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Journal of Experimental Marine Biology and Ecology 342 (2007) 175–178

Journal of EXPERIMENTAL MARINE BIOLOGY AND ECOLOGY

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

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Received 1 September 2006; received in revised form 1 October 2006; accepted 9 October 2006

Keywords: Ascidian; Bio-diversity; Bio-indicator; Nitrogen pollution; Water quality

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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0022-0981/$ - see front matter
doi:10.1016/j.jembe.2006.10.037

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