Aquatic Invasions (2009) Volume 4, Issue 1: 249-258
This is an Open Access article; doi: 10.3391/ai.2009.4.1.25

Special issue "Proceedings of the 2nd International Invasive Sea Squirt Conference"
(October 2-4, 2007, Prince Edward Island, Canada)

Research article

Rapid response to non-indigenous species. 2. Case studies of invasive tunicates in Prince Edward Island

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Received 18 March 2008; accepted for special issue 14 May 2008; accepted in revised form 22 December 2008; published online 16 January 2009

Abstract

The term "rapid response" refers to the steps taken upon the detection of a non-indigenous species and encompasses a range of possible actions ranging from eradication, management of population abundance or dispersal, to a decision against an active response. Rapid response to non-indigenous species in Canadian waters is in its infancy and has been carried out on *ad hoc* basis in the absence of formal rapid response plans. Even so, many of the essential elements of a rapid response plan were in fact implemented in the management of recent invasions of the non-indigenous tunicates *Styela clava*, *Botryllus schlosseri*, *Botrylloides violaceus*, and *Ciona intestinalis* in estuaries of Prince Edward Island (PEI), Canada. In this second of a three-part series, we examine case studies of the PEI tunicate invasions, as a step in formulating a rapid response framework that can be used in Canadian waters to manage future invasions by nuisance or noxious species.

Key words: rapid response, invasive species management, tunicate

Introduction

The capacity to quickly respond to detection of colonization by a non-indigenous species is known as "rapid response" and is an essential element of marine invasive species management programs (McEnnulty et al. 2001; NEANS 2003; WANS 2003; Wotton and Hewitt 2004). The primary goal of most rapid response plans is eradication of the non-indigenous species or reduction of its population below levels needed for reproductive success (Crooks and Soulé 1999; Myers et al. 2000; McEnnulty et al. 2001; WANS 2003). However, eradication is not always an attainable or affordable goal. In decreasing order of desirability, the goal of the rapid response may entail: eradication, containing the problem to a given area, suppressing the population to slow its spread, developing management strategies to keep the species at an abundance which is below an economic or ecological threshold, or learning to live with the problems caused by the species (Myers et al. 2000).

A formal procedure to identify and mitigate establishment of noxious non-indigenous species does not exist for aquatic habitats in Canada. Concerted efforts to develop prevention and management strategies for non-indigenous species in marine waters of Atlantic Canada began in 2001 due to the arrival of several non-indigenous tunicate species that rapidly became pests of bivalve aquaculture in Prince Edward Island. The scope of the available strategies was limited. The main emphasis has been on the management of intentional introductions and associated diseases, fauna, and flora through an Introductions and Transfers screening process (National Code on Introductions and Transfers of Aquatic Organisms 2003). A similar approach has been used to address the role of factories that process fishery products in the dispersal of invasive tunicates between estuaries in Prince Edward Island. While mandatory offshore ballast water exchange for all commercial shipping entering Atlantic Canadian waters came into effect in 2006 (Transport Canada 2006), there is no regulation of other vectors, such as hull fouling, recreational boating, fisheries, and the aquarium trade. Consequently, unplanned introductions of marine species will continue.

This paper is the second in a three-part series about rapid response to non-indigenous marine species. In the first part, we reviewed published examples of rapid response in the marine environment (excluding Canada) and the scope and goals of rapid response (Locke and Hanson 2009a). In the present paper, we present case studies of tunicate invasions that have occurred in the estuaries of Prince Edward Island (PEI) within the past decade, the management response, and its success. In the third paper, we propose a framework for the planning and execution of rapid responses to species invasions in aquatic habitats in Canada (Locke and Hanson 2009b).

Case studies of responses to non-indigenous tunicates in Prince Edward Island

Since the mid-1990s, the coastal waters of PEI (Figure 1) have become one of the most heavily invaded marine ecosystems in Canada (Locke et al. in prep.). Among the recent arrivals are four non-indigenous tunicates: *Styela clava* Herdman, 1881, *Botryllus schlosseri* (Pallas, 1766), *Botrylloides violaceus* (Oka, 1927), and *Ciona intestinalis* (Linnaeus, 1767). In this section, we review the history of these tunicate invasions and the responses of federal and provincial fisheries departments and affected industries.

(1) Clubbed tunicate, *Styela clava*

Styela clava was first found on aquacultured blue mussels *Mytilus edulis* Linnaeus, 1758 harvested from the Brudenell River adjacent to the Georgetown commercial wharf (Figure 1, Location 11). It was brought to the PEI Department of Agriculture, Fisheries and Aquaculture (DAFA) in January 1998 by the mussel grower, who had first noticed it during 1997. Specimens were sent by DAFA to the Atlantic Reference Centre (St. Andrews, NB, Canada), which retained voucher specimens and forwarded material to G. Lambert (University of Washington, Friday Harbor Laboratories, Friday Harbor, WA, USA) who confirmed the identity. The tunicate was immediately reported to the PEI Introductions and Transfers (I&T) Committee, the body responsible for licensing movement of aquacultured organisms in PEI.

DAFA informed the mussel aquaculture industry of their findings in the spring of 1998 and *Styela* was included on an aquatic invasive species (AIS) poster developed by Fisheries and Oceans Canada (DFO) and DAFA. In 1999, this poster was distributed with all commercial fishing licenses in PEI and posted at all public boat launches alongside metal “clean your boat” signs. Commercial fisheries and aquaculture stakeholders were informed through presentations at annual meetings of industry associations, and workshops about the ecology and management of the tunicate. A brochure featuring *Styela,* along with recommendations for reducing its spread, was produced by DFO in 2002 and approximately 10,000 copies were distributed in PEI, New Brunswick, and Nova Scotia. The Young Environmentalists (a youth group organized by the PEI Department of the Environment) met with recreational boat owners over three years and handed out AIS brochures and floatable key chains while conducting a survey of invasive species knowledge. The group conducted a similar survey with commercial fish harvesters.

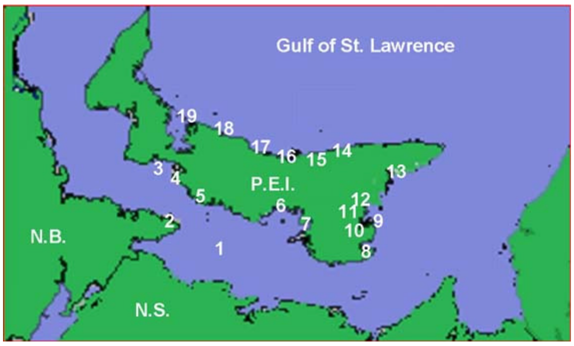

Figure 1. Map of Prince Edward Island (P.E.I.), New Brunswick (N.B.) and Nova Scotia (N.S.), Canada, showing places named in the text. 1=Northumberland Strait, 2=Cape Tormentine, 3=Bedeque Bay, 4=Seacow Head, 5=Borden, 6=Charlottetown Harbour, 7=Vernon and Orwell Rivers, 8=Murray River, 9=St. Mary’s Bay, 10=Montague River, 11=Brudenell River, 12=Cardigan River and Bay, 13=Souris Harbour, 14=St. Peter’s Bay, 15=Savage Harbour, 16=Tracadie Bay, 17=Rustico Bay and Hunter River, 18=New London Bay, 19=Malpeque Bay, including March Water and Darnley Basin. The town of Georgetown, not marked on the map, is located at the confluence of the Montague (10) and Brudenell (11) Rivers.

The I&T committee attempted to determine if *Styela* would adversely affect aquaculture or fisheries in PEI. International experts consulted early in 1998 were of the opinion that the species would not survive the winter. Also, there was no indication in the literature that the species was likely to have serious impacts on marine biota or harvests. Moreover, a SCUBA survey conducted by DAFA in the spring of 1998 found no *Styela* in the original area of discovery. Consequently, no management actions were initially undertaken; but, over the next three years, *Styela* spread rapidly among the estuaries of south-eastern PEI (Figure 2) and, by 2001, had become a serious fouling pest of mussel aquaculture operations. In 2001, a Tunicate Subcommittee of the I&T Committee was formed, consisting of federal and provincial government resource managers, scientists from government and academia, and industry representatives. This group provided recommendations on the scientific research requirements and possible management measures for tunicates to the I&T Committee, but had no power to implement management actions. Researchers from the Tunicate Subcommittee formed a Styela Clava Action Research Group (SCARG) in 2001 to collaborate on research projects and provide scientific advice to the Tunicate Subcommittee and, through it, the I&T Committee. SCARG researchers started studies of seasonal growth and reproductive cycles, natural mortality, the possibility of biological control using crabs, effects on mussel growth and meat yield, and vectors of secondary spread, in the summer of 2001 (e.g., Bourque et al. 2007; Darbyson et al., 2009a, 2009b). The feasibility of installing adequate screening of effluent released into the estuaries by processing plants was investigated. It was known that *Styela* reproductive products were being released into the outflow water during declumping and cleaning of the mussel socks, and indeed this was identified as the likely vector for the spread to the Orwell-Vernon River system. At that time, only one of the dozen plants on PEI had an outflow screening system adequate to contain tunicates.

It was apparent as early as 2000 that mussel aquaculture practices could contribute to dispersal of *Styela* and, since this was the affected stakeholder group, it had a vested interest in managing the problems caused by the tunicate. In consultation with the aquaculture industry, the I&T Committee decided in 2001 that containment should be immediately implemented. On Monday, 24 October 2001, the first restrictions of aquaculture transfers and harvests from Montague, Brudenell, Murray, Orwell and Vernon rivers were brought into effect by the I&T Committee, under Section 55 of Canada's federal Fisheries General Regulations. Transfers and processing of the harvest were to be contained within the tunicate-infested area.

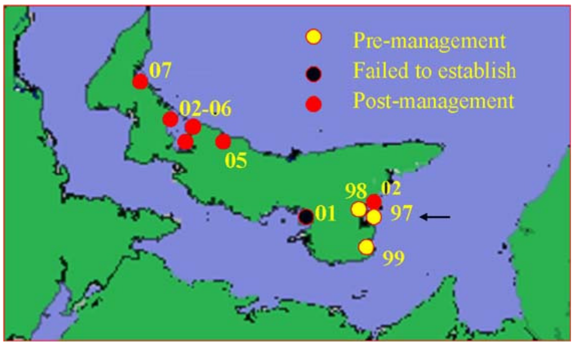

Figure 2. Distribution of *Styela clava* in Prince Edward Island, 1997-2007, showing point of introduction (black arrow), and dispersal (sites marked by last two digits of year of discovery) before and after management was initiated.

Unfortunately, growers were informed of the restrictions several days before they came into effect, and it is suspected that many used that time to move spat and gear from infested to uninfested estuaries and to process the harvested mature mussels in plants located outside the quarantine zone. In early November 2001, the growers of Tracadie Bay, an important mussel-producing bay lacking a tunicate infestation, imposed their own management practice; they decided on a voluntary ban of all mussel seed originating from outside the Tracadie Bay system, with the exception of seed inspected for tunicates and originating from other north shore estuaries. In this and several other estuaries, peer pressure has been partially effective in encouraging responsible management practices among growers.

No quantitative risk-benefit analysis was conducted at the time to determine the need for control of *Styela*. A conservative estimate by a grower/processor of the additional handling and disposal costs was CAN $0.24/kg of harvested mussels (R. Fortune, pers. comm.). Based on this estimate and the qualitative observations of scientists and the aquaculture industry, the benefits of control were judged to outweigh the costs. In 2005, DFO attempted an economic assessment of the effect of tunicates on bivalve aquaculture but the growers declined to provide the necessary quantitative data (DFO Policy and Economics Branch 2006).

There were no known control options at the time of the initial *Styela* population outbreaks. DAFA examined the efficacy of several chemical sprays and dips in killing tunicates without harming non-target species, the environment, or personnel. Experiments conducted over the winter of 2001-2002 identified white vinegar

(5% acetic acid) spray as the preferred treatment for both equipment and mussel socks. In addition, by April of 2003, the mussel aquaculture industry had invested in a technology developed in New Zealand for use against *Ciona intestinalis,* but it was ineffective against the tough tunic of *Styela.*

Eradication of existing *Styela* infestations was eventually judged impossible and management efforts focused on restricting dispersal, and reducing infestations to an economically tolerable level. There also were limited attempts to market the tunicates, which are a delicacy in some Asian counties. In 2002, the I&T Committee recommended that the restrictions on the movements of spat and harvested mussels be continued. Additionally, as a condition of license, all bivalve harvesters working in the tunicate-infested area were required to clean their boat and gear with vinegar before moving them out of the area. DAFA and DFO contacted colleagues at federal and provincial environment departments to determine the environmental acceptability of the vinegar treatment on boats and gear, and the treatment was judged to be acceptable.

Monitoring of PEI estuaries to assess the effectiveness of the control and quarantine measures has been ongoing since 2001. Several new populations of *Styela* were discovered in the summer of 2002, but most could be traced back to transfers from southeastern PEI estuaries before the October 2001 restrictions. For example, in September 2002, tunicates were found on mussels from March Water (part of Malpeque Bay) that were being processed at a plant in New London Bay; this first indication that *Styela* was present in March Water was subsequently confirmed by divers. The likely vector to March Water was a purchase of seed from Murray River in 2001. March Water was placed under the same restrictions as southeastern PEI. As in the previous year, 24 hr notice was given to growers, and some worked all night to complete their harvest before the restrictions came into effect. By December 2004, the effect on the industry in March Water and nearby Darnley Basin was severe enough that the growers agreed upon a set of voluntary guidelines that included protocols for the treatment of buoys with visible tunicate growth, the handling of infested gear removed from March Water, and cleaning boats and washboards. By September 2005, the industry was promoting a revised protocol incorporating a treatment of mussel socks and gear with hydrated lime during late summer or autumn when temperatures were 10-13°C. The efficacy, and environmental acceptability, of this treatment is still under review (Locke et al. 2009).

Since 2005, there has been limited further dispersal of *Styela,* and monitoring and management continue on existing infestations. Some improvements to management protocols have been made. For example, many growers now harvest mussels from *Styela*-infested waters only at water temperatures < 10°C to ensure that the tunicates are not spawning at the time of processing.

(2) Golden star tunicate, *Botryllus schlosseri*, and Violet tunicate, *Botrylloides violaceus*

(a) *Botryllus* - St. Peters Bay, 2001

In the summer of 2001, an unknown fouling organism found in St. Peters Bay (Figure 1, Location 14) by an oyster grower/processor was sent to DAFA. The specimen was positively identified as *Botryllus schlosseri* by G. Lambert, and the incursion was reported to the I&T committee. DAFA consulted international experts who concluded that this tunicate was unlikely to survive the PEI winter or to be as invasive and problematic for aquaculture as *Styela*. Indeed, the available literature indicated this to be a southern species - unlikely to live successfully north of Cape Cod (Van Name 1945). There was no communication of the finding of *Botryllus* to the public or industry because the species was not expected to become established. For the same reason, containment was not deemed necessary. In the spring of 2002, no *Botryllus* colonies were found in St. Peters Bay and it was thought that they had not survived; but, as with *Styela*, this assumption of no over-winter survival was incorrect. Small amounts of *Botryllus* were found in St. Peters Bay in autumn 2002. Since that time, the number and size of colonies has increased, but *Botryllus* is considered the least problematic of the PEI tunicate invaders and management is rarely undertaken for this species unless it is present in combination with *Botrylloides*.

(b) *Botryllus* and *Botrylloides* - Savage Harbour, 2002

In late August 2002, mussel growers in Savage Harbour (Figure 1; Location 15) notified DAFA that three barges contracted by Public Works and

Government Services Canada (PWGSC) to construct a breakwater were heavily fouled. PWGSC hired divers to complete a video survey of the barges. From the video, DAFA identified *Botryllus schlosseri*. Another tunicate, unknown on PEI, was sent to G. Lambert and identified as the colonial violet tunicate, *Botrylloides violaceus*.

The diver survey determined that the tunicate was found only on the barge hulls and not on structures in Savage Harbour itself. The risk of spread to the harbour was considered high. Representatives of PWGSC, DFO and DAFA met to discuss options: bringing the barges onshore, scraping the hulls, and disposing of the removed material in a landfill; or towing the barges offshore over deep water for pressure-washing of the hull. “Do nothing” was not considered given the adverse experiences of PEI aquaculture with tunicates by that time. Moreover, local aquaculturists strongly requested removal of the tunicates. Bringing the barges onshore for cleaning was considered undesirable because of the likelihood that tunicates would be scraped into the water during the removal process and the cost, which was estimated at CAN $120,000. In contrast, towing the barges offshore for cleaning was estimated to cost about $30,000. Thus, in early September, 1-1.5 weeks after the arrival of the barges in Savage Harbour, they were towed ~2.5 km offshore into 25 m of water, and the hulls were power-washed.

A monitoring program, conducted annually by PWGSC until 2004 on four sites in Savage Harbour and one offshore near the area where the barges were cleaned, found small amounts of the tunicates in the harbour in 2003 and 2004. These findings were reported immediately to the I&T Committee but the species had already spread to bivalve aquaculture facilities.

On December 2 2004, DAFA was informed by mussel growers of extensive fouling on mussel socks located in Savage Harbour. DAFA identified these as the two colonial tunicate species, received confirmation from G. Lambert, and reported the new infestations to the I&T committee. This was the first instance of non-indigenous colonial tunicates being considered as pests in PEI. Subsequently, DAFA and DFO updated their tunicate communications materials and publicized the existence and possible threats posed by the two colonial species during meetings with the aquaculture industry.

When the outbreak was reported in 2004, *Botryllus* was found in both Savage Harbour and St. Peters Bay and *Botrylloides* was recorded only in Savage Harbour (Figures 3 and 4). The I&T subcommittee met with growers from Savage Harbour in the winter of 2004-2005 to determine what transfers of living material and equipment had taken place. At least six estuaries had received mussel spat, and at least one plant located on the other side of PEI (Borden) had processed mussels harvested from Savage Harbour in 2004. *Botrylloides* was detected in 2004 in the Northumberland Strait adjacent to Borden where mussels from Savage Harbour had been processed. Processing is the likely vector as initially the species occurred only within several metres of the processing plant discharge. By 2005, it had spread north from Borden to Seacow Head near Bedeque Bay, lobster fishermen from the Borden area started finding it on their gear, and it was observed by fishermen on floating vegetation well offshore in Northumberland

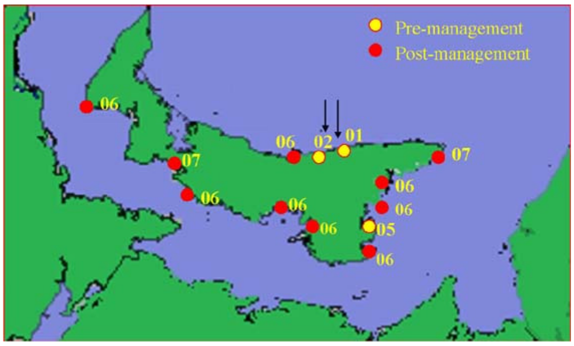

Figure 3. Distribution of *Botryllus schlosseri* in Prince Edward Island, 2001-2007, showing two apparently independent points of introduction (black arrow), and dispersal (sites marked by last two digits of year of discovery) before and after management was initiated.

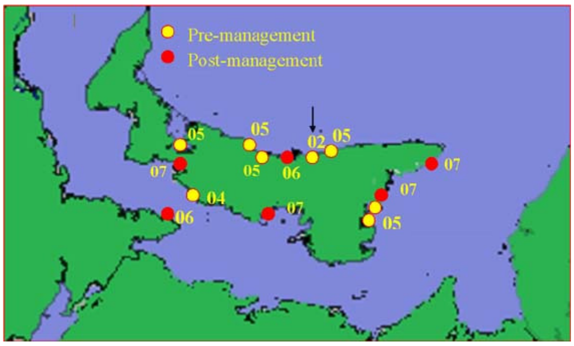

Figure 4. Distribution of *Botrylloides violaceus* in Prince Edward Island, 2002-2007, showing point of introduction (black arrow), and dispersal (sites marked by last two digits of year of discovery) before and after management was initiated.

Strait. By 2006, *Botrylloides* had spread across Northumberland Strait to Cape Tormentine, New Brunswick. In the summer of 2005, surveys were undertaken of the estuaries receiving material from Savage Harbour in 2004. *Botrylloides* was found in Hunter River (Rustico Bay), Cardigan, St. Peter's Bay, March Water, Brudenell, Tracadie, and Georgetown. *Botryllus* was found in Cardigan River and St. Mary's Bay (Livingstone Bay only).

With the expansion of the tunicate problem, a Tunicate Coordinator and monitoring staff were hired by DFO in September 2005 for information compilation and outreach, and to conduct site visits. The presence of tunicates would be confirmed for management purposes only if observed *in situ* in an estuary by government biologists; this was done to maintain a standard of evidence.

The I&T committee decided that containment through restriction of mussel movement from infested to uninfested areas, similar to that used for *Styela*, was an appropriate management strategy for the colonial tunicates. Starting in spring of 2005, mussel spat transfers and harvest from Savage Harbour were restricted to water bodies which already had infestations of *Botryllus* and *Botrylloides*.

In 2004, no control options for colonial tunicates were known and nothing was known about their biology in PEI. DAFA started treatment experiments in December 2004 with the chemicals that had been effective against *Styela*. Research on the reproduction and ecology of *Botryllus* and *Botrylloides* began in Savage Harbour in the spring of 2005. As colonial species, capable of establishing a new infestation from a small fragment of the colony, they were more challenging to control than *Styela*, which only reproduces sexually.

The I&T Tunicate Subcommittee, which had met frequently in 2001-2003 to discuss *Styela*-related problems and rarely in 2004 when it appeared that there were no new issues to discuss with regards to non-indigenous tunicates, was reinstated in 2005. The addition of several new estuaries to the list of sites with non-indigenous tunicates led to an expansion of the I&T Tunicate Subcommittee to include representatives from the mussel aquaculture industry in each estuary. For the first time, participation of other industries, particularly the oyster, lobster, and scallop fisheries, was sought. Policy to guide and standardize management decisions was developed during a series of meetings with mussel growers and other aquatic resource users around PEI. Containment was adopted as the preferred option, pending further tests of *in situ* treatments, and was immediately implemented. Containment was acknowledged to be only a temporary holding measure. Meanwhile, numerous PEI estuaries were monitored for tunicate dispersal using PVC settlement plates anchored near high-risk sites including aquaculture operations, processing plants, and ports.

(c) *Botrylloides* - Cardigan River, 2005

Cardigan River was one of the estuaries monitored for colonial tunicates because it was reported by growers that mussels had been moved there from Savage Harbour in August 2004 - without the required I&T permit. *Botrylloides* was detected on a mussel lease in Cardigan River by a grower in the summer of 2005 and reported to DAFA, which confirmed the identification. The new colonization was reported to the I&T Committee and a meeting with all aquaculture stakeholders in Cardigan Bay and the I&T Tunicate Subcommittee was held almost immediately.

DFO and DAFA quickly developed a project, supported through federal and provincial aquaculture development funds, to survey the distribution, which was limited to four aquaculture leases in the Cardigan River. The major vectors of spread were assumed to be only those associated with aquaculture activities. Risk of spread was a concern because of the close proximity of the Cardigan River to the uninfested Brudenell and Montague Rivers. Management options under consideration were: removal of the infested aquaculture socks; or use of chemical treatments being tested by DAFA. Containment was not an option because of the shared tidal flow of the three rivers. "No action" was not an option because of the high value of the area to the aquaculture industry. One grower removed his infested mussels from the river immediately following the discovery. Other growers obtained support from federal and provincial agencies to treat all their mussels with a vinegar spray as an experiment on the efficacy and feasibility of eradication in September 2005. Monitoring by divers and settlement plates in the autumn of 2005 indicated that the population was greatly diminished but not eradicated. In June 2006, there were disturbing discoveries. Colonies were found on eelgrass *Zostera marina*, carapaces of living crabs, and on drifting *Fucus* in addition to occuring on the aquaculture gear and the mussels themselves. It was now apparent that non-human vectors of secondary spread had to be considered in the attempts to control the spread of colonial tunicates – an unexpected and daunting task.

(3) <u>*Ciona intestinalis* – Brudenell River and others, 2004-2007</u>

Ciona intestinalis was first detected in PEI in the Brudenell River (Figure 1, Location 11) by a grower who reported it to DAFA in October 2004. DAFA identified the species and the discovery was reported to the I&T committee, which met with local growers. In this instance, all parties had been watching for the arrival of *Ciona* due to its presence as a major pest in aquaculture sites in Nova Scotia waters outside of the Gulf of St. Lawrence (Carver et al. 2003; Howes et al. 2007).

Diver surveys were immediately conducted to determine *Ciona*'s distribution, which was restricted to the Brudenell and Montague rivers. A second independent infestation was also detected in Nova Scotia waters of the Gulf of St. Lawrence, immediately across the Northumberland Strait from the Brudenell-Montague location (Locke et al. 2007). By the summer of 2005, *Ciona* abundance had greatly increased in the Brudenell and Montague rivers and had spread to the adjoining St. Mary's Bay. In fact, it was often found overgrowing *Styela* on mussel socks. The vectors and risks of spread were assumed to be similar to those of *Styela*, since both were solitary tunicates.

Initially, no specific management action was taken against *Ciona* as it occurred within the *Styela* management zone and growers were supposed to get permits to move any mussels, even between rivers within the zone. Several rivers in the zone were infested with *Styela* but not *Ciona*. Growers evidently were not diligent about obtaining permits or inspections for transfers or harvesting within the zone as *Ciona* spread in 2006 to Cardigan and Murray rivers. Until 2007, there had been no dispersal outside the *Styela* management zone, but *Ciona* was found in Charlottetown Harbour in the fall of 2007 and Souris in 2008 (A.H. Smith, pers. obs.; Figure 5).

During the winter of 2005, studies commenced on the life cycle characteristics, impacts on industry, and control of the species. The control options are similar to those used against other tunicates in PEI: restriction to the infested area through the I&T permitting process, vinegar spray, immersion in hydrated lime, and pressure-washing. "No control" was not considered an option given the history of this species as a major pest of bivalve aquaculture operations in Nova Scotia (Carver et al. 2003). *Ciona*, in fact, is by far the most problematic fouling tunicate for aquaculture in PEI (Ramsay et al. 2009).

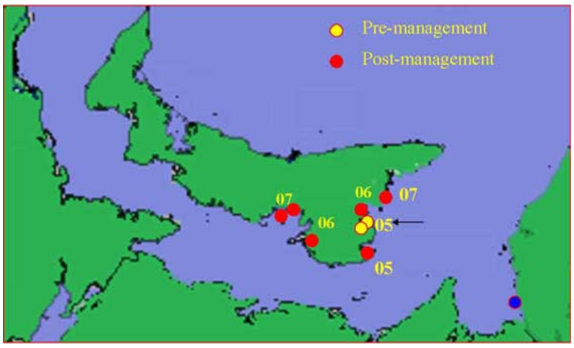

Figure 5. Distribution of *Ciona intestinalis* in Prince Edward Island, 2004-2007, showing point of introduction (black arrow), and dispersal (sites marked by last two digits of year of discovery) before and after management was initiated.

<u>Lessons learned from the PEI case studies</u>

Eradication was not successful against tunicates in PEI; however, suppression of abundance and partial containment to quarantined areas were attained. Containment was more successful against the solitary tunicates *Ciona* and *Styela* than against the colonial tunicates *Botryllus* and *Botrylloides*. All management has taken place through the Introductions and Transfers permitting process, but it can only address the aquaculture transfer vector. No legal instruments exist to address other known vectors, such as hulls of recreational and commercial fisheries vessels. For species that have natural vectors (in particular, the two colonial tunicates), no control of dispersal is possible. Responses to tunicates in PEI have taken place as a series of crises to the aquaculture industry associated with urgent demands for intervention and little time for research needed to inform the management efforts. Initially, lack of experience and incorrect assumptions as to the over-winter survival of the invaders in the PEI ecosystem resulted in management efforts beginning too late to control the spread of species. Moreover, containment efforts were sometimes undermined by actions of the mussel aquaculture industry itself, which at first did not understand the economic implications of dispersal of tunicates. Subsequent management successes are the result of cooperative work on the part of federal, provincial, academic and industry partners.

A high level of effort is required to sustain tunicate management in PEI. Since September 2005, a temporary employee of DFO has worked fulltime to coordinate AIS management, and receive and follow up on reports from the public and industry. The part-time assistance of a communications professional has aided in spreading the message to the aquaculture industry and other stakeholders. An Aquatic Invasive Species Steering Committee was formed in 2006, with members from federal and provincial government, industry and academia. Weekly meetings of this committee keep all partners apprised of new developments, and are used to formulate recommendations for the Introductions & Transfers Committee, which implements management actions.

Discussion

Most "rapid responses" against invasive species in the marine environment have been conducted with the goal of eradication of the species, but successful eradication has been carried out only in a very specific set of circumstances (Locke and Hanson, 2009a). The few successful eradication efforts have several common elements: early detection and correct identification of the invader; the pre-existing authority to take action; the AIS could be sequestered to prevent dispersal, or else had very limited dispersal capabilities; there was political and public support for eradication, and acceptance of some collateral environmental damage; and follow-up monitoring verified the completeness of the eradication. Another common element of successful eradications was a high degree of certainty that a lack of action would have major consequences, usually based on knowledge of the adverse effects of the same or closely related species elsewhere. Examples where all these elements were in place include the successful eradication of the green alga *Caulerpa taxifolia* (Vahl, 1802) in California and of the black-striped mussel *Mytilopsis sallei* (Recluz, 1849) in Australia (McEnnulty et al. 2001; Hutchings et al. 2002; Anderson 2005). In PEI, early detection (monitoring) programs were developed in response to the arrival of non-indigenous tunicates but they did not become widespread until 2005, so they documented the spread but not the initial arrival of the tunicates. Authority to take action against non-indigenous species in PEI extends only to control of vectors associated with transfers and harvests of species, excluding many other possible vectors. The adverse effects of the tunicates are almost entirely restricted to the aquaculture industry; consequently, other fisheries stakeholders and the general public may be less likely to accept collateral damage to the environment caused by eradication attempts. In any case, the inability to contain the tunicates once they were established prevents any serious attempt at eradication. There have been no successful eradications reported from "open" coastal or estuarine systems, i.e., those in which complete physical containment was not possible (Locke and Hanson 2009a), except in the case where the AIS had poor dispersal capabilities (e.g., the parasitic polychaete *Terebrasabella heterouncinata* Fitzhugh and Rouse, 1999 in California) or the response took place before the occurrence of a dispersal phase in the life cycle (e.g., the brown alga *Undaria pinnatifida* (Harvey, 1860) in New Zealand) (Culver and Kuris 2000; Wotton and Hewitt 2004). Neither of these scenarios applies to the response to non-indigenous tunicates in PEI.

In most marine situations, as in PEI, management of the spread of the AIS, management to limit abundance, or adaptation to its effects were the only viable options (e.g., the Atlantic oyster drill *Urosalpinx cinerea* (Say, 1822) in England; Hancock 1959). In PEI, management of spread through regulation of aquaculture transfers and harvests has to date been successful in limiting the spread of the solitary tunicates *Styela clava* and *Ciona intestinalis,* which reproduce only sexually and have limited larval dispersal capabilities. These strategies, used against colonial tunicates, failed in part because many aquaculture transfers had already taken place from an infested area, but also because the containment of colonial tunicates, capable of reproducing asexually from a small fragment of the colony, was far more difficult than the containment of solitary tunicates. Moreover, colonial tunicates have been detected on the hulls of recreational and commercial vessels, in Summerside in 2007 and Souris and Charlottetown in 2008. This discovery means that colonial tunicates could be spread to any estuaries visited by these boats.

Reproductive *Ciona* were found for the first time on a boat hull at a marina in Souris in 2008 (A.H. Smith, pers. obs.), and small non-reproductive *Ciona* were found drifting on eelgrass *Zostera marina* in two estuaries (A. Locke, pers. obs.), which may represent the imminent failure of the containment strategy for solitary tunicates.

Control of population levels, in selected geographic areas of interest, may be a more attainable goal than eradication for marine rapid response. This approach was adopted to limit the effects of *Urosalpinx cinerea* on fishing grounds in England (Hancock 1959), and has been used against tunicates on mussel aquaculture sites in PEI. Typically, the goal is to suppress AIS abundance below a threshold of effects on a commercial species or ecosystem. We are, however, aware of no cost-benefit analysis of population management practices, or indeed of data that would define threshold levels for the AIS presently found in PEI. Population reduction of tunicates on mussel aquaculture sites has been carried out to the extent possible, but without a specific goal or threshold. Some aquaculture growers are convinced of the value of population reduction, but others leave the tunicates to grow on their sites. In the case of *Styela clava*, a full exploration of the commercial potential of the tunicate is warranted (Karney and Rhee 2009). A model of the costs and benefits of different levels of population control, similar to that developed for *Caulerpa taxifolia* by Ruesink and Collado-Vides (2006), would provide some much-needed guidance on the best removal strategies. For example, such models have demonstrated that plant invasions are slowed more by the removal of small emerging populations than by a similar reduction in area of well-established monocultures. Indeed, a recent conceptual framework consisting of multiple treatments (to eradicate all life stages) has been proposed for all bays in PEI that contain *Ciona* but the cost would be high – about CAN $5 million (Edwards and Leung 2009). Moreover, their framework does not include efforts to prevent new colonization events; consequently, the proposed treatments would likely need to be repeated periodically albeit at reduced intensity.

A second goal of population control is to maintain low numbers to prevent “outbreaks” of rapid population growth. The application of Allee effects, i.e., diminished per capita population growth rates at low densities, to risk assessment of AIS is an area of ongoing research (e.g., Drake and Lodge 2006), but suppressing population density below the Allee threshold may have an important application in the management of AIS. As yet, those thresholds, and the benefits of such suppression, are unknown.

Adaptive management is required as a component of AIS rapid responses where eradication has not been accomplished. If environmental (e.g., light, turbidity, nutrients) or biological (populations of existing species) changes have resulted from the presence of the AIS, the management of fisheries, water quality, or other uses of a water body must be adapted to the altered conditions. Effective revision of management strategies can only be accomplished on the basis of scientific understanding of the changes that have occurred – assuming baseline data on what used to be present actually exist. Also, some of the changes (e.g., removal of algae and tying up nutrients in the tissue of a large tunicate) might be positive if increased water clarity (with concomitant increase in abundance and distribution of valued ecosystem components such as seagrasses) or reduction in nutrient transport from estuaries to adjacent coastal waters is an ecosystem management goal.

Prince Edward Island is arguably one of the most advanced jurisdictions in Canada in terms of the capability of conducting rapid responses to AIS, yet this capability is still in its infancy. An AIS steering committee meets weekly; however, responsibilities of federal, provincial, and industry partners have not been clearly defined. Nevertheless, the ability of these groups to work toward a common goal is commendable. For the most part, however, compliance with sound management procedures has been on a voluntary basis and it is clear that there have been numerous violations. Monitoring and detection are critical elements of rapid response but, before 2006, detection of most species was largely serendipitous (with the notable exception of some targeted monitoring conducted by DAFA). Although small-scale federally-funded monitoring programs are now in place, the methodologies are preliminary and long-term funding is not assured. Baseline data on the pre-invasion ecosystem are lacking for many areas. Responses taken to date have been entirely *ad hoc*. This is not to belittle the work done in PEI, but to point out areas in which further development should take place, both in PEI and in other regions of Canada.

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