EFFECT OF ALGAL CONCENTRATION, SALINITY AND BODY SIZE ON FILTRATION AND INGESTION RATES OF A FEW CULTIVABLE INDIAN BIVALVES

Dissertation submitted by

RAJESH K.V.

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Central Marine Fisheries Research Institute
Cochin - 682 014.

Dedicated to

My beloved Parents,
brother and Roshi

CONTENTS

CERTIFICATE

Certified that the dissertation entitled ***"Effect of algal concentration, salinity and body size on filtration and ingestion rates of a few cultivable Indian bivalves"***, is a bonafide record of work done by **Mr. Rajesh K.V.** under our guidance at the Central Marine Fisheries Research Institute during the tenure of his M.F.Sc. (Mariculture) programme (1996-98) and that it has not previously formed the basis for the award of any other degree, diploma or other similar titles or for any publication.

Dr. K. Sunilkumar Mohamed,
Scientist (Sr. Scale),
CMFRI, Cochin,
Major Advisor, Advisory Committee.

Mrs. V. Kripa
Scientist (Sr. Scale),
CMFRI, Cochin,
Member, Advisory committee.

Shri. P.E. Sampson Manickam
Senior Scientist and Officer-in-Charge,
FHL of CMFRI, Thoppumpady,
Member, Advisory committee.

Declaration

I hereby declare that this thesis entitled ***"Effect of algal concentration, salinity and body size on filtration and ingestion rates of a few cultivable Indian bivalves"*** is based on my own research work and has not previously formed the basis for the award of any degree, diploma, associateship, fellowship or other similar titles or recognition.

Cochin - 682 014

RAJESH K.V.

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सारांश

प्रयोगशाला परिस्थितियों में भारतीय द्विकपाटियों की प्रमुख चार जातियों जैसे हरित शंखु पेरना विरिडिस, खाद्य शुक्ति कोसोस्ट्रिआ माड्रासेन्सिस, काली सीपी जेलोइना बंगालेन्सिस और वेनेरिड शोर्टनेक सीपी पैफिआ मलबारिक के निस्यंदन और अशन दर पर शैवाल सांद्रता, लवणता और शरीर के आकार के प्रभाव का अनुसंधान किया गया । यह अध्ययन परोक्षविधि द्वारा किया गया जिसमें प्रति एकक समय के परीक्षण माध्यम की कण सांद्रता की घटती के अनुसार निस्यंदन दर (।. एच, एनिमल $^{-1}$) और अंतर्ग्रहण दर (सेलस.एच$^{-1}$.एनिमल $^{-1}$) का आकलन किया जाता है ।

परीक्षण के विलयनों में 3 × 10^4 से 5 × 10^5 तक सांद्रता परास के साफ़ एककोशिक शैवाल आइसोक्रोइसिस गालबाना का. उपयोग किया गया, सीपी जी.बंगालेन्सिस में अधिकतम निस्यंदन दर देखने पाया । विभिन्न जाति सीपियों को निस्यंदन क्षमता उच्च से निम्न जेलोइना कोसोस्ट्रिआ > पेरना > पेफिआ >के क्रम में है । शैवाल सांद्रता बढ़ जाने पर निस्यंइदन दर में चलती फिरती वृद्धि होकर 10^5 कोश एम एल^1 के सीमांत सर तक पहूँच गई, फिर भी इस साद्रंता में सभी जातियों में कूटविष्ट (स्पूडोफीक्स) (शैवालों युक्त विसर्ज्य) कर उत्पादन दिखाया पडा । प्रति द्विकपाटी द्वारा अंतग्रहित शैवाल कोशों की मात्रा और शैवाल कोशों की सांद्रता में सीधा अनुपात दिखाया पडा । परीक्षण की गई द्विकपाटियों में निस्यंदन दर शरीर के आकार के आनुपातिक देखी गई । परीक्षित जाति में साधारण परिवेश लवणता में अधित्मि निस्यंदन दर और अंतर्ग्रहण दर आंकलित किया गया ।

द्विकपाटियों को विभिन्न परीक्षणों के लिए प्रयोगशाला में रसे जाने के लिए इन अध्ययनों का परिणाम सहायक निकलेगा । इसके अतिरिक्त एकीकृत पालन व्यवस्था में विशेषता:मछली / झींगा तालों में शैवालों की बढ़ती रोकने केलिए द्विकपाटियों का पालन बडी मात्रा में किया जाता है ।

Preface

1. PREFACE

Farming of mussels, oysters and clams has been developed along empirical lines, very often based exclusively on practical experience. A better understanding, however, of the complex interactions of the biotic and abiotic environmental parameters on growth of these molluscs and a more specific interpretation of the results obtained in the field, can be achieved only by laboratory experiments where all the experimental conditions are precisely defined and kept constant as much as possible. By a precisely defined change of one of these experimental conditions, it is possible to find out how an animal is affected by this specific change of its environment.

For successful aquaculture and laboratory rearing of aquatic organisms it is of great importance to know the optimal conditions necessary for the candidate species. The present work is aimed at studying the filtration rate and ingestion rate of four commercially important bivalve species available along Indian coast and its variation with differing algal concentration, salinity and body size. The bivalve species used were Green mussel (*Perna viridis*), Edible oyster (*Crassostrea madrasensis*), short neck clam (*Paphia malabarica*), and corbiculid black clam (*Geloina bengalensis*). The present study employed indirect method for finding out the filtration rate and ingestion rate using the

microalga Isochrysis galbana. The findings may have significant impacts on understanding optimum conditions for laboratory rearing of these bivalve species as well as in various aspects of aquaculture practices like integrated farming, biofilters, etc.

Scope of the Study

The data from the present study can be made use of in integrating a bivalve aquaculture system, designed to take advantage of excessive phytoplankton production with an intensive fish aquaculture system (on a pilot scale). Farmer is benefitted in two ways from this integrated approach. In addition to providing a commercial product from otherwise unutilized biomass, the bivalve culture system functions as a biological filter to remove excessive and dangerous levels of phytoplankton from the fish pond water. Further more, sufficiently reduced phytoplankton levels allow a 50% reduction in fresh seawater input to the fish ponds. A reduction in phytoplankton levels would preclude oxygen supersaturation and elevated pH levels. This would reduce fish mortalities, allow economical production of an additional commercial product, and reduce nutrient load in the run-off water.

Use of bivalves as filters in bio-ponds and effluent treatment ponds of shrimp farms and fish farms.

The present work aimed at determining the filtration rate & ingestion rate according to animal size, food concentration and salinity is important for understanding the optimum food concentrations required in bivalve cultures under laboratory conditions.

As the molluscan aquaculture is gaining rapid momentum nowadays, the introduction of new artificial diets can also be expected in the near future. An understanding of the filtration rate & ingestion rate in accordance with algal cell concentration, salinity, algal cell size, size of the animal, etc. is especially important in determining the optimum characteristics like size, density, surface properties, etc. of particles used in artificial diets. eg. spray dried phytoplankton microcapsules, enriched yeast cells, micro bound feeds, microencapsulated diets, etc.

The combined production of pseudofaeces and faeces (material that is ingested but cannot be absorbed or metabolically utilized), is referred to as the biodeposition rate. Bivalve biodeposits represent an important source of water fouling and can have a major impact on the environment in large scale culture systems. (Tenore, *et al*, 1982).

Fouling by biodeposits is expected to be more significant for mussels and oysters than for some of the clam species. The exponental increase in biodeposition rates

of bivalves with increasing algal concentrations primarily reflects increasing pseudofaeces production. The present work provides a good understanding about the maximum and threshold algal density for each species at which no pseudofaeces are produced, eventhough it varies with the algal species used. The information may help to prevent the indiscriminate use of algal cultures and thereby deterioration of water quality in the laboratory culture environment.

Introduction

2. INTRODUCTION

Molluscs are one of the very few invertebrate groups with representatives that have widespread commercial mariculture potential. Bivalves in particular lend themselves well to the myriad of habitats and broad environmental ranges.

In India, a consistent number of bivalves support commercial and subsistence fisheries. In response to declining natural populations, much attention has been paid towards the aquaculture of these important bivalve species in recent years. Clams, mussels and oysters are most important among them.

Filtration Mechanism of Bivalves

Bivalves are predominanlty siphonate, microphagous, ciliary suspension feeders, which process large volumes of the surrounding water in order to meet their food requirements. Water currents are produced by ciliary action along the surface of the gills or ctenidia, which serve both respiratory and feeding functions. Particles are retained by the gill and transferred by ciliary action to the labial palps and then to the mouth. The rate at which food is filtered from suspension is determined by :

(a) The rate of water transport through the gills (pumping or ventillation rate) and (b) the efficiency with which the particles are retained by the gill (Retention efficiency).

Efficiency of Particle Retention

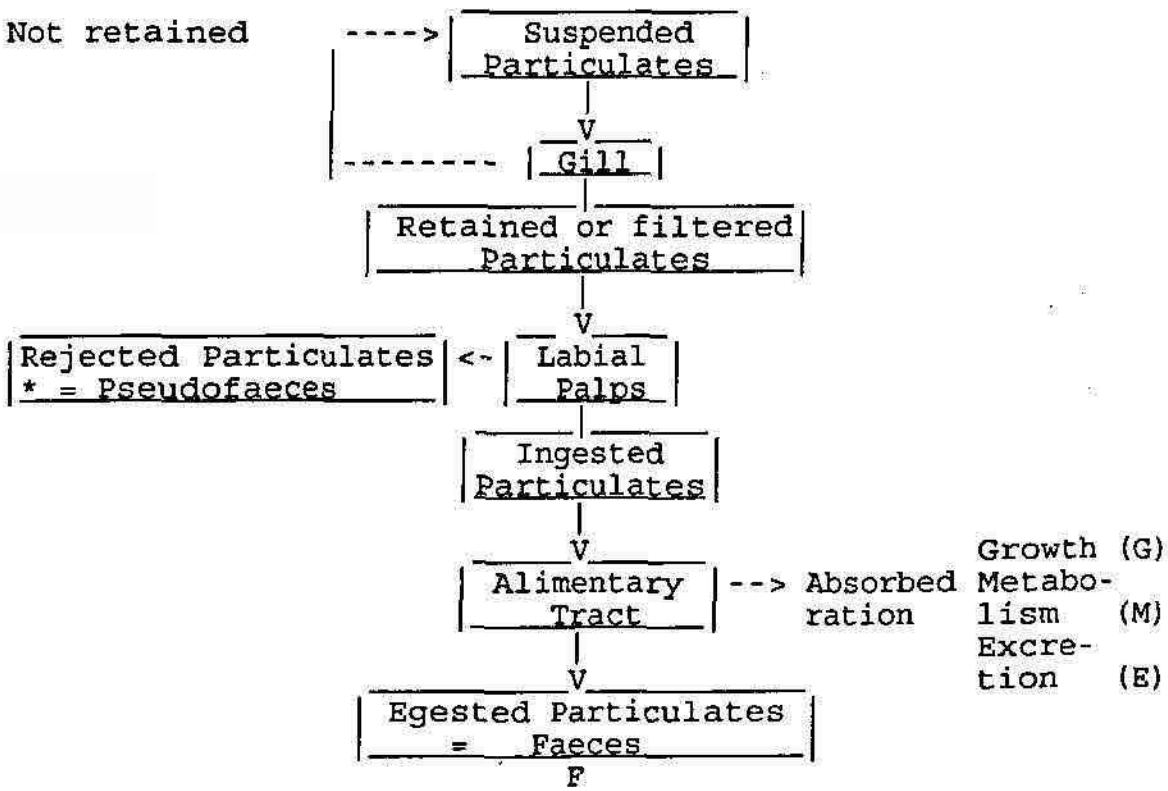
Mohlenberg and Riisgard (1978) showed that bivalve species, retained particles above 4 μ with 100% retention efficiency. The decline in retention efficiency with reduction in particle size is non linear. The effect of particle concentration on retention efficiency remains controversial. Hildreth and Mallet (1980) showed that retention efficiency of 5 μm diatoms by *M. edulis* remained constant over a wide range of particle concentrations. On the other hand, Palmer and Williams (1980) found that retention efficiency of *C. virginica* and *Argopecten irradians* increased in response to total seston concentration.

Particle Selection by Bivalves

Not all materials retained by the gill is necessarily transferred to the mouth for ingestion. Above a threshold particle concentration, an increasing proportion of material retained by the gill is rejected at the labial palps, bound in mucous, and eliminated as 'Pseudofaeces' through the exhalent siphon. However, particle

concentrations in coastal waters generally lie well above the threshold concentration of pseudofaeces production. Under culture conditions, the maximum algal density at which no pseudofaeces are produced varies with the bivalve and algal species used, as well as with algal cell volume.

Particle selection is a potentially advantageous mechanism which allows bivalves to concentrate the more nutritious particles from mixed, natural suspensions. The pathways of transfer of particulate matter throwing the complex feeding apparatus of a typical suspension feeding bivalve are shown in figure.



* Pseudofaeces are only produced above a threshold concentration of particulates.

In determining the feeding activity of bivalves, it is important to distinguish between the clearance rate (= filtration rate) and the pumping (= ventillation) rate.

Clearance rate is defined as the volume of water filtered completely free of particles per unit time, while pumping rate is the volume of water flowing through the gills per unit time. When all suspended particles are removed by the gill with 100% retention efficiency, clearance rate is the same as the pumping rate. The ingestion rate is also a critical parameter in assessing the organism's water flow requirements in flow-through aquaculture systems. The number or biomass of shell fish held in a system, or alternatively, the flow rate can be adjusted in order to achieve a desired reduction in food concentration, using the equation : (Hildreth & Crisp 1976).

Clearance Rate = $[(C_1 - C_0) \times C_0] \times$ Flow rate (l/h)

CR (l/h)

Where C_1 and C_0 are the inflow and outflow concentration respectively.

The pumping rate is generally determined by : (a) direct method, ie, measurement of water volumes by isolating the exhalent stream (Hildreth, 1976), or measurement of flow velocities in the inhalant or exhalent streams using thermistor flowmeter probes (Brand & Taylor,

1994), or (b) Indirect methods in which the rate of removal (clearance rate) of particles from a suspension is measured, and particles are assumed to be retained with 100% efficiency (Walne, 1972).

Filtration rate and Body size

The filtration rate of bivalves increases with increasing body weight or shell length.

An increase in the clearance rate of bivalves with increasing flow rates was reported by Walne, (1992). This positive correlation was ascribed to recirculation of exhalent water caused by inadequate geometry of the experimental chamber and / or low flow rates used in measuring clearance rates (Hildreth and Crisp, 1976, Mohlenberg and Riisgard, 1979). It was found that filtration rate becomes independent of flow rate above a critical flow rate, above which recirculation is negligible.

Filtration rate in relation to Food concentration

Bivalves are capable of regulating the amount of particulates ingested by reducing their pumping rates and/or by increasing the amount of material rejected in Pseudofaeces. (Foster-Smith, 1975). Clearance rates may also vary considerably with the quality of the diets provided.

Interspecies comparison of Filtration rate

Reliable interspecies comparison are difficult to make, since published values are obtained with different experimental methods, with animals varying widely in size, and at different temperatures, food concentrations and particle types. The wide range in values, even when temperature and body size have been accounted for, probably reflects differences in experimental conditions, as much as interspecies differences. Several authors have suggested that epifaunal, siphonate bivalves, eg. scallops, oysters and mussels have higher filtration rates, when adjusted for tissue weight differences, than infaunal, non-siphonate species, eg. clams (Allen, 1962; Jorgensen, 1966; Winter, 1969).

Filter feeding Mechanism

In the lamellibranchiate bivalves, the gills represent the main food collecting organs. They are well equipped to create a current of water (lateral cilia) and to collect (eu-latero-frontal cirri) and to transport (frontal cilia) particulate material. The frontal cilia transport the collected particles, bound in mucous strings to the marginal grooves, the ciliary tracts of which in turn carry the retained particles via the palps to the mouth. Various mechanisms have been developed in suspension-feeding

bivalves to regulate the efficiency of particle retention, and pumping rate. It is quite obvious that various bivalves have the ability for local and independent control of both pumping and particle retention efficiency. There exists an inverse relationship between pumping activity and retention efficiency. With an increase in pumping activity there was a decrease in retention efficiency and vice versa.

Selection of Particles

It has been generally supposed that bivalves have the ability to select particles for ingestion by the activity of the gills and palps. Winter, (1992) feeding *M. edulis* with suspensions of unicellular algal cells and ferric hydroxide, pointed out that at low concentrations no pseudofaeces were produced.

There is every reason to think that the triumph of future aquaculture of these cultivable bivalves in par with technological developments shall largely depend on a sound understanding of all aspects of filtration & ingestion activities. However, information is relatively less in this regard compared to those available for other cultured animals.

Review of Literature

3. REVIEW OF LITERATURE

The determination of filtration and ingestion rates according to animal size, food concentration and salinity is important for efficient mariculture production of bivalves in controlled environments. Although there is considerable information concerning the filtration and pumping rates of bivalves, there is little consensus regarding rates of ingestion.

Many experiments have been made to determine the rate of water transport through the gills without influencing the animal by the experimental conditions. The rate of water propulsion in several bivalves were studied in the past using direct and indirect methods. The advantages and disadvantages of these two methods have been discussed in detail by Winter (1978) and Hildreth (1976).

One of the main disadvantages of the indirect method is the continuously changing food concentration in the experimental medium. Further more, the theoretical basis of the equation for the calculation of filtration rates using the indirect method are based on the assumptions that

(a) the animal's pumping rate is constant and that

(b) a constant percentage of particles is retained throughout the experiment (Coughlan, 1969). With

the help of indirect method using a volume of suspension, Coughlan (1969) described a graphical method by which the filtering rate can be obtained directly from the ratio between the initial and final concentration of suspensions.

General Review

Ali (1970) studied the rate of filtering *Phaeodactylum tricornutum* and *Isochrysis galbana* in *Hiatella artica* by the indirect suspension depletion method which was monitored by optical density measurements. The importance of using low cell concentrations and of eliminating any inhibitory metabolic products when measuring filtration rates of bivalves is stressed. The filtration rate of *Mytilus edulis* was measured in a flowing system by estimating the particulate matter concentrations at the inflow (C_1) and outflow (C_2) of the experimental chamber and immediately surrounding the bivalve (C_0). The formula used was

Filtration rate, $RF = F\ (C_1-C_2)\ /\ C_0$

where, F is the flow rate. [Hildreth and Crisp, 1976]

Riisgard (1977) measured the filtration rates of suspension feeding bivalves particularly *Mytilus edulis* in a flow system by estimating the concentrations of yeast cells entering (C_1) and leaving (C_2) the troughs. He calculated

the clearance rate (Y) as a function of flow rate (F) using the equation, $Y = F \times (1-c_2/C_1)$.

Winter (1978) reviewed the suspension-feeding in lamellibranchiate bivalves, with reference to artificial aquaculture systems. The principles of the mechanism of filter feeding in suspension feeding bivalves are described with particular reference to food selection, particle retention efficiency, formation of pseudofaeces and food concentration. Laboratory experiments on the filter feeding activity carried out in relation to body size, temperature, and food concentration are summarized. Relations existing between body size and filtration rate, pumping rate, oxygen consumption and gill area are expressed as functions of dry tissue weight. Mohlenberg and Riisgard (1979) determined the filtration rate in 13 species of suspension feeding bivalves using a new indirect technique. Concentrations of particulate matter in the water collected in inhalant and exhalent currents were estimated with an electronic particle counter. Further, Riisgard and Mohlenberg (1979) used an improved automatic recording apparatus for determining the filtration rates of *Mytilus edulis* as a function of size and algal concentration. The concentration of algae in the experimental medium is kept constant throughout each experiment by addition of *Phaeodactylum tricornutum* from a chemostat.

Shumway *et al.* (1985) studied the particle selection, ingestion and absorption in the filter feeding bivalves. Measurements were made of the clearance rate of six bivalve species. Use of flow cytometry allowed estimation not only of the clearance rate of individual cell types, but also of their proportional occurrence in the pseudofaeces and faeces.

More recently, a new technique was described for observing the structure and mechanism of filtration feeding in bivalves using Endoscopic examination and Video Image Analysis. (Ward, *et al.*, 1991).

Feeding, particle selection and absorption of micro alga *Tetraselmis* Sp. in cockle *Cerastoderma edule* were studied by Iglesias, *et al.* (1992). Cockles were exposed to food suspensions consisting of mixtures of sediment and *Tetraselmis* Sp. particles were maintained in suspension by aeration and stirring and their packed volume concentration frequently monitored with a Coulter multisizer with a 50 μ aperture tube.

Filtering activity and filtration rate were determined in infaunal estuarine bivalve *Solen cylindracens*. The animals were subjected to a variety of natural seston concentration (5-500 mg/l). Filtration rates were determined using a flow system and Coulter counter. (De Villers and

Hoogson; 1993). Very recently, a direct method of measuring the filtration volume in the Pearl-Oyster, *Pinctada fucata* has been developed. (Yamamoto, *et al.*, 1996). The system measured continuously and directly the filtration volume with an Electromagnetic flow meter, and the dissolved oxygen concentration of the expired water from the pallial cavity with the oxygen content analyser.

Filtration and Ingestion Studies on Mussels

Filter feeding activity is a function of cell concentration which has been well documented by several authors for different species of lamellibranchiate bivalves.

Winter (1973) showed that *Mytilus edulis* regulates the filtration rate within the range 10 x 10^6 to 40 x 10^6 *Dunaliella marina* cells/l, in such a way that the amount of algae filtered out is more or less constant (as an average over a period of 5 days). Examples concerning the relationship between filtration rate and algal cell concentration have been summarized and discussed by Winter (1977). This summary includes the investigations carried out by Ali (1970) Walne (1972) and Foster-Smith (1975).

A number of experiments have been done in mussels on this aspect, mainly in *Mytilus edulis*. Tenore and Dunstan (1973) compared, feeding and biodeposition of *Mytilus edulis* with that of other two bivalves using flowing system. At all

levels of food concentration, the order of increasing filtering rate was Clam < Oyster < mussel. The effect of concentration of suspension on the filtration rates and pseudofaecal production was studied for *Mytilus edulis* by Foster-Smith (1975). The rates of ingestion of particles at any one concentration was roughly proportional to the size of the particles with the exception of *Isochrysis* Sp. and *Platymonas* Sp. which were ingested in smaller amounts than accounted for by their size alone.

Schuttle, E.H. (1975) studied the influence of algal concentration and temperature on the filtration rate of *Mytilus edulis* using the alga, *Platymonas suecica* in concentrations ranging from 3×10^5 to 1.5×10^8 cells/l. The rate of filtration (ml/h/mussel) generally decreased as cell concentrations increased and dropped to low values when concentrations above 5×10^7 cells / 1 were supplied.

The combined effects of body size, food concentration and season on the physiology of *Mytilus edulis* were studied by Widdows, J (1978). He found food assimilation efficiency and filtration rate declined exponentially with increasing food concentration and is dependent on body size at high food levels. Riisgard and Mohlenberg (1979) studied the filtration rate of *Mytilus edulis* as a function of size and algal concentration. They

found that within the range of a particular body size and algal concentration, filtration rate increased proportionally. Feeding and filtration activity in relation with seston concentration was studied by Widdows, *et al.*, (1979) in *Mytilus edulis*. According to them, pseudofaeces production was initiated at relatively low seston concentration.

Riisgard and Randlov (1981) showed that the filtration rate of *Mytilus edulis* is independent of algal concentration between about 1.5×10^3 to 30×10^3 *Phacodactylum tricornutum* cells / ml. The rate of filtration and feeding on six species of diatoms, by the green mussel *Perna viridis* was studied by Rajarethnam, *et al.* (1987). The number of cells removed per hour depended upon the size and suspension density of the diatom cultures. They found, rate of ingestion was enhanced when the suspension density and cell size were less.

Filtration rate and assimilation of *Mytilus edulis* at low temperatures were studied by Loo-lo (1992) with natural seston composition. Smaal and Twisk (1997) conducted experiments on filtration and absorption of *Phaeocystis globosa* by the mussel, *Mytilus edulis*. They found that filtration at reduced rate was not compensated by increased particle concentrations and no adaptive response to the diet was observed. Experiment on size dependent rejection of

large particles within pseudofaeces production by *Mytilus edulis* was conducted by Defossez and Hawkins (1997). They suggested that preferential size dependent rejection of larger particles could be of significant adaptive value in the natural environment.

Horgan and Mills (1997) studies the filtering activity of Zebra mussel (*Dreissena polymorpha*) using short term suspension depletion experiments. They found out that clearance rate depended upon mussel size, but filtering activity did not differ among shell length classes considerably.

Filtration and Ingestion studies on Oysters

The rate of filtration of four algal species from suspension by the oyster *Crassostrea virginica* was determined by Epifanio and Ewart (1977) and found out maximum ration for the oyster. They concluded that the filtration rate was dependent upon the density of algal suspension and large quantity of pseudofaeces were produced by oyster when algal density was more than 10 mg/ml.

The ingestion rates of oyster larvae (*Crassostrea virginica*) appeared to be most strongly regulated by food quantity and nutritional quality and not particle size or numerical abundance. [(Baldwin and Newell, 1995)].

Kim (1995) studied the filtering rate model of *Crassostrea gigas* with effect of water temperature and size. Absorptiometric determination of filtering rates with oysters being fed diatom (*Chaetoceros* Sp.) in a closed system were made. He concluded that filtering rate increased on exponential function with increasing temperature and size while not over a certain limit.

Studying the effect of flow speed on filtration and growth of oyster, *C. virginica* Leninhan, *et al.* (1996) made clear that filtration and growth increased with food concentrations and increased monotonically with flow velocity overall flows tested for both food concentrations.

Studying the potential impact of selective grazing by filter feeding bivalves, Bougrier, *et al.* (1997) observed that *Crassostrea gigas* preferentially filtered and rejected diatom species relative to flagellates and these differences appear to depend upon differences in algal shape and flexibility.

Barille; *et al.*, (1997) observed a positive effect of high natural seston concentration on the feed selection and absorption by the oyster *Crassostrea gigas*, but within a certain limit.

Filtration and Ingestion studies on clams

Filtration and ingestion studies on clams and cockles are relatively less in literature. But quite a few studies were made in *Mercenaria* Sp. *Meretrix* Sp, etc. Ali, (1970) studied the rate of filtering *Phaeodactylum tricornutum* and *Isochrysis galbana* by *Hiatella artica* using indirect suspension depletion method monitored by optical density measurement.

The rate of water propulsion in several lamelli-branch bivalves was studied including *Meretrix casta* using direct or indirect methods by Durve, (1963). The indirect method, involving the removal of particles by the filtering mechanism was adopted. $CaCO_3$, celloidal graphite and unicellular algae were used. Durve (1963) studied the filtering activity of *M. casta* in different sizes and also in different salinities.

Foster-Smith (1975) investigated the assimilation efficiency and rates of ingestion by *Venerupis pullastra* using *Phaeodactylum Sp.* The growth rate of Bay Scallop, *Argopecten irradians* was studied in relation to phytoplankton concentration and temperature. Results suggested that increased phytoplankton concentration brought about increased ingestion and growth rate (Smith and Barber (1974).

The ingestion of C^{14} labelled phytoplankton by *Solemnya velum*, a symbiont containing clam was compared to *Mya arenaria*, a suspension - feeding bivalve that is not associated with symbionts. (Krueger, *et al.*, 1992).

Riisgard, (1988) studied the feeding rates in hard clam, *Mercenaria mercenaria* larvae as a function of algal (*Isochrysis galbana*) concentration and found that a positive correlation exists between the rate of feeding and algal cell concentration. Bricelj and Malouf, (1984) showed the influence of algal and suspended sediment concentrations on the feeding physiology of the hard clam *Mercenaria mercenaria*.

Tenore and Dunstan, (1973) compared the feeding and biodeposition of *M. mercenaria* with other bivalves, using flowing systems and showed that both are affected by food concentration.

Changes in filtering and ingestion rates of adult Japanese Bay Scallop, *Pecten albicans* were examined by feeding four species of micro algae, (*Chaetoceros*, *Pavlova lutheri*, *Nannochloropsis* and *Tetraselmis*) at various concentrations by Semura (1995). He reported that filtering rate was high for *Chaetoceros* and low for *Nannochloropsis* and ingestion rates decreased with increasing algal concentration. The filtration and ingestion rates of *Tapes decussatus* were determined in relation to food concentration and clam dry tissue weight (Khalil, 1996). He found that

filtration rate and the weight specific filtration rate generally decreased with increased algal concentration for *Dunaliella* Sp. In another study to examine the size dependent rejection of large particles within pseudofaeces formation, Defossez and Hawkins, (1997) used *Ruditapes phillippinarum* and *T. decussates*. These were fed with particles of same shape, same density and the same chemical composition but varied in diameter (5 to 37 um).

Bivalves in Polyculture ponds

The goal of a commercial aquaculture enterprise is to produce the maximum amount of high quality product in a short time with minimum expense. Bivalves can be integrated to fish or shell fish culture systems not only to economically reduce the algal burden but as a commercial shell fish product also. Shpigel and Blaylock (1990) described the use of Pacific oyster, *Crassostrea gigas*, as a biological filter for a marine fish aquaculture pond. To take advantage of excess phytoplankton production, they integrated an oyster aquaculture system with an intensive fish aquaculture system. They reported that the oyster culture system functioned as a biological filter to remove excessive and dangerous levels of phytoplankton from the fish pond water.

It was after the scanning of all these peripheral and primary literature, the present study was undertaken.

Materials & Methods

4. MATERIALS AND METHODS

Experimental Animals

Green Mussel, (*Perna viridis*) and the Edible oyster (*Crassostrea madrasensis*) were collected from the CMFRI oyster farm site in the Ashthamudi Lake, Quilon. The Venerid clam, *Paphia malabarica* were taken from the natural bed existing in the same lake, whereas the corbiculid clam, *Geloina bengalensis* was procured from stocks maintained at FHL, Thoppumpady.

The Ashthamudi Lake is situated between lat. $8^{o}45'$ - 9^{o} 28' N and long. 76^{o} 28' - 77^{o} 17' E. It has a waterspread of 32 Km^2 and is connected to the Arabian Sea through a perennial opening, permitting an estuarine condition almost throughout the year. The Kallada river which joins at the north-eastern part is the source of freshwater to the lake. The depth ranged from 0.5 m to 3.5 m. The sediment was composed of coarse, medium and fine sand clay. Water temperature varied from $29^{o}C$ to $31.3^{o}C$ at the surface and from $28.6^{o}C$ to $31^{o}C$ at the bottom. Salinity range was 22-25‰ .

PLATE-I

EXPERIMENTAL SET-UP

PLATE - II

ALGAL CULTURE SET-UP

Two size groups were collected for all the four bivalve species,

	Size group (mm)	
	I	II
Perna viridis	64-67	100-105
Crassostrea madrasensis	65-70	100-105
Paphia malabarica	30-32	45-47
Geloina bengalensis	45-50	75-80

All the collected animals were kept for acclimatization for 2 weeks in the laboratory at a temperature of 30+ 1°C in 10 l plastic basins at a salinity of 32 ppt, with continuous air supply. The water was changed every second day and the animals were fed on axenic cultures of the micro alga, *Isochrysis galbana*.

Animals were selected for the experiment on their good external appearance, were cleared free of sand, mud and epizooic growth.

Culture of Micro Alga

The micro alga used for the present study was *Isochrysis galbana* (7 μ). The stock culture has been procured from Algal culture facility of FHL of CMFRI. Subcultures were made in 3 lit flasks using Walnes' medium for Algal culture.

PLATE-III Perna viridis

PLATE-IV Crassostrea madrasensis

PLATE-V Paphia malabarica

PLATE-VI Geloina bengalensis

Formula of Walne's Medium

Solution - A

$FeCl_3 \cdot 6 H_2O$	1.30 gm
$MnCl_2 \cdot 4 H_2O$	0.36 gm
H_3BO_3 (Boric Acid)	33.60 gm
EDTA (Na salt)	45.00 gm
$NaH_3PO_4 \cdot 2 H_2O$	20.00 gm
$NaNO_3$ or KNO_3	100.00 gm
Distilled water	1000 ml

Added 1 ml of solution-A per litre of sea water.

Solution - B

$ZnCl_2$	2.1 gm
$CoCl_2$ 6 H_2O	2.0 gm
(NH_4) Mo_7 O_{24} 4 H_2O	0.9 gm
$CuSO_4 \cdot 5 H_2O$	2.0 gm
Distilled water	100 ml

Added 1 ml per litre of sea water

Solution - C

Vitamin B_{12} (cyanocobalamin)	10 mg
Vitamin B_1 (Thiamin)	200 mg
Distilled water	100 ml

Added 0.1 ml / litre of sea water.

$1/4^{th}$ of the stock was used as inoculum for the subcultures. Since the experiments required considerable amount of alga, outdoor cultures were made in 15 lit. transparent buckets using 3 lit subcultures as stock. For outdoor culture, instead of Walne's medium, prescribed fertilizer in standard ratio were used.

Fertilizers used for outdoor *Isochrysis* culture.
(per 1000 litre)

Ammonium sulphate	-	100 gm
Urea	-	10 gm
Calcium super phosphate	-	10 gm

Within 3-4 days, desirable algal counts were obtained.

Determination of Algal cell concentration

Among the many available procedures for determining the algal cell concentration, haemocytometric counting is the simplest method. Other means such as coulter counters, Turbidometers, Spectrophotometes, Video endoscopy, etc. have been used. Their drawbacks are that they usually require a great deal of technological expertise, expensive instrumentation and do not afford visual microscopic inspection of algal cultures. The apparatus used for counting the algal cells was a haemocytometer with an improved Neubaeur ruling. The device is quite suitable for counting algal cells less than 30 μ in size.

Before counting, both the coverslip and the chamber were rinsed with clean distilled water and dried with blotting paper. Occasional cleaning with alcohol ensures the free flow of algae over the counting area. The face of the counting chamber is composed of two gridded surfaces separated by canals. The coverslip is placed on the support bars along the canals and a drop of homogeneously mixed algal suspension is delivered from a Pasteur Pipette by touching the pippette tip to the edge of the coverslip where it hangs over the V-shaped loading port. Slight pressure will cause the algal suspension to flow evenly across the surface, but not into the canals or on top of the coverslip. Both sides of the chamber must be loaded to seat the coverslip properly.

Each half of the haemocytometer surface contains nine large grids. (see fig). Only those algal cells which fall within the four large corner grids are counted. Each large corner grid is further sub-divided into 16 small squares. Cells which fall on a border are counted if atleast half the cell is within the square, but only two borders are acknowledged (either top or bottom and either left or right) so that cells are not counted twice. To determine the algal cell density (number of algal cells per millilitre) in the suspension, the number of algal cells counted is divided by the large corner grid area covered, multiplied by 10^4. All

the four corner grid areas can be covered and the mean can be taken. The mean value when multiplied by 10^4 gives the actual cell concentration per ml. of the sample. Similarly, three to four samples were taken from each algal suspension and the average value was taken as the final concentration.

The average number of cells in 1 ml is calculated as,

Average count per chamber x 10^4 = Total number of cells/ml.

Experimental Design and Treatments

Of the two principal methods available for measuring the filtration rate and ingestion rates, the indirect method was applied. The advantages and disadvantages of both methods are discussed in detail by Winter (1969).

The direct method allows the real pumping rate to be determined, while the indirect method provides information on the filtering rate ie, the volume of water which is filtered clear within a certain period of time. ("Swept-clear volume", Winter, 1969).

The indirect method requires a measurement of the concentration of the suspended particles at certain intervals of time in order to calculate the filtration rates. The filtered volume of water is an estimate or

measure of the minimum volume (filtration rate) which the bivalve must have filtered in order to reduce the particle concentration to the observed values. For the present study the indirect method was chosen because of the relatively low degree of disturbance for the filtering bivalves during the experiment and because no prior preparation of the experimental animals was necessary before experiments.

The experiments were designed to measure the effect of,

(a) different algal concentrations ranging from $3x10,^{4}$ $5x10,^{4}$ $7.5x10,^{4}$ 10^{5} & $1.25x10^{5}$ cells. ml^{-1}

b) Body size & mean dry tissue weight

and

c) Varying salinity

On the filtration rate and ingestion rate of four selected species of bivalves.

Each experiment was carried out using three numbers each of bivalves (Mussel, Oyster and *Geloina sp*) except *Paphia malabarica* where five individuals were used in 5 l filtered sea water in plastic basins. All treatments were replicated three times. The basins were kept at ambient temperature (30+ $1^{0}C$).

The bivalves were acclimated in the containers at the required algal concentration and salinity before the experiment. Prior to each set of experiment, the animals were starved for atleast 24 hour. The experiment was conducted in stagnant water; no air input was given to prevent the artificial circulation of water in the basin.

Before starting the experiment, the water was changed completely. Fresh, filtered seawater of required salinity was gently added without much disturbance or stress to the animal. After the re-immersion, bivalves particularly, the mussels, opened their valves immediately. Except the mussels, the other bivalves used for the experiment took 15-20minutes to open their valves and start normal filtration activity. As they started normal filtration, *Isochrysis galbana* cell suspension of desired concentration was added with least disturbance to the animals. Keeping salinity to the required level, the total volume of water in the basin was made upto 5 litre mark. Control basins containing algal suspensions without animals were set up to correct for any error which might result from flocculation or reproduction of the algae during the period of experiment.

A simple calculation was used to estimate the amount of *Isochrysis galbana* suspension required to have the

desired concentration in the experimental basin. The formula was,

$$\frac{\text{Desired concentration (cells/ml)} \times \text{Volume of water (5 lit)}}{\text{Available concentration (cells/ml)}} = \text{Volume to be added (in litre)}$$

At fixed intervals of time (every 30 minutes), algal samples were collected randomly from the basins and algal concentration was determined. Similarly, the faecal matter from the bottom of basins were collected using a suction pipette and examined under the microscope to find out any pseudofaeces production by the experimental animals.

The filtration rate was determined by the following formula, which has been used in modified form by many other authors (Gauld, 1951, 1964, summary by coughlan, 1969; Ali, 1970, Walne, 1972).

Filtration rate (ml/h)

$$F = V \times \frac{\log \text{conc. to} - \log \text{conc. } t_1}{\log e.t} \times 60$$

where,

V = Volume (ml of algal solution used) (Here, 5 lit)

Conc. to = Initial algal concentration

Conc. t_1 = Algal concentration after time t_1

similarly,

Ingestion Rate (I) (Cells-h^{-1} . $bivalve^{-1}$)

$$I = \frac{C_1 - C_2}{nt} \times V \times 60$$

where,

C_1 = Initial cell concentration in the medium
C_2 = Final cell concentration in the medium after time (t)
t = Duration of the experiment (minutes)
V = Volume of water
n = Number of bivalves per replicate

Table of treatments

Species of Bivalves	Size groups (mm)	Salinity regimen (ppt)	Algal concentration used(cell/ml)
Perna viridis	64-67 mm ---------- 100-105 mm	15 ppt 25 ppt 32 ppt	3×10^4 5×10^4 7.5×10^4 10^5 1.25×10^5
Crassostrea madrasensis	65-70 mm ---------- 100-105 mm	10 ppt 20 ppt 32 ppt	3×10^4 5×10^4 7.5×10^4 10^5 1.25×10^5
Geloina bengalensis	45-50 mm ---------- 75-80 mm	5 ppt 20 ppt 32 ppt	3×10^4 5×10^4 7.5×10^4 10^5 1.25×10^5
Paphia malabarica	30-32 mm ---------- 45-47 mm	15 ppt 25 ppt 32 ppt	3×10^4 5×10^4 7.5×10^4 10^5 1.25×10^5

The mean filtration rates and ingestion rates were determined for every triplicates at different algal cell concentrations for each bivalve of two size groups. Likewise three different salinity regimes for every species were also tried.

Soft tissues of samples selected from either size groups were removed from their shells, rinsed in filtered seawater, blotted by filter paper and weighed. They were dried to a constant weight at 60°C in a hot air oven and the mean values were used to calculate the weight specific filtration and the weight specific ingestion rates.

Statistical Analysis

For statistical analysis three factors were considered.

Factor - I : Size group (Block)
Levels -: 2

Factor - II : Algal concentration
Levels -: 5

Factor - III : Salinity Regimen
Levels -: 3

Analysis of variance was carried out with these factors for the asymmetrical factorial type experiment. (Snedcor and Cochran, 1967). The statistical analysis was done with the SPSS/PC program at the computer centre of C.M.F.R.I.

Result

5. RESULT

Mussels (*Perna viridis*)

1) Effect of Algal cell concentration

The filtration and ingestion rate of *Perna viridis* as a function of different algal concentrations are shown in Table - 1A & Table 1B. It is obvious from the results of experiments that a clear correlation exists between algal concentration and filtered volume per hour. Of the different algal concentrations tried, maximum filtration rate was observed at 1 lakh cells/ml of *Isochrysis galbana*.

Since ingestion rate is strongly in connection with both algal suspension density as well as the filtration rate, there exists a positive correlation between the ingestion rate and algal concentration tried.

2) Effect of Salinity :

Table - 1A & Table - 1B show the effect of salinity on filtration and ingestion rate of *Perna viridis*. Salinity has got a strong influence which is evident from the table. Maximum filtration and ingestion rates were observed at 32 ppt which seems to be ambient for *Perna viridis*.

3) Effect of Body size

The influence of body size on the filtration rate and ingestion activity of *Perna viridis* is shown in the Table - 1A and Table - 1B which represent size group-1 (64-67 mm) and size group -2 (100-105 mm) respectively. High degree of filtration and ingestion activity is observed in size group-2 (100-105 mm).

4) Statistical Analysis of the Data

Statistical analysis of the data is tabulated in Table - 1C & 1D showing the level of significance at each treatment levels.

5) Graphical Representation

The graphical representation of filtration rate and ingestion rate with varying salinities and algal concentration for both size groups are given in Graph-1A & Graph-1B. Graph - 1A is for size group - 1 (64-67 mm) and Graph-1B is for size group -2 (100-105 mm).

Table - 1A

Perna viridis

Size : 64-67 mm
Dry tissue wt. : 775 mg

Algal conc. (cells/ml)	Salinity Regimen ‰.	FR (l/hr/animal)	Wt. specific FR (l/hr/mg tissue)	IR ($x10^6$) (Cells/hr/animal)	Wt. specific IR ($x10^6$) (Cells/hr/mg
3×10^4	32	3.23 ± 0.0805	0.0042	23.86 ± 2.120	0.0307
	25	1.141 ± 0.0438	0.0015	8.553 ± 0.316	0.0110
	15	1.289 ± 0.1324	0.0017	5.72 ± 0.149	0.0074
5×10^4	32	3.501 ± 0.0555	0.0045	39.96 ± 0.531	0.0515
	25	3.518 ± 0.1703	0.00454	41.40 ± 1.639	0.0534
	15	2.423 ± 0.0532	0.00313	16.5 ± 1.080	0.0213
7.5×10^4	32	5.348 ± 0.2414	0.0069	85.53 ± 3.158	0.1104
	25	7.184 ± 0.1725	0.0093	107.5 ± 1.926	0.1387
	15	3.171 ± 0.0784	0.0041	32.3 ± 0.726	0.0416
10^5	32	10.802 ± 0.0931	0.0139	190.3 ± 1.042	0.2455
	25	8.032 ± 0.1648	0.0104	155.56 ± 2.333	0.2007
	15	2.237 ± 0.2788	0.0028	31.67 ± 3.579	0.0408
1.25×10^5	32	3.845 ± 0.1803	0.0049	63.11 ± 2.154	0.0814
	25	3.17 ± 0.2922	0.0041	53.73 ± 4.199	0.0693
	15	1.752 ± 0.0164	0.0023	16 ± 0.899	0.0206

FR = Filtration rate
IR = Ingestion rate

UP = Mean Value
down = Standard Deviation

Table - 1B

Perna viridis

Size : 100-105 mm
Dry tissue wt. : 1413 mg

Algal conc. (cells/ml)	Salinity Regimen ‰.	FR (l/hr/animal)	Wt. specific FR (l/hr/mg tissue)	IR ($x10^6$) (Cells/hr/animal)	Wt. specific IR ($x10^6$) (Cells/hr/mg
3×10^4	32	7.179 ± 0.2186	0.0051	42.99 ± 0.976	0.0304
	25	7.001 ± 0.7739	0.0049	45.83 ± 4.249	0.0324
	15	4.60 ± 0.3526	0.0033	32 ± 2.160	0.0226
5×10^4	32	11.188 ± 0.5165	0.0079	97.63 ± 3.068	0.0690
	25	8.136 ± 0.3898	0.0058	86.5 ± 3.342	0.0612
	15	7.297 ± 0.4791	0.0052	79.16 ± 4.249	0.0560
7.5×10^4	32	15.472 ± 0.3590	0.0109	175.33 ± 2.055	0.1240
	25	14.369 ± 0.6138	0.0102	197.83 ± 5.720	0.1400
	15	10.294 ± 0.4516	0.0073	147.5 ± 1.620	0.1044
10^5	32	18.199 ± 0.4083	0.0128	253.03 ± 4.212	0.1790
	25	17.015 ± 0.3940	0.0120	194.27 ± 4.212	0.1374
	15	13.708 ± 0.4096	0.0097	255.5 ± 5.212	0.1808
1.25×10^5	32	11.143 ± 0.4791	0.0079	242.43 ± 6.560	0.1716
	25	11.430 ± 0.2846	0.0081	280.83 ± 5.137	0.1987
	15	9.389 ± 0.2485	0.0066	242.16 ± 4.938	0.1714

FR - Filtration rate
IR - Ingestion rate

UP = Mean Value
down = Standard Deviation

Table - 1C

ANOVA TABLE FOR
FILTRATION RATE OF *Perna viridis*

Level of significance : 5%
** : Significant

Source of Variation	Sum of Squares	DF	Mean Square	F	Signif of F
Main Effects	94.224	7	13.461	758.657	.000**
BLOCK	39.180	1	39.180	2208.250	.000**
ALGAL	45.848	4	11.212	631.928	.000**
SAL	10.196	2	5.098	287.318	.000**
2-Way Interactions	35.304	14	2.522	142.127	.000**
BLOCK ALGAL	5.697	4	1.424	80.276	.000**
BLOCK SAL	13.833	2	6.916	389.810	.000**
ALGAL SAL	15.774	8	1.972	111.132	.000**
3-Way Interactions	15.563	8	1.945	109.643	.000**
BLOCK ALGAL SAL	15.563	8	1.945	109.643	.000**

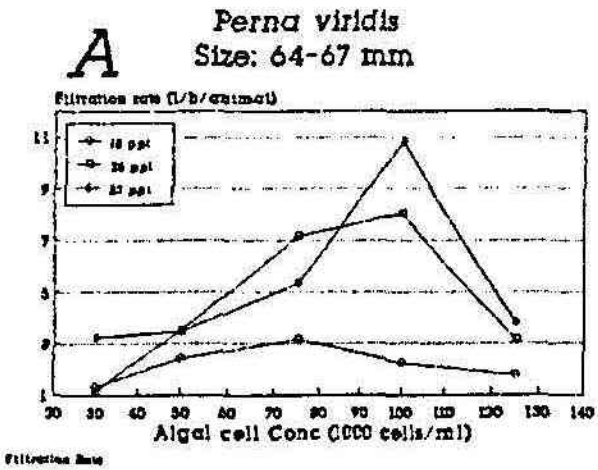
Table - 1D

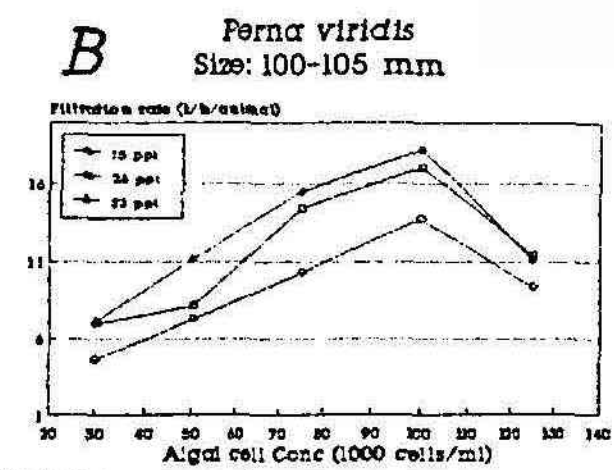
ANOVA TABLE FOR
INGESTION RATE OF *Perna viridis*

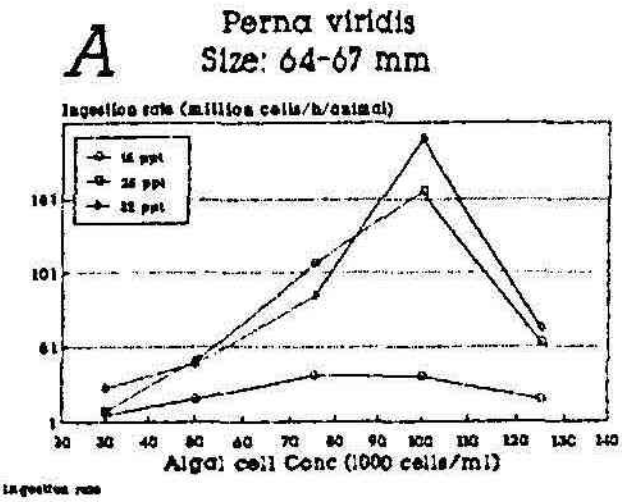
Level of significance : 5%
** : Significant

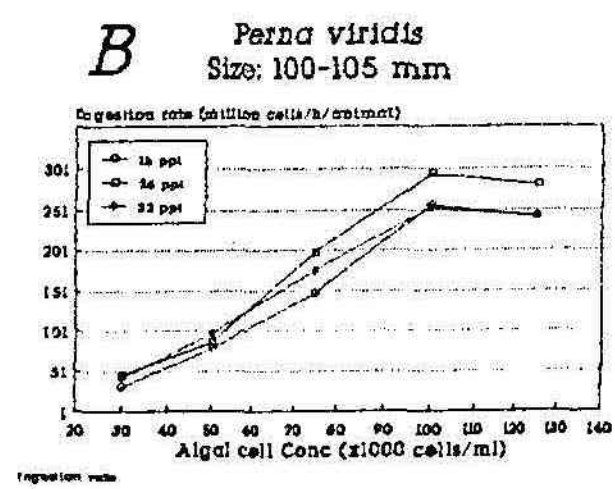
Source of Variation	Sum of Squares	DF	Mean Square	F	Signif of F
Main Effects	18601.226	7	2657.318	547.520	.000**
BLOCK	9446.402	1	9446.402	1946.358	.000**
ALGAL	8677.341	4	2169.335	446.975	.000**
SAL	477.483	2	238.741	49.191	.000**
2-Way Interactions	19544.659	14	1396.047	287.645	.000**
BLOCK ALGAL	4135.585	4	1033.896	213.026	.000**
BLOCK SAL	368.070	2	184.035	37.919	.000**
ALGAL SAL	15041.004	8	1880.126	387.385	.000**
3-Way Interactions	13314.177	8	1664.272	342.910	.000**
BLOCK ALGAL SAL	13314.177	8	1664.272	342.910	.000**

Graph: 1


A
Perna viridis
Size: 64-67 mm
Algal cell Conc (1000 cells/ml)


B
Perna viridis
Size: 100-105 mm
Algal cell Conc (1000 cells/ml)


A
Perna viridis
Size: 64-67 mm
Algal cell Conc (1000 cells/ml)


B
Perna viridis
Size: 100-105 mm
Algal cell Conc (x1000 cells/ml)

Oyster (*Crassostrea madrasensis*)

1) Effect of algal concentration

From the result obtained there exists a gradual and clear correlation exists between the algal concentration and filtration activity. The results are tabulated in Table - 2A & 2B. Maximum filtration rate was observed within a range of 7.5×10^4 to 10^5 cells/ml of *Isochrysis galbana* concentration. Similarly, maximum ingestion rate was also observed in this range. Table 2A represents size group - 1 (65-70 mm) while Table - 2B represents size group - 2 [100-105 (mm)].

2) Effect of Salinity

The varied effect of salinity on the filtration and ingestion rate of *Crassostrea madrasensis* is evident from Table 2A & 2B which shows maximum filtration rate at 20 ppt salinity.

3) Effect of body size :

The marked effect of body size on filtration as well as ingestion rate of *Crassostrea madrasensis* is evident from the comparison of Table 2A & 2B. Both FR & IR are higher for larger size group (Table - 2B).

4) Statistical analysis

The Statistical Analysis has been given in Table - 2C & 2D showing the level of significance at different treatment levels.

5) Graphical Representation

The graphical representation of FR & IR with varying salinities (10 ppt, 20 ppt & 32 ppt) and algal concentrations for both size groups are given in Graph - 2A and Graph - 2B where former one stands for size group-1 (65-70 mm), the latter being size group - 2 (100-105 mm).

Table - 2A

Crassostrea madrasensis

Size : 65-70 mm
Dry tissue wt. : 300 mg

Algal conc. (cells/ml)	Salinity Regimen ‰.	FR (l/hr/animal)	Wt. specific FR (l/hr/mg tissue)	IR ($x10^6$) (Cells/hr/animal)	Wt. specific IR ($x10^6$) (Cells/hr/mg
3×10^4	32	4.865 ± 0.2547	0.0162	31.66 ± 1.347	0.1055
	20	5.728 ± 0.4126	0.0190	36.1 ± 2.084	0.1203
	10	6.452 ± 0.2069	0.0215	39.65 ± 0.9975	0.1322
5×10^4	32	5.658 ± 0.1164	0.0189	59.63 ± 0.974	0.1987
	20	6.214 ± 0.2203	0.0207	64.2 ± 1.770	0.214
	10	7.177 ± 0.1833	0.0239	71.63 ± 1.347	0.2387
7.5×10^4	32	11.233 ± 0.4023	0.0374	146.23 ± 3.2826	0.4874
	20	15.509 ± 0.2996	0.0517	175.73 ± 1.7442	0.5857
	10	11.244 ± 0.3259	0.0375	146.3 ± 2.624	0.4876
10^5	32	8.227 ± 0.0984	0.0274	158.3 ± 1.388	0.5276
	20	16.578 ± 0.1377	0.0553	242.3 ± 0.9626	0.8076
	10	13.202 ± 0.1516	0.0440	214.76 ± 1.426	0.7158
1.25×10^5	32	6.759 ± 0.1795	0.0225	171.23 ± 3.431	0.5707
	20	11.325 ± 0.2711	0.0378	244.96 ± 3.626	0.8165
	10	9.023 ± 0.2585	0.0300	211.13 ± 4.160	0.7037

FR = Filtration rate
IR = Ingestion rate

UP = Mean Value
down = Standard Deviation

Table - 2B

Crassostrea madrasensis

Size : 100-105 mm
Dry tissue wt. : 1370 mg

Algal conc. (cells/ml)	Salinity Regimen ‰.	FR (l/hr/animal)	Wt. specific FR (l/hr/mg tissue)	IR ($x10^6$) (Cells/hr/animal)	Wt. specific IR ($x10^6$) (Cells/hr/mg
3×10^4	32	6.238 ± 0.2108	0.0045	38.63 ± 1.007	0.1055
	20	8.299 ± 0.4096	0.0060	47.76 ± 1.666	0.1203
	10	8.882 ± 0.3139	0.0065	50.13 ± 1.228	0.1322
5×10^4	32	6.854 ± 0.2422	0.0050	69.23 ± 1.837	0.1987
	20	8.985 ± 0.1052	0.0066	84.2 ± 0.698	0.214
	10	9.784 ± 0.1137	0.0071	89.2 ± 0.697	0.2387
7.5×10^4	32	16.388 ± 0.5248	0.0119	180.66 ± 2.855	0.4874
	20	21.389 ± 0.6682	0.0156	203.1 ± 2.453	0.5857
	10	12.103 ± 0.3624	0.0088	153.03 ± 2.720	0.4876
10^5	32	11.573 ± 0.4826	0.0084	198.57 ± 5.123	0.5276
	20	24.088 ± 0.3884	0.0176	282.7 ± 1.5176	0.8076
	10	14.379 ± 0.1944	0.0105	225.2 ± 1.639	0.7158
1.25×10^5	32	9.852 ± 0.5299	0.0072	223.96 ± 7.932	0.5707
	20	12.656 ± 0.2754	0.0092	262 ± 3.335	0.8165
	10	11.212 ± 0.3564	0.0082	243.4 ± 4.825	0.7037

FR = Filtration rate
IR = Ingestion rate

UP = Mean Value
down = Standard Deviation

Table - 2C

ANOVA TABLE FOR
FILTRATION RATE OF *Crassostrea madrasensis*

Level of significance : 5%
** : Significant

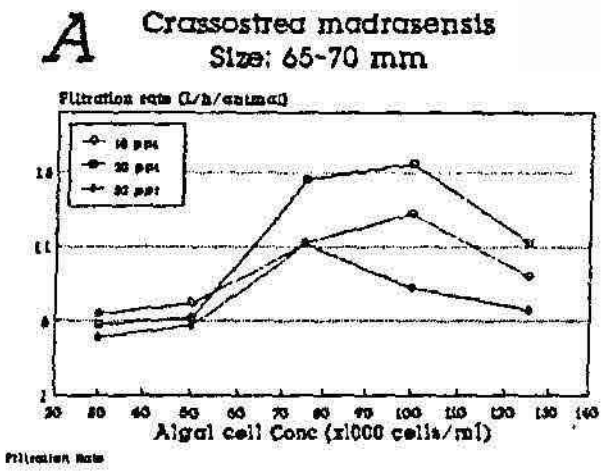
Source of Variation	Sum of Squares	DF	Mean Square	F	Signif of F
Main Effects	1519.714	7	217.102	1396.104	.000**
BLOCK	190.052	1	190.052	1222.157	.000**
ALGAL	1044.096	4	261.024	1678.550	.000**
SAL	285.566	2	142.783	918.186	.000**
2-Way Interactions	295.775	14	21.127	135.859	.000**
BLOCK ALGAL	18.141	4	4.535	29.164	.000**
BLOCK SAL	17.268	2	8.634	55.523	.000**
ALGAL SAL	260.365	8	32.546	209.289	.000**
3-Way Interactions	40.989	8	5.124	32.948	.000**
BLOCK ALGAL SAL	40.989	8	5.124	32.948	.000**

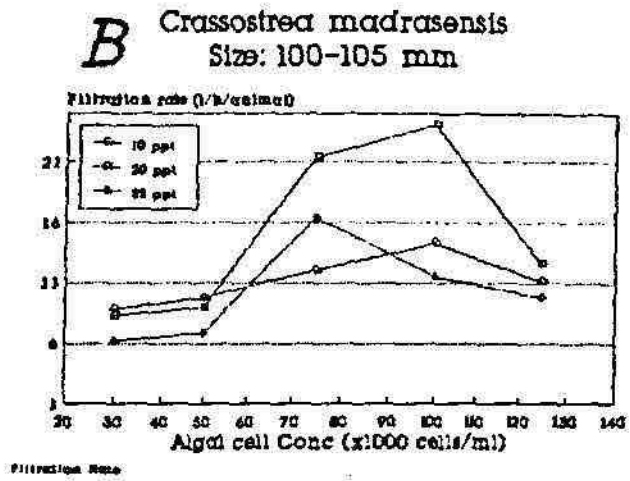
Table - 2D
ANOVA TABLE FOR
INGESTION RATE OF *Crassostrea madrasensis*

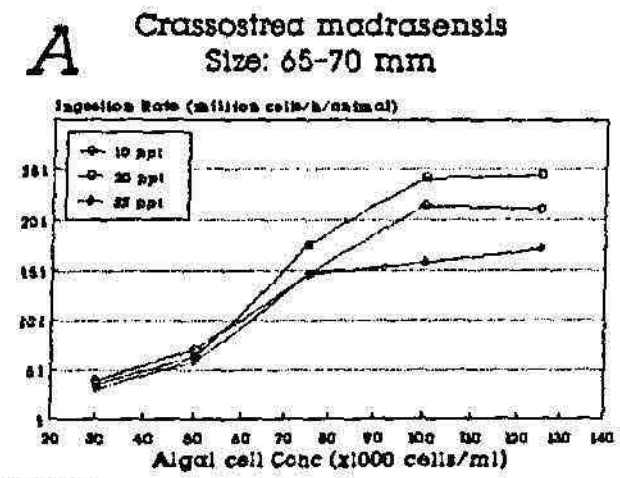
Level of significance : 5%
** : Significant

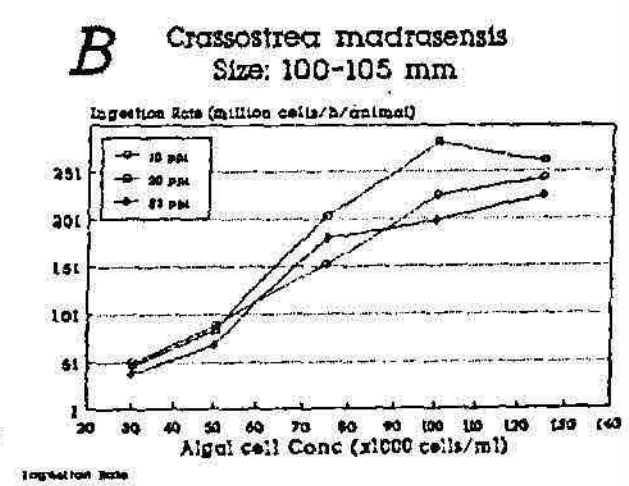
Source of Variation	Sum of Squares	DF	Mean Square	F	Signif of F
Main Effects	550339.055	7	78619.865	6531.951	.000**
BLOCK	11422.823	1	11422.823	949.039	.000**
ALGAL	518880.360	4	129720.090	10777.496	.000**
SAL	20035.871	2	10017.936	832.317	.000**
2-Way Interactions	19019.509	14	1358.536	112.871	.000**
BLOCK ALGAL	1820.427	4	455.107	37.811	.000**
BLOCK SAL	671.224	2	338.612	27.884	.000**
ALGAL SAL	16527.859	8	2065.982	171.647	.000**
3-Way Interactions	1917.306	8	239.663	19.912	.000**
BLOCK ALGAL SAL	1917.306	8	239.663	19.912	.000**

Graph: 2


A
Crassostrea madrasensis
Size: 65-70 mm
Filtration rate (l/h/animal)
Algal cell Conc (x1000 cells/ml)


B
Crassostrea madrasensis
Size: 100-105 mm
Filtration rate (l/h/animal)
Algal cell Conc (x1000 cells/ml)


A
Crassostrea madrasensis
Size: 65-70 mm
Ingestion Rate (million cells/h/animal)
Algal cell Conc (x1000 cells/ml)


B
Crassostrea madrasensis
Size: 100-105 mm
Ingestion Rate (million cells/h/animal)
Algal cell Conc (x1000 cells/ml)

Clam (*Paphia malabarica*)

1) *Effect of algal concentration*

From the results observed, algal concentrations do not influence strongly on filtration and ingestion rates of *Paphia malabarica*, still a gradual positive correlation upto a certain limit exists. The details are presented in Table 3A and 3B. 3A is for size group - 1 (30-32 mm) while 3B is for size group - 2 (45-47 mm).

2) Effect of salinity

The effect of salinity on FR & IR of *Paphia malabarica* is shown in Table - 3A & 3B. From the table, it is found that at 25 ppt the animal shows fairly good FR.

3) Effect of body size

There exists a marked influence of body size on FR & IR of *Paphia malabarica* at all salinities. A comparison of Table - 3A & 3B underlines this effect.

4) Statistical Analysis

The Statistical Analysis of the data is presented in Table - 3C & 3D which shows the significance of variation and level of significance at each levels of treatment.

5) Graphical Representation

The graphical representation of FR & IR with varying salinities (15 ppt, 25 ppt & 32 ppt) for both size groups are presented in Graph - 3A & 3B. Graph - 3A is for size group - 1 (30-32 mm) while 3'B represents size group - 2(45-47 mm).

Table - 3A

Paphia malabarica

Size : 30-32 mm
Dry tissue wt. : 165 mg

Algal conc. (cells/ml)	Salinity Regimen ‰.	FR (l/hr/animal)	Wt. specific FR (l/hr/mg tissue)	IR ($x10^6$) (Cells/hr/animal)	Wt. specific IR ($x10^6$) (Cells/hr/mg
3×10^4	32	1.404 ± 0.0438	0.0085	9.28 ± 0.2465	0.0562
	25	1.440 ± 0.0808	0.0087	9.4 ± 0.4320	0.0569
	15	1.056 ± 0.0341	0.0064	72.33 ± 2.054	0.0438
5×10^4	32	1.46 ± 0.0415	0.0088	16.16 ± 0.6299	0.0979
	25	1.769 ± 0.0498	0.0107	18.5 ± 0.4082	0.1121
	15	1.413 ± 0.0362	0.0086	15.43 ± 0.3299	0.0935
7.5×10^4	32	2.413 ± 0.0558	0.0146	36.86 ± 0.6182	0.2234
	25	2.776 ± 0.0233	0.0168	27.83 ± 0.2867	0.1686
	15	2.6433 ± 0.0491	0.0160	26.16 ± 0.6236	0.1585
10^5	32	1.373 ± 0.2237	0.0083	30.78 ± 4.052	0.1865
	25	1.453 ± 0.0367	0.0088	31.58 ± 0.6544	0.1914
	15	1.858 ± 0.1474	0.0113	38.4 ± 2.4055	0.2327
1.25×10^5	32	1.152 ± 0.0889	0.0069	332.5 ± 1.1045	0.1969
	25	1.216 ± 0.0514	0.0074	34 ± 1.224	0.2060
	15	1.531 ± 0.0603	0.0093	41.16 ± 1.3123	0.2494

FR = Filtration rate
IR = Ingestion rate

UP = Mean Value
down = Standard Deviation

Table - 3B

Paphia malabarica

Size : 45-47 mm
Dry tissue wt. : 740 mg

Algal conc. (cells/ml)	Salinity Regimen ‰.	FR (l/hr/animal)	Wt. specific FR (l/hr/mg tissue)	IR ($x10^6$) (Cells/hr/animal)	Wt. specific IR ($x10^6$) (Cells/hr/mg
3×10^4	32	2.04 ± 0.0367	0.0027	14 ± 0.249	0.0189
	25	2.2 ± 0.0616	0.0029	18.76 + 0.205	0.0253
	15	1.661 ± 0.0160	0.0022	16.2 + 0.141	0.1322
5×10^4	32	2.345 ± 0.2770	0.0032	43.8 ± 4.385	0.1987
	25	3.953 ± 0.1507	0.0053	23.2 ± 0.571	0.214
	15	2.183 ± 0.1228	0.0029	37.8 ± 1.657	0.2387
7.5×10^4	32	5.61 ± 0.2375	0.0076	76.7 ± 9.428	0.4874
	25	5.213 ± 0.0871	0.0070	41.93 ± 0.449	0.0566
	15	2.929 ± 0.0473	0.0039	51.4 + 1.019	0.0694
10^5	32	5.521 ± 0.0620	0.0075	116 ± 0.816	0.1567
	25	2.031 ± 0.1688	0.0027	27.3 ± 1.909	0.0368
	15	2.499 ± 0.1190	0.0034	55.6 ± 3.766	0.0751
1.25×10^5	32	3.912 ± 0.0144	0.0053	99.9 ± 0.286	0.135
	25	1.3425 ± 0.0556	0.0018	23.4 ± 0.418	0.032
	15	1.274 ± 0.1054	0.0317	60.4 ± 4.339	0.0816

FR = Filtration rate
IR = Ingestion rate

UP = Mean Value
down = Standard Deviation

Table - 3C

ANOVA TABLE FOR
FILTRATION RATE OF *Paphia malabarica*

NS : Not significant
Level of significance : 5%
** : Significant

Source of Variation	Sum of Squares	DF	Mean Square	F	Signif of F
Main Effects	1927.074	7	275.296	1622.391	.000**
BLOCK	1113.377	1	1113.377	6561.412	.000**
ALGAL	628.595	4	157.149	926.118	.000**
SAL	185.102	2	92.551	545.426	.000**
2-Way Interactions	129.696	14	9.264	9.264	.000**
BLOCK ALGAL	71.133	4	17.783	104.801	.000**
BLOCK SAL	.614	2	.307	1.810	.172NS
ALGAL SAL	57.949	8	7.244	42.688	.000**
3-Way Interactions	35.260	8	4.407	25.974	.000**
BLOCK ALGAL SAL	35.260	8	4.407	25.974	.000**

Table - 3D

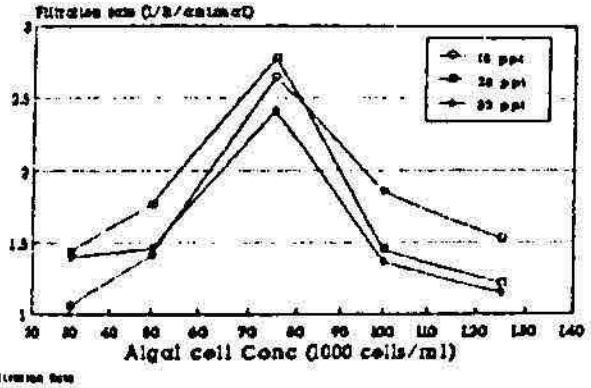
ANOVA TABLE FOR
INGESTION RATE OF *Paphia malabarica*

Level of significance : 5%
** : Significant

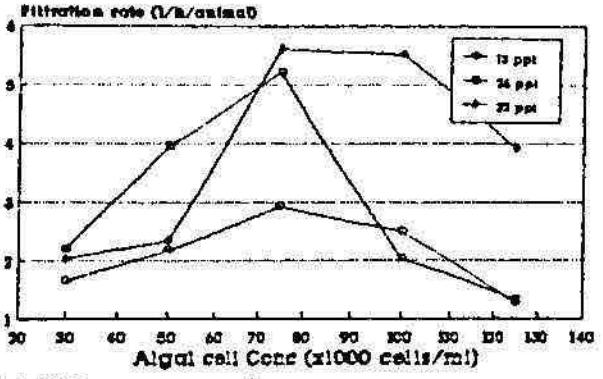
Source of Variation	Sum of Squares	DF	Mean Square	F	Signif of F
Main Effects	624089.153	7	89155.593	3108.712	.000**
BLOCK	255927.472	1	255927.472	8923.778	.000**
ALGAL	338057.667	4	84514.417	2946.881	.000**
SAL	30104.015	2	15052.007	524.839	.000**
2-Way Interactions	117715.872	14	8408.277	293.183	.000**
BLOCK ALGAL	94545.920	4	23636.480	824.166	.000**
BLOCK SAL	9011.772	2	4505.886	157.113	.000**
ALGAL SAL	14158.180	8	1769.773	61.709	.000**
3-Way Interactions	13829.899	8	1728.737	60.278	.000**
BLOCK ALGAL SAL	13829.899	8	1728.737	60.278	.000**

Graph: 3

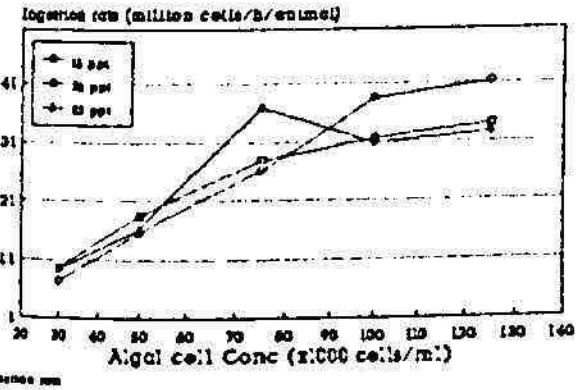
A Paphia malabarica
Size: 30-32 mm



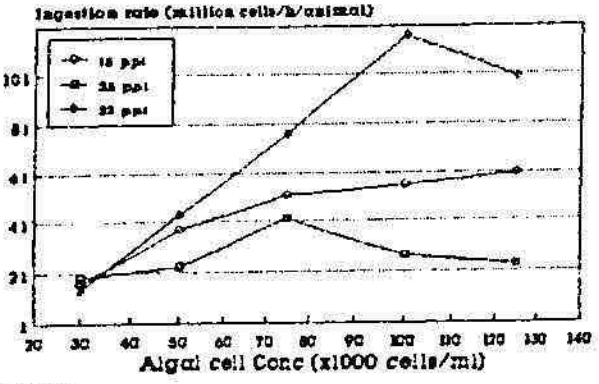
B Paphia malabarica
Size: 45-47 mm



A Paphia malabarica
Size: 30-32 mm



B Paphia malabarica
Size: 45-47 mm



Clam (*Geloina bengalensis*)

1) **Effect of algal concentration**

Algal concentration seems to have much influence on FR & IR of *Geloina bengalensis*. The result of experiments are given in Table - 4A and Table 4B. Of the different algal concentrations tried, maximum FR & IR have been observed at 10^5 cells/ml *Isochrysis galbana* concentration.

Table - 4A is for size group - 1 (45-50 mm) and Table - 4B is for size group - 2 (75-80 mm).

2) **Effect of salinity**

From the results obtained (Table - 4A & Table - 4B), it is clear that salinity regimen (5 ppt, 20 ppt & 32 ppt) do not have much influence on the FR & IR of this bivalve species. Obviously it is a euryhaline species.

3) **Effect of Body size**

Results show clearly that body size is positively correlated with the FR & IR of *Geloina bengalensis*. (Table - 4A & Table - 4B).

4) Statistical Analysis of the Data

Statistical Analysis is given in the Table - 4C & 4D. Data shows there is not much variation exists within treatments with varying salinities.

5) Graphical Representation

Graphical Representation of FR & IR with varying salinities for both size groups are given in Graph-4A & Graph - 4B.

Graph-4A represents size group - 1 (45-50 mm) where as Graph - 4B is for size group -2 (75-80 mm).

Table - 4A

Geloina bengalensis

Size : 45-50 mm
Dry tissue wt. : 315 mg

Algal conc. (cells/ml)	Salinity Regimen ‰.	FR (l/hr/animal)	Wt. specific FR (l/hr/mg tissue)	IR ($x10^6$) (Cells/hr/animal)	Wt. specific IR ($x10^6$) (Cells/hr/mg
3×10^4	32	5.466 ± 0.3600	0.0174	34.53 ± 1.4267	0.1096
	20	5.946 ± 0.0694	0.0188	37.2 ± 0.4546	0.1180
	5	5.22 ± 0.2539	0.0165	33.63 ± 1.247	0.1068
5×10^4	32	6.04 ± 0.1212	0.0192	63.08 ± 1.002	0.2002
	20	7.95 ± 0.1852	0.0252	77.03 ± 1.5584	0.2445
	5	7.76 ± 0.1979	0.0246	75.76 ± 1.1145	0.2405
7.5×10^4	32	16.653 ± 0.3030	0.0528	182.33 ± 1.6579	0.5788
	20	19.093 ± 0.1020	0.0606	193.8 ± 0.8640	0.6152
	5	20.536 ± 0.3456	0.0652	199.86 ± 1.3299	0.6344
10^5	32	20.04 ± 0.1639	0.0636	63.657 ± 0.8164	0.8368
	20	22.19 ± 0.2491	0.0704	274.6 ± 1.1897	0.8717
	5	22.63 ± 0.2951	0.0718	276.7 ± 1.1376	0.8784
1.25×10^5	32	17.530 ± 0.2845	0.0556	310.66 ± 2.494	0.9862
	20	19.947 ± 0.1674	0.0633	329.3 ± 1.061	1.045
	5	19.033 ± 0.3627	0.0604	32.27 ± 0.2628	0.1024

FR = Filtration rate
IR = Ingestion rate

UP = Mean Value
down = Standard Deviation

Table - 4B

Geloina bengalensis

Size : 75-80 mm
Dry tissue wt. : 855 mg

Algal conc. (cells/ml)	Salinity Regimen ‰.	FR (l/hr/animal)	Wt. specific FR (l/hr/mg tissue)	IR ($x10^6$) (Cells/hr/animal)	Wt. specific IR ($x10^6$) (Cells/hr/mg
3×10^4	32	5.787 ± 0.1242	0.0067	34.06 ± 0.3858	0.0398
	20	7.324 ± 0.2861	0.0086	43.63 ± 1.4190	0.0510
	5	6.07 ± 0.2639	0.0071	38.2 ± 1.8832	0.0466
5×10^4	32	6.928 ± 0.3616	0.0081	69.73 ± 2.2752	0.0815
	20	9.381 ± 0.3123	0.0100	86.43 ± 1.644	0.1011
	5	9.68 ± 0.3091	0.0113	88.00 ± 1.835	0.1029
7.5×10^4	32	21.877 ± 0.4009	0.0255	202.53 ± 0.0555	0.2368
	20	22.135 ± 0.2777	0.0258	205.9 ± 1.349	0.2408
	5	23.934 ± 0.2022	0.0279	211.73 ± 0.659	0.2476
10^5	32	24.775 ± 0.3212	0.0289	285.6 ± 0.5312	0.3340
	20	26.643 ± 0.4095	0.03116	290.73 ± 2.525	0.3400
	5	25.323 ± 0.3680	0.0296	287.2 ± 0.8286	0.3359
1.25×10^5	32	20.42 ± 0.6249	0.0238	332.9 ± 4.115	0.3893
	20	23.41 ± 0.5255	0.0273	348.4 ± 1.395	0.4075
	5	23.30 ± 0.6159	0.0273	348.06 ± 2.042	0.4070

FR = Filtration rate
IR = Ingestion rate

UP = Mean Value
down = Standard Deviation

Table - 4C

ANOVA TABLE FOR
FILTRATION RATE OF *Geloina bengalensis*

NS : Not significant
Level of significance : 5%
** : Significant

Source of Variation	Sum of Squares	DF	Mean Square	F	Signif of F
Main Effects	5024.180	7	717.740	4560.905	.000**
BLOCK	167.745	1	167.745	1065.941	.000**
ALGAL	4789.939	4	1197.485	7609.460	.000**
SAL	66.496	2	33.248	211.277	.000**
2-Way Interactions	61.355	14	4.382	27.849	.000**
BLOCK ALGAL	39.544	4	9.886	62.820	.000**
BLOCK SAL	.135	2	.068	.430	.653NS
ALGAL SAL	21.676	8	2.709	17.217	.000**
3-Way Interactions	10.722	8	1.340	8.517	.000**
BLOCK ALGAL SAL	10.722	8	1.340	8.517	.000**

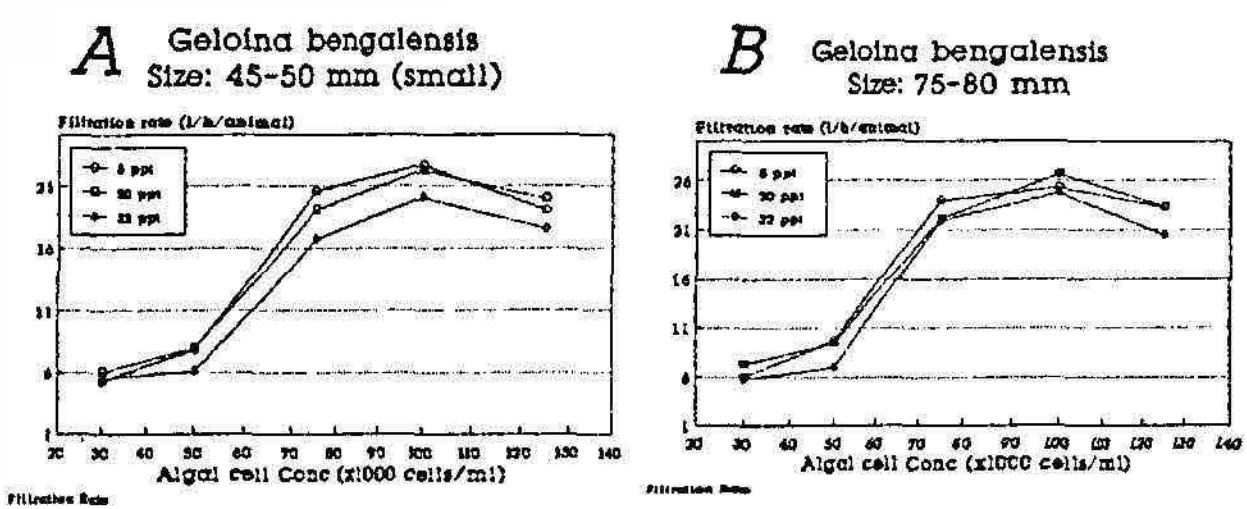
Table - 4D

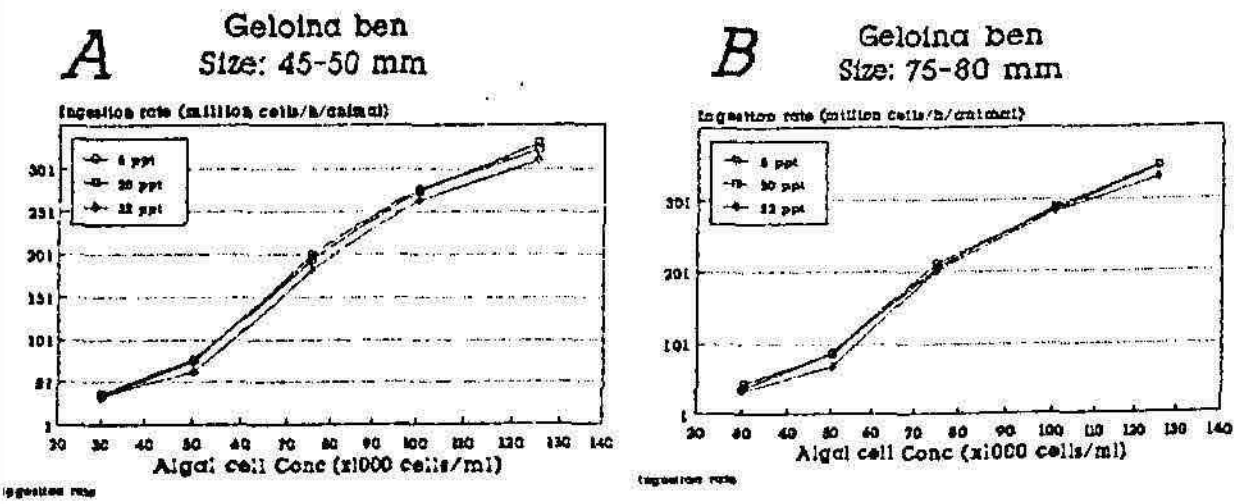
ANOVA TABLE FOR
INGESTION RATE OF *Geloina bengalensis*

Level of significance : 5%
** : Significant

Source of Variation	Sum of Squares	DF	Mean Square	F	Signif of F
Main Effects	1166686.139	7	166669.448	39234.927	.000**
BLOCK	3931.231	1	3931.231	925.434	.000**
ALGAL	1160527.077	4	290131.769	68298.653	.000**
SAL	2227.831	2	1113.916	262.222	.000**
2-Way Interactions	1509.622	14	107.830	25.384	.000**
BLOCK ALGAL	902.871	4	225.718	53.135	.000**
BLOCK SAL	9.715	2	4.858	1.144	.000**
ALGAL SAL	597.036	8	74.630	17.568	.000**
3-Way Interactions	249.881	8	31.235	7.353	.000**
BLOCK ALGAL SAL	249.881	8	31.235	7.353	.000**

Graph: 4


A
Geloina bengalensis
Size: 45-50 mm (small)
Filtration rate (l/h/animal)
Algal cell Conc (x1000 cells/ml)
B
Geloina bengalensis
Size: 75-80 mm
Filtration rate (l/h/animal)
Algal cell Conc (x1000 cells/ml)


A
Geloina ben
Size: 45-50 mm
Ingestion rate (million cells/h/animal)
Algal cell Conc (x1000 cells/ml)
B
Geloina ben
Size: 75-80 mm
Ingestion rate (million cells/h/animal)
Algal cell Conc (x1000 cells/ml)

Discussion

6. DISCUSSION

The measurement of filtration and ingestion rates of different bivalves has been the subject of many investigations in recent decades (Ali, 1970; Bayne, 1972; Winter 1973; Schuttle, 1975; Khalil, 1990). These studies used different methods, experimental conditions and a variety of suspended materials such as graphite, clay, chalk and unicellular algae (Winter, 1973).

Of the two methods available for measuring the rate of passage of water through the mantle cavities of bivalves, the indirect method was chosen for the present study. The indirect method was preferred by many investigators (Ali, 1970; Winter, 1973; Schutle, 1975; Epifanio, 1977; Khalil, 1990).

In most previous works, calculations of filtration and ingestion rate relied on counting the initial and the final cells in a certain volume of water by using either a haemocytometer (eg. Winter, 1973; Khalil, 1990) or Coulter Counter (Iglesius, *et al.* 1992, De Villers and Hoogson, 1993). Ali (1970) determined the filtration rate by the indirect suspension depletion method monitoring by optical density measurements. Flow cytometers has been used recently by Shumway *et al.* (1985) to study the grazing rate of filter feeding bivalves because it can distinguish

simultaneously between cells and particles of nearly equal size but of different optical properties.

The experiments described in the present work determined the filtration rate and ingestion rate of four species of cultivable bivalves in relation to various algal concentrations (*Isochrysis galbana*), body size and at different salinities employing the indirect method.

1. Effect of Algal concentration:

The importance of food concentration on the filtration activity of lamellibranchs was pointed out by several authors. Loosanoff (1942) found in experiments with *Ostrea virginica* that a low concentration of unicellular algae seemed to stimulate filtration activity, whereas a high concentration caused a decrease in the quantities of water pumped amounting to 80% or more. Also, Thompson and Bayne (1972) reported that mussels respond to a food stimulus by increasing their rates of ventillation, filtration and oxygen consumption above routine values.

Mussel (*Perna viridis*)

The filtration rates recorded in present experiment suggest a strong correlation between the *Isochrysis galbana* concentration and filtration rate. Maximum

rate of filtration was observed at a cell density of 1 lakh cells / ml. above which a sudden decrease in filtering rate was noticed. The algal concentration at which a tolerable disturbance of filtration activity of mussels occurs is called the "critical cell density". At this particle density the mussel still filters normally, and produces no pseudofaeces.

However, in the present study, mussel (*Perna viridis*) started producing 'pseudofaeces' at a cell density of 1 lakh cells/ml and above. At food concentrations higher than the "critical cell density", a steady decrease in filtration rates occurs together with an increasing rate of pseudofaeces production. The "critical cell concentration", which was found to be around 7.5×10^4 lakh cells/ml, therefore, seems to be an optimum food concentration for mussel, since filtration activity is reduced to low energy consuming filtration rates and all food particles are ingested, no pseudofaeces being produced or dispelled.

Oyster (*Crassostrea madrasensis*)

Early studies showed that a low concentration of algal suspension seemed to stimulate filtration activity in *Ostrea virginica*, where as a high concentration caused a decline of 80% or more in the quantities of water

pumped. In the present work too a high algal concentration caused a decline in the filtration rate.

Compared to mussel, the filtration and ingestion activity of oyster was higher reaching a maximum value around 1 lakh cells/ml *Isochrysis galbana*. However, above a concentration of 75,000 cells/ml, oyster *Crassostrea madrasensis* started pseudofaeces production. So we, must presume that a large amount of *Isochrysis* removed from suspension at densities above 75,000 cells/ml concentration are not utilised efficiently, and that the majority of the cells were probably not digested but passed directly through the gut and are egested as pseudofaeces.

Epifanio and Ewart (1977) reported that at the highest concentration of *Isochrysis*, the rate of removal by *Crassostrea virginica* was elevated throughout the experimental period. However, data from the present study shows a gradual decline in the rate of removal above a concentration of 1 lakh cell/ml of *Isochrysis*.

In general, though it seems clear that in a medium of algal suspension, oysters ingest a critical maximum quantity of algal material through active filtration and then decrease their filtration rate considerably while digesting the material. These periods of

activity and quiescence are dependent upon sufficient quantities of algal material being in suspension. At low concentrations, such as that generally occuring in natural waters, the rate of filtration is probably more constant over time, with digestive activity occurring simultaneously with filtration.

Clams:

Khalil (1996) reported that, a high algal concentration (10^5 cells/ml) caused a 57% decline in the filtration rate of *Tapes decussatus*.

In the present study, with two clams namely *Paphia malabarica* and *Geloina bengalensis*, the results differed between the two species. *Paphia malabarica* showed the least filtration activity while *Geloina bengalensis* recorded the maximum among all the four species of bivalves tested. *Paphia malabarica* showed maximum filtration activity at a concentration of 7.5×10^4 cells/ml of *Isochrysis*. However, at this same concentration pseudofaeces production was noticed.

The clam *Geloina bengalensis* was found to be the most efficient bivalve both in filtration as well as ingestion of *Isochrysis* cells from the medium. Filtration rate went upto 26.643 lit/hr/animal at a concentration of 1 lakh cells/ml for the size group-II

(large) Pseudofaeces production also was noticed at this concentration above which (at 1.25×10^5 *Isochrysis* cells/ml) there was a slight reduction in filtration and ingestion rates.

2. **Effect of Salinity**

Effect of varying salinities on the filtration rates of lamellibranchs have been studied by Dodgson (1928), Cole and Hepper (1954), Nagabhushanam (1956) and Durve, 1963). These workers observed a depressing effect of low salinities on the rate of filtration.

Mussel (*Perna viridis*):

Of the three salinity regimens tried. *Perna viridis* showed maximum filtration and ingestion rate at 32 ppt. However, it should be remembered that mussel is a marine species and 32 ppt is its ambient salinity at which it performed maximum filtration and ingestion activity. And also there is a size wise difference in FR in varying salinities which has got importance in estuarine mussel culture where the seeds used are well adjusted to 20-25 ppt salinity.

Oyster (*Crassostrea madrasensis*)

There was little effect of salinity on the filtration and ingestion of oyster, *C. madrasensis*. The same

effect was evident in both the size groups. The different salinities tested were 32 ppt, 20 ppt and 10 ppt. High rate of filtration was observed at a 20 ppt salinity which underlines the fact that *C. madrasensis* is more of an estuarine species. In higher salinities (32 ppt) the FR & IR tend to decline considerably showing that in purely marine conditions, *C. madrasensis* feeding activity is comparatively less.

Clams:

Durve (1963) studied the rate of filtration of the clam, *Meretrix casta* at different salinities and reported that the rate of filtration is adversely affected both at low and high salinities. According to his observations, the clams were seen fully extending their siphons without filtration for considerable time at high salinities. He suggested that very high salinities may have benumbing effect on the clams.

In the present study, the clams *Paphia malabarica* as well as *Geloina bengalensis* exposed to different salinity regimens showed varied salinity effects on their FR & IR.

Both size groups of *P. malabarica* exhibited comparatively high filtration & ingestion rate at 25 ppt and 32 ppt showing that it can tolerate higher

salinities. It is noteworthy here that *M. casta* has a greater degree of physiological adaptation in the salinity range 25 to 56 ppt (Durve, 1964).

Geloina bengalensis which were exposed to three very wide salinity regimens showed no significant correlation between the filtration and ingestion rate and salinity regimen. Fairly high FR and IR were recorded at all three levels of salinity tried, lower salinity (5 ppt) being found as ideal. The results obtained point towards the euryhaline nature of *G. bengalensis* which can adapt very well to varying salinities with good filtration and assimilation efficiencies.

Durve (1964) summarized that the filtration rate falls in excessive low and high salinities, while the clams can readily adapt themselves for a wide range of salinities from 25 to 56 ppt. It appears that very high concentration of salts in the water have more or less benumbing effect on the clams. The experiments on the acclimation of clams to different experimental salinities support these observations (Durve, 1964).

3. <u>Effect of Body size</u>

The effect of body size on the filtration and ingestion rates is evident from the results obtained. It would be

further evident that the rate of filtration is directly related to the size of the bivalve. Larger the bivalve more is the rate of filtration per hour.

The present results show a statistically significant proportionality of filtration and ingestion rates to body size for all the four bivalves tested. Similar results were recorded by Winter (1973) for *M. edulis*. Khalil (1996) showed that filtration rate increased to 6 times the initial value for a tenfold increase in dry tissue weight and ingestion rate to 4 times the initial value in the clam, *Tapes decussatus*.

For all the four species of bivalves in the present study, two distinct size groups were tested. All the experimental observations showed a positive correlation between body size and FR as well as IR. There were marked differences in the FR and IR between size group - 1 and 2 for each bivalve species.

It is well documented in the literature that filtration rate (FR) increases with increasing body size, following the general allometric equation $F = a W^b$. Several earlier studies (Winter, 1973) have related the rate of filtration of bivalves to the size of the animal by the equation,

$F/W = a\ W^{b-1}$, where F is the rate of filtration, W, the weight of the animal in gm, 'a' the filtration rate of an animal of unit weight, and b-1 is a constant.

4. Weight specific filtration and ingestion rates

For every experimental observations of FR & IR, corresponding weight specific filtration and ingestion rates were also measured.

The weight specific filtration rate of the bivalves generally decreased with increased dry tissue weight. The weight specific ingestion rate decreased with increased dry tissue weight and increased with algal concentration (Table 1-4).

Statistical Analysis

Filtration Rate

With regard to filtration rate, size groups differed significantly for all the four species tested. Algal concentration differences caused significant changes in filtration rates of all the four species, so also the salinity levels. Filtration rates were significantly different for different combinations of size groups and algal levels.

But there was no significant interaction between size groups and salinity levels with regard to filtration rate both in *Geloina bengalensis* as well as *Paphia malabarica* according to results of the statistical analysis.

Since the analysis of 3-way interactions between size groups, algal concentration and salinity showed highly significant difference for all the four bivalves, it has to be inferred that algal concentration and salinity levels produce significantly different filtration rates for different combinations.

Ingestion Rate

With regard to ingestion rate also almost same statistical results were obtained. For all the bivalves tested, the size groups differed significantly in their ingestion rates. Different algal concentrations as well as salinity levels caused significant changes in the ingestion rates. And also, the ingestion rate significantly differed for different combinations of size groups and algal levels tried.

In the case of *Geloina bengalensis*, the interaction between size group and salinity levels with regard to ingestion rate was not significant. Again as with the filtration rate, the 3-way interaction between size groups, algal concentration and salinity showed highly significant difference for all the four bivalves.

Summary & Conclusion

7. SUMMARY & CONCLUSION

This study entitled *"Effect of algal concentration, salinity and body size on filtration and ingestion rates of a few cultivable Indian bivalves"* was carried out at FHL of CMFRI, Thoppumpady, Cochin, during April - June, 1998.

The parameters studied during the experimental period were,

(1) Filtration rate & (2) Ingestion rate of following bivalve species :

a) *Perna viridis*
b) *Crassostrea madrasensis*
c) *Paphia malabarica* and
d) *Geloina bengalensis*

The data obtained were subjected to One-way Analysis of Variance. Results indicated statistically significant difference in the filtration as well as ingestion rates among the size groups and also between different algal concentrations for varying salinity regimens (Table 1 to 4).

The salient findings of the present study are,

1) Algal concentration was found positively correlated with the filtration & ingestion rate of all the four bivalves tested. Upto a certain level of algal concentration both FR & IR showed significant increase beyond which a gradual decline was observed.

2) Effect of salinity on FR & IR varied with species. The effect was much evident in *P. viridis*. However, there was no effect of salinity on FR & IR of *G. bengalensis*.

3) FR & IR were directly related to the body size of bivalve. Larger the bivalve, more was the filtration & ingestion per hour. At varying salinities, *P. viridis* showed size-wise difference in filtration activity.

4) The algal cell densities at which the psuedofaeces production started were arrived at for all the bivalves tested.

Conclusion

The present study has been undertaken with the following objectives viz. study of (1) effect of algal concentration, (2) effect of salinity and (3) effect of body

size, on the filtration and ingestion rates of four selected bivalves. Quantifications of this kind make possible some useful predictions for the culture of economically important species.

The results of the present study admittedly allow only an approximation of the maximum and minimum filtration and ingestion rate of the selected bivalves with the single algal species (*Isochrysis galbana* at five different concentrations. However, it may be mentioned here, that reasons for the variations in the rates of filtration in different lamellibranchs observed by various workers, may be perhaps be found in different experimental techniques employed by these workers.

Nonetheless, they represent an advance that can be applied immediately with significant economic gains to the molluscan mariculturist. The knowledge, of maintenance ration in relation to body size and salinity may be used as a deciding factor for calculating the amount of food necessary for optimum growth in artificial bivalve culture systems or for the selection of suitable sites with respect to aquaculture efforts in the field. On the other hand, high food concentrations result in the production of pseudofaeces, represent a loss of potentially utilizable algal cells and organic matter in the form of mucous, and

increase the risk of fouling. For maximum growth bivalves should be maintained at a constant optimum food level, by replacement of food removed in unit time.

With respect to aquaculture, the application of conclusions derived from the present work would result in increased efficiency and reduced cost of production. Further studies of assimilation, filtration and ingestion, and growth efficiencies of bivalves fed different rations of different and algal species should allow precise definition of the most efficient or minimum ration of a given algal diet.

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