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Water quality, nitrogen pollution, and ascidian diversity in coastal waters of southern Massachusetts, USA

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Nitrogen is the main contaminant causing degradation of water quality in the temperate coastal waters of Massachusetts (Buzzards Bay, Pleasant Bay, Vineyard Sound, and southern Cape Cod Bay), USA (Valiela et al., 1997; Costa and Rasmussen, 1999; Howes, 2002). In order to assess whether differences in water quality influenced the presence or absence of native and non-native ascidians, we conducted field surveys at 17 different sites in southern Massachusetts, Cape Cod and Martha's Vineyard in 2002 and 2003. We selected sites based on their water quality and divided them into three groups: (a) sites with 'good' water quality that had low levels of excess nitrogen, good water clarity and infrequent algal blooms, (b) sites with 'fair' water quality that had moderate levels of excess nitrogen, reduced water clarity, low oxygen levels and periodic algal blooms, and (c) sites with 'poor' water quality that had high levels of nitrogen, low oxygen (hypoxia), no eelgrass beds and poor water clarity (Fig. 1). Sites with fair water quality were often in transition, with water quality either improving, or more commonly, declining.

We found ascidians living on most artificial and natural hard substrate (including floating docks, piers, rope, tires, hoses, boat hulls, girders, lobster traps, rocks and other sessile organisms); ascidians were absent from soft substrate habitats (e.g., sandy beaches, salt marshes and mud flats). A total of nine species at 17 sites were identified: the non-native species, *Didemnum* sp. A, *Botrylloides violaceus* Okra, 1927, *Ascidiella aspersa* (D. F. Müller, 1776), *Styela clava* Herdman, 1881, *Diplosoma listerianum* (Milne-Edwards, 1841), *Botryllus schlosseri* (Pallas, 1774), and the native species, *Molgula manhattensis* (Dekay, 1843), *Ciona intestinalis* (Linnaeus, 1767), and *Aplidium stellatum* (Verrill, 1871). We found the greatest diversity of ascidians (5–9 spp.) at sites with fair water quality and intermediate levels of nitrogen, the most common water conditions in the survey area. A lower diversity of ascidians (2–3 spp.) occurred in areas with good water quality and low excess nitrogen levels. In areas with poor water quality the number of ascidians ranged from 0 to 3 species. Both native and non-native ascidians were most diverse in areas with fair water quality conditions. The native species *Molgula manhattensis* was tolerant of good, fair, and poor water quality, while the other two native species, *Ciona intestinalis* and *Aplidium stellatum*, were found only in areas of fair water quality. Of the invasive, nonindigenous species, *Botryllus*

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Fig. 1. Location of study sites in Massachusetts.

schlosseri and *Styela clava* inhabited good, fair, and poor water quality sites; *Botrylloides violaceus* was found at sites of good and fair water quality; *Diplosoma listerianum*, *Ascidiella aspersa*, and *Didemnum* sp. A, were found only in fair water quality areas. Nonindigenous species dominated the ascidian population at good, fair, and poor water quality sites whether attached to artificial or natural substrates (Table 1).

The diversity of most taxa of marine organisms is highest at good water quality sites (Cape Cod Commission, 1998; Howes, 2002). In contrast, ascidian diversity was highest at sites with fair water quality. This was unexpected and represents a pattern of diversity unlike most other taxa. Although ascidian diversity was low at sites with poor water quality, we found relatively few low quality sites that could support ascidians (i.e. presence of hard substrates).

Polluted marine environments may affect the development of marine communities directly by excluding pollution-sensitive species (S. Kaartvedt, unpublished data) and creating space for pollution-tolerant species. Certain invasive ascidian species may not only be more tolerant of nitrogen-polluted water, but may also prefer it. For example, *Didemnum* sp. A, the most recently

Table 1
Ascidian survey sites

Location	Water quality	Rank	*Botryllus*	*Botrylloides*	*Styela*	*Didemnum*	*Diplosoma*	*Ascidiella*	*Molgula*	*Ciona*	*Aplidium*
Megansett Harbor	81A	Good	x		x						
Quissett Harbor	78.5A	Good		x	x				x		
Barnstable Harbor	ORWJ	Good	x	x					x		
New Bedford Harbor, inner	68.8A; SAF	Fair	x		x				x	x	
Pocasset Harbor	68.6A	Fair	x	x	x				x		
Sandwich Tide Pool	0.015–0.049I	Fair	x	x	x	x					
Vineyard Haven	0.050–0.099I	Fair	x	x	x	x	x				
Wellfleet Harbor	Fair, SAG; 0.015–0.049I	Fair	x	x				x	x		x
Red Brook Harbor	64.9A 61.1A; 15,027, SAF; 59	Fair	x	x	x	x			x		
Nasketucket Bay	H	Fair	x	x	x	x				x	
Chatham Harbor	0.576, fairE	Fair	x	x		x	x				x
Eel Pond, Woods Hole	0.1–0.2I	Fair	x	x	x	x	x	x	x	x	x
West Falmouth Harbor	49.7A; fair, SAG	Fair	x	x		x			x		
Waquoit Bay	0.6C; 26,781D	Poor	x		x				x		
Great Pond, Falmouth	EutrophicB	Poor	x		x				x		
New Bedford Harbor, upper	44.4A; SBF	Poor									
Hammett Cove, Marion	32.1A	Poor									

A Howes (2002) health index score (0–100); B Massachusetts Department of Natural Resources (2003) eutrophication index; C Rosen (2003) weight % total nitrogen; D Waquoit Bay National Estuarine Research Reserve (2002) kg total nitrogen/year; E Pleasant Bay Resource Management Alliance (2002) mg total nitrogen/year; F Costa and Rasmussen (1999) kg total nitrogen/year, Massachusetts Department Environmental Protection (MDEP) grade; G Cape Cod Commission (1998) MDEP grade; H Costa et al. (1996) index score (0–100); I Poppe and Lane-Bostwick (1990) weight % total nitrogen; J MDEP (1978) area of critical environmental concern-outstanding water resource (OWC).
x = present.

introduced ascidian species to southern Massachusetts (Carman and Roscoe, 2003) was only found at sites with fair water quality, as were the nonindigenous species *Ascidiella aspersa* and *Diplosoma listerianum.* The nonindigenous *Botrylloides violaceus* occurred in fair and good water. Only the nonindigenous species *Botryllus schlosseri* and *Styela clava* were found at sites with poor, fair, and good water quality. Similarly, the native *Ciona intestinalis* and *Aplidium stellatum* were only found at sites with fair water quality, while *Molgula manhattensis* was found at sites with poor, fair, and good water quality. Thus, in coastal Massachusetts most species of ascidians, regardless of whether they are native or nonindigenous, inhabit sites with fair water quality and moderate nitrogen levels. Additional work with a standardized nitrogen sampling method should be conducted to determine whether these patterns are typical for ascidians in other locations.

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