on the invaded community. A study of the exotic rusty crayfish (*Orconectes rusticus*) in Lake of the Woods and the Winnipeg River system examined its current distribution, the relationship between invasion success and environmental variables, and its negative impact on the exotic papershell crayfish (*O. immunis*) and the native virile crayfish (*O. virilis*) were documented in a study in the C&A region (Jansen *et al.* 2009, Rosenberg *et al.* 2010). The study influenced management decisions, as the Province of Manitoba used the results to ban the possession of crayfish.

Biodiversity

Many studies examined potential community and ecosystem impacts, such as the role of the invasive species in the food web, possible interactions with other species, tolerances, habitat association, and distribution.

While the impact by invasive tunicates on the aquaculture industry has been the focus of several projects, little is known about their impact on native ecosystems. The objectives of a research project in the Maritimes are to determine the impact and biology of the two species of invasive colonial tunicates in native ecosystems, especially seagrass beds and rocky habitats. The research addresses scientific gaps identified by a biological synopsis of the species (Carver *et al.* 2006b). The project is ongoing.

The impact of an invader varies throughout its invaded range. It is therefore important to identify the factors limiting the impact of an invader in order to identify areas where the invader will have a high impact and subsequently implement measures to protect these areas. A national comparison of the impact of the green crab on biodiversity and ecosystems was conducted, thus addressing gaps identified in the green crab risk assessment (Therriault *et al.* 2008) and biological synopsis (Klassen and Locke 2007). The project had two main objectives, to (1) examine the factors that contribute to the successful establishment of green crab populations in order to identify areas susceptible to invasion, and (2) examine the impacts of the green crab on biodiversity in various habitat types and its interactions with other predators with similar resource requirements. The project resulted in a regional assessment on the green crab (DFO 2010c, Best *et al.* 2009) and science advice (DFO 2011) that influenced management and mitigation decisions. Additional requests for science information and advice, such as population density estimates, threshold levels for mitigation action, impact assessment and measures of success, are being addressed in a subsequent green crab AIS project (started 2010) that builds on the previous green crab impact research.

Throughout its invaded range, the green crab has had a documented negative impact on several species on native crabs. In a study led by the Quebec region, the interactions between the green crab and the native rock crab (*Cancer irroratus*) were examined to better understand the impact of the green crab on an important native benthic predator in eastern Canada. The research addressed gaps identified in the national green crab risk assessment (Therriault *et al.* 2008). Studies of interspecific competition revealed that the rock crab is little affected by the presence of green crabs, which suggests that the two species will coexist in nature (Bélair and Miron 2009ab).

The marine macrophyte algae *Codium fragile* ssp. *fragile*, also known as "Dead Man's Fingers" and "oyster thief", is widespread on the Canadian east coast. While the impact of *Codium* on rocky substrate is well understood, little is known about its impact on other habitats. A biological synopsis was carried out to identify knowledge gaps and to produce a risk assessment of *Codium*, while also evaluating the utility of using the Quantitative Biological Risk Assessment Tool (QBRAT v2) framework and software (Drouin and McKindsey 2007). The risk assessment included a determination of the potential distribution of *Codium* on the east coast of Canada and identified a number of issues with respect to this species that would improve estimates of its impact in the environment,

which were addressed in subsequent research projects. The AIS Program contributed to two ongoing projects in the Quebec region that focus on the factors that allow *Codium* to expand its range. One of the projects is an evaluation of its growth potential at different temperatures and light levels, and the results indicate that *Codium* can grow under any of the temperature regimes that occur in eastern Canada. The other project is an evaluation of the factors that encourage the spread/dispersal of *Codium* at small scales. Results from the temperature-related growth study had impacts on I&Ts for aquaculture by causing some proposed transfers in the region to be disallowed. The objective of another project is to gain a better understanding of the impact of *Codium* on eelgrass (*Zostera marina*) and on the communities of organisms that grow associated with eelgrass. The results will be presented in two scientific publications. A follow up project (starting fall 2010) will focus on settlement and differentiation/growth and methods to reduce the risk of transferring the algae with aquaculture products (using funds from the industry and the ACRDP).

The bloody-red mysid is a recent invader in the Great Lakes – St. Lawrence River, and little is known about its ecology and potential ecosystem impacts. Its distribution, abundance, occurrence in the food chain, and effects on native species, was the focus of a project in the C&A region. The project addressed gaps identified in a previous risk assessment on *Hemimysis* (Koops *et al.* 2010), and the results will be presented in 3 scientific publications. Funding from the AIS monitoring program is contributing to another research project on *Hemimysis* that focuses on its feeding ecology and distribution (Marty *et al.* 2010), with many collaborators including DFO researchers, provincial researchers, universities, the St. Lawrence River Institute, and three US organizations (USGS, Cornell U and NOAA).

Developing tools to better identify, and more rapidly screen through risk assessment, potential invaders and pathways before they arrive, will be useful to allow managers to take actions to prevent their initial introduction. Predicting impact of potential fish invaders in the Great Lakes basin is the objective of three ongoing research projects. One project will develop tools to identify the ecological characteristics of potential invaders and their potential impacts (i.e. develop "Ecological Invader Guilds"), and the environmental characteristics of "invasion hot spots". The objective of the second project is to investigate the potential impacts of invasive fish species on fish habitat suitability in coastal areas and the occurrence and density of native fishes. The work builds on previously developed models of habitat productive capacity. Statistical software used to investigate habitat use of native species in the presence of AIS has been developed, but the project has not yet been completed. The objective of the third project is to quantify the impact on fish habitat suitability in coastal wetland habitats by fish species that are predicted to expand their range and establish in the Great Lakes due to climate change. These habitats are forecasted to change dramatically in their thermal regimes and habitat characteristics under different climate scenarios, but the added stressor of potential invasion by non-native fishes through range extension may also result in significant shifts to habitat usage and carrying capacity.

The potential vectors involved in the establishment and spread of invasive species of zooplankton, algae, and fish into the Hudson Bay watershed of central Canada from the Great Lakes and Mississippi River watersheds was identified in a project in the C&A region (Harris *et al.* 2006).

Habitat association

In order to clarify the mechanisms responsible for AIS establishment success, it is necessary to identify the relationship between habitat characteristics and AIS abundances. This information can be used to identify dispersal mechanisms and vectors, and predict potential impact on sympatric species. This relationship was the focus of two projects in the Pacific region, one focusing on AIS abundances in intertidal habitats around the Strait of Georgia, while the other project focused on the community assemblages and dynamics of subtidal invasive species along the entire coast of BC. The results from the surveys have been used to inform monitoring for AIS in marine waters (identification of priority areas for AIS detection and the design of optimal longer-term monitoring protocols). The data on the intertidal communities is the basis of a Masters' thesis (MSc). The objective of the project focusing on subtidal communities is also to identify the current influx of AIS, compare their temporal and spatial rates of introduction, and to identify vectors and pathways responsible for delivering subtidal AIS to the BC coast. Information on temporal dynamics of recruitment will determine which time of year is best for AIS settlement prevention. Data collected on invasive tunicates were used in the tunicate risk assessment (Herborg and Therriault 2007). The distributional data on non-indigenous subtidal species has contributed to several primary publications (Frey *et al.* 2009, Herborg *et al.* 2008, Lejeusne *et al.* 2011, Therriault and Herborg. 2008ab). The data is also the basis of a MSc thesis and part of a doctoral thesis (PhD).

Knowledge about the distribution and demographic differences between invaded sites can also be used to evaluate the persistence of the populations and subsequently be used to develop a commercial fishery on the invader. A study in the Pacific region documented the current distribution and historic rate of spread of manila clam (*Venerupis philippinarum*)**,** varnish clam (*Nuttallia obscurata*) and other non-indigenous intertidal bivalves (primarily Pacific oysters, softshell clams) in BC coastal waters. Population demographics were used to determine/confirm minimum lengths of colonization and describe demographic differences between beaches. Results from the study helped inform the Pacific Region AIS Monitoring Program, and led to the development of a commercial fishery for Manila clams in the North Coast, as the expected persistence of populations in the area led to a decision to actively manage the fishery with conservation targets. This is a clear example of adaptive management, where an AIS is being considered as an asset rather than a nuisance.

The relationship between anthropogenic disturbance and the presence/absence and abundance of AIS is not fully understood, and this knowledge gap has been identified in various risk assessments. Two projects on PEI examined the relationship between AIS infestation and eutrophication/nutrient levels in embayments with mussel culture. No link between eutrophication and AIS loads was identified, and AIS loads were rather a function of time since invasion and presence/absence was found to be a function of

introduction effort. The projects are ongoing and the work has contributed to other projects examining the link between eutrophication and the impact of AIS (McKindsey *et al.* 2009).

Changes in the distribution of non-native oceanic species are strongly correlated with changes in temperature and salinity. A project in the Pacific region developed tools used to link temperature and salinity anomalies in the ocean to invader dynamics. Maps of average summer and winter temperature and salinity of the ocean region were prepared (Galbraith and Crawford 2009) and thereafter used to map anomalies in temperature and salinity in BC waters in each summer and/or winter (Crawford 2010). The maps are presented annually at the Fisheries and Oceanography Working Group Meeting, and in the Ocean Status Reports. Scientists working with invasive species use the maps to match ocean anomalies with the advancement of non-native species through BC, the most recent being the Humboldt Squid.

Management options

One of the challenges in managing AIS is to determine how early in the invasion process it is necessary to detect a species in order to prevent establishment and successfully eradicate it to prevent spread. A model that can be used to predict the probability of establishment of AIS was developed by the C&A region. The model was used to evaluate the potential effectiveness of the IMO ballast water discharge standards (discussed above) (Bailey *et al.* 2009). It was also used to assess how an established population may be controlled by analyzing the spread phase of round gobies in Hamilton harbour (Vélez-Espino *et al.* 2010). The model showed that the arrival of a very low number of adults can be enough for the species to establish in the area, while much higher concentrations of
juveniles would be needed to pose a significant risk of invasion. A back-calculation to determine the time of establishment and the time required to reach habitat saturation revealed a short elapsed time between arrival and establishment, which indicates that the transition between these two phases can be characterized as a deterministic process. Therefore, only very aggressive management actions can stop population growth and spread of this invader once it has established, which suggests that preventative measures are the most effective management options.

Eradication is a management option that can be used only very early in the invasion process, before the invader has become widespread. However, in order to be able to apply the appropriate eradication method if a new AIS was to be detected early, is important to evaluate the effectiveness of existing methods and potential adverse effects on non-target organisms. The objective of a project in the C&A region was to evaluate the effectiveness of an attempt to eradicate the round goby in Lake Simcoe using rotenone and the impact of the method on the native community. The results were used as a case study in the development of a DFO Science National Rapid Response Framework (Dimond *et al.* 2010). Although the eradication was not successful, valuable experience was gained that will enhance rapid response planning and implementation as well as the management of the round goby in other waters. Another publication focusing on the effect of the eradication method on the native fish community is underway.

DISCUSSION AND CONCLUSIONS

The research projects funded by DFO have covered a wide range of issues, many of which were directly linked to the key areas identified in the Canadian Action Plan. The largest proportion of the funding (one third) was allocated to projects focusing on vectors and pathways, mainly the shipping pathway (Fig. 2). While ship-mediated invasions to the Great Lakes have been declining since 1995, likely a result of the voluntary/mandatory ballast water exchange practices introduced in 1989 (which applied only to ships that declared "Ballast-on-Board" until 2006 when ships declaring "No-Ballast-on-Board" also had to undergo ballast water exchange), recent shipping research is examining additional shipping pathways (i.e. domestic and coastal shipping) that are not addressed in the current regulations. This research will inform decisions by policy and management that will contribute to further reducing the risk of new introductions and control of the spread of already established invaders. We expect Transport Canada will update their regulations shortly as a result of both CAISN and DFO research (S. Bailey, Fisheries and Oceans Canada, pers. comm.). Almost one fifth of the research funding was allocated to projects focusing on adaptive management of already established invaders (i.e. control of the impact of invasive tunicates on the aquaculture industry).

The research carried out by CAISN was in many ways complementary to the research carried out by DFO. The CAISN was co-funded by DFO, Transport Canada, Ontario Ministry of National Resources, NSERC, and University of Windsor and included participation by various DFO researchers. CAISN had three research themes; (1) identification and quantification of vectors of pathways that transmit AIS to and within Canada, (2) assessment of factors affecting invasion success, and (3) development of prevention and mitigation strategies. The overall objectives of the projects carried out by CAISN complemented the research questions addressed by DFO as part of the research activities addressed in this summary.

Both CAISN and the DFO focused on the shipping industry as a pathway of AIS. While the projects funded by DFO examined the risk of transferring AIS over short distances by domestic ships and identified potential invaders in foreign ports that may be introduced to Canadian waters, CAISN examined AIS in ballast water in vessels arriving to coastal ports, and to ports in the Great Lakes. In addition, CAISN examined the temporal dynamics of planktonic AIS, viruses and bacteria on transoceanic ships, and also conducted experimental ballast water release on vessels in ports to assess whether water mass movements in recipient ports lowers the densities of AIS and hence the risk of establishment. The risk of transferring AIS in ballast sediments was examined in a project co-funded by CAISN and DFO. Hull fouling as a vector of AIS was examined by both parties. While the project lead by CAISN examined AIS fouling ships in the Great Lakes and coastal ports, the project carried out by the DFO focused on fouling AIS associated with sea-chests. CAISN also examined the diversity of AIS in marine ports on the Canadian east and west coasts.

The second theme covered by CAISN focused on factors influencing establishment success, including tolerance to the abiotic environment and the role of species interactions. This theme was included in several projects funded by DFO that examined the factors limiting the distribution of invasive tunicates. One CAISN project revealed that eight Great Lakes' invaders were intolerant to salinity conditions experienced in a vessel that had undergone mid-ocean exchange of their ballast water, and that these invasions might have been prevented if current regulations had been implemented earlier.

CAISN researchers have been very active in developing mathematical risk assessment models to predict which AIS are more likely to invade, where they will invade, and the relative importance of human vs. natural dispersal. The CAISN research was used to develop risk assessment of major freshwater fish pathways in Canada, including the aquarium, baitfish, biological supply, live food and water garden trades. The risk of introducing AIS through baitfish release was addressed in only one project funded by DFO. CAISN was also very active in modeling the establishment success, population dynamics, and spread of the spiny water flea, which was not a focus of the AIS Program.

Together, the AIS research funded by DFO, the risk assessment work of CEARA at DFO, and CAISN targeted most of the species listed by the provinces and regions as being of elevated concern (Table 3). While AIS research funds, CEARA and CAISN targeted tunicates, green crab, *Hemimysis*, *Codium*, and round goby, CEARA and CAISN targeted several species that were not targeted by the DFO research funds, such as the spiny water flea, the fishhook waterflea, the invasive bryozoan *Membranipora membranacea*, Dreissenid mussels, Asian carps, northern snakehead, smallmouth bass, Chinese mitten crab, and the New Zealand mud snail. Two species, the rusty crayfish and the skeleton shrimp, were targeted only by DFO. Six of the listed species were not the focus of any study (Chain pickerel, Eurasian ruffe, common rudd, *Corbicula* spp. and *Didymosphenia geminate*). It is important to note half of the funding spent by DFO on AIS research was spent on species of elevated concern (Fig. 3), while 40% of the funding was spent on projects with a "broad taxonomic scope", mainly ballast water and ballast sediment linked to the shipping vector, which was also a key priority. In total, 90% of the funding was spent on issues of high priority.

The results from the first five years indicate a good priority setting approach and aligned with the vision outlined in the Science Framework for the Future, that DFO Science activities should be relevant, effective, affordable and valued. The AIS research projects carried out by DFO were relevant, as they supported the Government of Canada's priorities, DFO's strategic objectives, and the needs of its client management sectors (Fisheries and Aquaculture Management, Oceans, Habitat, Species at Risk, and the Canadian Coast Guard). The AIS research activities were effective, as the results from the research projects were communicated to a wide range of stakeholders, and used in the decision making and policy. The research activities were affordable, as a large proportion of the funding was spent on issues of high priority, often carried out in collaboration with industry, academia and other federal institutions, and resulted in a large number of publications (Appendix C). The research projects were also valued, as they have provided useful scientific advice to DFO's clients, such as the aquaculture and shipping industry.

A suggestion for the future is to develop an annual reporting system (Appendix D), to avoid the loss of information due to retirements and staff turnover.

Table 3. **Species of elevated concern as listed by the provinces and regions in 2009-2010 that were targeted by DFO AIS research funds, DFO/ CEARA, and CAISN.**

List of species of elevated concern	DFO Research funds		CEARA	CAISN
	Year funded	Amount ($1000)		
Fish (finfish)				
Round goby (*Neogobius melanostomus*)	2005/06 2006/07 2007/08 2008/09 2009/10	15	√	√
Carps			√	
Northern snakehead (*Channa argus*)			√	
Chain pickerel (*Esox niger*)				
Smallmouth bass (*Micropterus dolomieu*)			√	
Eurasian ruffe (*Gymnocephalus cernuus*)				
Common rudd (*Scardinius erythropthalmus*)				
Tunicates	2005/06 2006/07 2007/08 2008/09 2009/10	157 120 209.3* 117 165	√	√
Molluscs				
Dreissena sp.				√
New Zealand mud snail (*Potamopyrgus antipodarum*)			√	
Corbicula spp.				
Crustaceans				
Rusty crayfish (*Orconectes rusticus*)	2005/06	10		
Green crab (*Carcinus maenas*)	2005/06 2006/07 2007/08 2008/09 2009/10	25 35 30.5 110 150	√	√
Chinese mitten crab (*Eriocheir sinensis*)			√	
Skeleton shrimp (*Caprella mutica*)	2007/08 2008/09 2009/10	45.3 47.5 11		
Blood red shrimp (*Hemimysis longimanus*)	2009/10	18	√	√
Spiny water flea (*Bythotrephes longimanus*)			√	√
Fishhook waterflea (*Cercopagis pengoi*)				√
Plants/Algae				
Codium spp.	2006/07 2007/08 2008/09 2009/10	59.8 50.6 78.8 12	√	√
Didymosphenia geminate				
Bryozoans				
Sea-mat (*Membranipora membranacea*)				√

*This amount includes the study ($33.9K) that also examined the green crab.

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Figure 3. **Funding allocation according to activity or species (amounts in $1000)[2].**

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LITERATURE CITED

Bailey, S.A., V élez-Espino, L.A., Johannsson, O.E., Koops, M.A., and Wiley, C.J. 2009. Estimating establishment probabilities of Cladocera introduced at low density: an evaluation of the proposed ballast water discharge standards. Can. J. Fish. Aquat. Sci. 66: 261-276.

Bélair, M.-C. and Miron, G. 2009a. Predation behaviour of *Cancer irroratus* and *Carcinus maenas* during conspecific and heterospecific challenges. Aquat. Biol.. 6: 41-49.

Bélair, M.-C. and Miron, G. 2009b. Time budget of *Cancer irroratus* (Say) and *Carcinus maenas* (L.) under various temperature and prey density conditions during conspecific and heterospecific challenges. J. Shellfish Res. 28: 923-930.

Bernier, R., Locke, A., and Hanson, J.M. 2009. Lobsters and crabs as potential vectors of tunicate dispersal in the southern Gulf of St. Lawrence, Canada. Aquat. Invasions 4: 105-110.

Best, K., McKenzie, C.H., and Couturier, C. 2009. Early life stage biology of a new population of green crab, *Carcinus maenas*, in Placentia Bay: implications for mussel culture in Newfoundland. Aquaculture Association of Canada Spec. Publ. No. 15: 48-50.

Blakeslee, A.M.H., McKenzie, C.H., Darling, J.D., Byers, J.E., Pringle, J.P., and Roman, J. 2010. A hitchhiker's guide to the Maritimes: anthropogenic transport facilitates long-distance dispersal of an invasive marine crab to Newfoundland. Diversity Distrib. 16: 879-891.

[2] Species listed as priority species by the provinces and regions are indicated with an asterix. The category "other (not species)" refers to projects that are not species-oriented, such as the development of a risk assessment framework. The category "Broad taxonomic scope" refers to projects that targeted multiple species, such as studies of ballast water.

Brickman, D. 2006. Risk assessment model for dispersion of ballast water organisms in shelf seas. Can. J. Fish. Aquat. Sci. 63: 2748-2759.

Brickman, D. and Smith, P.C. 2007. Variability in invasion risk for ballast water exchange on the Scotian Shelf of eastern Canada. Mar. Poll. Bull. 54: 863-874.

Carver, C.E., Mallet, A.L., and Vercaemer, B. 2006a. Biological Synopsis of the Solitary Tunicate *Ciona intestinalis*. Can. Man. Rep. Fish. Aquat. Sci. 2746: v+55 p.

Carver, C.E., Mallet, A.L., and Vercaemer, B. 2006b. Biological Synopsis of the colonial tunicates, *Botryllus schlosseri* and *Botrylloides violaceus*. Can. Man. Rep. Fish. Aquat. Sci. 2747: v+42 p.

Clarke, K.D., Scruton, D. A., and Porter, T.R. 2006. Preliminary observations of a recent invader, rainbow trout (*Oncorhynchus mykiss*), in Trout River, Newfoundland and its potential to affect native salmonids. Canadian Conference for Fisheries Research, Calgary, Alberta, January 5-7, 2006. 28 p.

Cranford, PJ., W. Li, Ø. Strand and T. Strohmeier. 2008. Phytoplankton depletion by mussel aquaculture: high resolution mapping, ecosystem modeling and potential indicators of ecological carrying capacity. ICES CM 2008/ H:12. http://ices.dk/products/CMdocs/CM-2008/H/H1208.pdf

Crawford, W.R. 2010. Global and North Pacific conditions – Temperatures in 2009: Globally warm but locally cool, p 21-26 In: Crawford, W.R., and J.R. Irvine. (Eds.). State of physical, biological, and selected fishery resources of Pacific Canadian marine ecosystems in 2009. DFO Can. Sci. Advis. Sec. Res. Doc. 2010/053: viii + 137 p.

Cudmore, B. and Koops, M.A. 2007. Risk assessment of round goby (*Neogobius melanostomus*) to Lake Simcoe, Ontario: a Qunatitative Biological Risk Assessment Tool (QBRAT) case study. DFO Can. Sci. Advis. Sec. Res. Doc. 2007/038: iv+36 p.

Cudmore, B., Koops, M.A. and Mandrak, N.E. 2007. National workshop on the evaluation of a Quantitative Biological Risk Assessment Tool (QBRAT) through various case studies, 29-30 November 2006. DFO Can. Sci. Advis. Sec. Proceed. Ser. 2007/014: v+14 p.

Darbyson, E., Hanson, J.M., Locke. A., and Willison, J.M.H. 2009a. Survival of European green crab exposed to simulated overland and boating-vector transport conditions. J. Shellfish Res. 28: 377-382.

Darbyson, E., Hanson, J.M., Locke. A., and Willison, J.M.H. 2009b. Settlement and potential for transport of clubbed tunicate (*Styela clava*) on boat hulls. Aquat. Invasions 4: 95-103.

Darbyson, E., Locke. A., Hanson, J.M., and Willison, J.M.H. 2009c. Marine boating habits and the potential for spread of invasive species in the Gulf of St. Lawrence. Aquat. Invasions 4: 87-94.

DFO. 2011. Proceedings of the Regional Advisory Process on European Green Crab, (*Carcinus maenas*), Populations and Mitigations in the Newfoundland and Labrador Region. March 17, 2010. DFO Can. Sci. Advis. Sec. Proceed. Ser. 2011/020: v+22 p.

DFO, 2010a. Proceedings of the National peer review on Alternate Ballast Water Exchange zones for vessel traffic to Newfoundland and the Arctic. January 13-14, 2009. DFO Can. Sci. Advis. Sec. Proceed. Ser. 2009/054: vi+23 p.

DFO. 2010b. Review of Alternate Ballast Water Exchange Zones for vessel traffic to Newfoundland and Labrador and the Canadian Arctic. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2010/026. 7 p.

DFO. 2010c. Ecological Assessment of the Invasive European green crab, (*Carcinus maenas*) in Newfoundland 2007-2009. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2010/033: 10 p.

Dimond, P.E., Mandrak, N.E., and Brownson, B. 2010. Summary of the rapid response to Round Goby (*Neogobius melanostomus*) in Pefferlaw Brook with an evaluation of the national rapid response framework based on the Pefferlaw Brook experience. DFO Can. Sci. Advis. Sec. Res. Doc. 2010/036: vi+33 p.

Drouin, A. and McKindsey, C.W. 2007. QBRAT v2 assessment: *Codium fragile* ssp. *tomentosoides* in the Gulf of St. Lawrence as a case study. DFO Can. Sci. Advis. Sec. Res. Doc. 2007/007: iv+28 p.

Epelbaum A, Pearce, C.M., and Therriault, T.W. 2008. A case of atrial siphon duplication in *Styela clava* (Tunicata: Ascidiacea). Journal of the Marine Biological Association of the U.K. 2 – Biodiversity Records. Online: http://www.mba.ac.uk/jmba/pdf/6243.pdf

Epelbaum A., Herborg, L.-M., Therriault, T.W., and Pearce, C.M. 2009a. Temperature and salinity effects on growth, survival, reproduction, and potential distribution of two non-indigenous botryllid ascidians in British Columbia. J. Exp. Mar. Biol. Ecol. 369: 43-52.

Epelbaum A., Therriault, T.W., Paulson, A., and Pearce, C.M. 2009b. Botryllid tunicates: culture techniques and experimental procedures. Aquat. Invasions 4: 111-120.

Epelbaum A., Pearce, C.M., Barker, D.J., Paulson, A., and Therriault, T.W. 2009c. Susceptibility of non-indigenous ascidian species in British Columbia (Canada) to invertebrate predation. Mar. Biol. 156: 1311-1320.

Fitzsimons J., Brown, S., Brown, L., Verreault, G., Lepak, J., and Drouillard, K. 2008 Thiamine Status of Lake Ontario American eel *Anguilla rostrata*: Could a Thiamine Deficiency Be Contributing to Population Decline? Thiamine Deficiency Complex Workshop, Final Report, November 6-7, 2008, Ann Arbor, MI. p. 24-25.

Frey, M.A., Gartner, H.N., Murray, C.C., and Therriault, T.W. 2009. First confirmed records of the non-native amphipod *Caprella mutica* (Schurin 1935) along the coast of British Columbia, Canada, and the potential for secondary spread via hull fouling. Aquat. Invasions 4: 495-499.

Frey, M.A., Simard, N., Martin, J. and Therriault, T.W. (in prep) The risk of fouling around: sea-chests as a potential vector for the introduction and dispersal of aquatic invasive species. Intended for submission to Mar. Poll. Bull.

Galbraith J., and Crawford, B. 2009. Contours of Average Temperature and Salinity in the Gulf of Alaska http://www.pac.dfo-mpo.gc.ca/science/oceans/data-donnees/Alaska/index-eng.htm (website accessed 2010-10-15)

Han, G., Lu, Z., Wang, Z., Helbig, J., Chen, N., and de Young, B. 2008. Seasonal variability of the Labrador Current and shelf circulation off Newfoundland. J. Geopys. Res. 113, C10013, doi:10.1029/2007JC004376.

Harris, A.G., Ratcliff, B., and Foster, R.F. 2006. Aquatic invasive species assessment for the Hudson Bay Drainage of central Canada. Unpublished report. Prepared for Fisheries and Oceans Canada, Central & Arctic Region. 43 p.

Herborg, L.-M. and Therriault, T.W. 2007. Application of QBRAT for a Risk Assessment of the Invasive Tunicate *Didemnum* sp. in British Columbia. DFO Can. Sci. Advis. Sec. Res. Doc. 2007/056: vi+22 p.

Herborg, L.-M., O'Hara, P., and Therriault, T.W. 2008. Forecasting the potential distribution of the invasive tunicate *Didemnum vexillum*. J. Applied Ecology 46: 64-72.

Jansen, W., Geard, N., Mosindy, T., Olson, G., and Turner, M. 2009. Relative abundance and habitat association of three crayfish (*Orconectes virilis*, *O. rusticus*, and *O. immunis*) near an invasion front of *O. rusticus*, and long-term changes in their distribution in Lake of the Woods, Canada. Aquat. Invasions 4: 627-649.

Johannsson, O.E. 2007. Risk assessment of *Bythotrephes longimanus* establishment in Muskoka Lakes: an assessment of QBRAT, the Quantitative Biological Risk Assessment Tool. DFO Can. Sci. Advis. Sec. Res. Doc. 2007/059: vi+26 p.

Kanary, L., Locke, A., and Watmough, J. 2010. Evaluating the effectiveness of SCUBA-based visual searches for tunicates in a Prince Edward Island estuary. Aquat. Invasions 5: 41-47.

Klassen, G. and Locke, A. 2007. A biological synopsis of the European green crab, *Carcinus maenas*. Can. Manuscr. Rep. Fish. Aquat. Sci. no. 2818: vii+75 p.

Koops, M.A., Gerlofsma, J., and Marty, J. 2010. Risk assessment of the bloody red shrimp (*Hemimysis anomala*) in Canada. DFO Can. Sci. Advis. Sec. Res. Doc. 2009/107: iv+20 p.

LeBlanc, A. R., Bourque, D., Landry, T., Davidson, J. and MacNair, N.G. 2007. The predation of zooplankton by the blue mussel (*Mytilus edulis*) and the clubbed tunicate (*Styela clava*). Can. Tech. Rep. Fish. Aquat. Sci. 2684: vii+18 p.

Lejeusne, C., Bock, D., Therriault, T.W., MacIsaac, H.J., and Cristescu, M.E. 2011. Comparative phylogeography of two colonial ascidians reveals contrasting invasion histories in North America. Biol. Invasions. 13:635-650.

Locke, A. and Klassen, G.J. 2007. Using the Quantitative Biological Risk Assessment Tool (QBRAT) to predict effects of the European green crab, *Carcinus maenus*, in Atlantic Canada. DFO Can. Sci. Advis. Sec. Res. Doc. 2007/077: vi+23 p.

Locke, A., Doe, K., Fairchild, W., Jackman, P., and Reese, E. 2009. Preliminary evaluation of effects of tunicate management with acetic acid and calcium hydroxide on non-target marine organisms in Prince Edward Island, Canada. Aquat. Invasions 4: 221-236.

Locke, A. 2008. Tabulated observations of the pH tolerance of marine and estuarine biota Ranges of pH tolerance in marine organisms. Canadian Manuscript Report of Fisheries and Aquatic Sciences 2857: iv+28 p.

Ma, Z., Han, G., De Young, B., and Foreman, M. 2010. Simulation of temperature and currents in Placentia Bay, The 2010 CMOS-CGU Congress, Ottawa. https://www1.cmos.ca/Amsoft%20Web%20Data/upload/abstracts115/2010-06-04archive.html

Mackas, D.L. and Galbraith, M.D. 2005. Appearance and rapid increase of the exotic copepod *Acartia tonsa* on the British Columbia continental margin, PICES 14th

Annual Meeting, Sep 29 - Oct 9, 2005, Vladivostok, Russia, http://www.pices.int/publications/presentations/PICES_14/S4/s4_Mackas.pdf

Mallet, J.-F., LeBlanc, A.R., Ouellette, M., and Comeau, L.A. 2009. Abundance and function of rock crabs (*Cancer irroratus*) in longline mussel (Mytilus edulis) farms. Can. Tech. Rep. Fish. Aquat. Sci. 2862: viii+53 p.

Marty J., Bowen, K., Koops, M.A., and Power, M. 2010. Distribution and ecology of *Hemimysis anomala*, the latest invader of the Great Lakes basin. Hydrobiologia. 647: 71-80.

McKenzie, C.H., Baines, T., Best, K., Boland, R., Dawe, E., Deibel, D., Drover, D., Johnson, E., Kenny, S., Macneill, S., Mouland, D., O'Donnell, R., Park, L., Sargent, P., Vickers, C., and Vickerson, A. 2007. The European green crab, *Carcinus maenas*, in Placentia Bay, Newfoundland AIS Survey 2007. Proceedings of Aquatic Invasive Species Newfoundland Workshop. St. John's, NL, November 16, 2007.

McKenzie, C. H., Han, G., He, M., Baines, T., and Maillet, G. 2010. Alternate Ballast Exchange zones for the Newfoundland and Labrador Region- An Aquatic Invasive Species Risk Assessment based on oceanographic modeling, ecologically and biologically significant areas and sustainability of fisheries and Aquaculture. Can. Sci. Advis. Sec. Res. Doc. 2010/087: viii+41 p.

McKindsey, C.W., Lecuona, M., Huot, M., and Weise, A.M., 2009. Biodeposit production and benthic loading by farmed mussels and associated tunicate epifauna in Prince Edward Island. Aquaculture. 295: 44-51.

Moore, J.E., Koops, M.A., and Cudmore, B. 2007. Quantitative Biological Risk Assessment Tool, v.3.2. Fisheries and Oceans Canada, Burlington, ON.

North/South Consultants Inc. 2006. Potential dispersal of aquatic invasive species into Hudson Bay from ballast water from ships travelling from ports in Europe and North America. A report prepared for Fisheries and Oceans Canada. Winnipeg. File No. F2408-050083. 156 p.

Ramsay A., Davidson, J., Landry, T., and Arsenault, G. 2008. Process of invasiveness among exotic tunicates in Prince Edward Island, Canada. Biol. Invasions. 10: 1311-1316.

Ramsay A., Davidson, J., Bourque, D., and Stryhn, H. 2009. Recruitment patterns and population development of the invasive ascidian *Ciona intestinalis* in Prince Edward Island, Canada. Aquat. Invasions. 4: 169-176.

Ramsay, A., Davidson, J., Landry, T., and Stryhn, H. 2008. The effect of mussel seed density on tunicate settlement and growth for the cultured mussel, *Mytilus edulis*. Aquaculture. 275: 194-200.

Rooney, R.C., and Paterson, M.J. 2009. Ecosystem effects of rainbow smelt (*Osmerus mordax*) invasions in inland lakes: a literature review. Can. Tech. Rep. Fish. Aquat. Sci. 2845: iv+33 p.

Rosenberg, D.M., Turner, M.A., Jansen, W., Mosindy, T. and Watkinson, D.A. 2010. Threats to Lake of the Woods and the Winnipeg River by the rusty crayfish (*Orconectes rusticus*), an aquatic invader. Ont. Min. Natur. Resour., Northwest Sci. & Info., NWSI Tech. Workshop Rpt. TWR-005. 54 p.+append.

Rup M.P., Bailey, S.A., Wiley, C.J., Minton, M.S., Miller, A.W., Ruiz, G.M., and MacIsaac, H.J. 2010. Domestic ballast operations on the Great Lakes: potential

importance of Lakers as a vector for introduction and spread of nonindigenous species. Can. J. Fish. Aquat. Sci. 67: 256-268.

Sutherland, T., Levings, C., and Wiley, C. 2009. Quantifying Aquatic Invasive Species in Accumulated Ballast Sediment Residuals - "Swish": Preliminary Results. Report completed for the Aquatic Invasive Species program funded by Fisheries and Oceans Canada. 36 p.

Therriault, T.W. and Herborg, L-M. 2007. Risk Assessment for Two Solitary and Three Colonial Tunicates in Both Atlantic and Pacific Canadian Waters. DFO Can. Sci. Advis. Sec. Res. Doc. 2007/063: iv+66 p.

Therriault, T.W. and Herborg, L.-M. 2008a. Predicting the potential distribution of the vase tunicate *Ciona intestinalis* in Canadian waters: informing a risk assessment. ICES Journal of Marine Science 65: 788-794.

Therriault, T.W. and Herborg, L.-M. 2008b. A qualitative biological risk assessment for vase tunicate *Ciona intestinalis* in Canadian waters: using expert knowledge. ICES Journal of Marine Science 65: 781-787.

Therriault, T.W., Herborg, L.-M., Locke, A., and McKindsey, C.W. 2008. Risk Assessment for European green crab (*Carcinus maenas*) in Canadian Waters. DFO Can. Sci. Advis. Sec. Res. Doc. 2008/042: iv+40 p.

Turcotte, C. 2010. La caprelle japonaise Caprella mutica et son impact sur l'élevage de moules *Mytilius* spp.: un cas de cleptoparasitisme? Mémoire M.Sc., Université du Québec à Rimouski, Rimouski, 98 p.

Turcotte, C. and Sainte-Marie, B. 2009. Biological synopsis of the Japanese skeleton shrimp (*Caprella mutica*). Can. Manuscr. Rep. Fish. Aquat. Sci. 2903: vii+26 p.

Vercaemer, B., Sephton, D., Nicolas, J.M., Howes, S., and Keays, J. 2011. *Ciona intestinalis* environmental control points: Field and laboratory investigations. Aquat. Invasions. 6: 477-490.

Vélez-Espino, L.A., Koops, M.A., and Balshine, S. 2010. Invasion dynamics of round goby (*Neogobius melanostomus*) in Hamilton Harbour, Lake Ontario. Biol. Invasions. 12: 3861-3875.

APPENDICES

Appendix A. Allocation of research funding per year and region

A total of $2,929,624 was spent on research projects from 2005-2010. Some of this funding ($34,000 in 2005/06 and $38,000 in 2006/07) was initially allocated to monitoring.

Table 4. **The amount of funding allocated to research per year during the period 2005-2010 through the AIS Program.**

Fiscal year	Amount ($)
2005/06	506,604
2006/07	668,420
2007/08	581,300
2008/09	672,300
2009/10	501,000
Total	**2929,624**

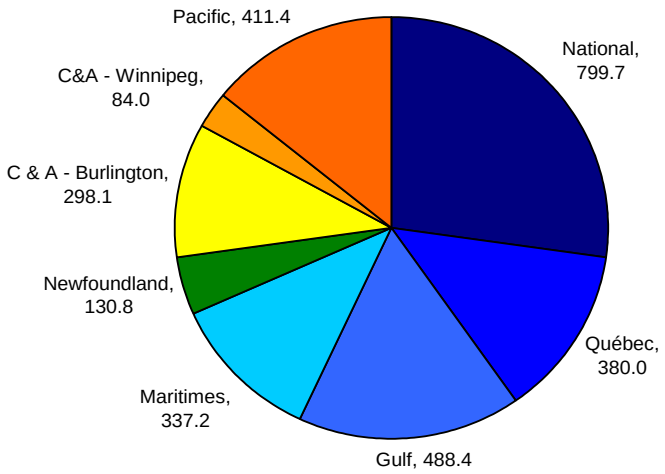

Figure 4. **Funding allocation according to region (amounts in $1000). The national projects are projects not linked to a specific region, or involve several regions.**

Appendix B. Summary information by individual research projects

Region	Year	Lead Scientist	Project Title	Research alloc. ($1,000)	Year							Scope (regional or national)								Species																								Research theme									Link to RA				
					2005/06 Research	2005/06 Coord/Netw.	2006/07 Research	2007/08 Research	2008/09 Research	2008/09 Coord/Netw	2009/10 Research	National	Coordination/Networking	Québec	Gulf	Maritimes	Newfoundland	C&A-Burlington	C&A -Winnipeg	Pacific	*Codium fragile*	*Carcinus maenas*	*Caprella mutica*	*Hemimysis anomala*	*Orc. rusticus & O. virilis*	*Acartia tonsa*	*Echinogamm. ischnus*	*Venerupis philippinarum*	*& Nuttalia obscurata*	*C. maenas* & tunicates	Tunicates	*Neogobius melanostomus*	*Oncorhynchus mykiss*	*Alosa pseudoharengus*	*Osmerus mordax*	Fish (broad taxon. scope)	Broad taxonomic scope	Other (not species)	Coordination/Networking	Vectors & pathways	Habitat ass. & vectors	Distribution/habitat ass.	Control/adapt. Managem.	Impact	Impact & habitat assoc.	Invasibility analysis	Eradication	RA framework	Mapp. water prop. anom.	Coordination/Networking	Fed into RA	Addressed gaps in RA	Addr. gaps & fed into RA	Not directly linked to RA	Coordination/Networking
Gulf	2005/06	T.Landry	Effect of temp and salinity on survival of colonial tunicates	14.000	●										●															●												●									●				
	2005/06	T.Landry	Effect of mussel size and density in socks on the success of IT	15.000	●										●															●														●									●				
	2005/06	T.Landry	Effect of epifauna on the settlement of IT	30.000	●										●															●														●									●				
	2005/06	T.Landry	Effects of anthropogenic and environmental factors on the establishment of IT in PEI embayments	13.104	●										●															●																●												
	2005/06	T.Landry	Effect of treatment on violet and star tunicates	47.000	●										●															●														●									●				
	2005/06	T.Landry	Impacts of IT on mussel productivity	51.000	●										●															●															●									●				
	2006/07	A.Locke	Natural dispersal and commercial fisheries as vectors of invasive species	40.000			●								●																					●						●													
	2006/07	A.Locke	Effects of IT management practices on target and non-target species and communities	40.000			●								●															●														●									●				
	2007/08			59.200				●							●															●														●									●				
	2008/09		Effects of tunicate management with hydrated lime on larval American lobster	10.000					●						●															●														●									●				
	2007/08	A.LeBlanc	Interactions between the green crab and IT in PEI	33.900				●							●														●														●									●				
	2007/08	A.LeBlanc, L.Comeau	The effect of vase tunicates on the availability of food particles for filter-feeders	32.200				●							●															●															●									●				
	2006/07	D.Bourque	Interspecific spatial competition between IT in PEI	45.000			●								●															●														●									●				
	2008/09	D.Bourque, A.Locke	The effect of the vase tunicate, *Ciona intestinalis* , on marine ecosystems in PEI/ecosystem productivity and biodiversity	15.000					●						●															●															●									●				
	2009/10			43.000							●				●															●															●									●				
Maritimes	2006/07	D.Brickman	Demonstration realtime risk assessment system for ballast water exchange on the Scotian shelf and Gulf of Maine.	60.000			●									●																					●						●									●				
	2007/08			59.200				●								●																					●						●									●				
	2008/09			60.000					●							●																					●						●									●				
	2007/08	B.Vercaemer, D.Sephton	Understanding the ecology and population dynamics of *Ciona intestinalis* : Identification of biological control points for effective mitigation and management	44.000				●								●															●															●									●				
	2008/09			52.000					●							●															●															●									●				
	2009/10	P.Cranford	Ecosystem interactions between IT and cultured mussels: Importance of food partitioning and phytoplankton size-structure	43.000							●					●															●															●													
	2009/10	M.Wong	Invasive colonial tunicates as ecosystem engineers: fouling impacts in natural nearshore habitats/seagrass beds	19.000							●					●															●															●									●				
Québec	2005/06	C.McKindsey	AIS in PEI embayments: Eutrophication, invasibility, and impacts	50.000	●									●																							●															●				
	2005/06	C.McKindsey	Green crab-rock crab interactions	25.000	●									●								●																															●				
	2006/07	C.McKindsey	Influence of *Codium fragile* ssp. *tomentosoides* on eelgrass *Zostera marina* communities	59.800			●							●							●																															●				
	2007/08			50.600				●						●							●																															●				
	2008/09			78.800					●					●							●																															●				
	2009/10	C.McKindsey	Temperature-related growth and spread of *Codium fragile* in eelgrass beds	12.000							●			●							●																															●				
	2009/10	N.Simard	Evaluation of the discharge of ballast sediments with deballasting	15.000							●	●																									●															●				
	2007/08	B.Sainte-Marie	Écologie de l'amphipode *Caprella mutica* sur les installations mytilicoles	45.300				●						●									●																														●				
	2008/09			47.500					●					●									●																														●				
	2009/10			11.000							●			●									●																														●				
Pacific	2006/07	T.Therriault	Determination of the relationship between habitat characteristics and AIS in the Strait of Georgia (Intertidal)	30.000			●													●																															●				

Region	Year	Lead Scientist	Project Title		Year							Scope (regional or national)								Species																				Research theme												Link to RA				
				Research alloc. ($1,000)	2005/06 Research	2005/06 Coord/Netw.	2006/07 Research	2007/08 Research	2008/09 Research	2008/09 Coord/Netw	2009/10 Research	National	Coordination/Networking	Québec	Gulf	Maritimes	Newfoundland	C&A-Burlington	C&A -Winnipeg	Pacific	*Codium fragile*	*Carcinus maenas*	*Caprella mutica*	*Hemimysis anomala*	*Orc. rusticus & O. virilis*	*Acartia tonsa*	*Echinogamm. ischnus*	*Venerupis philippinarum*	*& Nuttalia obscurata*	*C. maenas* & tunicates	Tunicates	*Botrylloides violaceus*	*Botryllus schlosseri*	*Oncorhynchus mykiss*	*Alosa pseudoharengus*	*Osmerus mordax*	Fish (broad taxon. scope)	Broad taxonomic scope	Other (not species)	Coordination/Networking	Vectors & pathways	Habitat ass. & vectors	Distribution/habitat ass.	Control/adapt. Managem.	Impact	Impact & habitat assoc.	Invasibility analysis	Eradication	RA framework	Mapp. water prop. anom.	Coordination/Networking	Fed into RA	Addressed gaps in RA	Addr. gaps & fed into RA	Not directly linked to RA	Coordination/Networking
Pacific	2006/07	Therriault	Using green crab (*Carcinus maenas*) larval characteristics to understand invasion dynamics and secondary spread in BC coastal waters	35.000			●												●		●																			●											●				
	2007/08			30.500				●											●		●																			●											●				
	2006/07	C.Pearce	Abiotic and biotic factors affecting the growth and reproduction of IT species in BC	35.000			●												●												●												●											●		
	2007/08			40.000				●											●												●												●											●		
	2008/09			40.000					●										●												●												●											●		
	2005/06	B.Crawford	Examine water property anomalies in BC waters based on new climatology	10.000	●														●																																				●			●	
	2006/07	D.Mackas	Invasion of BC marine waters by the copepod *Acartia tonsa*	5.000			●												●							●																												●			●	
	2005/06	G.Gillespie	Factors affecting dispersal of manila clam and varnish clam in BC coastal waters	14.000	●														●									●																												●			●	
	2006/07	G.Jamieson, T.Therriault	Community structure and population dynamics of subtidal AIS in the Strait of Georgia, BC	38.000			○												○																																				○				
	2007/08			33.900				●											●																																				●				
	2008/09			40.000					●										●																																				●				
	2005/06	C.Levings	Bibliography of Canadian publications on ballast water research and management	10.000	●							●																																											●			●	
	2008/09	T.Sutherland	Examination of AIS in sediments accumulated in ship ballast tanks in the APEC region	60.000					●										●																																				●			●	
Newfoundland	2006/07	C.McKenzie	Ballast water exchange zones - modelling	45.000			●										●																																					●				●	
	2007/08		Ballast water exchange in the Newfoundland and Labrador Region- Ocean shelf and coastal impacts on fishery resources and aquaculture - modeling	42.300				●									●																																					●				●	
	2005/06	K.Clarke	Understanding a recent invader, rainbow trout in Trout River NL: Why has it been successful and what are the potential ecosystem effects on native salmonid populations	43.500	●												●																	●																							●			●	
Central & Arctic - Burlington	2006/07	S.Bailey	Propagule pressure and establishment success of aquatic invertebrates: Will regulations based on the proposed IMO ballast treatment standards result in decreased invasion risk for the Great Lakes?	50.000			●												●																																					●					
	2007/08	S.Bailey	Analysis of the domestic ship trade as a secondary vector of species' invasions in the Great Lakes	33.900				●											●																																					●					
	2008/09			50.000					●										●																																					●					
	2009/10	S.Bailey	Ship transit and species' impact research to support CEARA shipping vector risk assessment	30.000							●	●																																											●					
	2005/06	R.Randall	Effect of invasive species on fish habitat suitability in coastal areas of the Great Lakes - lessons for proactive management	20.000	●														●																																											●					
	2005/06	R.Dermott	Survival of the native amphipod *Diporeia* in the presence of the exotic amphipod *Echinogammarus*	10.000	●														●								●																																	●					
	2005/06	N.Mandrak	Evaluating the effectiveness of AIS eradication: round goby in Lake Simcoe	15.000	●														●													●																													●					
	2005/06	J.Fitzsimons	Thiamine dynamics of Lake Ontario American eels and the potential to affect survival	25.000	●														●																																											●					
	2005/06	S.Doka	Impact assessment of potential invading fish species due to climate change on future coastal wetland habitat carrying capacity in the lower Great Lakes	30.000	●														●																																											●					
	2006/07	M.Koops	Quantitative biological RA framework: Evaluation – Year 2 of 2	65.000			●					●																																																		●					
	2006/07	M.Koops, A.Velez-Espino	Development of a population invasibility analysis (Year 1): Modelling the probability of establishment in Cladoceran populations	30.000			●					●																																																		●					
	2007/08		Developing models to predict the probability of establishment (Year 2)"	33.900				●				●																																																				●					

Region	Year	Lead Scientist	Project Title		Year							Scope (regional or national)								Species																						Research theme												Link to RA						
				Research alloc. ($1,000)	2005/06 Research	2005/06 Coord/Netw.	2006/07 Research	2007/08 Research	2008/09 Research	2008/09 Coord/Netw	2009/10 Research	National	Coordination/Networking	Québec	Gulf	Maritimes	Newfoundland	C&A-Burlington	C&A -Winnipeg	Pacific	*Codium fragile*	*Carcinus maenas*	*Caprella mutica*	*Hemimysis anomala*	*Orc. rusticus & O. virilis*	*Acartia tonsa*	*Echinogamm. ischnus*	*Venerupis philippinarum*	*& Nuttalia obscurata*	*C. maenas* & tunicates	Tunicates	*Botrylloides violaceus*	*Botrylloides leachi*	*Botryllus schlosseri*	*Membranipora membranacea*	*Oncorhynchus mykiss*	*Alosa pseudoharengus*	*Osmerus mordax*	Fish (broad taxon. scope)	Broad taxonomic scope	Other (not species)	Coordination/Networking	Vectors & pathways	Habitat ass. & vectors	Distribution/habitat ass.	Control/adapt. Managem.	Impact	Impact & habitat assoc.	Invasibility analysis	Eradication	RA framework	Mapp. water prop. anom.	Coordination/Networking	Fed into RA	Addressed gaps in RA	Addr. gaps & fed into RA	Not directly linked to RA	Coordination/Networking
Central & Arctic - Burlington	2007/08	B.Cudmore, N.Mandrack	Development of ecological invader guilds and identification of areas vulnerable to invasion in the Great Lakes	21.200				●										●																			●															●	
	2008/09			25.000					●									●																			●															●	
	2009/10	K.Bowen, C.Brousseau, J.Fitzsimons	Monitoring and research of *Hemimsys anomala* impacts and their role in the aquatic food web	18.000							●							●						●																											●				
	2009/10	M.Koops, B.Cudmore	Evaluation of methodologies for pathway RAs (initially funded, but funding later cut)	10.000							●	●																													●												●					
Central & Arctic - Winnipeg	2005/06	B.Franzin	Vectors for the establishment and spread of invasive species of zooplankton, algae, and fish into central Canada	30.000	●													●																								●															●	
	2005/06	M.Turner	Monitoring and research to mitigate the distribution and ecosystem impacts of benthic invasions – the crayfish (*Orconectes rusticus* and *O. virilis*)	10.000	●													●								●																											●	
	2005/06	M.Paterson	Paleolimnological reconstruction of the effects of smelt introductions to freshwater lakes	10.000	●													●																					●															●	
	2005/06	P.Blanchfield	Baitfish as a potential high-risk pathway for the transfer and spread of alien invasive species into Lake of the Woods	34.000	○														○																			○															○	
National	2006/07	N.Simard	Sea-chests as a potential vector for AIS along Canadian coasts	90.620			●					●		●		●	●			●																								●															●	
	2007/08			21.200				●				●		●		●	●			●																								●															●	
	2008/09			84.000					●			●		●		●	●			●																								●															●	
	2009/10			90.000							●	●		●		●	●			●																								●															●	
	2008/09	C.McKenzie	National comparison of the impact of the European green crab, *Carcinus maenas*, on biodiversity and habitat	110.000					●			●		●	●	●				●		●																																	●					
	2009/10			150.000							●	●		●	●	●				●		●																																	●					
	2009/10	T.Therriault, T.Landry	IT and shellfish aquaculture: assessing impacts and testing solutions	60.000							●	●			●					●												●																								●				
Gulf	2005/06	T.Landry	Coordination of efforts to control IT	29.896		●							●		●					●																																				●				●
Qc	2008/09	C.McKindsey	Support of ongoing networking/management within the CAISN	36.000						●			●	●						●																																				●				●
C&A - B	2005/06	S.Millard	Funding to H. MacIssac to provide effective communication and collaboration between DFO and the NSERC AIS Network	25.000		●							●						●																																				●				●

● funding received from the research theme

○ funding received from the monitoring theme

IT = Invasive tunicates

Appendix C. Objectives and outcomes of individual research projects

Region	Year	Lead Scientist	Project Title	Objectives	Use by management/legislation/policy	Publications
Gulf	2005/06	T.Landry	Effect of temp and salinity on survival of colonial tunicates	Assess the effect of temperature and salinity on golden star and vilet tunicate larvae and buds.	The results were useful to identify the time of the year when mussels could be transported to minimize the risk of spread. Transport is now authorized to occur in winter.	The results have not been published.
	2005/06	T.Landry	Effect of mussel size and density in socks on the success of IT	Examine if the density of mussels in the mussel socks have an impact on fouling density.	NA	• Ramsay, A, J. Davidson, T. Landry, and H. Stryhn. 2008. The effect of mussel seed density on tunicate settlement and growth for the cultured mussel, *Mytilus edulis* . Aquaculture. 275: 194-200.
	2005/06	T.Landry	Effect of epifauna on the settlement of IT	Assess if current treatment methods to remove epifauna from mussel socks make the socks more vulnerable to tunicate settlement.	NA	The results have not been published.
	2005/06	T.Landry	Effects of anthropogenic and environmental factors on the establishment of IT in PEI embayments	Examine the link between the degree of eutrophicaton and tunicate settlement.	Not yet, as the project is still ongoing.	The study is still ongoing and results have not yet been publshed.
	2005/06	T.Landry	Effect of treatment on violet and star tunicates	Identify treatment methods to control invasive tunicates.	The results were used by management to reduce the risk of spread.	The results have not been published.
	2005/06	T.Landry	Impacts of IT on mussel productivity	Develop a field approach for measuring food uptake and thereby the competition between invasive organisms and shellfish.	NA	• LeBlanc, A. R., D. Bourque, T. Landry, J. Davidson and N.G. MacNair. 2007. The predation of zooplankton by the blue mussel (*Mytilus edulis*) and the clubbed tunicate (Styela clava). Can. Tech. Rep. Fish. Aquat. Sci. 2684: vii+18 p.
	2006/07	A.Locke	Natural dispersal and commercial fisheries as vectors of invasive species	Identify the main vectors (ocean currents, commercial boating activities, and natural movemens of crabs and lobsters) contributing to the spread of invasive tunicates and planktonic AIS in the Gulf region.	Ocean currents and commercial activities were identified as the two most important vectors. The results are being used by the regional office of DFO when issuing permits for I&T of aquaculture products between bays in PEI.	• Bernier, R., A. Locke and J.M. Hanson. 2009. Lobsters and crabs as potential vectors of tunicate dispersal in the southern Gulf of St. Lawrence, Canada. Aquat. Invasions 4: 105-110. • Darbyson, E., J.M. Hanson, A. Locke and J.M.H. Willison. 2009. Survival of European green crab exposed to simulated overland and boating-vector transport conditions. J. Shellfish Res. 28: 377-382. • Darbyson, E., J.M. Hanson, A. Locke and J.M.H. Willison. 2009. Settlement and potential for transport of clubbed tunicate (*Styela clava*) on boat hulls. Aquat. Invasions 4: 95-103. • Darbyson, E., A. Locke, J.M. Hanson and J.M.H. Willison. 2009. Marine boating habits and the potential for spread of invasive species in the Gulf of St. Lawrence. Aquat. Invasions 4: 87-94. • Kanary, L., A. Locke and J. Watmough. 2010. Evaluating the effectiveness of SCUBA-based visual searches for tunicates in a Prince Edward Island estuary. Aquat. Invasions 5:41-47.
	2006/07	A.Locke	Effects of IT management practices on target and non-target species and communities	Examine if the control measures to control invasive tunicates have negative consequences for non-target organisms, such as lobster larvae.	The results will be useful to the aquaculture industry, as the current management strategies might have to be altered depending on the results.	• Locke, A., K. Doe, W. Fairchild, P. Jackman and E. Reese. 2009. Preliminary evaluation of effects of tunicate management with acetic acid and calcium hydroxide on non-target marine organisms in Prince Edward Island, Canada. Aquat. Invasions 4: 221-236. https://www1.cmos.ca/Amsoft%20Web%20Data/upload/abstracts115/2010-06-04archive.html • Locke, A. 2008. Tabulated observations of the pH tolerance of marine and estuarine biota Ranges of pH tolerance in marine organisms. Can. Manuscr. Rep. Fish. Aquat. Sci. 2857: iv+28 p.
	2007/08					
	2008/09		Effects of tunicate management with hydrated lime on larval American lobster			The results have not yet been published.
	2007/08	A.LeBlanc	Interactions between the green crab and IT in PEI	Examine intractions between invasive green crabs and tunicates and native rock crabs and the impact of these interactions on the mussel production.	The results were useful to management, as they showed that it is beneficial for the mussel production to let crabs colonize the mussel socks.	• Mallet, J.-F., A.R. LeBlanc, M. Ouellette and L.A. Comeau. 2009. Abundance and function of rock crabs (*Cancer irroratus*) in longline mussel (Mytilus edulis) farms. Can. Tech. Rep. Fish. Aquat. Sci. 2862: viii+53 p.
	2007/08	A.LeBlanc, L.Comeau	The effect of vase tunicates on the availability of food particles for filter-feeders	Examine if invasive tunicates substantially reduce the amount of suspended food particles available to cultivated mussels and natural grazers (e.g. zooplankton)..	Results indicated that *Ciona* consume ca 6% of the phytoplankton in the water column. Too early to tell if the results will influence management. The methodology developed for the project was applied to an ACRDP project titled "Measuring chlorophyll fluxes in an oyster farm."	The results will be incorporated in a 2012 publication linked to another ongoing project funded by the AIS Program. The ACRDP project lead to one primary publication: Comeau, L.A., Sonier, R., Lanteigne, L., Landry, T. 2010. A novel approach to measuring chlorophyll uptake by cultivated oysters. Aquac. Eng., 43(2): 71-77.
	2006/07	D.Bourque	Interspecific spatial competition between IT in PEI	Identify the high-impact AIS that will end up replacing other lower-impact AIS and identify the timing of recruitment.	Indintification of high-impact invaders was useful to management so more emphasis could be put on efforts to control their spread. The identification of the timing of recruitment helped the aquaculture industry to determine the best time of year for control measures.	• Ramsay A., J. Davidson, T. Landry, and G. Arsenault. 2008. Process of invasiveness among exotic tunicates in Prince Edward Island, Canada. Biol. Invasions. 10: 1311-1316 (this publication was only partially funded by the AIS Program). • Ramsay A., J. Davidson, D. Bourque, and H. Stryhn. 2009. Recruitment patterns and population development of the invasive ascidian *Ciona intestinalis* in Prince Edward Island, Canada. Aquat. Invasions. 4: 169-176.
	2008/09	D.Bourque, A.Locke	The effect of the vase tunicate, *Ciona intestinalis* , on marine ecosystems in PEI/ecosystem productivity and biodiversity.	Examine indicators of ecosystem changes of nutrients, productivity and biodiversity in bays with and without *Ciona* .	Too early to tell.	The results have not yet been published.
	2009/10					
Maritimes	2006/07	D.Brickman	Demonstration realtime risk assessment system for ballast water exchange on the Scotian shelf and Gulf of Maine.	Develop a realtime risk assessment model for vessel ballast water exchange, with the aim of preventing the entry of generic planctonic AIS contained in ballast water into Canadian waters.	The model will be made available to vessel operators in Maritime Canada during the first half of 2011. This will assist the shipping industry in identifying suitable areas for ballast water exchange for ships that will not undertake an offshelf trip diversion.	• Brickman, D. 2006. Risk assessment model for dispersion of ballast water organisms in shelf seas. Can. J. Fish. Aquat. Sci. 63: 2748-2759. • Brickman, D., and P.C. Smith. 2007. Variability in invasion risk for ballast water exchange on the Scotian Shelf of eastern Canada. Mar. Poll. Bull. 54: 863-874.
	2007/08					
	2008/09					
	2007/08	B.Vercaemer, D.Sephton	Understanding the ecology and population dynamics of *Ciona intestinalis* : Identification of biological control points for effective mitigation and management.	Better understand basic biology and population dynamics of *Ciona* so that biological control points can be identified in order to develop better timing of control measures and better manage the species on infested mussel farms.	The information on larval recruitment and dynamics of Ciona infestations were useful to onsite management of tunicate populations on mussel farms on the south shore of Nova Scotia. This allowed the operator of Indian Point Marine Farms to time his treatment and harvesting schedules to minimize the impact *Ciona* .	• Vercaemer et al. 2011. *Ciona intestinalis* environmental control points: Field and laboratory investigations. Aquat. Invasions. 6(4): 477-490.
	2008/09					
	2009/10	P.Cranford	Ecosystem interactions between IT and cultured mussels: Importance of food partitioning and phytoplankton size-structure	Examine the competition (aspects of food partitioning) between invasive tunicates and native filter-feeding organisms for available food resources.	Too early to tell.	The results have not yet been published.

Region	Year	Lead Scientist	Project Title	Objectives	Use by management/legislation/policy	Publications
Marit.	2009/10	M.Wong	Invasive colonial tunicates as ecosystem engineers: fouling impacts in natural nearshore habitats/ seagrass beds.	Examine the impacts of invasive colonial tunicates on seagrass ecosystems.	The results will be useful for the future management of valuable seagrass ecosystems which have now been identified by DFO as an ecological significant species. The research will provide information as to loss of ecosystem functioning, particularly when partnered with research conducted in 2010-2011, and will help guide management decisions.	The project is still ongoing and no publications have yet been completed.
Québec	2005/06	C.McKindsey	AIS in PEI embayments: Eutrophication, invasibility, and impacts	Evaluate the link between eutrophication loads and AIS infestation levels in Prince Edward Island.	No, as there were no identifiable links between eutrophication and AIS loads.	The project is still ongoing and no publications have yet been completed. The work contibuted to the following publication: • McKindsey, C.W., Lecuona, M., Huot, M., Weise, A.M., 2009. Biodeposit production and benthic loading by farmed mussels and associated tunicate epifauna in Prince Edward Island. Aquaculture. 295: 44-51.
	2005/06	C.McKindsey	Green crab-rock crab interactions	Evaluate the interactions between the invasive green crab and the native rock crab to better understand the impact of the green crab in eastern Canada.	No	• Bélair, M.-C. and G. Miron. 2009a. Predation behaviour of *Cancer irroratus* and *Carcinus maenas* during conspecific and heterospecific challenges. Aquat. Biol.. 6: 41-49. • Bélair, M.-C., and G. Miron. 2009b. Time budget of *Cancer irroratus* (Say) and *Carcinus maenas* (L.) under various temperature and prey density conditions during conspecific and heterospecific challenges. J. Shellfish Res. 28: 923-930.
	2006/07 2007/08 2008/09	C.McKindsey	Influence of *Codium fragile* ssp. *tomentosoides* on eelgrass *Zostera marina* communities	Evaluate the impact of *Codium* on eelgrass and the associated fauna as well as the factors correlated to its recruitment.	The work has had impacts on I&T for aquaculture in the region (i.e., it has caused proposed transfers to be disallowed).	• Drouin A, McKindsey CW, Johnson LE. Higher abundance and diversity in faunal assemblages due to the invasion of *Codium fragile* in eelgrass meadows. Resubmitted to Mar. Ecol. Prog. Ser., Sept 2010. • Drouin A, McKindsey CW, Johnson LE. Detecting impacts of invaders: reconciling experiments and observations of the invasion of eelgrass beds by the green alga *Codium* . Submitted to Oecologia, Oct 2010. • Drouin, A., McKindsey, C.W., 2007. QBRAT v2 assessment: *Codium fragile* ssp. *tomentosoides* in the Gulf of St. Lawrence as a case study. DFO Can. Sci. Advis. Sec. Res. Doc. 2007/007: pp. iv + 28.
	2009/10	C.McKindsey	Temperature-related growth and spread of *Codium fragile* in eelgrass beds	Examine the dispersal of *Codium* at small scales and its growth at different temperatures.	The results from the temperature-related growth study are used in the I&T decision-making process.	The results have not yet been published.
	2009/10	N.Simard	Evaluation of the discharge of ballast sediments with deballasting	Understand the importance of propoagule pressure associated with ballast sediments to the introduction of AIS to Canadian waters.	The results will be used to inform the management of this vector.	The project is still ongoing and no publications have yet been completed.
	2007/08 2008/09 2009/10	B.Sainte-Marie	Écologie de l'amphipode *Caprella mutica* sur les installations mytilicoles	Understand the spatial and temporal dynamics in the developement of fouling communities, and of the trophic relationships that determine the structure of the fouling community on collectors of spat.	The project contributed to developing a project by the The Aquaculture Collaborative Research and Development Program (ACRDP) with the objective to reduce the risk of spreading Caprella in transfers of scallop spat.	• Sainte-Marie, B., C. Turcotte, F. Pernet and R. Tremblay. Trophic relationships among fouling organisms on mussel culture lines. In preparation. • Turcotte, C., B. Sainte-Marie & R. Tremblay. Facultative kleptoparasitism as a factor explaining invasion success of a caprellid amphipod. Soumis à: Mar. Ecol. Progr. Ser. (août 2010, no. ms 6624). • Turcotte, C. 2010. La caprelle japonaise *Caprella mutica* et son impact sur l'élevage de moules *Mytilius* spp.: un cas de cleptoparasitisme? Mémoire M.Sc., Université du Québec à Rimouski, Rimouski, 98 p. • Turcotte, C. and B. Sainte-Marie. 2009. Biological synopsis of the Japanese skeleton shrimp (*Caprella mutica*). Can. Manuscr. Rep. Fish. Aquat. Sci. 2903: vii+26 p
Pacific	2006/07	T.Therriault	Determination of the relationship between habitat characteristics and AIS in the Strait of Georgia (Intertidal)	Obtain information on the distribution and relative abundance of intertidal invaders along the coast of BC, and to characterize the specific habitat types supporting AIS in intertidal habitats.	No, as intertidal invaders are not managed in BC.	The results have not yet been published.
	2006/07 2007/08	T.Therriault	Using green crab (*Carcinus maenas*) larval characteristics to understand invasion dynamics and secondary spread in BC coastal waters	Assess the role of natural larval dispersal via ocean currents contributing to the spread of the green crab.	The results fed into a national risk assessment, which was used to inform management actions for this species when it established in Newfoundland.	The results have not yet been published.
	2006/07 2007/08 2008/09	C.Pearce	Abiotic and biotic factors affecting the growth and reproduction of IT species in BC	Examine the tolerances of various species of invasive tunicates to variations in temperetures and salinity as well as their susceptibility to predation by benthic invertebrates, to identify the factors that could potentially control their spread.	The results will be useful to provincial and federal habitat managers as it will help identifying where the species occur and where they might spread. The identification of natural predators on the invasive tunicates will be useful to aquaculture management.	• Epelbaum A., L.M. Herborg, T.W. Therriault, C.M. Pearce. 2009a. Temperature and salinity effects on growth, survival, reproduction, and potential distribution of two non-indigenous botryllid ascidians in British Columbia. J. Exp. Mar. Biol. Ecol. 369: 43-52. • Epelbaum A., T.W. Therriault, A. Paulson, C.M. Pearce. 2009b. Botryllid tunicates: culture techniques and experimental procedures. Aquat. Invasions 4: 111-120. • Epelbaum A., C.M. Pearce, D.J. Barker, A. Paulson, T.W. Therriault. 2009c. Susceptibility of non-indigenous ascidian species in British Columbia (Canada) to invertebrate predation. Mar. Biol. 156: 1311-1320. • Epelbaum A, C.M. Pearce, TW Therriault (2008) A case of atrial siphon duplication in *Styela clava* (Tunicata: Ascidiacea). J. Mar. Biol. Assoc. U.K. 2 – Biodiversity Records. Online: http://www.mba.ac.uk/jmba/pdf/6243.pdf
	2005/06	B.Crawford	Examine water property anomalies in BC waters based on new climatology	Prepare maps of average summer and winter temperature and salinity of the BC ocean region.	The maps are used to determine temperature and salinity anomalies in the coastal and deep-ocean waters. This information is being used by researchers to determine the impact of these anomalies on the ability of invasive species to thrive in some regions and years, and not in others.	• Galbraith J., and B. Crawford. 2009. Contours of Average Temperature and Salinity in the Gulf of Alaska http://www.pac.dfo-mpo.gc.ca/science/oceans/data-donnees/Alaska/index-eng.htm (website accessed 2010-10-15) • Crawford, W.R. 2010. Global and North Pacific conditions – Temperatures in 2009: Globally warm but locally cool, p 21-26 In: Crawford, W.R., and J.R. Irvine. (Eds.). State of physical, biological, and selected fishery resources of Pacific Canadian marine ecosystems in 2009. DFO Can. Sci. Advis. Sec. Res. Doc. 2010/053: viii + 137 p.
	2006/07	D.Mackas	Invasion of BC marine waters by the copepod *Acartia tonsa*	Study a climate-driven range expansion of a marine crustacean copepod, with ocean currents as the supply mechanism.	The result from the study could be used as a model for invasions by other species with planctonic dispersal stages.	• Mackas, D.L., and M.D. Galbraith. 2005. Appearance and rapid increase of the exotic copepod *Acartia tonsa* on the British Columbia continental margin, PICES 14th Annual Meeting, Sep 29 - Oct 9, 2005, Vladivostok, Russia, http://www.pices.int/publications/presentations/PICES_14/S4/s4_Mackas.pdf *Conference presentation*
	2005/06	G.Gillespie	Factors affecting dispersal of manila clam and varnish clam in BC coastal waters	Assess the current distribution, population demographics at different sites, and the historic rate of spread for both species.	Results led to the development of a commercial fishery for Manila clams on the the North Coast of BC. Expected persistence of populations in the area led to decision to actively manage the fishery with conservation targets.	The results have not yet been published.

Region	Year	Lead Scientist	Project Title	Objectives	Use by management/legislation/policy	Publications
Pacific	2006/07 2007/08 2008/09	G.Jamieson, T.Therriault	Community structure and population dynamics of subtidal AIS in the Strait of Georgia, BC	Identify subtidal invaders in the Strait of Georgia and their distribution.	The results on invasive tunicates were used to inform managment options on the east coast of Canada (PEI, NL, Magdalen Islands).	The results have not yet been published, but the project contributed to the following publications: • Frey, M.A., H.N. Gartner, C.C. Murray, and T.W. Therriault. 2009. First confirmed records of the non-native amphipod *Caprella mutica* (Schurin 1935) along the coast of British Columbia, Canada, and the potential for secondary spread via hull fouling. Aquat. Invasions 4: 495-499. • Herborg, L.-M., P. O'Hara, and T.W. Therriault. 2008. Forecasting the potential distribution of the invasive tunicate *Didemnum vexillum* . J. Appl. Ecol. 46: 64-72. • Lejeusne, C., D. Bock, H.J. MacIsaac, T.W. Therriault, and M.E. Cristescu. 2011. Comparative phylogeography of two colonial ascidians reveals contrasting invasion histories in North America. Biol. Invasions 13: 635-650. • Therriault, T.W., and L.-M. Herborg. 2008a. Predicting the potential distribution of the vase tunicate Ciona intestinalis in Canadian waters: informing a risk assessment. ICES J. Mar. Sci. 65: 788-794. • Therriault, T.W., and L.-M. Herborg. 2008b. A qualitative biological risk assessment for vase tunicate Ciona intestinalis in Canadian waters: using expert knowledge. ICES J. Mar. Sci. 65: 781-787.
	2005/06	C.Levings	Bibliography of Canadian publications on ballast water research and management	Create a comprehensive web based bibliography required to inform managers and new researchers of past work.	The bibliography was available on Transport Canada's website and used by managers and researchers.	A database was produced in this project, but no publications.
	2008/09	T.Sutherland	Examination of AIS in sediments accumulated in ship ballast tanks in the APEC region	Assess the risk of introducing AIS associated with particle-rich sediments from ports in the APEC region.	The results will be used to assess the risk of introducing AIS to Canadian waters via the commercial shipping vector.	• Sutherland, T., C. Levings, and C. Wiley. 2009. Quantifying Aquatic Invasive Species in Accumulated Ballast Sediment Residuals - "Swish": Preliminary Results.
Newfoundland	2006/07	C.McKenzie	Ballast water exchange zones - modelling	Continue and enhance the work started with the Newfoundland Ballast water exchange risk assessment, aimed at identifying areas in Newfoundland suitable for establishing Alternate Ballast Water Exchange Zones.	The results from the study will be used by Transport Canada when revising current ballast water regulations. The developed oceanic models were used to provide information on the possible route of introduction and potential spread of the newly established green crab in Placentia Bay.	• Best, K., C.H. McKenzie, and C. Couturier. 2009. Early life stage biology of a new population of green crab, *Carcinus maenas* , in Placentia Bay: implications for mussel culture in Newfoundland. Aquac. Assoc. Can. Spec. Publ. No. 15: 48-50. • Blakeslee, A.M.H., C.H. McKenzie, J.D. Darling, J.E. Byers, J.P. Pringle, and J. Roman. 2010. A hitchhiker's guide to the Maritimes: anthropogenic transport facilitates long-distance dispersal of an invasive marine crab to Newfoundland. Diversity Distrib. 16: 879-891. • DFO, 2010. Proceedings of the National peer review on Alternate Ballast Water Exchange zones for vessel traffic to Newfoundland and the Arctic. January 13-14, 2009. DFO Can. Sci. Advis. Sec. Proceed. Ser. 2009/054: vi+23 p. • DFO. 2010. Review of Alternate Ballast Water Exchange Zones for vessel traffic to Newfoundland and Labrador and the Canadian Arctic. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2010/026. 7 p. • Han, G., Z. Lu, Z. Wang, J. Helbig, N. Chen, and B. de Young. 2008. Seasonal variability of the Labrador Current and shelf circulation off Newfoundland. J. Geopys. Res. 113, C10013, doi:10.1029/2007JC004376.
	2007/08		Ballast water exchange in the Newfoundland and Labrador Region- Ocean shelf and coastal impacts on fishery resources and aquaculture - modeling			• Ma, Z., G. Han, B. De Young, M. Foreman. 2010. Simulation of temperature and currents in Placentia Bay, The 2010 CMOS-CGU Congress, Ottawa • McKenzie, C. H., G. Han, M. He, T. Baines and G. Maillet. 2010. Alternate Ballast Exchange zones for the Newfoundland and Labrador Region- An Aquatic Invasive Species Risk Assessment based on oceanographic modeling, ecologically and biologically significant areas and sustainability of fisheries and Aquaculture. Can. Sci. Advis. Sec. Res. Doc. 2010/087: xx+41 p. • McKenzie, C.H., T. Baines, K. Best, R. Boland, E. Dawe, D. Deibel, D. Drover, E. Johnson, S. Kenny, S. Macneill, D. Mouland, R. • O'Donnell, L. Park, P. Sargent, C. Vickers, and A. Vickerson. 2007. The European green crab, *Carcinus maenas* , in Placentia Bay, Newfoundland AIS Survey 2007. Proceedings of Aquatic Invasive Species Newfoundland Workshop. St. John's, NL, November 16, 2007.
	2005/06	K.Clarke	Understanding a recent invader, rainbow trout in Trout River NL: Why has it been successful and what are the potential ecosystem effects on native salmonid populations	Investigate potential impacts of the introduced rainbow trout on native salmonid populations, and the possibility to control the rainbow trout population through physical removal.	The objective of controling the population through physical removal was abandoned as it proved to be ineffective due to the amount of effort involved.	• Clarke, K.D., D. A. Scruton, and T.R. Porter. 2006. Preliminary observations of a recent invader, rainbow trout (*Oncorhynchus mykiss*), in Trout River, Newfoundland and its potential to affect native salmonids. Canadian Conference for Fisheries Research, Calgary, Alberta, January 5-7, 2006. 28 p.
Central & Arctic - Burlington	2006/07	S.Bailey	Propagule pressure and establishment success of aquatic invertebrates: Will regulations based on the proposed IMO ballast treatment standards result in decreased invasion risk for the Great Lakes?	Evaluate the effectiveness of the IMO ballast water treatment standards, i.e. assess if they result in a decreased invasion risk for the Great Lakes.	The results were used by Transport Canada in their decision to renew their commitment to the ballast water regulations, and have also been referred to by the US Coast Guard, the US Environmental Protection Agency, the 8 American states bordering the Great Lakes, and California.	• Bailey, S.A., L.A.V élez-Espino, O.E. Johannsson, M.A. Koops, and C.J. Wiley. 2009. Estimating establishment probabilities of Cladocera introduced at low density: an evaluation of the proposed ballast water discharge standards. Can. J. Fish. Aquat. Sci. 66: 261-276.
	2007/08 2008/09	S.Bailey	Analysis of the domestic ship trade as a secondary vector of species' invasions in the Great Lakes	Assess the risk of introducing new AIS to and spreading AIS within the Great Lakes associated with the the domestic shipping vector. This vector is currently unregulated.	The results have been referred to by Transport Canada who is currently revising the ballast water regulations, as well as the US Coast Guard, the US Environmental Protection Agency, the 8 American states bordering the Great Lakes, and California.	• Rup M.P., S.A. Bailey, C.J. Wiley, M.S. Minton, A.W. Miller, G.M. Ruiz, H.J. MacIsaac. 2010. Domestic ballast operations on the Great Lakes: potential importance of Lakers as a vector for introduction and spread of nonindigenous species. Can. J. Fish. Aquat. Sci. 67: 256-268.
	2009/10	S.Bailey	Ship transit and species' impact research to support CEARA shipping vector risk assessment	Perform a vector analysis for selected regions in Canada (identify origin ports and probability of negative impacts of potential invaders from these ports).	The results will feed into the CEARA national shipping risk assessment.	The results have not yet been published.
	2005/06	R.Randall	Effect of invasive species on fish habitat suitability in coastal areas of the Great Lakes - lessons for proactive management	Determine the impact of invasive species on habitat suitability in the Great Lakes.	The results could be useful for the management of AIS once published.	The project has not been completed, and the results have not yet been published.
	2005/06	R.Dermott	Survival of the native amphipod *Diporeia* in the presence of the exotic amphipod *Echinogammarus*	Examine if the invasive amphipod *Echinogammarus ischnus* may be a source of disease that is reducing the survival of the native deepwater amphipod Diporeia sp.	No.	Project not completed

Region	Year	Lead Scientist	Project Title	Objectives	Use by management/legislation/policy	Publications
Central & Arctic - Burlington	2005/06	N.Mandrak	Evaluating the effectiveness of AIS eradication: round goby in Lake Simcoe	Evaluate the effectiveness of the attempted eradication of Round Goby in Pefferlaw Brook, a tributary of Lake Simcoe, and to determine the effect on the entire fish community.	The project revealed that eradication was not successful and that the eradication method (rotenone) did not have a lasting effect on the native fish community.	• Dimond, P.E., N.E. Mandrak, and B. Brownson. 2010. Summary of the rapid response to Round Goby (*Neogobius melanostomus*) in Pefferlaw Brook with an evaluation of the national rapid response framework based on the Pefferlaw Brook experience. DFO Can. Sci. Advis. Sec. Res. Doc. 2010/036: vi+33 p. • Marson, D., and N.E. Mandrak. Draft. Changes in fish assemblages in Pefferlaw Brook following rotenone treatment, 2005-2006. DFO Can. MS Fish Aquat. Sci.
	2005/06	J.Fitzsimons	Thiamine dynamics of Lake Ontario American eels and the potential to affect survival	Identify if the maintenance of high alewife biomass in Lake Ontario to support Pacific salmon is a threat to American eel.	No.	The results have not yet been published. • Fitzsimons J., S. Brown, L. Brown, G. Verreault, J. Lepak, and K. Drouillard. 2008 Thiamine Status of Lake Ontario American eel *Anguilla rostrata*: Could a Thiamine Deficiency Be Contributing to Population Decline? Thiamine Deficiency Complex Workshop, Final Report, November 6-7, 2008, Ann Arbor, MI. p. 24-25. Conference presentation.
	2005/06	S.Doka	Impact assessment of potential invading fish species due to climate change on future coastal wetland habitat carrying capacity in the lower Great Lakes	Conduct an analysis of the habitat overlap of native fish species and species that will establish in the Great Lakes due to climate change, and subsequently identify pressures on carrying capacity of different habitat types in coastal wetlands.	No, as the project has not yet been completed.	The project has not been completed, and the results have not yet been published.
	2006/07	M.Koops	Quantitative biological RA framework: Evaluation – Year 2 of 2	Develop and evaluate a tool for conducting risk assessments of AIS.	The tool has been used for risk assessments and evaluating risk assessment guidelines.	• Moore, J.E., M.A. Koops and B. Cudmore. 2007. Quantitative Biological Risk Assessment Tool, v.3.2. Fisheries and Oceans Canada, Burlington, ON. • Cudmore, B., M.A. Koops and N.E. Mandrak. 2007. National workshop on the evaluation of a Quantitative Biological Risk Assessment Tool (QBRAT) through various case studies, 29-30 November 2006. DFO Can. Sci. Advis. Sec. Proceed. Ser. 2007/014. • Locke, A. and G.J. Klassen. 2007. Using the Quantitative Biological Risk Assessment Tool (QBRAT) to predict effects of the European green crab, *Carcinus maenus*, in Atlantic Canada. DFO Can. Sci. Advis. Sec. Res. Doc. 2007/077. • Cudmore, B. and M.A. Koops. 2007. Risk assessment of round goby (*Neogobius melanostomus*) to Lake Simcoe, Ontario: a Qunatitative Biological Risk Assessment Tool (QBRAT) case study. DFO Can. Sci. Advis. Sec. Res. Doc. 2007/038. • Johannsson, O.E. 2007. Risk assessment of Bythotrephes longimanus establishment in Muskoka Lakes: an assessment of QBRAT, the Quantitative Biological Risk Assessment Tool. DFO Can. Sci. Advis. Sec. Res. Doc. 2007/059. • Herborg, L.-M. and T.W. Therriault. 2007. Application of QBRAT for a risk assessment of the invasive tunicate *Didemnum* sp. in British Columbia. DFO Can. Sci. Advis. Sec. Res. Doc. 2007/056. • Drouin, A. and C.W. McKindsey. 2007. QBRAT v2 assessment: *Codium fragile* ssp. *tomentosoides* in the Gulf of St. Lawrence as a case study. DFO Can. Sci. Advis. Sec. Res. Doc. 2007/007.
	2006/07	M.Koops, A.Velez-Espino	Development of a population invasibility analysis (Year 1): Modelling the probability of establishment in Cladoceran populations	Present models predicting the probability of establishement of AIS. The study also included an assessment of how an established population may be controlled.	See comment to Bailey propoagule study.	• Bailey, S.A., L.A.V élez-Espino, O.E. Johannsson, M.A. Koops, and C.J. Wiley. 2009. Estimating establishment probabilities of Cladocera introduced at low density: an evaluation of the proposed ballast water discharge standards. Can. J. Fish. Aquat. Sci. 66: 261-276.
	2007/08		Developing models to predict the probability of establishment (Year 2)"		By showing that the spread of the round goby is practically impossible to control once the species has established, the study highlighed the importance of prevention as the most effective management option.	• Vélez-Espino, L.A., M.A. Koops and S. Balshine. 2010. Invasion dynamics of round goby (*Neogobius melanostomus*) in Hamilton Harbour, Lake Ontario. Biol. Invasions. 12: 3861-3875.
	2007/08 2008/09	B.Cudmore, N.Mandrak	Development of ecological invader guilds and identification of areas vulnerable to invasion in the Great Lakes	Predict the impact of potential fish invaders in the Great Lakes basin.	The results will be very useful for future risk assessments.	The project is still in progress, and no results have yet been published.
	2009/10	K.Bowen, C.Brousseau, J.Fitzsimons	Monitoring and research of *Hemimsys anomala* impacts and their role in the aquatic food web	Assess the distribution and abundance of Hemimysis, its occurrence in the food chain, and its effects on native species.	Too early to tell.	• Fitzsimons J.D., C. Brousseau, T. Johnson, M. Yuille, and K. Bowen. In prep. The occurrence of *Hemimysis* in round goby: A case of hiding in plain sight? • Fitzsimons J.D., R.M. Claramunt, N.T. Barton, and T.L. Galarowicz. In prep. Competition between *Hemimysis* and larval salmonids for zooplankton: A non-event? • Claramunt R.M., N.T. Barton, J.D. Fitzsimons, and T. L. Galarowicz. In prep. Microhabitat association of *Hemimysis* on fish spawning reefs in Lake Michigan. • Marty J., K. Bowen, M.A. Koops, and M. Power. 2010. Distribution and ecology of *Hemimysis anomala*, the latest invader of the Great Lakes basin. Hydrobiologia. 647: 71-80.
	2009/10	M.Koops, B.Cudmore	Evaluation of methodologies for pathway RAs (initially funded, but funding later cut)	Evaluate the relative performance of pathway risk assessment methodologies.	Refined risk assessment methods would be useful to DFO when evaluating the risk of AIS to Canada's aquatic ecosystems, and would assist DFOin setting priorities.	
Central & Arctic - Winnipeg	2005/06	B.Franzin	Vectors for the establishment and spread of invasive species of zooplankton, algae, and fish into central Canada	Identify AIS that may potentially establish in the Hudson Bay and the Hudson Bay watershed coming from the neighbouring watersheds and from the ballast water of ships travelling to Hudson bay.	Not known if the results were used by management.	• Rosenberg, D.M., M.A. Turner, W. Jansen, T. Mosindy and D.A. Watkinson. 2010. Threats to Lake of the Woods and the Winnipeg River by the rusty crayfish (*Orconectes rusticus*), an aquatic invader. Ont. Min. Natur. Resour., Northwest Sci. & Info., NWSI Tech. Workshop Rpt. TWR-005. 54 p.+append. • Jansen, W., N. Geard, T. Mosindy, G. Olson, and M. Turner. 2009. Relative abundance and habitat association of three crayfish (*Orconectes virilis*, *O. rusticus*, and *O. immunis*) near an invasion front of O. rusticus, and long-term changes in their distribution in Lake of the Woods, Canada. Aquat. Invasions 4: 627-649.
	2005/06	M.Turner	Monitoring and research to mitigate the distribution and ecosystem impacts of benthic invasions – the crayfish (*Orconectes rusticus* and *O. virilis*)	Assess the current distribution of crayfish in Lake of the Woods, and how far the rusty crayfish has moved up the Winnipeg River system from Lake of the Woods.	The Province of Manitoba used the results to ban the possession of crayfish.	• Rosenberg, D.M., M.A. Turner, W. Jansen, T. Mosindy and D.A. Watkinson. 2010. Threats to Lake of the Woods and the Winnipeg River by the rusty crayfish (*Orconectes rusticus*), an aquatic invader. Ont. Min. Natur. Resour., Northwest Sci. & Info., NWSI Tech. Workshop Rpt. TWR-005. 54 p.+append. • Jansen, W., N. Geard, T. Mosindy, G. Olson, and M. Turner. 2009. Relative abundance and habitat association of three crayfish (*Orconectes virilis*, *O. rusticus*, and *O. immunis*) near an invasion front of *O. rusticus*, and long-term changes in their distribution in Lake of the Woods, Canada. Aquat. Invasions 4: 627-649.

Region	Year	Lead Scientist	Project Title	Objectives	Use by management/legislation/policy	Publications
Central & Arctic - Winnipeg	2005/06	M.Paterson	Paleolimnological reconstruction of the effects of smelt introductions to freshwater lakes	Identifiy the ecosystem effects of rainbow smelt invasions.	No, as the research part of the project was never funded as the AIS program changed its objectives.	• Rooney, R.C., and M.J. Paterson. 2009. Ecosystem effects of rainbow smelt (*Osmerus mordax*) invasions in inland lakes: a literature review. Can. Tech. Rep. Fish. Aquat. Sci. 2845: iv+33 p.
	2005/06	P.Blanchfield	Baitfish as a potential high-risk pathway for the transfer and spread of alien invasive species into Lake of the Woods	Identify the risk of introducing AIS associated with the dumping of baitfish. This activity was not an important vector of introduing AIS into Lake of the Woods.	The results from the study had no direct influence on decisions regarding the management of AIS. However, the results are important to management of AIS as this vector has been identified as being of low priority.	• 2007. "Survey reports winter anglers handling bait properly", Kenora Daily & Miner News, Lake of the Woods Enterprise, Article ID# 1858388, 25th Jan. 2007 http://www.lotwenterprise.com/ArticleDisplay.aspx?archive=true&e=1858388 • Gillespie, M.A., Blanchfield, P.J. and Mosindy, T. Baitfish as an invasion pathway: a case study of the Lake of the Woods winter fishery. 60th Canadian Conference for Fisheries Research, 04 - 06 January 2007, Montreal, QC (page 111/123) http://www.phys.ocean.dal.ca/ccffr/abs07.pdf Abstract
National	2006/07	N.Simard	Sea-chests as a potential vector for AIS along Canadian coasts	Assess the importance of sea-chests as a vector for the introduction and transport of AIS along Canadian coasts.	The results will help establish guidelines for policy.	• Frey, M.A., Simard, N., Martin, J. and Therriault, T.W. (in prep) The risk of fouling around: sea-chests as a potential vector for the introduction and dispersal of aquatic invasive species. Intended for submission to Mar. Poll. Bull.
	2007/08					
	2008/09					
	2009/10					
	2008/09	C.McKenzie	National comparison of the impact of the European green crab, *Carcinus maenas,* on biodiversity and habitat	Determine the impact on biodiversity and habitat of the invasive green crab in several different Canadian habitats in areas where they have invaded in high concentrations.	The results will be useful to guide managent, as it will help determine to what extent and by which method the green crab could be managed and mitigated the most effectively.	• DFO. 2011. Proceedings of the Regional Advisory Process on European Green Crab, *Carcinus maenas* , Population and Mitigation in Newfoundland. March 17, 2010. DFO Can. Sci. Advis. Sec. Proceed. Ser. 2011/020: v+22 p. • DFO. 2010c. Ecological Assessment of the Invasive European green crab, (*Carcinus maenas*) in Newfoundland 2007-2009. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2010/033: 10 p.
	2009/10					
	2009/10	T.Therriault, T.Landry	IT and shellfish aquaculture: assessing impacts and testing solutions	Examine and validate various mechanical, biological, and chemical means for eradicating invasive tunicates in shellfish aquaculture.	The results may be used by the aquaculture industry for controlling tunicates on their shellfish and/or gear.	The results have not yet been published.

Appendix D. Questionnaire to compile information

List of questions sent to the lead scientists in order to gather the information used in this report.

1. Title of project:

2. We would like you to identify which category/categories the project best fits into. Please elaborate on how they fit into those categories.

- identification of pathways and vectors
- prevention of entry
- response to AIS already introduced:
    - eradication
    - control measures
    - adaptive management
- other

3. What species/theme was/were the focus of the study?

4. Did the research follow what was outlined in the proposal? If not, please indicate what section was left out and/or was done instead.

5. Did the research feed into a risk assessment, or did it address gaps identified in previous risk assessments?

6. Were the results useful to the management of AIS, and did they influence management decisions? If yes, please elaborate (managers could also be asked this question).

7. Did the results from the project feed into other projects, or was it used by other researchers/organizations? If yes, please elaborate.

8. Did any publications result from the project? If yes, please provide list of publications

9. Are the results available to the public in any other way (e.g. are they available on the DFO website)?

10. Other relevant information