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Research article

Marine boating habits and the potential for spread of invasive species in the Gulf of St. Lawrence

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Abstract

The potential for boating to disperse the clubbed tunicate *Styela clava* Herdman, 1881 and green crab *Carcinus maenas* (Linnaeus, 1758) in the southern Gulf of St. Lawrence was investigated using interviews with recreational and commercial boaters in eastern Prince Edward Island (PEI). Boaters were asked how long their boat had been at the present location; the primary use of the boat; if anchors, sounding equipment or fishing gear were used; whether any organisms were attached to these items when retrieved; and the fate of those organisms. Bilge water and hull scrapings from the vessels contained 31 and 47 taxa, respectively. Recreational boats, nearly half of which were docked outside their home estuary, were a more likely vector of dispersal than commercial fishing boats that tended to return to the same port each night. Northeastern Nova Scotia and the southern coast of PEI were most at risk for the spread of clubbed tunicate, while green crab could be transported to PEI and eastern New Brunswick. The Magdalen Islands, Quebec, were also predicted as a site to which green crabs could spread, and the first green crabs were detected there two years after our study.

Key words: Biological invasions, tunicate, *Styela clava*, *Carcinus maenas*, dispersal, vectors, interviews

Introduction

Epidemiological studies show that movement of infected hosts to uninfected populations affects the rate and pattern of disease transmission (Rothman 2002). Similarly, the frequency of transport of non-indigenous species from infested to uninfested areas, and the number of locations connected by vectors to an infested hub, determine the rate of dispersal of invasive species (Padilla et al. 1996, Buchan and Padilla 1999). This secondary dispersal ultimately determines the extent of the spread and subsequent economic and ecological effects of invasive species within a region (Lodge et al. 1998).

Few studies have investigated small boats as vectors of secondary dispersal of invasive species in the marine environment. In Elkhorn Slough, a California estuary distant from primary sites of shipborne introductions, 70% of the exotic species may have been introduced by hull fouling of recreational or fishing boats (Wasson et al. 2001). Likewise, the hulls of recreational boats in Australian coastal waters carried 38 fouling taxa (Floerl and Inglis 2005). In North American fresh waters, recreational boating is implicated in the spread of invasive macrophytes and invertebrates (Les and Mehrhoff 1999; Johnson et al. 2001). In New Zealand lakes, the spread of invasive macrophytes is attributed to plant fragments carried on boats and trailers (Johnstone et al. 1985).

In this study, we investigated boating as a vector of secondary spread of the clubbed tunicate, *Styela clava* Herdman, 1881, and the green crab, *Carcinus maenas* (Linnaeus, 1758), in the southern Gulf of St. Lawrence (sGSL). The potential for green crab to disrupt ecosystem structure outside its native range is well established (Cohen et al. 1995; Davis et al. 1998; Jamieson et al. 1998). More-over, because green crabs are attracted to and consume large numbers of small bivalves, they can be a major pest for enterprises attempting to seed bivalves for stock recovery or aquaculture purposes (Walton and Walton 2001; Audet et al. 2003; Wong et al.

2005). In sGSL estuaries, there is almost no natural substrate available and clubbed tunicate is primarily found on mussel-culture gear, such as ropes, socks, buoys and anchors (Bourque et al. 2007; LeBlanc et al. 2007; Locke et al. 2007). Clubbed tunicates attain high densities (Holmes 1976; Darbyson et al. 2009), overgrow the aquaculture gear making it difficult to handle, and make the end product (the bivalves) expensive to clean. Primary introductions of green crabs and clubbed tunicates worldwide are attributed to vectors that reflect the relative dispersal ability of their planktonic larvae and contrasting adult (mobile vs. attached) life histories. Green crab, with a larval duration up to 90 days, is typically dispersed to new regions in ballast water and by coastal currents (Carlton 1985; Paduan and Rosenfeld 1996). In contrast, most long-distance introductions of the clubbed tunicate, which has a short-lived larva, are attributed to hull fouling or contamination of bivalve aquaculture equipment or products (Coughlan 1969; Lützen 1999). In the sGSL, we predicted the likely anthropogenic mechanisms for secondary spread of the green crab would be hitchhiking of adults on recreational or commercial fishing vessels plus transport of larvae in water transported in the bilge or containers that hold equipment (such as nets and ropes) while the clubbed tunicate was likely dispersed as a fouling organism on boats or with aquaculture products. To assess this prediction, we conducted interviews with recreational boaters and commercial fishermen on boating habits, and collected samples from their boats. This study sought to determine: (1) activities commercial and recreational boaters were undertaking that might disperse non-indigenous species; (2) the predominant movement patterns of vessels, to predict sites of future spread; and (3) by direct sampling, whether clubbed tunicate, green crab, or ecologically similar species were being dispersed by boaters.

Materials and methods

During June through August 2003 and July through September 2004, interviews were solicited from boaters as they arrived at marinas or docks in eastern Prince Edward Island (PEI), Canada (Figure 1). Potential interviewees were given a brief overview of the interview procedure and the purpose of the information being gathered. Boaters who agreed to be interviewed were asked to read a standard letter of informed consent and to sign a consent form for the interview and sampling procedure.

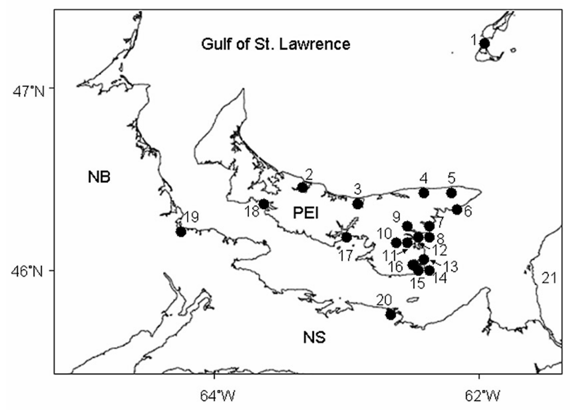

Figure 1. Map of Prince Edward Island (PEI), New Brunswick (NB), Nova Scotia (NS) and Quebec (Magdalen Islands) showing locations of marinas where interviews were conducted (*), and next ports-of-call. (1=Magdalen Islands, 2=New London, 3=Grand Tracadie, 4=Naufrage, 5=North Lake*, 6=Souris*, 7=St. George's*, 8=Newport*, 9=Cardigan*, 10=Montague*, 11=Lower Montague*, 12=Georgetown*, 13=Mink River*, 14=Beach Point*, 15=Murray Harbour*, 16=Murray River*, 17=Charlottetown*, 18=Summerside, 19=Shediac, 20=Pictou, 21=Cape Breton Island).

All boaters were asked how long their boat had been in the water at the present location, where it had been in recent weeks, and where they planned on taking the vessel next. They were asked the primary use of the boat, whether they had used their anchor or sounding equipment recently, and if there had been entangled macrophytes or other organisms on this equipment when it was retrieved from the water. Commercial and recreational fishermen were asked to describe their fishing activities, what species they fished most often, how their bait and catch were stored, if they had live wells or tanks on board and how they disposed of any water in these devices, if they used nets or traps, if anything was entangled in these items when removed from the water, and how they disposed of entangled items.

Upon completion of the interview, samples of bilge water and hull scrapings were collected from the participant's vessel. Either the boat's own equipment was used to pump water from the bilge or a turkey baster was used to directly sample the bilge, resulting in sample volumes of 15 to 400 mL. Live wells were not sampled. The sponge side of a 25 cm squeegee was used to scrape the hull from as close to the keel as possible to the water line, similar to the method of Johnson et al. (2001). The squeegee was employed within a dip net (mesh size 500 µm) so that any items dislodged from the hull were caught in the net. The area sampled ranged between 323 and 2580 cm^2, depending on the size of the boat. All samples were stored in a 5% formalin-seawater solution buffered with limestone chips. In the laboratory, contents were identified to the lowest practical taxonomic level.

Results

During the summers of 2003 and 2004, 94 and 56 interviews were conducted, respectively. More than half (59%) of the 150 boaters interviewed used sounding equipment, while relatively few (17%) used anchors (Table 1). Of those who used these types of equipment only 1/3 reported entangled algae or organisms.

Fifty-five of the 150 boaters used their vessels for fishing, including: recreational fishing; commercial fisheries on American lobster (*Homarus americanus* H. Milne Edwards, 1837), snow crab (*Chionoecetes opilio* J.C. Fabricius, 1788), northern bluefin tuna (*Thunnus thynnus* (Linnaeus, 1758)), or Atlantic herring (*Clupea harengus* Linnaeus, 1758); and blue mussel (*Mytilus edulis* Linnaeus, 1758) aquaculture. Of those fishing, 69% had live wells, holding tanks, or buckets to store the catch. Most boaters emptied these at sea but a few dumped the water in port. The majority (65%) of fishermen stored their bait on ice, and water in the bait storage devices was most often dumped at sea. Traps or nets were used by 69% of fishermen, and 74% of them reported that algae collected on this gear. Again, most fishermen (86%) discarded entangled items at sea.

Most (77%) of the commercial fishermen were docked at their home port, 67% were planning to dock at their home port after the next use of their vessel, and only 9% were docked outside their home estuary (Table 2). Nearly half the recreational boaters (46%) were docked outside their home estuary and planned to dock outside their home estuary (47%) after the next use of the vessel. Most vessels were to be moved by sea, but 4% were to be carried by trailer to the next destination (Table 1). Based on the next intended port-of-call of vessels moving from infested to uninfested ports, Pictou and Cape Breton Island, Nova Scotia, and locations in PEI (Charlottetown, Souris and New London), could be exposed to clubbed tunicate. Green crab could be transported further along the coast of PEI (Summerside), to northeastern New Brunswick (Shediac), and to the Magdalen Islands (Table 3).

Bilge water samples were collected from 35 vessels and hull scrapings from 54 vessels. Depending on the amount of water present in the bilge, sampling volume ranged from 15-400 mL (mean 140.9 mL). The area of hull scraped was 323-2581 cm^2 (mean 1352.1 cm^2). We identified 31 taxa in bilge water and 47 taxa in hull scrapings (Table 4). No clubbed tunicates or green crabs were found; however, there were numerous zooplankton including brachyuran zoeae, which demonstrates the potential for any species with a planktonic life history stage to be similarly transported.

Discussion

To our knowledge, this is the first published study investigating the potential for commercial and recreational boaters in marine waters of eastern North America to disperse non-indigenous species. Many of the vectors that spread invaders in fresh water, such as bait buckets, live wells and the anchor (Johnson and Carlton 1996), appear to pose relatively little risk in the sGSL because marine boaters tend to dispose of entrained organisms in the water from which they originated. However, without having directly sampled the organisms present on this equipment, it is impossible to quantify this risk. Additional mechanisms that we did not investigate could be of importance in the sGSL, e.g., the movement of fishing gear and products, the use of recreational equipment such as SCUBA gear, and other types of commercial fishing. In addition, this study was conducted during June to September and important recreational activity and fishing continues well into October. Inspecting boats as they are hauled out for the winter would have permitted a more thorough examination of the hulls and recesses in the hulls. Finally, only a few bivalve aquaculture boats were sampled because their industry association refused to participate in the study despite the fact that the aquaculture industry itself suffers the vast majority of the negative effects associated with establishment of invasive

Table 1. Responses of 150 boaters interviewed in Prince Edward Island during 2003 and 2004.

Interview question	Positive responses	
	No. of vessels	Percentage of total
Used vessel for fishing	55	36.7
Vessel equipped with live wells or tanks	38	25.3
Used live wells or tanks in last 5 days	28	18.7
Dumped water from live wells or tanks at sea	31	20.7
Dumped water from live wells or tanks in port	2	1.3
Used bait	48	32.0
Used live bait	13	8.7
Used salted bait	2	1.3
Stored bait on ice	31	20.7
Stored bait in a bucket	2	1.3
Dumped bait water at sea	38	25.3
Used a net or trap	38	25.3
Found algae on net or trap	28	18.7
Dumped algae at sea	24	16.0
Dumped algae on land	1	0.7
Dumped algae in port	2	1.3
Used scientific or sounding equipment	88	58.7
Found algae on equipment	25	16.7
Dumped algae at sea	1	0.7
Dumped algae in port	5	3.3
Dumped algae on land	14	9.3
Did not dump algae	1	0.7
Cleaned off algae at the end of the season	2	1.3
Used an anchor	26	17.3
Found algae on the anchor	8	5.3
Dumped algae at sea	8	5.3
Traveled overland to next port of call	6	4.0

Table 2. Boater movement patterns as derived from interview responses in Prince Edward Island.

Interview question	Commercial fishing vessels (N=53)		Recreational vessels (N=85)	
	Number	Percentage of total	Number	Percentage of total
Docked in home port	41	77.4	25	29.4
Docked in home estuary (but not home port)	7	13.2	21	24.7
Docked outside home estuary	5	9.4	39	45.9
Planning to dock next in home port	33	67.3	23	26.7
Planning to dock next in home estuary (but not home port)	6	12.2	23	26.7
Planning to dock next outside home estuary	10	20.4	40	46.5

Table 3. Uninfested areas at risk for invasion by green crab and clubbed tunicate based on next intended port-of-call of commercial fishermen and recreational boaters from eastern PEI in 2003 and 2004.

Traveling from areas with, to areas without, target species	# Commercial boats (N=53)	# Recreational boats (N=85)
Green crab	0	4 Summerside (2), Shediac (1), Magdalen Islands (1)
Clubbed tunicate	8 Cape Breton (6), Naufrage (1), Grand Tracadie (1)	26 Pictou (9), Charlottetown (9), Cape Breton (6), Souris (1), New London (1)

Table 4. Vegetation, zooplankton, and benthic organisms found in bilge water and on hulls of vessels in Prince Edward Island ports.

Taxon	Bilge water	Hull
Plants:		
Bryopsis plumose (Hudson) C. Agardh, 1823		X
Ceramium sp.	X	X
Enteromorpha sp.	X	X
Polysiphonia sp.	X	X
Ulothrix sp.	X	
Filamentous algae	X	X
Other algae	X	X
Zostera marina Linnaeus, 1753	X	X
Terrestrial plants		X
Cnidaria:		
Aurelia aurita (Linnaeus, 1758)		X
Laomedea sp.		X
Campanulariidae		X
Hydrozoa	X	X
Medusozoa	X	X
Sertulariidae		X
Unidentified Cnidaria		X
Copepoda:		
Acartia hudsonica Pinhey, 1926	X	X
Acartia tonsa Dana, 1849		X
Acartia sp.	X	X
Calanus finmarchicus (Gunner, 1765)		X
Centropages hamatus (Lilljeborg, 1853)		X
Eurytemora hirundoides (Nordquist, 1888)		X
Eurytemora sp.		X
Oithona similis Claus, 1866	X	X
Oithona sp.	X	
Pseudocalanus minutus (Krøyer, 1845)		X
Pseudocalanus sp.	X	
Temora longicornis (O.F. Müller, 1785)	X	X
Calanoida	X	X
Harpacticoida	X	X
Unidentified Copepoda	X	X
Copepoda nauplii	X	X
Other Crustacea:		
Evadne nordmanni (Lovén, 1836)		X
Evadne sp.		X
Podon sp.		X
Ostracoda	X	X
Idotea sp. juveniles		X
Unidentified Isopoda	X	X
Cancer irroratus Say, 1817, zoea		X
Dyspanopeus sayi (S.I. Smith, 1869) zoea		X
Brachyura zoea	X	

Table 4. (continued)

Taxon	Bilge water	Hull
Other Crustacea:		
Unidentified Decapoda		X
Hyperia sp.		X
Ischyroceridae	X	
Calliopius laeviusculus (Krøyer, 1838)		X
Gammarus lawrencianus Bousfield, 1956		X
Gammarus oceanicus Segerstråle, 1947		X
Ampithoe longimana S.I. Smith, 1873		X
Gammaridea	X	
Caprellidea	X	X
Unidentified Amphipoda		X
Cirripedia		X
Cirripedia nauplii	X	X
Arachnida:		
Acaridae	X	X
Araneae	X	
Insecta:		
Chironomidae		X
Other Insecta	X	X
Mollusca:		
Bivalvia	X	X
Bivalvia veligers	X	X
Mytiloida	X	X
Patellogastropoda	X	
Unidentified Gastropoda	X	X
Gastropoda larvae		X
Gastropoda egg case	X	
Polychaeta:		
Ampharete arctica Malmgren, 1866		X
Cirratulidae		X
Pectinariidae larva		X
Spionidae larvae	X	X
Sigalionidae larvae		X
Unidentified Polychaeta	X	X
Polychaeta larva	X	
Echinodermata:		
Asterias sp.	X	
Ctenodiscus crispatus (Retzius, 1805)	X	
Echinodermata juvenile	X	X
Other Taxa:		
Foraminifera	X	X
Nematoda	X	X
Oligochaeta		X
Parasagitta elegans (Verrill, 1873)	X	
Bugula turrita Desor, 1848		X
Unidentified Bryozoa		X
Invertebrate eggs		X
Fish eggs	X	X
Gasterosteidae larvae		X

tunicates in estuaries of Atlantic Canada (and PEI in particular). Consequently, while aquaculture growers themselves acknowledge that transfers of gear and blue mussels (as spat or commercial-sized animals) between estuaries have dispersed invasive tunicates, the role of their boats as a vector could not be assessed quantitatively.

Boater movements, considered accurate predictors of the probability of spread of aquatic species (Buchan and Padilla 1999), indicate that recreational boaters in the sGSL are more likely to act as vectors than commercial fishermen. Not only were recreational vessels moving from place to place with greater frequency, vessels leaving infested estuaries were more often going to areas uninfested by the clubbed tunicate and a few planned to go to areas lacking green crabs. Sailboats moved between ports more often than recreational power boats; many power boats in the sGSL are small day boats, whereas most sailboats have a cabin and are more likely to be taken on overnight trips (E. Darbyson, pers. obs.). The ports that were most at risk for the spread of these invaders, based on intended ports of call, are also some of the largest and most frequented in the region. This is similar to the results of Padilla et al. (1996) who found that, in Wisconsin, the 80 most heavily used lakes were most at risk and had been colonized by zebra mussels. Furthermore, translocation of invaders to such hub ports may function as a stepping stone to promote further dispersal (Floerl and Inglis 2005).

The interviews with commercial fishermen (mainly lobster boats) indicate that this group does not move between infested and uninfested areas very often, at least within a given fishing season. However, transfers of commercial fishing boats between ports in the sGSL do occur where fishing locations are remote from the home port, boats are switching between fisheries (e.g., from lobster to herring, which might take place on different fishing grounds), or if boats are shared between fishermen in different regions with sequential open seasons. Boats engaged in the tuna fishery are particularly far-ranging, moving seasonally between ports of southern Nova Scotia and eastern PEI. Some fishing boats are used for recreation outside of the fishing season, and in this capacity may travel all over the Atlantic Provinces. In this study, our sampling of commercial boaters was the result of an opportunistic sampling schedule and future work should target the different fleets over the whole of the sGSL.

As with any opportunistic survey and sampling program, the current study contains limitations in design not evident until after the study was completed. The sites at the east end of PEI were chosen because this area has very high abundances of invasive tunicates and green crab. The marinas surveyed are in brackish water but marinas located in full salt water, of which there are many in Atlantic Canada, may well have yielded propagules of invasive species. A second limitation was that only one boater could be interviewed at a time; other boaters might have been missed or interviewed later if they arrived while the interview was underway. As sampling could not always be performed immediately after the boat's arrival, adult green crabs or megalopae that hitchhiked might have dropped off the boat by the time of sampling. Sampling later in the season may have yielded different results as fouling tunicates would have been larger and the anti-fouling paint wears off or becomes chipped during the boating season, which increases the likelihood of tunicates successfully colonizing a vessel. Finally, it is highly likely that the survey responses contain biases or mis-information. Human behavior being what it is, it is a given that respondents only tell interviewers what they want them to know. In the current study, there may well have been a desire to avoid potential liabilities where an individual's boat-use practices might have contributed to the spread of an invasive species. The absence of green crabs and clubbed tunicates in the samples collected in this study may be an artifact of ineffective sampling or may truly reflect the absence of target species from the boats. Certainly, collection of hull samples using the squeegee may have limited effectiveness relative to more destructive techniques. However, to secure the cooperation of participants it was necessary to ensure that vessels would not be damaged by sampling. We also chose not to sample with divers due to safety considerations, which limited sampling to the portion of the hull that could be reached from the dock. This also reduced the number of vessels that could be sampled. Despite some likely shortfalls in our methodologies, we think that our samples reflected absence of the target species. Larvae and settling stages of both clubbed tunicate and green crab should have been available to infest boats in the estuaries during the period of our study, June through September. Clubbed tunicate larvae were present in surface waters of southeastern PEI estuaries from early July to late September (Bourque et al. 2007). While the centre of clubbed tunicate distribution was downstream of the marinas, boaters would traverse that zone in the course of their activities. Adult green crab occurred in and adjacent to the marinas, stage I zoea larvae would be in the water column from June to August (but tend to be advected from the estuaries and would be mainly accessible to boats in coastal waters), but megalopae would be returning to the estuary and settling from August to October (Queiroga et al. 1994; Cameron and Metaxas 2005). Logically, the next step should be to direct sampling at marinas and commercial harbors in full salt water.

Despite there being no alien species identified in any of the collected samples, small boats clearly have a high potential to spread marine organisms. Furthermore, given the large taxonomic diversity of organisms on board and the relatively small sample size of this study, it is not unlikely that boaters in the sGSL are transporting non-indigenous species such as green crabs and clubbed tunicates. Indeed, the Magdalen Islands, one of the sites we considered to be at risk of green crab dispersal in 2003-2004 has since been invaded by green crabs (Paille et al. 2006). While the vector is unknown, transport by anything but a boat-related vector is highly unlikely. Larval dispersal on currents from known locations of green crab was unlikely based on recent ocean-current models (J. Chassé and A. Locke, unpub. data), and the only non-boat means of access to the islands is by air. Whether the vector was a recreational vessel, commercial fishing vessel, other boat-based vector or on aquaculture products is unknown. If a commercial freighter was involved, the vector was more likely to be hull fouling or transport in a sea-chest than ballast water, as ballast water discharge has been prohibited within 10 nautical miles of the islands since 1982.

Since completion of this study, three additional species of invasive tunicates have colonized the aquaculture sites of PEI (Locke et al. 2007) and green crab have become established in the Magdalen Islands (Paille et al. 2006) – one of the locations we predicted were at high risk due to boating activities and aquaculture transfers. While *S. clava* has not been reported from Charlottetown, PEI, *Botrylloides violaceus*, *Botryllus schlosseri* and *Ciona intestinalis* were each first recorded in the harbour or its approaches in 2006 or 2007 (A.H. Smith, pers. comm.). In October 2007, the hulls of some recreational vessels being removed from the water in Summerside, PEI, were found to be colonized by *B. violaceus and B. schlosseri* (A.H. Smith, pers. comm.). Similarly, in October 2007, the hull of a dredging barge working in one of the busiest ports of the Magdalen Islands, and which had arrived the previous day from PEI, was found to be contaminated with *C. intestinalis* and *B. violaceus* (C. McKindsey, pers. comm.). A diver removed all visible tunicates from the hull, but aquaculture workers, divers and government scientists are currently monitoring closely the waters around the Magdalen Islands in a hope of avoiding, or detecting in the earliest stages, colonization by any of the four invasive tunicate species now present in the coastal waters of PEI. If detected early enough, it may be possible to eradicate initial colonies assuming a comprehensive rapid response program is in effect. Such a plan, for the Atlantic Provinces, is still in development (see Locke and Hanson 2009). For the southern Gulf as a whole, it is likely too late for eradication efforts as all four species are well-established in PEI waters and some species are likely to spread quickly to mainland waters. The bivalve aquaculture industry in all five provinces in Atlantic Canada simply will have to adapt to these invasive tunicates or cease operations. In contrast, the effects of invasive tunicates on the other users of marinas, harbors, and estuaries in Atlantic Canada appear to be minimal; consequently, there is little incentive for these individuals to change their behavior or boating practices, and to incur additional expenses, to minimize the spread of invasive tunicates.

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