Eversole et al 2004

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Effect of Temperature and Phytoplankton Concentration on Freshwater Mussel Filtration in the Partitioned Aquaculture System

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Abstract

The freshwater mussel Elliptio complanata was provided green algal-dominated water from a Partitioned Aquaculture System (PAS) over a range of water temperatures (7-32 C) and suspended particulate organic carbon (POC) concentrations (1-32 mg POC L^{-1}) to determine filtration rates as mg POC kg^{-1} wet tissue weight h^{-1}. Filtration rates increased with both increased water temperature and POC concentration. The predicted filtration rate (PFR) response to water temperature and POC concentrations is: $PFR = 160.36 - 33.27T + 2.57T^2 - 0.06T^3 + 0.02T*POC^2$. Within the test conditions the predicted maximum filtration rate of 510 mg POC kg^{-1} wet tissue h^{-1} occurred at 26 C and 32 mg POC L^{-1} and predicted minimum filtration rate of 25 mg POC kg^{-1} wet tissue h^{-1} at 10.5 C and 1 mg POC L^{-1}. A model to describe a mussel filtration rate response to PAS water conditions requires both water temperature and POC concentration data.

Key words: filtration rate, freshwater mussel, PAS, culture system

Introduction

The Partitioned Aquaculture System (PAS) separates a culture pond into four distinct components (paddlewheels, algal basin, filter feeder area and culture species area) linked by a homogeneous water velocity field (Brune et al. 2004). Paddlewheels provide water flow, nutrient mixing, and uniform sunlight exposure throughout the algal basin and the filter feeder and culture species areas.

Phytoplankton in the algal basin (95% of the PAS area) use inorganic fish metabolic wastes (nutrients) to sustain high primary productivity levels. Feeding rates and carrying capacity of the PAS is about 3-5 times that of conventional channel catfish (Ictalurus punctatus) culture ponds as a result of sustained high phytoplankton productivity. Filter-feeding organisms, by harvesting phytoplankton, reduce cell age and stabilize a standing crop of faster growing phytoplankton cells at reduced respiration rates and increased oxygen production per unit volume (Brune et al. 2004).

Several filter-feeding species including Nile tilapia (Oreochromis niloticus), silver carp (Hypophthalmichthys moltrix), and the native freshwater mussel (Elliptio complanata) have been used in PAS production trials. Each species has attributes and drawbacks in their use in a PAS production model. For example, both Nile tilapia and silver carp effectively control cyanobacteria in PAS waters (Turker et al. 2003b, Mueller et al. 2004); however, both are also non-native species which may be either prohibited by law or require time-consuming use permits and expensive precautions for use in aquaculture. Nile tilapia, a tropical and a thermophilic species, filtration rates in a cool-water regime (17-23 C) were significantly lower than in the 26-32 C warm-water regime (Turker et al. 2003c). Tilapias cease feeding below 16 C and mortality occurs below 13 C (Chervenski 1982, Ross 1999). A catfish feed-rate protocol used in PAS production trials, based on Q_{10}, provided for feeding to continue at water temperatures below 10 C (Elvidge 1998). Although silver carp survives and may filter at temperatures lower than tilapia, we were reluctant to use silver carp because of permitting and supply difficulties and the dangers associated with an escaped over-wintering species. Elliptio complanata also filtered phytoplankton from PAS waters at water temperatures lower than Nile tilapia (Stuart et al. 1999). Use of a native filter feeding organisms such as freshwater mussels would avoid many of the potential problems associated with the use of either tilapia or silver carp in the PAS.

Nile tilapia, silver carp and E. complanata filtration rates increase with increasing particulate organic carbon (POC) levels in PAS water (Stuart et al. 2001, Turker et al. 2003a, b). Within a restricted water temperature range (26-30 C), Nile tilapia and silver carp filtration rates both reach asymptotic maxima at POC levels which are different for green-algal and cyanobacterial dominated PAS waters (Turker et al. 2003b). At a lower temperature range (23-27 C), E. complanata filtration rate also increases to a maximum in green-algal dominated water with increasing POC; however, a maximum filtration rate was not achieved by Stuart et al. 2001 in the experiment using cyanobacterial-dominated PAS water.

Since the classic papers of Walz (1978) and Winter (1978) we have known that bivalve filtration was a function of phytoplankton (seston) concentration and water temperature. Very few studies have investigated bivalve filtration rates simultaneously over a range of water temperatures and phytoplankton concentrations. One of these was Lui's (1985) study of the freshwater pearl mussel (Anodonta woodiana) where filtration rate increased with suspension concentration and peaked at an intermediate water temperature.

Unfortunately only three water temperatures and an inorganic suspension concentration were tested. The purpose of this study was to determine E. complanata filtration rates over a range of POC levels and water temperatures that may be encountered during a typical catfish production schedule in the PAS. Filtration rate, which is sometimes referred to as uptake rate, in this study is defined as the POC mass removed from the water column per unit of mussel mass per time.

Materials and Methods

Filter-feeding experiments were conducted using algal-rich water from PAS units at Calhoun Field Station, Clemson University, SC, USA. Mussels collected from Big Garvin Creek, SC, were held in PAS culture units between filtration rate experiments. Test mussels were stocked at the same biomass (1.22 kg wet tissue weight per tank) in eight 127-L continuous stirred tank reactors (CSTR) while a ninth CSTR without mussels was used as a control. The tissue biomass of E. complanata was estimated from the relationship: tissue wet weight (g) = 1.8806 + 0.2626 whole animal weight (g); r^2=0.94; n=110 (Starkey 1999).

Each CSTR received PAS water for 24 h before the addition of mussels. Individual timers and solenoid valves provided an intermittent addition of water at 0.07, 0.1, 0.2, 0.6, 1.0, 1.5, 2.0, 2.5, and 3.0 L min^{-1} to CSTRs for 72-h experimental periods. Water was discharged through a standpipe and an airstone helped maintain a mixed water column. Mussels were held off the bottom (approx. 8 cm) by screening to avoid suspension of feces and pseudofeces. After each experiment mussels were returned to the PAS, and the CSTRs and water delivery pipes were thoroughly cleaned.

Water temperatures were recorded at 2-4 h intervals from 0700 to 2300 h during the 72-h experimental periods. Dissolved oxygen, pH and nitrite-nitrogen were measured once every 24 h during the experiments. Dissolved oxygen and temperature values were measured with an YSI polargraphic oxygen meter (model 58, YSI Inc. Yellow Springs, OH). Nitrite-nitrogen was measured using a spectrophotometer (APHA 1989) and pH values with a Hach kit (model FF-1A, HACH Company, Loveland, CO).

A water sample taken from a representative CSTR before stocking mussels was centrifuged at 15,000 rpm for 15 min and decanted. The pellet representing the suspended matter was then resuspended in a known volume of water. Aliquots (n=5) of the sample were rediluted and the particulate organic carbon (POC) levels were determined with a Rosemount Dohrman total organic carbon analyzer (model DC-190, Rosemount Dohrman, Cincinnati, OH). Optical transmission values of each aliquot were determined at 750 nm with the spectrophotometer (APHA 1989). A standard curve of aliquot POC and transmittance for each experiment was determined by regression analysis. The coefficient of determination (r^2) for these linear regression models (n=13) ranged from 0.93 to 0.97. Water samples for subsequent POC values were taken at timed intervals from the incoming and outgoing (mussel filtered) water. The POC values for these samples were determined from the initial sample transmittance values using the specific standard curve for each filter-feeding experiment. The net change between the incoming and the outgoing water in the control (CSTR without mussels) represented incidental settlement and was used to correct filtration rates for each experiment. Filtration rates used in the analysis were restricted to those samples after the incoming water replaced twice the volume of CSTR. Mussel filtration rate (FR as mg POC kg wet tissue^{-1} h^{-1}) was calculated as:

$$FR = (POC_i - POC_o) \times \text{flow rate/mussel biomass}$$

where POC_i is the suspended particulate organic carbon in incoming water (mg POC L^{-1}), POC_o is the suspended particulate carbon in outgoing water, flow rate is L min^{-1} and mussel biomass is kg wet tissue.

Algal cells in water samples from PAS units were counted and if the number of green-algal cells exceeded 60% of total cell abundance in duplicate hemocytometer counts, the water was classified as green-algal dominated for the experiments. Filter experiments using water dominated by green algae were replicated over a range of ambient water temperatures from May to January. Controlled flow rates and mussel filtering activity provided a set of POC concentrations for the experimental temperature range.

Analysis of variance (ANOVA) using the general linear model was used to detect differences in water quality values between incoming and outgoing water from the control (CSTR without mussels). Multiple regressions were run to obtain a response of the mussels (i.e., filtration rate) to water temperature and

POC levels. The alpha level was set at 0.05 and SAS was used for statistical procedures.

RESULTS

Water quality parameters were similar among the 13 experimental trials. Mean (range) dissolved oxygen, pH and nitrite-nitrogen were 7.55 mg L^{-1} (5.2-10.9), 7.8 (6.5-8.5) and 0.07 mg L^{-1} (0.01-0.35), respectively. *Scenedesmus, Ankistrodesmus* and *Planktospheria* were the most abundant taxa in the green-algal experimental water. Pennate diatoms were observed in each of the experimental waters whereas the cyannobacteria, Microcystis and Merismopedia, were observed in three of the experimental trials and in only limited numbers.

Mean (±SE) POC levels of the incoming and outgoing water in the control CSTR (without mussels) were 18.53 ± 0.34 mg POC L^{-1} and 17.01 ± 0.32 mg POC L^{-1}, respectively. The difference between incoming and outgoing water POC concentrations in the control was not significant, indicating phytoplankton suspensions were not affected by sedimentation or wall attachment.

Filtration estimates (n=1046), 42 outliers removed when mussels experienced unusual conditions (e.g., algal bloom crash), are plotted in Figure 1a. High POC levels (> 20 mg POC L^{-1}) were not experienced at low water temperatures (<15 C) in the PAS and because of water delivery system limitations at low flow rates (< 0.07 L min^{-1}), POC levels < 10 mg POC L^{-1} were not observed at high water temperatures. The highest individual filtration rates were observed at 26-28 C and 25-32 mg POC L^{-1}, and the lowest individual filtration rates were at 10 C and 7-10 mg POC L^{-1}.

Figure 1b represents the mussel's predicted filtration rate (PFR) in water temperatures from 7 to 32 C and POC levels from1 to 32 mg POC L^{-1}. The response surface relationship is:

$$PFR = 160.36 - 33.27T + 2.57T^2 - 0.06T^3 + 0.02T * POC^2;\ r^2 = 0.69.$$

Water temperature was the most important variable explaining the response surface. The rate of change in the mussel filtration rate in response to increased POC concentration was slower at low water temperatures (e.g., <15 C) than at water temperatures > 20 C. Predicted maximum filtration rates occurred at progressively higher water temperatures with increased POC concentrations. Within the range of experimental conditions experienced, the predicted maximum filtration rate of 510 mg POC kg^{-1} wet tissue h^{-1} was at 26 C and 32 mg POC L^{-1}, and the predicted minimum filtration rate was 25 mg POC kg^{-1} wet tissue h^{-1} at 10.5 C and 1 mg POC L^{-1}. The predicted filtration rates at low water temperature/high POC levels and high temperature/low POC need to be viewed with some caution because of the limited data in these sections of the response surface.

Discussion

Several factors in the water column influence filtration rates in freshwater mussels including water temperature and phytoplankton (particle) size, composition, and concentration (Wagner 1976, Walz 1978, Lui 1985, Sprung and

Rose 1988, Helfrich et al. 1995, Vanderploegetal et al. 1995, Lei et al. 1996). The test water phytoplankton was dominated by Scenedesmus and Ankistrodesmus, both within the size range of phytoplankton effectively filtered by E. complanata (Paterson 1986, Stuart et al. 2001). Over a limited temperature range (23-27 C), E. complanata filtration rate increased to 511 mg POC kg^{-1} wet tissue h^{-1} as POC levels increased from 10 to 28 mg POC L^{-1}(Stuart et al. 2001). Similar increases in filtration rate, defined as the mass of phytoplankton (seston) removed from the water column per time, have been observed in other freshwater bivalves (Walz 1978, Lui 1985, Hornbach et al. 1984, Sprung and Rose 1988, Lei et al. 1996). In these cases, the bivalves responded to increased phytoplankton concentration by increasing pumping rate the volume of water filtered (e.g., ml h^{-1}) up to a concentration with further phytoplankton increases resulting in a decrease in the volume of water filtered and the eventual stabilization of filtration rate (e.g., Lei et al.1996). A reduction in the volume of water filtered at high phytoplankton concentrations would represent an energy-saving measure for the same food reward per unit of energy expended. Although the regulatory mechanism was not determined, it is clear that E. complanata filtration rate responded to the quantity of POC in the PAS water.

Temperature influences physiological activity and consequently, also the filtration rate of freshwater mussels. Filtration and pumping rates of freshwater mussels have been observed to increase with increasing temperature to a maximum, and with further temperature increases a decrease in these rates (Wagner 1976, Lui 1985, Lei et al. 1996). Elliptio complanata exhibited the same pattern of increasing filtration rate to a peak followed with a decrease in filtration rate as temperature increased from 7 to 32 C. Filtration rates estimated over a range of ambient water temperatures should represent more accurately the temperature optimum for E. complanata filtration than data collected from mussels acclimated to different laboratory temperatures (e.g., Wagner 1976).

Water temperature and POC concentration variables interacted to influence filtration rate of E. complanata. The rate E. complanata increased filtration with POC concentration levels was faster at water temperatures near the optimum than under suboptimum temperatures, including low and high water temperatures. Conversely, as the POC levels increased, maximum filtration rates occurred at progressively higher water temperatures. A model to describe E. complanata filtration rate responses to the prevailing PAS water conditions would require both temperature and POC concentration data.

Rarely do high POC levels occur at low water temperatures or low POC levels occur at high temperatures in PAS waters during a production season (Brune et al. 2004). However unexpected low POC concentrations (20 mg POC L^{-1}) were observed at high water temperatures (25 C) in the PAS unit following a sharp decrease in the algal standing crop biomass during the week of June 12, 2000 (e.g., water temperature and POC that were 28 C and 32 mg POC L^{-1} before the decrease were 25 C and 20 mg POC L^{-1} after). The predicted filtration rate of *E. complanata* was 500 mg POC kg^{-1} wet tissue h^{-1} prior to the decrease in POC and more than doubles the 197 mg POC kg^{-1} wet tissue h^{-1} expected after the POC decrease.

Freshwater mussels offer an alternative to the use of tilapia as a filter feeder in culture operations. Mussels operate over a wider range of temperatures than tilapia, over winter in culture ponds and avoid the expense of a wintering tilapia facility. Both green algae and cyanobacteria are filtered by mussels but not at the same rates reported for tilapia and silver carp (Stuart et al. 2001, Turker et al. 2003a, b). Mussels however appear more effective with the smaller-sized phytoplankton taxa than either tilapia or silver carp and should provide a nice compliment to the filtering capabilities of either of these fish taxa.

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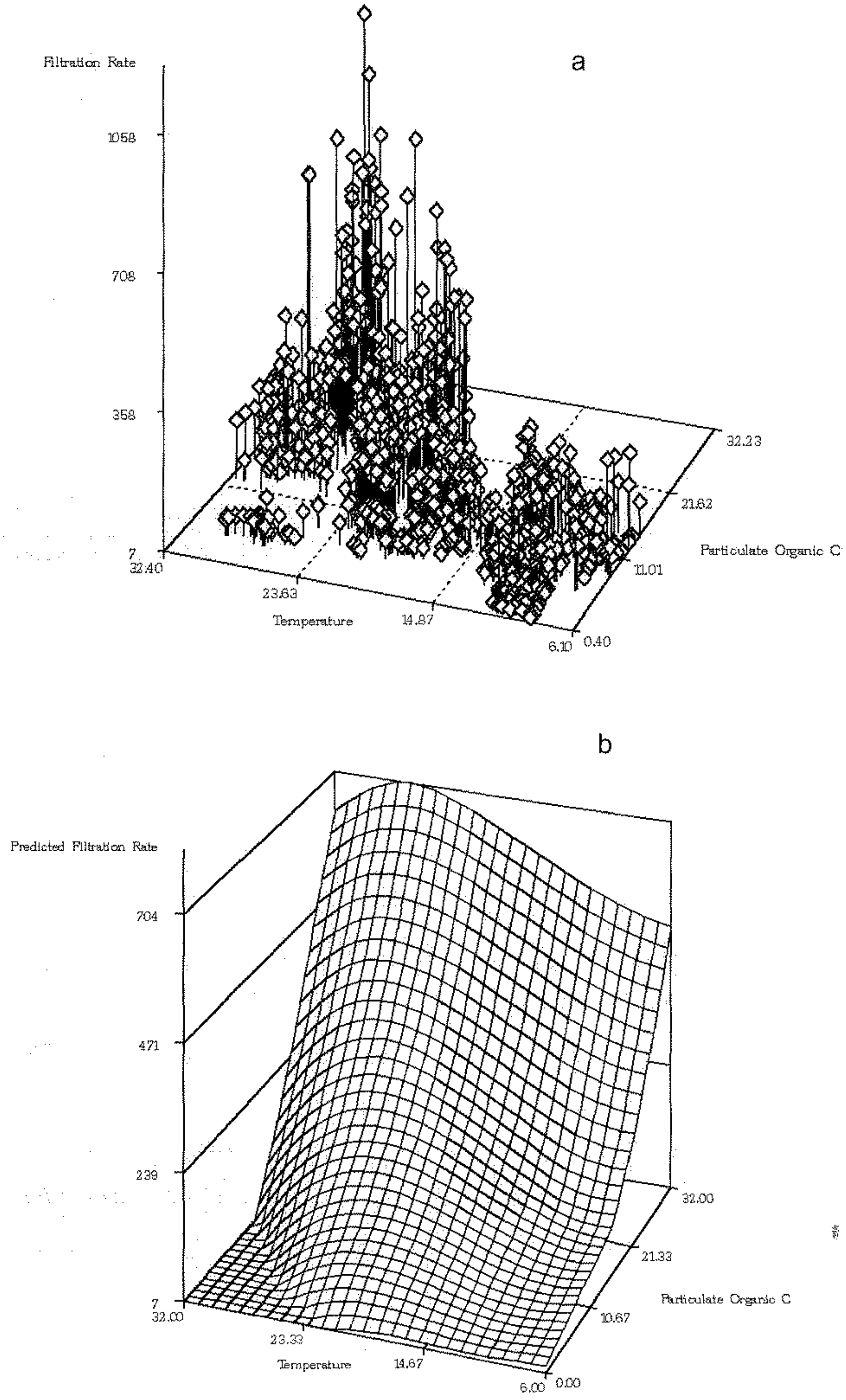
List of Figures

Figure 1. Filtration rate of Elliptio complanata in terms of mg POC kg^{-1} wet tissue h^{-1} versus temperature (T, C) and suspended particulate organic carbon (POC, mg POC L^{-1}) from 7 to 32 C and 1 to 32 mg POC L^{-1}. The upper panel (a) represents the individual observations (n=1046) and the lower panel (b) is the response surface described by the predicted filtration rate (PFR) equation: $PFR = 160.36 - 33.27T + 2.57\,T^2 - 0.07\,T^3 + 0.02T*POC^2$.


a
Filtration Rate
1058
708
358
7
32.40
23.63
Temperature
14.87
6.10
0.40
11.01
21.62
32.23
Particulate Organic C
b
Predicted Filtration Rate
704
471
239
7
32.00
23.33
Temperature
14.67
6.00
0.00
10.67
21.33
32.00
Particulate Organic C