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Research Article

A cost-benefit analysis of four treatment regimes for the invasive tunicate *Ciona intestinalis* on mussel farms

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Editor's note:

This study was first presented at the 9th International Conference on Marine Bioinvasions held in Sydney, Australia, January 19–21, 2016 (http://www.marinebioinvasions.info/previous-conferences). Since their inception in 1999, ICMB series have provided a venue for the exchange of information on various aspects of biological invasions in marine ecosystems, including ecological research, education, management and policies tackling marine bioinvasions.

Abstract

This study demonstrates the importance of selecting the appropriate treatment regime to maximize productivity and profit in mussel farms affected with the infestation of *Ciona intestinalis*. This study also showed that the profitability associated to a treatment regime is primarily related to the mussel biomass being harvested. Results indicated that initiating treatment early in the season (July) and treating another 2 or 3 times on a monthly basis had the greatest effect on reducing tunicate numbers and size and enabling greater mussel productivity and farm profitability. Beginning treatment when tunicates are small was also demonstrated to be a significant part of a profitable treatment strategy. While the cost of treatment remains a relatively minor expense, the increase in mussel biomass at harvest, and hence grower profitability are considerably higher.

Key words: aquaculture, aquatic invasive species, *Ciona intestinalis*, cost-benefit analysis, farm management, *Mytilus edulis*

Introduction

Biofouling or **biological fouling** is the accumulation of microorganisms, plants, algae, or animals on wetted surfaces.

An inherent and costly issue with off-bottom shellfish culture is biofouling. The term biofouling refers to the unwanted accumulation of microorganisms, plants, algae or animals on wetted surfaces (Bixler and Bhushan 2012). In mussel farms, such surfaces correspond to mussel long lines, gear or equipment, as well as the mussels themselves. Biofouling typically impedes the growth of the culture organism or the maintenance or operation of the culture system (Adams et al. 2011). The Collective Research on Aquaculture Biofouling (C.R.A.B. 2004) suggests that controlling biofouling costs between 5 and 10% of the total European Union aquaculture industry value. More specifically, the estimated cost of biofouling to the shellfish aquaculture industry is 20% of the final market price for the flat oyster *Ostrea edulis* (Enright 1993), 30% of the price for the scallop *Placopecten magellanicus* (Claereboudt et al. 1994) and 5 to 30% of the price for oysters (C.R.A.B. 2004).

In a survey completed by 510 shellfish aquaculture growers from United States, efforts to control biofouling accounted for an average of 14.7% of the total annual operating costs (Adams et al. 2011). In the North East region, 87.2% of respondents indicated that increased operation costs related to biofouling control, accounting for near 20.4% of those costs ($23,130 USD). The types of costs most directly related to control of biofouling included labour, repair and maintenance, and fuel. Surprisingly, despite their importance for the shellfish industry, all of these estimates were based largely on anecdotal information, as the costs of biofouling have not been rigorously assessed (Adams et al. 2011).

Invasive tunicates are some of the most detrimental biofoulers to the shellfish aquaculture industry (Eno et al. 1997; Campbell 2002; Ross et al. 2002, 2004), in particular, the mussel industry. These tunicates have reduced mussel productivity by adding substantial weight to mussel aquaculture gear resulting in additional labour and/or crop loss (Ramsay et al. 2008), while competing with mussels for food and space (Daigle and Herbinger 2009). In the province of Prince Edward Island (PEI), Canada, the profitability of the mussel industry has been hampered by the rapid and heavy fouling of mussel socks, that has resulted in a serious increase in production and processing costs (Locke et al. 2009). Among the species creating this problem, the tunicate *Ciona intestinalis* has been particularly difficult to remove from mussel aquaculture gear and is considered today the greatest threat to the PEI industry (Carver et al. 2006; Daigle and Herbinger 2009).

Although the cost of biofouling and its control to the PEI shellfish aquaculture industry has been investigated in the past, rather limited knowledge is currently available on the best economic mitigation strategies to control biofouling by invasive tunicates. Hence, the main objective of this study was to assess the cost and benefit of treatment regimes to control *C. intestinalis* in two representative mussel operations on Prince Edward Island. Information on productivity and effectiveness of these treatment regimes has been previously published (Davidson et al. 2016).

Materials and methods

High pressure water treatment and optimal treatment regimes in the study area

The PEI mussel farm industry uses a long-line system in which mussels are suspended in socks for two or more growing seasons. Biofouling by tunicates (primarily *Ciona intestinalis*) reduces both weight and numbers of mussels and affects associated epifauna (Carver et al. 2006; Lutz-Collins et al. 2009a, b). Tunicates also create issues for the handling of mussel lines, decreasing overall farm productivity (e.g. Ramsay et al. 2008), prompting research on mitigation measures to control biofouling (e.g. Bakker et al. 2011; Paetzold and Davidson, 2011; Parent et al. 2011). Since over a decade ago high pressure water treatment is the preferred mitigation measure employed by the local farming industry (Carver et al. 2006). Using custom-made machinery and equipment, mussel lines and socks are pulled above the surface of the water and exposed to high pressure water for standard frequencies and periods of time. The pressure water treatment removes a considerable amount of tunicates and its optimal application regime was studied in detail in a previous article (Davidson et al. 2016) conducted in the same study areas described below. The main conclusion of that study was that initiating treatment early (July) and treating the socks another two or three times during the season was most detrimental to tunicate size and number, while enabling greater mussel productivity (Davidson et al. 2016). This article complements that previous study by focusing on cost-benefits estimates associated to those treatment regimes.

Table 1. Infrastructure details of mussel farms used in the study.

Infrastructure characteristics	Estimations
Mean size of farm (hectares)	22.7
Mean number of long lines per hectare	5.91
Mean number of long lines per farm	134
Mean number of socks per long line	300
Mean length of sock (meter)	2.1
Mean number of treatments per year	3
Total number of long line treatments	402

Farm selection

PEI mussel farmers were invited to participate in this study by the PEI Aquaculture Alliance, the local mussel industry interest group. Selection criteria for choosing farms to be included in this study were primarily i) the willingness of the grower to participate in the study, ii) the awareness that the particular farms were adversely affected by *C. intestinalis*, and iii) the availability of accurate, up to date data on farm productivity and finances.

Six mussel growers who met the selection criteria were identified by the PEI Aquaculture Alliance and all agreed to participate in this study. The mussel farms were located in eastern PEI namely in the areas of St. Mary’s Bay, Montague River, Brudenell River, Murray River and Cardigan River. Growers were assured that the data to be gathered and used in this study were to be treated as strictly confidential.

Farm structure and treatment frequency

The average size of the farms was 22.7 ha with 5.91 long lines per ha averaging 134 long lines per farm. Each long line averaged 300 socks with a mean length of 2.1 m (Table 1). Each long line was treated an average of three times per year, resulting in 402 long line treatments (Table 1). The survey was conducted individually by a verbal *in situ* interview. These interviews occurred between January and December 2012 after completion of the field trial described by Davidson et al. (2016).

Cost benefit analysis

A cost benefit analysis was conducted to determine the most economically beneficial treatment regime for the mitigation of *C. intestinalis* in two mussel growing areas at two sampling times. The mussel farming areas were Murray River (MR) and Brudenell River (BR), located on the eastern shore of PEI. The two sampling times were November 2010 and May 2011.

Productivity data was obtained from the field study by Davidson et al. (2016). Productivity was measured for mussel lines treated with four different tunicate treatment regimes in two PEI mussel farming areas at two points in time. The four treatment regimes considered were as follows: a) four tunicate treatments during July, August, September and October (4JASO), b) three treatments during July, August and September (3JAS), c) two treatments in July and September (2JS), and d) two treatments in August and September (2AS).

Farm management and financial data were obtained from interview surveys conducted with the selected mussel farmers, who were either the owner or manager of the farm. These surveys were primarily designed to capture the costs associated with treating mussel lines infested with *C. intestinalis* but also captured the overall cost of operating their mussel farm.

Fixed costs of the farm, defined as expenses that do not change as a function of the activity of a farm (e.g. the treatment of tunicates), were not essential to the objectives of this project. However, the survey captured both fixed costs and variable costs of treatment to ensure data validity. This was done with the goal of preventing misclassification or omission of costs to either category. Fixed costs do not vary according to the treatment regime or whether the farm was infested or treated for tunicates. For this reason, the emphasis of this manuscript is not on fixed costs but they were considered in the analyses to allow estimating a monetary value for the treatment regime and control.

Variable costs of treatment

Variable costs, defined as a cost that varies in relation to changes in the volume of activity e.g. number of tunicate treatments, were identified as those expenses solely associated with the management and treatment of *C. intestinalis*. The two main expense categories were the additional investment required to purchase specialized equipment for treatment management and the additional operating costs including labour and boat fuel. The cost of treatment was calculated for each treatment regime. As this was a variable cost, costs increased as the number of treatments in the regime increased.

Benefits

The benefits of treatment by the various treatment regimes were calculated by the field-based trial by Davidson et al. (2016). Outcomes defining benefit consisted of the mean biomass, length, count and condition index of the mussels, and the mean biomass, length and count of *C. intestinalis*. The unit of concern in that study was 30 cm sock sampling sections from each treatment group in Brudenell and Murray Rivers during the sampling that took place in November 2010 and May 2011. In this study, the unit of concern was the long line, considering that this was the treatment unit employed by the farmers. In order for the calculations to refer to that unit of concern, results were extrapolated from the sampling section to the full sock then to a long line. The biomass (or weight) of the mussels harvested was the unit of financial concern. It was multiplied by the cost per unit weight to determine the revenue generated by the sale of the mussels for each treatment regime.

Gross profit margin

The gross profit margin for a long line was calculated by subtracting the gross profit from the total expenses. Gross profit was calculated by multiplying the average weight (kg) of mussels by average price per kilogram mussels ($1.21 CAD/kg) (all values will be reported as Canadian dollars in this study). A bench mark for the control in each group was adjusted to $0 for ease of interpretation of results.

Results

Fixed costs

Fixed costs of the farm included all expenses associated with the purchase and operation of the farm excluding those used exclusively for tunicate treatment. Mussel farmers identified major expenditures to include equipment/supplies and human resources. Major equipment costs included mussel boat(s), truck(s), buoys, rope, anchors, socking facilities and equipment (or purchase of seed) and miscellaneous equipment. Average fixed costs for a single long line from deployment to harvest was estimated to be $1,750 for a 22.7 ha farm. As this cost does not differ between treatment regimes or the control, no further details of these costs are presented.

Variable costs of treatment

Mussel farmers identified the costs associated solely with treatment of their crop for the mitigation of tunicates. Equipment required with approximate associated costs is presented in Table 2. The equipment was estimated to be used in production for three years before replacement was necessary, so depreciation took place over that period of time. Depreciation resulted in a yearly cost for equipment of $52,117. The depreciation of this treatment equipment was considered constant, whether treatment occurred two, three or four times a year. If no treatment occurred, as in the controls, this cost was $0. Assuming the number of treatments for all treatment groups was 400 long line treatments, the average cost of treatment equipment per year for all treatment groups was $130 per treatment.

The cost of labour to treat one long line was $28, which was the result of 2 hours labour at an average hourly wage (with benefits) of $14 per hour. The cost of fuel to treat one long line was $26, which was the result of 20 L of fuel consumed at a cost of $1.30 per L. The cost of labour and fuel to treat a long line two, three and four times was $108, $162 and $216 respectively (see Table 3). Table 4 summarizes the total costs of treating two, three, four times or no treatment (control).

Benefits

The biomass (weight) of mussels harvestable for each treatment, date of harvest and river system was obtained from the results of the field based trial by Davidson et al. (2016). Overall results from this study indicated that initiating pressure water treatment early in the season (July) and treating another 2 or 3 times during the season had the greatest effect on reducing tunicate numbers and enabling greater mussel productivity. The biomass was extrapolated to represent the biomass for one long line (Table 1).

Cost benefit analysis

The four treatment regimes considered were as follows: a) four tunicate treatments during July, August, September and October (4JASO), b) three treatments during July, August and September (3JAS), c) two treatments in July and September (2JS), and d) two treatments in August and September (2AS).

Table 2. Equipment costs to treat tunicates on mussel lines.

Type of equipment	Approximate cost ($CAD)
Boat (dedicated to tunicate treatment)	85,000
Bow thruster (add on to boat)	15,000
High Pressure Water Sprayer Unit	52,500
Trailer for Boat Storage	4,000
Total Equipment Cost	156,000
Depreciation over 3 years	52,117
Cost to treat 1 long line	130

November 2010

In Murray River all treatment regimes had a positive effect on the gross profit margin. The greatest benefit was obtained from treating the mussel lines three times ($3,324), followed by treating them four times ($2,811), two times starting in July ($1,592) and two times starting in August ($721) (Table 5). In Brudenell River all treatment regimes had a positive effect on the gross profit margin except for treating two times starting in August which resulted in an actual loss of $648 per long line. The gross profit margin was greatest when socks were treated four times ($1,282) followed by three time treatment ($890) and two time treatment starting in July ($668) (Table 6). When the mean value from Murray River and Brudenell River is calculated, the benefit of treating either three times or four times was minimal ($2,107 and 2,046, respectively), but it was considerably more beneficial than treating two times starting in July or August ($1,130 and $36 respectively).

May 2011

The profit margin in May 2011 was affected by the treatment regimes in 2010 and the effect of overwintering under the ice. In Murray River all treatment regimes had a positive effect on the profit margin. The greatest benefit was to treat the mussel socks three times ($5,210), followed by treating four times ($3,912) and two times starting in July and August ($1,883 and $1,818 respectively) (Table 7). In Brudenell River, the greatest benefit was to treat four times ($2,063) followed by three times ($1,341) and two times starting in July and August ($788 and $42 respectively) (Table 8). Considering both Murray River and Brudenell River together, the mean benefit of treating either three times or four times was minimal ($3,275 and $2,987 respectively), but was considerably more beneficial than treating two times starting in July or August ($1,335 and $930 respectively).

Table 3. Costs for labour and fuel for different treatment regimes.

Cost details	Treatment regimes (Times treated)			
	2	3	4	Control
Labour @ $28/long line	$ 56	$ 84	$ 112	$ 0
Boat fuel @ $26/long line	$ 52	$ 78	$ 104	$ 0
Total labour/fuel costs	**$108**	**$162**	**$ 216**	**$ 0**

Table 4. Total costs for treatment regimes.

Cost details	Treatment regimes (Times treated)			
	2	3	4	Control
Fixed cost of a long line	$ 1,750	$ 1,750	$ 1,750	$ 1,750
Treatment equipment	$ 130	$ 130	$ 130	$ 0
Fuel/labour	$ 108	$ 162	$ 216	$ 0
Total labour/fuel costs	**$ 1,988**	**$ 2,042**	**$ 2,096**	**$ 1,750**

Table 5. Gross profit margin for treatment regimes for one long line in Murray River (November 2010).

	Treatment				
	3JAS	4JASO	2JS	2AS	Control
Mussel biomass (kg)	3,766	3,388	2,294	1,575	784
Value ($ per kg)	$1.21	$1.21	$1.21	$1.21	$1.21
Gross Profit	$4,567	$4,108	$2,781	$1,910	$951
Total Costs	$2,042	$2,096	$1,988	$1,988	$1,750
Gross Profit Margin (unadjusted)	$2,525	$2,012	$793	-$78	-$799
Gross Profit Margin (control adjusted to $0)	**$3,324**	**$2,811**	**$1,592**	**$721**	**$0**

Discussion

Our results show that in the two study areas, which are representative of the PEI mussel farm industry, the application of a treatment regime for the mitigation of *C. intestinalis* is important to maintain or improve the economic potential of a mussel farm. Although we cannot directly extrapolate these results to mussel farm operations elsewhere, the main conclusions that we present below are in principle applicable and should be useful in case similar cost-benefit studies are attempted. The results of this study show that in our system a treatment regime that includes three or four treatments consistently results in an economic advantage over treating two times. If treating mussel socks only two times, treating them early shows also substantial economic advantage.

This study is the first of its kind to assess the cost benefit of variable treatment regime for the mitigation of *C. intestinalis,* or any other biofouling organism infestation on shellfish aquaculture farms, including mussel farms. Although other major mussel growing areas have been infested with *C. intestinalis* (Carver et al. 2006; Howes et al. 2007; Sargent et al. 2013), investigations into the economics of various treatments has not been deemed critical due to a number of reasons. For example, the *C. intestinalis* infestation of mussel farms in the Marlborough Sound, New Zealand was severe in the late 1990s (Willis et al. 2007) and has sporadically and unpredictably re-appeared afterwards (e.g. in 2014). Despite these sporadic infestation events, it is not feasible or practical for the mussel industry there to treat for tunicates, so and this has limited further research into treatment options and regimes (Carver et al. 2006). Although New Zealand does not have a production issue at the scale of the one affecting PEI, the initial infestation of their mussel farms prompted the development of the high pressure water treatment for *C. intestinalis*. That treatment was transferred to the PEI aquaculture industry and remains the main measure currently employed on all infested PEI mussel farms. Another example is Italy, where the lifting of mussel socks out of the water for 24 hours has been used as a mitigation strategy. The success of that strategy has precluded further investigation into other treatment options (Caputi et al. 2014). Meanwhile, in the Galician coast of Spain, where mussels have been grown for over 100 years up to the point of being considered the highest production region in the world, the occurrence of *C. intestinalis* is surprisingly incidental and sporadic. In sharp contrast to those locations, the infestation by *C. intestinalis* that took place in PEI has been constant and severe since its initial identification in 2004 (Carver et al. 2003, 2006; Ramsay et al. 2008).

Table 6. Gross profit margin for treatment regimes for one long line in Brudenell River (November 2010).

	Treatment				
	3JAS	4JASO	2JS	2AS	Control
Mussel biomass (kg)	2,649	3,017	2,421	1,336	1,674
Value ($ per kg)	$1.21	$1.21	$1.21	$1.21	$1.21
Gross Profit	$3,212	$3,658	$2,936	$1,620	$2,030
Total Costs	$2,042	$2,096	$1,988	$1,988	$1,750
Gross Profit Margin (unadjusted)	$1,170	$1,562	$948	-$368	$280
Gross Profit Margin (control adjusted to $0)	**$890**	**$1,282**	**$668**	**-$648**	**$0**

Table 7. Gross profit margin for treatment regimes for one long line in Murray River (May 2011).

	Treatment				
	3JAS	4JASO	2JS	2AS	Control
Mussel biomass (kg)	5,131	4,105	2,343	2,289	594
Value ($ per kg)	1.21	1.21	1.21	1.21	1.21
Gross Profit	$6,222	$4,978	$2,841	$2,776	$720
Total Costs	$2,042	$2,096	$1,988	$1,988	$1,750
Gross Profit Margin (unadjusted)	$4,180	$2,882	$853	$788	-$1,030
Gross Profit Margin (control adjusted to $0)	**$5,210**	**$3,912**	**$1,883**	**$1,818**	**$0**

Table 8. Gross profit margin for treatment regimes for one long line in Brudenell River (May 2011).

	Treatment				
	3JAS	4JASO	2JS	2AS	Control
Mussel biomass (kg)	2,922	3,562	2,421	1,806	1,575
Value ($ per kg)	1.21	1.21	1.21	1.21	1.21
Gross Profit	$3,543	$4,319	$2,936	$2,190	$1,910
Total Costs	$2,042	$2,096	$1,988	$1,988	$1,750
Gross Profit Margin (unadjusted)	$1,501	$2,223	$948	$202	$160
Gross Profit Margin (control adjusted to $0)	**$1,341**	**$2,063**	**$788**	**$42**	**$0**

This has prompted the exploration of treatment strategies and, as this study reports, the economic benefits of such strategies.

The profitability of a treatment regime is highly related to the mussel biomass being harvested. This is because the largest expense of a long line is the fixed cost ($1,750) as compared to variable costs of treatment ($238 to $346). While the cost of treatment remains modest, the changes (increases) in mussel biomass resulting from additional treatments are considerable. For example, the application of a four treatment regime averaged 3,518 kg for an estimated value of $4,257, while the application of the two treatment regime starting in August averaged 1,751 kg for a value of $2,119. The $108 additional treatment cost of treating four times instead of two resulted in an additional profit margin of $2,138 per long line. Even if the treatment equipment costs of $130 were to be eliminated for the two treatment regime, the cost of treating four instead of two times would only be $238, which is not a significant factor in the overall profit margin.

Interestingly, treating three times produced the highest gross margin in Murray River while treating four times produced the highest margin in Brudenell River. Although this part of the study only involved two mussel farming areas, this particular result suggests that there is some variation among locations (Wadowski 2009) and that at least three treatments are required to achieve maximum gross margin. The decision to treat three, four or more times may be dependent on the particularities of a given growing area and, likely, the farmer's husbandry practices as well. Although there is no published literature to explain this difference among locations, a reasonable hypothesis is the mean difference in tunicate length at the time of the first treatment (Carver et al. 2006). When the treatment of socks was initiated, Brudenell River had tunicates with a mean length of 21 mm while Murray River had a length of 33 mm. The increased stress on the byssal attachment of mussels with larger tunicates (Moeser and Carrington 2006) could have caused increased mussel fall off during the initial treatment in Murray River.

The phenomenon of mussel fall off during treatment may become more common as reports suggest that mussel byssus attachment is weakened by ocean acidification (O'Donnell et al. 2013). Anecdotal observations by PEI mussel farm workers also report another challenge: *C. intestinalis* treatment is requiring increased water pressure to adequately treat the mussel socks. This could be due to increased resistance of the ascidian tunic to water pressure or increased strength of its attachment to mussels and sock material. Regardless of the cause, this may have serious consequences for the future of treating tunicate infested socks with high pressure water. If the mussel byssal attachments become increasingly weakened, the treatments, even at the same water pressure may cause increased loss of mussels. The mussel aquaculture industry should consider establishing an integrated pest management program for *C. intestinalis* control, rather than simply continue to apply a given treatment regime program. Integrated pest management is a sustainable approach to managing pests by combining biological, cultural, physical and chemical tools in a way that minimizes economic, health and environmental risks (ACRDP Workshop Final Report 2009). These tools could include employing naturally occurring biological control or alternative method treatments. These could be conducted in conjunction with the adoption of cultivation that reduces tunicate biomass, or the alteration of the habitat to make it incompatible with tunicate development. Along with environmental considerations, cost-benefit analyses like the one presented here for two representative mussel farms, should be given serious consideration in the further development of the aquaculture industry.

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