A STUDY OF ALGAL BIOFOULING ON PEARL NETS IN CHARLES ARM, NOTRE DAME BAY, NEWFOUNDLAND

DEREK J. MOULAND

A STUDY OF ALGAL BIOFOULING ON PEARL NETS IN CHARLES ARM, NOTRE DAME BAY, NEWFOUNDLAND.

by

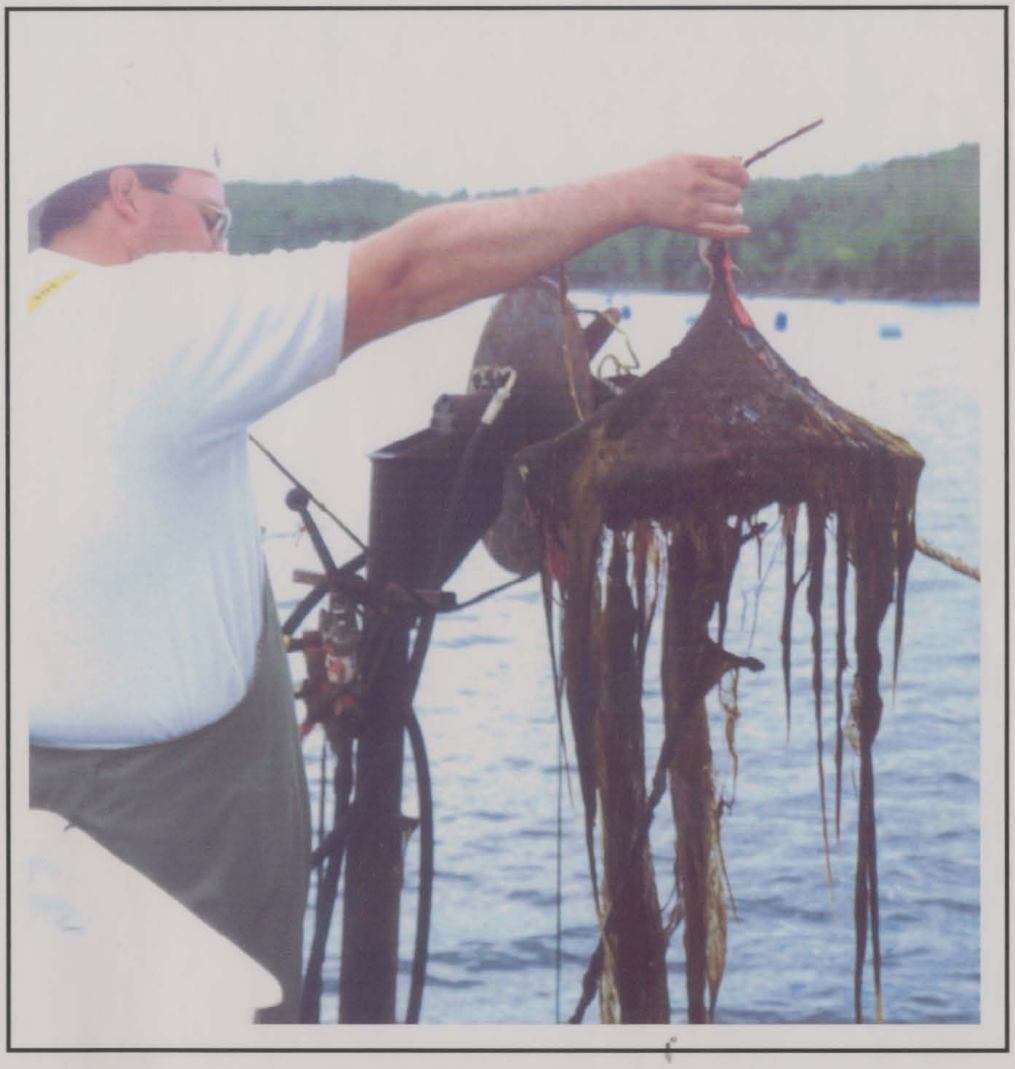
©Derek J. Mouland. B.Sc. (Hons.)

A thesis submitted to the School of Graduate Studies in partial fulfillment of the requirements for the degree of Masters of Science in Aquaculture.

Department of Biology
Memorial University of Newfoundland

March 2003

St John's Newfoundland



Frontispiece. Multiyear fouling on a pearl net at Thimble Bay Farm, Charles Arm, Notre Dame Bay, Newfoundland.

ABSTRACT

This study examined the development of biofouling on pearl nets used for culture of the sea-scallop (*Placopecten magellanicus*) in Charles Arm, Notre Dame Bay, Newfoundland over a two year period, May 1998 until July 2000. The site showed salinities of approximately 30 ISU and surface seasonal temperature fluctuation between –1.5C and 20C. The greatest part of the fouling biomass consisted of macroalgae : Chlorophyta (10 species), Phaeophyta (24 species), Rhodophyta (19 species), together with Cyanobacteria (33 species) and two species of tube dwelling diatoms. All the species recorded were common members of the local benthic flora. Fouling biomass was measured on nets placed at two, and four metre depths. Rapid colonization occurred with growth initially faster at the shallow depth, but after the first year biomass stabilized at approximately 1 kg per net wet weight, with no significant differences between depths. The fouling community was analyzed using two multivariate techniques, Detrended Correspondence Analysis (DECORANA) and Two-Way Indicator Species Analysis (TWINSPAN). The first year's growth showed considerable floristic changes as the algal fouling developed, with samples from the latter part of the year showing considerable differences from the late spring and early summer. After one years growth few floristic changes were noted. There was no obvious difference in the algal communities between the two depths.

Two algal grazers, the periwinkle, *Littorina littorea* and the green sea urchin *Strongylocentrotus droebachiensis* were investigated as potential biofouling control organisms. Two experiments were conducted, one in the summer months and one over winter. The pearl nets with the urchin treatment showed no significant decrease in

fouling, while the periwinkle treatments significantly reduced fouling in the summer. DECORANA and TWINSPAN analysis showed no differences in algal community structure between the experiments and controls, showing that grazing was not species preferential.

During the course of this study there was a large, and as yet still unexplained, die-off of the cultured scallops at the site, which confounded attempts to determine if the inclusion of algal grazers in the nets affected growth and survival of the scallops. These preliminary studies, however, showed no differences in the growth rate of the scallops with depth, or treatment with snails or urchins. Survival of the scallops was, however, significantly enhanced by the snail treatment in both experiments including enhanced survival in the summer experiment, when scallop loss was greatest.

ACKNOWLEDGMENTS

My thanks and gratitude go to Dr. Alan Whittick for supervising this study, as an educator and as a good friend, for his invaluable assistance throughout the duration of my research and for being there every time he was needed. I thank Dr. Robert Hooper who first developed my interest in marine biology and phycology. Most importantly, I thank Bob for introducing me to Alan. I would also like to thank Bob for his help in identifying invertebrates and the more difficult algal species. Dr. Pat Dabinett, with his encyclopedic knowledge of scallop aquaculture, provided valuable advice and information on the scallop growth literature. Much of the temperature and salinity data for Charles Arm was obtained by Jason Nichols of the Marine Institute of Memorial University and was kindly made available to the author. The help of another good friend, Randy Batten, for his diving assistance in the collection of the sea urchins and periwinkles and for his advice and friendship is also gratefully acknowledged. I am indebted to Terry Mills, operator and owner of Thimble Bay Farms, at the Charles Arm site, for providing a research site, a boat and barge to work from as well as the farm personnel (Dave, Rick and Roger Bret and Darren Mills) to work with. Terry also supplied all of the site equipment and supplies such as fuel, ropes, pearl nets and scallops as well as invaluable information on the farm, and its day-to-day activities.

My final thanks are for my family, most importantly, to my sister Debbie and my brother in-law Brian, who have seen me through many stages of my academic career including this study. They gave me a roof over my head and a place to lay it, as well as putting up with my samples and sampling equipment. Last, but certainly not least, I would like to thank my parents, Roy and Viola, who would never hesitated for an instant

when help of any kind was needed, and thanks Dad for the extra pair of hands you provided down on the site.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

The number of marine plants and animals that have been recorded as fouling organisms ranges from 2000 to 4000 and occurs as a result of the settlement and growth of sedentary and semi-sedentary organisms on artificial structures placed in water (Crisp 1974). Marine fouling communities include a variety of microorganisms such as bacterial slimes, microalgae, macroalgae and macroinvertebrates. The larger species, particularly those with calcareous bodies as well as the seaweeds provide habitats and food for other associated organisms (Osman & Whitlatch 1995). The serious economic consequences of algae in marine biofouling, and the constant search to prevent it or minimize its effects, have challenged anti-fouling strategists for as long as the oceans have been in use to mankind (Benson *et al.* 1973).

Fouling is thus a major problem for marine submerged surfaces, and aquaculture equipment is no exception, with floating cage culture, using nets and suspended nets in the water column, being particularly vulnerable (Porter 1981, Dubost *et al.* 1996, Hall 1996). Multi-filament netting material favored by the industry is an ideal substrate for fouling. It is non-toxic, especially as used in shellfish aquaculture, has a high surface to volume ratio, and rough surfaces that may entrap propagules and protect developing organisms. In addition, the fouling of aquaculture enclosures by algae will be enhanced by the nutrients from excretion and production of fecal material. Finfish farms are also nutrient enriched from feed wastage (Hodson *et al.* 1997).

One problem associated with biofouling on aquaculture nets is physical loading, which is especially important when materials are removed from the water for examination and harvest. The algal fouling of aquaculture nets contributes to the fatigue

and failure of immersed topside equipment that may lead to the escape/loss of shellfish. However, the most important aspect is the restriction of the flow of water through netting, and consequently, the reduction in the supply of dissolved oxygen, plankton as food for shellfish, and the potential build up of waste products. Hence fouling is an important growth limiting factor in suspension culture of many bivalves (Lee *et al.* 1983, Mallet & Carver 1991, Côté *et al.* 1993, 1994, Claereboudt *et al.* 1994, Hodson & Burke 1994, Hodson *et al.* 1997, Devaraj & Parsons 1997, Grecian *et al.* 2000). Filter feeding fouling species may compete for food with the scallops (Mook 1981, Lesser *et al.* 1992, Côté *et al.* 1993), while some algae have the potential for producing toxins, which may affect scallops (Shumway & Cembella 1993).

This study was undertaken at Thimble Bay Farms, Charles Arm, Notre Dame Bay, Newfoundland; this is an established blue mussel farm (*Mytillus edulis* L.), owned and operated by Terry Mills, which was in the process of moving into sea scallop (*Placopecten magellanicus* Gmelin) aquaculture. At the time of this study Thimble Bay Farms was one of two commercial farms in Newfoundland undertaking the aquaculture of sea scallops, the other was Shell Fresh Farms Ltd., located at Pool's Cove (47° 42' N, 55° 25' W) at the head of Fortune Bay, on the south coast of Newfoundland. A study by Grecian *et al.* (2000) at Shell Fresh Farms included measures of fouling biomass and its affects on scallop growth and mortality.

Placopecten magellanicus is a sub-tidal benthic suspension feeder ingesting a supply of seston that includes small zooplankton, phytoplankton, algal propagules, spores and detritus (Shumway *et al.* 1987). Growth and survival can vary from site to site, and from year to year, and some individuals are known to live up to 20 years (MacDonald &

Thompson 1988). The environmental factors affecting mortality and growth rates in scallop culture are seasonal parameters such as temperature, food availability, salinity and fouling (Claereboudt *et al.* 1994, MacDonald & Thompson 1985a,b, Grecian *et al.* 2000). In culture, however, other activities carried out by the grower may also affect growth and survival, including size at grow out, depth of deployment, culture method, mesh size, type of gear and time of deployment (Dadswell & Parsons 1991, 1992, Parsons & Dadswell 1992, Couturier *et al.* 1995, Grecian *et al.* 2000). Commercial sized scallops (~80 mm) are normally reached between three and five years of age (Black *et al.* 1993). It takes four years of growth to reach commercial size in Charles Arm (Mills pers. com.). This is ample time for the development of extensive biofouling on pearl nets.

A preliminary survey of the study site, as well as information from the owner and workers, determined that the principal fouling organisms at the Charles Arm site were macroalgae. Over time, operators have come to recognize seasonal changes in fouling, which are generally categorized in three phases. An initial early spring growth often referred to as "slub", which consists of diatoms and small filamentous algae, together with a catch of laravacean houses in more open waters (Taggart & Frank 1987). The late spring growth of "brown hair grass" is primarily of ectocarpalean filamentous algae, followed by a fall growth of "red weed", collectively, but often erroneously, identified as "*Polysiphonia*". In New Brunswick, farmers have also indicated similar patterns of fouling have occurred usually at the same time each year (Hall 1996). These observations by farm operators are a source of operationally relevant fouling data i.e. traditional ecological knowledge, which is a valuable starting point for studies such as this one.

While copper based antifoulants are still available to finfish farmers, shellfish growers have always had to rely on physical methods to manage fouling. This is due to the sensitivity of bivalves to heavy metals as well as the potential for their accumulation in such filter feeders (Enright *et al.* 1983, 1993). Furthermore, antifouling treatments that use metal-based toxins are ineffective against masses of drifting algae that become entangled in netting (Finlay & Callow 1996). Even when their use is appropriate, antifoulants have a limited life span, and treated substrates are eventually colonized by a variety of micro- and macro-organisms (Hodson & Burke 1994, Hodson *et al.* 1997).

Depending on the type of facility, immersed nets are changed at regular intervals, monthly in salmon farms (Hall 1996) and, ideally, yearly at Thimble Bay Farms, although cost and other operational concerns frequently lead to longer immersion times (Mills pers. com.). Net changing incurs a major cost to the industry, necessitating the purchase of a large number of nets and the need for skilled net-changing/cleaning personnel. The handling and cleaning procedures are labour and capital-intensive and may cause damage to the type of net in use as well as to the farmed organisms (Dadswell & Parsons 1991, Parsons & Dadswell 1992).

The cost of control of biofouling is thus substantial, and in the USA in 1980 it was estimated that the total cost of all biofouling ranged from US$1.8 - 2.9 billion (Knox-Holmes 1993). In New Brunswick, Canada, in 1988, the costs of mechanical cleaning of net fouling on a 20-cage salmon farm were CAN$38,000 (Hall 1996). While at the Thimble Bay Farm, the operator, Terry Mills reported in 1996-1997 that the cost to change and clean pearl nets in one year was estimated at CAN$ 20,000. Therefore, the fouling related costs over a four year time period to bring approximately one million

scallops to a marketable size at Thimble Bay Farms would be CAN$80,000. The data obtained in this study suggest this would involve the removal of more than 100,000 kg wet weight of biofouling.

In the Atlantic Provinces of Canada, a small number of macroalgae have been recorded as fouling organisms. They are common members of the epilithic and epiphytic communities occurring in the vicinity of the sampling sites (Whittick *et al.* 1982, Hall 1996). This is not surprising given the numbers of macroalgae in the flora of the area that are reported as growing epiphytically and which should be equally adapted to grow on artificial substrates (South & Hooper 1980, Sears 1998).

The process of algal biofouling has been extensively studied on a number of substrates and initially depends on the formation of bacterial biofilms, followed by development of diatoms and other microalgae (Kawamura *et al.* 1988, Hodson & Burke 1994, Scott *et al.* 1996). One of the features of microalgal community development, particularly by diatoms, is the production of extracellular polymeric substances (EPS) in the form of stalks, tubes, and adhering films (Callow 1993). Macroalgal fouling may follow and it is this component that is the focus of this study. Initial development involves the settlement of propagules, such as spores, gametes and other vegetative structures, which may be enhanced by the initial presence of microalgal EPS. Settling macroalgal propagules also produce attachment EPS, which promotes adhesion until the growth of attachment organs such as basal rhizoids or other holdfast organs (Fletcher & Callow 1992, Callow 1993). While spores and gametes will contribute to fouling development, vegetative propagation by fragments of filamentous algae is also undoubtedly important. Nets may also catch vegetative algal fragments found in the

water column, but development of such entrapped fouling requires the production of attachment organs, these may be heterotrichous bases, rhizoids, or specialized horizontal stolons (Fletcher & Callow 1992). Coastal waters, with their rich seaweed flora, are a major source of algal fragments with the potential of forming attachment structures after recruitment on the net surfaces (Santelices 1990). Several species of algae in Newfoundland waters are known to propagate by vegetative fragmentation e.g. *Callithamnion corymbosum* (Whittick 1978). Other fouling species e.g. *Enteromorpha spp.* and *Ectocarpus spp.* are reported to propagate by fragmentation due to cleaning activities on ships hulls Fletcher & Callow (1992) and on aquaculture nets (Hodson *et al.* 1997). High-pressure water cleaning of equipment used at Thimble Bay Farms may therefore contribute in producing vegetative propagules. Nets may also become self-infecting as hydrodynamic loading will lead to break away of algal filaments capable of recruitment on other nets (Denny 1988).

However, while such vegetative propagation with, or without human aid, is undoubtedly present, fouling is also likely to be derived from spores and gametes released in to the water from the normal flora of Charles Arm and surrounding waters. Benthic algae in Newfoundland show considerable seasonal response of growth and reproduction, thus providing spores for seasonal settlement (South & Hooper 1980, Hooper *et al.* 1980 and Whittick *et al.* 1989). The fouling development would therefore be controlled by the availability of propagules and its growth to be similar to that shown in the epiphytic and epibenthic population.

While the propagules for colonization of the nets will come from the local algae it would seem unlikely that similar algal communities to those found on the local benthos

would develop. The nets are not a solid substrate as is the benthos, they are relatively small and flexible, above all they are isolated from the benthos, and any organisms that cannot attach firmly, will be unlikely to successfully maintain themselves on the nets. Suspension within the water column should, however, enhance the growth of fouling algae in reducing predation by benthic invertebrate grazers. Two such predators known to control the development of algal communities in the northwestern Atlantic are intertidal littorinids such as *Littorina littorea* (Lubchenco 1978, McQuaid 1996) and the subtidal green sea urchin *Strongylocentrotus droebachiensis* (Himmelman and Steele 1971, Breen & Mann 1976).

Littorina littorea is an omnivorous grazer with a radula that enables foraging in a range of habitats and feeding on a wide variety food resources, including both microscopic and macroscopic algae; it is thus a versatile opportunistic herbivore (Norton *et al.* 1990, McQuaid 1996). Littorinids may be selective feeders, preferring certain species of algae to others (Norton *et al.* 1990, McQuaid 1996). *L. littorea* consumes ephemeral green algae such as *Ulva lactuca* and *Enteromorpha intestinalis* in preference to more robust species, such as coralline algae and larger brown seaweeds (McQuaid 1996). However, there is evidence that sporelings and juveniles (<3cm) of larger seaweeds, such as fucoids, are more susceptible to grazing by *L. littorea* than the adult plants due to the lower levels of phenolics and other herbivore deterrent compounds (Norton *et al.* 1990, McQuaid 1996). *Littorina littorea* would thus seem to be an ideal agent to control algal fouling on pearl nets.

Another well studied algal predator, which greatly influences the structure of shallow water marine communities in the North Atlantic, is the green sea urchin

Strongylocentrotus droebachiensis (Himmelman & Steele, 1971, Breen & Mann 1976, Himmelman 1984, Himmelman & Nédélec 1990). Studies by Breen and Mann (1976) in Nova Scotia and by Himmelman (1984), and by Keats *et al.* (1990) in Newfoundland have shown that when urchins are removed from the inshore benthos, algae rapidly come to dominate the community. Both species are locally abundant at the Charles Arm site and thus their use would not create potential contamination problems, which might be associated with their importation from other sites.

Biological control is the utilization of other species to control the abundance of undesirable organisms and several experiments relating to aquaculture problems have been undertaken (Enright *et al.* 1983, Hidu *et al.* 1981, Newkirk *et al.* 1995). Enright *et al.* (1983) showed *Littorina littorea* to be an effective biological control agent for reducing algal fouling on juvenile European oysters (*Ostrea edulis* L.). A density of 200 *Littorina* /m^2 of 1 mm. mesh screens. Periodical visual inspections showed that the *Littorina* kept the mesh cleaner than those obtained with a weekly manual scrubbing of the screen (Enright *et al.* 1983). Enright *et al.* (1993) added hermit crabs as well as *Littorina* to control invertebrate and algal fouling on lantern net culture of *Ostrea edulis*. The major algal fouling organisms were *Ectocarpus* (90%), *Enteromorpha* (3%), *Ulva* (1%). The crabs were small enough to feed on the settling invertebrates, but too small to feed on the oysters. With the addition of the *Littorina* to the oyster trays, the oysters showed a 30% increase in growth rate when compared to a control. The growth of the oysters reared in the lantern nets with hermit crabs for twelve months was 10-60% greater than oysters reared in a control with out the hermit crabs.

In the present study fouling development has been followed on pearl nets over a two year period, both quantitatively to determine biomass development, and qualitatively to determine which species contributed to the fouling biomass, and whether these changed seasonally. In addition to providing baseline information on the nature and seasonality of the fouling development it was hoped that this study would provide information which might be incorporated into formulating net changing and/or cleaning strategies.

In addition to the fouling development studies, experiments were undertaken to determine the efficacy of the use of snails (*L. littorea*) and urchins (*S. droebachiensis*) to reduce fouling, and to determine if these treatments had any affect on scallop growth and mortality. However, a confounding problem that occurred during this study was the still unexplained mass die off of scallops in Charles Arm, in 1998. This also occurred at the Shell Fresh Farm site in 1999(Mills pers. com.). The loss of over two million scallops caused the operator of Thimble Bay Farms to abandon scallop aquaculture and to expand the core mussel farming operation.

MATERIALS AND METHODS

Study site

This study was conducted between June 1998 and July 2000. The experimental site was a commercial shellfish farm (Thimble Bay Farms, owned and operated by Terry Mills). Thus the sampling protocols and experiments were designed and implemented around its day-to-day operations, which were primarily to produce blue mussels (*Mytillus edulis*), together with a diversification into the production of scallops (*Placopecten magellanicus*).

The farm is located in Charles Arm (49° 21.7' N 55°17.2' W), which is a semi-enclosed, inlet of Notre Dame Bay, on the northeastern coast of Newfoundland, Canada, (Figure 1). It is a small (69 hectares) shallow, calm, and partially muddy inlet 3.1 km in length; it averages approximately 100m in width and is 50m wide at its narrowest. The maximum depth is 14 m and the water volume at low tide is 3.7×10^6 m^3 (Mills pers.com.). Mudflats border the east side of the inner arm and the basin's bottom is covered with fine silt. Freshwater input is from several streams and there are also submarine springs in the experimental area (Mills pers. com.). Previous dye testing showed a counter clockwise movement of surface water in the arm. The site begins to freeze over in late December producing a maximum ice depth of approximately 1m, the ice usually melts by the end of April and the site is usually free from arctic and pack ice.

Environmental data

Temperature and salinity were recorded using a Seabird SBE 25-03 Sea logger CTD at approximately monthly intervals, but with more limited measurements when the site was ice covered; the sampling dates are shown in Figures 5 and 6. Continuous seasonal temperatures were also recorded using a VEMCO 8-bit Minilog-TR

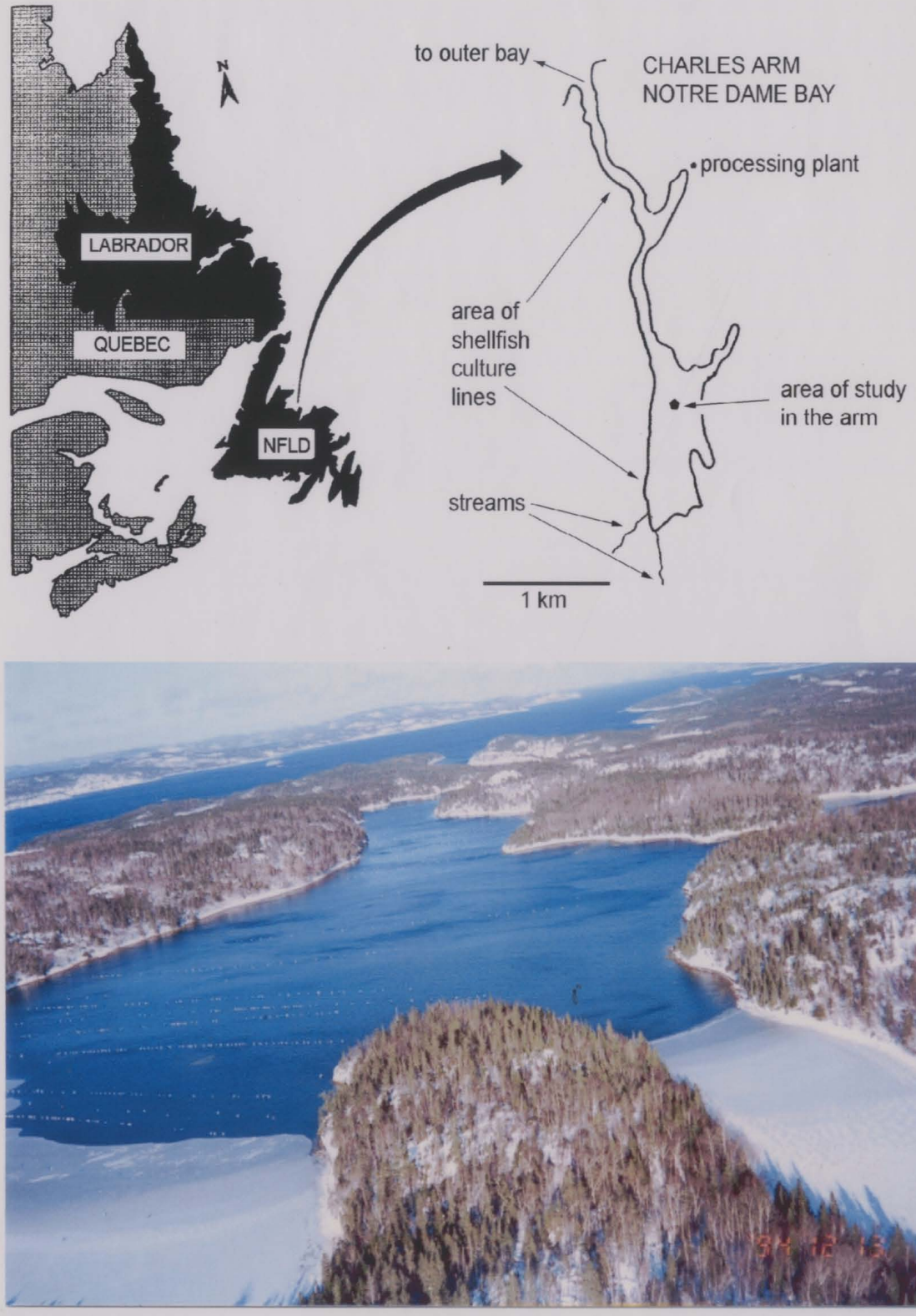


Figure 1. Sample site in Charles Arm, Notre Dame Bay, Newfoundland (49° 21.7 'N 55° 17.2 'W).

thermograph set at 2m for the years 1998-2000.

The study substrate – pearl nets

The study substrates were side loading pyramidal pearl nets (Figures 2a and 2b), i.e. with four triangular sides and 33cm on the base side, with a height of 33cm giving a total surface area of ca 0.325 m^2; the mesh size was 6mm. It proved impossible to remove all the fouling, with any degree of consistency from these nets, therefore, fouling biomass was estimated from wet weights of fouled nets minus the wet weight of an unfouled net.

Pearl nets were weighed with an Acculab V-1200g top pan balance to a precision of 0.1g. The average wet weight of clean nets was calculated by soaking the nets in seawater, shaking off the excess water and then allowed to drain for one minute prior to weighing. No facilities were available at the Charles Arm site to obtain dry weight measurements of fouling biomass. However, some fouled pearl nets were air dried in order to provide data for comparison with other studies, where dry weight measurements of fouling organisms are given. Thirty-six fouled pearl nets were air dried to constant weight under sunny, windy and low humidity conditions at 25C.

Drops

At Thimble Bay Farms, the nets were attached together in a line of eight and suspended in a drop so that the upper net was at a depth of 2m and the lower at approximately 4m. For this study the two sample depths chosen were top and bottom nets i.e. shallow as at 2m and deep at 4m (Figures 2b and 3). The normal protocol for Thimble Bay Farms was to place 25 scallops (Year class of two, ~50-60 mm in length, Figure 4) in each pearl net and this procedure was followed for all nets examined in this study.

(A)

(B)

Figure 2. (a) A pearl net. (b) A single drop of eight pearl nets in a vertical row.

Each drop was suspended from a horizontal long line. In total there were 60 drops making a total of 120 sampled nets, 60 shallow and 60 deep. Thirty-six drops, with 72 sampled nets, 36 at 2m and 36 at 4m depths, were used to study seasonal growth of fouling biomass and also served as controls for the grazing experiments. Twelve of these 36 drops (August 1998) and (May 1999) were also used as controls for the grazing experiments. Twelve drops (24 nets in total, 12 at 2m and 12 at 4m) were used to examine the effects of grazing of *Littorina littorea* (snails) and 12 drops to examine the effects of grazing of *Strongylocentrotus droebachiensis* (urchins). The sequence of the arrangement of these experimental and control drops is shown in Figure 3.

Sampling dates

The experiment was conducted from April 1998 to July 2000. The fouling experiment was divided into six single study periods throughout the two-year period.

1. April 20th 1998. One hundred and twenty clean nets placed in water.
2. June 30th 1998. Twelve nets removed for fouling measurement and analysis. First grazing experiment of twelve snail and twelve urchin treatments begun by adding snails and urchins to fouled nets, which were in the water since April 20th.
3. August 26th 1998. Thirty-six nets removed. Including twelve for fouling measurement and analysis, which were also used as controls for the first grazing experiment. The first grazing experiment was terminated with the removal of the twelve urchins and twelve snail treatments.
4. November 4th 1998. Twelve nets removed for fouling measurement and analysis. Second grazing experiment begun with twelve snail and urchin treatments. Snails and urchins for experiment 2 were added to bags, which had been in the water since April 20th and were already fouled.

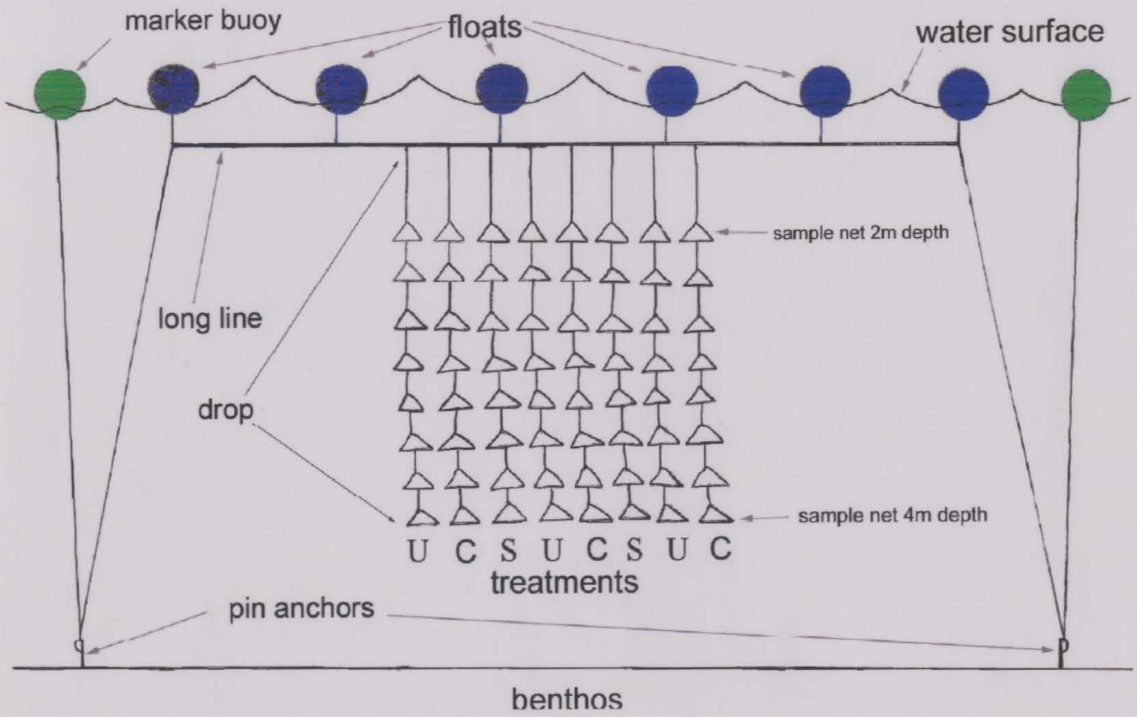


Figure 3. Arrangement of pearl nets and drops suspended from a horizontal long line. Each drop is a treatment, U = urchin (*Strongylocentrotus droebachiensis*), C = no grazers, and S = snail (*Littorina littorea*).

5. May 20th 1999. Second grazing experiment terminated. Sampling identical to August 26th 1998.
6. July 19th 1999. Twelve nets removed for fouling measurement and analysis.
7. July 27th 2000. Twelve nets removed for fouling measurement and analysis.

Sampling for fouling biomass

On removal from the water the nets were opened and the scallops, and grazers where appropriate, were removed and weighed as described above. The weight of the fouling was calculated by subtracting the mean wet weight of a fouled pearl net from that of a wet clean pearl net. Each net was photographed to provide a permanent record.

Sampling for fouling community analysis

Forceps were used to remove the fouling from three areas of each of the triangular sides of the pearl net. The bottom was usually free of fouling and was not sampled. The fouling samples were placed in vials, labeled with date, depth, and grazing treatment where applicable, and preserved in 4% formalin in seawater buffered with TRIS (Sigma-Aldrich, St Louis, Mo). Eosin was added as a marker to show that formalin had been added and the samples were stored at 5C until analysis. For laboratory examination, the contents of the vial were placed in Petri dishes and examined and sorted using a Olympus SZ40 stereomicroscope. Further detailed examinations of specimens were made using an Olympus BH-2 compound microscope. Preliminary examination confirmed that the fouling organisms were principally algae and Cyanobacteria. With the exception of occasional hydroids, bryozoans, sponges, tubeworms and mussel spat there were few invertebrates.

Algal specimens belonging to the divisions Chlorophyta, Phaeophyta and Rhodophyta were identified using available keys and Floras, Taylor (1957), South &

Hooper (1980), Bird & McLachlan (1992) and Sears (1998). Nomenclature and authorities follow Sears (1998). There are no reliable keys for the Cyanobacteria of the region and these were identified to morphological form using the keys and illustrations of Humm and Wicks (1980). It is realized that such names may not identify valid biological species. The colonial diatoms of the region were identified using the keys of Lobban (1984).

In order to obtain a quantitative weighting for the fouling rather than just presence and absence data, estimates were made of the abundance of each species in each sample vial. Based on abundance each species was placed in one of five categories.

(1) Present <1%,

(2) 1-10%,

(3) 10-30%,

(4) 30-60%.

(5) >60%.

For the TWINSPAN (Two-way Indicator Species Analysis) and DECORANA (Detrended Correspondence Analysis) procedures, species weighting was achieved by multiplying the percentage obtained from each sample by the total weight of the fouling on the sampled net. These were then scaled to percentage by taking the heaviest net and expressing all values as a percentage of this, thus ensuring that the maximum value could be 100%. After identification all samples were returned to their vials and deposited as voucher specimens in the Memorial University of Newfoundland algal herbarium (MUN).

Data analysis

Univariate analysis was undertaken using the Minitab Version 12 using various ANOVA models (see results) to test the effects of time, depth and grazers on fouling biomass. These data as means and 95% confidence error bars are also presented graphically. The effects of the treatments on scallop mortality are treated in a similar manner. Two multivariate techniques were used to visualize the fouling community: DECORANA and TWINSPAN (Gauch 1982, Kershaw & Looney 1985). The program used in this study was written by Hill (1994) for use on DOS based IBM PC's. Both DECORANA and TWINSPAN have found wide use in descriptive plant ecology, and are particularly useful when the data is in the form of large sparse matrices. A simple description of the use and interpretation of these techniques can be found in Kershaw and Looney (1985).

DECORANA is an eigenvector method similar to Principle Component Analysis. The output is similar to PCA with components that are extracted orthogonal to each other, and with first axes accounting for the largest component of the variance. Unlike PCA, which only examines linear relationships between species DECORANA can account for higher order relationships. This supposedly removes the problems associated with so called "horseshoe" effects, which arise when non-linear data are plotted against each other on a linear scale; this makes the interpretation of the data easier (Gauch 1982).

TWINSPAN is a form of cluster analysis, which unlike the usual cluster analyses based on hierarchical clustering of appropriate distance or similarity measures, is a polythetic divisive method. The original data set is divided into smaller units based on a group of attributes rather than a single attribute, in this instance a group of species or samples. Both species and samples are clustered in this technique, and the data are presented as a matrix with species clusters on one axis and sample clusters on the other. TWINSPAN is dependent on the creation of "pseudospecies" for analysis, based on the abundance of a species. This requires that the investigator provide "cut levels" prior to

the analysis, this is an arbitrary decision based on the structure of the data and the ease of interpretation of the subsequent output. In this instance the input data, based on the species abundance within the samples, had been scaled to a percentage as described above. Four cut levels were chosen at 0-1%, 1-10%, 10-50%, and 50-100%, for the analysis of the changes in algal community over the two-year period, and four cut levels at 0-1%, 1-20%, 20-50%, and 50-100% for the changes in algal community for the grazing experiments (Gauch 1982, Kershaw & Looney 1985, Hill 1994).

Grazing experiments

Two sets of experiments were undertaken to determine the effectiveness of two algal grazers, urchins (*Strongylocentrotus droebachiensis*) and periwinkles (*Littorina littorea*) in preventing fouling buildup on the pearl nets. These were conducted from June 1998 until August 1998 and from November of 1998 until May 1999 respectively. In the case of the snail treatment 75 individuals were added to each net along with the 25 scallops. This number was chosen based on the recommendation of 200 individuals per square meter and was based on a pearl net surface are of approximately $0.325m^2$ (Enright *et al.* (1983). A single urchin was placed together with the 25 scallops in the experimental pearl nets. It had initially been expected that the first experiment would run until November 1998, but it was terminated due to a massive die off of scallops in August 1998. At Thimble Bay Farms over one million scallops died at this time; the cause of which is still unknown and no previous mortality of scallops on this scale had occurred in the previous 12 years during the operation of the farm.

At the end of the experiments the nets were removed, and treated in the same manner as those used to determine increase in fouling biomass and species composition. The only difference being that the snail and urchins were removed along with the scallops prior to weighing.

Scallop growth measurements

In addition to measuring the effects of snails and urchins in controlling pearl net fouling, their effect on the growth of the scallops was also measured. All juvenile scallop spat used for culture at Charles Arm and at the time of the study were obtained from the Belleoram Sea Scallop Hatchery (BSSH) in Belleoram (47^{o} 32' N, 55^{o} 25' W). Scallop lengths were measured by using vernier calipers (Mitutoyo Digamatic) and were recorded to 0.01mm. The normal growth parameter measured at Thimble Bay Farms is the length measured from the hinge or "ear" to the ventral margin of the shell (Figure 4). Nine hundred scallops in the grazing experiments, including urchin, snails and controls, were measured at the beginning of the experiment and again at the end. Unfortunately given the time constraints and the operational activities of the farm it was impossible to tag individual scallops, which would have allowed greater precision in the measurement of growth. All scallops were alive at the beginning of the experiment and the number that had died was noted at the end of the experiment.

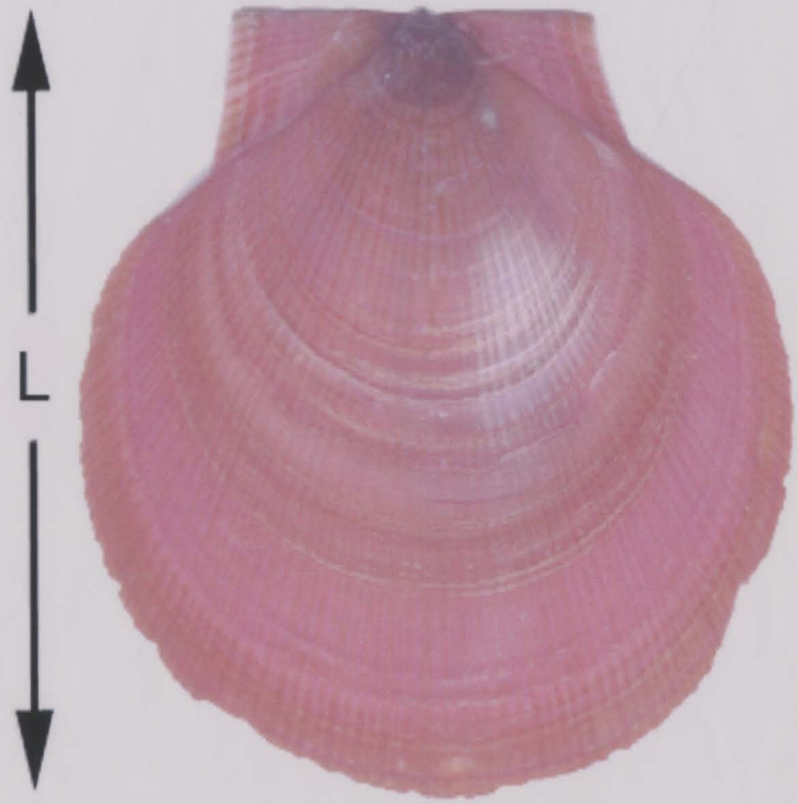


Figure 4. External view of a sea scallop *Placopecten magellanicus* from year class two, indicating the shell length as measured from the ventral margin to the dorsal hinge. For this specimen L=50 mm.

RESULTS

Environmental data

Measurements of water temperature and salinity for Charles Arm, Notre Dame Bay, for three years (1998-2000) spanning the six study periods, are presented in Figures 5 (thermograph) and 6 (CTD). Figure 5 shows a continuous water temperature record from a thermograph immersed at 2m depth from January 1998-November 2000. Water temperature varies from a maximum of 20C in July, August and September to a minimum of minus one to minus two celsius in February, March and April. The same trends in temperature occur each year. An unusual spike in temperature in August 2000 is attributed to the brief removal of the thermograph from the water during farm operations. Figure 6 shows the change in water temperature and salinity over the same period at 2m and 4m depths, based on CTD records. The same seasonal trends can be seen in the water temperature at 2m depths as in Figure 5, with similar trends at the 4m depths. There is little change in salinity over the three-year period, which remained at approximately 30 ISU throughout the study.

The fouling organisms

Fouling communities were composed mainly of algae from the three divisions Chlorophyta, Phaeophyta and Rhodophyta, together with members of the Cyanobacteria and Bacillariophyceae. Some macro-invertebrates occurred, principally composed of small mussels (*Mytilus edulis)* and various colonial hydroids, but were only a minor role component of the overall fouling community. A total of 88 algal and cyanobacterial species were identified comprising 10 species of the Chlorophyta, 24 species of the Phaeophyta, 19 species of the Rhodophyta, 33 species of the Cyanobacteria and two

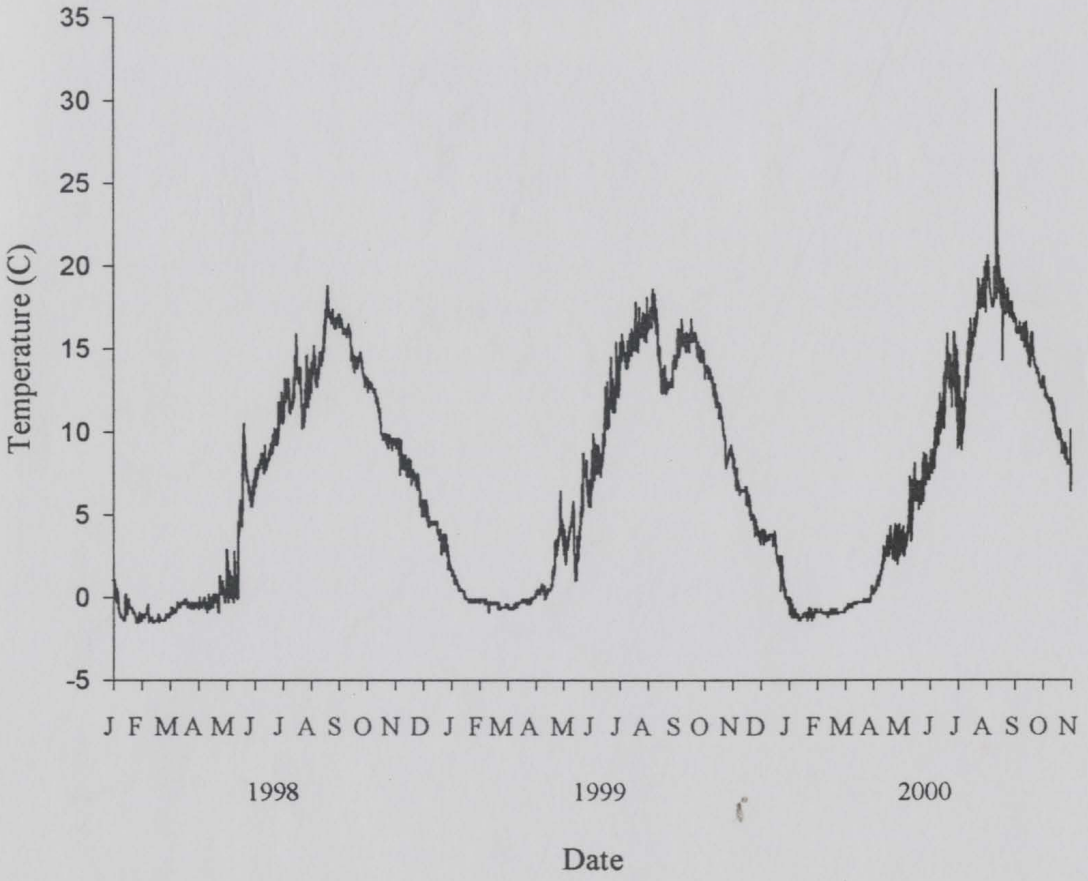


Figure 5. Continuous water temperature record from January 1998-November 2000, data from a VEMCO 8-bit Minilog-TR thermograph set at 2m depth.

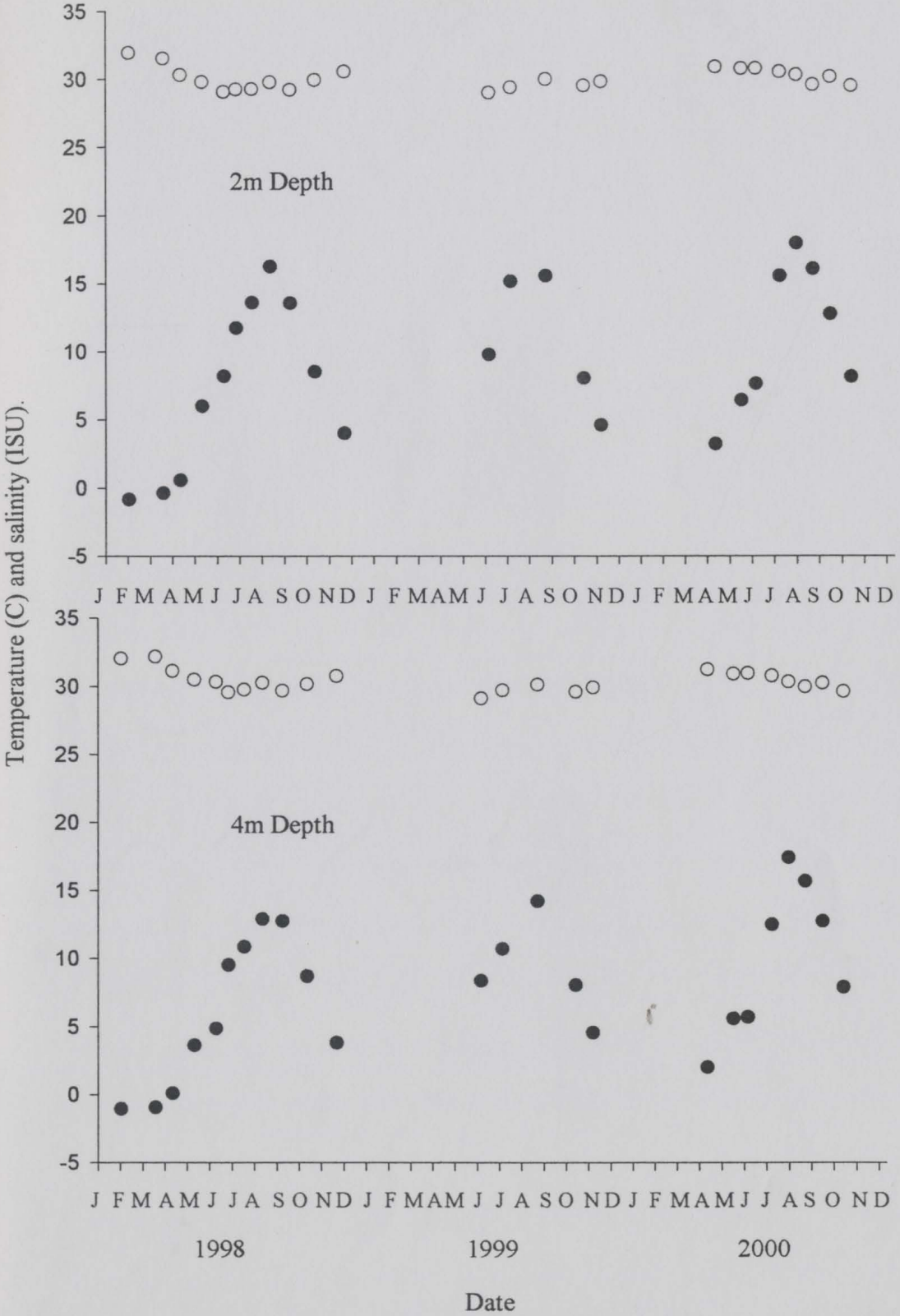


Figure 6. Temperature ● (C) and salinity ○ (ISU) in Charles Arm at 2m and 4m depths from February 1998-November 2000, data from a Seabird SBE 25-03 Sea logger CTD.

species of colonial diatoms (Bacillariophyceae). A systematically arranged list of these together with their authorities, seven-letter code for DECORANA and TWINSPAN analyses, as well as time and depth of occurrence is given in Appendices (Tables A1-A8).

Fouling biomass

The average dry weight of the pearl nets (N=10) was 149.2 ± 0.73g and the average wet weight (N=10) was 192.8 ± 2.98g. The development of fouling on the pearl nets is illustrated in Figure 7. These fouled nets clearly show a change in abundance of fouling organisms. Nets A, C, E, are typical of those from shallow water June, August, and November 1998 respectively. In addition to showing increase in biomass, they also show that there is a greater abundance of fouling organisms, than the comparable deeper water samples on nets B, D, F. Differences between nets G and H (samples for June 1999) are not as obvious as earlier samples such as A and B.

Table 1 shows a two-way analysis of variance (ANOVA) of fouling biomass with time and depth as treatments. Examination of residual plots showed the initial data to be normally distributed. Both depth and time are significantly different, but depth and time interaction is not significant. The means and 95% confidence intervals for each sample at the two depths (2m and 4m) are presented in Figure 8. These graphs show fouling biomass increases with time for the first year, to reach a maximum, at both depths, of approximately one kilogram wet weight per pearl net, but no significant increase occurred in the second year; this is seen at both 2m and 4m depths. During early development June 1998-November 1998 the 2m depth nets show greater fouling biomass than those from 4m depth. This difference is not seen after one and two years immersion.

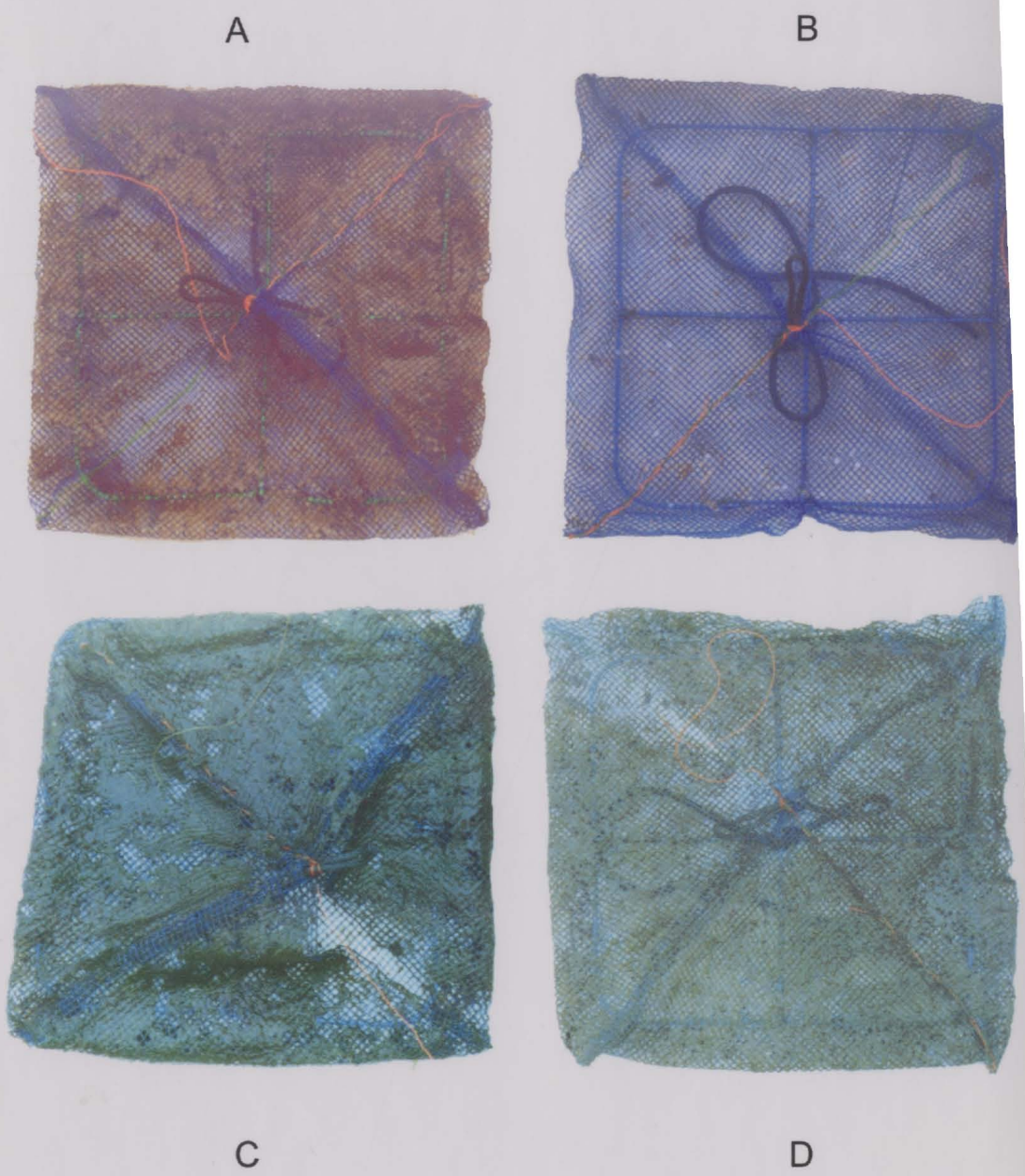


Figure 7a. Fouled pearl nets. (A) June 1998, at 2m depth, (B) June 1998, at 4m depth, (C) August 1998, at 2m depth, (D) August 1998, at 4m depth.

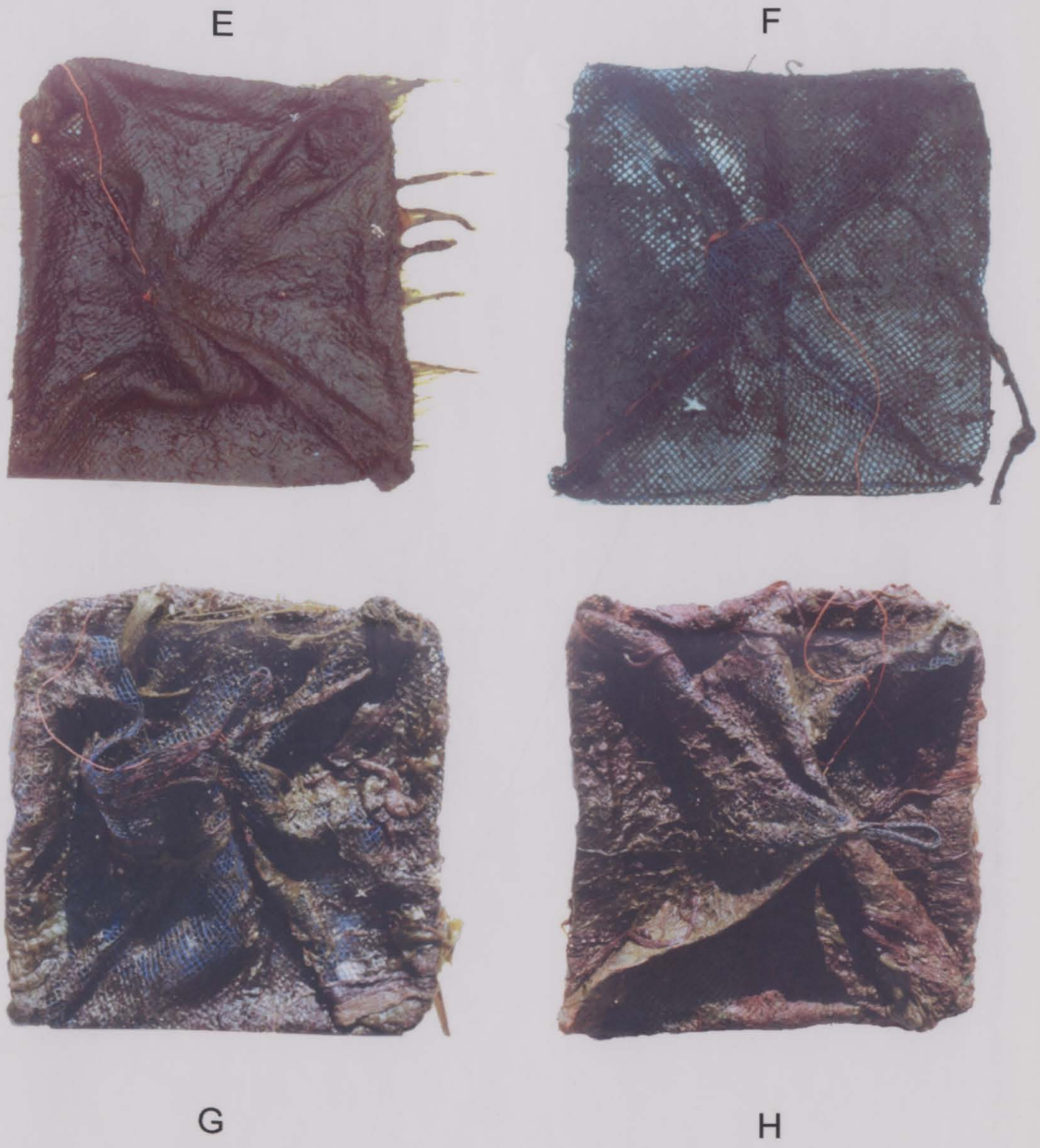


Figure 7b. Fouled pearl nets. (E) November 1998, at 2m depth, (F) November 1998, at 4m depth, (G) May 1999, at 2m depth, and (H) May 1999, at 4m depth.

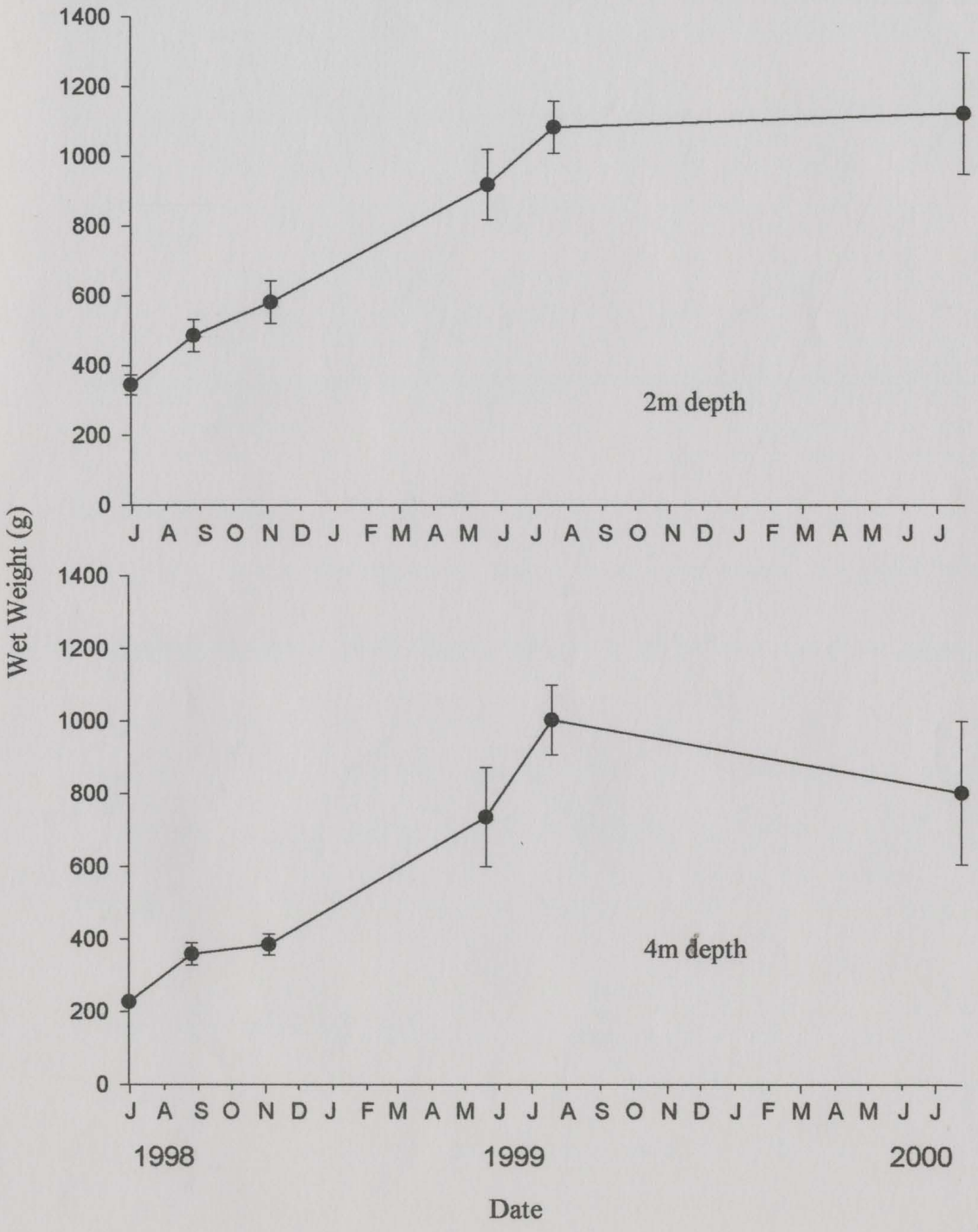


Figure 8. Algal biomass on pearl nets at 2m and 4m depths over the experimental period from June 1998 - July 2000. Error bars are 95% confidence intervals. N=6.

Table 1. Analysis of variance (Balanced ANOVA, p=0.05) of algal biomass over the two-year study period (date) April 1998- July 2000 at 2m and 4m depths (depth) and interaction between date and depth.

Study Period	Source	DF	SS	MS	F	P
April 1998	Date	5	6116290	1223258	36.19	0.000
July 2000	Depth	1	624720	624720	18.48	0.000
	Date x Depth	5	137477	27495	0.81	0.545
	Error	60	2028150	33803		
	Total	71	8906637			

Fouling dry weight

The data from the thirty-six fouled pearl nets, which were air-dried, is presented in Figure 9, as a plot together with the regression equation

$$\text{Dry weight} = 9.89 + 0.11 \text{wet weight}$$

with $r^2 = 0.88$. While data in this thesis are presented and discussed as wet weights, the equation was used to convert the wet weight measures for comparison with fouling data published as dry weights.

Fouling community structure

The results of DECORANA analysis for the algal biofouling data is based on the analysis of the 72 pearl nets from the two-year experimental period, using the first two extracted axes, are given in Figure 10. The 72 samples are seen as six groups of twelve points, which are delimited and highlighted in colour for clarity. Group one shows the June 1998 sample, group two the August 1998 sample and group three the November 1998 sample. These groups show relatively little overlap. Groups four, five and six are

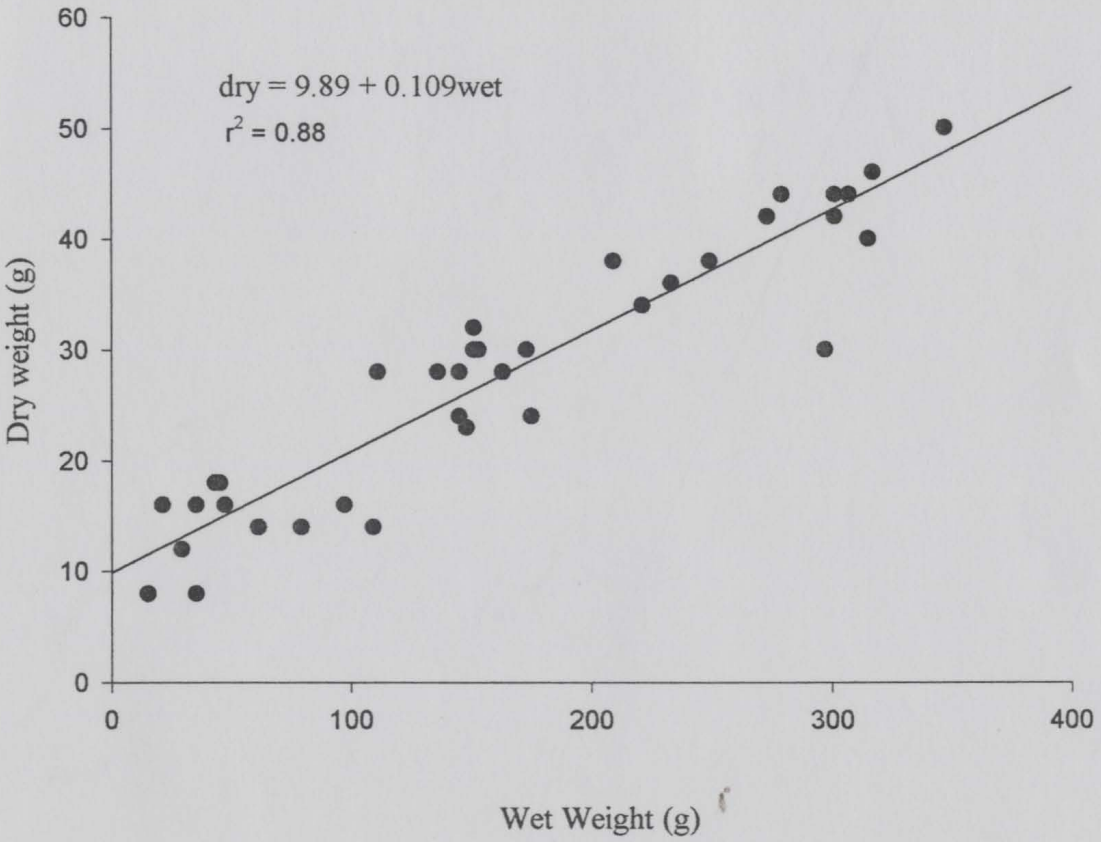


Figure 9. Regression plot of pearl net wet weight vs. dry weight.

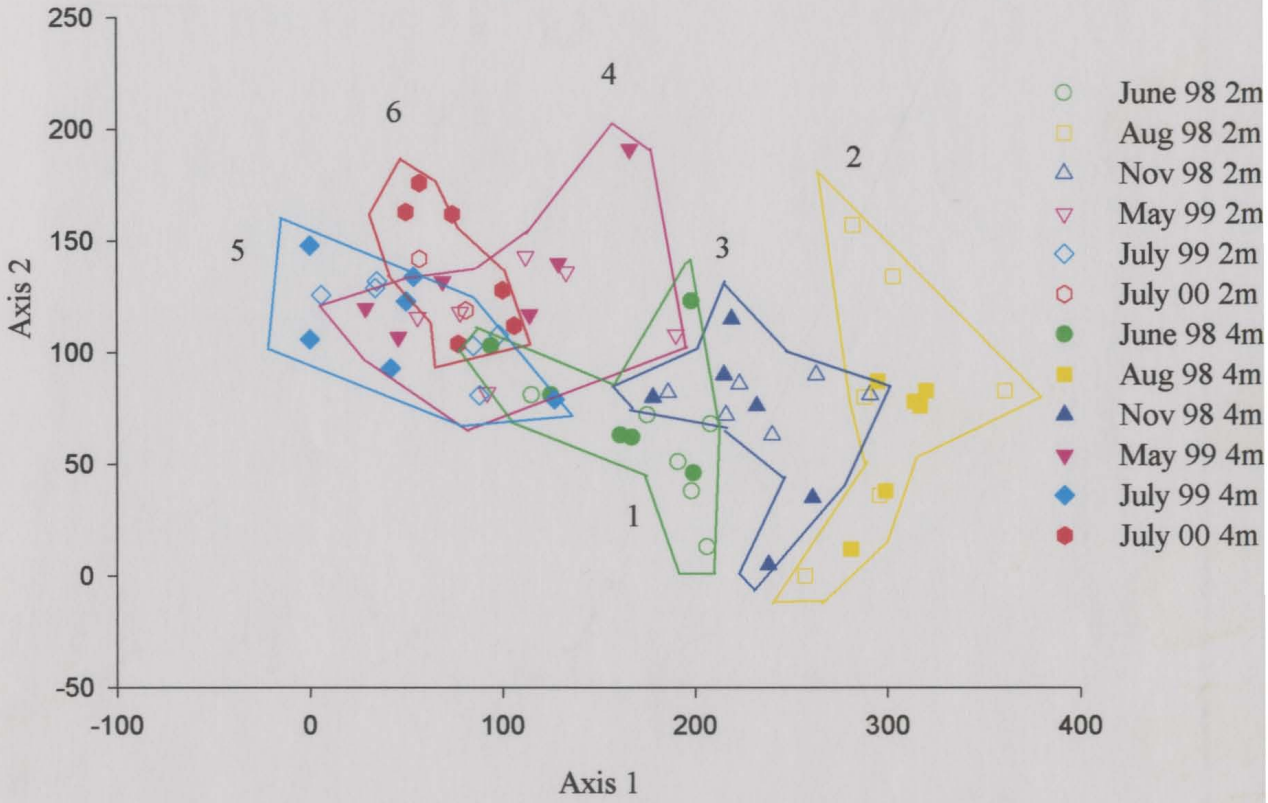


Figure 10. DECORANA plot of algal fouling at 2m and 4m depths over the two-year study period. The numbers delimit the sampling dates: 1=June 98, 2=Aug 98, 3=Nov 98, 4=May 99, 5=July 99, and 6=July 00.

samples from May 1999, July 1999 and July 2000 respectively, they show considerable overlap, while being distinct from Groups 2 and 3, but showing some similarity with Group1. Each group of 12 points consists of six 2m samples (open points) and six 4m samples (closed points); there is no indication of separation of points with depth.

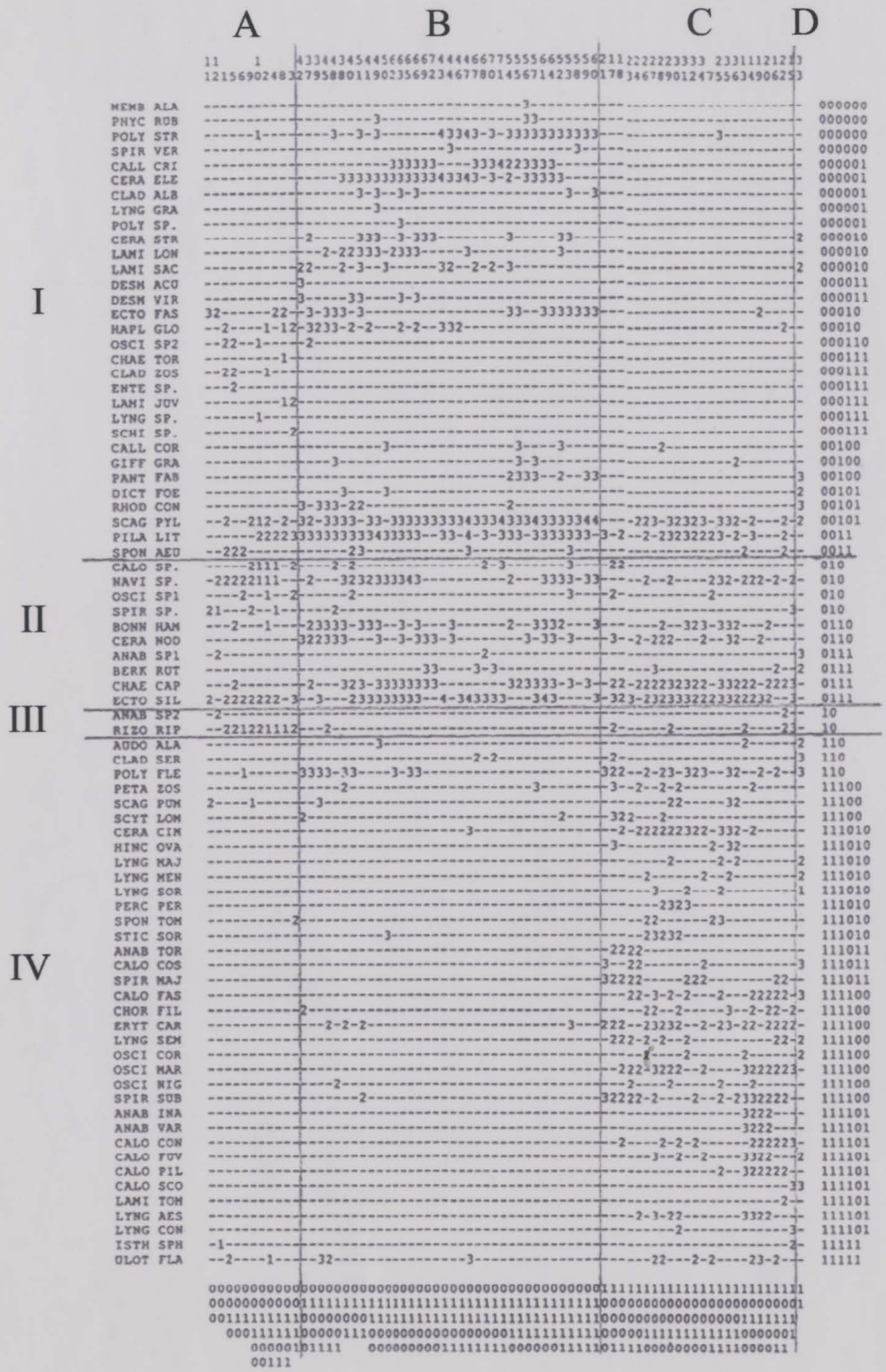
Table 2 shows the TWINSPAN analysis of the same data. At the top of each table are the sample numbers. Each sample represents the data from a single pearl net with six sample periods, and six sample replicates at each of the two depths making a total of 72 samples in all. These data are those presented in the previous DECORANA. In addition, the species found in the samples are presented on the vertical axis of the table. The seven letter name codes for the species are given on the left of the table, the keys to these can be found in the Appendix, Tables A1-A4. Number values in the TWINSPAN table refer to abundances, and are based on the four cut levels chosen for the analysis, - indicates absence of the species. At the bottom and to the right of each table, the hierarchical divisions (in binary notation) are indicated. The major divisions are highlighted by horizontal and vertical lines drawn on the table, this divides the table into blocks of species associated with samples and allows for clearer description of the groups. Both vertical lines and horizontal lines separate classes of samples and species based on the second cluster level. Hill (1994) recommends a maximum of six levels for interpretation, but the final decision as to when and where to halt the dichotomy is subjective, depending on the ecological interpretation of the sub-groupings. The investigator is also free to interpret other minor patterns in the table, which may occur at lower cluster levels (Gauch 1982, Kershaw & Looney 1985).

For description of Table 2, the three columns are labeled A, B, C. Column D, which is not delimited, comprises the single sample 33. In similar manner horizontal

Table 2. TWINSPAN table of algae fouling pearl nets. Samples from two depths shallow (2m) and deep (4m), and six dates. June 1998, August 1998, November 1998, May 1998, July 1999 and July 2000. Numbers are cut levels corresponding to algal abundance, - = absence, 1= <1%, 2 = 1-10%, 3 = 10-50%, 4 = >50%. Seven-letter codes on left of table are species names (see Appendix A1-A4 for key). Numbers are at top of table are codes for the individual pearl nets samples (see key below). Numbers to right of the table show cluster dichotomies to six levels for the species, and numbers at the bottom of the table to six levels for the species. For ease of interpretation lines are drawn to delimit the table into blocks showing the first two dichotomies for both species and samples.

Legend for sample dates:

1 June 1998 2m
2 June 1998 4m
3 June 1998 2m
4 June 1998 4m
5 June 1998 2m
6 June 1998 4m
7 June 1998 2m
8 June 1998 4m
9 June 1998 2m
10 June 1998 4m
11 June 1998 2m
12 June 1998 4m
13 August 1998 2m
14 August 1998 4m
15 August 1998 2m
16 August 1998 4m
17 August 1998 2m
18 August 1998 4m
19 August 1998 2m
20 August 1998 4m
21 August 1998 2m
22 August 1998 4m
23 August 1998 2m
24 August 1998 4m
25 November 1998 2m
26 November 1998 4m
27 November 1998 2m
28 November 1998 4m
29 November 1998 2m
30 November 1998 4m
31 November 1998 2m
32 November 1998 4m
33 November 1998 2m
34 November 1998 4m
35 November 1998 2m
36 November 1998 4m
37 May 1999 2m
38 May 1999 4m
39 May 1999 2m
40 May 1999 4m
41 May 1999 2m
42 May 1999 4m
43 May 1999 2m
44 May 1999 4m
45 May 1999 2m
46 May 1999 4m
47 May 1999 2m
48 May 1999 4m
49 July 1999 2m
50 July 1999 4m
51 July 1999 2m
52 July 1999 4m
53 July 1999 2m
54 July 1999 4m
55 July 1999 2m
56 July 1999 4m
57 July 1999 2m
58 July 1999 4m
59 July 1999 2m
60 July 1999 4m
61 July 2000 2m
62 July 2000 4m
63 July 2000 2m
64 July 2000 4m
65 July 2000 2m
66 July 2000 4m
67 July 2000 2m
68 July 2000 4m
69 July 2000 2m
70 July 2000 4m
71 July 2000 2m
72 July 2000 4m


A
B
C
D
I
II
III
IV

lines producing blocks labeled I to IV divide the species. The first vertical division is between samples 3 and 42, the second occurs between samples 60 and 21 and between 15 and 33. This divides the table into four columns A, B, C. and D. Column A comprises the first samples obtained in June 1998, B are samples from May 1999, July 1999 and July 2000. Column C is samples from August of 1998 and November of 1998. D is a single sample from November 1998. As in the DECORANA analysis, the TWINSPAN analysis shows differences between sampling times, but no obvious differences between depths.

The species of blocks I and II are horizontally divided between *Spongomorpha aeruginosa* and *Calothrix spp.* Blocks II and III are divided between species *Ectocarpus siliculosus* and *Anabaena spp.*2, while blocks III and IV are divided by species *Rhizoclonium riparium* and *Audouinella alariae.* The species in block I show those species primarily found in the samples from May 1998 and May 1999 through July 2000, but which are not characteristic of the intermediate sampling times of August and November 1998. Species of block II shows those species that are found in relative abundance throughout the study period. An anomaly is that some species in block I, notably *Scagelia pylaisaei*, and *Pilayella littoralis*, appear to be candidates for inclusion in block II. Block III contains *Rhizoclonium riparium,* which might also be considered for inclusion in this group. Block IV is of species found principally in August and November 1998, but which only occur rarely in June 1998 and the later sampling periods of May 1998 through to July 2000.

Grazing experiment – the affect on fouling biomass

Figure 11 shows the affect of snails on fouling biomass with pearl nets selected to show the most striking differences. Figures A and B are nets from the beginning and end of the first experiment (June –August 1998), while C and D are from the beginning and

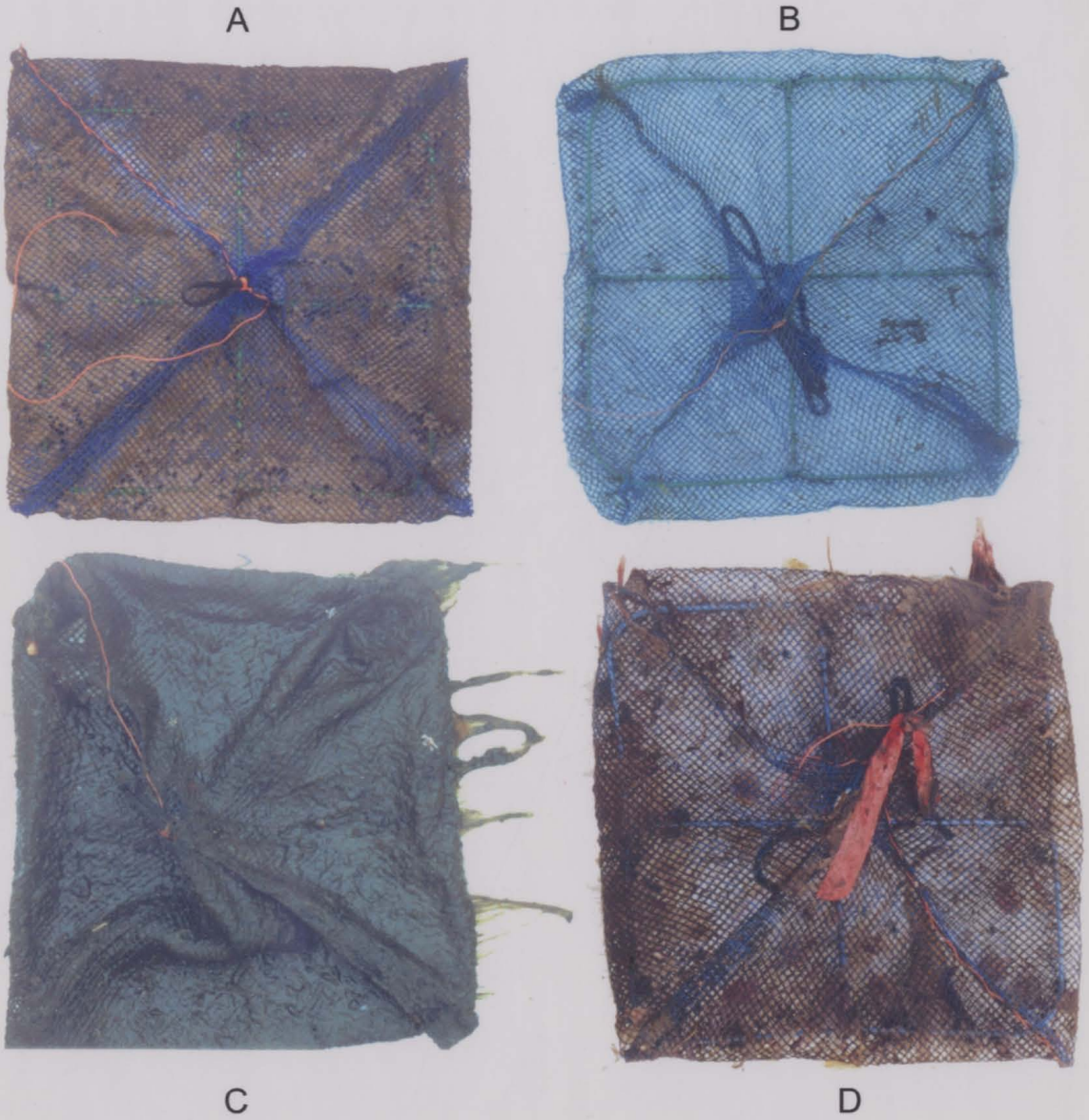


Figure 11. The effect of snail grazing on pearl net fouling selected showing the most striking changes in fouling biomass. Figures A and B are nets from the beginning and end of the first experiment, June 1998–August 1998 respectively, while C and D are from the beginning and end of the second experiment, November 1998–May 1999 respectively.

end of the second experiment (November 1998–June 1999). The difference between A and B is obvious while that between C and D is less marked.

The quantitative results of the effects of the experimental grazers, urchins and snails, on fouling biomass are presented in Table 3, which shows the results of two-way (treatment, depth, treatment x depth) ANOVA for the two experiments, on the affects of

Table 3. Analysis of variance (Balanced ANOVA, p=0.05) of algal biomass for grazing experiments of snails (*Littorina littorea*) and urchins (*Strongylocentrotus droebachiensis*) and their interaction with depth. Data for the two experiments June 1998- August 1998 and November 1998-May 1999.

Study Period	Source	DF	SS	MS	F	P
June-Aug 98	Depth	1	76544	76544	65.30	0.000
	Grazer	2	216544	108729	92.76	0.000
	Depth x Grazer	2	25275	12638	10.78	0.000
	Error	30	35164	1172		
	Total	35	354442			
Nov98-May 99	Depth	1	262144	262144	2.95	0.096
	Grazer	2	201297	100648	1.13	0.336
	Depth x Grazer	2	49309	24654	0.28	0.760
	Error	30	2669753	88992		
	Total	35	3182503			

grazers on fouling biomass conducted between June 1998 to August 1998. The second, over- winter experiment (Table 3) was conducted from November 1998 until May of 1999. For these analyses, the final biomass of the fouling is the measured value, the depths are 2m and 4m and the treatments are snails, urchins and the controls. The first experiment shows significant differences in fouling biomass with depth and with treatments. There is also a significant interaction between depth and treatments. In the

second over- wintering experiment, no significant differences were seen between depth, treatments and depth-treatment interaction. The results of these grazing experiments are presented graphically in Figure 12. In the controls of the first experiment (June – August 1998) there is significantly greater fouling at 2m than at the 4m depth. The snails produced a significant reduction in fouling biomass at both 2m and 4m, when compared to the controls. For the urchin treatments, at both 2m and 4m depths, there is no significant difference in fouling biomass. The data for the second experiment (November 1998- May 1999) shows that the mean fouling biomass is greater under all conditions than that of the first experiment, but as shown by the ANOVA, there are no significant differences between treatments or depths.

Affects of grazers on algal fouling community structure

The algal species occurring on the pearl nets at the end of the two experiments were examined in a similar manner to that of the fouling growth over the two-year period, and presented as a DECORANA plot and a TWINSPAN table. Each experiment consisted of 6 controls, 6 urchin treatments and 6 snail treatments, each at 2m and 4m depths, making a total of 36 samples. For the two experiments there were therefore 72 samples. Both experiments were analyzed together to determine if there were species differences between the fouling communities at the end of the two experiments as well as if any species differences occurred due to the treatments and the depth. The DECORANA plot using the first two extracted axes is given in Figure 13. Two distinct groups emerge, one containing the samples for the first experiment (August 1998) the other the second.

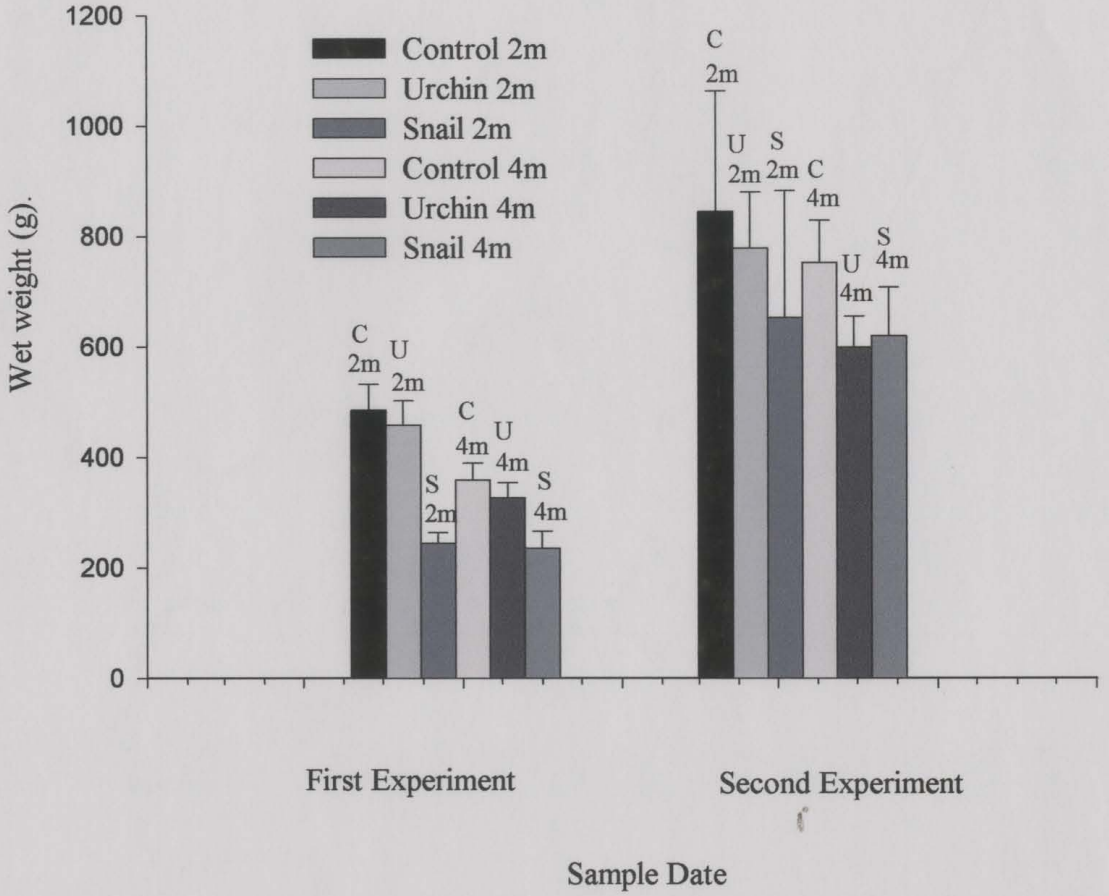


Figure 12. Algal biomass at 2m and 4m depths for control, urchin (*Strongylocentrotus droebachiensis*) and snail (*Littorina littorea*) treatments. Error bars are 95% confidence intervals. N=6. First experiment from June 1998-August 1998, and second experiment from November 1998-May 1999.

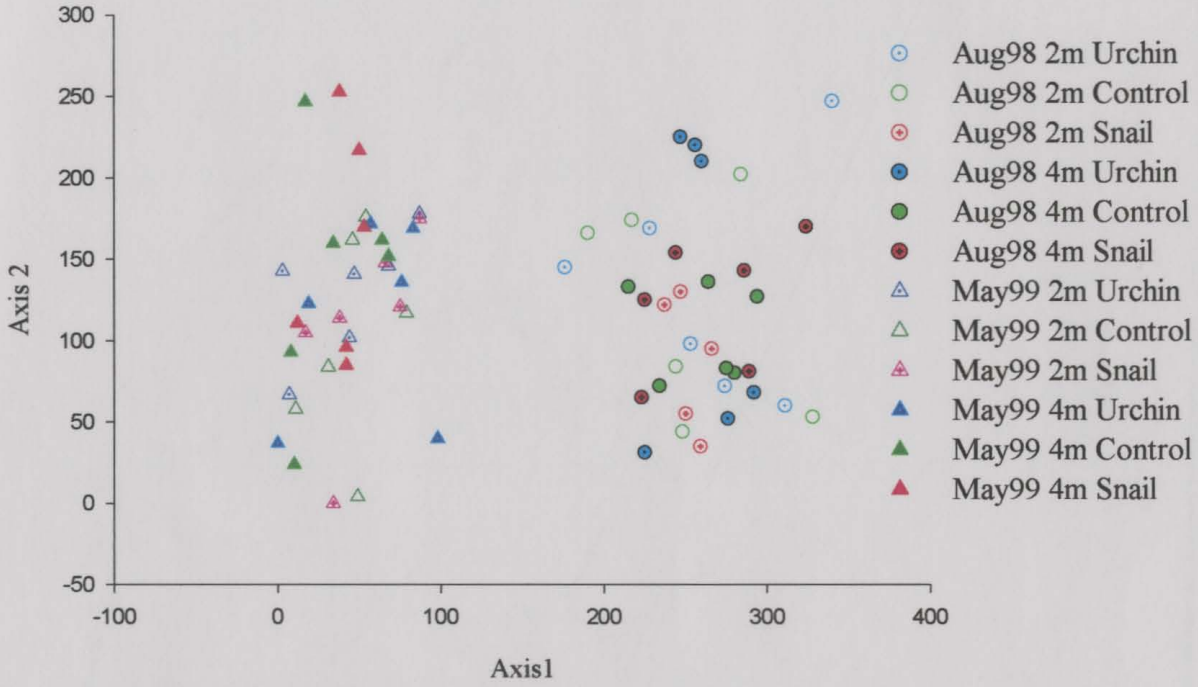


Figure 13. DECORANA plot of algal fouling to show the affects of grazing by urchins (*Strongylocentrotus droebachiensis*), and snails (*Littorina littorea*), together with controls, on fouling species composition at 2m and 4m depths, sampled at the end of two experiments terminated in August 1998 and May 1999.

experiment (May 1999). There are no indications of any differences that might be attributed to either grazers or depth.

The TWINSPAN data are presented in Table 4 and are best interpreted using the first divisions in both the samples and the species, giving columns A and B. The first, column A represent all samples from the first experiment, while the second, column B represents samples from the second experiment. The division of the species is more difficult to interpret. There are a large number of species in the upper part of block I which are present in the August 1998 samples but missing from the May 1999 samples. The lower part of block I has many species that are found in both experiments. Block II is not so clear, as many species are found more abundantly in May 1999, while others are also found less abundantly in the August 1998 samples. As in the DECORANA analysis there is no indication of either depth or grazers altering the species composition in the either experiment.

Scallop growth and survival during grazing experiments

These experiments were conducted as part of the fouling control experiments. The ANOVA (Table 5), of the changes in lengths shows no significant differences in scallop growth between depths and treatment. Figures 14 and 15 show the means and the 95% confidence intervals for the lengths of the scallops at the beginning and end of the experiments. In all instances, the means of the lengths had increased but no significant increases were seen.

Scallop mortality during the grazing experiments was also investigated. In both series of experiments, the 25 scallops were examined to determine if they were alive at

Table 4. TWINSPAN table of algae fouling pearl nets to analyze treatment effects of urchins (*Strongylocentrotus droebachiensis)*, controls and snails (*Littorina littorea*) on fouling biomass at 2m and 4m depths sampled at two time periods (August 1998 and May 1999). Numbers are cut levels corresponding to algal abundance, - = absence, 1= <1%, 2 = 1-10%, 3 = 10-50%, 4 = >50%. Seven-letter codes on left of table are species names (see Appendix A1-A4 for key). Numbers are at top of table are codes for the individual pearl nets samples (see key below). Numbers to the right of the table show cluster dichotomies to six levels for the species and numbers at the bottom of the table to six levels for the species. For ease of interpretation lines are drawn to delimit the table into blocks showing the first dichotomies for both species and samples.

Legend for sample dates:

1 August 1998 2m Urchin Net
2 August 1998 2m Control Net
3 August 1998 2m Snail Net
4 August 1998 4m Urchin Net
5 August 1998 4m Control Net
6 August 1998 4m Snail Net
7 August 1998 2m Urchin Net
8 August 1998 2m Control Net
9 August 1998 2m Snail Net
10 August 1998 4m Urchin Net
11 August 1998 4m Control Net
12 August 1998 4m Snail Net
13 August 1998 2m Urchin Net
14 August 1998 2m Control Net
15 August 1998 2m Snail Net
16 August 1998 4m Urchin Net
17 August 1998 4m Control Net
18 August 1998 4m Snail Net
19 August 1998 2m Urchin Net
20 August 1998 2m Control Net
21 August 1998 2m Snail Net
22 August 1998 4m Urchin Net
23 August 1998 4m Control Net
24 August 1998 4m Snail Net
25 August 1998 2m Urchin Net
26 August 1998 2m Control Net
27 August 1998 2m Snail Net
28 August 1998 4m Urchin Net
29 August 1998 4m Control Net
30 August 1998 4m Snail Net
31 August 1998 2m Urchin Net
32 August 1998 2m Control Net
33 August 1998 2m Snail Net
34 August 1998 4m Urchin Net
35 August 1998 4m Control Net
36 August 1998 4m Snail Net
37 May 1999 2m Urchin Net
38 May 1999 2m Control Net
39 May 1999 2m Snail Net
40 May 1999 4m Urchin Net
41 May 1999 4m Control Net
42 May 1999 4m Snail Net
43 May 1999 2m Urchin Net
44 May 1999 2m Control Net
45 May 1999 2m Snail Net
46 May 1999 4m Urchin Net
47 May 1999 4m Control Net
48 May 1999 4m Snail Net
49 May 1999 2m Urchin Net
50 May 1999 2m Control Net
51 May 1999 2m Snail Net
52 May 1999 4m Urchin Net
53 May 1999 4m Control Net
54 May 1999 4m Snail Net
55 May 1999 2m Urchin Net
56 May 1999 2m Control Net
57 May 1999 2m Snail Net
58 May 1999 4m Urchin Net
59 May 1999 4m Control Net
60 May 1999 4m Snail Net
61 May 1999 2m Urchin Net
62 May 1999 2m Control Net
63 May 1999 2m Snail Net
64 May 1999 4m Urchin Net
65 May 1999 4m Control Net
66 May 1999 4m Snail Net
67 May 1999 2m Urchin Net
68 May 1999 2m Control Net
69 May 1999 2m Snail Net
70 May 1999 4m Urchin Net
71 May 1999 4m Control Net
72 May 1999 4m Snail Net

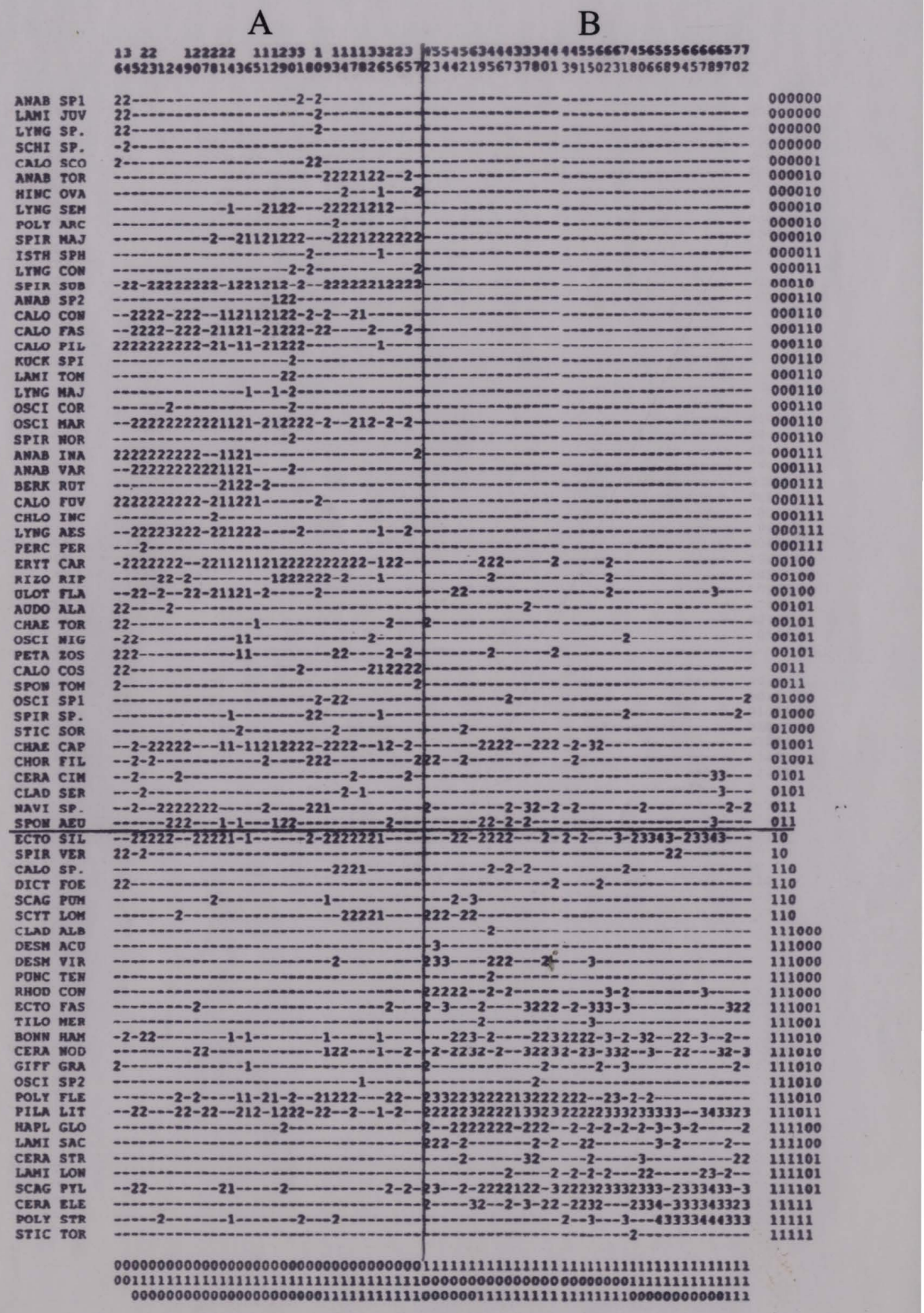

A
B
I
II

Table 5. Analysis of variance (Balanced ANOVA, p=0.05) of scallop (*Placopecten magellanicus*) length for grazing experiments of snails (*Littorina littorea*) and urchins (*Strongylocentrotus droebachiensis*) and their interaction with depth. Data for the two experiments June 1998- August 1998 and November 1998-May 1999.

Study Period	Source	DF	SS	MS	F	P
June-Aug 98	Depth	1	146.93	146.93	2.71	0.100
	Grazer	2	139.13	69.56	1.28	0.278
	Depth x Treat	2	23.20	11.60	0.21	0.807
	Error	894	48442.64	54.19		
	Total	899	48751.89			
Nov98-May99	Depth	1	36.02	36.02	0.77	0.382
	Grazer	2	26.06	13.03	0.28	0.758
	Depth x Treat	2	134.70	67.35	1.43	0.240
	Error	894	42070.32	47.06		
	Total	899	42267.10			

Table 6. Analysis of variance (Balanced ANOVA, p=0.05) of scallop (*Placopecten magellanicus*) percentage mortality for grazing experiments of snails (*Littorina littorea*) and urchins (*Strongylocentrotus droebachiensis*) and their interaction with depth. Data for the two experiments June 1998- August 1998 and November 1998-May 1999.

Study Period	Source	DF	SS	MS	F	P
June-Aug 98	Depth	1	0.50463	0.50463	5.13	0.031
	Grazer	2	1.78573	0.89287	9.08	0.001
	Depth x Grazer	2	0.27523	0.13761	1.40	0.262
	Error	30	2.94952	0.09832		
	Total	35	5.51512			
Nov98-May99	Depth	1	0.007511	0.007511	0.88	0.355
	Grazer	2	0.121689	0.060844	7.15	0.003
	Depth x Grazer	2	0.001156	0.000578	0.07	0.934
	Error	30	0.255200	0.008507		
	Total	35	0.385556			

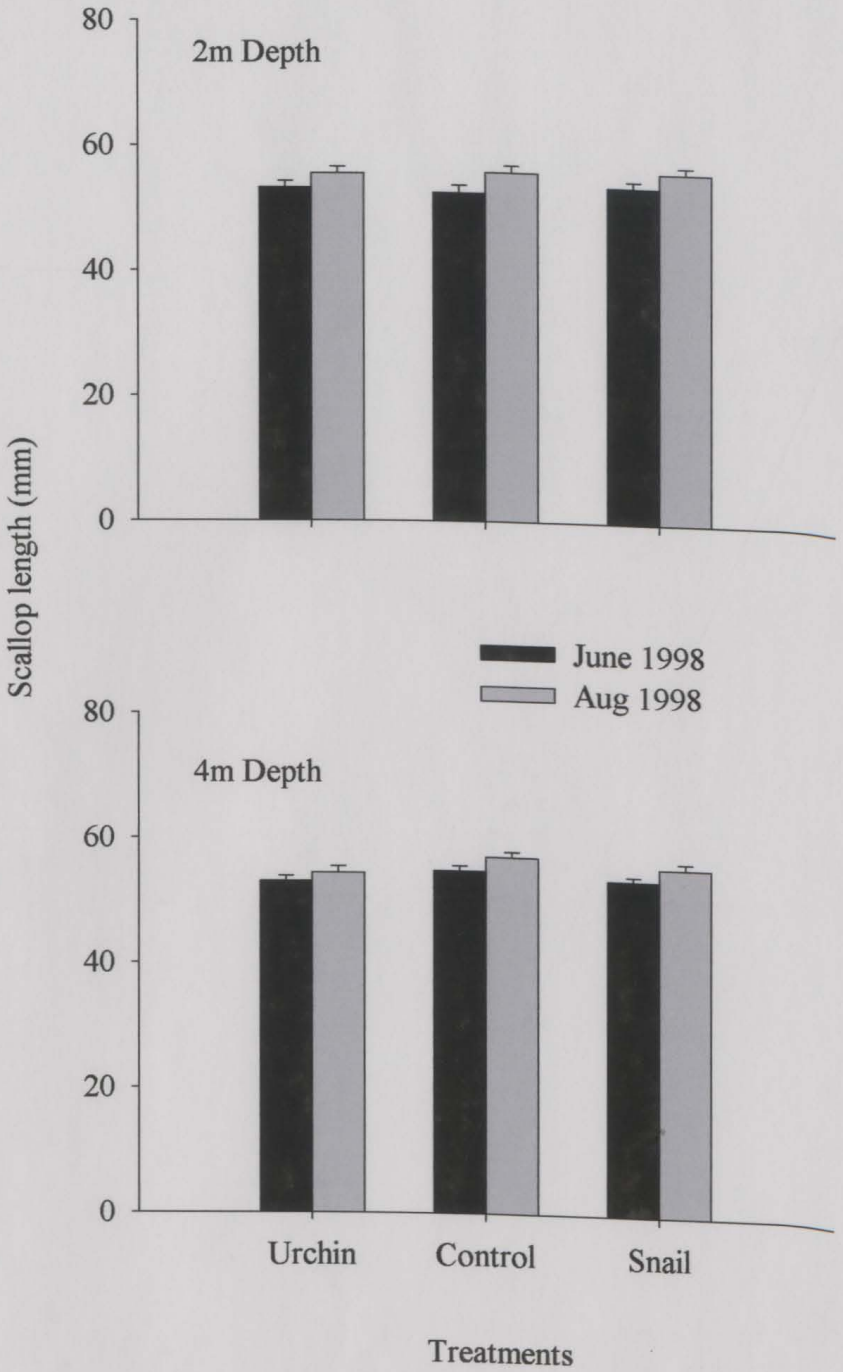


Figure 14. Scallop growth (*Placopecten magellanicus*) measured by change in length (mm) under urchin (*Strongylocentrotus droebachiensis*), control and snail (*Littorina littorea*) treatments over the period of June 1998 - August 1998 at 2m and 4m depths. Error bars are 95% confidence intervals. (N=25).

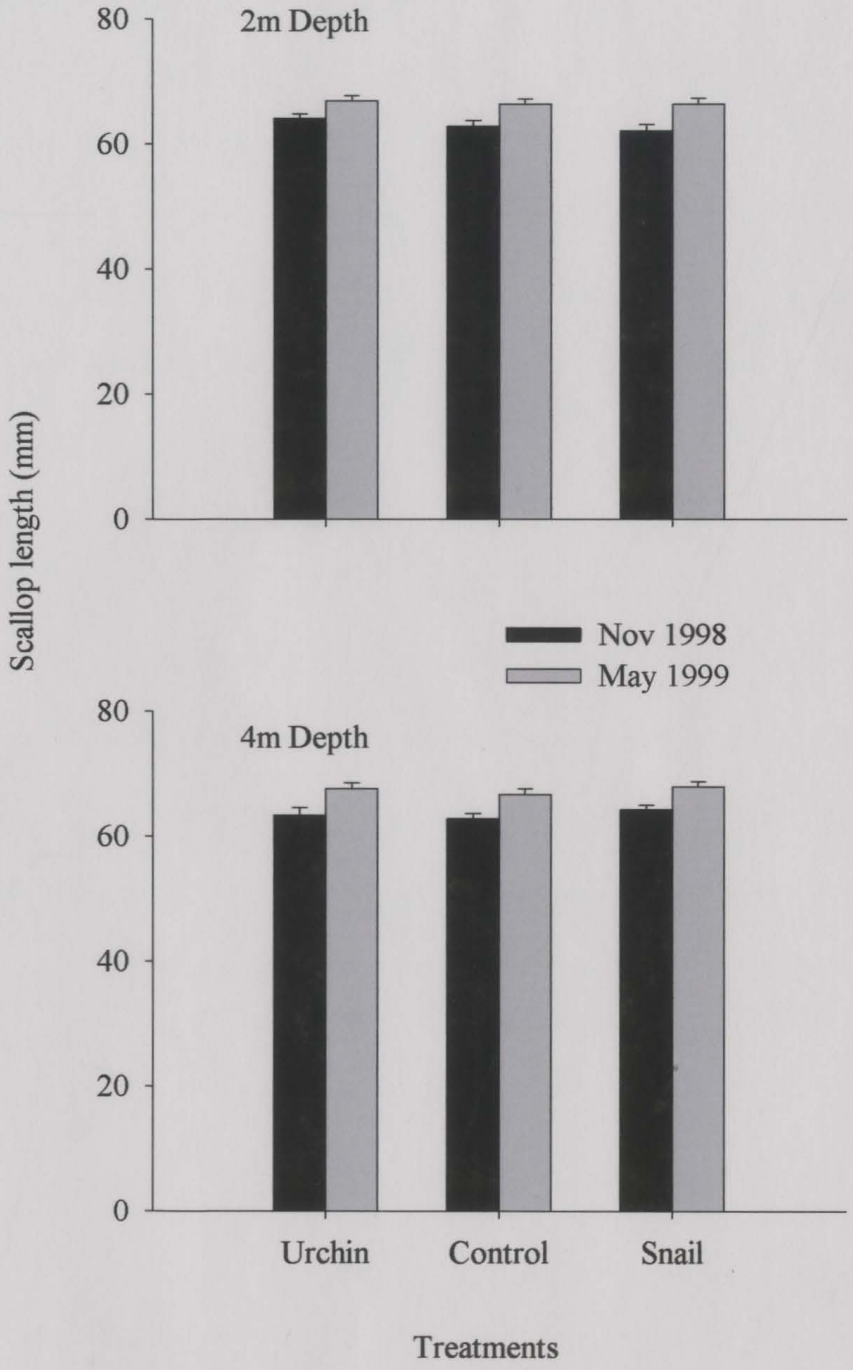


Figure 15. Scallop growth (*Placopecten magellanicus)* measured by change in length (mm) under urchin (*Strongylocentrotus droebachiensis*), control and snail (Littorina littorea) treatments over the period of November 1998 - May 1999 at 2m and 4m depths. Error bars are 95% confidence intervals. (N=25).

the end of the experiments. The ANOVA table for the percentage survival data is presented in Table 6. The percentage data was arcsine transformed as is usually recommended for percentage data (Zar 1984), and an examination of the ANOVA residuals showed the data to be normally distributed. The ANOVA table for the first experiment shows that grazer treatments are significantly different from the controls, but that depth and depth x treatment (grazer) interaction showed no significant differences in mortality. The ANOVA of the second set of experiment shows the same result with the grazers having significant effects on survival while depth and depth x treatment (grazer) interaction had no significant effects. These survival data are also presented in Figure 16. In the first experiment scallop mortality shows no significant differences between controls and urchins, but is reduced to half the amount in the snail treatments with no obvious differences with depth. The second over-winter experiment shows more striking differences, with much less mortality under all treatments at both depths than for the first experiment. While there were no significant differences with depth or urchins, the snail treatments, at both depths significantly reduced mortality to less than 5%.

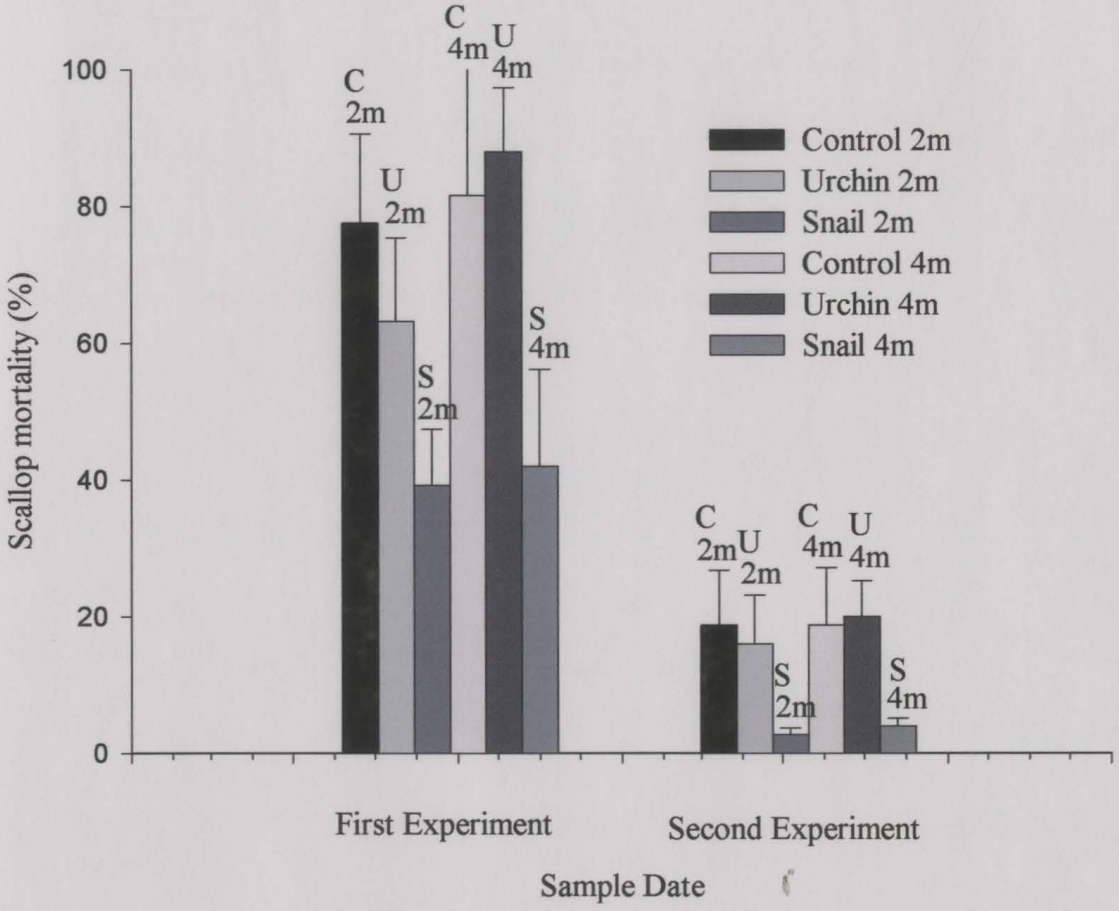


Figure 16. Percent mortality (%) of scallops (*Placopecten magellanicus*) at 2m and 4m depths for control, urchin (*Strongylocentrotus droebachiensis*) and snail (*Littorina littorea*) treatments. Error bars are 95% confidence intervals. N=25. First experiment from June1998-August 1998, and second experiment from November 1998-May 1999.

DISCUSSION

Environment

The experimental site at Charles Arm shows considerable seasonal variation in temperature, which would be expected to have a pronounced effect on the development of the benthic algal community. Temperature has been shown to be important in controlling geographic range, growth and reproduction of benthic marine algae (Hutchins 1947, Hoek 1982, Yarish *et al.* 1984, 1986, Lüning 1990) and is especially important in Newfoundland inshore with its almost 20C seasonal range (Whittick *et al.* 1989). The temperatures reported in this study, based on continuous thermograph recordings set at 2m-depth show a similar range. The CTD data show little difference in water temperature with depth over the 2m-4m-depth range, any differences are found in the early to mid summer when the 2m depth could be 2-3 degrees higher than that at 4m. No temperatures were observed which were outside the normal range that shallow benthic organisms would normally be exposed to in the Newfoundland inshore. The water temperature*s* are essentially those reported elsewhere for the island of Newfoundland (Steele 1983) including those of previous studies of algal seasonality (Hooper *et al.* 1980, South 1983, Whittick *et al.* 1989).

The salinity measurements are approximately 30 ISU for most of the period of the study. This is typical of salinities found in the inshore of the north coast of Newfoundland influenced by the Labrador current (Steele 1983). No major seasonal fluctuations were seen in salinity.

Fouling biomass

Biomass is the standard measure of net fouling in an aquaculture setting (Milne 1970, 1975a,b, Lovegrove 1979, Hall 1996, Hall *et al.* 1989). The industry uses wet weight for a range of operational measures (e.g. production, feed and harvest) and any antifouling strategies are more likely to be accepted if biomass-based rather than floristically based. As a measure, however, biomass it is not ideal as it lumps all fouling organisms together, and these will have different structures, and morphologies, and which may produce different affects on the fouled substrate. For example, one or two large organisms may have a greater mass compared to smaller filamentous algae covering the net, but would not impede water movement to the same extent.

In this study most of the fouling was by filamentous algae and Cyanobacteria, which would reasonably be expected to have similar affects on the hydrodynamic environment of the pearl nets. The mesh of pearl nets made it difficult to remove the fouling for assessment of biomass with any degree of accuracy and this together with the number of pearl nets examined, together with the time constraints of working around the operations of the farm, led to the choice of the sampling protocol used to assess biomass. There are, however, inherent inaccuracies in the adopted method. These include variation in net weight, plus the problems of dealing with wet weights of algae and the retention of adherent water by the algae and to the nets. Wet weight has inherently more variation than dry weight, as the differing morphologies of the algae would be expected to retain different amounts of water. The problems of wet weight were minimized by the standardization of treatments of the nets.

Fouling biomass was significant on the nets, with up to one kilogram being produced after the one years immersion. Initial colonization was rapid, with significantly greater amounts of fouling on the shallow nets for June, August and November of 1998, the first year of sampling. Grecian *et al.* (2000) studied fouling at the Shell Fresh Farm site on the south coast of Newfoundland on pearl nets. The biomass of fouling at the end of Grecian's *et al.* (2000) study ranged from 1 – 2.5 mg dry weight cm^{-2}, while the amount produced over the winter period October 1996-July 1997 averaged 0.8 mg dry weight cm^{-2}. Similar data obtained in this study were converted from wet to dry weight using the regression equation from Figure 9, and were then converted from weight per pearl net to weight per cm^2. These conversions gave weights of 2.7 mg to 10.1 mg cm^{-2} fouling at the end of the first year of the study, with an average biomass of 6.5 mg cm^{-2} for the period November 1998 to July 1999. These figures are higher than those obtained by Grecian *et al.* (2000), but direct comparisons are difficult because of the different protocols employed and also the differences in environment between the too study sites. Grecian *et al.* (2000) dried samples to constant weight at 80C for 24hrs while dry weights in this study were obtained by air-drying, which would have led to under- drying in comparison, giving greater values on conversion from wet weights. In the Grecian *et al.* (2000) study the nets were suspended at greater depths in the water column, which could also have reduced the light available for photosynthesis leading to reduction in biomass. The nets were also different in having smaller mesh sizes in the range of 1.4 to 3 mm size, though it is difficult to explain what, if any difference, this would have made to the fouling biomass.

It is difficult to interpret biomass as a measure of growth, as it is a measurement of the interaction of both growth and loss, factors that were not measured independently. As is seen in the floristic analysis there is little difference and no systematic trends in differences between nets from the two depths during one sampling period. It is unlikely therefore that these differences are due to the differential growths of different species. Likewise, the factors controlling loss of algae, due to water movement and/or grazers are unlikely to be significantly different. A simple explanation would therefore be that the algae initially grow more slowly on the deeper nets due to lower light availability. While there are no light data available, the Charles Arm site has significant run off in the spring and early summer of peaty water, as well algal blooms, as indicated by the chlorophyll-a maxima in Nichols *et al.* (2002), which might reduce the light from the surface over a 4m depth range. In addition the shading of seven other pearl nets, each with developing fouling may have reduced the available light.

Fouling community development

Hall (1996) observed considerable differences in both floristics and biomass over the one metre depth range he used for test nets in the Bay of Fundy. In this instance the upper part of his test net was at the surface and become fouled with green algae such as *Entermorpha spp.* and *Ulva lactuca* L., which are largely intertidal in Newfoundland (South & Hooper 1980), and reported as fouling organisms in the splash zone (Fletcher 1980, Terry & Picken 1986). The dominance of these organisms was not seen in this study with the shallow nets set at 2m (Table A1) one metre deeper than Hall's deepest sample. After one years growth there are no significant differences in biomass between

the two depths and this does not change significantly over the next year, equilibrium is achieved between the factors involved in growth and loss.

The DECORANA ordination diagram, Figure 10, also shows that there is little difference between the two sample depths at any of the study periods. This agrees with the biomass data that differences in depth are unimportant in the development of algal fouling at this site. While there is much information showing that depth clearly influences algal distribution in Newfoundland (South & Hooper 1980, Hooper *et al.* 1980, South 1983) this 2m range on pearl nets in the immediate subtidal of Charles Arm is unimportant. Figure 10 shows that there is a development of the fouling over time, with the initial settlement in June 98, showing some similarities with the May 1999, July 1999 and July 2000 algal community, while the communities for August 1998 and November 1998 are clearly different. It is also apparent that the communities for August 98 and November 98 are very differently on the DECORANA plot, suggesting that a seasonal change in flora might be superimposed on a more long-term development. Seasonal changes in the subtidal epilithic flora of Newfoundland coastal waters are well documented (South & Hooper 1980, Hooper *et al.* 1980, Whittick *et al.* 1989). Such changes in the algal floras have been explained principally by changes in water temperature and day length (Yarish *et al.* 1984, 1986, Lüning 1990).

In order to explain these changes shown on the ordination diagram, reference is made to the TWINSPAN classification table (Table 2). This two-way polythetic divisive classification table shows the species on the vertical axis and the samples on the horizontal axis, for ease in interpretation, the major four major divisions on each axis have been drawn to divide the table into a number of columns and blocks of samples and

species respectively. It is apparent from both this and from Tables A1-A4, that the species found as fouling organisms are common components of the Newfoundland inshore flora (South & Hooper 1980). The fouling algae are largely small and filamentous is also shown in the photographs of the fouled nets (Figures 7 & 11). There are a larger number of species than found on the shallower nets in the Bay of Fundy (Hall 1996). The number is considerably higher than those for other studies in the region where fouling was examined primarily for its affects on the cultured organisms, rather than from a floristic approach (Grecian et al. 2000) or Claereboudt *et al.* (1994), a study from the Baie des Chaleur, P.Q., where only invertebrate fouling was reported.

While most algae reported in this study are small and filamentous there is a potential for large fouling seaweeds. *Laminaria* sporelings were recorded in the first year and larger plants of *Laminaria digitata*, *L. saccharina*, *Desmarestia aculeata* and *D. viridis* were observed in the second and third growing seasons. There is a potential of considerable hydrodynamic loading and drag if they are allowed to grow to maturity.

Members of the Cyanobacteria were found in all sampling periods, but were particularly abundant in the summer (August) and fall (November) of the first field season 1998. Cyanobacteria are frequently an obvious component of the inshore subtidal flora of Newfoundland in the warmer summer months, particularly in sheltered bays and estuaries, which warm to levels beyond those recorded for more open locations (Whittick pers. com.). Unfortunately the only quantitative samples available were in the latter part of 1998 and thus it is impossible to determine with certainty if their abundance was part of the initial development of the fouling, which was subsequently succeeded by other eukaryotic algal species over the next two years, or whether their appearance is an

annual, seasonal, event. The latter would appear most likely, given the observations from other, non-quantitative, samples in the summer and fall in the region, when Cyanobacteria are an abundant part of the normal epilithic and epiphytic flora. The appearance of Cyanobacteria as an important component of the fouling community and proved problematic as usually these prokaryotic organisms are ignored in marine benthic phycological studies. There are problems in their identification as their morphological features are sufficiently plastic as to defy unambiguous identification, at best what is recorded is a name relating to a morphological form, which may or may not coincide with a valid species name. The name applied may not be that used by other workers, and usually little or nothing is known about the ecology and distribution of these species. However, given their importance in the fouling community it was decided to use the work of Humm & Wicks (1980) to put a form name on the specimens. The limitations of this approach are realized, but are better than ignoring these organisms themselves or simply recording them collectively as Cyanobacteria. However, no attempt is made to discuss their ecological significance beyond noting their occurrence and their potential, as with other fine filamentous algae, for impeding water flow through the nets under conditions of highest water temperature when the scallops might be expected to be at the most stressed (MacDonald & Thompson 1985a,b).

The four first vertical divisions, A-D, in the TWINSPAN table delimit developmental changes in the growth of the fouling communities, with A being the initial development in June 1998, C being the latter part of the first years fouling from August and November 1998 while B represents the more developed fouling communities of May and July 1999 and July 2000. The TWINSPAN table (Table 2) therefore shows the same

large divisions as seen in the DECORANA ordination (Figure 10). Column D is a single, somewhat anomalous sample, from November 1998, which in addition to the fall species shows links to the algal communities from the early part of the year. The horizontal divisions I-IV divided the species into blocks that can be used to explain the differences between the temporal developments shown in the vertical columns. While the block delimitations are useful in examining the development of the fouling, the actual dichotomies seem to frequently differ from those that perhaps would have been made using a more subjective delimitation of the table. For example the last three rows of block I seem to have more in common with block II than with the remainder of block I. As pointed out by Gauch (1982) the interpretation of TWINSPAN tables ultimately depends on the investigator, and in this study the procedure is useful in providing a sorted and weighted matrix capable of interpretation.

It is not intended to discuss all the species listed in the TWINSPAN tables; some have only one or two occurrences in the total of 120 samples. However many are more abundant and characteristic of specific sampling times. Representatives of these will be discussed in light of what is known of their ecology, specifically their distribution and phenology in Newfoundland.

The species found in block II are largely ubiquitous throughout the period of the study and show little seasonal change. To this group the lower three rows of block I might be added along with *Ulothrix flacca* found in block IV. Representative species in these groups include common filamentous brown algae such as *Ectocarpus siliculosus,* and *Pilayella littoralis,* red algae include *Scagelia pylaisaei* and *Ceramium nodulosum.* While the *C. nodulosum* is not present in column A, the May 1998 samples, it is heavily

represented in all other periods. This is not surprising as this species is a common perennial in Newfoundland, and once established would be expected to be present year round (South & Hooper 1980). The other species in this group are also abundant and found throughout the year in Newfoundland as epiphytes and epiliths. They are fertile throughout the year are also well adapted to fragmentation with the potential for vegetative reproduction. Another red alga in this group is *Bonnemaisonia hamifera*, present as the tetrasporophytic *Trailliella* form, this species is perhaps the most widespread, non-calcareous, red alga in the immediate subtidal of Newfoundland (South & Hooper 1980), where it reproduces and perennates almost exclusively by fragmentation and as such it is well adapted to fouling. The commonest green algae in this group is *Chaetomorpha capillaris,* a simple, unbranched, predominantly unattached species, usually found in pools in the low intertidal tangled amongst other algae, most commonly in the summer and fall (South & Hooper 1980); again it is a species well adapted to fouling of pearl nets.

Apart from the species mentioned above, block I consists primarily of species found in the initial sample of June 1998 and the samples from the spring and early summer of 1999 and 2000, at a time before the water temperature in Charles Arm has reached its maximum. Column A, with the ubiquitous species removed, has a sparse flora, the dominant species of the Phaeophyta being *Ectocarpus fasciculatus* and *Haplospora globosa*, which are also found in the 1999 and 2000 samples, though apparently almost absent in the August and November samples from 1998. Both species are widely distributed in Newfoundland. *Ectocarpus fasciculatus* is found year round, principally as an epiphyte and is especially abundant in the summer (Whittick pers.

com.). *Haplospora globosa* is widespread in Newfoundland and is also most abundant in late spring and early summer (Kuhlenkamp 1990), which agrees with the results of this study. *Cladosiphon zosterae* and a few juvenile *Laminaria spp.* are also found in Column A, both would be expected to be found in the early summer in Newfoundland and *C. zosterae*, as its name suggests, is usually reported as an epiphyte on eel grass *Zostera marina* L. (Whittick pers. com.). Another common species in this group is the green alga *Rhizoclonium riparium,* which as found in all but one sample. This species is ubiquitous in Newfoundland and its recurved, short, rhizoidal branches make it an ideal fouling organism to attach to pearl nets. While this species in found later in 1998 (Column C) it was only recorded on a single occasion in column B suggesting that it is better adapted as an early colonizer. In Newfoundland it grows best in habitats that are perhaps marginal to other species, i.e. in salt marshes, or in the high intertidal of more exposed rocky shores, suggesting that in other habitats it may be at a competitive disadvantage (Whittick pers. com.).

Column B, samples like those from Column A, are from the late spring and early summer, before water temperatures have reached a maximum in Charles Arm. They differ in that they are from years two and three of the study, and in addition to the ubiquitous species, would be expected to have more perennial species reflecting the further one or two years of immersion.

The most obvious difference is the presence of larger members of the Phaeophyceae such as *Laminaria longicruris* and *L. saccharina*, together with *Desmarestia viridis* and a single occurrence of *D. aculeata*. The presence of juvenile *Laminaria spp.* in June 1998 (Column A) shows the potential for early settlement of

these large algae. In this study plants identified as *Laminaria longicruris* had hollow stipes, while those of *L. saccharina* had solid stipes and narrower ruffled laminae. *D. viridis* in Newfoundland develops in the late winter and spring, when water temperatures are low, and would not be expected to be abundant in the late summer and fall at a site such as Charles Arm with its relatively high water temperatures (Hooper pers. com.)

The members of the Rhodophyta, which characterize the fouling in the second and third years of the study (Column B), are also larger and perennial, although some may show considerable changes in growth and abundance with season. *Polysiphonia stricta* is ubiquitous in Newfoundland and is a common epiphyte with its maximum abundance in the spring and early summer, as recorded in this study. *Callophyllis cristata* is also ubiquitously distributed in Newfoundland and is frequently found growing epiphytically (Hooper & South 1974, South & Hooper 1980). *Rhodomela confervoides* is also widely distributed with growth confined to the spring and early summer as also seen in this study, with senescence occurring in warmer locations such as Charles Arm in the late summer and fall. *Ceramium spp.* were abundant fouling organisms in this group, *C. strictum* is locally abundant in sheltered bays in Newfoundland especially in the early summer, but dies back in the fall. While, as previously noted, *C. nodulosum* is seasonally ubiquitous. *Pantoneura fabriciana* is also usually found growing epiphytically, commonly on the stipes of *Laminaria longicruris.* It is commonest in sheltered fjords and usually associated with colder waters. When it occurs in shallower water it shows maximum growth in the spring and early summer with considerable die back in the late summer and early fall (Whittick pers. com.).

The samples making up Column C are from August and November of 1998. They include the summer and fall, warm water species, which in Newfoundland may persist until water temperatures decrease at the years end. Samples were only available for 1998 and this poses the question as to whether the species are stages in a succession from year one (Column A) to years two and three (Column B), or seasonal ephemerals. The Cyanobacteria are especially abundant, while being almost absent from the samples from the early part of the year. Little is known of the distribution and ecology of this important group of prokaryotic autotrophs in Newfoundland waters. They reach their maximum abundance in the warmer months, especially in sheltered embayments such as Charles Arm (Whittick pers. com.). Personal observations in the late summer of 2002 showed them to be especially abundant in Charles Arm and surrounding areas.

In addition to the Cyanobacteria a number of algal species also characterize this group. The filamentous member of the Bangiophyceae, *Erythrotrichia carnea,* while also being found in Column B, was especially abundant. This species is ubiquitous in Newfoundland and is especially abundant in the late summer and fall, particularly as an epiphyte, in sheltered bays and harbours (Hooper pers. com.); this distribution fits the observations of this study. *Polysiphonia flexicaulis* shows similar patterns and is also common and widespread throughout Newfoundland, both as an epiphyte and an epilith. It shows maximum growth in the early summer, but persists into the late fall, which fits the pattern seen in this study. Two members of the Phaeophyceae, which also characterize this group, are *Chorda filum* and *Stictyosiphon soriferus. C. filum* in Newfoundland does not usually become prominent until July and may persist as dense beds, especially on disturbed coarse gravels until the late fall (Whittick pers. com.). *Stictyosiphon soriferus* is

also predominantly a fall species in Newfoundland, usually first appearing in July. It is also found growing on small rocks in sheltered locations (South & Hooper 1976). It would seem likely that both these species of the Phaeophyceae would be found in Charles Arm, and be available to colonize the pearl nets showing greatest abundance in the late summer and fall.

It is apparent that the fouling species found on the pearl nets sampled in Charles Arm are members of the local marine algal flora of the region and that their growth and phenology is similar to that of non-fouling populations (Hooper *et al.* 1980, South 1983, Whittick *et al.* 1989). Most species are relatively small filamentous forms, many capable of vegetative reproduction by fragmentation as well as by spores and gametes. As such the major problem associated with the fouling would appear to be reduction of the flow of water through the apertures of the pearl nets. This in turn could lead to a reduction in the amount of food available to the scallops as well as reducing oxygen and perhaps also leading to a build up of excretory products (Lee *et al.* 1983, Mallet & Carver 1991, Côté *et al.* 1993, 1994, Claereboudt *et al.* 1994, Hodson & Burke 1994, Hodson *et al.* 1997, Grecian *et al.* 2000). The latter two problems may however be reduced by the presence of the fouling as the algae would absorb nitrogenous wastes and also carbon dioxide during their photosynthesis and growth. During photosynthesis oxygen would be produced and may be available to the scallops for use in respiration during the day. However, such suggestions are only speculative without detailed measurement of oxygen, carbon species and waste nitrogenous products from within fouled, and non-fouled control pearl nets, which is beyond the scope of this study.

Grazing experiments – affects on fouling biomass

In an attempt to control algal fouling two known algal predators were assessed as potential biocontrol agents, these were the gastropod *Littorina littorea* and the green sea urchin, *Strongylocentrotus droebachiensis,* referred to respectively as snails and urchins. Two sets of grazing experiments were conducted, one in the summer of 1998 between June and August, the other over the winter of 1998-1999, between November and May. The pearl nets sampled at these times for the seasonal development of fouling served as controls for these grazing experiments.

The ANOVA (Table 3) showed that in the first experiment significant differences in biomass occurred with depth, grazer treatments and in the interaction between grazers and depth. These results can be interpreted by reference to Figure 12; the error bars are 95% confidence limits allowing direct comparison between pairs of means. Lower fouling biomass occurred at 4m than at 2m in both controls and grazing treatments, which has been noted and discussed for the controls alone above. Examination of the error bars on Figure 12 shows considerable overlap between the controls and the urchins treatments suggesting they are not significant at either depth, the significant differences are due to the considerable reduction in biomass by the snails which reduced the fouling biomass to less than half that of the controls at 2m, while at 4m the snails also significantly reduced the biomass. This difference between depths accounts for the significant interaction between treatment and depth in the ANOVA, and suggests that snail grazing is not independent of depth. This study shows the potential of *Littorina* for reducing algal

fouling and is in agreement with the fouling control experiments of Enright *et al.* (1983, 1993).

For the over winter experiment, Table 3 shows no significant differences with depth, grazers or interaction between depth and grazers. The overall higher fouling biomass at the end of the second experiment can be explained by the longer period of immersion of the pearl nets, as those used in the second experiment were in the water for over a year in comparison to the three months of the first experiment. This agrees with the seasonal biomass data that showed no significant differences occurring with depth after the initial establishment of the fouling. In all instances the grazers reduce the mean of the fouling biomass and larger sample sizes might have shown significant differences. Snail grazing activity is dependent on temperature and is much lower in the colder, winter months, (Newell *et al.* 1971, Norton *et al.* 1990, Petraitis 1992, Kim & DeWreede 1996, McQuaid 1996 and Atsushiito *et al.* 2002). McQuaid (1996) found that *L. littorea* grazed at only half the rate at 5C as it did at 15C, while Newell *et al.* (1971), studying the crawling rates of *L. littorea* concluded that they become inactive during of the winter months when seawater temperatures were between 6C – 8C. These temperatures are higher than those found in Charles Arm in the winter, and even with possibility of the existence of physiological races of *L. littorea,* more adapted to the colder water, it would seem likely that their grazing activities would be reduced with winter water temperatures.

A reduction of fouling was seen when urchins were found grazing on the outside of pearl nets (Mills pers. com.), however, no significant reduction occurred when they were placed inside the nets. The feeding activities of *S. droebachiensis* are correlated with its reproductive cycle, which is linked to food availability for the adult, as well as

plankton availability triggering gamete release (Starr *et al.* 1993). Chlorophyll-a studies in Charles Arm show that peak plankton blooms occur immediately after the melting of surface ice in the spring (Nichols *et al.* 2002), a seasonal change characteristic of Eastern Newfoundland and Atlantic coastal areas (Parrish *et al.* 1995). However, a simpler explanation would be that urchins inside pearl nets are less competent grazers than the snails. This could be due to the snail's radula (Newell 1979, Norton *et al.* 1990) being better adapted to grazing on the net substrate than the Aristotle's lantern apparatus of urchins (De Ridder & Lawrence 1982). The urchin spines might also inhibit movement within the nets in contrast to the smaller smoother littorinids.

Affects of grazers on algal community structure

The algal species composition on the grazer treated pearl nets was also examined using both DECORANA and TWINSPAN. The intention of this analysis was to determine if the urchins and snails affected the species composition of the fouling community irrespective of whether biomass was reduced. Studies have shown that grazers show preferences for, or are adapted to grazing on, particular species of algae (Steneck & Watling 1982, Watson & Norton 1985). For example, *S. droebachiensis* will only eat the kelp *Agarum clathratum* Dumort if other algae are unavailable, and will not eat *Ptilota serrata* Kütz at all (Himmelman & Steele 1971, Keats *et al.* 1982.). *Littorina littorea* shows a clear preference for the smaller filamentous and more delicate thalloid species of algae (Lubchenco 1978, Watson & Norton 1985, Norton *et al.* 1990, Kim & DeWreede 1996), while apparently eschewing the tougher fucoids, which may also have

higher levels of phenolic compounds to deter these herbivores (Norton *et al.* 1990, McQuaid 1996).

Figure 13 shows the results of the DECORANA analysis applied to the algal samples on the pearl nets at the termination of both fouling control experiments. These include those of snail and urchin treatments as well as the controls. The two experiments were analyzed together to determine if the seasonal difference effects of grazing, seen in the biomass studies, would also be seen in the specific composition of the grazed fouling. The analysis shows two distinct groups: those from the first experiment and those from the second. These seasonal differences have already been noted (Figure 10) and discussed. In both of these groups there is no sign of separation of samples by either depth, or by treatment. The DECORANA results show there is no preferential grazing of one species over another, at least at this stage of fouling development. The TWINSPAN table (Table 4) also shows the first major vertical divisions into Columns A and B occurs between the first and second experiments. No further division in the table can be seen that could be interpreted either by depth of by grazing treatment. As with the seasonal development data seen in (Table 2) the same distribution of species is seen with those at the end of the first experiment terminated in August showing a greater development of Cyanobacteria that those from the second over winter experiment. Once again some species appear at relatively high abundance in both experiments these include *Ectocarpus siliculosus*, *Pilayella littoralis, Scagelia pylaisaei* as well of *Polysiphonia spp.* and *Ceramium spp.* There are no species that obviously distinguish between grazing and controls in either experiment, or at either depths. Most of the fouling seen on the pearl nets is small and filamentous, with the larger species such as *Laminaria spp.* and

Desmarestia spp. being represented by juvenile stages, and it is likely that at these stages the grazers are less likely to discriminate between species (Lubchenco 1983, Norton *et al.* 1990). There are no species recorded as foulers that are likely to present a problem in grazing to either snails or urchins. One species, *Desmarestia viridis*, has vesicles that produce sulphuric acid, and this has been cited as a potential herbivore deterrent (Himmelman & Nédélec 1990). *D. viridis* was, however, abundant on the nets from the over winter experiments with no apparent differences between the grazed and control nets and in the summer in Newfoundland, is grazed by both gastropods and urchins (Hooper pers. com.).

Scallop growth and survival during grazing experiments

In addition to effects of grazers on the fouling of the pearl nets, the scallops they contained were also examined for survival and growth. The survival data are difficult to interpret due to the widespread death of scallops during the period of the first experiment. The growth data is not as robust as it might have been had individual scallops been tagged and measured at the beginning and end of the experiments, and growth data presented here is for the mean of the scallops at the beginning and end of the experiments. In both series of experiments an increase in the mean of the scallop length occurred under all conditions of depth, and treatment (Figures 14 & 15), but the ANOVA (Table 5) shows no significant differences in growth with any treatment of depth.

In previous studies of *Placopecten magellanicus* growth was shown to decrease with increasing depth, which might be attributed to lower food availability (Côté *et al.* 1993, MacDonald & Thompson, 1985a,b, Claereboudt *et al.* 1994, Parrish *et al.* 1995 and

Grecian *et el.* 2000). Dadswell & Parsons (1991) found a decrease in growth with a 5m increase in depth. However, this is unlikely to be important over the two-metre depth range of this study.

Biofouling has been reported as an important growth-limiting factor in the culture of bivalves (Mallet & Carver 1991, Côté *et al.* 1993, Claereboudt *et al.* 1994 and Grecian *et al.* 2000). However, in neither of the two experiments of this study was any significant difference seen in the effects of the grazers on scallop growth. Algal fouling reduces water flow and, as already discussed in relation to the grazer activities, may cause a decrease in oxygen as well as a decrease in the flushing of metabolic wastes from within the pearl nets. Scallops are filter feeders and a restriction of water flow might be expected to decrease the amount of available food, while fouling filter feeders might compete for the same food resource (Côté *et al.* 1993, MacDonald & Thompson, 1985a,b, Claereboudt *et al.* 1994, Parrish *et al.* 1995 and Grecian *et al.* 2000). While fouling biomass was lower at 4m than 2m during the time of the first experiment (Figure 12) no differences in growth of the scallops were observed. The snail treatments also significantly reduced the algal fouling biomass in the first experiment, but again no effects on scallop growth were seen. It is also possible that under culture conditions in which fouling does not significantly affect water flow that the various reproductive propagules (spores, gametes, vegetative fragments), produced by the sessile algae, would act as a food source and contribute to the food availability to the filter feeding scallops.

Comparisons with the second experiment are difficult because of the different lengths of immersion, together with the greater mortality of the scallops during the first grazing experiments. The amount of fouling in August 1998 was significantly less than

in May 1999 (Figure 12). The scallops were significantly bigger at the start of the second experiment in November 1998 than in the first in April 1998 (Figures 14 & 15). They also increased in size over winter with the mean increase being perhaps slightly greater than that shown in the first experiment (Figures 14 & 15). This may be due to the larger initial size or to the longer period of immersion. Mills (pers. com.) also reports that significant growth of scallops occurred during the winter months. MacDonald & Thompson (1985a,b) concluded that food availability, rather than temperature, is the main factor responsible for scallop growth. Parrish *et al.* (1995) also found that substantial growth in mean shell height occurred over the winter months from December 1991 to April 1992 and somatic tissue weight increased 20% over the same period. This study also shows that growth occurs during this period and is unaffected by either depth or fouling.

While the scallops used in both experiments belonged to the two-year class, the first experiment ended in August 1998 and the second began in November 1998 and the slightly larger scallops of this second experiment may reflect their further three months of growth. This small size difference appears unlikely to be important in any mortality studies. Dadswell and Parsons (1991, 1992) suggest handling is the principle cause of scallop mortality at initial deployment, with losses ranging from 7-9%. Acclimation and predation under normal culture conditions may account for a further 5-10% mortality during the duration growth over the four-year grow-out period (Couturier *et al.* 1995, and Mills pers. com.).

However, these factors would not account for the high mortality of scallops recorded in the first experiment, but may explain the lower percentage of mortality of

scallops seen in the second experiment (Table 6 & Figure 16). During the course of the first experiment a massive and a yet still unexplained death of scallops occurred at the Charles Arm site. This is reflected in the mortalities shown in the first experiment in which in the controls and urchin treatments at both depths mortality was in the order of 80%. Mortality in the snail treatments was, however, significantly lower which accounts for the significant grazing effects shown in the ANOVA (Table 6) The p value of 0.031 for the depth treatment shows that the effect of depth is also significant in scallop mortality if the p=0.05 confidence level is used, however, little differences are seen in Figure 16. The first experiments were concluded in August 1998, when water temperature was approaching its maximum in Charles Arm (Figures 5 & 6). If temperatures are above the optimum for *P. magellancius,* these, especially when coupled with a reduced food or oxygen supply, may lead to stress reduced growth and even death (MacDonald & Thompson 1985a,b, Couturier *et al.* 1995, Mills pers. com.). Given the confounding effects of the massive scallop die off, it is difficult to discuss these experiments in a meaningful manner. The results from the over winter experiment show a much reduced mortality under all conditions, when compared to the first experiment, with the overall losses less than 20% and are within the normal mortality range for the Charles Arm site (Mills pers. com.). In this instance the effect of depth is not significant at the p=0.05 confidence level but the there is a significant effect of grazing (Table 6). Figure 16 shows that while urchins had no effect on scallop mortality, a considerable decrease occurred at both depths with snail treatments. It is interesting that while snails significantly reduced algal fouling biomass in the first experiment, together with a decrease in scallop mortality, no significant reduction in fouling biomass was seen in the

second experiment and yet a relatively much greater reduction in scallop mortality occurred. This suggests that the effect of snails on scallop mortality may due to some scallop – snail interaction other than simply being due to fouling reduction. Further experiments are clearly needed to clarify these observations.

Conclusions

The massive die off of cultivated scallops in Newfoundland in 1998-1999 led to a re-assement of their potential for farming and, in the case of Thimble Bay Farms, a decision to abandon their cultivation and concentrate on farming of the blue mussel (*Mytilus edulis).* This study has, however, shown a number of points of potential interest should scallop farming be re-introduced.

Algal biofouling will always be a problem on any structure placed in the photic zone of sites such as Charles Arm. The degree to which it is tolerated is best left to the judgment of the operator who must balance the costs of losses and reduced growth potentially caused by the fouling, against the costs of, and losses due to cleaning of nets and/or transfer of scallops to clean nets during the grow-out period.

It is apparent, at the Charles Arm site, that the fouling is due mainly to sessile algae (seaweeds) and Cyanobacteria, and that sessile invertebrates are an insignificant part of the fouling community. It is also clear that, contrary to traditional ecological wisdom, and to the reports of previous surveys, that a large number of algal and cyanobacterial species are involved, which cannot be collectively dismissed as "*Polysiphonia*". In this regard, this study confirms that of Hall (1996), and shows that even more species occur as fouling organisms. The floristic studies, as shown by the data,

in the appendix and in the TWINSPAN tables, show that the fouling species are not unique, but are common components of the benthic algal community in the region, and that their phenology is also similar to that occurring in these natural communities. Little differences are seen between the depths and this is not surprising given that only two metres separated the shallowest from the deepest samples. This could be an important consideration if cultivation over a greater depth range is contemplated and extrapolation from the data presented here, to greater depth should not be done without further experiments. While a substantial amount of fouling was seen on the nets, it appears that a maximum is reached after one year in the water, suggesting that, if scallop growth is adequate up to this point, it is unlikely to deteriorate due to increased fouling in future years. However, if fouling can be reduced in a simple and economic manner it is clearly to the advantage of the operator to do so, as the nets are easier to handle, and there are literature citations suggesting that growth is enhanced in the absence of fouling.

This study examined the possibility of reducing fouling in an environmentally friendly, and potentially cost effective manner, using locally occurring algal grazers. The use of urchins (*Strongylocentrotus droebachiensis*) within the pearl nets did not appear to be effective, however, this may be due to the confining nature of the nets on these relatively large algal predators. The observation that they are effective at removing fouling, when on the outside of the nets suggests their potential use if scallop culture resumes using cages or other non-net enclosures. The snails (*Littorina littorea*) proved much more effective in reducing fouling, but while decreasing fouling biomass, did not significantly alter the structure of the fouling community. *Littorina* has been previously used to control fouling in this manner, most prominently by Enright *et al.*, (1983, 1993)

and the results of this study confirm her observations as to their efficacy. Whether it is economically feasible to use *Littorina* on a large scale in a scallop farm is debatable. With 75 snails per pearl net, the time and cost of collecting *L. littorea* for use in many thousands of nets would be daunting and perhaps not economically viable unless a substantial market could be found for the snail as well. Perhaps adequate algal fouling control could be achieved with fewer snails per pearl net and further experiments are clearly needed to determine the optimum density of snails in such biocontrols. In addition, while snails reduced fouling in the first study, most significantly at 2m, they were not as effective at 4m. The observations of the effects of grazers on growth and survival of scallops conducted in this study are preliminary. They should be repeated over different time periods using the more sensitive approach of individually marked and measured scallops. However, this study has shown some very interesting trends, especially in the relationship of snails to scallop survival, which clearly worthy of further study.

REFERENCES

Atsushiito, A.I., Seiji, G. & Shigeru, N. 2002. Seasonal and tidal-height variations in body weight and radular length in *Nodilittorina radiata* (Eydoux & Souleyet, 1852). *J. Mol. Stud.*, 68, 197-203.

Benson, P. H., Brining, D. L. & Perrin, D. W. 1973. Marine fouling and its prevention. *Mar. Technol. J.*, 10, 30-37.

Bird, C.J. & McLachlan, J.L. 1992. *Seaweed Flora of The Maritimes. I. Rhodophyta-The Red Algae*. Biopress Ltd, Bristol. v + 177 pp.

Black, G.A.P., Mohn, R.K., Robert, G. & Tremblay, M.J. 1993. Atlas of biology and distribution of the sea scallop *Placopecten magellanicus* and Iceland scallop *Chlamys islandica* in the northwest Atlantic. Canadian Technical Report of Fisheries and Aquatic Sciences. No. 1915, vi + 34 pp.

Breen, R.C. & Mann, K.H. 1976. Destructive grazing of kelp by sea urchins in eastern Canada. *J. Fish. Res. Bd. Can.*, 33, 1278-1283.

Callow, M. E. 1993. A review of fouling in fresh waters. *Biofouling*, 7, 313-327.

Claereboudt, M.R., Bureau, D., Côté, J. & Himmelman, J.H. 1994. Fouling development and its effect on the growth of juvenile giant scallops (*Placopecten magellanicus*) in suspended culture. *Aquaculture*, 121, 327-342.

Côté, J., Himmelman, J.H., Claereboudt, M.R. & Bonardelli, J.C. 1993. Influence of density and depth on the growth of juvenile sea scallops (*Placopecten magellanicus*) in suspended culture. *Can. J. Fish. Aquat. Sci.*, 50, 1857-1869.

Côté, J., Himmelman, J.H. & Claereboudt, M.R. 1994. Separating effects of limited food and space on growth of the giant scallop *Placopecten magellanicus* in suspended culture. *Mar. Ecol. Prog. Ser.*, 106, 85-91.

Couturier, C., Dabinett, P. & Lanteigne, M. 1995. Scallop culture in Atlantic Canada. In: *Cold-water Aquaculture in Atlantic Canada*. Ed. Boghen A., The Tribune Press, Sackville, NB, Canada, pp. 297-340.

Crisp, D. J. 1974. *Factors influencing the settlement of marine invertebrate larvae*. In: Ed. Grant P.T, Mackie, A. T. *Chemoreception in Marine Organisms*. London and New York, Academic Press, pp. 177-265.

Dadswell, M.J. & Parsons, G.J. 1991. Potential for aquaculture of sea scallop, *Placopecten magellanicus* (Gremlin, 1791) in the Canadian Maritimes using naturally produced spat. In: *An International Compendium of Scallop Biology and Culture* Ed. S.E. Shumway and P. Sandifer, *The World Aquaculture Society Publication,* 1, Baton Rouge, L.A., USA, pp. 300-307.

Dadswell, M.J. & Parsons, G.J. 1992. Exploiting life-history characteristics of the sea scallop, *Placopecten magellanicus* (Gmelin, 1971), from different geographical locations in the Canadian maritimes to enhance suspended culture grow-out. *J. Shellfish. Res.,* 11, 299-305.

Denny, M. W. 1988. *Biology and the mechanics of the wave-swept environment.* Princeton, USA, Princeton University Press. 344 pp.

De Ridder, C. & Lawrence, J.M. 1982. *Food and feeding mechanisms: Echinoidea.* In: Echinoderm Nutrition (Ed. M. Jangoux. & J.M. Lawrence). Balkema, Rotterdam. pp. 57-115.

Devaraj, M. & Parsons, G. J. 1997. Effect of fouling on current velocities in pearl nets of various mesh size. *Bull. Aquacul. Assoc. Can.,* 2, 72-75.

Dubost, N., Masson, G. & Moreteau, J. 1996. Temperate freshwater fouling on floating net cages: method of evaluation, model and composition. *Aquaculture*, 143, 303-318.

Enright,C.T, Krailo, D., Staples, L., Smith, M., Vaughan, C., Word, D., Gaul, P. & Borgese, E. M. 1983. Biological control of fouling algae in oyster aquaculture. *J. Shellfish Res.*, 3, 41-44.

Enright, C.T., Elner, R.W., Griswold, A. & Borgese, E.M. 1993. Crabs and periwinkles as control agents for biofouling in suspended culture of European oysters. *World Aquaculture,* 24, 49-51.

Finlay, J. A. & Callow, M. E. 1996. The potential of alkyl amines as antifouling biocides. I: Toxicity and structure activity relationships. *Biofouling*, 9, 257-268.

Fletcher, R. L. & Callow, M. E. 1992. The settlement, attachment and establishment of marine algal spores. *Br. Phycol. J.*, 27, 303-329.

Fletcher, R. L. 1980. The algal communities on floating structures in Portsmouth and Langstone Harbours (South Coast of England). In: Systematics Association Special Volume No. 17(b). *The shore environment,* Vol 2. Ecosystems. Ed. J.H. Price, D.E.G.Irvine and W.F. Farnham. Academic Press, London and NewYork, pp 843-874.

Gauch, H. G. Jr. 1982. Multivariate Analysis in Community Ecology. Cambridge University Press. Cambridge. x + 298pp.

Grecian, L.A., Parsons, G.J., Dabinett, P. & Couturier, C. 2000. Influence of season, initial size, gear type and stocking density on the growth rates and recovery of sea scallop, *Placopecten magellanicus*, on a farm-based nursery. *Aquaculture International*, 8, 183-206.

Hall, A. D. 1996. *Aspects of the biofouling of salmon Aquaculture nets in Southwestern New Brunswick*. M.Sc. Thesis, Memorial University of Newfoundland. vii + 109pp.

Hall, A.D., South, G.R. & Tracy, E.J. 1989. Biofouling of salmonid aquaculture systems: preliminary observations from the Bay of Fundy, Canada. *Brit. Phycol. J., 17, 304.*

Hidu, H., Conary, C. & Chapman, S. R. 1981. Suspended cultures of oysters: biological fouling control. *Aquaculture*, 22, 189-192.

Hill, M.O. 1994. *DECORANA and TWINSPAN, for ordination and classification of multivariate species data: a new edition, together with supporting programs, in FORTRAN 77.* Huntingdon, Institute of Terrestrial Ecology. 58pp.

Himmelman, J.H. 1984. Urchin feeding and macroalgal distribution in Newfoundland, Eastern Canada. *Naturaliste Can.*, 111, 337-348.

Himmelman, J.H. & Nédélec, H. 1990. Urchin foraging and algal survival strategies in intensely grazed communities in Eastern Canada. *Can. J. Fish. Aquat. Sci.*, 47, 1011-1026.

Himmelman, J.H. & Steele, D.H. 1971. Foods and predators of the green sea urchin *Strongylocentrotus droebachiensis* in Newfoundland waters. *Mar. Biol.*, 9. 315-322.

Hoek, C. van den 1982. The distribution of benthic marine algae in relation to the temperature regulation of their life histories. *Bot. J. Linn. Soc.* 18, 81-144.

Hodson, S. L. & Burke, C. M. 1994. Microfouling of salmon-cage netting: a preliminary investigation. *Biofouling*, 8, 93-105.

Hodson, S. L., Lewis, T. E. & Burke, C. M. 1997. Biofouling of fish-cage netting: Efficacy and problems of *in situ* cleaning. *Aquaculture*, 152, 77-90.

Hooper, R.G. & South, G.R. 1974. A taxonomic appraisal of *Callophyllis* and *Euthora* (Rhodophyta). *Brit. Phycol. J.*, 9, 423-428.

Hooper, R.G. South G.R. & Whittick, A. 1980. Ecological and Phenological Aspects of Marine Phytobenthos of the Island of Newfoundland. In: Systematics Association Special Volume No. 17(b). *The shore environment,* Vol 2. Ecosystems. Edited by J.H. Price, D.E.G.Irvine and W.F. Farnham, Academic Press. London and NewYork. pp. 395-423.

Humm, H. J. & Wicks, S.R. 1980. *Introduction and guide to the Marine Bluegreen Algae.* Wiley- Interscience Publication. New York. x + 194 pp.

Hutchins, L.W. 1947. The basis for temperature zonation in geographical distribution. *Ecol. Mongr.,* 17, 81-114.

Kawamura, T., Nimura, Y. & Hirano, R. 1988. Effects of bacterial films on diatom attachment in the initial phase of marine fouling. *J. Oceanog. Soc. Japan.*, 44, 1-5.

Keats, D.W., G.R. South & D.H. Steele, 1982. The relationship of *Agarum cribrosum* (Mert.) Bory (Phaeophyta, Laminariales) with its competitors and predators in Newfoundland. *Phycologia,* 21, 189-191.

Keats, D.W., G. R. South & D.H. Steele, 1990. The effects of the experimental removal of Green Sea Urchins on benthic macro-algae in eastern Newfoundland. *Mar. Ecol. Prog. Ser.*, 68, 181-193.

Kershaw, K.A. & Looney, J.H. 1985. *Quantitative and Dynamic Plant Ecology.* Third edition. Edward Arnold, London. iv + 282 pp.

Kim, J.H. & DeWreede, R.E. 1996. Distribution and feeding preference of a high intertidal littorinid. *Bot. Mar.,* 39. 561-569.

Knox-Holmes, B. 1993. Biofouling control with low levels of copper and chlorine. *Biofouling*, **7**, 157-166.

Kuhlenkamp, R. 1990. Field and culture studies on Newfoundland Tilopteridales. M.Sc Thesis, Memorial University of Newfoundland. ix – 119 pp.

Lee, H. D., Lim, L. C. & Chang, L. 1983. Observations on the use of antifouling paint in net cage fish farming in Singapore. *Singapore J. Primary. Ind.*, 13, 1-12.

Lesser, M., Shumway, S., Cucci.,T. & Smith, J. 1992. Impact of fouling organisms on mussel rope culture: interspecific competition for food among suspension-feeding invertebrates. *J. Exp. Mar. Biol. Ecol.*, 165, 91-102.

Lobban, C.S. 1984. Marine tube-dwelling diatoms of eastern Canada: descriptions, checklist, and illustrated key. *Can. J. Bot.*, 62, 778-794.

Lovegrove, T. 1979. Control of fouling in farm cages. *Fish Farming International,* 6, 33-37.

Lubchenco, J. 1978. Plant species diversity in a marine intertidal community: importance of herbivore food preference and algal competitive abilities. *Am. Nat.,* 112, 23-39.

Lubchenco, J. 1983. *Littorina* and *Fucus*: effects of herbivores, substratum heterogeneity and plant escapes during succession. *Ecology*, 64, 1116- 1123.

Lüning, K. 1990. *Seaweeds: their environment, biogeography and ecophysiology*. New York, USA, John Wiley and Sons. xxi + 527 pp.

Mallet, A.L. & Carver, C.E. 1991. An assessment of strategies for growing mussels in suspended culture. *J. Shellfish Res.*, 10, 471-477.

MacDonald, B.A. & Thompson, R.J. 1985a. Influence of temperature and food availability on the ecological energetics of the giant scallop *Placopecten magellanicus*. I. Reproductive output and total production. *Mar. Ecol. Prog. Ser.*, 25, 270-294.

MacDonald, B.A. & Thompson, R.J. 1985b. Influence of temperature and food availability on the ecological energetics of the giant scallop *Placopecten magellanicus*. II. Reproductive output and total production. *Mar. Ecol. Prog. Ser.*, 25, 295-303.

MacDonald, B.A. & Thompson, R.J. 1988. Intraspecific variation in growth and reproduction in latitudinally differentiated populations of the giant scallop *Placopecten magellanicus* (Gmelin). *Biol. Bull.*, 175, 361-371.

McQuaid, C.D. 1996. Biology of the gastropod family Littorinidae. II. Role in the ecology of intertidal and shallow marine ecosystems. *Oceanogr. Mar. Biol. Ann. Rev.*, 34, 263-302.

Milne, P.H. 1970. Fish farming: a guide to the design and construction of net enclosures. *Mar. Res.,* 1, 3-31.

Milne, P.H. 1975a. Fouling of marine cages (Part 1). *Fish Farming International*, 2, 15-19.

Milne, P.H. 1975b. Fouling of marine cages (Part 2); further trials in Scottish lochs. *Fish Farming International*, 2, 18-21.

Mook, D. 1981. Removal of suspended particles by fouling communities. *Mar. Ecol. Prog. Ser.*, 5, 279-281.

Newell, R.C. 1979. *Biology of Intertidal Animals*. 3rd ed. Marine Ecological Surveys Ltd. Faversham. ix + 781 pp.

Newell, R.C., Pye, V.I. & Ahsanullah, M. 1971. Factors affecting the feeding rate of the winkle *Littorina littorea*. *Mar. Biol.*, 9, 138-144.

Nichols, J., Couturier, C., Pryor, M. & Macneill, S. 2002. Environmental and biological characteristics of Newfoundland Shellfish Farms for 1993-2001. ACERA Mussel Project Final Report. Fisheries and Marine Institute of Memorial University of Newfoundland. MSS Report. x + 83 pp.

Newkirk, G.F., Muise, B.C. & Enright, C.E. 1995. *Ostrea edulis,* in Nova Scotia. In: Boghen, A.D. *Cold-Water Aquaculture in Atlantic Canada*. Moncton, New Brunswick: Tribune Printing. pp. 227-253.

Norton, T.A., Hawkins, S.J., Manley, N.L., Williams, G.A. & Watson D.C. 1990. Scraping a living: a review of littorinid grazing. *Hydrobiologia*, 193, 117-138.

Osman, R. W. & Whitlatch, R. B. 1995. Predation on early ontogenetic life stages and its effect on recruitment into a marine epifaunal community. *Mar. Ecol. Prog. Ser.*, 117, 111-126.

Parrish, C.C., McKenzie, C.H., MacDonald, B.A. & Hatfield, E.A. 1995. Seasonal studies of seston lipids in relation to microplankton species composition and scallop growth in South Broad Cove, Newfoundland. *Mar. Ecol. Prog. Ser.*, 129, 151-164.

Parsons, G.J. & Dadswell, M.J. 1992. Effect of stocking density on growth, production, and survival of the giant scallop, *Placopecten magellanicus*, held in intermediate suspension culture in Passamaquoddy Bay, New Brunswick. *Aquaculture*, 103, 291-309.

Petraitis, P.S. 1992. Effects of body size and water temperature on grazing rates of four intertidal gastropods. *Australian Journal of Ecology*, 17, 409-414.

Porter, C. 1981. Cage culture of gilthead bream (*Sparus aurata*) at an exposed site on the red sea. *Spec. Publ. Eur. Maricult. Soc.*, 6, 15-24.

Santelices, B. 1990. Patterns of reproduction, dispersal and recruitment in seaweeds.*Oceanography and Marine Biology: an Annual Review*, 28, 177-276.

Scott, C., Fletcher, R. L. & Bremer, G. B. 1996. Observations on the mechanisms of attachment of some marine fouling blue-green algae. *Biofouling*, 10, 161-173.

Sears, J.R. 1998. *NEAS Keys to the Benthic Marine Algae of the Northeastern Coast of North America from Long Island Sound to the Strait of Belle Isle.* North East Algal Society (NEAS). Dartmouth, MA. xi + 161 pp.

Shumway S.E. & Cembella, A.D. 1993. The impact of toxic algae on scallop culture and fisheries. *Reviews in Fisheries Science,* 1, 121-150.

Shumway, S.E., Selvin R. & Schick, D.F. 1987. Food resources related to habitat in the scallop *Placopectin magellanicus,* (Gmelin 1791): quantitative study. *J. Shellfish. Res.*, 6, 89-95.

South G.R. 1983. *Benthic marine algae.* In: Biogeography and Ecology of the Island of Newfoundland. Ed. South, G.R. Dr. W. Junk Publishers, The Hague. pp. 385-420.

South G.R. & Hooper, R.G. 1976. *Stictyosiphon soriferus* (Phaeophyta, Dictyosiphales) from eastern North America. *J. Phycol.,* 12, 24-29.

South, R. G. & Hooper, R. G. 1980. A catalogue and atlas of the benthic marine algae of the Island of Newfoundland. *Memorial Univ. Nfld. Occas. Pap. Biol.*, 3, 1-136.

Starr, M., Himmelman, J.H. & Therriault, J.C. 1993. Environmental control of green sea urchin, *Strongylocentrotus droebachiensis,* spawning in the St. Lawrence Estuary. *Can. J. Fish. Aquat. Sci.*, 50, 894-901.

Steele, D.H. 1983. *Marine ecology and zoogeography.* In: Biogeography and Ecology of the Island of Newfoundland. Ed. South, G.R. Dr. W. Junk Publishers, The Hague. pp. 421-465.

Steneck, R.S. & Watling, L. 1982. Feeding capabilities and limitation of herbivorous mollusks: a functional approach. Mar. Biol., 68, 299-312.

Taggart, C.T. & Frank, K.T. 1987. Coastal upwelling and *Oikopleura* occurrence ("slub"): a model and potential application to inshore fisheries. *Can. J. Fish. Aquat. Sci.*, 44, 1729-1736.

Taylor, W.T. 1957, *Marine algae of the northeastern coast of North America.* University of Michigan Press. Ann Arbor. viii + 509 pp.

Terry, L.A. & Picken, G.B. 1986. Algal fouling in the North Sea. In: Evans, L.V. & Hoagland, K.D. (eds*) Algal Biofouling*. Elsevier, Amsterdam, Netherlands, pp.179-192.

Watson, D.C. & Norton, T.A. 1985. Dietary preferences of the common periwinkle, *Littorina littorea* (L.). *J. Exp. Mar. Biol. Ecol.*, 88, 193-211.

Whittick, A. 1978. The life history and phenology of *Callithamnion corymbosum* (Sm.) Lyngbye (Rhodophyta, Ceramiaceae) in Newfoundland. *Can. J. Bot.*, 56, 2495-2499.

Whittick, A., Knight, K. & Hooper, R.G. 1982. Fouling algae on steel structures in the Newfoundland inshore. *Br. Phycol. J.*, 17, 241.

Whittick, A., Hooper, R. G. & South, G. R. 1989. Latitude, distribution and phenology: reproduction strategies in some Newfoundland seaweeds. *Bot. Mar.*, 32, 407-417.

Yarish, C., Breeman, A.M. & van den Hoek, C. 1984. Temperature light and photoperiod responses of some northeast American and west European endemic rhodophytes in relation to their geographic distribution. *Helgol. Meeresunters.*, 38, 273-304.

Yarish, C., Breeman, A.M. & van den Hoek, C. 1986. Survival strategies and temperature responses belonging to different biogeographic distribution groups. *Bot. Mar.*, 24, 215-230.

Zar, J.H. 1984. *Biostatistical Analyisis.* Second Edition. Prentice Hall, New Jersey. xiv + 718pp.

APPENDIX TABLES

Table A1. Occurrence of the Chlorophyta on pearl nets at each sampling period (Present = +, Absence = -, 1&2 = 2m & 4m depths and 123 = Three treatments, urchin, control and snail respectively).

DIVISION / CLASS / **ORDER** / Family / *Genus species*	STUDY PERIOD / DEPTH / TREATMENT	1 June 6/30/98		2 August 8/26/98		3 November 11/4/98		4 May 5/20/99		5 July 7/19/99		6 July 7/27/00	
		1	2	1	2	1	2	1	2	1	2	1	2
		2	2	123	123	2	2	123	123	2	2	2	2
Species names & authorities	Name code												
CHLOROPHYTA													
CHLOROPHYCEAE													
Acrosiphonales													
Acrosiphonacea													
Chlorochytrium inclusum Kjellman	CHLO INC				+								
Spongomorpha aeruginosa (L.) Hoek	SPON AEU	+	+	++	++			++	+	+	+		
Cladophorales													
Cladophoraceae													
Cladophora albida (Nees) Kütz.	CLAD ALB							+		+	+	+	+
Cladophora sericea (Hudsun) Kütz.	CLAD SER			+	+		+		+			+	+
Chaetomorpha linium (O.F. Muell.) Kütz.	CHAE LIN	+		+	+	+		+	+			+	+
Chaetomorpha capillaris (Kütz.)	CHAE CAP	+		+++	+++	+	+	+++	+	+	+	+	
Rhizoclonium riparium (Roth) Kütz. ex Harvey	RHIZ RIP	+	+	+++	+++	+		++					
Ulotrichales													
Ulotrichaceae													
Ulothrix flacca (Dillwyn) Thuret in LeJolis	ULOT FLA	+	+	++	++	+	+	++	++				
Uvales													
Percursariaceae													
Percursaria percursa (C.Agardh) Rosenv.	PERC PER				+	+	+						
Enteromorpha spp. Link in Nees, 1828	ENTE SPP	+						+					
	TOTAL	6	3	4,5,3	6,6,2	5	4	5,5,2	1,2,3	3	3	4	3

Table A2. Occurrence of the Phaeophyta on pearl nets at each sampling period (Present = +, Absence = -, 1&2 = 2m & 4m depths and 123 = Three treatments, urchin, control and snail respectively).

DIVISION		1		2		3		4		5		6	
CLASS		June		August		November		May		July		July	
ORDER	STUDYPERIOD	6/30/98		8/26/98		11/4/98		5/20/99		7/19/99		7/27/00	
Family	DEPTH	1	2	1	2	1	2	1	2	1	2	1	2
Genus species	TREATMENT	2	2	123	123	2	2	123	123	2	2	2	2
Species names & authorities	Name code												
PHAEOPHYTA													
PHAEOPHYCEAE													
Chordariales													
Chordariaceae													
Cladosiphon zosterae (J.Agardh) Kylin	CLAD ZOS	+	+										
Tilopteridales													
Tilopteridaceae													
Haplospora globosa Kjellm.	HAPL GLO	+	+		+			+++	+++			+	+
Tilopteris mertensii (Turner in Sm.) Kütz.	TILO MER							+	+				
Sphacelariales													
Cladostephaceae													
Dictyosiphonales													
Dictyosiphonaceae													
Dictyosiphon foeniculaceus (Hudson) Grev.	DICT FOE							+	+	+	+		
Myriotrichiaceae													
Punctariaceae													
Punctaria tenuissima (C.Agardh) Grev.	PUNC TEN							+					
Striariaceae													
Isthmoplea sphaerophora (Carmich.ex Harv. in Hook.) Kjellm.	ISTH SPH		+	+	+								

Stictyosiphon soriferus (Reinke) Rosenv.	STIC SOR			+ +		+	+	+		+					
Stictyosiphon tortilis (Rupr.) Reinke	STIC TOR							+							
Scytosiphonales															
Scytosiphonaceae															
Petalonia zosterifoila (O.F. Müll.) O. Kuntze	PETA ZOS			+++	+++	+					+				
Scytosiphon lomentaria (Lyngbye) Link	SCYT LOM			+++	+	+		+++	+	+					
Ectocarpales															
Ectocarpaceae															
Ectocarpus fasciulatus Harv.	ECTO FAS	+	+		++		+	+++	+++	+	+				
Ectocarpus siliculosus (Dillwyn) Lyngbye	ECTO SIL	+	+	+++	+++	+	+	+++	+++	+	+	+	+		
Hincksia granulosa (J.E.Smith.) P.C. Silva	HINC GRA		+	+++	+	+	+	+	+ +						
Giffordia ovata (Kjellm.) P.C. Silva	GIFF OVA				+ +	+	+		+++	+					
Kuckuckia spinosa (Kütz.) Kuck.	KUCK SPI				+										
Laminariocolax tomentosoides (Farl.) Kylin	LAMI TOM				+										
Pilayella littoralis (L.) Kjellman	PILA LIT	+	+	+++	+++	+	+	+++	+++	+	+	+	+		
Spongonema tomentosum (Huds.) Kütz.	SPON TOM	+	+	+		+									
Desmarestiales															
Desmarestiaceae															
Desmarestia aculeate (L.) J.V. Lamour.	DESM ACU							+							
Desmarestia viridis (O.F. Müll.) J.V. Lamour.	DESM VIR			+				+++	+++			+	+		
Laminariales															
Chordaceae															
Chorda filum (L.) Stackh.	CHOR FIL			+++	++	+	+		+++						
Laminariaceae															
Laminaria longicuris Bach.Pyl.	LAMI LON							+++	+++	+	+	+	+		

Laminaria saccharina (L.) J.V. Lamour.	LAMI SAC							+ +	++	+		+	+
Laminaria spp.	LAMI JUV			+									
	TOTAL	6	8	6,9,8	6,9,6	9	7	11,9,10	12,9,9	9	6	6	6

Table A3. Occurrence of the Rhodophyta on pearl nets at each sampling period (Present = +, Absence = -, 1&2 = 2m & 4m depths and 123 = Three treatments, urchin, control and snail respectively).

DIVISION / CLASS / **ORDER** / Family / *Genus species*	STUDY PERIOD / DEPTH / TREATMENT	1 June 6/30/98		2 August 8/26/98		3 November 11/4/98		4 May 5/20/99		5 July 7/19/99		6 July 7/27/00	
		1	2	1	2	1	2	1	2	1	2	1	2
		2	2	123	123	2	2	123	123	2	2	2	2
Species names & authorities	Name code												
RHODOPHYTA													
RHODOPHYCEAE													
Erythropeltidales													
Erythrotrichiaceae													
Erythrotrichia carnea (Dillwyn) J.Agardh	ERYT CAR			+++	+++	+	+	+++	+	+			
Acrochaetiales													
Acrochaetiaceae													
Audouinella alariae (H. Jónss.) Woelk.	AUDO ALA			+	+			+		+			
Bonnemaisoniales													
Bonnemaisoniaceae													
Bonnemaisonia hamifera Har.	BONN HAM	+	+	+	+++	+	+	+++	+++	+	+	+	+
Gigartinales													
Kallymeniaceae													
Callophyllis cristata (C.Agardh) Kütz.	CALL CRI									+	+	+	+
Ceramiales													
Ceramiaceae													
Callithamnion corymbosum (Sm.) Lyngb.	CALL COR					+				+	+		+

Ceramium nodulosum (Lightfoot) Ducluzea	CERA NOD			+++	++	+	+	+++	+++	+	+	+	+
Ceramium cimbricum H.E. Peterson in Rosenv.	CERA CIM				++	+	+	++					
Ceramium elegans (Roth) Ducluzea	CERA ELE						+	+++	+++	+	+	+	+
Ceramium strictum Harv.	CERA STR							++	+ +	+	+	+	+
Scagelia pylaisei (Mont.) M.J. Wynne	SCAG PYL	+	+	+++	+++	+	+	+++	+++	+	+	+	+
Scagelia pulmosa	SCAG PUL		+		++	+	+	++					
Delesseriaceae													
Membranoptera alata (Huds.) Stackh.	MEMB ALA										+		
Pantoneura fabriciana (Lyngb.) M.J. Wynne	PANT FAB									+	+		
Phycodrys rubens Batters	PHYC RUB									+	+		
Rhodomelaceae													
Polysiphonia flexicaulis (Harv.) F.Collins	POLY FLE		+	+++	+++	+	+	+++	+++			+	+
Polysiphonia artica J.Agardh	POLY ARC			+									
Polysiphonia stricta (Dillwyn) Grev.	POLY STR		+	+	+	+		+++	+++	+	+	+	+
Polysiphonia fucoides (L.)Tandy	POLY FUC	+		+++	++	+	+	+++	+	+		+	
Rhodomela confervoides (Huds.) P.C. Silva	RHOD CON							+++	+++	+	+		
	TOTAL	3	5	8,5,6	7,8,7	10	9	12,12,10	8,9,8	14	12	9	9

Table A4. Occurrence of the Cyanobacteria and colonial diatoms on pearl nets at each sampling period (Present = +, Absence = -, 1&2 = 2m & 4m depths and 123 = Three treatments, urchin, control and snail respectively).

DIVISION CLASS **ORDER** Family *Genus species*	STUDY PERIOD DEPTH TREATMENT	1 June 6/30/98		2 August 8/26/98		3 November 11/4/98		4 May 5/20/99		5 July 7/19/99		6 July 7/27/00	
		1	2	1	2	1	2	1	2	1	2	1	2
		2	2	123	123	2	2	123	123	2	2	2	2
Species names & authorities	Name code												
CYANOPHYTA													
CYANOPHYCEAE													
Nostocales (Oscillatoriales)													
Spirulina major Kützing	SPIR MAJ			+++	+++	+	+						
Spirulina subsalsa Oersted.	SPIR SUB			+++	+++	+	+			+			
Spirulina vesi-color Cohn.	SPIR VES				+				++		+		
Spirulina nordstedtii Gomont.	SPIR NOR				+								
Spirulina spp.	SPIR SPP	+	+	+	+ +				++				
Oscillatoria margoritifera Kützing	OSCI MAR			+++	+++	+	+						
Oscillatoria corallinae Gomont.	OSCI COR			+	+	+	+						
Oscillatoria nigro-viridis Thwaites	OSCI NIG			++	+++	+			+				
Oscillatoria spp. (1)	OSCI SP1	+	+	++	+				++	+			
Oscillatoria spp. (2)	OSCI SP2	+	+		+			+					
Lyngbya conferviodes C. Agardh	LYNG CON			++	+		+						
Lyngbya semiplena (C. Agardh) J. Agardh	LYNG SEM			+++	+++	+	+						
Lyngbya aestuarii Gomont.	LYNG AES			+++	+++	+	+						
Lyngbya majuscula Gomont.	LYNG MAJ				+	+	+						
Lyngbya sordida (Zanardini) Gomont.	LYNG SOR					+	+						
Lyngbya meneghiniana (Kützing) Falkenburg	LYNG MEN					+	+						

Lyngbya gracilis (Meneghini) Rabenhorst	LYNG GRA									+			
Lyngbya spp.	LYNG SPP		+		+								
Anabaena inaequalis (Kützing) Trevisan	ANAB INA			+++	+++								
Anabaena tortulosa (Carmichael) Lagerheim	ANAB TOR			+++	+++								
Anabaena variabilis Kützing.	ANAB VAR			+++	+++								
*Anabaena spp.*1	ANAB SP1		+		++								
*Anabaena spp.*2	ANAB SP2		+	+	+								+
Calothrix pilosa Harvey.	CALO PIL			+++	+++	+							
Calothrix fasciculate C.Agardh	CALO FAS			+++	+++	+							
Calothrix contarenii (Zanardini) Bornet	CALO CON			+++	+++		+						
Calothrix consociata (Kützing) Bornet	CALO COS			++	+++	+	+						
Calothrix scopulorum (Weber and Mohr) C. Agardh	CALO SCO			+	+								
Calothrix confervicola (Roth) C. Agardh	CALO CON	+	+	++	++			++	+	+		+	+
Calothrix fusco-violacea Crouan.	CALO FUS			+++	+++	+	+						
Calothrix spp.	CALO SPP	+	+	+				++	+	+			+
Schizothrix spp.	SCHI SPP				+								
*Unknown spp.*1	UNKN SPP	+	+	+									
CHRYSOPHYTA													
BACILLARIOPHYCEAE													
Naviculaceae													
Berkeleya rutilans (Trentepohl) Grunow	BERK RUT			+	++	+						+	+
Navicula spp.	NAVI SPP	+	+	+++	++	+	+	++	+++	+	+	+	+
	TOTAL	7	10	18,20,16	21,22,20	16	13	2,3,2	3,6,3	6	2	3	5

Legend for tables A5-A10.

Algal Amount (% Cover)	Code number Assigned.
Absent	0
0-1 (%)	1
1-10 (%)	2
10-30 (%)	3
30-60 (%)	4
60-100 (%)	5
Treatment #1	Nets treated with Urchins.
Treatment #2	Untreated nets (control).
Treatment #3	Nets treated with Snails.
Depth #1	Shallow depth (2m).
Depth #2	Deep depth (4m).
Dates #1-4	Four sample dates within the first year of net fouling (1998-1999).
Dates # 5	Fouled nets in the second year (1999).
Dates # 6	Fouled nets in the third year (2000).
Replication	Replicates 1 through 6.
Biomass (g)	Wet weight of fouled net, minus wet weight of unfouled net.
Scallop lengths (mm)	Scallop lengths (N=25) in each pearl net. Measurements in bold face are scallops that died during the experiments

Table A5. Fouling biomass (g) on pearl nets from April 1998-July 2000 (1&2= 2m & 4m depths).

Algae												
Date	1	1	1	1	1	1	1	1	1	1	1	1
Replicate	1	2	3	4	5	6	1	2	3	4	5	6
Depth	1	1	1	1	1	1	2	2	2	2	2	2
Biomass	345.3	373.4	312.7	330.1	325	378.5	220.1	225.8	228.1	231.2	224.2	232.6
Date	2	2	2	2	2	2	2	2	2	2	2	2
Replicate	1	2	3	4	5	6	1	2	3	4	5	6
Depth	1	1	1	1	1	1	2	2	2	2	2	2
Biomass	540.3	510.4	494.6	466.7	494.3	410.9	414.5	341.1	338.7	346.8	368.1	344.5
Date	3	3	3	3	3	3	3	3	3	3	3	3
Replicate	1	2	3	4	5	6	1	2	3	4	5	6
Depth	1	1	1	1	1	1	2	2	2	2	2	2
Biomass	526.2	520.4	578.9	572.8	618.1	676.5	374.7	348.5	390.8	390.9	430.5	376.6
Date	4	4	4	4	4	4	4	4	4	4	4	4
Replicate	1	2	3	4	5	6	1	2	3	4	5	6
Depth	1	1	1	1	1	1	2	2	2	2	2	2
Biomass	576.4	435.1	790.2	1358.3	984.4	1924.5	650.6	602.8	965.8	668.2	780.6	750.5
Date	5	5	5	5	5	5	5	5	5	5	5	5
Replicate	1	2	3	4	5	6	1	2	3	4	5	6
Depth	1	1	1	1	1	1	2	2	2	2	2	2
Biomass	1192.1	1024.3	1056.5	1014.7	1066.9	1144.	1100.2	956.4	892.6	921.8	1050.5	1098.2
Date	6	6	6	6	6	6	6	6	6	6	6	6
Replicate	1	2	3	4	5	6	1	2	3	4	5	6
Depth	1	1	1	1	1	1	2	2	2	2	2	2
Biomass	1258.1	948.2	1108.3	990.4	1056.6	1380.5	956.6	786.4	672.5	639.2	660.3	1100.5

Table A6. Fouling biomass (g) on pearl nets. Grazing experiments (urchins, control and snails respectively) at four sampling periods. (1&2=2m & 4m depths).

Urchins												
Date	1	1	1	1	1	1	1	1	1	1	1	1
Replicate	1	2	3	4	5	6	1	2	3	4	5	6
Depth	1	1	1	1	1	1	2	2	2	2	2	2
Biomass	345.4	373.5	312.3	330.9	325.8	378.2	220.5	225	228.3	231.6	224.6	232.4
Date	2	2	2	2	2	2	2	2	2	2	2	2
Replicate	1	2	3	4	5	6	1	2	3	4	5	6
Depth	1	1	1	1	1	1	2	2	2	2	2	2
Biomass	442.2	402.5	426.8	500	472.2	508.8	344.7	356.5	329.6	304.8	338.8	286.2
Date	3	3	3	3	3	3	3	3	3	3	3	3
Replicate	1	2	3	4	5	6	1	2	3	4	5	6
Depth	1	1	1	1	1	1	2	2	2	2	2	2
Biomass	526.4	520.5	578.6	572.4	618.6	676.7	374.5	348.8	390.4	390.9	430.2	376.3
Date	4	4	4	4	4	4	4	4	4	4	4	4
Replicate	1	2	3	4	5	6	1	2	3	4	5	6
Depth	1	1	1	1	1	1	2	2	2	2	2	2
Biomass	796.3	466.5	426.6	812.4	870.7	1216.1	560.2	542.8	590.5	695.6	715.7	766.5
Control (No grazers)												
Date	1	1	1	1	1	1	1	1	1	1	1	1
Replicate	1	2	3	4	5	6	1	2	3	4	5	6
Depth	1	1	1	1	1	1	2	2	2	2	2	2
Biomass	345.4	373.5	312.3	330.9	325.8	378.2	220.5	225	228.3	231.6	224.6	232.4
Date	2	2	2	2	2	2	2	2	2	2	2	2
Replicate	1	2	3	4	5	6	1	2	3	4	5	6
Depth	1	1	1	1	1	1	2	2	2	2	2	2
Biomass	540.2	510.4	494.6	466.8	494.1	410.3	414.5	341.7	338.9	346.1	368.2	344.3

Date	3	3	3	3	3	3	3	3	3	3	3	3
Replicate	1	2	3	4	5	6	1	2	3	4	5	6
Depth	1	1	1	1	1	1	2	2	2	2	2	2
Biomass	526.2	520.3	578.1	572.2	618.4	676.5	374.5	348.6	390.5	390.7	430.8	376.8
Date	4	4	4	4	4	4	4	4	4	4	4	4
Replicate	1	2	3	4	5	6	1	2	3	4	5	6
Depth	1	1	1	1	1	1	2	2	2	2	2	2
Biomass	576.9	435.8	790.7	1358.6	984.5	1924.4	650.3	602.1	965	668.1	780	750.2
Snails												
Date	1	1	1	1	1	1	1	1	1	1	1	1
Replicate	1	2	3	4	5	6	1	2	3	4	5	6
Depth	1	1	1	1	1	1	2	2	2	2	2	2
Biomass	345.4	373.5	312.3	330.9	325.8	378.2	220.5	225	228.3	231.6	224.6	232.4
Date	2	2	2	2	2	2	2	2	2	2	2	2
Replicate	1	2	3	4	5	6	1	2	3	4	5	6
Depth	1	1	1	1	1	1	2	2	2	2	2	2
Biomass	254.1	272.3	240.9	228.2	302.2	222.2	228.5	208.6	236.5	214.0	290.5	238.4
Date	3	3	3	3	3	3	3	3	3	3	3	3
Replicate	1	2	3	4	5	6	1	2	3	4	5	6
Depth	1	1	1	1	1	1	2	2	2	2	2	2
Biomass	526.5	520.6	578.5	572.1	618.5	676.2	374.5	348.4	390.5	390.4	430.7	376.5
Date	4	4	4	4	4	4	4	4	4	4	4	4
Replicate	1	2	3	4	5	6	1	2	3	4	5	6
Depth	1	1	1	1	1	1	2	2	2	2	2	2
Biomass	574.1	416.3	622.9	800.4	1178.7	1128.4	588.5	454.5	906.3	694.4	632.5	742.8

Table A7. Species abundance values for input into DECORANA and TWINSPAN analysis from April 1998-July 2000 (Depth 1=2m, depth 2=4m).

	Date	1	1	1	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	2	2	2	2	3	3	3	3	3	3	3	3	3	3	3	3	4	4	4	4	4	4	4	4	4	4	4	4	5	5	5	5	5	5	5	5	5	5	5	5	6	6	6	6	6	6	6	6	6	6	6	6
	Replicate	1	1	2	2	3	3	4	4	5	5	6	6	1	1	2	2	3	3	4	4	5	5	6	6	1	1	2	2	3	3	4	4	5	5	6	6	1	1	2	2	3	3	4	4	5	5	6	6	1	1	2	2	3	3	4	4	5	5	6	6	1	1	2	2	3	3	4	4	5	5	6	6
	Depth	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2
Genus species	**Treatment**	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Species names & authorities	**Name Code**																																																																										
Anabaena inaequalis (Kützing) Trevisan	ANAB INA	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Anabaena spp. 1	ANAB SP1	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
Anabaena spp. 2	ANAB SP2	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	2	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Anabaena tortulosa (Carmichael) Lagerheim	ANAB TOR	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Anabaena variabilis Kützing.	ANAB VAR	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	2	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Audouinella alariae (H. Jónss.) Woelk.	AUDO ALA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bonnemaisonia hamifera Har.	BONN HAM	0	0	2	1	0	0	0	0	2	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	5	3	0	3	0	4	1	4	0	3	0	4	2	3	4	3	2	0	0	1	0	0	0	2	2	0	0	0	3	4	1	0	0	0	1	3	2	0	0	0	4	0	2	0	0	0	4	0
Callithamnion corymbosum (Sm.) Lyngb.	CALL COR	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	3	0	0	0	3	0	0	0	0	0	0	0	0	0	0	2	0	0	0	3	0	0
Callophyllis cristata (C.Agardh) Kütz.	CALL CRI	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	2	0	3	0	0	0	0	1	0	4	5	3	5	3	4	4	5	3	5	3	4
Calothrix contarenii (Zanardini) Bornet	CALO CON	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	4	0	0	0	3	3	4	4	0	0	0	1	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Calothrix consociata (Kützing) Bornet	CALO COS	0	0	0	0	0	0	0	0	0	0	0	0	2	4	0	5	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Calothrix fasciculate C.Agardh	CALO FAS	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	2	3	2	2	2	3	1	1	0	0	3	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Calothrix fusco-violacea Crouan.	CALO FUS	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	3	0	0	0	0	0	0	0	0	3	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Calothrix pilosa Harvey.	CALO PIL	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	4	4	3	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Calothrix scopulorum (Weber and Mohr) C. Agardh	CALO SCO	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Calothrix spp.	CALO SPP	0	0	2	0	1	3	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0
Calothrix confervicola (Roth) C. Agardh	CAL CON	0	0	2	0	1	3	1	1	0	0	0	0	0	0	0	0	0	0	0	3	4	4	3	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ceramium elegans (Roth) Ducluzea	CERA ELE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0	0	0	0	0	0	0	4	0	0	0	0	0	4	3	3	2	4	2	0	3	4	3	3	2	0	0	0	1	0	2	3	3	0	2	2	2	3	3	0	2	2
Calothrix confervicola (Roth) C. Agardh	CAL CON	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	3	2	4	2	3	2	3	2	4	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ceramium elegans (Roth) Ducluzea	CERA ELE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	2	2	2	3	2	4	0	4	1	4	3	5	0	3	2	2	0	0	0	4	3	0	0	4	0	0	0	0	1	0	0	0	3	0	0	0	2	3	3	0	0	0	2	3
Ceramium strictum Harv.	CERA STR	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	3	0	2	0	1	0	2	0	0	0	0	0	2	3	0	0	0	0	2	3
Chaetomorpha capillaris (Kütz.)	CHAE CAP	0	0	0	0	0	0	0	0	3	0	0	0	0	2	4	0	2	0	0	0	3	3	3	2	4	3	4	2	1	4	4	3	4	4	4	4	0	0	0	0	1	0	2	0	2	0	0	0	4	1	4	3	4	2	0	0	4	1	3	0	4	0	4	0	4	1	4	0	4	0	4	1
Chaetomorpha linium (O.F. Muell.) Kütz.	CHAE LIN	0	0	1	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	2	0	0
Chlorochytrium inclusum Kjellman	CHLO INC	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Chorda filum (L.) Stackh.	CHOR FIL	0	0	0	0	0	0	0	0	0	0	0	0	2	0	2	0	2	0	1	0	2	0	0	0	0	0	1	0	1	0	0	0	0	3	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cladophora albida (Nees) Kütz.	CLAD ALB	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	2	0	0	0	2	0	0	0	3	0	0	1	0	0	0	0	3	0	0	0	0	0	3	0
Cladophora sericea (Hudson) Kütz.	CLAD SER	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0
Cladosiphon zosterae (J.Agardh) Kylin	CLAD ZOS	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Navicula spp.	NAVI SPP	2	2	2	0	0	1	1	1	2	0	4	3	0	0	2	0	1	2	2	3	2	0	0	0	4	0	3	0	0	1	0	0	1	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	4	0	4	0	4	0	3	0	2	1	1	4	4	0	5	0	4	0	4	0	5	0	4	0
Berkeleya rutilans (Trentepohl) Grunow	BERK RUT	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	2	0	2	0	0	0	2
Desmarestia aculeate (L.) J.V. Lamour.	DESM ACU	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Desmarestia viridis (O.F. Müll.) J.V. Lamour.	DESM VIR	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0	4	0	4	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	3	0
Dictyosiphon foeniculaceus (Hudson) Grev.	DICT FOE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ectocarpus spp.	ECTO SPP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	4	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	2	0	0	4	0	0	3	3	3	2	0	0	0	4	0	4	0	2	3	0	0	0	0	0	0	0	3	0	2	0	0	0	3	0	2	0	0
Ectocarpus fasciulatus Harv.	ECTO FAS	0	0	0	4	0	0	5	0	0	5	0	5	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	3	0	0	3	0	4	5	5	4	5	3	4	0	0	0	0	0	4	0	0	0	0	0
Ectocarpus siliculosus (Dillwyn) Lyngbye	ECTO SIL	5	5	5	0	5	5	5	4	5	4	5	0	0	0	4	0	4	0	0	0	0	0	0	0	0	4	0	0	4	3	3	0	5	4	0	0	0	0	0	0	4	0	0	0	0	4	3	4	0	0	0	0	3	0	0	0	0	0	0	3	5	0	4	0	4	0	5	0	4	0	4	0
Enteromorpha spp. Link in Nees, 1828	ENTE SPP	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Erythrotrichia carnea (Dillwyn) J.Agardh	ERYT CAR	0	0	0	0	0	0	0	0	0	0	0	0	0	2	2	2	3	2	3	1	2	3	3	4	2	0	2	0	3	0	3	3	3	2	4	0	0	0	0	1	1	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Giffordia ovata (Kjellm.) P.C. Silva	GIFF OVA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Haplospora globosa Kjellm.	HAPL GLO	2	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	2	2	0	2	0	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0
Hincksia granulosa (J.E.Smith.) P.C. Silva	HINC GRA	0	2	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Isthmoplea sphaerophora (Carmich.ex Harv. in Hook.) Kjellm.	ISTH SPH	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Kuckuckia spinosa (Kütz.) Kuck.	KUCK SPI	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Laminaria spp.	LAMI JUV	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Laminaria longicuris Bach.Pyl.	LAMI LON	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	1	1	0	0	0	2	0	2	0	0	0	0	0	0	0	1	0	2	0	0	0	1	0	2	0
Laminaria saccharina (L.) J.V. Lamour.	LAMI SAC	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	2	0	0	0	0	0	2	0	0	1	0	0	0	0	0	1	0	0	0	0
Laminariocolax tomentosoides (Farl.) Kylin	LAMI TOM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Lyngbya aestuarii Gomont.	LYNG AES	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	5	0	0	0	2	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Lyngbya conferviodes C. Agardh	LYNG CON	0	0	0	0	0	0	0	0	0	0	0	0	4	0	3	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Lyngbya gracilis (Meneghini) Rabenhorst	LYNG GRA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

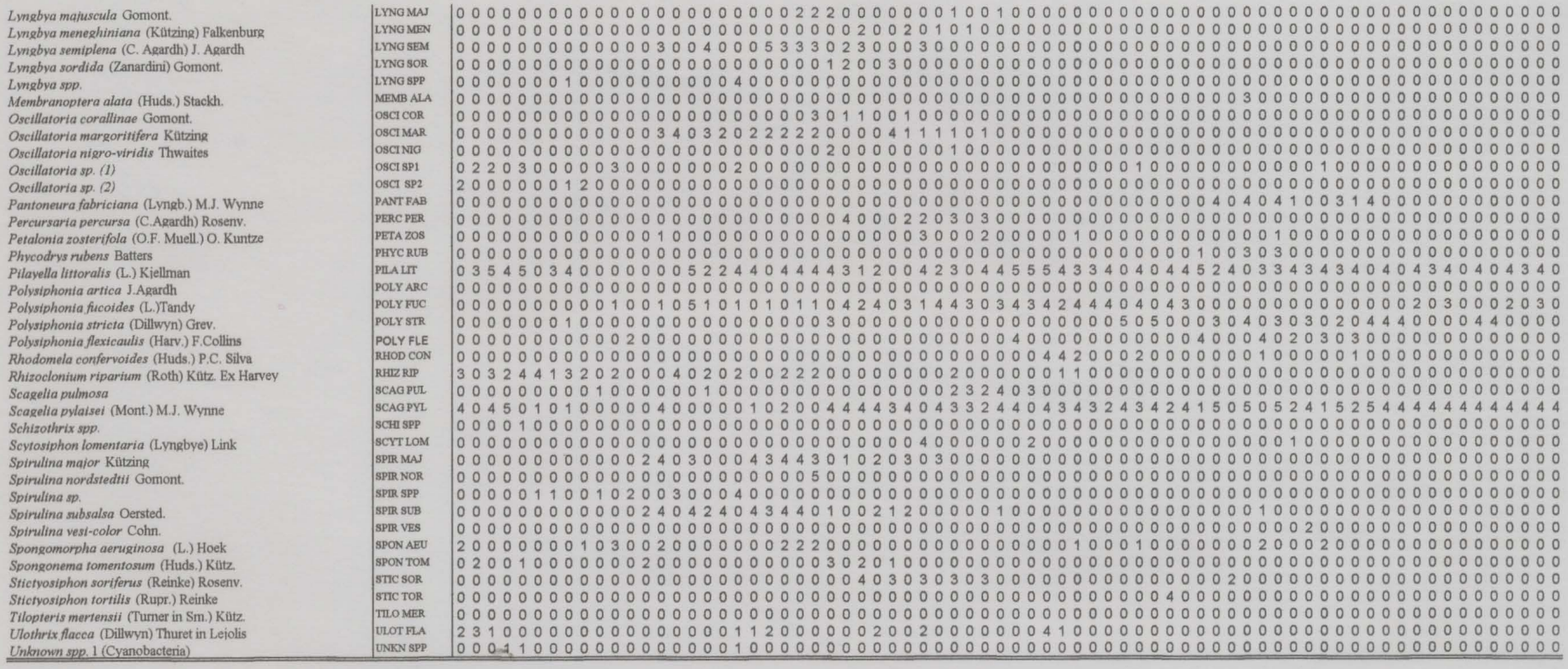

Lyngbya majuscula Gomont. LYNG MAJ
Lyngbya meneghiniana (Kützing) Falkenburg LYNG MEN
Lyngbya semiplena (C. Agardh) J. Agardh LYNG SEM
Lyngbya sordida (Zanardini) Gomont. LYNG SOR
Lyngbya spp. LYNG SPP
Membranoptera alata (Huds.) Stackh. MEMB ALA
Oscillatoria corallinae Gomont. OSCI COR
Oscillatoria margoritifera Kützing OSCI MAR
Oscillatoria nigro-viridis Thwaites OSCI NIG
Oscillatoria sp. (1) OSCI SP1
Oscillatoria sp. (2) OSCI SP2
Pantoneura fabriciana (Lyngb.) M.J. Wynne PANT FAB
Percursaria percursa (C.Agardh) Rosenv. PERC PER
Petalonia zosterifola (O.F. Muell.) O. Kuntze PETA ZOS
Phycodrys rubens Batters PHYC RUB
Pilayella littoralis (L.) Kjellman PILA LIT
Polysiphonia artica J.Agardh POLY ARC
Polysiphonia fucoides (L.)Tandy POLY FUC
Polysiphonia stricta (Dillwyn) Grev. POLY STR
Polysiphonia flexicaulis (Harv.) F.Collins POLY FLE
Rhodomela confervoides (Huds.) P.C. Silva RHOD CON
Rhizoclonium riparium (Roth) Kütz. Ex Harvey RHIZ RIP
Scagelia pulmosa SCAG PUL
Scagelia pylaisei (Mont.) M.J. Wynne SCAG PYL
Schizothrix spp. SCHI SPP
Scytosiphon lomentaria (Lyngbye) Link SCYT LOM
Spirulina major Kützing SPIR MAJ
Spirulina nordstedtii Gomont. SPIR NOR
Spirulina sp. SPIR SPP
Spirulina subsalsa Oersted. SPIR SUB
Spirulina vesi-color Cohn. SPIR VES
Spongomorpha aeruginosa (L.) Hoek SPON AEU
Spongonema tomentosum (Huds.) Kütz. SPON TOM
Stictyosiphon soriferus (Reinke) Rosenv. STIC SOR
Stictyosiphon tortilis (Rupr.) Reinke STIC TOR
Tilopteris mertensii (Turner in Sm.) Kütz. TILO MER
Ulothrix flacca (Dillwyn) Thuret in Lejolis ULOT FLA
Unknown spp. 1 (Cyanobacteria) UNKN SPP

Table A8. Species abundance values for input into DECORANA and TWINSPAN analysis at each sampling period (Depth 1=2m, depth 2=4m). Grazing experiments.

| *Genus species* | Date | 2 2 2

Lyngbya majuscula Gomont.	LYNG MAJ	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	2	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Lyngbya meneghiniana (Kützing) Falkenburg	LYNG MEN	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Lyngbya semiplena (C. Agardh) J. Agardh	LYNG SEM	0	0	2	0	3	0	0	0	1	0	0	1	0	4	0	0	0	0	0	0	0	0	0	0	0	5	2	0	3	0	0	3	1	1	3	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Lyngbya sordida (Zanardini) Gomont.	LYNG SOR	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Lyngbya spp.	LYNG SPP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Membranoptera alata (Huds.) Stackh.	MEMB ALA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Oscillatoria corallinae Gomont.	OSCI COR	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Oscillatoria margoritifera Kützing	OSCI MAR	2	0	0	1	3	1	4	4	0	1	0	1	2	3	0	1	2	0	2	0	0	1	2	0	3	2	1	1	2	1	2	2	1	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Oscillatoria nigro-viridis Thwaites	OSCI NIG	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
Oscillatoria sp. (1)	OSCI SP1	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1
Oscillatoria sp. (2)	OSCI SP2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pantoneura fabriciana (Lyngb.) M.J. Wynne	PANT FAB	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Percursaria percursa (C.Agardh) Rosenv.	PERC PER	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Petalonia zosterifola (O.F. Muell.) O. Kuntze	PETA ZOS	0	0	1	0	1	0	0	0	3	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
Phycodrys rubens Batters	PHYC RUB	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pilayella littoralis (L.) Kjellman	PILA LIT	0	0	0	5	0	1	0	0	0	0	5	0	4	2	3	0	2	1	4	4	0	4	4	0	4	0	2	0	4	0	2	4	0	0	4	1	4	5	4	2	5	3	5	5	3	3	4	4	4	3	4	4	3	4	4	4	4	4	0	3	4	4	2	4	0	4	3	4	2	3	4	4
Polysiphonia artica J.Agardh	POLY ARC	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Polysiphonia fucoides (L.)Tandy	POLY FUC	0	0	3	0	1	0	0	0	2	1	5	0	1	1	0	0	0	0	1	1	0	0	0	0	0	1	3	0	0	0	1	1	0	0	1	0	4	4	4	0	3	0	4	4	0	0	2	0	4	4	4	0	4	0	4	4	4	0	0	0	2	4	4	0	0	0	4	4	4	0	3	0
Polysiphonia stricta (Dillwyn) Grev.	POLY STR	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	5	0	5	0	0	0	5	0	5	0	0	0	3	0	5	0	0	0	4	5	5	0	0	0	5	5	4	0	0	0	0	0	4
Polysiphonia flexicaulis (Harv.) F.Collins	POLY FLE	1	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Rhodomela confervoides (Huds.) P.C. Silva	RHOD CON	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	4	0	0	4	0	0	2	0	0	0	0	0	0	2	0	0	0	0	2	2	0	0	3	3	0	2	0	0	0
Rhizoclonium riparium (Roth) Kütz. Ex Harvey	RHIZ RIP	2	0	0	2	0	2	1	4	1	0	0	0	0	2	0	0	0	0	2	0	0	0	0	0	0	0	0	0	2	0	0	2	0	0	2	1	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Scagelia pulmosa	SCAG PUL	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Scagelia pylaisei (Mont.) M.J. Wynne	SCAG PYL	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	4	0	2	0	0	0	1	1	0	1	0	0	0	2	2	0	0	0	3	0	0	2	4	2	3	0	4	2	4	4	3	3	4	4	4	4	4	3	3	0	2	2	0	4	0	4	3	4	3	4	4	2	2	0	3	4	4
Schizothrix spp.	SCHI SPP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Scytosiphon lomentaria (Lyngbye) Link	SCYT LOM	1	0	0	0	0	0	0	0	4	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	5	0	0	0	0	0	4	0	0	1	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	2	0	0	1	0	1	0	0	0
Spirulina major Kützing	SPIR MAJ	0	2	3	0	4	1	0	0	1	0	3	1	2	0	1	0	0	0	0	0	0	0	4	0	0	3	2	0	4	1	1	4	1	0	3	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Spirulina nordstedtii Gomont.	SPIR NOR	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Spirulina sp.	SPIR SPP	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0
Spirulina subsalsa Oersted.	SPIR SUB	3	2	1	3	4	1	3	0	1	3	4	1	2	2	1	0	4	0	3	0	0	0	4	0	5	3	2	1	4	2	3	4	2	2	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Spirulina vesi-color Cohn.	SPIR VES	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	2	0	0	0	0	0	0	0	0
Spongomorpha aeruginosa (L.) Hoek	SPON AEU	0	0	0	2	2	0	1	0	0	0	0	0	1	0	0	1	0	0	3	0	0	0	0	0	0	0	0	0	2	0	0	2	0	0	2	0	2	0	0	0	0	0	0	0	0	0	0	1	2	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Spongonema tomentosum (Huds.) Kütz.	SPON TOM	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Stictyosiphon soriferus (Reinke) Rosenv.	STIC SOR	0	0	4	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Stictyosiphon tortilis (Rupr.) Reinke	STIC TOR	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0
Tilopteris mertensii (Turner in Sm.) Kütz.	TILO MER	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ulothrix flacca (Dillwyn) Thuret in Lejolis	ULOT FLA	1	0	0	1	0	0	0	0	0	4	0	0	2	0	0	2	0	0	0	1	0	3	1	0	1	2	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	4	0	0	1	2	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Unknown spp. 1 (Cyanobacteria)	UNKN SPP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table A9. Scallop length (mm) and survival data for first grazing experiment in pearl nets from each sampling period (Depth 1=2m and depth 2=4m).

Scallop Measurements																								
Summer Experiment	**Parameters**																							
	Date	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	
	Replicate	1	1	1	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	2	2	
	Depth	1	1	1	1	1	1	2	2	2	2	2	2	1	1	1	1	1	1	2	2	2	2	
	Treatment	1	1	2	2	3	3	1	1	2	2	3	3	1	1	2	2	3	3	1	1	2	2	
	Measurement	Initial	Final	Initial	Final	Initial	Final	Initial	Final	Initial	Final	Initial	Final	Initial	Final	Initial	Final	Initial	Final	Initial	Final	Initial	Final	
	Scallop lengths (mm)	51.5	60.3	58.18	60.6	71.12	65	41.74	60.2	52.47	65.7	50.42	64.97	58.12	64.96	56.6	62.26	65.3	63.48	58.79	64.78	56.07	60.99	
		47.76	56.8	58.08	52.9	62.7	56.2	47.3	58.6	48.37	55	49.91	67.7	55	65.98	47.69	48.45	50.18	57.56	58.52	65.6	46.74	60.82	
		32.52	51.5	68.37	73.9	60.85	53.7	53.12	**49.1**	59.42	65	47.42	55.09	49.07	59.89	53.09	53.33	57.81	54.38	45.39	60.92	61.56	**57.69**	
		38.78	57	55.77	68.2	57.27	55.5	52.67	**47.3**	49.33	61.6	62.85	62.07	60.21	60.46	54.26	**58.35**	60.68	58.28	54.98	57.73	62.44	**55.82**	
		44.33	56	58.32	62.3	60.25	56.3	54.25	**61.6**	57.46	58.3	51.31	58.44	58.21	67.66	56.81	**49.55**	53.75	56.44	59.81	53.8	60.25	**54.73**	
		55.55	57.6	59.26	65.1	58.19	56.4	53.59	**52.8**	53.99	61.4	55.78	52.81	53.95	59.81	55.32	**49.04**	55.76	59.28	53.26	**59.45**	56.63	**61.62**	
		62.03	54.2	57.09	60.1	61.69	59.1	52.06	**42.5**	60.08	73.5	62.24	56.97	60.05	59.53	51.94	**55.52**	52.92	60.7	59.12	**57.48**	56.26	**56.67**	
		54.9	39	53	54.7	52.89	65.1	50.83	**51.9**	49.42	60.4	50.46	51.31	57.13	60.81	45.76	**57.45**	49.28	51.4	58.33	**57.4**	57.58	**56.01**	
		52.51	39.3	58.68	60.9	53.4	62	51.06	**46.2**	56.44	62.1	50.43	51.21	61.99	43.46	36.24	**51.07**	49.7	53.61	60.56	**53.6**	68.64	**58.71**	
		48.74	**50.9**	59.89	60.4	56.71	73	37.99	**38.3**	55.98	58.7	63.8	55.92	51.19	65.23	43.67	**55.24**	57.3	57.73	52.56	**56.75**	49.97	**53.81**	
		57	**64.9**	64.34	61.7	57.42	59.9	46.78	**55.4**	54.91	68.1	59.71	61.98	38.92	55.03	28.7	**42.04**	53.83	53.88	57.85	**54.82**	56.83	**53.61**	
		53.24	**55.7**	64.06	66.4	57.97	61.7	37.09	**54.5**	54.53	56.5	55.74	50.81	43.2	61.67	42.7	**55.06**	49.46	52.11	67.5	**53.46**	58.4	**69.06**	
		59.77	**60.7**	57.25	62	54.61	60.5	57.52	**53.9**	55.09	65.2	54.74	57.55	55.82	63.96	47.82	**43.95**	49.16	61.02	56.17	**45.8**	57.62	**50.91**	
		39.02	**41.9**	57.17	64.6	51.06	61.5	42.21	**53.2**	55.7	62.9	53.25	48.19	54.74	**57.82**	58.89	**60.44**	56.18	58.53	61.26	**60.01**	58.66	**55.97**	
		48.14	**56.9**	50.28	65	56.41	61.7	39.26	**61.2**	52.81	36.6	54.47	57.92	46.72	**57.64**	31.02	**53.34**	58.69	69.02	56.06	**54.21**	51.49	**60.72**	
		39.27	**49.6**	51.04	56.7	50.7	59.4	30.8	**55**	57.45	**67.9**	57.92	56.85	55.26	**50.41**	33.18	**53.95**	53.78	57.84	55.01	**51.1**	56.61	**58**	
		51.02	**55.4**	51.19	**63.5**	58.5	57.9	61.76	**42.8**	59.73	**63.4**	56.68	57.61	56.85	**54.07**	34.45	**51.43**	58.32	**51.22**	57.4	**53.2**	57.99	**47.1**	
		54.84	**51.2**	54.99	**60.8**	69.79	59.1	54.45	**31.39**	54.77	**60.6**	59.44	57.66	50.71	**42.26**	40.08	**45.8**	45.97	**50.78**	56.56	**60.07**	54.17	**57.57**	
		50.92	**52.7**	56.88	**52.7**	53.65	**67**	55.36	**51.5**	54.69	**57.6**	45.79	**59.67**	55.38	**58.6**	31.42	**52.98**	49.66	**46.81**	56.61	**55.03**	53.93	**61.51**	
		56.64	**56.7**	50.54	**59.7**	64.61	**51.7**	52.58	**56.65**	55.82	**44.4**	52.18	**52.86**	53.67	**48.68**	34.78	**49.49**	55.18	**62.99**	54.55	**58.77**	56.48	**48.42**	
		54.25	**42**	59.82	**53.1**	59.97	**63.9**	53.38	**56.5**	51.59	**61.2**	54.18	**57.09**	54.4	**43.13**	38.76	**53.93**	51.27	**54.61**	55.18	**56.24**	51.97	**63.59**	
		54.08	**55.4**	53.65	**53.2**	61.05	**58**	55.81	**52.9**	56.73	**58.6**	55.64	**66.5**	53.02	**55.57**	53.98	**47.39**	54.88	**51.32**	60.26	**55.04**	53.44	**60.93**	
		51.52	**48.8**	55.58	**59.9**	58.79	**58.6**	51.73	**51.3**	46.42	**60.1**	55.66	**54.24**	48.45	**48.08**	40.78	**57.44**	62.43	**54.47**	55.12	**56.01**	53.48	**55.05**	
		51.64	**51.7**	60.29	**67.3**	55.08	**71.4**	52.71	**39.7**	56.73	**50.3**	56.95	**57.83**	53.02	**56.91**	49.08	**45.93**	51.4	**50.4**	55.14	**66.54**	49.41	**51.32**	
		41.65	**42.5**	58.6	**58.1**	48.94	**60.2**	55.25	**38.2**	59.03	**52.4**	55.94	**63.75**	38.76	**54.43**	52.93	**45.32**	52.26	**59.84**	54.2	**62.02**	60.07	**61.86**	
		1251.62	1308.7	1432.32	1523.8	1453.62	1514.8	1241.3	1262.64	1368.96	1487.5	1372.91	1437	1323.84	1416.05	1119.95	1298.75	1355.15	1407.7	1420.19	1429.83	1406.69	1432.49	

1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1
2	2	3	3	3	3	3	3	3	3	3	3	3	3	4	4	4	4	4	4	4	4	4	4	4	4	5
2	2	1	1	1	1	1	1	2	2	2	2	2	2	1	1	1	1	1	1	2	2	2	2	2	2	1
3	3	1	1	2	2	3	3	1	1	2	2	3	3	1	1	2	2	3	3	1	1	2	2	3	3	1
Initial	Final	Initial	Final	Initial	Final	Initial	Final	Initial	Final	Initial	Final	Initial	Final	Initial	Final	Initial	Final	Initial	Final	Initial	Final	Initial	Final	Initial	Final	Initial
64.96	53.88	56.09	68.5	59.51	65.16	54.49	65.59	49.79	68.31	38.12	63.44	59.29	55.22	58.76	66.34	57.02	54.27	52.87	55.35	52.66	63.92	57.68	**61.82**	55.1	49.76	56.36
58.64	63.3	55.95	66.05	45.21	57.01	48.13	61.35	50.32	58.96	54.96	55.86	56.85	55.19	57.8	54.23	47.31	56.55	58.13	53.93	53.4	62.53	50.14	**50.81**	59.45	46.16	55.95
49.19	56.73	51.08	60.18	53.29	58.43	47.48	57.09	58.38	58.45	57.9	57.55	56.78	56.73	57.89	62.13	53.27	61.61	58.32	46.75	50.03	64.92	61.5	**56.64**	51.78	57.77	49.21
48.52	61.38	57.45	60.84	49.61	**62.08**	48.48	62.73	55.68	54.05	58.7	58.4	53.24	53.52	61.24	54.29	55.71	60.45	54.64	60.65	51.83	58.59	60.22	**54.3**	52.35	55.4	53.55
52.38	43.26	54.76	55.76	52.08	**52.5**	47.47	52.66	52.13	**56.98**	57.87	72.61	54.52	66.84	51.24	54.88	52.76	55.61	51.63	50.45	57.12	**56.34**	52.39	**64.86**	52.36	52.4	47.82
51.92	54.04	61.27	49.31	51.26	**52.78**	47.08	62.26	47.45	**48.78**	55.85	59.95	64.64	58.04	48.05	61.31	57.9	51.56	59.53	50.34	52.46	**54.69**	63.1	**58.64**	53.21	52.56	54.68
51.9	56.24	60.57	67.09	53.85	**51.66**	57.52	60.21	47.91	**53.24**	57.73	52.83	53.87	57.39	49.16	60.75	47.63	57.54	54.4	57.74	55.18	**50.96**	53.66	**60.58**	56.65	53.61	34.84
52.08	49.34	48.34	**58.39**	49.68	**60.15**	56.39	51.97	51.8	**58.77**	62.33	45.58	60.48	55.56	56.17	60.02	51.82	**62.05**	59.74	43.96	54.68	**51.06**	59.66	**56.59**	56.8	64.98	45.22
52.17	51.07	50.62	**59.86**	59.25	**55.56**	55.37	59.14	55.27	**64.54**	48.99	51.3	52	50.31	57.64	54.9	44.39	**60.75**	47.6	47.92	56.65	**54.48**	50.84	**51.55**	57.76	50.2	55.96
51.96	60.3	53.97	**56.31**	55.81	**50.71**	50.55	61.67	46.99	**56.9**	49.98	58.26	56.59	59.78	55.64	**62.19**	59.4	**49.52**	58.52	53	51.88	**55.03**	61.18	**60.41**	53.45	54.91	42.58
58.77	**52.72**	58.96	**65.35**	54.55	**53.1**	56.91	**61.25**	50.2	**52.64**	45.86	49.22	47.61	64.78	62	**60.51**	39.74	**46.23**	49.33	59.2	50.84	**46.19**	57.14	**48.68**	49.73	**51.21**	44.15
44.4	**64.78**	64.72	**53.4**	59.04	**56.27**	54.93	**54.85**	63.79	**49.6**	44.59	55.42	56.4	63.18	54.4	**50.36**	56.93	**56.87**	46.64	44.41	57.46	**55.41**	55.59	**53.54**	52.7	**54.13**	44.05
40.53	**54.91**	55.53	**54.88**	55.96	**47.54**	57.39	**47.09**	44.32	**51.35**	56.6	48.31	49.94	58.11	48.64	**58.25**	45.81	**40.38**	42.83	49.32	54.63	**47.17**	57.39	**60.23**	49.8	**50.24**	47.41
61.52	**55.12**	54.88	**59.54**	55.02	**52.19**	56.66	**58.21**	56.68	**50.43**	46.54	38.32	58.93	58.86	56.25	**58.39**	50.89	**52.05**	50.82	50.29	44.95	**48.03**	53.85	**63.51**	53.73	**54.77**	42.83
63.36	**54.6**	61.76	**64.22**	55	**61.59**	60.13	**55.76**	51.05	**47.92**	48.14	57.34	50	59.56	52.52	**58.52**	60.76	**56.83**	43.13	61.08	55.04	**58.14**	55.52	**58.86**	53.13	**55.57**	53.71
52.76	**42.72**	49.38	**53.14**	49.66	**58.44**	57.38	**49.4**	51.83	**43.07**	56.88	59.48	55.03	59.99	59.62	**49.51**	49.82	**49.11**	41.98	50.7	59.31	**52.35**	56.74	**61.18**	48	**59.27**	36.24
53.96	**54.15**	52.25	**50.4**	58.77	**56.87**	55.79	**55.11**	52.06	**53.26**	46.52	56.41	49.17	60.61	50.2	**49.85**	49.42	**57.03**	50.98	**29.87**	56.63	**54.46**	51.53	**54.3**	38.81	**54.83**	49.54
52.99	**65.91**	60.85	**57.24**	59.63	**48.02**	52.76	**46.6**	51.84	**52.49**	53.58	60.03	51.55	55	65.73	**58.31**	51.18	**51.03**	36.78	**55.46**	55.11	**48.87**	52.37	**49.19**	56.33	**57.27**	55.26
57.62	**60.47**	54.91	**52.79**	50.86	**52.31**	52.8	**51.05**	41.1	**53.55**	72.2	61.56	54.57	53.94	58.74	**52.23**	49.78	**57.07**	46.31	**37.94**	48.54	**51.07**	63.69	**56.05**	57.03	**53.96**	51.93
51	**53.31**	49.92	**51.83**	51.74	**59.88**	44.21	**59.2**	56.36	**54.28**	56.97	45.83	45.63	52.61	52.52	**57.78**	49.71	**44.48**	45.06	**58.01**	45.57	**61.04**	54.34	**59.31**	57.58	**54.72**	51.62
53.72	**54.79**	55.13	**48.89**	54.08	**47.32**	47.81	**49.38**	46.99	**56.57**	52.13	61.07	52.96	60.27	57.4	**54.59**	53.4	**52.96**	47.65	**42.58**	47.17	**54.76**	48.99	**51.9**	48.23	**55.56**	59.67
48.02	**55.69**	52.91	**57.18**	49.08	**51.07**	45.49	**56.03**	52.78	**50.01**	54.78	50.36	54.95	**57.4**	56.68	**67.7**	44.08	**52.45**	41.73	**50.96**	48.2	**54.06**	59.45	**65.28**	49.84	**56.39**	58.58
55.64	**45.47**	55.38	**58.27**	50.13	**62.72**	51.67	**45.93**	63.54	**48.49**	52.77	**60.24**	52.9	**50.46**	56.22	**52.54**	50.24	**55.37**	34.3	**41.93**	61.1	**50.15**	59.52	**56.65**	49.56	**60.65**	58.22
54.34	**53.5**	53.41	**56.1**	45.65	**51.56**	54.79	**56.83**	52.26	**44.14**	58.72	**55.23**	55.8	**53.71**	58.2	**58.13**	33.44	**51.56**	24.2	**58.51**	49.15	**54.3**	56.98	**61.74**	53.36	**56.26**	42.52
42.1	**57.6**	47.42	**51.13**	52.02	**55.2**	47.25	**48.68**	50.53	**39.22**	60.28	**50.61**	58.89	**60.24**	49.5	**57.97**	50.8	**33.51**	28.55	**35.1**	52.51	**55.27**	57.26	**59.7**	39.52	**40.91**	45.46
1324.45	1375.28	1377.51	1436.65	1330.74	1380.12	1308.93	1390.04	1301.05	1326	1348.99	1385.21	1362.59	1437.3	1392.21	1435.68	1263.21	1326.84	1185.67	1245.45	1322.1	1363.79	1410.73	1436.32	1306.26	1353.49	1237.36

2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2
5	5	5	5	5	5	5	5	5	5	5	6	6	6	6	6	6	6	6	6	6	6	6
1	1	1	1	1	2	2	2	2	2	2	1	1	1	1	1	1	2	2	2	2	2	2
1	2	2	3	3	1	1	2	2	3	3	1	1	2	2	3	3	1	1	2	2	3	3
Final	Initial	Final	Initial	Final	Initial	Final	Initial	Final	Initial	Final	Initial	Final	Initial	Final	Initial	Final	Initial	Final	Initial	Final	Initial	Final
60.05	61.7	62.35	50.96	62.55	50.07	53.45	53.57	54.49	50.07	58.17	62.3	67.04	56.52	65.15	53.32	60.73	53.62	**61.54**	53.22	65.85	57.98	59.91
48.05	65.67	55.3	50.72	54.16	44.5	**49.81**	59.81	**59.04**	44.5	52.85	54.05	56.24	57.37	52.73	56.26	57.35	55.59	**61.66**	57.92	**61.74**	51.83	60.13
58.27	58.73	58.65	53.34	60.71	56.24	**51.94**	54.67	**55.65**	56.24	59.01	54.81	61.7	52.74	66.03	53.18	62.62	58.56	**65.88**	52.29	**55.73**	58.14	60.08
46.37	63.34	62.99	60.61	62.54	46.18	**55.74**	54.42	**53.67**	46.18	56.07	48.34	60.56	49.43	57.56	58.11	57.81	58.04	**58.44**	51.2	**59.69**	54.78	50.14
56.75	50.85	62.71	55.57	51.11	54.64	**52.91**	55.72	**55.91**	54.64	50.95	55.4	51.7	53.21	61.98	56.57	62	55.42	**63.17**	57.91	**56.68**	62.14	50.9
45.63	58.2	57.57	57.58	51.41	50.04	**52.77**	56.22	**55.29**	50.04	53.21	53.6	65.03	60.32	60.88	53.02	58.8	52.54	**60.73**	50.44	**57.92**	57.08	51.17
54.03	57.99	61.44	56.4	54.5	55.52	**52.63**	58.32	**57.05**	55.52	54.07	54.65	53.96	41.35	57.68	54.61	51.46	50.04	**54.84**	52.73	**57.48**	58.55	77.7
50.11	51.68	**57.68**	57.52	48.79	53.68	**51.52**	56.31	**53.46**	53.68	53.45	56.4	60.54	47.53	49.12	57.17	58.3	55.42	**65.64**	57.44	**53.15**	57.18	54.52
57.13	63.38	**59.2**	56.97	54.75	53.26	**49.71**	57.22	**51.45**	53.26	48.66	56.42	64.41	38.54	55.2	59.11	53.18	56.41	**61.64**	60.69	**57.97**	54.85	53.96
55.25	57.66	**55.19**	61.45	55.56	46.76	**45.35**	55.62	**55.96**	46.76	58.32	52.27	61.05	50.79	**59.1**	52.75	59.47	50.52	**66.98**	45.99	**56.36**	60.5	60.52
49.15	55.38	**55.99**	57.5	62.02	51.98	**45.93**	57.68	**57.69**	51.98	53.53	54.96	58.29	34.63	**37.15**	57.59	55.85	44.83	**60.64**	43.22	**54.02**	59.84	60.06
48.99	58.58	**60.31**	53.46	60.22	52.29	**49.57**	55.26	**57.57**	52.29	**51.56**	49.6	**59.54**	52.7	**53.29**	57.28	62.32	51.54	**55.76**	51.69	**58.42**	59.32	62.14
59.49	54.33	**62.34**	58.63	56.51	51.92	**47.31**	56.63	**57.24**	51.92	**52.58**	56.5	**63.83**	47.84	**43.93**	51.98	68.7	56.96	**55.6**	32.92	**50.29**	56.01	58.74
46.09	64.19	**65.9**	55.65	55.04	49.11	**57.34**	58.09	**60.48**	49.11	**50.03**	52.85	**54.8**	59.49	**48.67**	63.61	63.69	56.93	**61.63**	40.19	**48.95**	50.37	**52.77**
54.48	59.15	**55.44**	57.62	**57.45**	55.95	**47.06**	59.79	**59.1**	55.95	**57.4**	59.03	**61.71**	47.7	**55.47**	55.59	**62.59**	49.74	**45.1**	55.68	**58.5**	56.11	**57.96**
38.36	54.91	**62.92**	53.63	**56.29**	56.9	**58.55**	53.6	**55.39**	56.9	**49.48**	63.4	**60.29**	54.91	**62.16**	58.83	**53.63**	57.77	**59.75**	48.09	**56.49**	51.17	**55.51**
58.35	57.1	**62.12**	53.07	**58.05**	54.19	**55.12**	55.74	**58.36**	54.19	**57.89**	61.16	**58.45**	62.21	**56.83**	49.37	**58.59**	57.18	**55.33**	50.67	**56.82**	52.9	**63.16**
52.61	54.5	**58.24**	61.24	**62.62**	49.56	**53.43**	56.53	**60.43**	49.56	**48.38**	55.99	**54.42**	59.98	**40.22**	50.94	**57.29**	57.49	**57.19**	58.89	**48.76**	47.51	**57.44**
50.05	56.01	**55.44**	58.62	**49.73**	50.18	**56.44**	56.83	**58.77**	50.18	**56.62**	58.93	**57.9**	53.02	**59.72**	51.62	**58.33**	55.73	**58.89**	53.49	**56.51**	49.18	**59.2**
49.12	57.02	**53.7**	59.47	**66.81**	51.91	**54.71**	53.18	**54.7**	51.91	**56.09**	55.75	**52.39**	61.54	**61.1**	56.52	**53.86**	53.9	**59.49**	48.71	**57.02**	54.76	**51.13**
46.4	59.53	**67.78**	54.54	**56.42**	46.7	**54.94**	56.41	**55.93**	46.7	**39.4**	62	**57.5**	60.52	**50.83**	53.15	**54.12**	54.04	**60.28**	40.62	**53.19**	56.9	**50.19**
55.79	57.96	**63.25**	54.91	**54**	53.78	**56.59**	56.84	**54.99**	53.78	**54.48**	57.09	**49.82**	54.26	**55.43**	54.65	**54.52**	54.24	**53.8**	50.79	**53.38**	57.33	**52.75**
47.43	51.6	**54.03**	46.97	**56.78**	54.45	**54.28**	58.05	**54.37**	54.45	**56.69**	53.77	**51.82**	54.91	**57.15**	53.09	**55.5**	60.29	**55.27**	52.89	**58.94**	55.16	**56.62**
37.61	53.86	**60.34**	48.72	**57.97**	47.62	**47.06**	53.98	**57.28**	47.62	**52.76**	60.6	**60.19**	36.76	**47.29**	53.8	**53.54**	60.06	**54.24**	52.93	**50.59**	51.69	**61.43**
58.76	55.14	**52.57**	49.15	**59.13**	58.1	**50.01**	52.32	**59.26**	58.1	**39.51**	59.24	**55.09**	49.34	**60.7**	54.25	**57.86**	54.19	**58.72**	56.62	**53.88**	50.03	**56.9**
1284.32	1438.46	1483.45	1384.3	1425.12	1295.53	1304.17	1402.81	1413.53	1295.53	1321.16	1409.11	1458.27	1297.61	1375.37	1376.37	1452.11	1371.05	1472.21	1277.23	1398.33	1381.31	1435.03

Table A10. Scallop length (mm) and survival data for second grazing experiment in pearl nets from each sampling period (Depth 1=2m and depth 2=4m).

Scallop Measurements																						
Over winter Experiment	**Parameters**																					
	Date	3	4	3	4	3	4	3	4	3	4	3	4	3	4	3	4	3	4	3	4	3
	Replicate	1	1	1	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	2
	Depth	1	1	1	1	1	1	2	2	2	2	2	2	1	1	1	1	1	1	2	2	2
	Treatment	1	1	2	2	3	3	1	1	2	2	3	3	1	1	2	2	3	3	1	1	2
	Measurement	Initial	Final	Initial	Final	Initial	Final	Initial	Final	Initial	Final	Initial	Final	Initial	Final	Initial	Final	Initial	Final	Initial	Final	Initial
	Scallop lengths (mm)	68.73	64.67	69.08	69.76	71.47	76.28	67.43	82.59	68.45	76.48	69.12	78.16	67.63	65.79	48.96	64.17	63.04	68.9	68.23	73.34	57.46
		67.66	65.05	63.27	74.29	67.79	75.92	64.93	72.57	51.59	68.25	65.61	73.01	59.33	65.9	52.08	72.69	70.23	56.78	59.99	63.19	58.39
		74.12	64.26	67.07	67.41	70.16	72.93	64	65.42	58.1	59.65	68.7	69.33	68.67	71.74	45.59	69.67	68.89	70.02	61.7	71.24	60.97
		58.37	62.5	66.86	67.48	60.44	72.28	54.31	57.09	70.92	68.76	69.64	65.78	77.58	79.92	45.33	69.13	68.4	70.12	64.3	72	64.84
		66.02	61.92	70.79	71.59	67.8	76.98	66.82	68.83	64.56	73.52	71.15	64.74	69.25	81.09	51.14	74.52	75.49	68.05	62.7	68.37	65.89
		68.12	69.14	61.95	73.72	63.49	72.82	76.25	68.52	67.94	73.4	55.21	68.9	77.37	68.3	51.85	56.03	60.83	67.12	67.02	62.36	53.11
		63.33	63.3	66.4	70.82	72.9	74.67	64.89	63.31	70.12	71.27	67.65	74.49	63.87	70.19	49.05	72.57	65.11	70.84	60.47	69.94	63.16
		65.84	70.83	67.66	68.81	68.43	61.13	51.38	70.37	64.37	76.49	60.55	67.44	64.96	66.21	54.79	60.95	67.56	81.28	67.59	73.06	68.08
		62.53	70.84	64.66	65.28	71.07	68.29	63.83	64.21	65.17	71.1	72.97	66.64	63.26	61.74	64.71	66.34	71.32	69.78	65.6	76.91	63.2
		65.07	70.6	62.57	74.42	59.2	59.54	67.53	71.86	55.32	55.69	66.58	70.43	60.94	64.92	36.72	65.2	60.87	77.49	63.1	66.92	68.85
		61.6	69.89	66.12	63.84	58.04	72.55	67.91	68.92	55.36	74.86	62.87	68.46	64.05	67.58	66.36	59.24	66.64	70.65	59.91	60.06	60.77
		61.93	67.73	69.45	63.65	62.01	58.33	67.64	67.67	59.84	75.28	59.4	65.24	70.68	69.68	70.54	65.57	53.82	59.89	62.48	64.72	61.28
		68.25	63.39	67.21	63.35	62.74	66.83	69.58	71.13	72	67.21	62.92	73.22	70.29	66.63	65.63	47.45	60.5	69.16	70.61	58.86	65.37
		58.8	73.97	66.41	71.79	64.21	67.78	60.31	70.72	59.23	74.36	67.68	64.89	62.5	65.61	63.61	69.47	54.54	73.41	47.52	66.02	61
		58.5	64.88	63.64	66.37	54.55	68.62	61.5	69.93	59.95	65.89	66.07	68.22	69.25	72.54	61.98	74.47	69.6	64.9	37.73	61.11	66.93
		62.82	79.72	66.14	69.5	55.83	57.39	64.4	65.76	66.66	59.82	61.12	67.26	62.82	69.43	60.38	69.92	55.74	61.53	41.32	65.99	61.8
		64.16	62.87	59.31	**66.75**	54.81	62.47	67.13	69.26	62.58	71.61	63.29	55.7	64.3	69.3	57.89	70.33	64.83	72.92	39.63	68.2	66.34
		59.89	**68.24**	67.92	**68.93**	56.88	61.69	67.89	69.12	68.6	62.33	62.88	63.56	65.37	72.26	42.61	69.37	64.82	73.12	41.56	67.81	60.2
		60.63	**63.39**	61.17	**65.43**	50.26	64.56	62.6	72.67	69.97	68.31	64.67	64.42	66.65	63.89	59.34	**74.28**	65.72	68.93	41.09	65.74	58.66
		63.65	**70.39**	62.61	**69.06**	52.43	53.5	61.74	74.97	63.11	64.06	53.22	70.37	67.89	73.88	70.09	65.24	65.53	73.76	43.13	**62.06**	62.72
		73.98	**74.43**	63.98	69.04	68.76	71.56	70.93	66.81	67.72	71.37	57.37	**58.78**	62.34	64.48	66.34	67.18	58.39	62.66	62.2	63.06	66.23
		63.67	64.86	61.77	**60.41**	55.21	58.82	67.34	73.24	63.04	64.38	68.68	**69.71**	60.04	59.16	61.15	62.1	55.02	58.41	60.93	63.91	60.41
		61.69	**63.2**	64.05	66.32	61.87	63.93	65.52	68.98	72	**73.65**	61.74	**63.66**	64.54	65.45	58.3	61.68	65.29	69.55	56.02	**55.95**	50.43
		64.22	**65.24**	67.57	76.67	63.67	67	63.26	67.39	60.34	60.77	63.19	68.92	64.53	65.78	63.45	64.32	72.85	75.88	62.45	66.5	66.99
		69.36	**73.9**	59.59	63.15	63.69	67.22	67.82	64.71	62.67	68.38	70.87	74.09	56.09	56.35	64.55	66.06	73.85	76.54	62.7	65.14	59.26
		1612.94	1689.21	1627.25	1707.84	1557.71	1673.09	1626.94	1726.05	1599.61	1716.89	1613.15	1695.42	1644.2	1697.82	1432.44	1657.95	1618.88	1731.69	1429.98	1652.46	1552.34

4	3	4	3	4	3	4	3	4	3	4	3	4	3	4	3	4	3	4	3	4	3	4	3	4	3	4	
2	2	2	3	3	3	3	3	3	3	3	3	3	3	3	4	4	4	4	4	4	4	4	4	4	4	4	
2	2	2	1	1	1	1	1	1	2	2	2	2	2	2	1	1	1	1	1	1	2	2	2	2	2	2	
2	3	3	1	1	2	2	3	3	1	1	2	2	3	3	1	1	2	2	3	3	1	1	2	2	3	3	
Final	Initial	Final	Initial	Final	Initial	Final	Initial	Final	Initial	Final	Initial	Final	Initial	Final	Initial	Final	Initial	Final	Initial	Final	Initial	Final	Initial	Final	Initial	Final	
72.86	61.97	71.99	65.4	86.94	70.24	76.36	67.62	68.79	63.06	82.21	55.75	65.34	64.19	72.22	68.24	71.13	61.29	75.82	64.57	66.85	74.02	79.07	70.12	69.4	70.42	70.85	
63.18	67.59	71.46	56.98	67.87	59.98	75.02	62.44	66.8	69.22	77.87	68.16	64.71	55.55	74.51	55.76	69.35	56.58	69.79	66.81	63.74	67.54	80.13	64.35	74.78	64.7	65.26	
70.2	59.4	64	63.02	67.63	64.86	75.73	66.21	62.64	55.5	73.28	62.1	73.5	71.76	75.77	72.58	70.69	59.57	63.79	52.69	63.07	58.46	77.78	48.85	74.62	65.25	67.72	
69.56	74.37	69.33	72.3	66.73	66.2	67.66	57.34	66.9	62.43	68.82	68.82	63.79	70.66	66.96	65.36	70.87	61.4	68.25	61.72	72.6	58.86	65.73	48.15	66.91	65.81	68.33	
66.53	66.1	80.02	63.05	62.9	61.37	66.55	57.26	70.31	76.5	73.35	68.28	68.79	64.36	55.68	61.88	64.35	58.47	64.15	63.52	71.2	69.27	66.62	50.81	67.59	64.63	61.04	
70.83	63.65	71.81	56.74	67.05	65	61.86	67.8	72.07	67.97	69.97	61.69	59.08	63.67	60.36	61	72.65	54.28	74.41	56	57.07	62.38	66.47	58.14	69.31	70	71.95	
67.93	66.12	65.25	65.49	59.55	63.26	68.74	64.79	69.29	64.72	69.27	55.55	76.82	54	66.95	58.92	67.52	66.72	64.11	57.16	68.57	60.49	71.34	64.86	63.45	59.67	67.62	
68.21	67.23	70.8	62.68	71.02	57.77	70.66	62.93	61.63	64.8	63	66.2	68.74	69.12	63.9	66.26	67.89	70.35	62.83	51.58	61.89	70.71	70.69	67.47	66.71	64.05	68.28	
67.62	62.92	68.25	81.55	68.26	70.77	69.16	65.32	65.29	56.33	70.25	56.46	65.29	59.49	65.15	66.61	75.87	57.99	63.11	66.26	64.53	56.98	73.8	64.81	52.94	52.97	69.61	
72.47	62.97	58.93	63.03	67.07	63.69	62.68	60.15	60.94	60	64.24	58.45	70.78	62.82	71.69	61.01	69.74	73.12	59.99	70.05	61.56	73.55	77.49	71.64	71.91	62.74	76.53	
65.66	66.68	71.73	59.37	63.18	69.27	61.79	62.14	67.27	66.15	59.74	60.14	68.37	66.92	67.28	58.22	63.98	59.08	61.8	56.78	65.29	60.89	71.57	64.9	67.95	61.9	62.84	
65.15	66.05	62.95	64.93	67.09	59.29	70.93	70.24	65.86	63.68	68.76	60.51	72.28	60.25	65.87	63.61	56.75	60.79	63.49	60.26	62.46	58.11	61.88	66.16	66.46	68.76	54.23	
54.87	61.84	67.49	59.9	66.61	63.1	72.61	63.5	64.77	72.08	69.43	66.82	61.94	67.53	68.17	66.34	64.09	61.73	62.65	56.55	71.72	71.85	61.85	60.89	70.66	63.76	73.54	
63.56	62.87	73.42	60.66	66.93	72.65	66.54	62.29	63.06	63.45	71.59	66.51	69.56	59.63	71.33	62.91	67.93	60.35	69.68	58.16	62.4	66.45	61.97	61.12	53.26	57.46	57.4	
57.69	66.75	69.53	62.61	62.15	60.31	66.76	65.71	70.26	63.21	57.72	63.5	70.35	65.75	69.3	64.66	65.27	60.26	59.73	59.26	68.71	56.01	61.64	73.03	77.85	68.11	73.72	
65.17	68.71	66.16	62.2	60.74	66.11	67.73	61.36	71.57	65.51	77.18	54.35	65.92	67.6	63.2	67.51	67.64	64.92	69.25	58.28	69.18	64.09	68.37	64.13	63.73	66.22	64.55	
65.38	63.3	69.77	62.87	78.08	68	65.13	59.23	70.23	64.78	80.38	61.76	56.99	60.02	69.64	63.49	65.11	63.5	67.5	62.49	69.51	64.52	60.97	61.9	58.97	53.35	69.31	
69.28	57.5	67.27	65.26	69.86	64.43	70.36	59.53	61.61	66.08	57.23	57.3	73.08	67.02	69.36	73.25	61.76	65.29	61.91	59.09	66.49	59.33	60.7	57.02	**67.4**	64.63	71.78	
61.76	58.18	67.68	62.23	67.46	55.92	**61.6**	53.5	62.06	71.29	**67.87**	63.32	68.14	62.82	74.64	61.51	**61.17**	57.27	57.88	65.64	55.61	64.57	**66.64**	63.38	**63.79**	61.1	64.04	
67.34	64.06	65.72	62.26	64.42	62.18	**64.26**	60.61	65.91	76.81	**61.54**	64.13	73.45	58.29	62.45	61.19	**66.83**	66.35	**53.84**	63.1	59.65	75.14	**66.18**	61.87	**60.7**	69.09	73.98	
67.19	66	70.02	62.19	64.41	71.33	72.95	69.96	73.45	60.09	**60.47**	66.11	**66.84**	64.09	65.83	64.21	**64.99**	65.05	**65.8**	65.06	67.07	64.97	**65.48**	60.05	62.1	67.72	71	
61.37	66.09	67.3	61.98	**62.67**	65.12	**65.85**	69.37	72.13	68.89	**69.35**	69.69	**70.84**	67.21	69.35	69.03	**69.89**	51.4	**51.71**	49.49	**52.03**	64.82	67.87	71.46	72.64	66.27	69.61	
51.51	55.76	**66.2**	75.2	79.56	63.7	**64.16**	70.11	73.15	66.14	68.1	64.89	**66.24**	66	68.31	61.11	**61.62**	64.44	**64.44**	65.64	68.77	63.4	**63.58**	65.05	65.49	70.2	73.56	
69.28	66.12	**67.27**	65.64	67.98	62.92	**63.08**	66.38	73.65	67.95	69.73	64.87	**66.38**	62.93	64.28	69.18	70.82	59.82	**60.37**	50.54	53.38	64.6	65.14	67.81	**67.87**	62.59	66.36	
59.54	71.04	**72.93**	60.02	**60.07**	63.18	66.3	77.77	81.65	58.46	**59.15**	75.03	**76.19**	64.23	68.35	63.4	**63.54**	68.58	**69.29**	63.95	66.48	67.22	**67.49**	60.73	60.98	58.26	64.11	
1634.14	1613.27	1717.28	1597.56	1686.23	1610.65	1694.47	1603.56	1701.29	1635.1	1710.5	1580.39	1703.41	1595.91	1690.55	1607.24	1671.45	1548.6	1605.59	1504.65	1609.83	1618.23	1700.45	1568.7	1657.47	1599.66	1697.22	

3	4	3	4	3	4	3	4	3	4	3	4	3	4	3	4	3	4	3	4	3	4	3	4
5	5	5	5	5	5	5	5	5	5	5	5	6	6	6	6	6	6	6	6	6	6	6	6
1	1	1	1	1	1	2	2	2	2	2	2	1	1	1	1	1	1	2	2	2	2	2	2
1	1	2	2	3	3	1	1	2	2	3	3	1	1	2	2	3	3	1	1	2	2	3	3
Initial	Final	Initial	Final	Initial	Final	Initial	Final	Initial	Final	Initial	Final	Initial	Final	Initial	Final	Initial	Final	Initial	Final	Initial	Final	Initial	Final
62.81	73.27	72.99	77.24	58.53	83.97	54.35	68.94	62.3	66.55	65.85	72.94	60.53	75.75	63.27	67.02	60.3	61.54	68.76	78.04	59.46	65.94	68.11	64.23
60.29	65.79	73.14	65.42	60.06	74.45	65.98	70.57	59.13	70.62	68.15	66.08	59.67	68.72	64.71	68.97	49.64	67.24	66.57	74.09	61.16	65.96	55.89	69.4
59.83	63.9	63.66	71.75	59.8	62.51	68.55	74.93	55.52	65.19	63.57	73.59	64.23	71.44	64.61	68.8	57.98	67.38	61.89	57.76	50	71.03	68.04	76.4
53.2	66.63	63.12	67.24	54.79	65.96	65.21	69.24	65.81	68.62	72.01	73.75	63.07	61.48	66.33	68.15	58.32	67.05	60.97	72.39	66.59	68.03	60.9	63.88
61.46	53.25	62.85	62.24	52.94	72.52	54.89	73.59	63.96	68.17	63.91	69.63	58.78	67.43	65.92	70.18	65.71	70.27	61.58	69.7	61.63	68.87	68.41	73.89
62.62	66.13	61.5	63.31	56.84	62.1	67.93	71.64	70.83	70.85	69.93	64.53	62.36	70.42	68.42	62.7	56.05	70.47	66.36	63.75	61.5	70.16	70.16	65.17
60.24	61.89	62.91	72.15	56.5	70.55	57.12	58.69	59.69	66.46	65.82	69.36	65.22	67.76	53.33	61.29	65.42	72.82	70.7	58.16	57.82	64.54	66.47	58.67
59.54	65.41	61.08	63.86	64.8	69.28	61.77	62.25	59.62	68.18	62.85	74.22	58.36	68.21	65.55	65.92	58.32	63.85	63.81	46.08	73.88	73.57	66.93	70.19
61.5	59.38	61.62	62.26	79.2	73.03	63.53	70.52	57.62	60.78	68.85	74.47	66.55	69.73	65.83	65.5	64.28	62.82	55.88	65.38	61	67.06	61.42	75.96
53.24	64.59	56.8	75.37	61.67	67.17	70.67	68.28	62.16	54.92	63.65	68.96	62.07	73.92	60.11	62.94	59.25	58.73	58.78	72.81	60.44	61	63.28	64.42
68.62	53.68	57.62	70.52	58.54	70.62	59.87	63.76	58.64	64.71	69.71	72.02	63.95	69.19	59.11	57.35	55.93	58.86	60.66	73.58	64.57	64.89	57.91	63.84
64.27	72.51	69.59	63.51	65.29	67.08	72.33	61.31	61.21	64.49	67.22	63.38	64.31	73.01	63.12	61.78	62.52	62.93	66.08	69.63	56.25	70.29	71.95	70.52
50.85	62.55	63.65	66.64	62.29	65.13	67.24	60.43	55.72	66.95	61.13	67.04	66.79	69.9	61.3	66.38	55.7	61.08	59.96	70.14	62.13	77.05	69.38	68.16
66.54	64.98	60.96	60.59	62.12	66	64.58	76.04	62.65	60.64	67	68.2	66.23	64.02	68.89	62.18	55.98	58.62	68.83	70.64	60.31	74.62	59.82	69.49
64.98	68.22	65.57	65.43	65.03	63.79	64.08	64.9	59.62	61.48	66.21	72.18	62.45	67.28	66.27	67.04	68.68	52.3	67.5	66.45	68.79	55.58	66.13	73.26
60.97	61.4	67.95	69.02	59.93	60.9	69.63	64.62	60.61	64.45	58.81	72.81	70.11	64.62	60.35	65.23	56.85	55.85	71.69	62.74	65.63	64.46	64.99	64.94
52.39	66.89	67.32	70.21	62.8	56.85	73.78	69.42	64.19	67.45	53.62	66.33	69.31	64.2	59.54	69.17	59.4	60.66	63.45	57.42	59.12	59.84	65.96	64.17
68.82	66.63	64.67	64.8	66.78	65.98	60.12	66.36	63.98	68.59	63.6	62.89	67.17	65.11	62.09	69.76	49.58	65.1	62.08	60.16	66.78	59.96	59.54	69.72
61.93	53.5	72.55	60.02	66.4	68.28	65.13	68.15	53.59	74.58	62.93	60.12	61.9	60.63	60.12	63.01	56.88	59.3	38.34	68.49	71.17	62.04	59.6	61.26
63.68	52.81	60.11	62.9	68.75	60.3	57.26	72.85	66.71	60.72	67.09	73.27	59.06	63.02	63.21	61.44	62.49	59.66	53.57	67.6	65.21	60.03	60.08	66.84
67.78	67.93	68.39	68.55	63.63	65.75	55.08	55.58	56.77	58.71	61.15	64.09	62.55	64.03	60.85	62.43	63.91	66.38	65.06	66.87	65.58	66.6	60.15	62.41
64.25	65.74	68.01	68.11	47.85	48.13	66.45	67.97	56.81	58.74	52.96	55.93	63.45	66.18	59.57	60.24	61.39	62.86	62.4	64.06	53.32	54.36	60.18	63.89
63.49	65.11	60.78	61.41	58.77	60.87	74.67	74.86	68.11	69.29	62.95	66	68	69.59	70.58	71.41	70.34	71.88	74.61	74.69	67.81	68.17	63.45	66.98
70.08	70.57	74.37	74.48	58.37	58.69	62.54	62.55	68.33	68.48	69.39	71.81	69.52	71.4	64.04	64.5	59.35	62.89	62.84	63.19	64.94	64.95	61.43	62.59
64.28	64.87	61.3	61.91	68.34	70.17	71.37	71.43	67.95	69.67	67.49	69.83	64.1	66.05	66.26	66.65	61.84	64.38	62.85	63.48	67.83	68.17	64.23	65.26
1547.66	1597.63	1622.51	1668.94	1540.02	1650.08	1614.13	1688.88	1541.53	1639.29	1615.85	1713.43	1599.74	1693.09	1583.38	1630.04	1496.11	1584.92	1575.22	1657.3	1572.92	1647.17	1594.41	1675.54