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Growth and condition index of mussel *Mytilus galloprovincialis* in experimental integrated aquaculture

Melita Peharda[1], Ivan Župan[2], Lav Bavčević[3], Anamarija Frankić[4] & Tin Klanjšček[5]

[1]Institute of Oceanography and Fisheries, Šetalište Ivana Meštrovića, Split, Croatia
[2]Convento Albamaris, Augusta Šenoe, Biograd, Croatia
[3]Croatian Agriculture Extension Institute, Ivana Mažuranića, Zadar, Croatia
[4]University of Massachusetts Boston, EEOS Department, Boston, MA, USA
[5]Ruđer Bošković Institute, Bijenička, Zagreb, Croatia

Correspondence: M Peharda, Institute of Oceanography and Fisheries, Šetalište Ivana Meštrovića 63, 21000 Split, Croatia. E-mail: melita@izor.hr

Abstract

Integrating mussel and finfish aquaculture has been recognized as a way to increase profits and decrease environmental impacts of finfish aquaculture, but not enough is known about the effects of finfish aquaculture on mussel growth. Here we present a pilot study aimed at determining how distance from finfish aquaculture affects mussel growth. To this end, we measured growth and condition index of mussel (*Mytilus galloprovincialis*) at three different distances (0, 60 and 700 m) from finfish aquaculture in the eastern Adriatic Sea. There was a statistically significant difference in growth of tagged mussels with respect to site. Average measured lengths of mussels at sites 1, 2 and 3 after the 10 months of the experiment were 57.60, 62.73 and 58.66 mm. Mussels grew fastest from March to May, and slowest from July to September, regardless of their position. Condition index showed spatial and temporal variations with higher values during fall and winter ($\sim$ 23), and lower values during spring and summer ($\sim$ 20). Our results show that production cycle in areas traditionally considered suboptimal for aquaculture can be equivalent to the cycle in areas traditionally considered optimal for mussel aquaculture if mussel aquaculture is integrated with finfish aquaculture.

Keywords: integrated aquaculture, polyculture, mussel, Adriatic Sea

Introduction

Simultaneous culture of several species in the same water body with the objective of optimizing the use of space and nutrients is termed integrated aquaculture, polyculture or co-culture. Integrated aquaculture is traditionally used in the fresh-water pond aquaculture (Marcel 1990; Landau 1992). Recently, potential for integration of marine fish and bivalve aquaculture is being assessed (Jones & Iwama 1991; Taylor, Jamieson & Carefoot 1992; Stirling & Okumus 1995; Mazzola, Favaloro & Sarà 1999; Mazzola & Sarà 2001; Cheshuk, Purser & Quintana 2003; Gao, Shin, Lin, Chen & Cheung 2006; Martinez-Cordova & Martinez-Porchas 2006).

Croatia's aquaculture production in 2005 was 6425 t of marine fish and 2600 t of bivalves (Jahutka, Mišura & Suić 2006). Only a small fraction of this production is from integrated aquaculture. The strategic goal of the Republic of Croatia is to reach an annual production of 10 000 t of fish and 20 000 t of bivalves from aquaculture operations in this decade (Katavić, Božanić, Cetinić, Dujmušić, Filić, Kučić, Vodopija & Vrgoč 2002). Meeting this goal requires either expanding areas devoted to aquaculture or a shift towards integrated aquaculture.

Expanding aquaculture operations in coastal waters is restricted due to conflicts with other human activities in the coastal zone. Large aquaculture operations reduce the area available for other activities, while influx of organic matter into the water column (eutrophication) resulting from fish farming can have unacceptable adverse impacts on the oligotrophic community of the Adriatic Sea. Hence, integrated aquaculture has been suggested as a preferred option (Frankic & Hershner 2003).

In a bivalve and fish-integrated aquaculture, fish aquaculture provides organic matter for bivalves to feed on (Chan 1993; Stickney & McVey 2002). Bivalves remove the organic matter from the water, thus reducing the environmental impact of fish aquaculture (Naylor, Goldburg, Primavera, Kautsky, Beveridge, Clay, Folke, Lubchenco, Mooney & Troell 2000). Such a configuration increases biomass production while decreasing eutrophication of the water column (Brooks, Mahnken & Nash 2002).

Mussel *Mytilus galloprovincialis* Lamarch 1819 is a natural choice for a bivalve species in integrated aquaculture in the Adriatic Sea because it is native to the region, fast growing and commercially viable. Mussel seed is collected in wild by ropes and after about 6 months mussels are transferred to nylon mesh nets hanging from lines. Production cycle is between year and a half and two years (Hrs-Brenko & Filić 1973; Benović 1997; Jasprica, Carić, Bolotin & Rudenjak-Lukenda 1997).

Previous studies have demonstrated that influence of fish cages is localized (Magill, Thetmeyer & Cromey 2006; Matijević, Kušpilić & Barić 2006) and it is the question, especially in oligotrophic environment, at which distance from fish cages mussel culture needs to be placed and what quantities of mussels can be supported by the fish farm. Here we present the pilot study dealing with determining the viability of bivalve and the fish integrated aquaculture and optimal placement of mussels relative to fish cages. We analysed spatial and temporal differences in *M. galloprovincialis* shell growth and condition index, and discuss implications of our findings for integrated aquaculture and future experiments aimed at understanding the optimal placement of mussel relative to fish cages.

Material and methods

The pilot study was carried out from August 2005 to November 2006 on an aquaculture farm of sea bass *Dicentrarchus labrax* (Linnaeus, 1758) and sea bream *Sparus aurata* (Linnaeus, 1758) located on the south side of Pašman island, middle Adriatic Sea (Fig. 1). This farm produces about 90–100 tons of fish annually. There are also two smaller nearby farms producing an additional 80–90 tons of fish. During the experiment, fish were fed with extracted pellets produced by BioMar or Aller. Temperature was measured once a week, while mussels were sampled around 15th of the month. *M. galloprovincialis* from fouling communities found at the fish aquaculture structures was used to set up the experiment.

For growth experiment, shell lengths ($N = 297$) were measured with vernier calipers to the nearest 0.1 mm and shells were individually marked with mollusc tags (HALL PRINT, Victor Harbour, South Australia, Australia) in November 2005. The mean initial length of mussels used in growth experiment was 39.4 ± 1.8 mm and they were six to eight months old. Marked shells were divided into three samples, placed in square-shaped plastic baskets (35×55 cm) commonly used in the Adriatic for oyster aquaculture and suspended at 2.5 m depth at three different sites. Site 1 was immediately neighbouring fish cages, site 2 was 60 m away from the cages and site 3 was 700 m away from the cages.

After 2 months, mussels were removed from the water, their lengths were measured and they were suspended again in the water column. This procedure was repeated every 2 months on the same mussels. A total of 33 (11%) mussels were found empty during the experiment and many of them had predation marks on their shells, which we presume were made by sea bream. Majority of them died before March 2006. In addition, tags have been missing from 86 mussels (29%) and these disappeared in different phases of the experiment. Because of poaching, mussels were not recovered from site 2 in November 2006. Only mussels that survived the whole experiment were used in the analysis, that is 77 mussels at site 1, 55 at site 2 and 44 at site 3.

For condition index analyses, mussels were kept in nylon mesh nets (22 mm opening) at the above-described sites. The base population used for measuring condition index was about 700 animals at each site. Each month 30 mussels were removed from each site and frozen for later laboratory analysis. Condition index was determined as the ratio between cooked meat weight and the sum of cooked meat weight and shell weight according to Davenport and Chen (1987).

Before the analysis data were tested for homogeneity of variance, growth increments were analysed using repeated measures ANOVA on animals that survived the experiment. With respect to condition index, one-way analysis of variance was applied for data analysis when variances were homogeneous, while non-parametric Kruskal–Wallis test was used

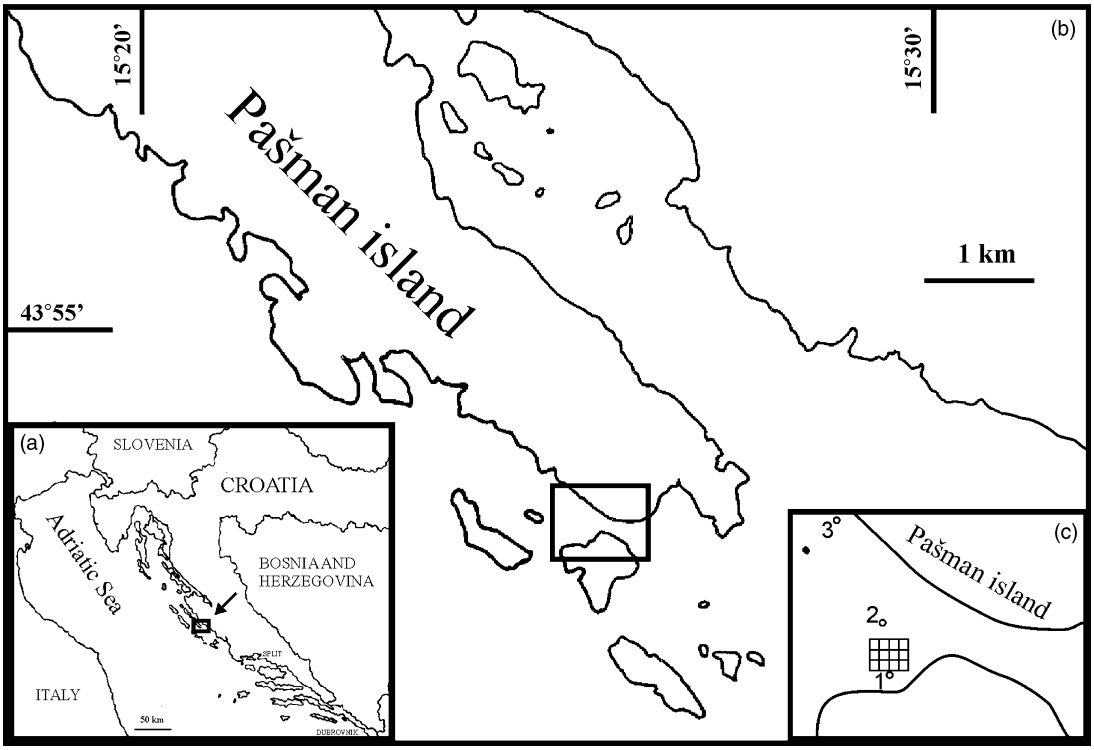

Figure 1 Map of the study area: (a) Adriatic Sea, (b) area around Pašman island, (c) Location of fish farm and sampling sites.

for analysis of data that did not have homogenous variances. Tukey and Mann–Whitney tests were applied for post hoc comparison respectively. Length-at-age data were analysed using the FiSAT II statistical package (v. 1.2.2.) and the asymptotic length (L_{α}) and the curvature parameter (k) parameters of the Bertalanffy growth equation $L_t = L_\infty \ (1–e^{-k(t-t_0)})$ were determined separately for each study site (Gayanilo, Sparre & Pauly 2005).

Results

Temperature

Temperature at fish aquaculture site ranged from 10.4 °C (February 2006) to 24.0 °C (August 2006). Temperature was below 13 °C in a period from January to March, while values above 21 °C were recorded in a summer period, from July to September (Fig. 2).

Growth rate

There was a statistically significant difference in growth of tagged mussels with respect to site and period (Fig. 3, Table 1). In a 10-month period, fastest growth was observed for mussels placed 60 m away from the fish cages at site 2 ($x = 23.46 \pm 4.25$ mm/2 months, $N = 55$), while mussels placed at fish cages ($x = 18.26 \pm 4.59$ mm/2 months, $N = 78$) and those placed at site 3 placed 700 m away from the fish cages ($x = 19.24 \pm 5.21$ mm/2 months, $N = 54$) grew slower. Average measured lengths of mussels at sites 1, 2 and 3 after the 10 months of experiment were 57.60, 62.73 and 58.66 mm. With respect to length frequency distribution and site, 42%, 80% and 53% of mussels were above the commercial size of 6 cm as defined in the Official Gazzet (96/2005). After 12 months, 59% of mussels at site 1 and 70% of mussels at site 3 were above the commercial size. As mussels used for the start of the experiment were 6–8 months old, we conclude that the production cycle of mussels placed at site 2 is between 18 and 20 months, while the production cycle of those placed at sites 1 and 3 is around 24 months.

The highest growth rates were recorded in a period from March to May ($x = 6.4 \pm 2.2$ mm/2 months, $N = 220$), while the mussels grew slowest from July to September ($x = 1.5 \pm 1.2$ mm/2 months, $N = 187$). The estimated asymptotic length was largest for mussels from site 2 ($L_\infty = 83.13$ mm), while those for sites 1 ($L_\infty = 66.94$ mm) and 3 ($L_\infty = 68.78$ mm) were

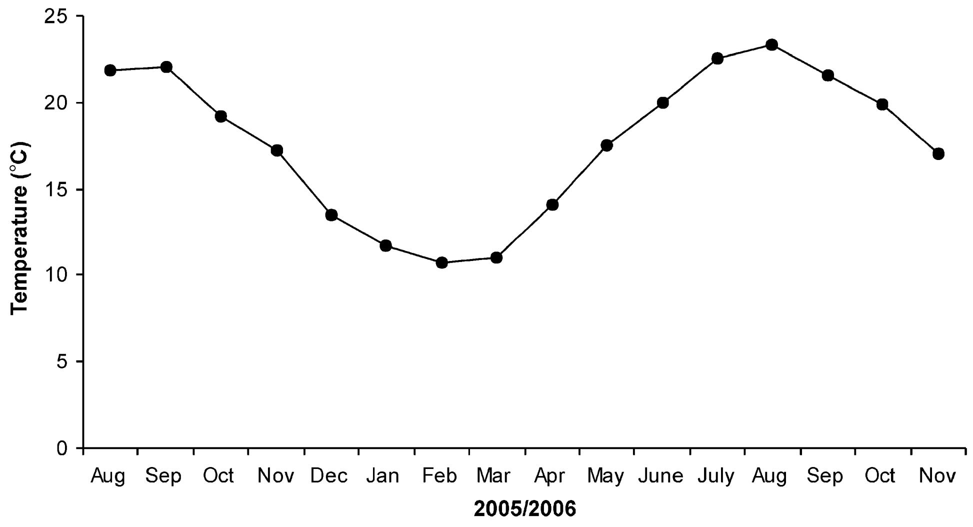

Figure 2 Seasonal variation in temperature.

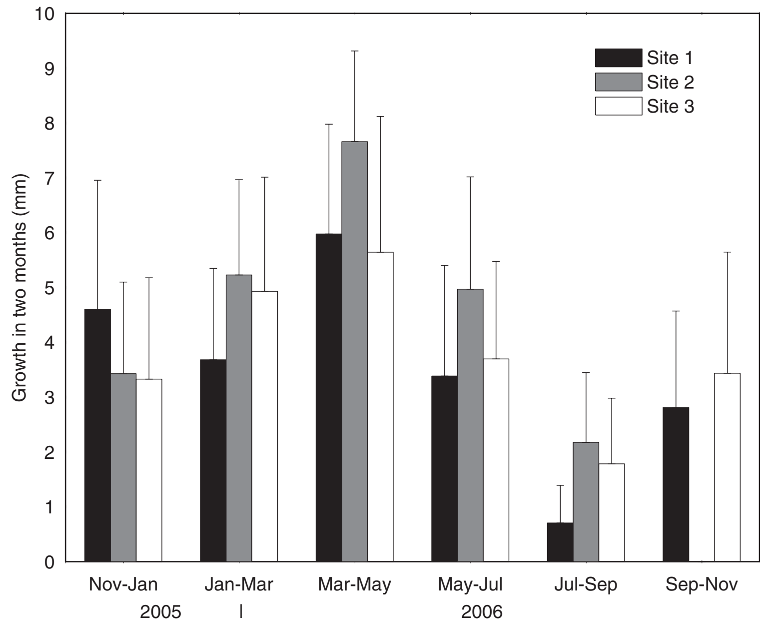

Figure 3 Average growth increment and standard deviation of tagged mussels that survived the whole study according to site and sampling period.

smaller and similar to each other. Values of curvature parameter (k) were 0.96, 1.44 and 1.32 respectively.

Condition index

The condition index showed spatial and temporal variations (Fig. 4, Table 2). The highest mean condition index values were recorded at site 1 in a period from September 2005 to January 2006 (range 28.0–31.0), while the lowest mean value was recorded in March 2006 at site 3 (11.3 ± 1.7). There was a statistically significant difference in condition indices recorded at different sites in the same period. In a period from September 2005 to April 2006, mussels from site 1 had significantly higher condition index than either mussels at sites 2 or 3, except for in February 2006. In February, mussels from sites 1 and 3

Table 1 Growth increment analysis using repeated measures ANOVA and post hoc Tukey test

Factor	d.f.	*F*	*P*	Post hoc comparison
Site	2	26.70	<0.001	1 = 3 < 2
Period	4	156.43	<0.001	E < A = D < B < C*
Interaction	8	10.22	<0.001	
Error	865			

*A, November–January; B, January–March; C, March–May; D, May–July; E, July–September.

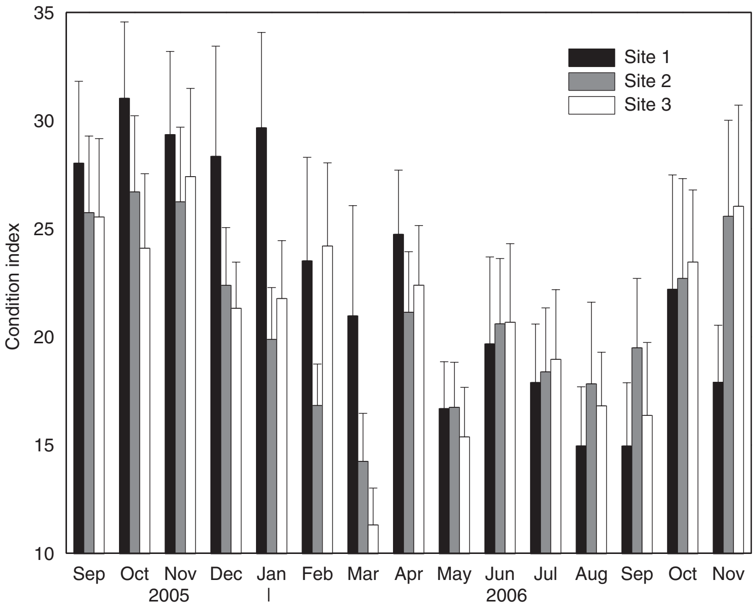

Figure 4 Average monthly condition index and standard deviation according to sampling site.

Table 2 Analysis of condition index according to sampling site and month

Month	ANOVA/KW	Post hoc comparison
September	$F = 4.30^{*}$	1 > 2 = 3
October	$F = 30.09^{***}$	1 > 2 = 3
November	$F = 5.13^{**}$	1 > 2, 2 = 3, 1 = 3
December	$H = 31.57^{***}$	1 > 2 = 3
January	$F = 69.82^{***}$	1 > 2 = 3
February	$H = 44.63^{***}$	1 = 3 > 2
March	$H = 59.76^{***}$	1 > 2 > 3
April	$F = 12.42^{***}$	1 > 2 = 3
May	$F = 3.79^{*}$	2 > 3, 1 = 2, 1 = 3
June	$F = 0.72$ NS	–
July	$F = 0.98$ NS	–
August	$F = 6.83^{**}$	2 > 1, 2 = 3, 1 = 3
September	$F = 16.08^{***}$	2 > 1 = 3
October	$F = 0.60$ NS	–
November	$F = 43.47^{***}$	2 = 3 > 1

* < 0.05.
** < 0.01.
*** < 0.001.
NS, not significant.
One-way ANOVA and Kruskal–Wallis test, Post hoc comparison – Tukey and Mann–Whitney tests, respectively.

had a higher condition index than mussels from site 2, but the condition index of mussels from sites 1 and 3 did not significantly differ from each other. In May, August and September, mussels collected from site 2 had the highest condition index. In November 2006, indices of mussels from sites 2 and 3 were similar, and both were higher than indices from site 1. No statistically significant differences in condition indices were observed in June, July and October 2006.

Discussion

In the eastern Adriatic Sea, mussel aquaculture is traditionally placed in coastal areas with reduced salinity and large primary productivity to maximize mussel production. The bulk of the Croatian mussel aquaculture is in the areas of the Lim channel, Krka estuary and Mali Ston Bay, which are moderately eutrophic areas compared with the otherwise mainly oligotrophic coastal waters (Viličić 1989). Production cycle in those areas range from 1.5 to 2 years (Hrs-Brenko & Filić 1973; Benović 1997; Jasprica *et al.* 1997).

Our results show that integrating fish and mussel aquaculture can offer the same mussel production cycle in areas traditionally considered suboptimal for mussel growth. The growth patterns observed in our pilot study are consistent with previously measured rates of mussel growth in monoculture conditions in the eastern Adriatic Sea. For example, growth of 23.6 mm in 10 months at site 2 compares well with growth in Mali Ston Bay where mussels grew an average of 27.3 mm in 12 months (Jasprica *et al.* 1997). The rate of growth of mussels at site 2 implicates that mussels at this site would be at least as large as the mussels in Mali Ston had they been growing the additional two months. Jones and Iwama (1991) observed enhanced growth of oyster *Crassostrea gigas* (Thunberg, 1793) next to a salmon farm, supporting our claim that integrated aquaculture improves bivalve production.

Growth rates at all sites were lowest during the summer months (July and August) when water temperature ranged between 21 °C and 24 °C, and highest during March and April, when the water temperature was as low as 10 °C. Mussels exhibited intermediate growth rates during all other periods. The observed pattern of mussel growth can partially be explained by the temperature dependence of mussel growth rate. For example, a stationary phase in mussel growth during summer (July and August) was also recorded in France where water temperatures during the summer reach 25.9 °C (Gangnery, Bacher & Buestel 2004), but not in Scotland where water temperatures reach only 16.3 °C (Karayücel & Karayücel 2000). Almada-Viella, Davenport and Gruffydd (1982) analysed the temperature dependence of mussel *Mytilus edulis* Linnaeus 1758 growth: growth rate increases logarithmically between 3 °C and 20 °C, but declines sharply above 20 °C. The sharp decline above 20 °C could explain the slow growth and low condition index during the warmest months, but not the growth rate pattern observed during the other periods. If mussel growth were dictated by temperature only, growth rates during the colder months (January through April) would be smaller than during the periods with moderate water temperature (October through December and May through July). We, however, observed larger growth rates during colder months (especially during March and April). Therefore, mussel growth must be affected by something other than the temperature.

The period of fastest growth coincides with the period of highest primary productivity in the Adriatic Sea (Marasović, Ninčević, Kušpilić, Marinović & Marinov 2005), suggesting that the higher growth rate may be a result of increased food availability. The decrease of growth rates in the period after the highest primary productivity, even though growth rate increase due to increase in temperature was expected, suggests that mussels are food-limited during large parts of the year.

We observed highest condition indices in the period from October to February at all sites, suggesting that the end of autumn and winter period is the optimum time for harvest. The market demand for seafood in Croatia is, however, linked to the summer tourist season, thus forcing mussel harvest in integrated aquaculture at a biologically sub-optimal time. Creating year-long processing facilities would help mitigate the problem by improving the winter market for mussels. Our results show that position did not consistently influence condition indices of mussels. This is in accordance with Taylor *et al.* (1992), who did not find a link between distance from the salmon farm and the condition index of mussel *M. edulis* either, but contrasts with Jones and Iwama (1991) who found that proximity to Chinook salmon *Oncorhynchus tshawytscha* (Walbaum, 1792) farm increases the oyster *C. gigas* condition index.

Our study suggests that placement of mussels relative to fish cages considerably influences mussel size, duration of the production cycle and – consequently – profits from the aquaculture. This contrasts with Cheshuk *et al.* (2003), who found no important differences in growth and condition index of mussels *Mytilus planulatus* (Lamarck, 1819) placed at different distances from Atlantic salmon *Salmo salar* (Linnaeus, 1758) culture. The differences in observations may come from differences in cultured fish, mussels or primary productivity in the area.

A number of other factors that may affect bivalve growth include depth, position of ropes on rafts and position of bivalves relative to currents. There is no conclusive evidence as to how mussel growth depends on depth: some studies suggest that deeper mussels grow faster (Mazzola *et al.* 1999), in others mussels placed shallower grew faster (Fuentes, Gregorio, Giraldez & Molares 2000), while some studies found no significant effect of depth on mussel growth (Jasprica *et al.* 1997; Karayücel & Karayücel 2000). Similarly, evidence is not conclusive regarding the effect of position. Karayücel and Karayücel (2000) found that in monoculture conditions position of the mussel on the raft significantly influenced its growth rate, while according to Fuentes *et al.* (2000) it was of lesser importance. To properly resolve these issues, as well as better determine the optimum position of mussel relative to fish aquaculture, we plan to devise a much broader experiment guided by this pilot study.

Acknowledgments

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