Aquaculture 295 (2009) 44–51

Contents lists available at ScienceDirect

Aquaculture

journal homepage: www.elsevier.com/locate/aqua-online

Biodeposit production and benthic loading by farmed mussels and associated tunicate epifauna in Prince Edward Island

Christopher W. McKindsey [a,b,*], Mayi Lecuona [b], Matthieu Huot [a,b], Andrea M. Weise [a]

[a] Fisheries and Oceans Canada, Institut Maurice-Lamontagne, Ocean and Environmental Sciences, 850 route de la Mer, P.O. Box 1000, Mont-Joli (Québec) Canada G5H 3Z4
[b] Institut des sciences de la mer (ISMER), Université du Québec à Rimouski, 310, allée des Ursulines, CP 3300, Rimouski (Québec) Canada G5L 3A1

ARTICLE INFO

Article history:
Received 21 February 2009
Received in revised form 12 June 2009
Accepted 15 June 2009

Keywords:
Suspended bivalve aquaculture
Mussel
Fouling organisms
Biodeposit production
Tunicate
Ciona intestinalis
Styela clava
Environmental impact
Shellfish-DEPOMOD

ABSTRACT

An experimental study was done to evaluate the biodeposition dynamics associated with mussels and two fouling tunicates, *Ciona intestinalis* and *Styela clava*, in mussel aquaculture in Prince Edward Island (PEI), eastern Canada. The presence of *C. intestinalis* on small constructed mussel socks increased biodeposition by a factor of about 2 relative to mussel socks without tunicates. *S. clava* were small and had a negligible effect on total biodeposition from mussel socks although they increased sedimentation rates relative to that of abiotic control socks. Sinking rates of faecal pellets from large *C. intestinalis* varied between 1.39 and 6.54 cm s^{-1} (LSMean = 2.35 cm s^{-1}). Using biodeposit production and sinking rates and hydrological data obtained in the present study, footprints of benthic loading due to mussel and tunicate biodeposition for a typical mussel farm in PEI were modelled using Shellfish-DEPOMOD. The results show benthic loading below longlines with *C. intestinalis* to be ca. 2 times greater than those from lines with only mussels with rates of up to 15.2 g m^{-2} d^{-1}. However, given the greater settling rate of *C. intestinalis* biodeposits relative to mussel biodeposits, the extent of the footprint (≥1 g m^{-2} d^{-1}) is similar or even more restrained.

1. Introduction

Suspended bivalve aquaculture has increased greatly over the past couple of decades and its influence on underlying infaunal communities is well known (Mattsson and Lindén, 1983; Callier et al., 2007). Responses by benthic infaunal communities are typically related to increased organic loading associated with biodeposition from the bivalves in suspended culture, which may be substantial (see Callier et al. (2006) for a review). Although site-specific, Callier et al. (2008) suggest that the response of benthic communities to biodeposition from suspended bivalve culture is consistent with the Pearson and Rosenberg (1978) model of organic enrichment. This includes decreased species richness but possibly an increased total number of individuals because of high densities of a few opportunistic species, a generally reduced biomass or a great biomass of opportunistic species, a general or species-specific decrease in body size, a shallowing of the portion of the sediment column occupied by infauna, and a shift in the relative dominance of trophic groups. Ultimately, this may also include anoxia and dominance by microbial mats in the most severe cases.

Fouling communities associated with suspended bivalve culture are a universal concern for the industry (Enright, 1993). The main fouling taxa include macroalgae, barnacles, hydroids, tunicate ascidians, and mussel spat (Heasman, 1996). The biomass of such communities may be substantial (e.g., Tenore and González, 1976; Dealteris et al., 2004), reaching up to 430 g dry weight (Tenore and González, 1976) and 1350 g (Grant et al., 1998) of fouling organisms m^{-1} mussel sock. Stenton-Dozey et al. (2001) and Giles et al. (2006) have suggested that sedimentation by suspended bivalve aquaculture-associated fauna may contribute considerably to the total flux of material to the bottom.

Recently, a number of invasive tunicates have become important fouling organisms in suspended bivalve culture areas around the world (Lambert, 2007; McKindsey et al., 2007). Examples include South Africa (Grant et al., 1998), eastern Canada (Ramsay et al., 2008), Chile (Castilla et al., 2005), and New Zealand (Denny, 2008). Although Yakovis et al. (2004) suggest that there is no direct data available on biodeposition by tunicates, a number of studies have looked at biodeposit production in a variety of solitary benthic tunicates (Fiala-Médioni, 1973, 1974; Young and Braithwaite, 1980; Hatcher, 1991; Armsworthy et al., 2001; Knott et al., 2004; Jiang et al., 2008; Tatián et al., 2008) as well as biodeposit production and sinking rates of biodeposits from planktonic tunicates (salps, e.g., Deibel, 1990; González et al., 2000). In general, these studies have shown that biodeposition by tunicates may be substantial. Moreover, Haven and Morales-Alamo (1966) found that, for a standardized weight, the solitary tunicate *Molgula manhattensis* typically produced a greater quantity of biodeposits than did the eastern oyster, *Crassostrea virginica*, and Tatián et al. (2008) found that the solitary tunicates *Cnemidocarpa verrucosa* and *Pyura setosa* produced

* Corresponding author. Fisheries and Oceans Canada, Institut Maurice-Lamontagne, Ocean and Environmental Sciences, 850 route de la Mer, P.O. Box 1000, Mont-Joli (Québec) Canada G5H 3Z4.
E-mail address: chris.mckindsey@dfo-mpo.gc.ca (C.W. McKindsey).

0044-8486/$ – see front matter.
doi:10.1016/j.aquaculture.2009.06.022

greater quantities of biodeposits per standardized weight than the co-occurring bivalve *Laternula elliptica*. Given this, the presence of invasive tunicates in suspended bivalve aquaculture is likely to have an important influence on fluxes of organic matter to the bottom and consequent impacts on benthic communities. As the magnitude of benthic loading determines the magnitude of benthic infaunal responses (Callier et al., in press), knowledge of such rates is important to predict the impacts of suspended bivalve culture on the benthic environment (Weise et al., 2009). However, the magnitude of the increase in benthic loading associated with fouling by tunicates in aquaculture is largely unstudied.

This study examines the influence of tunicates growing on suspended mussel aquaculture "socks" (individual polyethylene sleeves of mussels suspended from subsurface longlines) on the flux of biodeposits to the benthos. Specifically, we compare how the presence of the two most detrimental tunicates impacting the mussel industry in Prince Edward Island (PEI), eastern Canada, the solitary tunicates *Ciona intestinalis* and *Styela clava*, influence the production of biodeposits from mussel socks. Most past studies examining biodeposit production by mussels have been done under laboratory conditions (e.g., Chamberlain, 2002; Miller et al., 2002; Giles and Pilditch, 2004). Those studies that have measured biodeposition under natural conditions have used single individuals or small groups of individuals in cages on top of sediment traps and measured biodeposit production either punctually or over extended periods using automated equipment (e.g., Cranford and Hill, 1999; Callier et al., 2006; Weise et al., 2009). However, a number of hydrological (Smith et al., 2006; Stevens et al., 2008) and biological (Fréchette, 2008) factors change as mussels aggregate into 3-dimensional structures in the form of a mussel sock such that the link between biodeposit production as measured in the above-cited works and biodeposit production by mussels on mussel socks in the field is questionable. To avoid such issues, which would also logically exist for associated tunicates, this study evaluated biodeposit production by small constructed mussel socks under field conditions. The study also evaluates the sinking velocity of tunicate (*C. intestinalis*) faeces and compares predicted benthic loading footprints around farms with and without fouling tunicates using the results from the present study within a hydrodynamic-based particle dispersion model.

2. Methods

2.1. Study sites

This study was done in the March Water area of Malpeque Bay, a 133 km^2 lagoon located on the northwestern coast of PEI, and in St. Marys Bay, on the southeastern coast of PEI, Canada (Fig. 1). March Water has a maximum depth of ca. 7 m and about 1.5 km^2 of the bay is leased for mussel aquaculture (DFO, Charlottetown, pers. comm.). St. Marys Bay has a surface area of 16.7 km^2, 2.7 km^2 of which is leased for mussel aquaculture. It has a maximum depth of ca. 6 m, although most of it is <5 m deep. The tidal range in both sites is between ca. 1 and 1.5 m and currents are often wind-driven.

2.2. Mussel sock construction

A total of 36 mussel socks (40 cm long) and an equivalent number of control socks were made. Half of each of these were placed on a commercial mussel line at ca. 3 m depth in each of March Water and St. Marys Bay between June 23 and 26, 2008. These two embayments have been invaded by *Styela* and the latter also by *Ciona*, such that mussel lines placed in the sites were expected to (and were) heavily and predominantly infested by *Styela* and *Ciona*, respectively. The mussel socks in March Water were constructed from commercial socks with ca. 3.5 to 4 cm long mussels purchased from a local grower. From these, roughly 60 cm lengths were reduced to 40 cm by removing mussels and associated organisms from 10 cm of each end of the socks and then tying

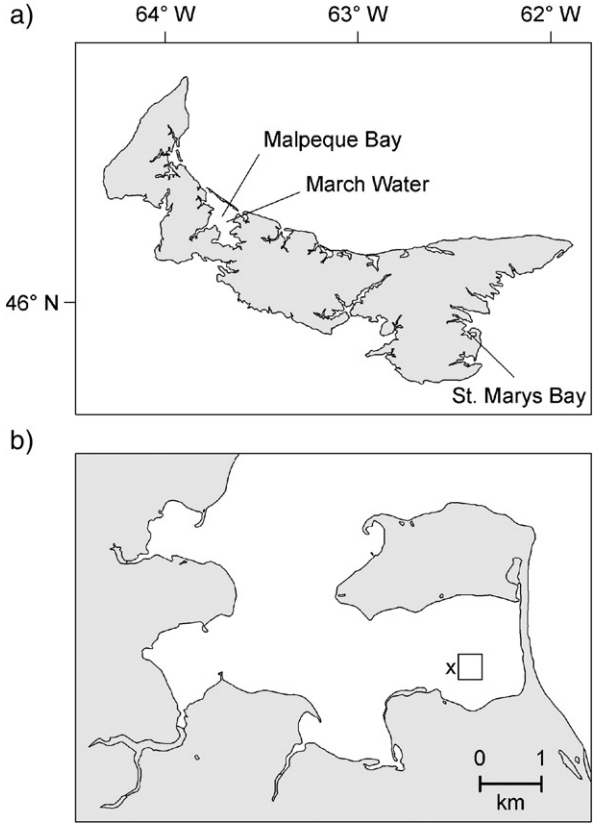

Fig. 1. Location of a) the study sites in Prince Edward Island, and b) St. Marys Bay. The "x" represents the location of the current profiler. The square represents the lease-site where the biodeposit production experiments were done. Backlines within the site run roughly from East to West. Currents in the site are given in Fig. 2.

a knot in the free 10 cm ends. These were then attached to the longline with 40 cm lengths of polypropylene string. In contrast, mussel socks used in St. Marys Bay were constructed by filling 60 cm lengths of 8cb mussel socking material (cotton bisected mussel socking with 8 columns of biodegradable cotton thread along one side of folded socking material with underlying poly mesh sock) with mussels of similar size to those used in March Water (ca. 100–150 mussels $sock^{-1}$) obtained from a local grower to a length of 40 cm and then similarly attached to the longline. Control socks were made in the same manner as the mussel socks placed in St. Marys Bay except they were filled to a length of 40 cm with a similar abiotic substrate (surf clam, *Spisula solidissima*, shells ca 8–10 cm long) and attached to longlines interspersed with the mussel socks.

Socks placed in March Water were transferred to the same longline as those initially placed in St. Marys Bay (all appropriate permits were obtained) on October 12. Tunicates were removed manually from half of the mussel and half of the control socks from each of the 2 sites *in situ* by SCUBA diving and the remaining socks similarly manipulated without removing the tunicates. This yielded a total of 8 treatments with 9 replicates (4 treatments per tunicate species): a) control (empty shells with tunicates removed), b) tunicates (empty shells with tunicates attached), c) mussels (live mussels with tunicates removed), and d) mussels and tunicates (live mussels and tunicates attached). After the experiment, the 72 socks were dissected in the lab, all tunicates and mussels identified and counted, and total tunicate and mussel dry weight (less shell weight) recorded after drying at 95 ºC for 36 h.

2.3. Biodeposit production

Biodeposit production was measured by placing individual mussel socks over/within large sediment traps (Fig. 3) and collecting