Aquaculture 465 (2016) 387–394

Contents lists available at ScienceDirect

Aquaculture

journal homepage: www.elsevier.com/locate/aquaculture

Preliminary model of tunicate infestation impacts on seston availability and organic sedimentation in longline mussel farms

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ARTICLE INFO

Article history:
Received 22 February 2016
Received in revised form 13 September 2016
Accepted 14 September 2016
Available online 16 September 2016

Keywords:
Mussel aquaculture
Tunicate fouling
Biodeposition
Numerical modelling

ABSTRACT

The productivity of a bivalve farm is largely determined by the availability of organic seston and the level of competition for that naturally limited resource. Farm production may also be curtailed by regulatory or certification frameworks concerned with controlling biodeposition, i.e. the sedimentation of organic material. Fouling communities dominated by filter-feeding tunicates which both compete for food resources and increase biodeposition levels thus have the potential to further limit bivalve farm productivity.

In the present study a farm-scale modelling approach was used to quantify the effects of the tunicate *Ciona intestinalis* on longline mussel farms. Both cultured and fouling species were simulated using physiological modules that took into account their interactions with organic seston dynamics in terms of filtration and biodeposition, and also predicted their growth over a typical growing season. Various treatment scenarios for reducing *C. intestinalis* infestation levels were also analyzed. Model results showed that *C. intestinalis* populations can rapidly dominate mussel sleeves in terms of their overall biomass and contribution to organic sedimentation. Early treatments during the tunicate reproductive season were the most effective at controlling the level of infestation and its impacts on sestonic food availability, mussel production and organic sedimentation. The proposed generic modelling approach could potentially become an essential aquaculture management tool, especially in the context of biological invasions.

Statement of relevance: The growing importance of bivalve aquaculture combined with its vulnerability to environmental conditions compels to ensure its sustainable development and management. Biofouling can potentially disrupt farm productivity and become a nuisance with profound socio-economic consequences. The numerical tool developed in this study provides valuable information for the management and mitigation of fouling by filter-feeding species on mussel farms.

1. Introduction

As bivalve aquaculture develops in many places around the world, new challenges arise in maintaining or increasing production levels. Biofouling constitutes one of the major challenges bivalve producers must address on a regular basis. Biofouling potentially impacts both cultured animals and infrastructures. Moreover, costs associated with fouling prevention or treatment measures can reduce farm profitability (Fitridge et al., 2012).

The biological productivity of a bivalve farm is largely determined by food (organic seston) availability and the level of competition for that naturally limited resource. At a local farm scale, seston availability is driven by water transport and cultured bivalve filtration rates (Ferreira et al., 2007). Additional filtering pressure from fouling epibionts may disrupt this delicate balance and lead to food limitation within the cultured population. This reduction in food availability can ultimately lead to a decrease in the growth of the cultured species (Daigle and Herbinger, 2009) and thus undermine farm productivity.

In terms of environmental impacts, the sedimentation of organic material or biodeposition represents a major concern for stakeholders. Bivalve biodeposits can disrupt the benthic ecosystem through organic enrichment (Aquaculture Stewardship Council, 2012; Cranford et al., 2009; McKindsey et al., 2011). Thus regulatory or certification frameworks aimed at limiting biodeposition may also curtail farm production, particularly when fouling filter-feeders augment the total biodeposition directed towards the benthic environment beneath farms (McKindsey et al., 2009). Moreover, fouling organisms may themselves constitute an additional source of organic sedimentation when treatment measures are applied.

Over the past 15 years, Prince Edward Island, Canada (PEI) coastal embayments have been invaded by several exotic tunicate species. Although two colonial species (*Botrylloides violaceus* and *Botryllus schlosseri*) are now widespread across the island (Paetzold et al., 2012), two solitary species (*Styela clava* and *Ciona intestinalis*) pose the greatest nuisance threat to mussel (*Mytilus edulis*) farmers.

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http://dx.doi.org/10.1016/j.aquaculture.2016.09.026

Currently, the invasion of *S. clava* (clubbed tunicate) and *C. intestinalis* (vase tunicate) is largely confined to eastern PEI. *S. clava* was first identified on cultured mussels in 1997, whereas *C. intestinalis* appeared in 2004. However, since 2005–2006 *C. intestinalis* has dominated the fouling community composition, and it now represents a major nuisance smothering both longline gear and the mussel crop (Ramsay et al., 2008a). The most common technique for controlling *C. intestinalis* (and colonial species) consists of applying high-pressure seawater to mussel sleeves and culture gear (Paetzold et al., 2012). Several applications of this treatment are required over the growing season to successfully constrain the development of the fouling biomass (Ramsay, 2014).

The present study aimed at quantifying the effects of *C. intestinalis* proliferation on longline mussel farms, specifically in terms of seston availability, mussel production and organic sedimentation at the farm scale. For this purpose we present the first numerical model that couples suspended particulate food transport to the food demand/organic waste release of cultured mussels and fouling *C. intestinalis*. The model is applied in a generic setting with conditions typical of PEI coastal embayments.

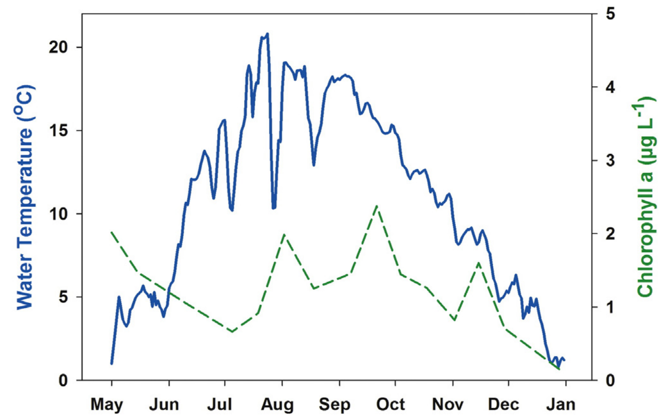

Fig. 1. Environmental forcing conditions imposed on the farm-scale model; water temperature (°C, left axis, solid line) and chlorophyll *a* concentration (μg L^{-1}, right axis, dashed line) used as a proxy for *M. edulis* and *C. intestinalis* food.

2. Materials and methods

2.1. Mussel culture practices and environmental forcing

In PEI, commercial mussel culture started in the early 1980s and developed in most of the northern and eastern coastal embayments. *M. edulis* is grown in polyethylene mussel sleeves suspended from a main longline, which is anchored to the bottom and maintained in suspension by a series of buoys. Mussel seed is naturally collected on ropes during the summer. In October, when the seeds are 20–30 mm in shell length (SL), they are transferred into the polyethylene sleeves and relocated to grow-out leases. Mussels can attain a harvestable SL of 55 mm late in the fall of their second year (~18-mo old mussels), but most of the harvest takes place the following spring-summer (~24-mo old mussels).

Drapeau et al. (2006) conducted an island-wide study on husbandry practices and described the typical mussel-growing system as parallel 100-m longlines spaced by 12-m wide corridors. Each line provides support for 200 2-m long sleeves with a 44-cm spacing between adjacent sleeves. Mussel density along a sleeve varies during the grow-out phase depending on the initial seeding density and mortality. For our modelling purposes, we used a constant normalized density representing mean conditions (mix of 1- and 2-y-old crop), and more specifically the value of 1051 ind sleeve^{-1} reported by Comeau et al. (2015). Harvesting would affect the 2-y-old crop abundance in the farm but is not considered in the present study which focuses on the main growing season of the mussel production cycle (first spring-summer-fall).

The environmental forcing factors were restricted to water temperature, sestonic food concentration and current velocity (Fig. 1). A daily temperature-time series of observations in Georgetown Harbour PEI (Patanasatienkul et al., 2014) was exploited and a fortnightly series of chlorophyll *a* (chl *a*) concentration collected in St. Peter's Bay PEI in 2011 (Guyondet et al., 2015) was used as a proxy to describe the dynamics of sestonic food concentration available to *M. edulis* and *C. intestinalis*. This proxy was used to force the Dynamic Energy Budget models of the filter-feeders in which ingestion is limited by a scaled function of food availability (relative value from 0 to 1). Finally, current velocity was kept constant at 7 cm s^{-1} but with an alternating direction to reproduce the mean tidal conditions reported for PEI culture embayments (Guyondet et al., 2015; McKindsey et al., 2009).

2.2. Farm-scale model

Our investigation is based on a farm-scale numerical model developed for mussel longlines (Aure et al., 2007; Rosland et al., 2011). The model includes a representation of corridors located between two adjacent longlines which is described using 10 boxes of uniform dimensions defined by longline spacing (B_W), the length of the mussel sleeves (B_H) and 1/10 of the longline length (B_L, Fig. 2). In our paper corridor geometry is derived from the typical husbandry practices in PEI as described in the previous section. Assuming the system is in steady-state and boundary conditions are known (see forcing in the previous section), the model estimates the decrease in current flow due to the drag from mussel sleeves, sestonic food transport, and food consumption by *M. edulis* and *C. intestinalis* along the corridor. Interactions between filter-feeders (*M. edulis* and *C. intestinalis*) and the pelagic environment (sestonic food filtration and faeces production) are derived from ecophysiological sub-models based on Dynamic Energy Budget (DEB) theory (Kooijman, 2000). The DEB sub-models also predict the growth of a generic individual both in terms of length and tissue weight for prescribed environmental conditions, i.e., sestonic food concentration (calculated by the transport model along the corridor) and water temperature (input as a forcing function). Farm-scale production of the cultivated species, *M. edulis*, and associated fouling species, *C.*

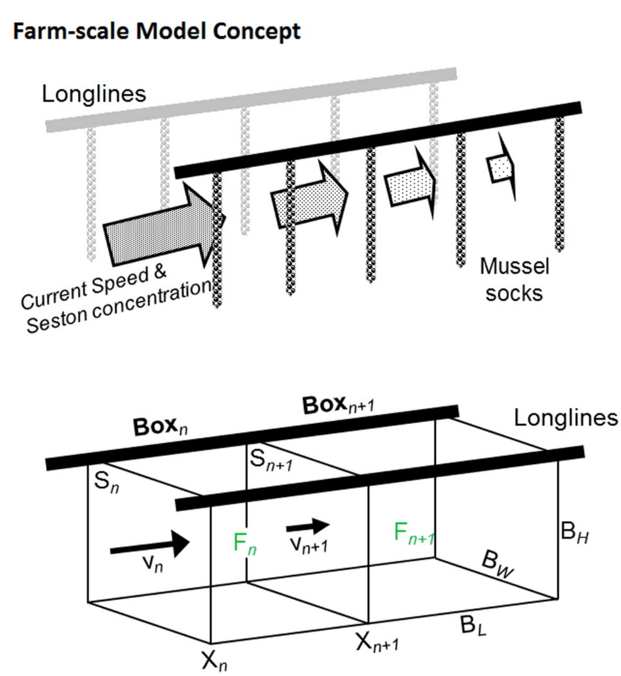

Fig. 2. Farm-scale model concept and box geometry definition representing the corridors between mussel longlines (modified from Rosland et al., 2011).