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# THE EFFECTS OF GREEN MUSSEL *PERNA VIRIDIS* (L.) (MOLLUSCA: MYTILIDAE) CULTURE ON NEMATODE COMMUNITY STRUCTURE IN THE GULF OF THAILAND

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***ABSTRACT.*** - Culture of the green mussel *Perna viridis* (L.) in Thai coastal waters is almost exclusively based on extensive pole culture, where spat are allowed to settle naturally on densely planted poles in shallow waters close to the shore. Such culture is limited in terms of space, and the shallow inshore regions suitable for it are vulnerable to pollution. There is immense potential for the development of suspended culture in Thai waters. In addition to increasing the yield and quality of the product, suspended cultures offer additional benefits such as providing habitats for the development of juvenile fish, and providing refugia from overfishing in relatively open waters. This study examines one potential drawback of suspended mussel culture in shallow waters such as are found in large areas of the Gulf of Thailand, namely the impact of such culture on the benthic communities. Nematode genera have been shown to be sensitive to ongoing physical and biological disturbance. In this study univariate and nonparametric multivariate analyses of nematode abundances are used to measure the extent of benthic impact resulting from a mussel raft. Although large differences in community structure are found beneath the raft, the areal extent of these changes is limited. It is concluded that if problems related to water quality and infrastructure can be dealt with, the localised benthic impact of such culture methods for the green mussel should not prevent their development in Thai coastal waters.

***KEY WORDS.*** - *Perna viridis*, rope culture, Nematoda, multivariate analysis, Thailand

## INTRODUCTION

Molluscs, principally bivalves, are cultured in inshore and coastal areas of Thailand. The main species cultured are the blood cockle (*Anadara granosa* (L.)), oysters (*Crassostrea* and *Saccostrea* spp.), the striped horse mussel (*Musculista senhousia* (Benson)) and the green mussel (*Perna viridis* (L.)) which has been cultured in Thai waters for more than 70 years (Juntarashote et al., 1987). The major culture provinces are Chon Buri, Chachoengsao, Phetchaburi, Prachuap Khiri Khan, Chumpom, Phangnga and Pattani (Network of Aquaculture Centres in Asia-Pacific, 1995). Mollusc culture, particularly of *P. viridis*, began to show a sharp increase in the eastern region between 1990 and 1993 which has continued to gather pace. In 1993 farms in Chachoengsao produced 3372 tonnes of green mussels from an area of 130 ha (114 farms), while in Chonburi, which accounts for some 30% of mollusc culture in Thailand, 15708 tonnes were produced from an area of 64 ha (72 farms) (Network of Aquaculture Centres in Asia-Pacific, 1995). By 1997, the green mussel accounted for more than half of total mollusc aquaculture production in Thailand, although only 14% of the area devoted to mollusc culture is used to produce this species (Table 1).

Table 1. Summary statistics of mollusc culture in Thailand for 1997 (data from Department of Fisheries, 1998).

| Species | Total Area (ha) | No. of Farms | Production (tonnes) |
|---|---|---|---|
| *Anadara granosa* | 2120 | 520 | 14403 |
| *Perna viridis* | 577 | 833 | 51184 |
| Oyster spp. | 1241 | 2127 | 23037 |
| *Musculista senhousia* | 73 | 61 | 4211 |
| Totals | 4011 | 3541 | 92835 |

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The culture systems in Thailand are mostly extensive (although yields may be extremely high on a unit area basis), with the seeding and harvesting of natural beds, or the harvesting of molluscs cultured on specialised poles, ropes or trays. The three main culture systems in operation are:

1. Bottom culture, where molluscs remain in their natural environment. This produces a good quality product for some species, but they are vulnerable to predation and siltation.
2. Pole (or stake) culture, in which rafts, trays or poles are placed in intertidal or shallow inshore areas and molluscs are allowed to grow on them, or in racks attached to poles.
3. Suspended or off-bottom culture, where molluscs grow on ropes suspended from rafts or long-lines. This method has the advantage of minimising predation of the species under culture by benthic predators, and usually results in a cleaner, thinner-shelled product.

Except for the blood cockle and the horse mussel, which are exclusively cultured on the sea bed, molluscs are generally cultivated using suspended culture methods. The prevalent culture method is pole culture, developed from a type of stationary fishing gear called a 'bamboo stake trap'. Green mussels grow in water 2 to 8 m in depth. Palm (mangrove date palm) and bamboo poles are commonly used. Although palm poles are cheap and relatively longer lasting (3 years instead of 1-1.5) they tend to be only 3 to 6 m long, so for culturing in areas of deeper water bamboo poles, which may be up to 10 m long, must be used. Mussels are allowed to settle naturally on poles planted 2 m deep into the sediment. About 5000 poles, set at 0.25 m intervals, are set in every hectare of farm. The culture period is 8 months and the shell length of the mussels at harvest is 7 to 8 cm (Thailand Development Research Institute, 1987). Each pole yields on average 10 to 20 kg of mussels (Juntarashote et al., 1987). The achievement of marketable size within 7-8 months is about twice as fast as *Mytilus edulis* L. in Europe.

Sivalingam (1977) examined different modes of culture for *P. viridis*, and found that the suspended rope culture technique practised efficiently in other parts of the world was also the most productive method in Penang, Northwest Malaysia. Although there are no published studies of the efficacy of the method in Thai waters it has been trialled experimentally for the purpose of establishing economical culture methods and it appears that the technique has good development potential, both biologically and economically (Juntarashote et al., 1987). From a purely aquacultural viewpoint, such development requires research into the biology of the mussel - how to fatten it and to determine the best time to harvest it. It also requires research into improved culturing methods such as determining the optimal method of collecting seed and conditions for grow-out to a marketable size.

This is, however, only part of the equation. There are many examples of aquacultural developments which have proceeded without due consideration of the environmental consequences of those developments. These have led to the subsequent collapse of seemingly promising enterprises. Whereas hanging cultures of molluscs do not require feeding, and might be expected to be relatively benign in comparison with other intensive aquacultural practices, such as shrimp production in ponds or the cage culture of finfish, mussels do produce large quantities of pseudofaeces which might be expected to enrich sediments below the cultures organically. Such cultures also produce large quantities of shell debris which may alter the physical characteristics of the sediment. There are few studies which have examined the impact of such cultures, and none in Southeast Asia.

This study examines the impact of a hanging culture of *P. viridis* on the benthos at a site in the Eastern Gulf of Thailand. As the culture was expected to have both organic enrichment and physical disturbance effects on the sediment, it was decided to examine changes in the community structure of freeliving nematodes in the sediment and to relate these changes to changes in sediment composition. Several elements of nematode ecology make them ideal for such studies. As they are in the meiofaunal size range smaller samples are required than would be the case if macrofaunal animals, which are more commonly used for benthic studies, were to be used. Nematodes reproduce quickly, with generation times of months rather than years, they develop directly within the sediment, and they have been shown to reflect ongoing conditions within the sedimentary environment more closely than faunal groups which are relatively long lived or mobile, or which have a planktonic dispersal phase (Somerfield et al., 1995; Warwick, 1993). Furthermore, in areas such as South East Asia where many marine invertebrates are inadequately described, it can be difficult to indentify specimens collected in benthic studies with certainty. It has been shown, however, that little information is lost by identifying nematodes to the level of genus

(Somerfield & Clarke, 1995; Moore & Somerfield, 1997), some genera have been shown to respond to differing types of disturbance in different ways (Somerfield et al., 1995), and the majority of freeliving marine nematode genera have cosmopolitan distributions and easy to use pictorial keys for those genera are available (e.g. Warwick et al., 1998).

## MATERIAL AND METHODS

The samples for this study were collected from the vicinity of a mussel raft moored in shallow water (approximately 3 m) at the Kasetsart University Sri Racha Research Station, north of Pattaya, Chonburi province, on the eastern coast of the Gulf of Thailand (13° 11.01' N, 100° 55.33' E). The raft selected for the study was 20 m by 20 m in size, supported dense aggregations of P. viridis growing on ropes set approximately 0.5 m apart, and had been in place for 5 years as part of an investigation into practical methods for the restoration of local fisheries in the Gulf of Thailand in the aftermath of overfishing by inshore trawlers in the 1980s.

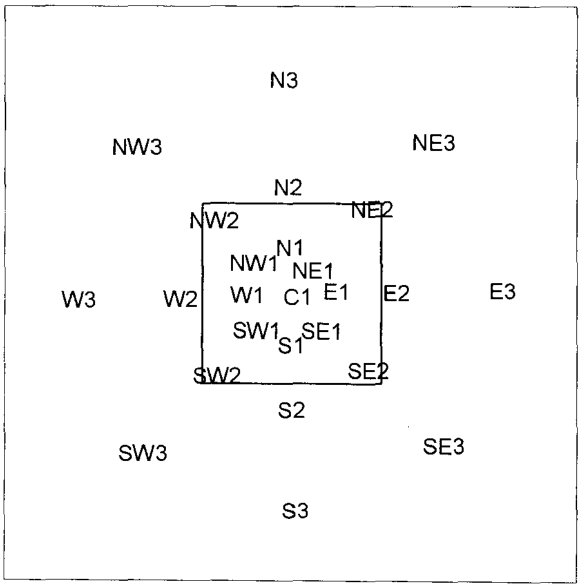


Fig. 1. Schematic showing the sampling design. The inner square indicates the extent of the mussel culture structure (approx. 20 X 20 m). Text in sample labels indicates direction from the raft centre, and numerals indicate sample groups: 1, samples < 10 m from the raft centre, underneath the raft; 2, samples 15 m from the raft centre, at the raft's edge, and; 3, samples 30 m from the raft centre, > 10 m away from the raft edge.

The sampling design (Fig. 1) consisted of 4 line transects crossing under the centre of the raft. Samples were collected from under the centre of the raft, and at distances of approximately 0, 5, 15, and 30 m from the raft centre. Samples were collected on 11 July 1998 using SCUBA. At each sampling point two samples (one for nematodes, and one for determination of sediment characteristics) were collected to a depth of 15 cm using a 8.7 cm diameter plastic core tube.

Samples for faunal analysis were fixed in 10 % formalin, then washed with filtered freshwater through a 500µm mesh nested over a 63µm sieve. The residue from the 63µm sieve was separated into heavy and light fractions using decantation (Warwick et al., 1998), repeated 6 times, and the light fraction (containing the nematodes) stored in 4 % formalin prior to examination. Methods used for examination followed Somerfield & Warwick (1996). Briefly, formalin was washed from each sample on a 63µm sieve. Remaining fine sand and inorganic material was removed using flotation in colloidal silica (Ludox-TM) with a specific gravity of 1.15, repeated 3 times. A subsample ($1/5^{th}$) was taken by resuspending the remaining sample in a known volume of filtered freshwater and withdrawing a known volume from it, washed into a cavity block using a mixture of 5 % glycerol and 10 % ethanol in filtered freshwater, and allowed to evaporate to pure glycerol. Finally, subsamples were spread on microscope slides and the coverslips were sealed using a paraffin wax ring and two coats of Bioseal (Northern Biological Supplies) prior to analysis using a differential interference phase contrast compound microscope. Nematodes were identified to genus following Lorenzen (1981, 1994), aided by the pictorial keys of Platt & Warwick (1983, 1988) and Warwick et al. (1998).

To assess sediment composition, 25 g sediment from each sampling point was oven dried at 105°C, passed through a graded series (2 mm, 1 mm, 500 µm, 250 µm, 125 µm and 63 µm) of sieves, and then weighed (Buchanan, 1984). The method of Walkley & Black (1934) was used to determine the organic content in sediment. 1g of dried sediment was digested with a chromic acid - sulphuric acid mixture and the excess of chromic acid (not reduced by the organic matter) was titrated with a standard ferrous salt ($FeSO_4$).

Data were analysed using the computer software package PRIMER (Plymouth Routines In

Multivariate Ecological Research) developed at the Plymouth Marine Laboratory (Clarke & Warwick, 1994). Environmental variables were ordinated using a correlation based principal components analysis (PCA). Intersample similarities in generic composition were calculated using the coefficient of Bray & Curtis (1957). Transformations are used to alter the relative contributions to sample similarities of abundant and rare taxa, and for this study a square-root transformation was selected as giving the best balance. The significance of differences between groups of samples selected *a priori* was tested using the randomisation/permutation procedure ANOSIM (Clarke, 1993) and the contributions of each genus to intergroup dissimilarities were explored using the similarities percentages procedure SIMPER (Clarke, 1993). Subsets of environmental variables 'best explaining' patterns in nematode community structure were explored using the BIOENV procedure (Clarke & Ainsworth, 1993). Intersample similarities were ordinated in two dimensions using nonmetric Multidimensional Scaling (Kruskal & Wish, 1978; Clarke & Green, 1988). The significance of relationships between intersample similarity and distance was tested using the non-parametric Mantel test RELATE (Clarke & Warwick, 1994; Somerfield et al., 1995).

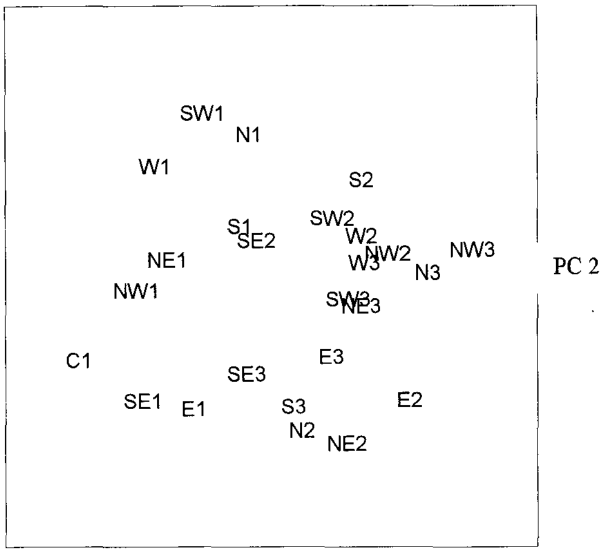


Fig. 2 Ordination by correlation based PCA of stations according to their measured environmental variables. Labels as in Fig. 1. Principal components 1 and 2 explain 63.4% of the variation in the data. PC1 represents a gradient in decreasing large particles (> 2 mm fraction) and percent organic carbon in the sediment.

# RESULTS

Ordination of samples, based on the measured environmental variables, by PCA (Fig. 2) shows that there are clear differences in sediment composition underneath the mussel raft. ANOSIM based on a normalised Euclidean distance matrix constructed from the environmental variables (Table 2) confirms the significance of differences between samples from underneath the raft (Group 1) and the rest of the samples, but the difference between samples from the edge of the raft (Group 2) and those further away

Table 2. Results of ANOSIM based on a normalised Euclidean distance matrix derived from the measured environmental variables. Sample groups are: 1, samples < 10 m from the raft centre, underneath the raft; 2, samples 15 m from the raft centre, at the raft's edge, and; 3, samples 30 m from the raft centre, > 10 m away from the raft edge.

| | *R* | *p* |
|---|---|---|
| Global test: | 0.508 | 0.001 |
| Pairwise tests | | |
| Group 1 v 2 | 0.532 | < 0.001 |
| Group 1 v 3 | 0.766 | < 0.001 |
| Group 2 v 3 | 0.143 | 0.082 |

(Group 3) is not significant. As ANOSIM compares average rank dissimilarities (or similarities) within groups to those between groups, it might be argued that if environmental variables are spatially autocorrelated apparent differences between groups could result from the fact that sample locations in Group 1 are closer together than in Group 2, and similarly Group 2 sample locations are closer together than those in Group 3. To test for such an effect the underlying environmental distance matrix was compared to a Euclidean distance matrix of intersample distances in a nonparametric Mantel test (RELATE) using the Spearman rank correlation as the test statistic. The result ( $\rho = 0.05$, $p = 0.31$) shows that there is no relationship between the two. Ordination of the biotic data by MDS (Fig. 3) shows that the clear differences in sediment composition underneath the mussel raft are also reflected in changes in nematode community structure. Note that MDS aims to reduce the multivariate information contained in a matrix to fewer (in this case 2) dimensions, so that the information can be presented as a plot in which the distances between symbols representing samples reflects their similarity. Thus it is not necessary to label the axes in such plots, as it is the relative distances between the symbols that matters. ANOSIM based on intersample similarites (Table 3) confirms the significance of differences

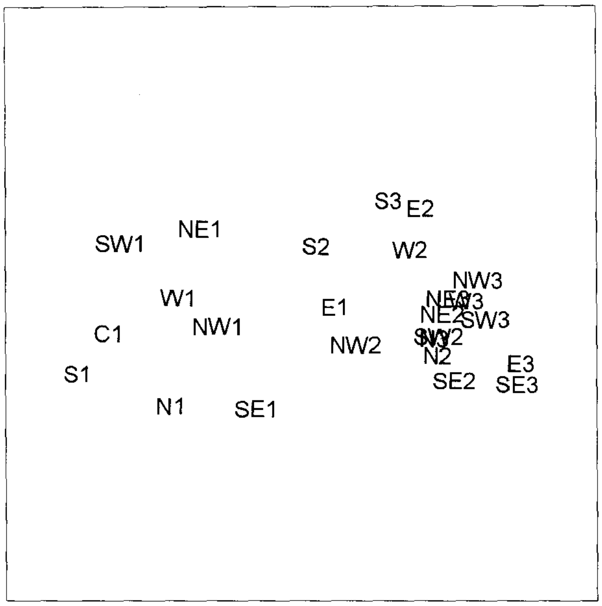


Fig. 3. Ordination by MDS of Bray-Curtis similarities between samples, calculated using square-root transformed abundances of nematode genera. Stress = 0.09. Labels as in Fig. 1.

between samples from underneath the raft (Group 1) and the rest of the samples, but again the difference between samples from the edge of the raft (Group 2) and those further away (Group 3) is not significant.

Table 3. Results of 1-way ANOSIM test for differences between groups, based on Bray-Curtis intersample similarities calculated using square-root transformed abundances of nematode genera. Sample groups are: 1, samples < 10 m from the raft centre, underneath the raft; 2, samples 15 m from the raft centre, at the raft's edge, and; 3, samples 30 m from the raft centre, > 10 m away from the raft edge.

| | *R* | *p* |
|---|---|---|
| Global test: | 0.548 | 0.001 |
| Pairwise tests | | |
| Group 1 v 2 | 0.749 | <0.001 |
| Group 1 v 3 | 0.907 | <0.001 |
| Group 2 v 3 | 0.090 | 0.065 |

To ensure that spatial autocorrelation in the biotic data was not contributing to the observed pattern the underlying similarity matrix was again compared to a Euclidean distance matrix of intersample distances in a nonparametric Mantel test (RELATE) using the Spearman rank correlation as the test statistic. The result ( $\rho$ = -0.105, $\rho$ = 0.87) shows that there is no relationship between the two, and in fact there is a suggestion that samples further apart are more similar to each other.

*K*-dominance curves (Lambshead et al., 1983) show that the nematode community in Group 1 samples is less diverse and more highly dominated (Fig. 4), although there is no major difference between sample Groups 2 and 3.

ANOVA of differences in univariate measures (Table 4) shows that there are significant differences in all measures between groups, with the exception of the evenness measure Pielou's *J'*. Examination of means plots (not reproduced here) shows that the differences result from reductions beneath the raft, and that differences between groups 2 and 3 are generally non-existant or relatively small.

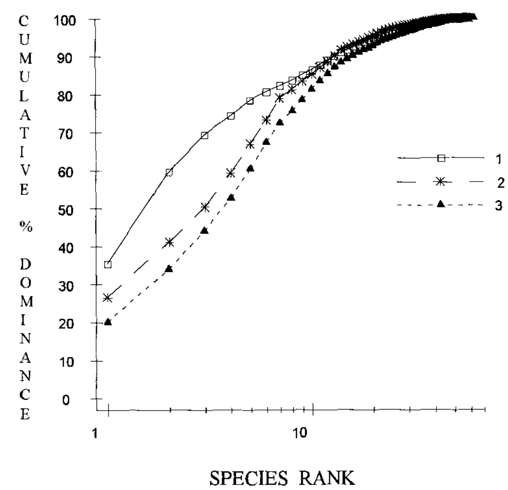


Fig. 4. *K*-dominance curves based on average abundances of nematode genera for sample groups 1, 2 and 3. Sample groups are: 1, samples < 10 m from the raft centre, underneath the raft; 2, samples 15 m from the raft centre, at the raft's edge, and; 3, samples 30 m from the raft centre, > 10 m away from the raft edge.

Table 4. Results from 1-way ANOVA (from $F_{2,22}$) of differences in univariate measures between sample groups 1, 2 and 3. *A* = total abundance and *S* = number of species.

| Univariate Measure | *R* | *p* |
|---|---|---|
| Log *A* | 14.437 | 0.0001 |
| Log *S* | 14.814 | 0.0001 |
| Margalef's *d* | 8.888 | 0.0015 |
| Shannon-Wiener *H'* | 6.836 | 0.0049 |
| Pielou's *J'* | 2.394 | 0.1146 |
| Simpson's $\lambda$ | 4.049 | 0.0318 |

The similarities between analyses of the environmental variables and of the biotic data suggest that the two are related. RELATE shows that the underlying environmental normalised Euclidean matrix and biotic Bray-Curtis similarity matrix are highly correlated ($\rho = 0.5$, $p < 0.001$). The results of PCA show that the percentages of coarse (> 2 mm) particles and organic matter in the sediment are highly correlated, and it is therefore difficult to disentangle their effects. The BIOENV procedure shows that the environmental variable combinations which are most highly correlated with patterns in nematode community structure are those that include the percentage of coarse material and organic matter, and also the percentage of silt/clay. The highest match was with the combination of all three (weighted $\rho = 0.473$).

The Similarities Percentages procedure SIMPER was used to examine the contribution of each nematode genus to within group similarities (Table 5) and between group dissimilarities (Table 6). Samples from Group 1 are characterised by the genera *Metoncholaimus*, *Terschellingia* and *Viscosia*. High abundances of *Metoncholaimus* also characterise samples from Group 2, but not Group 3. No genus contributes more than 10 percent of intergroup dissimilarity. The overall pattern is one of reduced abundances of a range of genera in Group 1.

Table 5. Summary of results from SIMPER, showing nematode genera contributing up to a cumulative 50 percent of within group Bray-Curtis similarity, calculated using square-root transformed abundances. Values are average abundances of nematode genera within sample groups, and percentage contributions (in parentheses) of nematode genera to within-group similarities (average value in first row of table).

| Sample Group | 1 | 2 | 3 |
|---|---|---|---|
| Average similarity | 54.97 | 62.06 | 68.12 |
| *Metoncholaimus* | 102 (28.26) | 100 ( 6.80) | |
| *Terschellingia* | 70 (13.14) | 285 (14.12) | 259 (11.49) |
| *Viscosia* | 28 (13.09) | | |
| *Perspiria* | | 155 ( 9.51) | 181 ( 9.96) |
| *Halaphanolaimus* | | 96 ( 8.51) | 98 ( 6.34) |
| *Daptonema* | | 81 ( 6.45) | 129 ( 7.50) |
| *Desmodora* | | 63 ( 6.41) | 89 ( 5.49) |
| *Gomphionema* | | | 112 ( 6.80) |
| *Spirinia* | | | 66 ( 6.11) |

Table 6. Summary of results from SIMPER, showing nematode genera contributing up to a cumulative 50 percent of between group Bray-Curtis dissimilarity, calculated using square-root transformed abundances. Values are average abundances of nematode genera within sample groups, and percentage contributions (in parentheses) of nematode genera to between-group dissimilarities (average value in first row of table).

| | Group 1 | | Group 2 | | Group 3 |
|---|---|---|---|---|---|
| Average dissimilarity | | 58.43 | | 36.52 | |
| *Terschellingia* | 70 | (9.47) | 285 | (6.46) | 259 |
| *Perspiria* | 4 | (8.94) | 155 | (5.47) | 181 |
| *Halaphanolaimus* | 4 | (7.20) | 96 | (3.92) | 98 |
| *Spirinia* | 2 | (5.62) | 67 | (3.50) | 66 |
| *Metoncholaimus* | 102 | (4.79) | 100 | (5.47) | 13 |
| *Desmodora* | 6 | (4.70) | 63 | (3.86) | 89 |
| *Daptonema* | 15 | (4.44) | 81 | (4.89) | 129 |
| *Terschellingia* | 3 | (3.25) | 20 | (2.84) | 43 |
| *Gomphionema* | 2 | (2.96) | 23 | (5.40) | 112 |
| *Steineria* | | | 23 | (3.26) | 30 |
| *Halalaimus* | | | 7 | (2.35) | 23 |
| *Viscosia* | | | 17 | (2.32) | 5 |
| *Dorylaimopsis* | | | 17 | (2.15) | 35 |

## DISCUSSION

The hanging culture of *P. viridis* had clear effects on the sediments and associated nematode fauna beneath it. The sediment contained increased quantities of coarse material and organic matter. The effects were, however, extremely localised and did not reach far beyond the perimeter of the raft from which the mussels were suspended.

The effects on the fauna were manifest as reduced abundances of a range of genera, and enhanced abundances of the oncholaimid genus *Metoncholaimus,* which is known to characterise disturbed sediments (Somerfield et al., 1995). This could be interpreted as a detrimental environmental impact resulting from the suspended culture of *P. viridis*. Intensive fin-fish farming in floating cages produces large quantities of waste, and the majority of studies on the benthic impact of aquaculture have focused on such sites (Gowen et al., 1991). Most of the solid waste settles to the sediment and can have an impact on the benthic ecosystem, for example changing the population structure of the macrofauna (Brown et al, 1987; Ritz et al, 1989; Weston, 1990). Structural changes in meiofaunal communities have been reported, such as a high abundance of large nematodes near fish culture sites (Lorenzen et al., 1987; Prien, 1988; Weston, 1990). While the effects of aquaculture on benthic communities may be dramatic, the impact is generally very localised (Gowen & Bradbury, 1987; Lumb 1989). The extent to which an impact is detected, however, is in part determined by the method used to measure that impact. Although a close match between environmental and biological measures of impact is demonstrated in this study, chemical measures may indicate no effect of culture although the faunal composition may show clear evidence of enrichment up to 150 m from salmonid cages (Weston, 1990). It should also be recognised that although the effects of a single aquacultural structure may be localised, the benthic communities of large embayments may be altered if a substantial portion of the water body is allocated to aquaculture (O'Connor et al., 1989).

The rate and successional sequence of benthic recovery following harvest of an aquaculture product or removal of the culture structures is not well documented, largely because studies have been too short in duration. The macrofaunal community beneath former mussel long-line sites remained very different from that of surrounding areas 1.5 years after the removal of the long-lines in one study (Mattson & Lindén, 1983), and four years in another (Stenton-Dozey et al., 1999). The timescale of recovery of benthic communities depends on a number of factors, including the initial level of enrichment and the nature of the local environment (Karakassis et al., 1999).

The Royal Thai Government Office of Environmental Policy and Planning has a mandate to formulate and co-ordinate natural resources policies in Thailand, and has a policy, strategy and operating plan for managing the coastal environment (Office of Environmental Policy and Planning, 1992). Although major areas of concern relating to aquaculture are conflicts between people over the use of freshwater and seawater, waste waters from coastal areas being discharged to public canals, and overfishing, policies and strategies to prevent environmental deterioration as a result of fisheries and coastal aquaculture also exist. Policies include the promotion of efficient use of fisheries resources, conservation and sustainable production. These are delivered through measures such as the designation of the allowable area and fishing effort for different types of fisheries and the improvement of fisheries resources, particularly the habitats of aquatic animals, for example by the construction of artificial habitats without changing or destroying the environment.

No environmental impact assessments are required for aquaculture activities in Thailand. Compared with intensive finfish culture, the environmental concerns associated with mollusc culture are generally considered to be relatively low, normally only occurring where culture areas cover a large area, have very high stocking densities or are not properly managed. Large areas of land-based mollusc culture may interfere with the direction and velocity of tidal currents, changing sedimentation patterns, or may interfere with navigation, and the Office of Environmental Policy and Planning has a policy to ensure that coastal lands are used efficiently for aquaculture. In water, it is recognised that accumulation of solid wastes beneath culture sites may lead to localised deterioration in environmental quality. On the other hand, the molluscs in question are filter feeders, dependant on particulate organic matter in the water column for their nutrition, and therefore mollusc culture can also have a positive impact on the environment, through the assimilation of particulate organic matter and the consequent reduction in coastal eutrophication.

Thus there may be conflicts. Although mollusc culture generally requires a productive environment, areas subject to heavy eutrophication may be unsuitable for some species. Also, molluscs have the capacity to filter large volumes of seawater, so if grown in contaminated areas they may concentrate pollutants, leading to problems with product quality. Mollusc culture is, therefore, particularly sensitive to environmental pollution, especially siltation and sedimentation, coastal eutrophication (which can reduce spat-fall from natural populations) harmful algal blooms (which may be toxic directly to the mollusc, or may make them unsuitable for consumption), and organic and industrial contamination (again making them unsuitable for consumption).

The current method of culture for *P. viridis*, namely pole culture, is concentrated in shallow inshore areas, normally in the vicinity of river mouths. These are precisely the areas where the types of environmental pollution outlined above are likely to be worst. Thus one of the potential advantages of the use of suspended culture is that it allows the culture of the mollusc to be located in areas where such problems may be avoided. Economic considerations, however, also need to be taken into account. Culturing molluscs in shallow waters requires little infrastructure, as the poles can be reached by wading at low tide. Suspended cultures further offshore can only be reached by boat, and thus for the farmer there are cost implications to be considered. Thus the potential benefits of improved yields and product quality need to be balanced against these additional costs. That being said, suspended cultures can be accessed at all states of the tide and can therefore be managed more efficiently. There are also spin-off benefits to be considered. Floating structures attract wild fish, and provide refuges for juvenile fish. Thus fisheries in the vicinity of such structures may be enhanced, providing added value to the operation. Juntarashote et al. (1987) recognised that one of the constraints on the development of mollusc aquaculture in Thailand is the sanitary condition of the product. Careless handling by the farmers during harvesting may cause serious contamination on occasions. They recommended that farmers decluster and clean mussels at the culture area, where clean seawater is available, rather than at landing-sites where water is generally polluted. By locating culture areas away from pollution sources, and servicing the cultures from boats, such practice may be promoted.

Mussel culture in Thailand is presently concentrated in areas lining the Inner and Eastern Gulf of Thailand. four large rivers (Mae Klong, Chao Praya, Tha Chin and Bang Pakong) flow into the Inner Gulf of Thailand, where contaminated water is retained during the months from April until mid-June, because of relatively long flushing times and reduced river discharges. BOD loadings in the inner gulf are also high in April, May and June. Increasing discharges normally occur by September and October when a large quantity of outflow from the Inner Gulf takes place (Ludwig, 1976). Thus intensive culture of *P. viridis* in the shallow muddy Inner Gulf must be considered risky, although it may be possible to manage growth cycles so as to ameliorate the effects of fluctuating water quality. At Sri Racha there are two peaks in natural spat-fall, the main one during the rainy season (May to August, with peak rainfall in June) and a second smaller one in winter (November to February). The availability of natural spat is one reason why mollusc culture is presently concentrated in areas that may be considered suboptimal. Through the use of modern methods of gathering and transporting spat to clean grow-out areas, where they may be ongrown in suspended culture, there is no reason why relatively large areas of Thai coastal waters with good water quality should not be used for mussel culture. This is one area where research could usefully be done prior to the development of a suspended mussel culture industry in Thailand. Improved declustering and packaging techniques should also be investigated.

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