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Short Communication

Generalized regional spatial patterns of larval recruitment of invasive ascidians, mussels, and other organisms along the coast of Maine

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Editor's note:
This paper is a contribution to the proceedings of the 3rd International Invasive Sea Squirt Conference held in Woods Hole, Massachusetts, USA, on 26-28 April 2010. The conference provided a venue for the exchange of information on the biogeography, ecology, genetics, impacts, risk assessment and management of invasive tunicates worldwide.

Abstract

Along the coast of Maine, recruitment of most invasive marine ascidians follows a generalized regional pattern, with higher recruitment rates at western sites. Using artificial collectors we found that *Botryllus schlosseri, Botrylloides violaceus, Ciona intestinalis, Ascidiella aspersa* and *Styela clava* were more abundant in the western (southwestern) sites than in the eastern (northeastern) sites. This general pattern also applies to a number of other recruiting species including native mussels, *Mytilus* spp., and the invasive crab, *Carcinus maenas*. While recruitment of many marine organisms can appear stochastic in space, there can be some consistent regional patterns. Higher recruitment in the western sites of Maine may be the result of greater oceanographic dispersal due to the westward flow of the Maine coastal current, higher seawater temperatures in the west, and more anthropogenic introductions having occurred in the western harbors.

Key words: invasive species, *Botryllus schlosseri, Botrylloides violaceus, Ciona intestinalis, Ascidiella aspersa, Mytilus*, Maine coastal current

Recruitment of marine organisms, while often spatially and temporally stochastic, can reveal generalized patterns across species on certain larger spatial scales (Doherty and Fowler 1994; McNaught 1999). These patterns can be due to large-scale oceanographic factors (e.g., currents and temperature regimes) or dispersal from larger source populations within the species ranges (McNaught 1999; Lockwood et al. 2005). For invasive species with relatively short-distance dispersal, such as most ascidians, local human-caused introductions may play a larger role in explaining their patchy distributions.

In order to understand the recruitment patterns of marine invasive species along the entire coast of Maine, we deployed submerged collectors from floating docks, from June to September 2009. Twelve sites were selected with three sites within each of four regions (all collectors at one site, Pemaquid Harbor, were lost). Blue Hill and Downeast regions were in the eastern Gulf zone, and Casco Bay and Mid-coast regions were in the western Gulf zone (Figure 1, Table 1). Under dissecting microscopes in the lab, we measured percent cover of colonies and recruit densities of solitary species of five different species of invasive ascidians including *Botrylloides violaceus* Oka, 1927, *Botryllus schlosseri* (Pallas, 1766), *Styela clava* Herdman, 1881, *Ascidiella aspersa* (Műller, 1776), and the cryptogenic *Ciona intestinalis* (Linnaeus, 1767). Other invasive species included the bryozoan *Membranipora membranacea* (Linnaeus, 1767), and the crabs *Carcinus maenas* (Linnaeus, 1758) and *Hemigrapsus sanguineus* (De Haan, 1853). (These crabs were distinguished by the number of marginal teeth on one side of the carapace, five versus three respectively). Several native

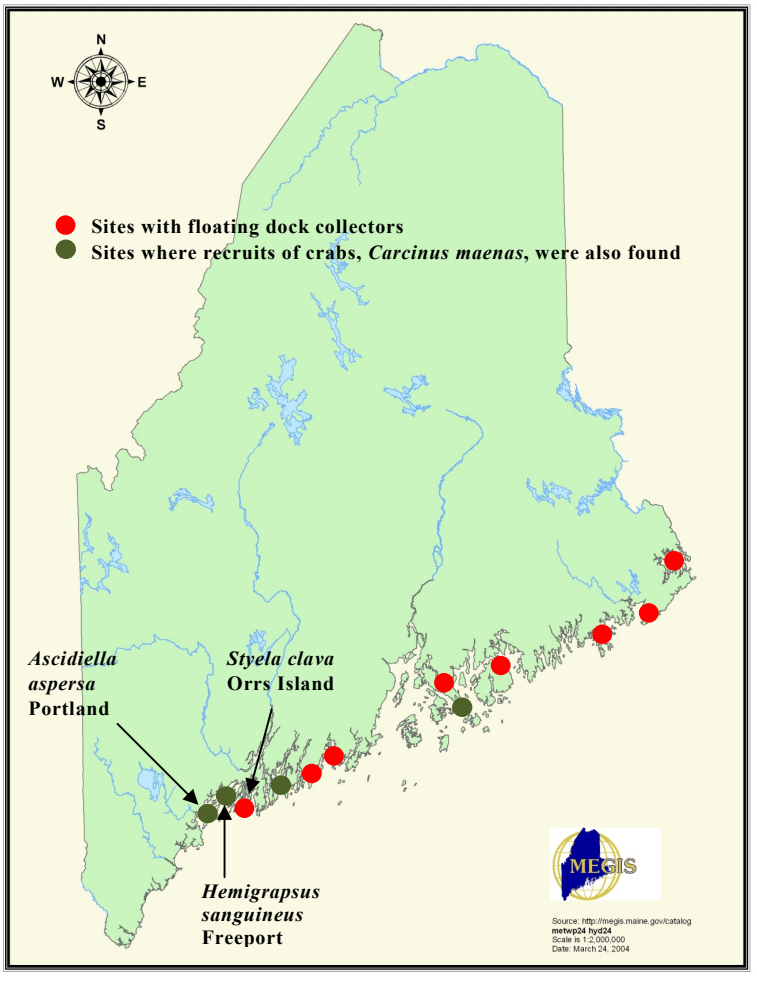

Figure 1. Location of all sites along the coast of Maine, USA, in the Gulf of Maine. Symbols in green signify sites where the invasive *Carcinus maenas* green crab recruits were found. Symbols in red signify other sites without them. Note that no green crab recruits were detected in most of the eastern sites. Species listed for certain sites indicate they were only found at that site. *Ascidiella aspersa, Hemigrapsus sangineus, Styela clava,* and *Membranipora membranacea* were only found in collectors in the Casco Bay Region (i.e., Portland, Freeport and/or Orrs Island). The design of the experiment included three sites within four regions within two zones. Five collector strings were deployed at each site. Names and positions of sites are listed in sequence from west to east in Table 1 and Figure 2.

species, such as mussels, *Mytilus* spp. (primarily *M. edulis* Linnaeus, 1758 but also including *M. trossulus* Gould, 1850), and ascidians, *Molgula* sp. [all subsampled individuals were identified as *Molgula manhattensis* (De Kay, 1843)], were also measured.

Collectors were constructed with six different artificial substrates to test for the effects of texture (smooth or roughened PVC plastic, versus fine or coarse plastic filamentous surfaces) and illumination (outside versus inside PVC tubes) on recruitment rates. Five replicate strings of these six substrates were deployed vertically in the water column 1 m below the surface of the water. In general, the colonial ascidians, *B. violaceus* and *B. schlosseri,* were more abundant per area on flat PVC surfaces than filamentous ones, which supported higher densities of mussels. The solitary ascidians, *C. intestinalis* and *Molgula* sp., occurred in higher densities on roughened PVC than any other surface.

Invasive ascidians and mussels had generally lower recruitment and growth rates at sites in eastern rather than western Maine (Figure 2). Percent cover of *B. violaceus* and *B. schlosseri* and densities of *C. intestinalis* were lower at eastern sites even though adult populations occurred throughout the entire range. Recruitment of the widely-dispersing mussels, *Mytilus* spp., was also higher at western sites compared to very low recruitment in the three easternmost

Table 1. The following sites are listed in sequence from west to east by region and zone, with dates of deployment and retrieval, and latitude and longitude of each dock location (see Figure 1). Contact persons are also listed and acknowledged for their assistance.

Site	Dock location and contact	Region	Zone	Latitude °N	Longitude °W	Date deployed	Date retrieved
Portland	Southern Maine Community College, Dr. B. Tarbox	Casco Bay	West	43°39.062'	70°13.695'	May 27, 2009	Oct. 18, 2009
Freeport	Freeport Town Dock, J.Pinkham	Casco Bay	West	43°49.222'	70°06.329'	May 27, 2009	Oct. 26, 2009
Orrs Island	Bowdoin College Marine Lab, R. Armstrong, M. Melendy	Casco Bay	West	43°47.520'	69°57.484'	May 27, 2009	Sept. 22, 2009
Boothbay	Maine Dept. Marine Resources, L. Bean	Mid-Coast	West	43°50.667'	69°38.457'	May 26, 2009	Sept. 1, 2009
Pemaquid Harbor	Pemaquid Harbor Town Dock	Mid-Coast	West	43°52.809'	69°31.301'	May 26, 2009	lost
Medomak	Maine Audubon, Todd Sanctuary	Mid-Coast	West	43°58.922'	69°25.085'	May 26, 2009	Sept. 1, 2009
Blue Hill	Blue Hill Yacht Club, D. Danielson	Blue Hill	East	44°24.574'	68°33.901'	May 26, 2009	Sept. 27, 2009
Opechee Island	private dock, M. Dwyer	Blue Hill	East	44°12.711'	68°29.165'	June 9, 2009	Sept. 29, 2009
Mt. Desert Island	Mt. Desert Island Biological Lab, Drs. G. Kidder, J. Disney	Blue Hill	East	44°26.018'	68°17.415'	May 19, 2009	Sept. 10, 2009
Jonesport	Jonesport Town Dock, R. Batson	Downeast	East	44°31.900'	67°35.664'	May 14, 2009	Aug. 28, 2009
Cutler	private dock, M. Lemaux	Downeast	East	44°39.418'	67°12.306'	May 13, 2009	Aug. 31, 2009
Eastport	Deep Cove Boat School, C. Bartlett	Downeast	East	44°54.417'	67°01.016'	May 20, 2009	Sept. 14, 2009

sites. Similar recruitment patterns have also been shown for some subtidal species including the green sea urchin, *Strongylocentrotus droebachiensis* (Műller, 1776), the northern seastar, *Asterias vulgaris* Verrill, 1866, and the rock crab *Cancer irroratus* Say, 1817 (McNaught 1999).

In nested ANOVA analyses of response variables by sites within region and regions within eastern or western zones of the Gulf, abundance of 2-5 mm shell length *Mytilus* had significant zone ($F_{1,41}$ = 54, p<0.001), region ($F_{2,41}$ = 15, p<0.001), and site effects ($F_{7,41}$ = 7, p<0.001) with significantly fewer recruits in the Downeast region, and significantly more in the Mid-coast region (Tukey's test: M>B=C>D). *Mytilus* mussels with shell length greater than 5 mm demonstrated similar patterns, with significant zone ($F_{1,41}$ = 42, p<0.001), region ($F_{2,41}$ = 13, p<0.001), and site effects ($F_{7,41}$ = 6, p<0.001) with significantly fewer recruits in the Downeast region, and significantly more in the Mid-coast region. *C. intestinalis* had significant zone ($F_{1,41}$ = 208, p<0.001), region ($F_{2,41}$ = 56, p<0.001), and site effects ($F_{7,41}$ = 29, p<0.001) with the fewest recruits in the eastern two regions. *B. schlosseri* had significant zone ($F_{1,41}$ = 10, p=0.0026), region ($F_{2,41}$ = 19, p<0.001), and site effects ($F_{7,41}$ = 35, p<0.001) with the fewest colonies in the Downeast region. *B. violaceus* had non-significant zone ($F_{1,41}$ = 0.738, p=0.395), significant region ($F_{2,41}$ = 6.8, p=0.003) and significant site effects ($F_{7,41}$ = 4.4, p=0.001) with the fewest colonies in the Downeast region. However recruitment of the native ascidian, *Molgula* sp., was significantly greater at one eastern site (Cutler) suggesting a large local source population there.

Recruits of more recent invasive species were only found at the three westernmost sites in the Casco Bay region: including solitary ascidians,

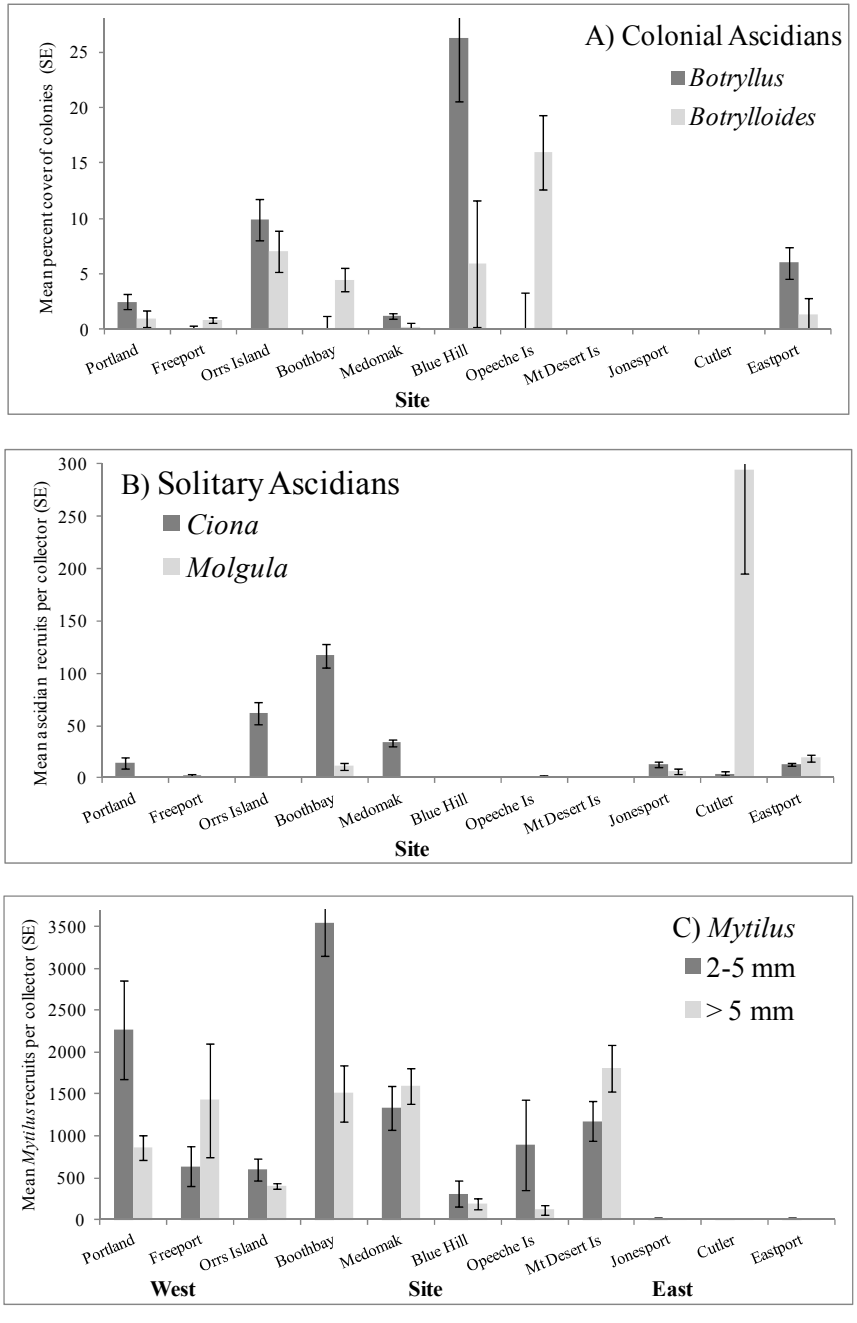

Figure 2. Mean abundance in coastal waters of Maine of recruited species per collector string (±1 SE; number of collectors per site, n=4-5; total number of collectors at all sites, N=52) arranged from west (left) to east (right) for: **A**) percent cover of colonial ascidians *Botryllus schlosseri* and *Botrylloides violaceus,* **B**) recruit densities per collector for solitary ascidians *Ciona intestinalis* and *Molgula* sp., and **C**) recruit densities per collector for two shell lengths of the mussels, *Mytilus* spp. (per 2100 cm^2). Sites by western regions: 1) Casco Bay: Portland SMCC, Freeport, Orrs Is., 2) Mid-Coast: Boothbay and Medomak. Sites by eastern regions: 3) Blue Hill: Blue Hill, Opeeche Is., Mt. Desert Is., and 4) Downeast: Jonesport, Cutler, and Eastport (see Table 1). For other invasive species, recruits of the ascidian, *Styela clava,* were only found at Orrs Is., the ascidian, *Ascidiella aspersa*, at Portland, and the invasive crab, *Hemigrapsus sanguineus,* at Freeport. Note generally higher recruitment of mussels, and invasive ascidians (except *Molgula* sp.) at sites in the west.

S. clava (at Orrs Island) and *A. aspersa* (at Portland); and the invasive crab *H. sanguineus* (at Freeport). These patterns for recent invasive species were perhaps a result of current range limitations of their adult populations to the west. Recruitment of the more-established invasive crab, *C. maenas,* occurred largely in the west, as small recruits were found only at Portland, Freeport, Boothbay, and Opeeche Island despite the presence of adult populations along the entire coast. Similarly, the invasive bryozoan, *M. membranacea,* was only detected at the western Casco Bay sites.

Sites and substrates with lower colonial ascidian cover (compared to others in their region) were inversely related to high cover of possibly inhibitory taxa such as *Mytilus* sp. or *C. intestinalis* (e.g., at Boothbay, Medomak, and Freeport, or on filamentous substrates) (Stachowicz et al. 1999). Low overall recruitment in eastern sites may be related to: 1) a lack of dispersal from source populations against the westward-flowing Maine coastal surface current (as for *Mytilus* sp., crabs, green sea urchins, and some ascidians) (McNaught 1999), 2) lower observed water temperatures for reproduction, survival, and/or growth (e.g., *B. violaceus* and *B. schlosseri*), and/or 3) greater distance from adult populations that serve as a source of propagules (Lockwood et al. 2005), as some of these sites are outside of the current range distribution of several invasive species (e.g., *S. clava* or *A. aspersa*). High recruitment rates of recent invasive ascidians at many sites may relate to higher rates of anthropogenic introduction in those busier western harbors (as in Casco Bay).

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