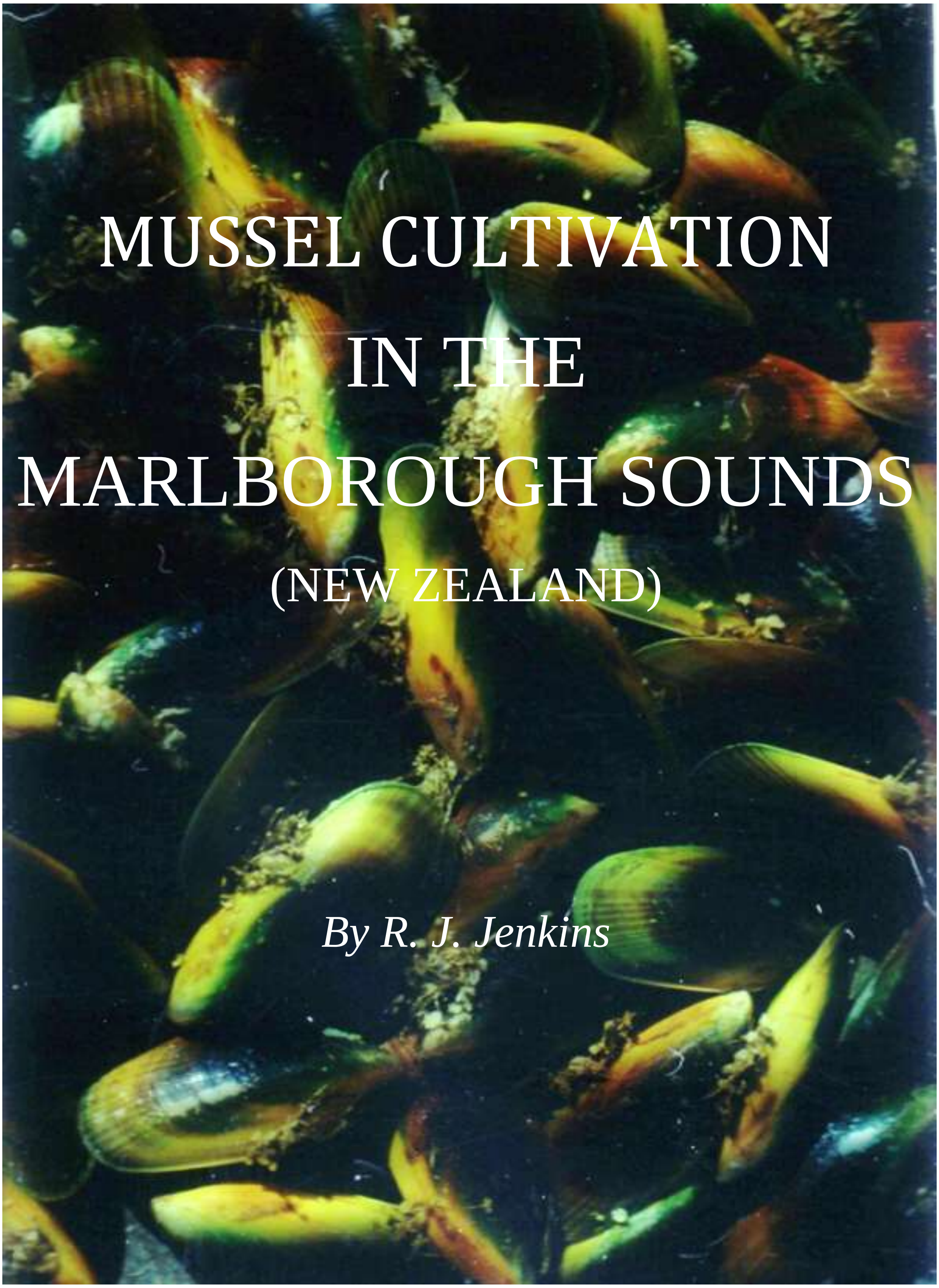

MUSSEL CULTIVATION IN THE MARLBOROUGH SOUNDS

(NEW ZEALAND)

By R. J. Jenkins

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Underwater view of long line marine farm in the Marlborough Sounds. (Courtesy M. Bull.)

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By R. J. Jenkins

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Wellington
New Zealand

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FOREWORD

It gives me great pleasure to introduce this handbook which will make available the results of the Board's work in this field to all who are interested in mussel farming.

The New Zealand Fishing Industry Board has wide responsibilities for the development of fisheries in New Zealand. From its inception it has recognised the potential of aquaculture to expand the production of fish as food. The Board selected mussel farming as the most promising aquaculture field in which its then limited resources of funds and manpower could be most advantageously deployed.

Mussel farming started, and has developed, in the Marlborough Sounds, one of the most beautiful scenic areas of New Zealand. The growth of mussel farming in this region has had to take into account the need to preserve the environment and the rival claims of water users — recreational interests, commercial fishing, forestry development and environmentalists. The Board has taken a lead in attempting to reconcile the conflicting interests in the mussel farming areas and in ensuring that the industry has developed in harmony with the environment.

It has also encouraged the development of a strong and representational mussel farmers' group who can speak on behalf of their industry. The Board has also attempted to promote a rational approach to meeting the processing and marketing requirements of the industry.

The major input provided by the Board, however, has been the financing of the investigational and field work which has been done by Mr Jim Jenkins of the Board's staff. The development of the mussel farming industry has depended very largely on this work. It is hoped that this handbook, which summarises the experience which has been gained with mussels in the Marlborough Sounds, will be of benefit to all existing and potential mussel farmers in New Zealand and elsewhere.

M. M. N. Corner
CHAIRMAN
N.Z. FISHING INDUSTRY BOARD

PREFACE

Jim Jenkins, the author of this handbook, joined the Fishing Industry Board as its first aquacultural technical officer in December 1972. At that time there was virtually no commercial aquaculture in the country other than the intertidal farming of rock oysters in the north. Some developmental work had been done by the Board in conjunction with Victoria University but mussel farming was not commercial and was in its infancy.

Jim spent his early days with the Board in surveying the many aquacultural possibilities that were thought to exist in New Zealand. These included the farming of salmonids and eels, as well as shellfish. He was also involved in assisting and advising existing or potential fish farmers.

It became apparent that there were promising and exciting possibilities for the development of an industry based on the farming of the indigenous green lipped mussel in the Marlborough Sounds. Some pioneers had already moved into this field and were using the heavy type of raft as developed by the Spanish mussel farming industry. They had many problems to face such as the uncertainties of spat supply, and the competition from fouling marine organisms.

As his main task, Jim took up the challenges posed by mussel farming. Information was sought throughout the world on the biology of mussels and the techniques needed to cultivate them. He collaborated with other biologists in New Zealand who were working in fields related to mussels. In particular, however, Jim undertook a tremendous amount of field work in the Marlborough Sounds and by 1976 it was apparent that full time attention was required. As a consequence Jim took up residence in the Sounds to concentrate on the development of mussel farming. He initially concentrated on work to identify the young mussel larvae amongst the plankton and was able to develop a spatfall forecasting system for the benefit of the farmers. He put into effect the Board's decision to organise annual communal spat catching lines in the areas of predicted heavy spatfall on which farmers could place their own ropes to ensure the season's supply of seed. He implemented the change over from rafts to the buoyed long lined system using buoys brought to New Zealand from Japan. Throughout this time he has been responsible for the introduction of many new or improved items of equipment or techniques now being used by mussel farmers.

This handbook contains the results of his work in the Marlborough Sounds in which he has been supported and assisted by colleagues at the Board, by staff of the Ministry of Agriculture and Fisheries, by other New Zealand scientists, and not least by the mussel farmers themselves. Specific reference should be made to the assistance provided by Fisheries Management Division, in particular in making available John Meredyth-Young who, working with Jim Jenkins, has contributed substantially to this work.

The techniques described in this handbook have led to the rapid development of an industry which is now producing between 600 and 1,000 tonnes of farmed mussels each year and which would be capable of producing many times that quantity if all space on existing licences was farmed to capacity. The Board hopes that mussel farmers, actual and potential, will gain much value from this book, a book which further demonstrates the Board's interest and support in aquaculture, but which also serves as a permanent record of Jim Jenkins' enthusiasm and dedication.

N. E. Jarman
GENERAL MANAGER
N.Z. FISHING INDUSTRY BOARD

INTRODUCTION

Mussels have long been a staple food in New Zealand, being traditionally eaten by the Maori and also being highly regarded by many Europeans. The supply, originally from inter-tidal picking and later from a dredge fishery in the Auckland district, began showing signs of depletion in the mid-1960's. Fisheries subsequently developed in the Marlborough and Nelson districts also showed signs of over-fishing and slow natural regeneration by the early 1970's. The green lipped mussel *Perna canaliculus* probably because of its wide availability, has dominated the local market whereas the edible blue mussel *Mytilus edulis aoteanus*, a more southern variety, has only recently begun to be exploited.

The cultivation of mussels in New Zealand was probably first considered in the early 1960's following the collapse of the Hauraki Gulf mussel fishery. The first efforts were by suspended raft culture and failed largely because of an inability to stabilise seed supply. Successive cultivation efforts in the late 1960's and early 1970's had some success, sometimes utilising beach transferred seed mussels, but it was not until the mid 1970's when spatfall forecasting techniques were perfected in the Marlborough Sounds, that a soundly based mussel cultivation industry could begin to evolve there.

Investigations into the life histories of the two commercial indigenous mussel species (referred to in the text as *Perna* and *Mytilus*) have been carried out since 1968 by Victoria University and the Ministry of Agriculture and Fisheries (earlier referred to as the Fisheries Division, N.Z. Marine Department). Developing interest in mussel cultivation led the Fishing Industry Board in 1969 to assist the Hauraki Gulf mussel cultivation trials and subsequently in 1973 in the Marlborough Sounds to embark upon a programme of applied research into mussel farming technology. Seed availability, shown to be the major limiting factor, received priority although investigation expanded into seed maintenance and development of general farming practices.

This handbook was originally intended solely as a guide to sound farming practices, but in the course of its assembly, additional information became available which has been incorporated into the text. Much information relating to mussels and their farming is not easily obtainable, and it is hoped that the material presented will cover, although in many instances only briefly, the topic as it concerns the grower. The chapters are arranged more or less in progression, with the first establishing the base-line with facts as to the area and the species, with the later chapters building upon this information and considering farm practices and related matters.

GEOGRAPHICAL SITUATION

The Marlborough Sounds are located in the extreme northeast of the South Island of New Zealand and were formed by coastal submergence. The area extends from 40°53'S to 41°18'S, and from 173°45'E to 174°23'E. The two major Sounds, the Pelorus and Queen Charlotte, are termed rias (drowned valleys) and closely resemble the rias of Galicia in Spain, a region well known for its well established mussel cultivation industry.

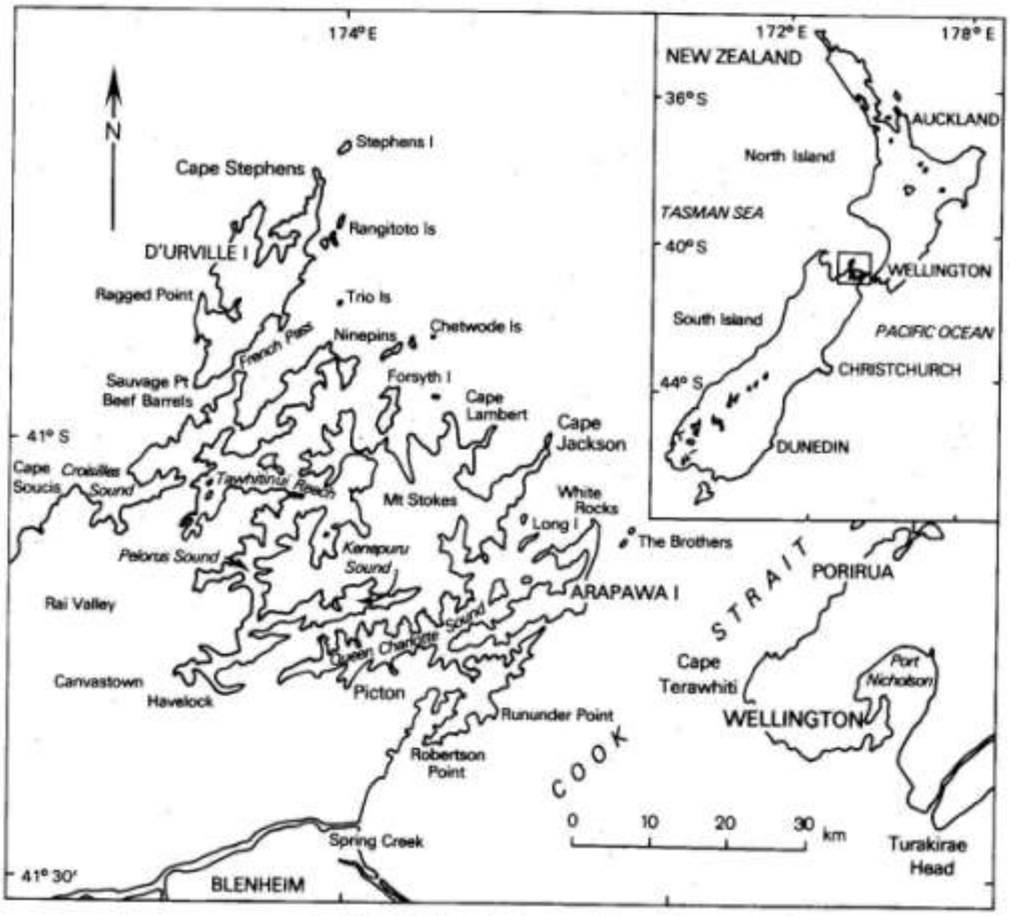


Fig. 1. The Marlborough Sounds.

WATER QUALITY

Land farmers need to understand the physical requirements which lead to a successful farming unit and the sea farmer must likewise understand the environmental conditions which influence the growth and survival of his selected farmed species. The most significant of these are available oxygen, salinity, temperature, food availability, depth, exposure and pollution. The sea farmer has few opportunities to rectify limiting factors once a farm is established, so checking the suitability of these factors is a critical part of his selection of his farm site.

DISSOLVED OXYGEN

Oxygen levels in enclosed inshore waters are generally high and stable unless excessive pollution or an abnormal plankton bloom occurs. Pelorus Sound, although not rigorously sampled, appears to have high dissolved oxygen levels throughout its entirety.

SALINITY

Coastal water in the area has a salinity of 33-35 parts per thousand (ppt). Salinity variations in the Pelorus Sound are a result of fresh water diluting the highly saline coastal water and this occurs most dramatically during heavy flooding of the Pelorus and Kaituna Rivers. Normally during summer and winter months of fair to moderate rainfall the Kenepuru and Pelorus Sounds remain at a high salinity, of between 30-35 ppt. However, in periods of heavy rainfall the inner Pelorus Sound, in the vicinity of Hikapu Reach, can have salinities less than 14 ppt in the surface layers down to 2m. Stratification of the waters in the Pelorus and Kenepuru Sounds is usually slight except for those times of high precipitation (Fig. 2).

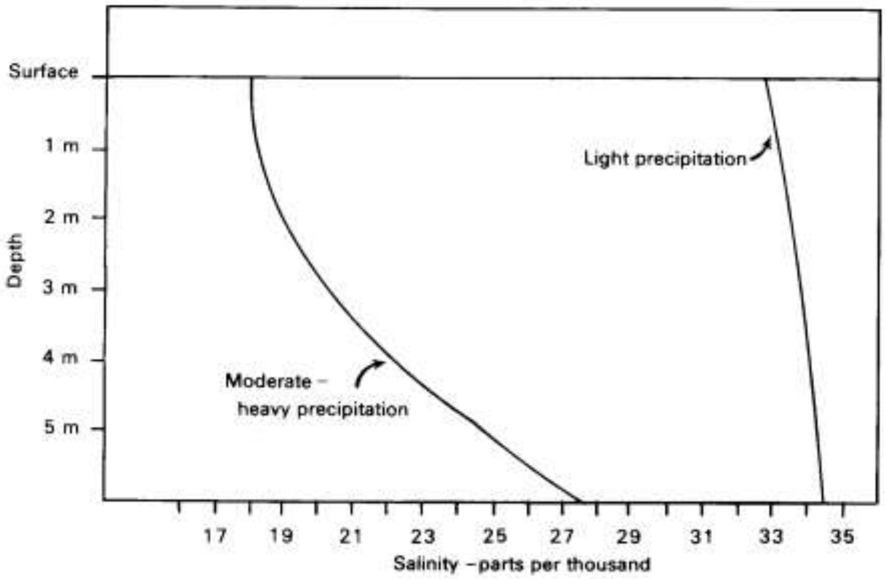


Fig. 2. Salinities experienced in the inner Pelorus Sound during light and moderate-heavy precipitation.

Unfortunately little is known of the tolerance of New Zealand mussels to salinity changes. Studies overseas have shown that mussels react to salinities less than 14 ppt by remaining closed and inactive while the salinity remains low. In September 1969 when 387mm of rain fell in the Marlborough district in 10 days, heavy mortalitites occurred amongst the beach mussels along the inner Kenepuru Sound. Under less severe conditions the effect of low salinities is believed to be the restricting of the growth of mussels by reducing their metabolic activity.

TEMPERATURE

The Pelorus Sound in most months of the year is nearly constant in temperature from surface to depth although temperature differences will occur between the inner Pelorus and Kenepuru Sounds and outer Pelorus in mid-summer and mid-winter (Fig. 3), and these differences may be as much as 2-3°C. The waters of the shallow inner Sounds do not have their temperatures stabilised by the coastal waters, and become correspondingly warmer in the summer and cooler in the winter. Inner Sound temperatures generally range between 9-21°C during the year, while outer Sound temperatures will range between 11-19°C.

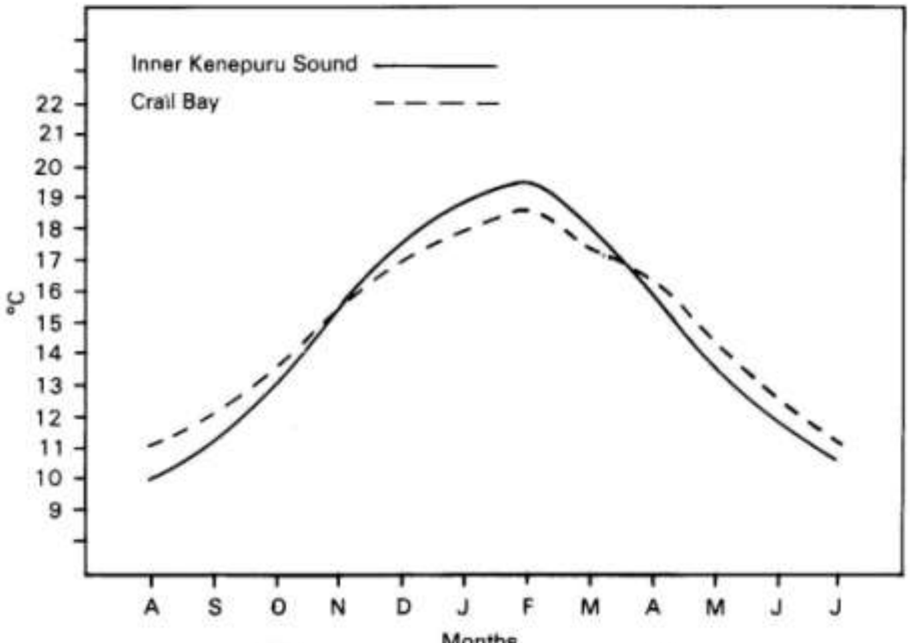


Fig. 3. Approximate mean monthly temperatures from August 1976 to July 1977 for the inner and outer Sounds.

Increasing water temperatures proportionately increase the rates of feeding and metabolism in mussels, which in turn effects growth rates. However, growth rates may be actually reduced during times of high water temperature because of a lowered abundance of food organisms. Seasonal growth rate differences can occur between the inner and outer Sounds although annual growth rates are relatively similar. The growth rates of mussels in the inner Sounds are generally suppressed in the summer months but high growth rates occur in the spring and autumn months. Since many factors simultaneously affect mussel growth, the true significance of water temperature in Pelorus Sound is not clear.

FOOD AVAILABILITY

Mussels will accept a wide range of food organisms including single celled algae, planktonic animals, detritus and bacteria. Measurement of marine productivity relating to mussel growth is extremely difficult and little information is available which is specific to the Marlborough Sounds.

However, consideration of comparative growth data for mussels throughout New Zealand and overseas, suggests that the Marlborough Sounds are equal or superior to other documented areas. This may or may not be a direct reflection of relative productivity, but it does imply comparatively good food availability.

DEPTH, TIDES AND EXPOSURE

Depth soundings in the Pelorus Sound, are shown in Fig. 4. Mussel farms are located mainly in the lateral bays and shorelines of the Sounds away from areas where there could be navigation conflicts, and in depths of 5 to 20 metres (MLW). Bottom conditions are typically soft grey mud occasionally changing to firm pebbly mud-shell conglomerate.

Fig. 4. Depth Soundings (fathoms) for the Pelorus and Kenepuru Sounds and Crail and Beatrix Bays. (Courtesy Hydrographic Branch, Department of the Navy, New Zealand).

The tidal range between high and low varies from 4.0 metres at spring tides to 1.5 metres at neap tides. Tidal flow varies with the localities, and also varies between the surface and deeper waters. A surface tidal flow of 50cm/sec (1 knot) is common in the narrower channels, although marine farms are more or less limited to sites having a tidal flow no greater than 25cm/sec (.5 knots) unless special mooring arrangements have been considered.

Near gale force winds can occur in the Sounds in most months of the year and can create sea conditions which are hazardous for small boats and raft structures. Waves can exceed 2 metres in height in exposed places, and are a factor which must be considered when farm locations are being selected.

POLLUTION

In natural situations the marine environment normally copes with land runoff and wastes by dispersion and biodegration of the organic matter. Once, however, wastes reach such high levels that the environment is unable to recycle wastes in instances of human domestic and industrial sewage a state of pollution exists. Mussels like many filter feeders may become easily contaminated with domestic sewage, heavy metals or toxic chemicals and can pose a human health hazard.

The respective catchment area in the Pelorus and Kenepuru Sounds being sparsely settled and having no industrialisation has shown to have little detrimental effect on the sea water quality. Present evidence suggests there are no grounds to suspect mussels farmed in this area and there are currently no restrictions limiting their sale in New Zealand. However, the export of mussels will most likely require proof of wholesomeness in the form of health certificates. These could be issued for individual consignments after testing samples from the consignment, or issued for all shellfish from an approved growing area.

Mussel growers must guard against localised water contamination caused by sea birds perching on the raft and float structures. Sea birds can pass faecal coliform bacteria to those mussels, and may act as carriers of human gastro-intestinal disease organisms. Rafts may require some form of bird netting and long-line floats can be affixed with barb devices shown in Fig. 5 to discourage birds from resting on them.

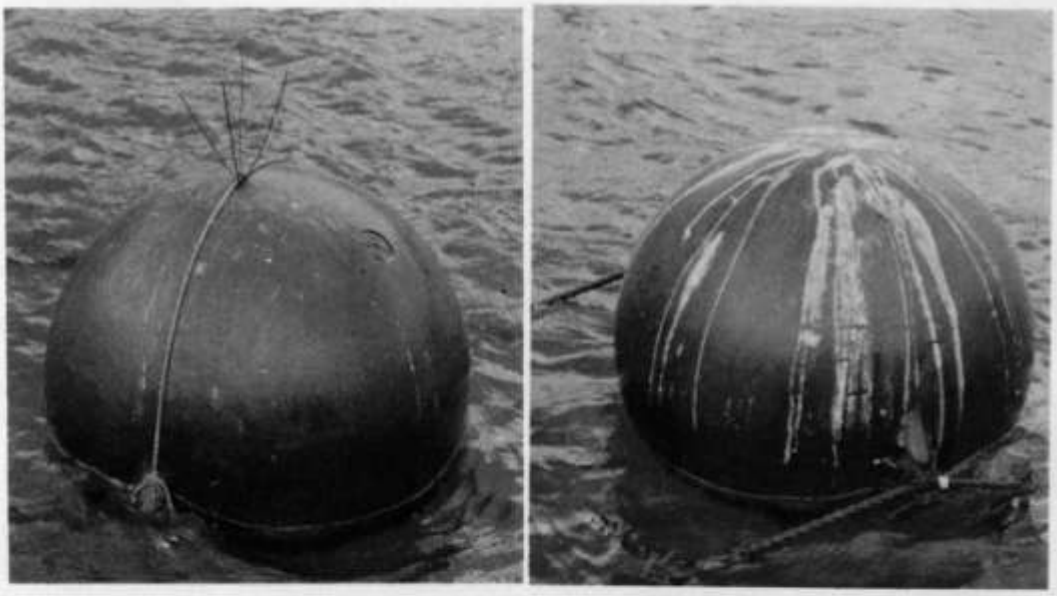


Fig. 5. Anti-bird device on float as compared to normal float.

It is desirable that waters in which shellfish are grown should be classified as SA by the Water Resources Council. The classification itself does not ensure that the waters are at the required standard, but it does tend to limit alternative uses of the water which could affect its suitability for growing high quality shellfish. Marine farmers may need to challenge water and land use changes which could reduce water quality. Since the Sounds are mainly intended for multiple use, communication is essential with the agricultural and forestry sectors and the County Council to ensure sound land management practices and effective regional sewage disposal.

TAXONOMY

Mussels belong to the phylum of animals called molluscs (Fig. 6) which generally possess a hard shell, a muscular ventral foot and a fleshy mantle. Three quarters of the over 80,000 species of molluscs are gastropods (snails, limpets, etc.) which more closely resemble the early mollusc forms. Mussels not however representative of the phylum in form, have tended to become specialised for specific habitats because of their overall limited mobility.

Eight species of mussels and numerous other bivalves have been found in the Marlborough Sounds. Marine farmers should have no difficulty in distinguishing mussels from other bivalves, but could experience some difficulty in distinguishing the mussel types which settle on the culture ropes. Only four mussel species seem to find the culture rope a suitable habitat. These are briefly discussed.

GREEN LIPPED MUSSEL *(Perna canaliculus)*

The developing mussel farming industry in the Marlborough Sounds is primarily based on this species. This mussel is native to the Sounds as well as most of New Zealand, and is primarily a warmer water variety. It can grow to a length exceeding 230mm (over 9 inches), and its habitat is usually low tidal to subtidal. Juveniles have a bright green external shell colour, but intertidal and exposed mussels often exhibit a dark, almost black, external shell. Raft cultivated mussels however usually maintain the vivid green external shell even with the older adults. All specimens possess the distinctive "green lip" on the mantle fringe. The most closely related species is *Perna perna* which is native to South America and Africa, and closely resembles the New Zealand *Perna*.

BLUE MUSSEL *(Mytilus edulis aoteanus)*

This mussel could have a commercial future in the Marlborough Sounds, although it is presently undergoing little exploitation. It is closely related to the European edible blue mussel which is widely distributed in other parts of the world as well. It grows to about 100mm (4 inches). It is naturally occurring in the high inter-tidal shore, and usually has a chalky white appearance around the anterior and hinge area. It is abundant along Cook Strait and south, although occasional isolated populations are found in Northern districts. When cultivated, the shell becomes a glossy smooth bluey-black on the exterior, and is quite fragile.

NESTING MUSSEL *(Modiolarca impacta)*

This mussel grows to about 25mm (1 inch) and is completely encased in a fibrous mat of byssus. The larvae of this mussel are found in abundance through most of the summer months. The young juveniles at about 1mm may possibly be confused with *Perna* juveniles by their green colouration, although their shell shape is distinct from *Perna*.

RIBBED MUSSEL *(Aulacomya maorianus)*

This is found occasionally among blue mussels in the intertidal zone, but is easily distinguishable by the pronounced radial ridges running from the anterior beak to the posterior. It does not usually grow to more than 75mm (3 inches) in length. It does not commonly occur on culture ropes in the Pelorus Sound.

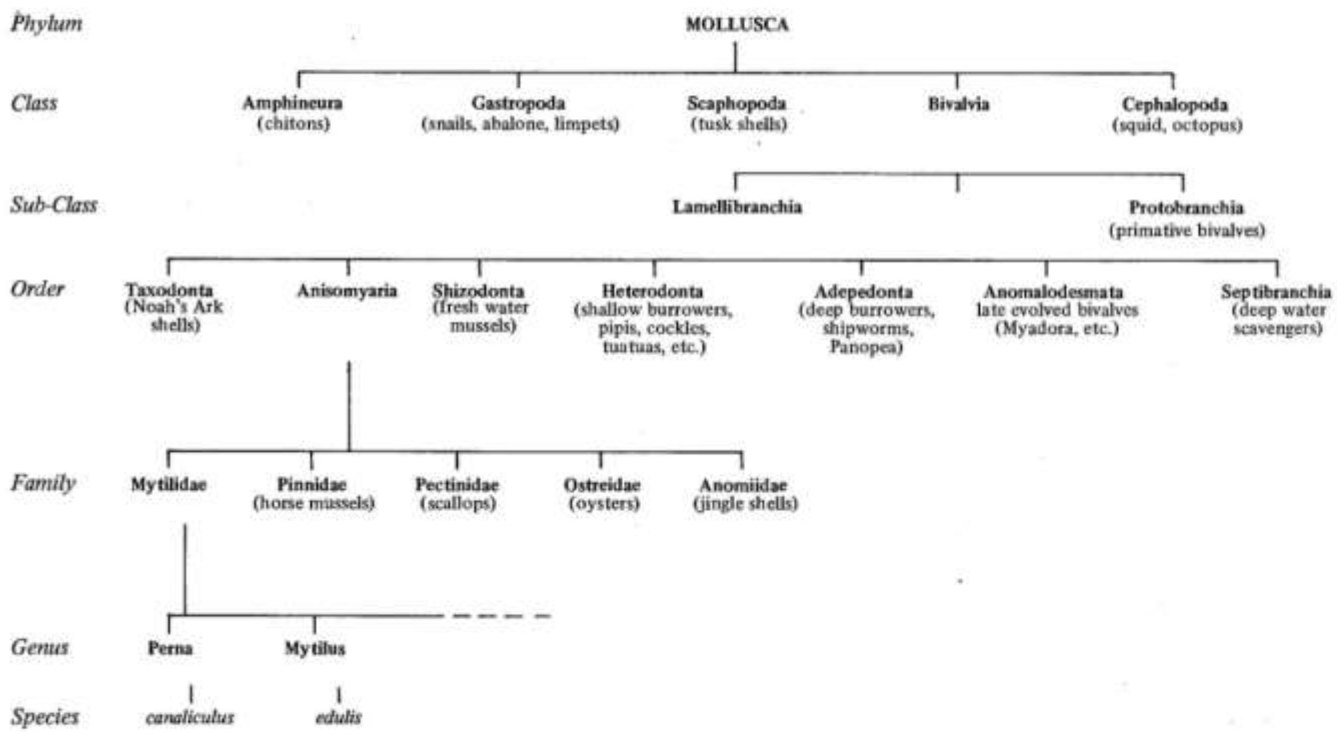


Fig. 6. The Phylum Mollusca.

ANATOMY

Mussel farmers may find it an advantage to be able to identify the anatomical features of mussels, and to understand the various body functions. The need may arise from queries from consumers unfamiliar with the shellfish, or the knowledge may be needed to improve farm practices. The following brief description relates mainly to *Perna*, with some reference to *Mytilus*. However, most mussels have a somewhat similar anatomy.

SHELL

Perna and *Mytilus* shells (each side is referred to as a valve and hence the term bivalve) are equally cupped. The hinge is located on the dorsal anterior end. The shell is composed of three layers, the outer horny periostracum, a middle layer of calcite crystals called conchyolin which provides the main support material, and an inner smooth nacreous layer.

Although the rings of ridges formed on mussels and many bivalves can at times be used for aging the animals, as with growth rings in trees, this is not the case for *Perna* and *Mytilus* in the Marlborough Sounds. The rings observed on these two species are generally caused by a physical disturbance. They can be seen on raft cultured mussels as a result of lifting ropes and exposing the mussels to the open air, or by the transferring of mussels (Fig. 8).

A darkening of the outer periostracum to almost black is sometimes seen with intertidal mussels and mussels on the topmost metre or so on culture ropes and is attributable to exposure to the sun. Generally the deeper or less exposed the mussels are to the sun, the lighter and greener their colour.

SOFT BODY PARTS

The anatomy viewed by the removal of the left valve with the body intact in the right valve, is shown in Fig. 9. The bulk of the tissue observed is the intermantle lobe which seasonally alternates as glycogen storage tissue, the animal equivalent of carbohydrate, and as reproductive tissue. The external lining of the lobe also lays down shell material to thicken the shell although the mantle on the outer margin is primarily responsible for shell growth.

The greeny mass adjacent to the hinge which surrounds the stomach is the digestive gland and aids digestion. The heart is contained in the pericardial cavity and consists of a single ventricle and two auricles. It can be seen at times through the translucent membrane, pulsating at about 25 beats per minute.

Most of the musculature attached to the left valve can also be seen from this view. The large posterior adductor muscle of *Perna*, which is responsible for shell closure, is quite evident. In *Mytilus* (Fig. 10) the posterior adductor muscle is much smaller than for a similar sized *Perna*. Another difference between the species is that *Mytilus* possesses a vestigial anterior adductor muscle while *Perna* has none. Two of the foot retractor muscles are easily seen, one adjacent to the posterior adductor muscle, and the other near the digestive gland. A third, the anterior retractor muscle is clearly seen in Fig. 10. All three foot retractor muscles indicated are paired muscles, one attached to the left shell and one attached to the right shell, with both joining at the base of the foot.

On lifting the left mantle lobe, several other organs can be seen (Fig. 11). Two paired gills extending along the length of the mussel have both respiratory and food gathering functions. Minute hair-like projections on the gills called cilia move in rhythmic beat and circulate water through the gill filaments. Food particles are entrapped in a mucus, which is then transported to the labial palps (two per paired gill). The palps select out the edible and non-edible matter and pass the selected

Fig. 7. (Upper) Clockwise from upper left, Perna canaliculus, Mytilus edulis aoteanus, Modiolarca impacta and Aulacomya maorianus. (Lower) The upper three mussels are raft cultivated Perna of approximately half the age of the lower three Perna grown inter-tidally.

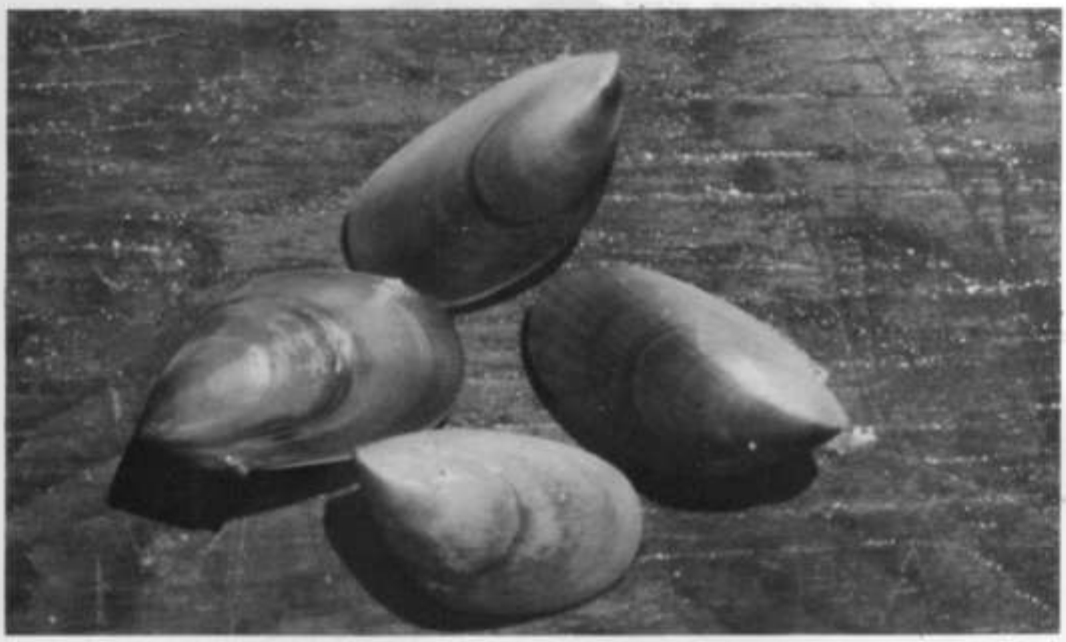


Fig. 8. Shell disturbance rings; note similiar ring on each juvenile mussel.

food to the mouth. The inedible matter discarded by the mussel is termed pseudo-faeces.

The circulation of water as viewed externally is shown in Fig. 9. The anus which is located in the exhalant aperture, releases the faecal matter into the exhalant current.

The foot, sometimes dubbed the tongue, allows mussels to move along surfaces. This movement occurs most significantly when juvenile mussels are seeking permanent attachment niches, and is accomplished by muscular lifting and shifting of the animal, or in the case of early settled mussels, by rhythmic movement along the length of the foot, permitting a snail like gliding movement. Once mussels find a suitable site, the foot also lays down the byssus attachments by injecting a fluid down the foot groove which immediately solidifies on contact with sea water. The foot then lifts away from the newly formed byssus thread. The quantity of byssus laid down varies according to the degree of exposure and the need of the animal to maintain its position.

The mesosoma, an organ lying between the gills posterior to the foot, is attached to the reproductive system and like the mantle lobes seasonally alternates from glycogen storage tissue to reproductive tissue. During the spring months when mussels usually reach their peak 'condition', the mesosoma becomes noticably large and swollen.

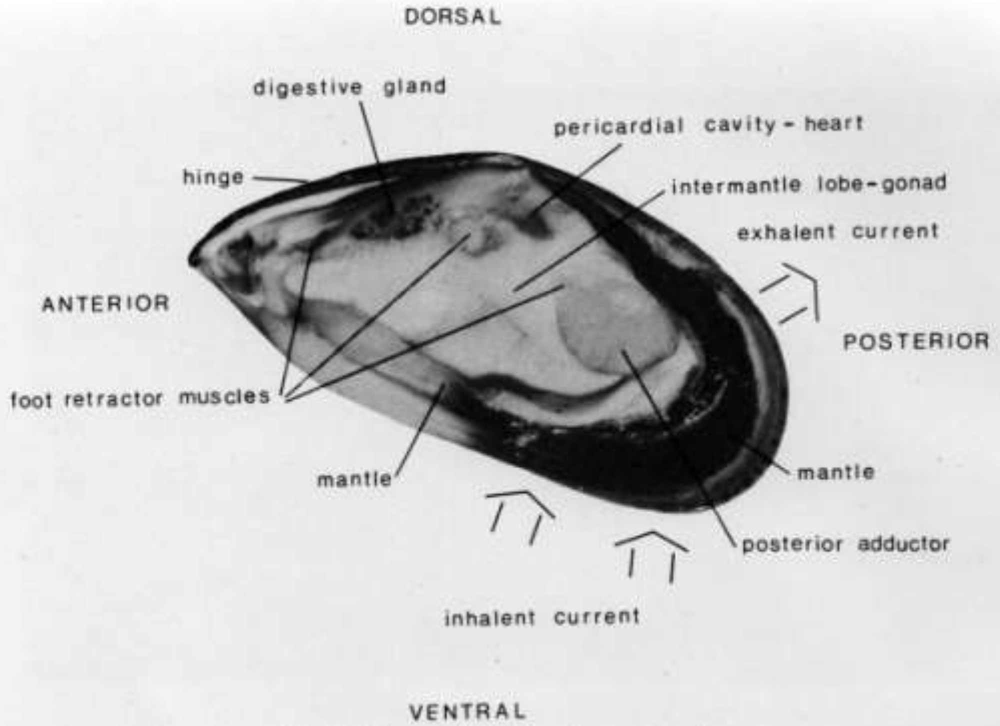
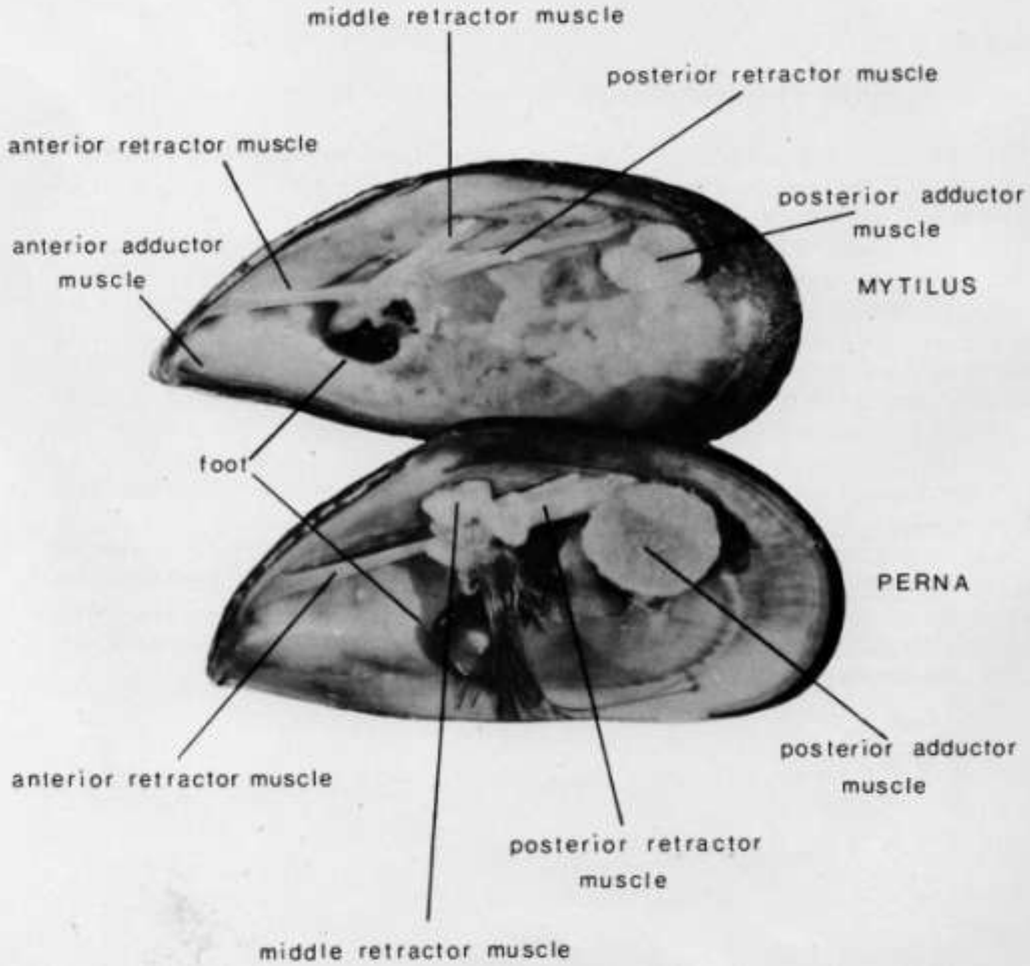


Fig. 9. Perna with left valve removed.



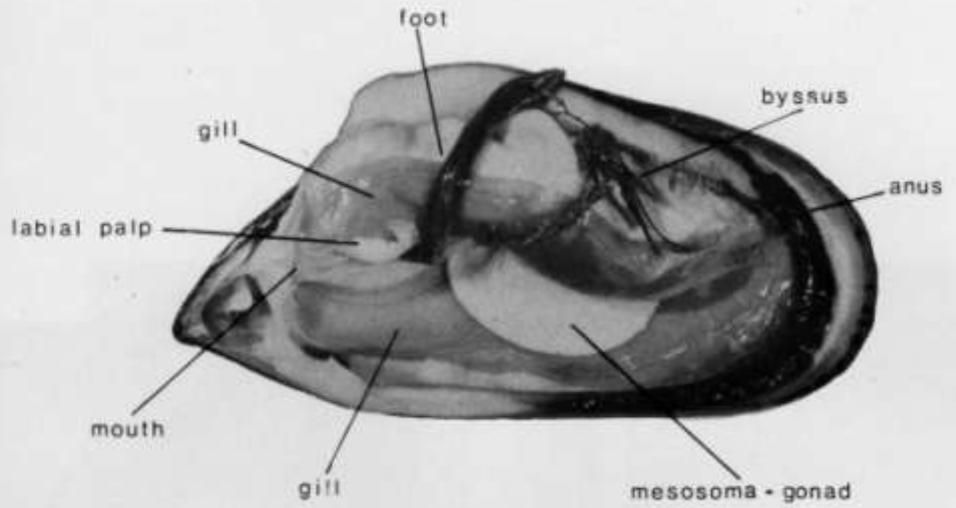


Fig. 11. Perna with left valve and intermantle lobe removed.

MUSSEL BIOLOGY

GROWTH

Mussels have two relatively distinct phases in their life cycle, a free swimming planktonic period or larval stage, and a sessile adult stage. Young developing larvae are seen after egg fertilisation at about 0.1mm and subsequently grow to approximately 0.3mm after 3-5 weeks. At about 0.25-0.3mm, the larvae seek a suitable substrate on which to settle, where final metamorphosis takes place, changing their internal organ structure to the adult form. The young adult then grows rapidly and usually within 4-8 weeks after settlement can be seen at 3-4mm. If the mussels are a late autumn settlement the colder water will inhibit their growth, and they will require a further 4 weeks or so to reach 3-4mm.

The subsequent growth of the 3-4mm spat to the harvestable product is the primary concern of the marine farmer. Here growth can be considered in two aspects, the shell growth and the body growth. The shell length does not necessarily reflect the meat content. In times of spawning or poor food availability, the body can atrophy or waste away while some shell growth continues. Although this variability does not concern the farmer during many months of the year, it is an important consideration during the harvest period.

The overall growth of *Perna* taken as a shell measurement is influenced by many factors, most significantly temperature, salinity, food availability and competition for space.

Fig. 14 shows the growth observed for farm cultivated mussels in the Marlborough Sounds. Length is defined as the anterior dorsal — posterior ventral axis length as shown on Fig. 15. Variability in mussel seeding density on ropes significantly affects the rate of growth, probably as a result of competition for both space and food. At a seeding density of 250 mussels/metre on 16mm diameter rope, *Perna* grows to approximately 70mm in 12 months, and to about 100mm in 18 months.

In contrast at a higher seed density of 725 mussels/metre, in the same time interval the mussels would have grown to 55mm and 85mm respectively.

Changes in the body fullness in mussels are usually seasonal and are primarily related to the sexual cycle, although overcrowding can at times also lower the body

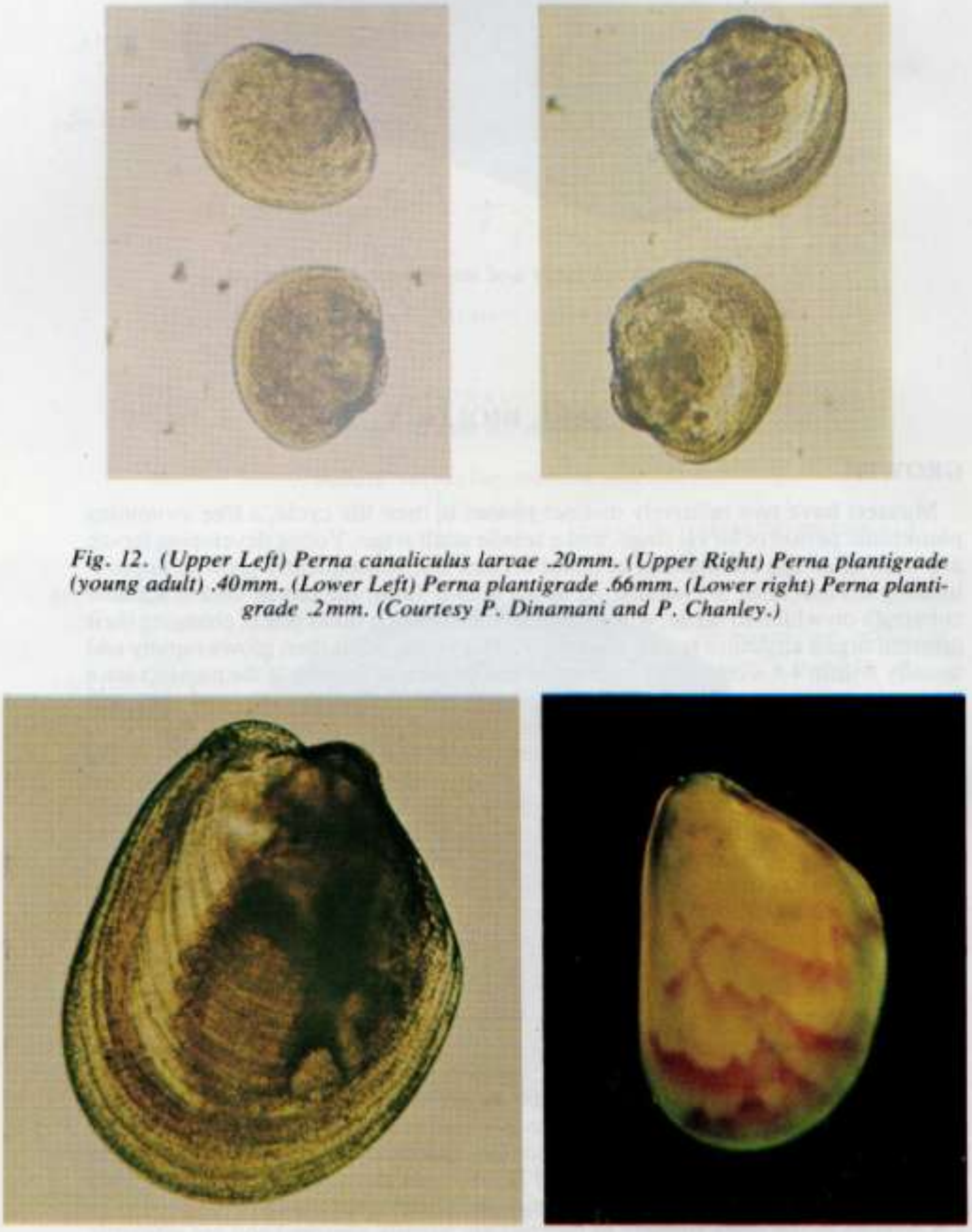


Fig. 12. (Upper Left) Perna canaliculus larvae .20mm. (Upper Right) Perna plantigrade (young adult) .40mm. (Lower Left) Perna plantigrade .66mm. (Lower right) Perna plantigrade .2mm. (Courtesy P. Dinamani and P. Chanley.)

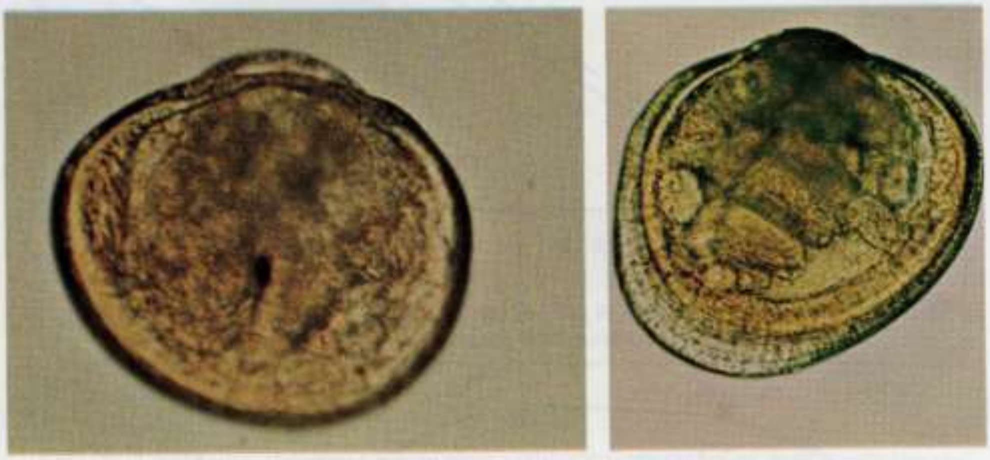
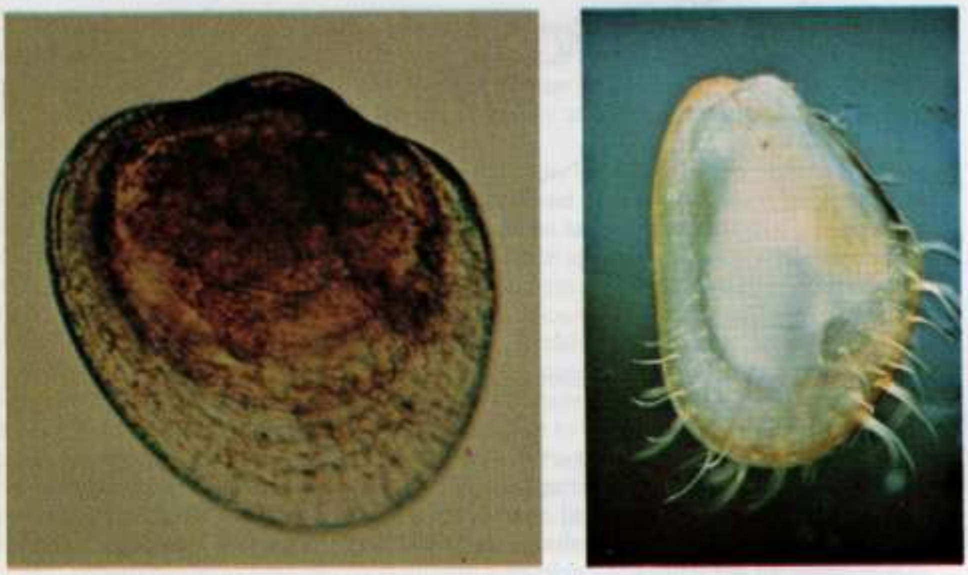


Fig. 13. *(Upper Left) Mytilus edulis aoteanus larvae .28mm. (Upper Right) Mytilus plantigrade (young adult) .31mm. (Lower Left) Mytilus plantigrade .65mm. (Lower Right) Mytilus plantigrade 2mm. (Courtesy P. Dinamani.)*



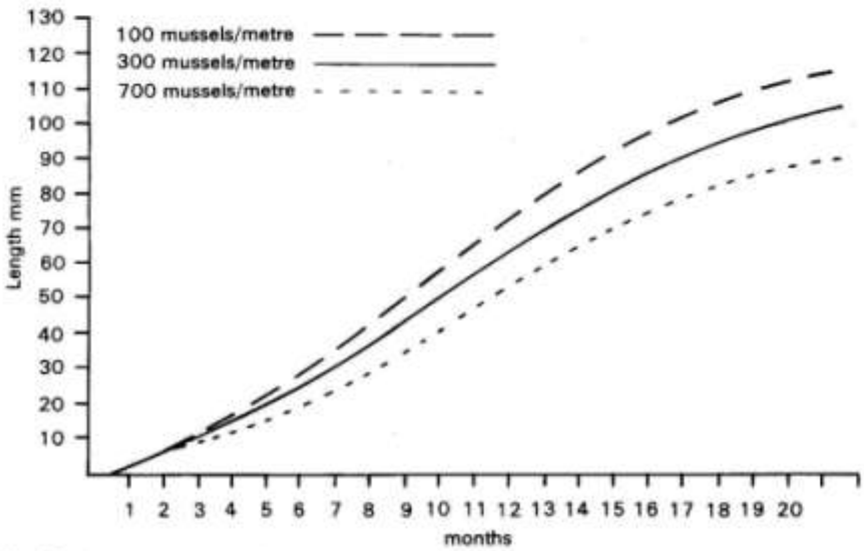


Fig. 14. Approximate shell growth for raft cultivated Perna in the Marlborough Sounds at varying rope seeding densities.

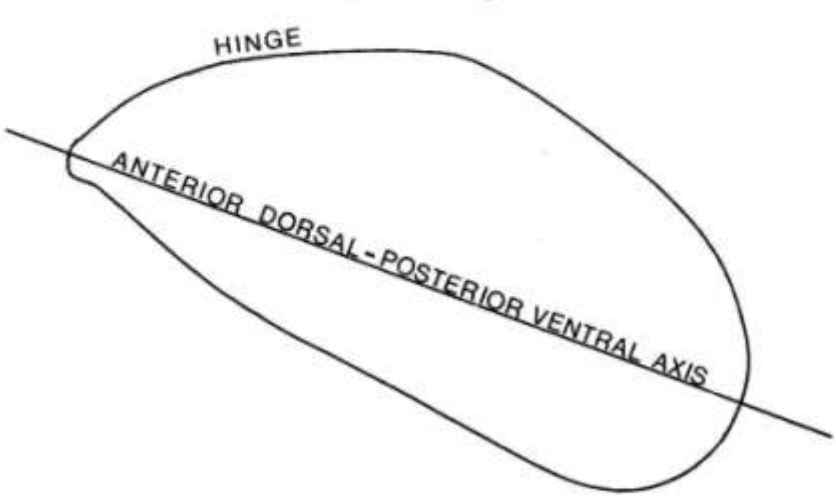


Fig. 15. Anterior dorsal—posterior ventral axis used for length measurement.

fullness. Glycogen, the animal equivalent of starch, accumulates in the gonad tissue in greatest quantities in the winter and spring months, and is then subsequently used up in the production of eggs and sperm. If the food supply of the mussel is inadequate the body fullness is reduced as the mussel uses up its stored glycogen.

An example of the seasonal cycle relating the body volume or more strictly; the proportion of the shell cavity filled by the mussel meat is shown in Fig. 16. Although the sample population as a whole shows a peak of body "fatness" in the spring, and a drop during the summer spawning period, large scale production of mussels in various localities in the Sounds would most likely reveal a much more complex fatness cycle due to local variations in growing conditions.

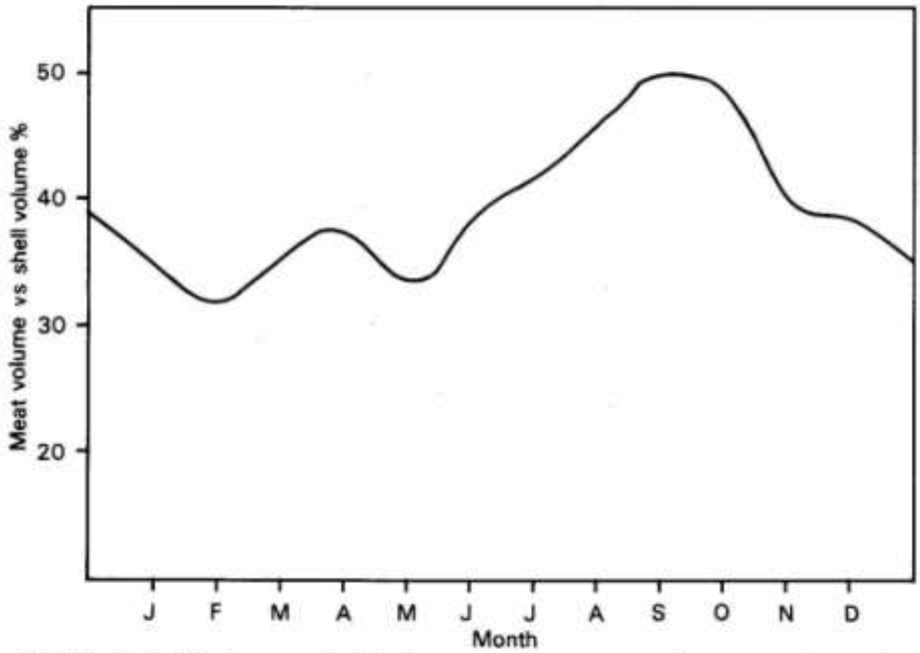


Fig. 16. A simplified seasonal cycle of meat condition represented as meat volume vs shell volume. This will vary from one locality to another and from year to year. (Courtesy D. Flaws.)

REPRODUCTION

The production of eggs and sperm in *Perna* and *Mytilus* is largely temperature dependent and primarily occurs in both species at temperatures above 13°C. The spawning periods from *Perna* and *Mytilus* appear to have a limited overlap, with *Perna* spawning more in the late spring and early autumn, and *Mytilus* in the early spring and early winter.

The sexes in *Perna* and *Mytilus* are separate, although some hermaphrodism (both sexes in the same animal) has been observed in *Mytilus*. The eggs and sperm are released into the open water, and fertilisation takes place externally. The inner mantle tissue of the sexually mature *Perna* male appears creamy white in colour, while that of the female is a reddish apricot, although young sexually immature females are sometimes indistinguishable in colour from males. Sexually mature *Mytilus* males are creamy white while the females are a deep reddish apricot.

Seasonal examination of naturally occurring mussels in the Marlborough Sounds reveals a broad range of sexual development among mussels in any one area. For *Perna*, less than 50 percent of the mussels appear to be sexually ripe even during the peak spawning period, while on the other hand a portion are in a spawning state even during the coldest winter months. Spawning condition is usually maintained in individual mussels for a lengthy period with eggs and sperm being shed for several months.

Sexual development usually occurs within the first year although the quantities of eggs and sperm are considerably less than with older large mussels. Female mussels which are several years old are capable of shedding up to 100 million eggs in a season, with male producing many more sperm.

The stimulus which initiates the release of eggs and sperm in mussels is not known. One theory postulates spawning as occurring at different moon phases as with many marine organisms, and other theories suggest it is caused by abrupt temperature changes, or chemical stimuli.

Little is understood about larval development, behaviour and settlement of New Zealand mussels. The eggs spawned at about 0.05mm are fertilised in the open sea and subsequently develop into D-shaped veliger larvae within 48 hours, exhibiting two complete larval shells, and appearing like a minature cockle. The veliger larvae are capable of locomotion by use of a swimming and feeding organ called a velum and move about at speeds upwards to 80cm per minute. Apart from this minor self locomotion, the larvae are at the mercy of tidal currents and water mass movements for their larval life of 3-6 weeks. Because of the minute size of the larvàe (0.1-0.3mm), it is extremely difficult to determine their net movement through the bays and to identify any behavioural mechanisms which may assist their survival (such as movement to upper estuaries as observed with some oyster species).

Mussel larvae are unlikely to eventually settle on the parent bed of mussels. Some recent studies have found evidence of larvae accumulating in current eddies some distance from their origin, and then being swept away again by a change in weather and wind conditions. The number of larvae remaining from an original spawning which eventually settle and survive among the natural mussel beds would number only a few per million.

Settlement generally occurs when the larvae reach 0.25 to 0.3mm in length. On ropes *Mytilus* larvae have a surface preference when settling, while *Perna* tends to be evenly distributed in depth. Settlement occurs when the larvae find a suitable substrate, usually a filamentous sea weed or possibly the byssus of adult mussels. After a suitable niche has been discovered, the final morphological changes occur, completing the metamorphosis of the larvae to the young adult.

CULTURE METHODS

The cultivation of shellfish has taken various forms in other parts of the world. These include suspended culture from rafts, intertidal racks, and bottom sea culture. Because of the nature of the Marlborough Sounds, the raft cultivation method which is recognised as the most productive, is suited for the conditions.

Suspended cultivation is advantageous because the mussels are constantly maintained in a near ideal habitat with abundant food and little disturbance. The method is basically the securing of raft structures in a licensed or leased area and suspending weighted ropes from the surface on to which the mussels attach. The crop is thus easily accessible for maintenance and harvesting.

The cultivation procedure, as with virtually all farming, requires careful consideration of seasonal and ecological factors. This is to ensure proper seed procurement as well as favourable growth and survival of the developing mussels through to harvest. The seasonal appearances of other marine organisms and changing hydrographic conditions must be taken into account.

The farm cycle is a somewhat fixed sequence of events. Seed procurement has been primarily limited to February-April because fewer problems are encountered in these months (e.g. settlement of fouling organisms). Subsequently farm procedures are timed from this event. Eventually some utilisation of the spring (November/December) settlement may also occur. The following flow diagram summarises the farm procedure, based on autumn seeding, which is discussed in detail in the succeeding chapters.

Fig. 17. Pacific and rock oyster production by the rack method in New Zealand.

Fig. 18. Pacific oyster and scallop production in Japan by the long line method.

FLOW DIAGRAM OF MUSSEL CULTURE OPERATION

Cumulative Time Months	Procedure
0	Seed procurement (February-April)
1-2	Transfer to farm site (March-June)
1-2	Optional: Transfer to net enclosures on farm site or to nursery area depending on extent of predation by fish
4-6	Thin and rebind mussels (July-October)
8-12	Optional: Remove ropes from net enclosures or from nursery area to final growing position (November-March)
8-12	Optional: Part and extend halved ropes (November-March)
10	Prepare new catching ropes (January-February)
13-21	Harvest (April-December)

Throughout the text, production calculations and discussion are based on the growing of *Perna* to 75-115mm in length. Although the New Zealand market has been traditionally supplied with larger picked and dredged *Perna*, the economics of culturing the larger mussels, 115-140mm is not favourable, and large scale production of mussel of this size is not foreseen. There could however be justification in producing some quantities of 115-140mm mussels, in conjunction with the main crop of 75-115mm mussels, without excessive additional costs, by simple float rotation (see chapter — Production).

The culturing methodology, spatfall forecasting and production calculations discussed essentially refer only to *Perna* as the cultivation techniques of *Mytilus* have yet to be developed. It is not however anticipated that the cultivation of *Mytilus* would be any more complicated than the cultivation of *Perna*.

SPATFALL FORECASTING

Relatively accurate spatfall forecasting has been possible in some overseas oyster industries by sampling only the planktonic larvae stages, and from this predicting their subsequent settlement. In particular, this has been very successful with the Pacific oyster in Japan and North America. However, mussel farming industries overseas do not appear to have found it necessary to go to such measures because of an abundance of seed mussels.

New Zealand experience with *Perna* has demonstrated that there is no obvious simple method which is sufficiently reliable to ensure consistent farm seeding. Although both *Perna* and *Mytilus* occur throughout the Sounds, and spatfall is widespread, mussel settlement is most frequently insufficient, or too variable for commercial use. Furthermore, areas which have demonstrated settlement in commercial quantities for several consecutive years, may have only minor settlement in other years.

The spatfall forecasting method employed in the Marlborough Sounds helps to facilitate the process of seed catching. The prime seed catching time usually begins in late February, and for many months prior to this, mussel settlement is constantly monitored in many bays and inlets throughout the Sounds. With this settlement knowledge, in early February the programme is stepped up by routine plankton sampling of the mussel larvae in the more stable settlement areas. Plankton sampling is limited to this time primarily because of the greater difficulty in processing the samples, and the need for frequent sampling at each station. The mussel grower is kept informed of the sampling data through the publication of a weekly spatfall bulletin. He can make seed catching preparations and when decided, can locate his catching ropes in one or several indicated spatting sites.

Mussel Settlement Monitoring

Mussel settlement is monitored by the use of PVC "I" frames (Fig. 19) which are suspended from a small buoy. For monitoring the settlement of *Perna*, collectors are normally suspended at a depth of two metres. However, with the recent interest shown in the cultivation of *Mytilus* and the spring settlement of *Perna*, additional collectors are located in the spring months at depths of one and four metres. There is space within each frame for four catching ropes of 30cm each. Usually only one is attached during the normal seven day sampling period, although, occasionally cumulative settlement information is desired over several weeks and additional sampling ropes are affixed. The sampling ropes are made up of three lays of two ply coir yarn, and when removed are easily separated into the three strands which exposes almost all of the settled mussels. The mussels when agitated in a vessel partially filled with water quickly disattach from the coir, and are subsequently counted with the aid of a dissecting microscope.

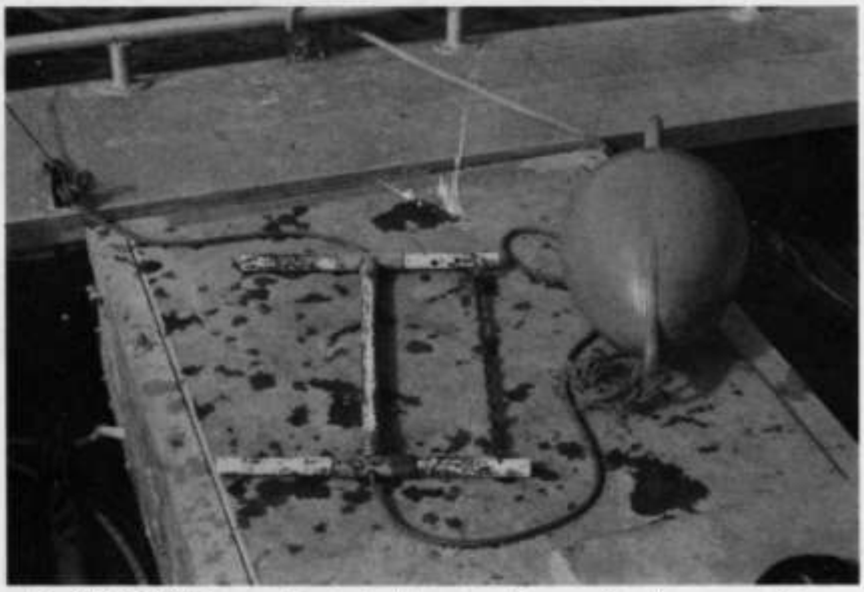


Fig. 19. PVC "I" frame with attached buoy used for mussel settlement sampling.

It is difficult to compare the catching rate of the sample collectors with farm catching ropes to any degree of accuracy, since farm catching ropes vary considerably in types (see cultivation ropes), surface condition, and the way in which they have been handled. Nevertheless, controlled experiments comparing the weekly settlement on the sample collector and the cumulative settlement on polypropylene cultivation ropes have suggested that the sample rope is approximately as efficient as the farm ropes.

Mussel settlement data as observed over three summer seasons at four localities in the Kenepuru Sound, Pelorus Sound and Wet Inlet (Fig. 20) is shown in Fig. 21, 22, 23.

The larvae settlement of *Perna* is highly variable throughout the sampling region although there are similarities between bays of close proximity.

Optimal seed catching has been observed to occur in the latter part of February through March at a time when the water temperatures are falling from the summer high. As temperatures drop from 18-17ºC, rope fouling by competing organisms such as colonial ascidians (see Fouling Organisms) are usually significantly less and seed catching can be organised to substantially avoid these fouling organisms.

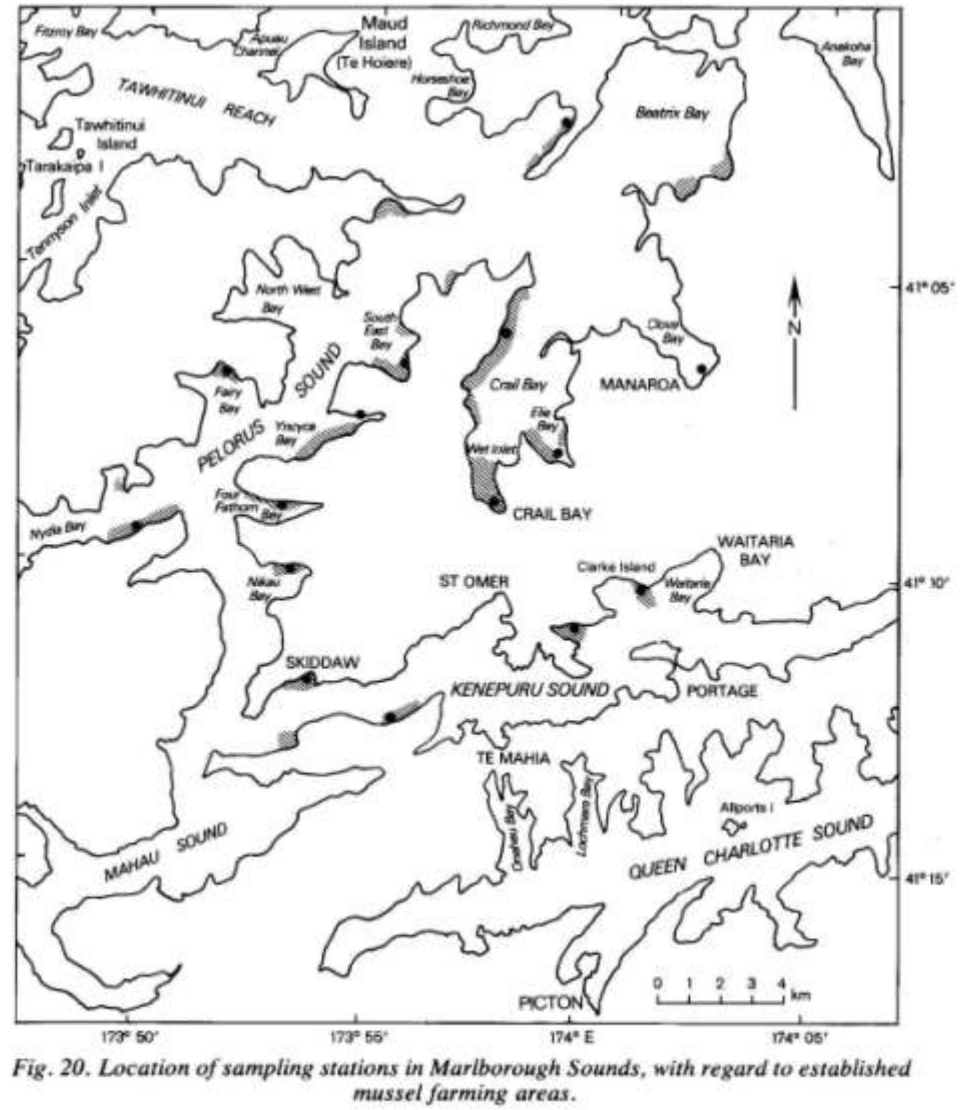


Fig. 20. Location of sampling stations in Marlborough Sounds, with regard to established mussel farming areas.

Commercial seed catches were obtained in February – March – April for the years 1973, 1974, 1975, 1976, 1977 and 1978, although eventual loss of a large proportion of the juvenile mussels resulted in the first three years. These losses were primarily due to fish predation and other factors described later in section "Predation". Mussel protection devices and evasive measures tested with the 1976, 1977 and 1978 seed catch have helped overcome this problem.

A low optimum mussel settlement for commercial use is shown in Fig. 24. This was observed in Waitaria Bay during February – March 1974. The resulting seed catch for all ropes was approximately 300 mussels per metre after taking into consideration moderate predation by fish at the depth lower than one metre. This settlement took place over a period of approximately four weeks, although a similar total catch can result from a shorter but more intense settlement such as occurred in Wet Inlet in March 1975 (Fig. 25). The Wet Inlet catch matured to an estimated 500 mussels per metre.

Very heavy settlement over a four week period as was experienced in March 1976 when the total catch averaged over 20,000 mussels per metre of rope is not necessarily desirable as overcrowding of the catching ropes result. Given sufficient time, the mussels will go through a period of self thinning, but generally smaller and poorer quality mussels result as compared with manually thinned mussels. The early transfer of mussel spat from the catching area, as discussed in "Seed Transfer", can lessen the problem of oversettlement, if the transfer takes place within several days after settlement, instead of 4-6 weeks suggested at times when extremely heavy settlement is encountered.

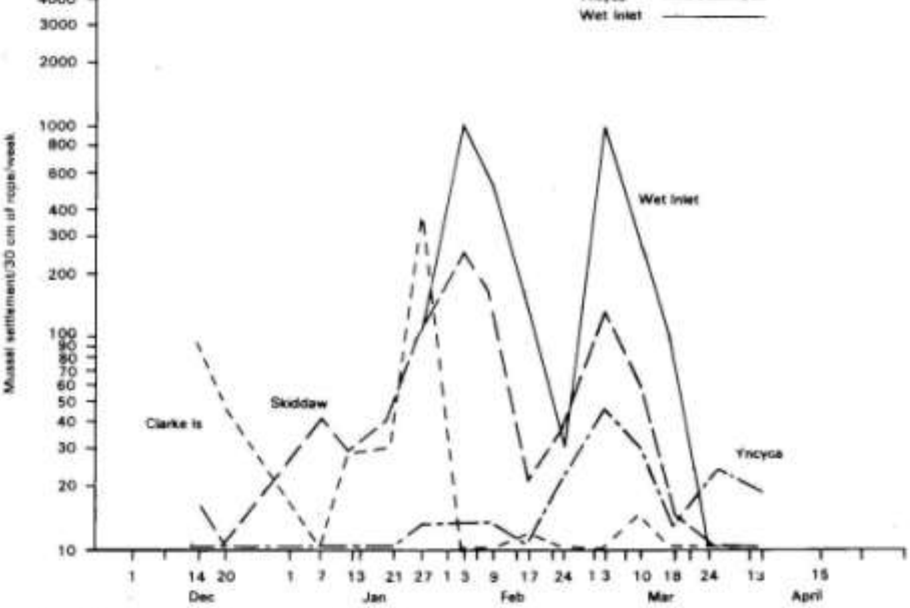


Fig. 21. Mussel settlement per 7 day interval December-April 1974/75 for four localities, inner to outer Sounds.

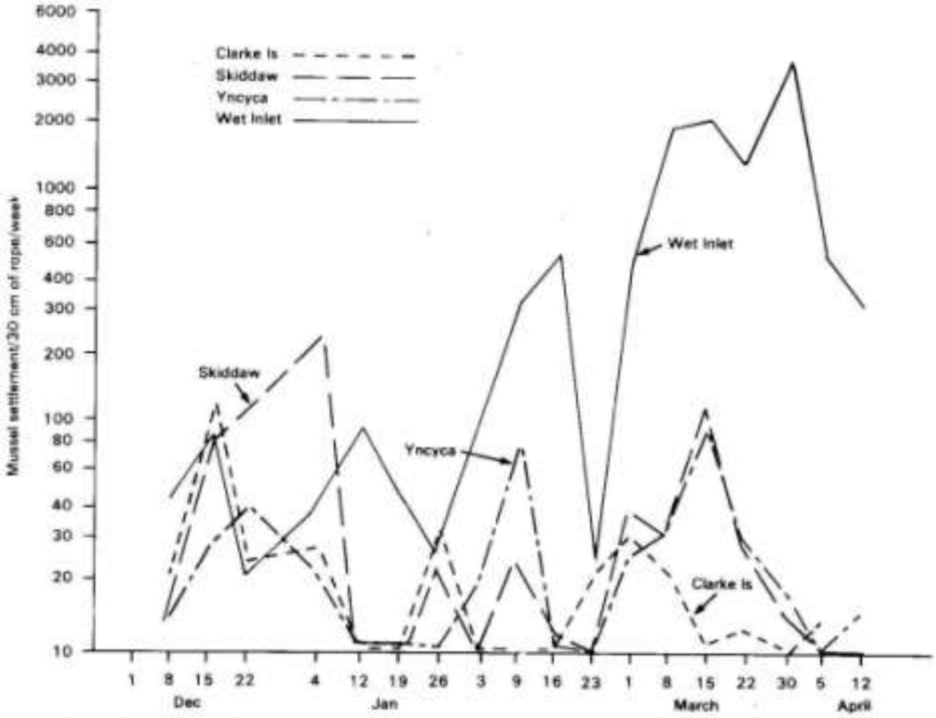
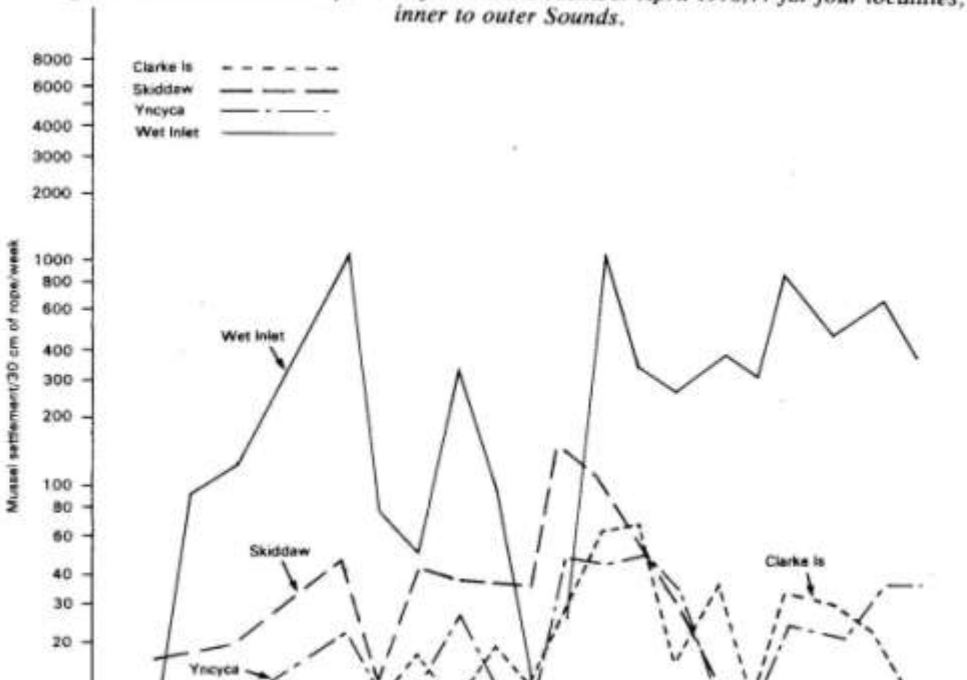


Fig. 22. Mussel settlement per 7 day interval December-April 1975/76 for four localities, inner to outer Sounds.

Fig. 23. Mussel settlement per 7 day interval December-April 1976/77 for four localities, inner to outer Sounds.



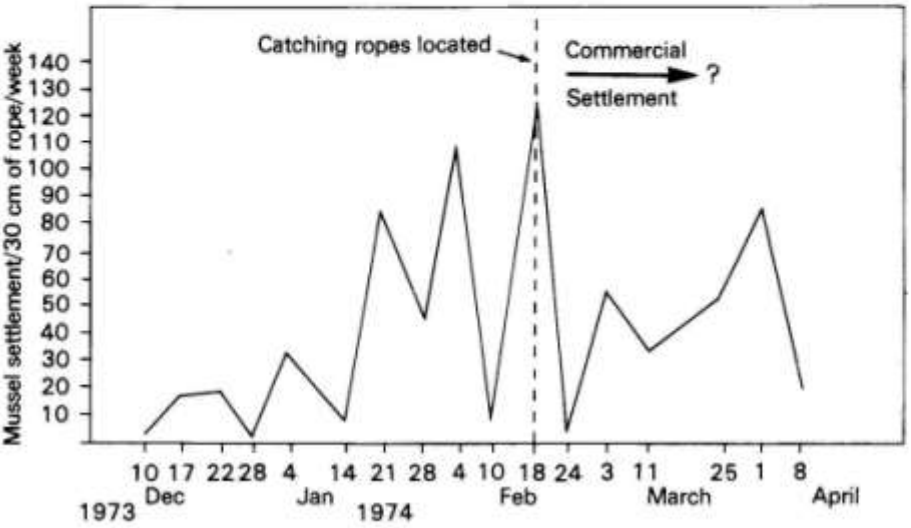


Fig. 24. Mussel settlement in Waitaria Bay with reference to a commercial seed catch obtained.

Fig. 25. Mussel settlement in Wet Inlet with reference to a commercial seed catch.

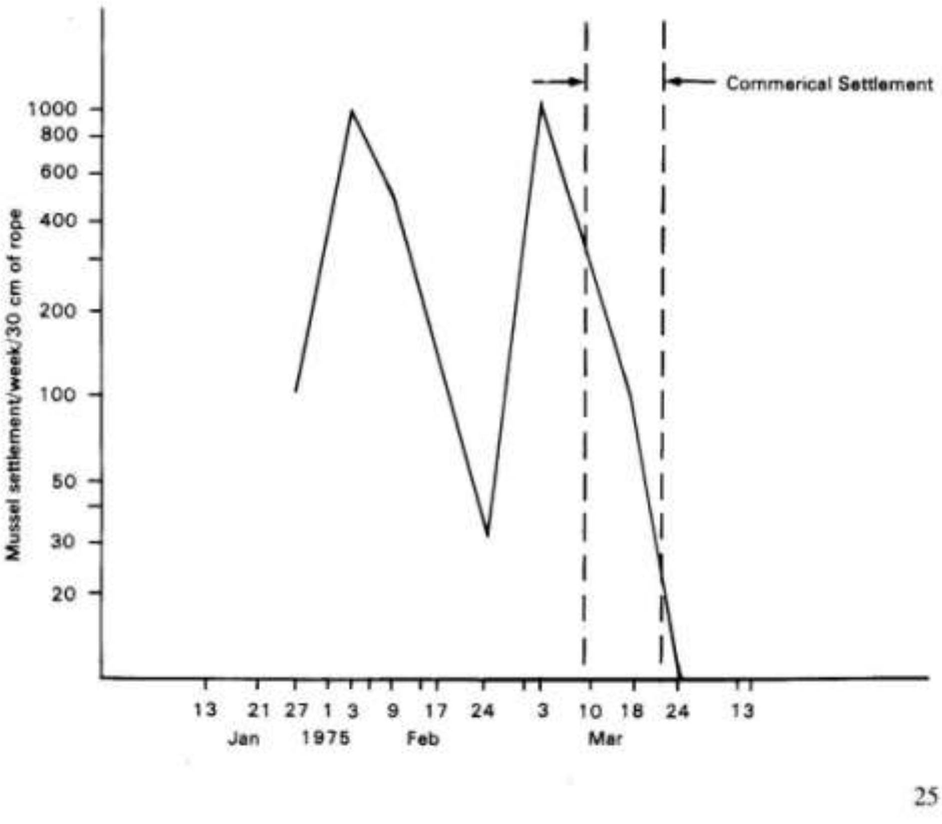


Fig. 26. (Right) Over-settlement needing thinning. (Left) Near optimum seeding. (Note: the ropes are doubled to half their length, and will be parted when risk of fish predation lessens. The left rope with approximately 20mm mussels is seeded at a rate of 300-400 mussels/metre or singularly 150-200/metre.)

Mussel Larvae Monitoring

Although mussel settlement trends are valuable in establishing stable mussel spatfall areas, information is needed about the planktonic larvae which are yet to settle if mussel settlement forecasting is to be effective. This can be done by plankton sampling, and accurately identifying and counting larvae in the growth stages present.

The plankton data however, has little meaning unless the sampling method is valid, with the sample truly representing the larva abundance in the water body sampled. Good results have been obtained with very small mouthed nets (Fig. 27) which can be accurately adjusted, to depths of 10 metres, and which enable a small flow of water to be filtered over distances up to 450 metres (750 litre sample). From earlier studies, the correct depth of sampling depends on the species studied. *Mytilus* larvae are sampled at 1-2 metres from the surface, while *Perna* larvae are generally found at greater stability at 4 metres.

To facilitate analysis, prior to microscopic examination the samples are sieved through 0.25mm, 0.20mm and 0.15mm mesh silkscreen to grade the larvae into four size groupings. Larvae retained on the 0.25mm sieve are settling size (SS); early settling size (ESS), are retained on the 0.20mm screen; early eyed (EE), are retained on the 0.15mm screen; and late umbo (LU), pass through the 0.15mm sieve, and are the earliest stage identifiable to any degree of accuracy. D-hinge and early umbo stages have not been considered, because of the difficulty of identification, and also

Fig. 27. Plankton net used for transect mussel larvae sampling. The lead weight maintains the net's depth position.

because their identification has less significance in predicting spatfall. SS larvae and to a lesser extent ESS larvae contribute to a particular spatfall near the time of sampling.

An example of the fluctuations experienced in Crail Bay, a repeatedly successful spat catching area, is shown in Fig. 28. Changes in wind direction in this area dramatically affect larvae abundance. As shown through three seven day sampling periods, mussel settlement appears to range from high and low daily settlement, and any one plankton sample does not necessarily relate to the overall weekly settlement.

Disproportionately high numbers of settling sized larvae are found, compared to younger larvae in the earlier counts, from which the later larvae supposedly originate. There is thus little evidence as to where the advanced stage larvae were originally spawned. It appears that either older larvae spawned in Crail Bay hold over and are joined up with later spawned larvae which all subsequently settle as the result of some stimulus, or alternatively such areas as Crail Bay have peculiar hydrological features causing larvae spawned over a much larger area to accumulate there because of wind conditions and/or tidal currents.

If the waters in the Sounds were static, mussel settlement could probably be relatively easily correlated with larvae numbers, but as the waters are not static, there is little attempt to precisely relate the observed larval numbers to the observed settlement. However, as a general observation, when the advanced stage larvae numbers (SS and ESS combined) are repeatedly less than 25 per 750 litre sample, a

Date	Time	Wind	Tide	*Larvae size distribution* LU	EE	ESS	SS	Settlement /week
13-2-77	16:15	S 0-5	.8+N	27	21	1	0	
13-2-77	"	"	"	37	55	3	2	
13-2-77	17:15	"	1.0 N	379	270	11	2	
13-2-77	"	"	"	161	340	3	1	
15-2-77	13:45	N 10-20	0	0	0	0	0	
16-2-77	15:15	N 8-10	.1+	0	16	12	0	
16-2-77	"	"	.1+	3	18	5	3	(14-21 Feb) 75/metre
21-2-77	14:15	N 10-15	.4–	0	0	5	2	
21-2-77	"	"	.4–	0	0	1	0	
23-2-77	10:20	S 10-20	.6+	63	65	64	19	
23-2-77	"	"	.6+	24	122	164	13	
24-2-77	12:30	S 5-10	.8+	19	20	35	11	
24-2-77	15:00	"	.3–	82	476	693	141	
27-2-77	12:20	N 15	.4+	0	1	13	21	(21-28 Feb) 3000/metre
27-2-77	12:40	"	.4+	0	4	11	7	
28-2-77	17:15	N 15-20	1.0 N	1	15	6	2	
28-2-77	17:30	"	1.0 N	2	7	2	7	
2-3-77	13:15	S 5-10	0	0	10	15	24	
2-3-77	15:00	"	.3+	0	6	29	60	
2-3-77	16:00	"	.4+	2	23	57	120	
3-3-77	16:45	Variable	.4+	0	8	20	32	
3-3-77	18:20	"	.6+	0	7	20	81	(28 Feb- 7 March) 1000/metre
5-3-77	11:20	N 5-8	.8–	0	17	26	49	
5-3-77	11:45	"	.7–	2	5	26	39	
7-3-77	10:20	N 10-15	1.0 S	0	1	9	42	
7-3-77	12:15	N 10-15	.7–S	0	2	3	16	

Note: *Wind approx. in Kts.*
Tide: 1.0 = high; 0 = low;
+ = flood; – = ebb;
N = Neaps; S = Springs

LU = Late umbo; not settling.
EE = Early eyed; not settling.
ESS = Early settling size.
SS = Settling size.

Fig. 28. Plankton data for Wet Inlet 13 February — 7 March 1977 with regard to wind, tides and weekly larvae settlement on ropes. (Note: the build up of Perna larvae during times of southerly wind and the resulting decline of larvae during northerly weather.

less than commercial settlement results (less than 150 mussels/metre of rope per week). When the advanced stage larvae numbers regularly exceed 25 per 750 litre sample, and the wind and water conditions remain relatively stable, then a commercial settlement usually results.

HATCHERY SEED PRODUCTION

The feasibility of hatcheries for the artificial propagation of commercially valuable shellfish was demonstrated in the early 1950's. Commercial application of the principle developed somewhat later, around the mid 1960's, primarily for oyster seed production on the East Coast of America and the United Kingdom. Hatcheries have been developed in Japan in recent years for the seed production of scallops and abalone.

No hatcheries for the production of mussel seed on a commercial basis presently exist. This is primarily because of an abundance of seed mussels in the regions where intensive cultivation is practised. There could however be a case developed for the artificial production of mussel seed in New Zealand if natural seed sources prove inadequate. This is assuming the economics of mussel farming justifies moderate seed costs, as hatchery produced seed would be comparatively expensive.

Hatchery produced seed could have the following advantages over natural seed:—

1. Constant availability, thus stabilising production and marketing.
2. Optimum seed availability relative to seasons to maximise juvenile mussel survival.
3. Permitting farm seeding at chosen intervals to broaden harvest time in regard to mussel size.
4. Selective breeding — to produce disease resistant mussel strains during time of persistent disease problems.

Investigations are presently being undertaken by Ministry of Agriculture and Fisheries scientists to evaluate the concept of a mussel hatchery under New Zealand conditions. The hatchery will also be used for research into larval and juvenile mussel biology and their relationship to practical field problems.

BEACH TRANSFERRED SEED MUSSELS

Both commercial mussel types, particularly *Perna*, appear in dense settlements on natural substrates such as shoreline rocks or seaweed, and may be used for farm seeding. Occasionally in the spring months in several North Island West Coast localities, most notably near Kaitaia, seaweed (Fig. 29), which has washed up on the beaches has contained as many as 50,000 juvenile *Perna* per 100 grams. This seaweed with its attached mussels has been successfully transported by air to the Marlborough Sounds where it is bound on the farm culture ropes using "netlon" tube, Spanish binding material or the knitted tube (see Thinning and Binding). Although it is impossible to predict when or where this seed will be available, when it does appear, it is an attractive farm seed supplement.

Sightings of large quantities of juvenile mussels, under one centimetre in size, are not frequent in the Marlborough Sounds. Recruitment to the established beds of *Perna* and *Mytilus* appear to be primarily by larval settlement amongst filamentous seaweed, and adult byssus attachments, and not by dense settlement on rock faces. A limited seed source may exist however, by rebinding on to ropes young mussels which are a by-product of shore picking large mussels for market. This process could prove to be destructive in some instances by limiting natural recruitment and conservation should be practised.

Fig. 29. Seaweed with attached juvenile mussels. (Courtesy of R. W. Hickman.)

SEED CATCHING PROCEDURE

Communal Long Lines

With the introduction of an industry oriented spatfall forecasting programme, a need arose for the organisation of raft space for seed catching. This was to avoid an almost unmanageable situation with the siting of several spat rafts from each farm unit in the forecasted catching area. The Fishing Industry Board adopted the concept of providing communal long lines and on which mussel growers could lease one or more 3 metre sections for their catching ropes. It is expected however, in the long term that the communal spat lines will be established and controlled by the industry. Applications for spat catching space are made about mid-January for the February–April settlement.

The communal long lines are located at the discretion of the Fishing Industry Board (but with the approval of the Harbour Board) in the area or areas most likely to produce a commercial spatfall. Farmers are still free to make application to the controlling authorities (Harbour Board) to site individual spat rafts.

Rope Placement for Seed Catching

The choice of cultivation ropes and procedures for rope preparation are discussed in "Cultivation Ropes".

Once a spatfall has been forecasted, rope laying must begin shortly after and early preparations are therefore necessary. It has been demonstrated that joining ropes into bundles or any other method which eliminates single rope handling, expedites rope laying. Ropes joined into bundles of 5-10 ropes each, have the added advantage of lessening the bottom concrete weight requirements and so reduce the overall weight and bulk of the ropes during spat catching and the later transfer to the farm site. It must be emphasised however, that rope bundles must be separated into single ropes within 4-8 weeks of the settlement to prevent the mussels migrating outwards and vacating the inner ropes. It is best to separate the ropes at the time of transfer, and this is discussed in the section "Seed Transfer".

As discussed in section "Fouling Organisms", mussel settlement is highly susceptible to competing fouling organisms, which apparently cause an off migration of the newly settled spat. Since forecasting techniques are not sufficiently advanced to also forecast the settlement of these fouling organisms, the general rule is, to attempt to select the latest occurring mussel spatfall. The problem is however, that in some years the spatfall may cease by mid or late March while in other years spatfall may continue well into May.

Mussel growers may therefore find it in their best interests to consider laying catching ropes throughout February, March and April so as not to rely entirely on any one particular spatfall. Ropes could be laid on a schedule, say fortnightly, or at times suggested by the spatfall forecasting programme. Since the seed catches obtained in April generally prove to be free of fouling organisms, growers may reserve half or more of their ropes for this month, with the remainder being laid through late February and March.

As earlier discussed in section "Mussel Biology" *Mytilus* larvae have a surface settlement preference while *Perna* settlement is evenly distributed to depth. Where only a *Perna* catch is desired during the spring or late autumn months when also the spawning of *Mytilus* occurs, catching ropes should be lowered below 2 metres from the surface to avoid the settlement of *Mytilus* on the ropes. Likewise if a predominately *Mytilus* catch is desired ropes should be contained in the topmost 2 metres of the water column.

In the event that earlier placed ropes have insufficient settlement, or fouling organisms are forcing spat to leave the ropes, ropes can be renewed for catching by several methods. The ropes must be removed from the water and reconditioned to assure a complete kill off of all marine growth which has earlier settled on the ropes.

This can be done by air drying for 2-4 days (Fig. 30) or by washing in fresh water such as a stream for 24-48 hours, or by scalding the ropes, which can be accomplished by heating a barrel of water on the beach and immersing the ropes for 30 seconds or so. Once the kill off is assured, the ropes are then ready for re-catching. Some growers have also found a good inexpensive back up is to lay bundles of coir yarn and/or frames wrapped with fibrillated film (Fig. 31). Once the coir or fibrillated film has caught mussels, the coir or film is wrapped around culture ropes or the mussels are grown to sufficient size to be later stripped and bound on culture ropes using the available binding materials.

Fig. 30. Frame used for drying fouled spat catching ropes. The floats are located 70cm from the section ends. One frame may service a number of 3 metre sections. One float accompanies the frame, while only one float is needed for flotation per section. Dimensions 290cm x 130cm.

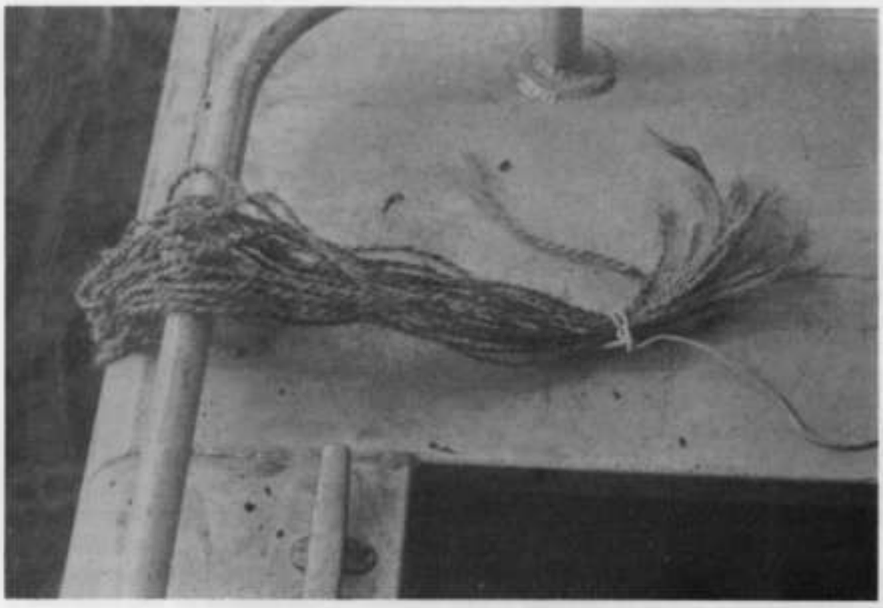
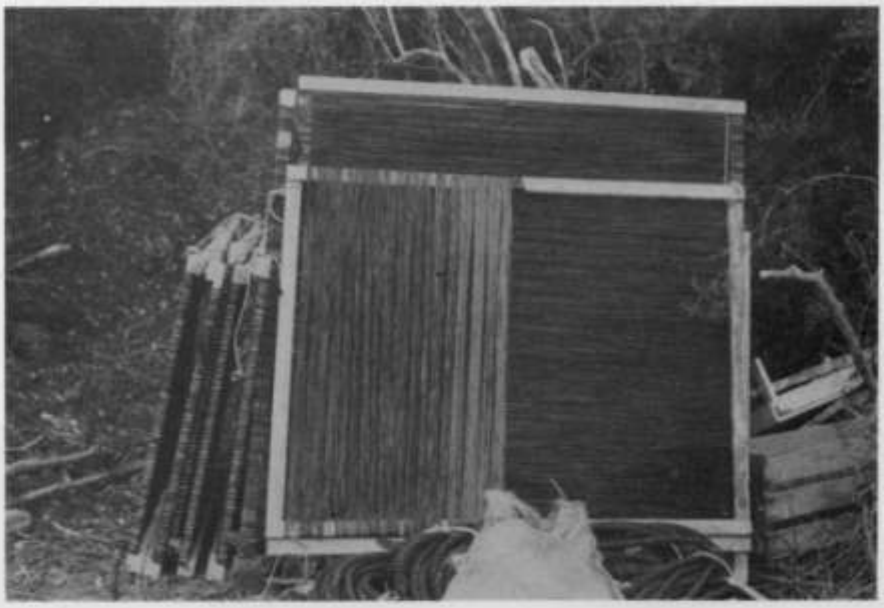


Fig. 31. (Top) Coir bundles. (Bottom) Fibrillated polyropylene film wound on frames.



SEED HANDLING AND MAINTENANCE

Seed Transfer

Farmers making use of the spatfall forecasting programme will in most circumstances need to travel some distance to obtain seed and will subsequently have to transfer the mussel culture ropes with the newly attached seed mussels from the catching area to the farm site or in some cases to a nursery area.

Satisfactory transfer of seed mussels has been achieved with mussels less than 1mm in size (i.e. 4-8 weeks after spatfall). A later transfer with larger mussels (3-20mm) is usually more difficult because of the tendency of the mussels to become detached from the ropes. At even later stages (when the mussel is greater than 20mm in size), the bulk and weight of the mussels make transfer difficult and costly.

The ropes can be safely removed from the water and placed in an open boat, but it is recommended that moistened damp sacks or polyethylene sheet is placed over the ropes in transit, to minimise dehydration. The transit time should probably not exceed twelve hours, although if held cool and moist mussels can survive out of water upwards for 48 hours.

Rope samples can be analysed microscopically for settlement before and after a transfer. As most farmers will not have access to a microscope, this can be done by the regional biologist.

If ropes are joined in bundles during catching, rope bundles will probably need to be separated into individual ropes about 4-8 weeks after spatfall. Both seed transfer and rope separation can therefore be accomplished in the same operation.

To facilitate rope handling through the first 6-10 months and to lessen mussel loss by fish as discussed in the following section, the ropes may be shortened by looping the bottom end to the surface. *The bottom rope end is then secured to the upper rope end with coir yarn or synthetic fibre cord which permits the easy parting of the doubled rope at a later date. It is also easier and quicker to rebind mussels on to the shortened double ropes. The cultivation ropes may be doubled prior to locating for spat catching which would lessen the work load at the time of transfer to the farm.

Predation

Suspended raft culture by its nature removes the mussels from one primary predator, starfish, into possibly an even more precarious position by unnaturally exposing the mussels to increased fish predation.

Two local fish species, snapper *Chrysophrys auratus* and spotty *Pseudolabrus celidotus* (Fig. 32) are known to feed on mussels, in particular cultivated mussels, although other fish species may also impose some problem to marine farmers.

Losses due to predation by fish are a serious problem for many developing marine farms, especially those located in shallow waters and with little tidal flow. The mussels appear to be most susceptible to predation from the time they appear visually on the ropes (3mm) to upwards of 80-90mm, (i.e. through most of their first year).

Predation can however, be selective. Mussels escaping early predation and stabilising their position on the rope will suffer little predation in comparison, while mussels of the identical size which have been hand seeded or otherwise transferred will experience high predation. Also, losses are generally less severe the greater the distance the mussels are from the sea bed, with usually fewer problems near the water surface (Fig. 33). Shallow sites, having less than 5 metres at MLLW, have generally shown greater problems with fish. These sites have sometimes suffered mussel loss of 100 percent with the mussels being consumed right to the water surface. Deeper sites have shown relatively fewer problems.

* Not recommended for soft lay ropes which may twist resulting from the pull of concrete weights which make for difficult parting.

Fig. 32. The smaller spotty as well as the larger snapper are known to feed on mussels.

Fig. 33. Rope showing lower section lost to fish predation.

The two problem fish species, spotty and snapper, appear to some extent to be specific in their feeding habits. The spotties, usually less than 20cm in length appear to predate on mussels not exceeding 40mm or so, while snapper upwards of 75cm in length, appear to feed predominantly on large mussels, sometimes even those over 90mm. Juvenile snapper may however predate on mussels similar in size to those fed on by spotties, although it is thought they frequent the mussel lines much less than spotties. As snapper are essentially a migrating fish, except for the few winter residing adults, they are predominantly a summer problem while spotties stay more or less in residence and can be a persistent problem throughout the year.

Mussel growers are advised to be cautious about transferring young seed mussels to their farms, especially when the young mussels are to be placed amongst an existing crop. A newly established marine farm will tend to have minimal fish problems through the first cycle but in subsequent years the problem can become more serious with the increasing farming activity.

When fish predation does become persistent the grower has several procedures to help overcome the problem. These include;

(a) Lift the seed mussels closer to the surface away from the sea bed:

This can be accomplished by halving the mussel culture ropes by looping the bottom to the top. With long lines the halved ropes can be made even more shallow by tying the bottom looped end across to the opposite main line (Fig. 34). If the procedure is effective then the ropes are cautiously lowered to their full length some time between October through March.

(b) Isolate the seed mussels from the existing crop on a separate long line or raft on the outside extremity of the licence:

Since most farms require a spat hold-over long line or raft because of the two crop overlap, predation losses may be kept at a low level by locating the hold-over longline or raft away from the main crop. Once the seed mussels are able to be transferred to the main lines or rafts, it is best to remove the hold-over structure to avoid a permanent fish build-up in the area.

(c) Locate the seed mussels on nursery sites known to be free of fish problems:

These could be identified by the regional farm advisor and held exclusively for the industry as nursery areas. Once the mussels reach a suitable transferable size as determined by trial transfers, the mussel ropes can be relocated back to the farms. As in the preceding, the nursery areas would best be cleared of long lines or rafts in the off season to avoid the chance of a gradual fish build up.

(d) Use nets to protect the seed mussels:

Nets attached to small hold-over rafts or to long lines (Fig. 34) effectively protect the young mussels but also present some problems. Even with routine cleaning, nets restrict the flow of water to the mussels within the net. This can unsettle the mussels causing their migration upwards on the ropes or can eventually cause them to detach altogether. Fewer problems are encountered if rope densities within these nets are maintained at a moderately low level and mesh sizes are increased in proportion to the size increase of the mussels. Once the mussels are large enough and the fish no longer pose a threat as found by trial transfers to the main long lines or rafts either the nets are removed or the mussel ropes are transferred to their final growing position.

(e) Fish out the problem fish species from the licence area:

This may be regarded as the ultimate solution although it is not known how practical such an undertaking would be. From trials, pots (Fig. 35) have been found to be effective in catching spotties while set nets and set lines are known to be effective in catching snapper.

Fig. 34. Seeded ropes doubled then tied to opposite side within an attached net.

With encouraged commercial and sports fishing adjacent to marine farms in conjunction with the farmers catching efforts, it may be possible to maintain fish population in these areas at tolerable levels such that normal marine farm activities can be carried out with only nominal losses due to fish.

Fig. 35. Fish pot used for catching spotties.

Thinning and Binding

Unfortunately natural mussel settlement on culture ropes is frequently not ideal in numbers per metre nor consistent along the length of the rope, or from rope to rope. Sometimes it is desirable to redistribute the mussels to obtain a more even distribution, or to intentionally adjust and alter seeding densities to manipulate production and harvest times (see sections "Growth and Production"). Seed rebinding is costly in labour and material and the cost benefit should be examined in each instance before it is undertaken.

Excessive mussel settlement densities are possible. These will impede mussel growth and fatness, and in turn will extend the time required to obtain a marketable sized mussel. Simple thinning in which surplus mussels are discarded is in this case straight forward. It is definitely much less labour intensive to catch a full complement of ropes and discard surplus mussels than to rebind mussels. Perhaps in the initial development stages the rebinding of surplus seed mussels can be justified when a mussel grower is cautiously considering expenditure for ropes, floats, etc.

Rope seeding falls within a broad acceptable range. Seeding densities less than 100 mussels per metre (harvest count) will probably be marginally economic but will obtain rapid growth, while seeding densities over 700 mussels per metre produce high yields but require extended culturing periods. With experience, each farmer will be able to determine the seeding densities best suited to his culturing schedule.

While the process of thinning alone can be carried out early when the mussels are less than 10mm (2-3 months), some additional growth is required for the rebinding operation, between 15-30mm (4-6 months).

Several types of binding materials have been in use in New Zealand. These have included a Spanish material and a New Zealand made plastic mesh tube (Fig. 36, 37). Up to the present, neither has had a clear advantage over the other and use has been largely determined by personal preference.

However, a new product has appeared which combines the favourable characteristics of both the Spanish and plastic tube materials and is likely to supersede

Fig. 36. Spanish binding material being applied with use of a holding trough.

their use. This is a knitted tube which is easy to apply like the plastic mesh, but also is a one step process like the Spanish material and rots away in a week or so. Using a plastic or stainless steel tube, (Fig. 38) the fabric is fed from the outside of the tube to the rope which passes through the tube. In this way the mussels are fed in at the top and as the rope and binding material are pulled through, the mussels become firmly bound. It is important that tension is maintained on the binding material to prevent the development of large bulges. The ends may be secured with string ties or wire twists. As discussed earlier, some advantage has been found in doubling the ropes which halves the rope length and saves on binding material. The cotton tube is available in several sizes, to accommodate the various sizes of mussels to be bound.

The Spanish binding material is applied as shown in Fig. 36 with the rope stretched horizontally between two posts. One 200m spool will cover approximately 30-40 metres of culture rope. To facilitate the binding process a shallow box holding the separated mussels is located under the rope extending the full rope length (in the photo, 2m as the ropes are halved). The Spanish material is a one step process where the mussels work their way through the net weave, avoiding the need for its later removal.

The plastic net tube which has been used has the trade name of "Netlon". It is applied in the same manner as the cotton tube, but after several days it must be removed as the mussels are incapable of breaking through the mesh.

Whatever type of rebinding material is used, mussels need to be separated into singles or small clumps. This improves reattachment to the rope surface as mussels in their original clumps frequently poorly reattach. Separation may be accomplished by hand or by a simple declumping apparatus shown in Fig. 40.

Fig. 37. Plastic "netlon" sock being applied with funnelled tube.

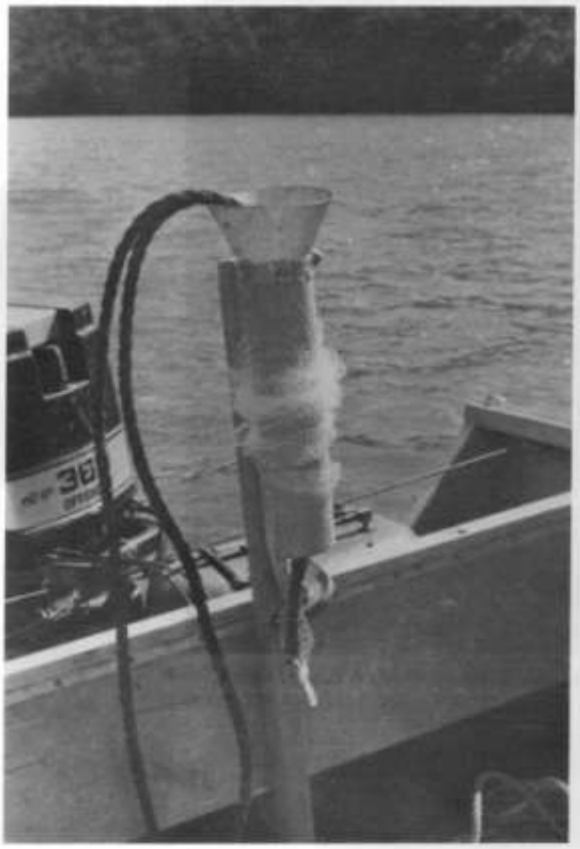


Fig. 38. Mussels being bound with knitted sock with inverted tube mounted through a holding tray.

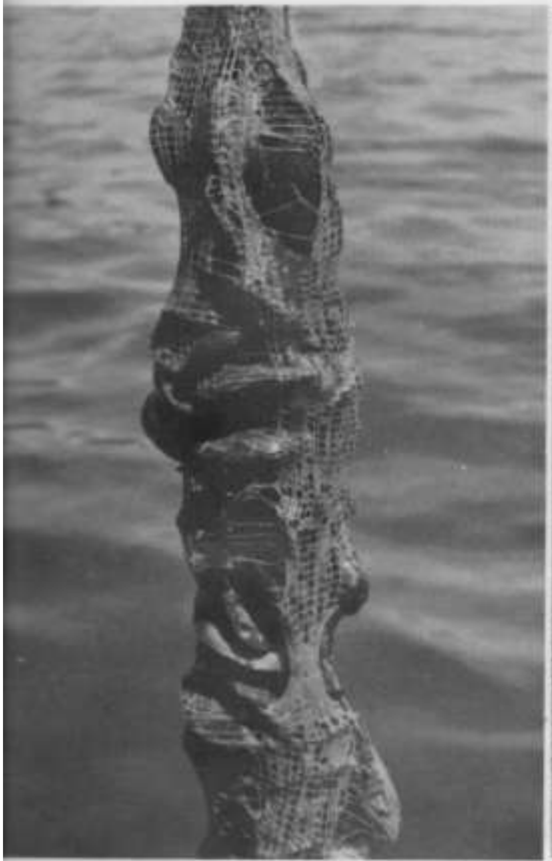
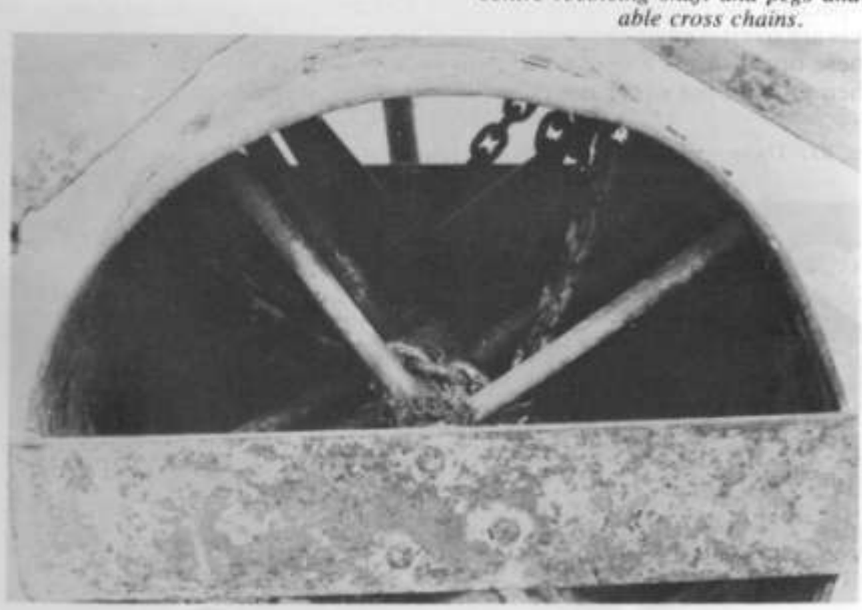


Fig. 39. Mussels breaking through knitted sock after 1-2 weeks.

Fig. 40. (Above Right) Hand powered declumping apparatus. (Below) Close up of centre revolving shaft and pegs and adjustable cross chains.



FOULING ORGANISMS

As the mussel culture ropes are constantly submerged they are susceptible to settlement by other marine organisms which may or may not interfere with the mussel crop.

As a rule once the mussels attain a size of about 25mm little difficulty is encountered with settling organisms, other than shell surface fouling. There are however two relatively critical periods, the interval between the placing of the catching ropes and the mussel spatfall when a rope surface fouling can interfere with mussel settlement, and the period immediately following the mussel spatfall when fouling organisms can compete with the newly settled mussels.

It has been observed that the surface of mussel ropes, especially coir or coir wrapped, deteriorate with time, and within about three weeks of being submerged offer little attraction to settling mussels. Whereas the maintenance of newly settled mussels on ropes is more of a seasonal problem, seed catching appears to be affected at almost any time of the year if the ropes are placed in position too early. As discussed in "Mussel Spatfall Forecasting", accurate spatfall forecasting followed up with prompt rope laying can minimise pre-spatting interference by settling organisms. (Note: rope surface condition can be renewed for spat catching, see section "Rope Placement for Spat Catching".)

The fouling of the catching ropes during or after the mussel spatfall, can result in a total seed catch loss. It is not understood what exactly happens or what organism or organisms are responsible, but there is some evidence to suggest that the mussels detach from the rope rather than the losses being due to mass mortality.

Although little difference is observed between regions or from the inner Sounds to the outer Sounds, the losses do occur more dramatically in the warmer summer months, usually from December to March. For this reason, industry spat catching is co-ordinated with the latest occurring spatfall, preferably that settling in March and April, although because of difficulties encountered occasionally even in these months, close adherence to the spatfall forecasting programme is essential.

More obvious competitors which are often found on mussel ropes include solitary and colonial ascidians, barnacles and hydroids (Fig. 41, 42, 43). Mussels are often seen partially or wholly overgrown by an ascidian colony, or amongst thick mats of hydroids. Space competition by these more obvious fouling organisms, especially the colonial ascidians, further limits summer spat catching, as the mussels are overtaken by their rapid proliferation. A later settlement in the autumn by these organisms is less of a problem, probably due to the colder water inhibiting their growth, but which does not so significantly slow the growth of the mussels.

Fig. 41. There is evidence the settlement of solitary ascidians (adult shown) on the mussel culture ropes encourages the off migration of mussel spat.

Fig. 42. (Lower) Colonial ascidians overtaking 8-10mm spat. (Right) Barnacle settlement completely encasing mussel culture rope.

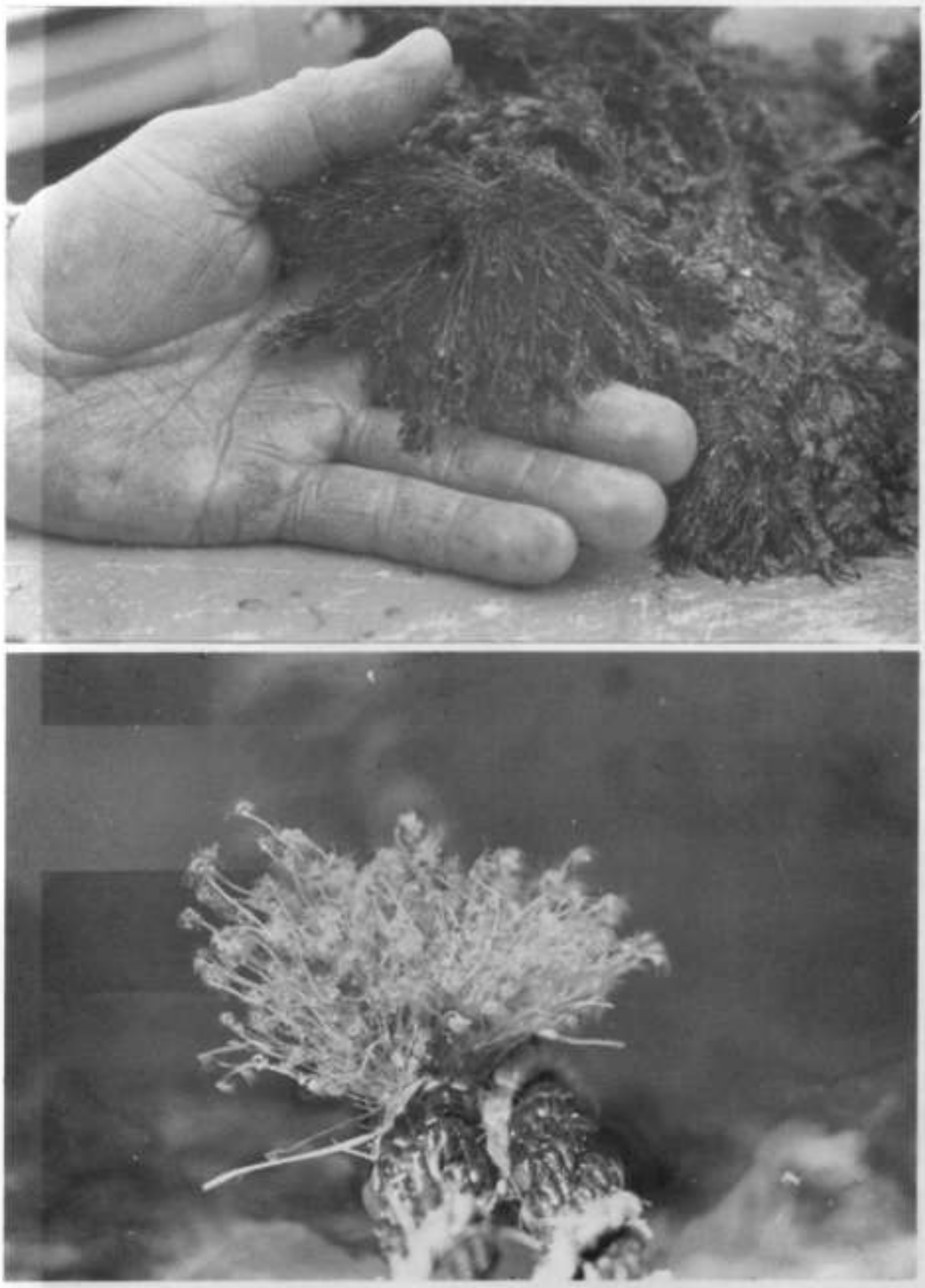


Fig. 43. Hydroids on mussel culture ropes.

Fig. 44. (Left) Close up of rope showing spatfall with mussels securely attached. (Lower) Last of mussels having earlier settled on the rope migrating out on coir fibres and eventually leaving the rope.

MUSSEL DISEASES AND PARASITES

The cultivation of shellfish, like other forms of husbandry, concentrates the shellfish much beyond their natural occurring numbers per unit area, and this increases the opportunities for the spread of disease and parasite organisms. These disease in shellfish. The known oyster and mussel diseases or parasites however, levels of incidence, although foreign infecting organisms introduced to a population or environmental stresses from man made pollution, can cause major outbreaks of disease in shell fish. The known oyster and mussel diseases or parasites however, are not apparently harmful to man.

Mussel cultivation overseas has had relatively few disease problems compared with other shellfish culture such as with oysters. A severe outbreak of a parasite copepod, *Mytilicola intestinalis* which invades the gut of the blue mussel, threatened the Dutch mussel industry in 1950, but fortunately immediate measures, including the reduction of the stocking densities and regional quarantine, controlled the outbreak. *Mytilicola intestinalis* was not known to naturally occur in the Netherlands, but was accidentally introduced from German waters. Since the identification of shellfish diseases is usually very difficult, coupled with the near impossibility of administering treatment, some severe outbreaks of disease in oysters have gone uncontrolled. The only hope of re-establishing stocks in such cases, besides slow natural selection and natural propagation is by selective breeding of disease-resistant stocks and their reintroduction to the growing areas.

Unfortunately it is impossible to predict potential disease or parasite problems which may occur with New Zealand *Perna* and *Mytilus* when intensively cultivated. Preliminary research into the naturally occurring diseases and parasites of *Perna* and *Mytilus* in New Zealand has indicated no obvious diseases, but some incidence of parasites. Intensive cultivation of mussels may increase the incidence of disease pathogens and parasitic organisms and thus facilitate their identification. To date, raft cultivated mussels have shown a lower incidence of infestation by parasites than naturally growing mussels. This may however, be because of the overall young age of the cultivated mussels, as compared to beach mussels comprising young to very old mussels.

Organisms which are more commonly associated with New Zealand mussels are briefly described:-

Trematode (flat worm)

The trematode *Cercaria haswelli* appears frequently in *Perna* and *Mytilus* sometimes as distinct red blotches, on the exterior of the mantle lobes (Fig. 45). This trematode has a complex life cycle partially in association with mullet as another host. There is evidence that the trematode is partially parasitic on mussels, not significantly reducing the mussel's condition, but capable of reducing the lipid content in female mussels below the level needed for the formation of ova. Raft cultivated mussels harvested within twenty months have shown virtually no signs of this trematode, although natural shore mussels although highly variable between regions, have high infestation rates, up to 50%.

Pea Crabs

The pea crab *Pinnotheres novaezelandiae* is commonly found within *Perna* while a similar species, *Pinnotheres sp* is equally common in *Mytilus* (Fig. 46). The pea crab is apparently not directly parasitic on mussels but does eat the entrapped plankton from the mussel gills and so reduces the mussel's food intake. In the spring and summer months, female mussels infested with pea crabs show a significant drop in condition although male mussels are less affected. For the remainder of the

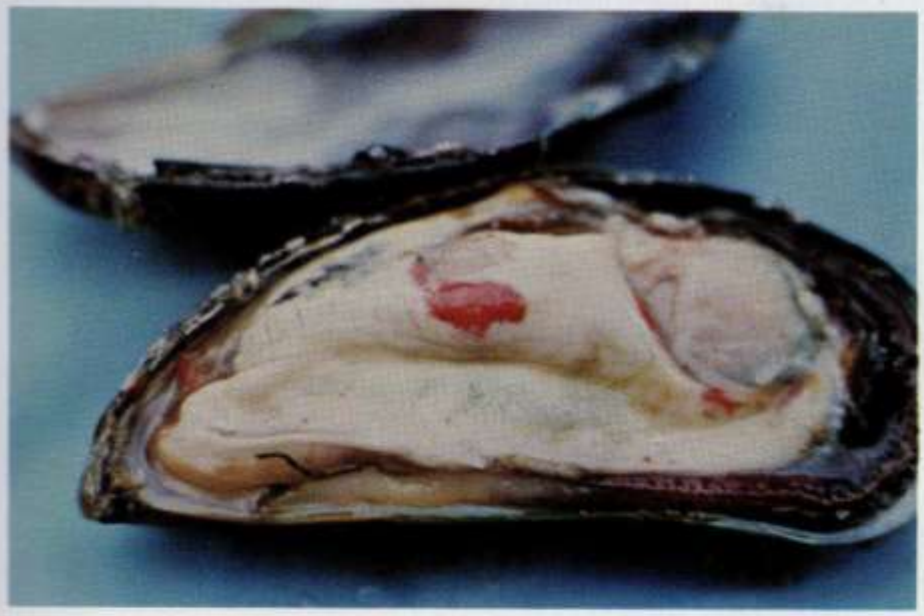


Fig. 45. An old intertidal mussel showing infestations of Cercaria haswellii (red blotch) and blue-green algae (green speckles).

Fig. 46. Shore mussel showing pea crab positioned in gill chamber.

year neither male nor female mussels are significantly affected. Pea crabs have been found in raft cultivated mussels, but their incidence is variable between regions.

Blue-green Algae

Older inter-tidal and sub-tidal natural mussels at times may possess dark green blotches of blue-green algae on any of the soft tissue parts (Fig. 45). It is not known whether the alga is parasitic or commensal. No incidence of blue-green algae has been observed with cultivated mussels in the Marlborough Sounds.

FARM EQUIPMENT

Shellfish have been cultivated on rafts for over 50 years. The concept of rafts was first initiated in Japan for the culture of oysters using bamboo, and was later adopted by the Spanish in about 1946, for the culture of mussels. The Spanish first utilised old boat hulls for flotation but later constructed large catamaran-type rafts capable of handling upwards of 1,000 culture ropes.

Since the first mussel cultivation trials in New Zealand, many raft designs have been tested. Without an adequate knowledge of farming methodology, several large rafts (60 x 40') which were constructed during the early farming trials, proved to be economically unsuitable and led to smaller less expensive designs. Perhaps with more knowledge of culturing methodology and the economics of mussel cultivation, large rafts may reappear.

However, the present needs of the industry have been satisfied with two basic types of growing structures. In addition there are seasonal needs for small, auxiliary rafts, termed "spat rafts", inexpensively built for special purpose use.

Long Lines

The long line system of cultivation was introduced from Japan by the Fishing Industry Board in 1974. The concept of utilising large polyethylene floats interconnected by paired horizontal support ropes from which the cultivation ropes are attached, had evolved in Japan for the suspended cultivation of oysters. This farming system has numerous inherent advantages over elaborate raft structures such as:

1. low capital cost
2. simplicity of design
3. biological suitability by maintaining mussels at a low density per unit area
4. aesthetic acceptability
5. safety with regard to small pleasure boat traffic

Several mooring arrangements and line types which have been proven in much of the Marlborough Sounds are shown in Fig. 47, 48, 49, 50, 51. It is suggested each site should be evaluated for exposure, sea currents, etc., and long line specifications should be modified according to possible extreme conditions experienced at the specific site. It is also suggested long lines may best be sited parallel to the dominant current, to lessen current drag and limit surface debris accumulation. It should be remembered that the grower is ultimately responsible for secure long line and mooring configurations.

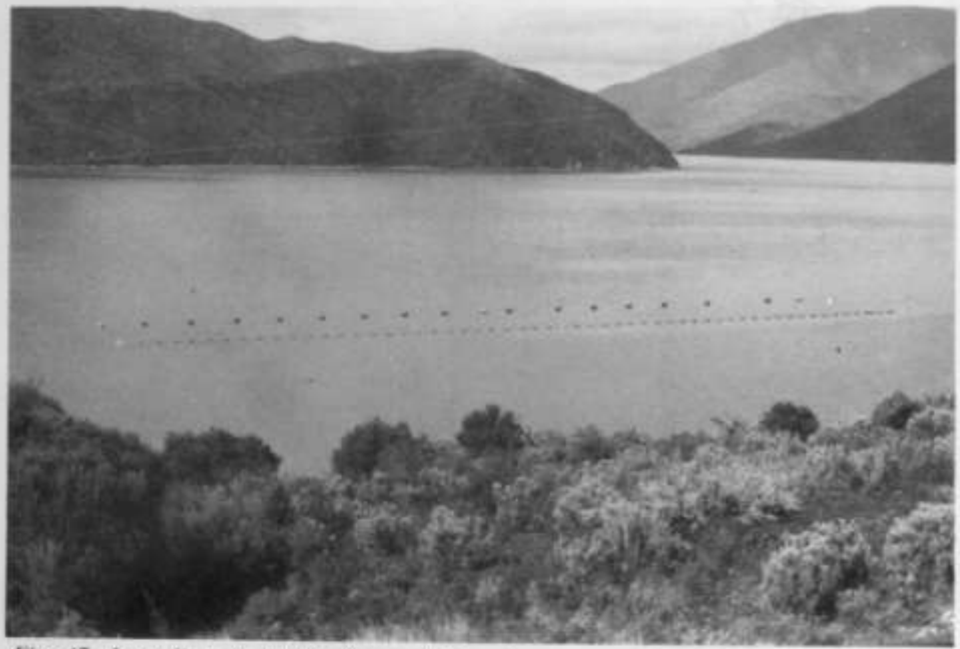


Fig. 47. Long lines in the Marlborough Sounds are generally no longer than 110 metres surface length. Except for the end and centre buoys which are orange all other buoys are of black polyethylene or fibreglass.

Fig. 48. The long line main lines are usually 18mm polypropylene superfilm. Buoy spacing varies but shown at 2 metres while culture ropes are at .5 metre spacing. (Photo taken of early demonstration long line having alternating black/orange buoys.)

Fig. 49. Long line bridle general.

Fig. 50. (Left) Long line bridle extending to two 18mm polypropylene anchor lines, or (Right) to one 24mm polypropylene anchor line.

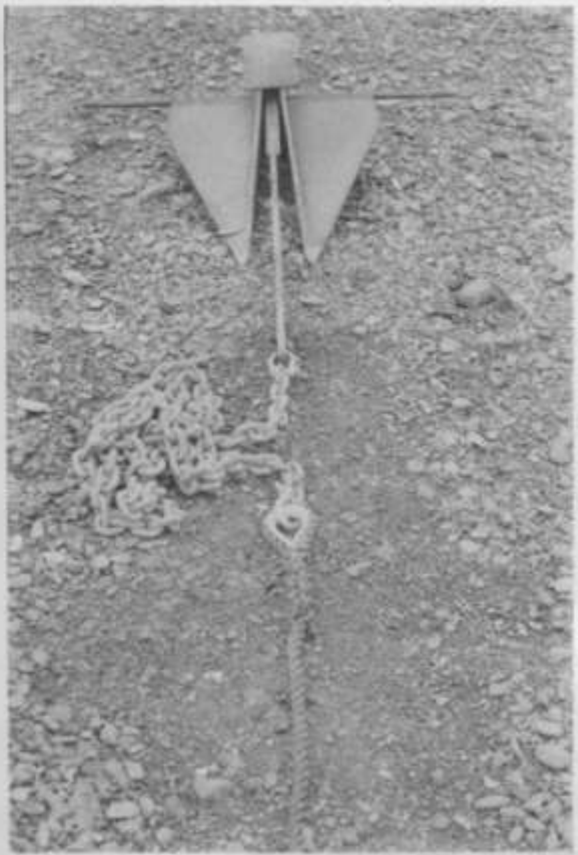
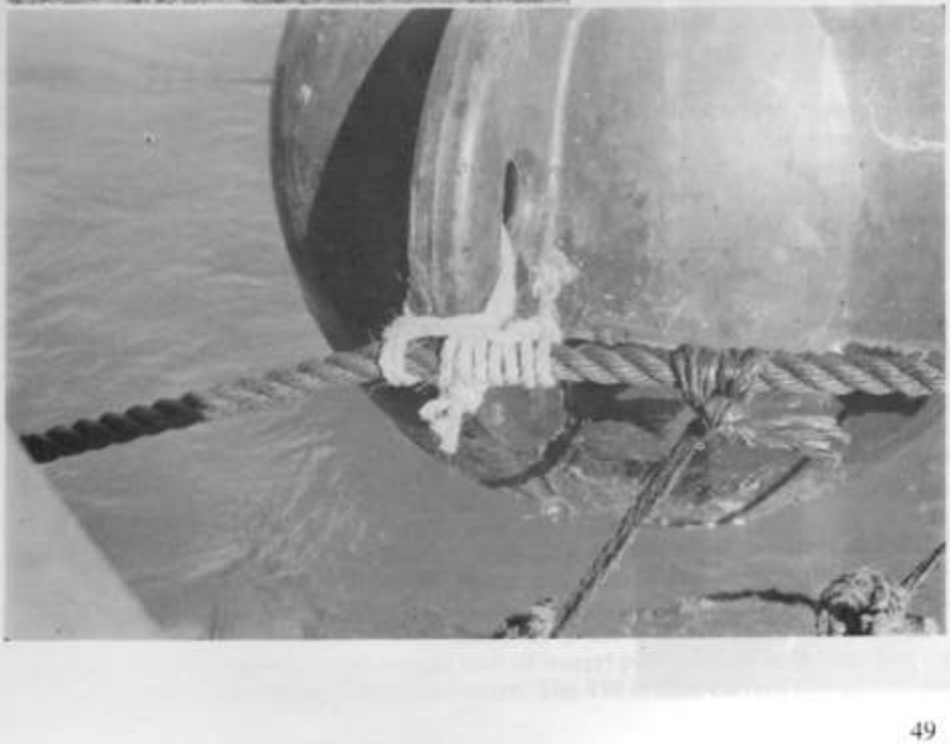


Fig. 51. Single anchor arrangements each end are usually 100kg plate type while double anchor arrangements are usually 50kg plate type. All anchors have a minimum requirement of 6 metres 13mm chain between the anchor and the anchor lines.

Fig. 52. Floats are usually lashed to the main lines with 6mm rope.



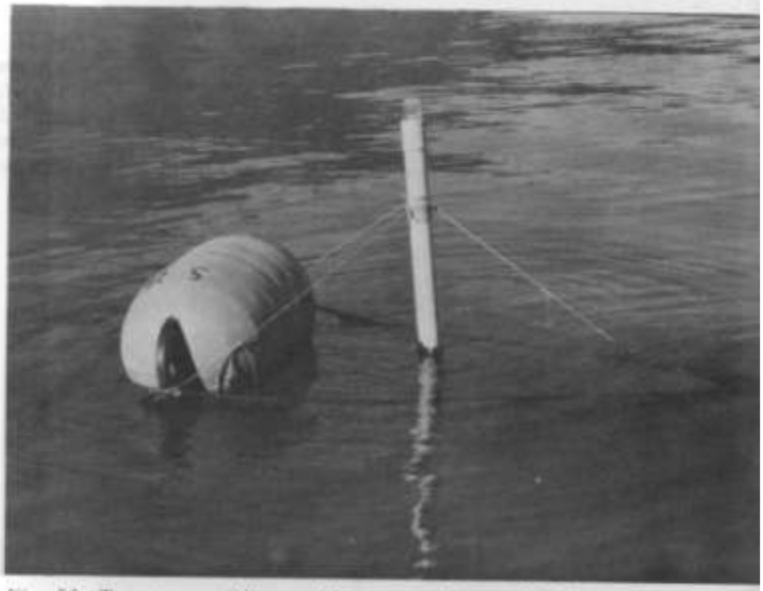


Fig. 53. Two types of line end beacons; (Upper) Tied into long line bridle. (Lower) Moulded into long line float.

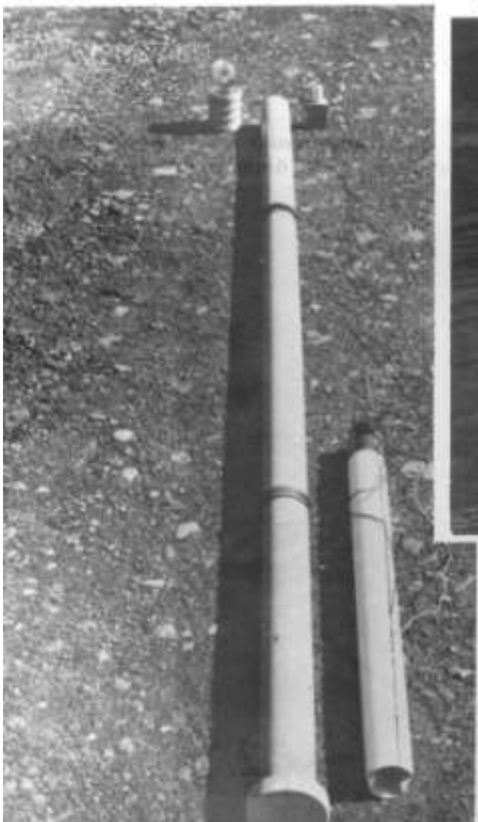


Fig. 54. Breakdown of light beacons. The outside cylinder is standard PVC 75mm soil pipe, 2.5 metres in length while the inner battery pack is made of 65mm Marley downspout. The transistorised flashing unit is locally made and will flash for about six months between battery changes.

Carrying capacities of long-lines using similar floats are calculated as follows:

$$\frac{\overset{(a)}{(\text{kg displacement/float})} \times \overset{(b)}{(\text{\% usable float displacement})} \times \overset{(c)}{(\text{no. of floats})}}{\underset{(d)}{(\text{comparative weight of mussels in sea water})}} =$$

= total production (kg)

Where:

(a) float displacement = 224kg per 8 cu ft
252kg per 9 cu ft
280kg per 10 cu ft
308kg per 11 cu ft

(b) usable float displacement varies between 66-75 percent

(d) comparable weight of mussels in sea water = 25 percent

An example of a line with 50 floats of 252kg displacement each float and 70 percent of each float used as follows:

$$\frac{\overset{(a)}{(252)} \times \overset{(b)}{.7} \times \overset{(c)}{(50)}}{\underset{(d)}{.25}} = 35{,}280\text{kg}$$

For long lines which are assembled with numerous float types, carrying capacity is calculated in the same manner except that (a) and (c) are substituted with the **sum of total float displacement (kg).**

As long lines are made up of many units of flotation, several options are open to the mussel grower on how to manage the long line flotation. If maximum utilisation is desired, float spacing will need to be adjusted according to the grower's production cycle, to maintain the balance between flotation and the weight of the maturing crop. (This is further discussed in section Production.) Otherwise float spacing may be based on the practical production upper limit of a long line, with the flotation more or less unaltered through the cultivation cycle.

For a long line which is to be assembled and unaltered through the growing cycle, the spacing of the cultivation floats is determined by numerous factors including the displacement of the floats, the culture rope length and spacing, the mussel seeding density on the culture ropes and the size at which the mussels are to be harvested. Although practical experience will best teach the mussel grower how to bring all these variables together, and result in a well managed long line, a more academic approach is discussed.

Calculation of long line float spacing with regard to loading factors

Included in Fig. 55A and 55B are an example (dotted line) showing the calculation of float spacing for an "average" type long line used in the Marlborough Sounds. The Fig. 55A, 55B, "fix" two variables – the mussel size at harvest, and the culture rope spacing on the long lines. The harvest size is taken to be a mean length of 100mm which results in a harvest size spread from about 80-120mm. The long line culture rope spacing is generally accepted at .5 metre.

In Fig. 55A selecting a moderate rope seeding density of 300 mussels/metre (left hand margin), the 300 mussels/metre figure is carried across to the right to the lines indicating culture rope length. In this case selecting the five metre culture rope length and at the point of intersect, dropping to the lower margin, a figure is read giving the resulting total crop weight (out of water) per metre of long line. For this example this reads 450kg of mussels/metre. The 450 is then carried to Fig. 55B and

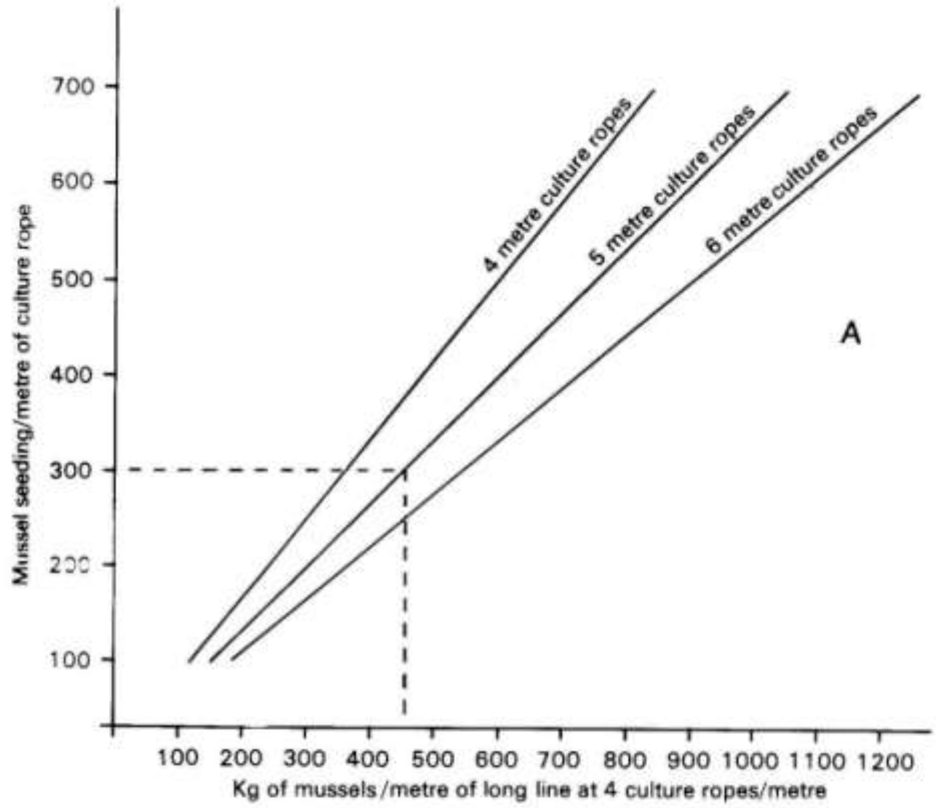
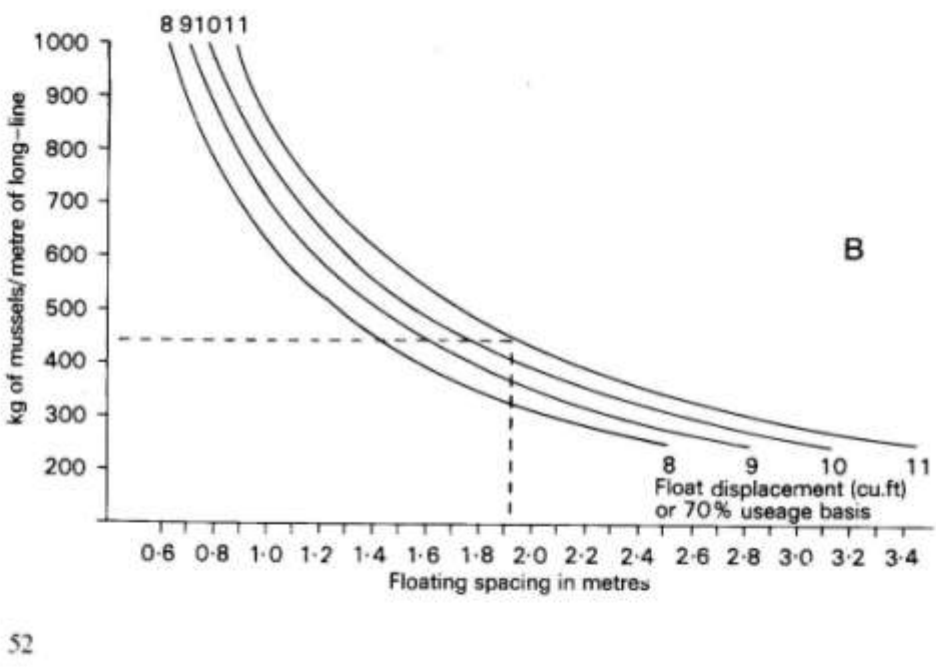


Fig. 55A. Maximum long line loading based on 100mm average mussel size in reference to mussel rope seeding and culture rope length.

Fig. 55B. Float spacing as related to long line loading and float size.



in the same manner, starting at the left hand margin at 450 moving across to the right, and selecting the eleven cu. ft., float size, the float spacing for this combination reads at the bottom, 1.92 metres. For all practical purposes this can be read as 2.0 metres.

Many growers find the 2.0 metre spacing satisfactory for the usual cultivation cycle of 16-20 months. During peak loading however, when using the smaller floats (8 cu ft) additional floats are necessary to maintain this line until harvest. Growers intending to adjust their cultivation rope seeding to either higher or lower levels than the example, can use this procedure to estimate their flotation needs.

When siting a long line on the farm site, the following simple procedure is suggested. Firstly, before cutting and splicing thimbles on the main horizontal ropes, the rope should be uncoiled and stretched (e.g. automobile, tractor, etc.). Secondly, when siting the long line, if all anchors are set while at low water, the line will exhibit minimum slackness after initial use. It is also highly recommended that anchors be visually examined by divers to ensure that they are correctly positioned in the sea bed.

Several manufacturers are producing, or are capable of producing, long line floats in New Zealand. Float specifications and prices are available from the manufacturers.

Polyurethane Foam Wood Rafts

A raft design developed by N.Z. Marine Culture Company has proved very satisfactory for its designed use. This raft, illustrated in Fig. 56, 57, utilises polyurethane foam pontoons sealed in fibreglass, making the raft virtually unsinkable and low in maintenance. The raft measures 8m x 6m and has a total gross displacement of approximately 15 tonnes or a carrying capacity of approximately 150 culture ropes. The raft is either anchored at two opposing ends with plate type anchors, or two rafts are bridled together, which eliminates the need for two anchors. This raft, as are all solid structured rafts (excluding spat rafts) is subject to marine survey regulations.

Spat Holding Rafts and Mini Long Lines

These are special use rafts with less than $14m^2$ deck surface area, and which are excluded under the marine survey regulations. The hold-over raft discussed in section Predation is also in this category. Spat holding rafts with attached nets can help in overcoming predation problems, and assist with the two crop overlap.

The long line farming system enables the assembly of small mini long lines of 3-5 floats with little added expense above the already purchased long lines. Mini long lines are easily transported to distant locations and make spat catching practicable in remote areas if communal long lines are not available. Mini long lines also function well as spat hold-over structures.

Anchors

It is important that the anchors selected are designed for the type of bottom within the licensed area. This may require an inspection by a diver if the adjacent areas have not been examined, or to provide assurance that the bottom type is continuous throughout the intended mooring area. A diver should also then be used to assure the anchors are properly imbedded in the sea bed.

Plate anchors (Fig. 60) are generally suitable in much of the Sounds, but in some instances larger anchors may be necessary where stronger currents are experienced. More stockily built anchors may be needed when the bottom is firmer and conventional pick type anchors may be necessary when bottom conditions are very

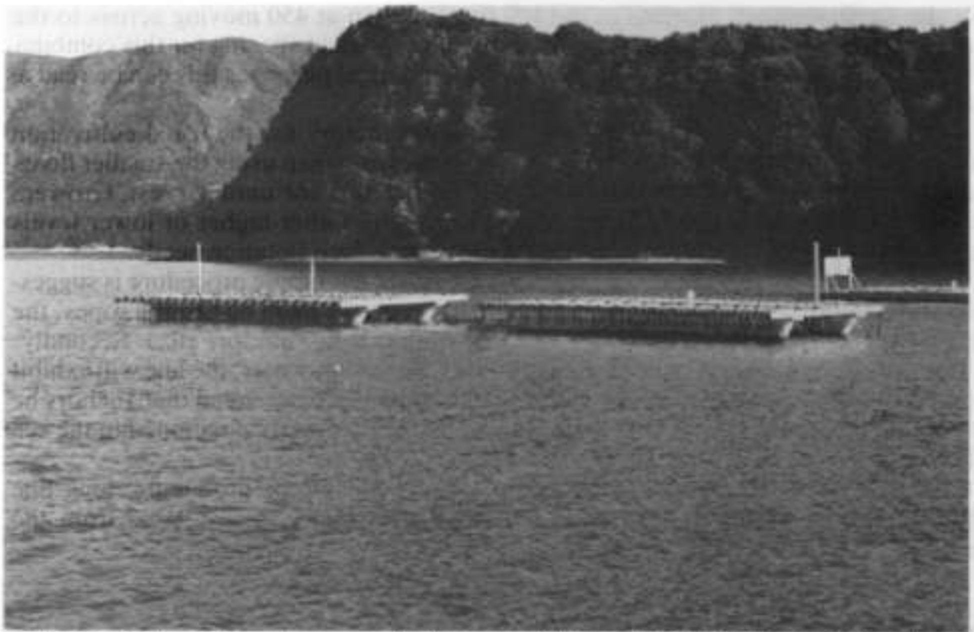
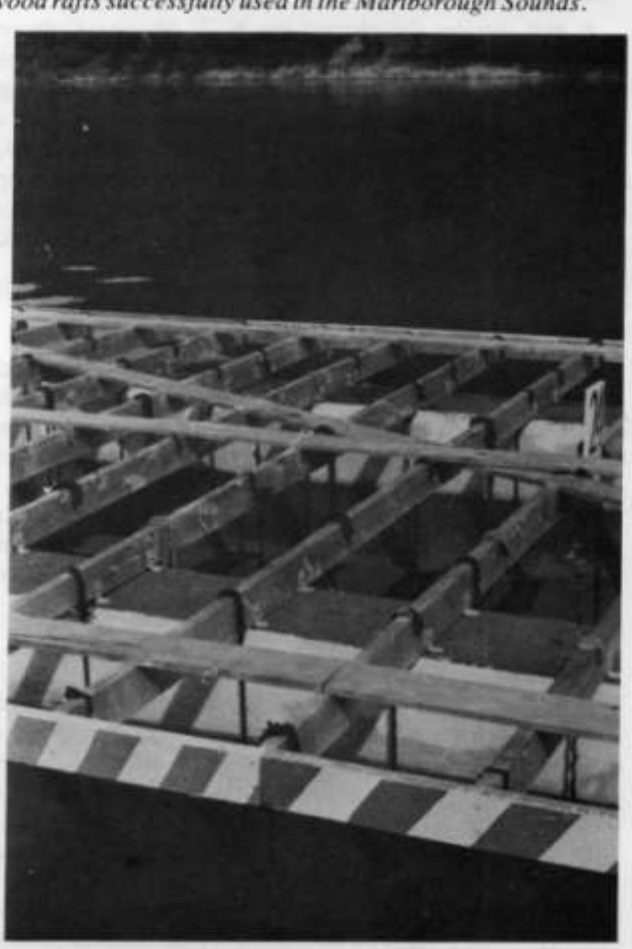


Fig. 56. Polyurethane foam-wood rafts successfully used in the Marlborough Sounds.

Fig. 57. Close-up of deck fittings on polyurethane foam-wood rafts.



firm or rocky. Less expensive concrete type moorings may be approved but may impose more difficulties for routine inspection.

Cultivation Ropes

The less expensive synthetic ropes such as the polypropylene fibrillated film type have good qualities for mussel cultivation. A black pigmented film rope is used for

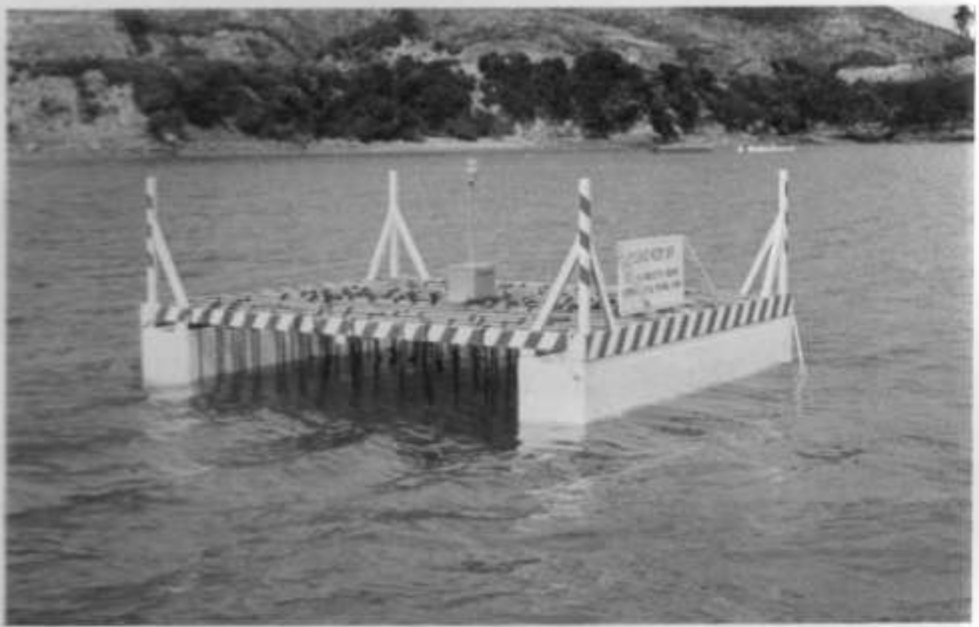


Fig. 58. A spat holding raft using fibreglass over polystyrene foam.

Fig. 59. A mini long line of about 10 metres in length used for spat hold-over or spat catching.

Fig. 60. Several types of plate-plow anchors (approx 50kg) used for mooring long lines or rafts.

both the construction of long line structures including anchor lines and for the main cultivation ropes (Fig. 61).

Synthetic ropes however, usually exhibit less than desirable surface qualities for attracting mussel settlement unless very heavy spatfalls occur. Their catching qualities can be improved by interweaving coir, a natural coconut fibre, amongst the synthetic braid during manufacture of the rope, or to wrap externally a coir 2-ply yarn around a normal synthetic rope which can be done by the mussel grower (Fig.

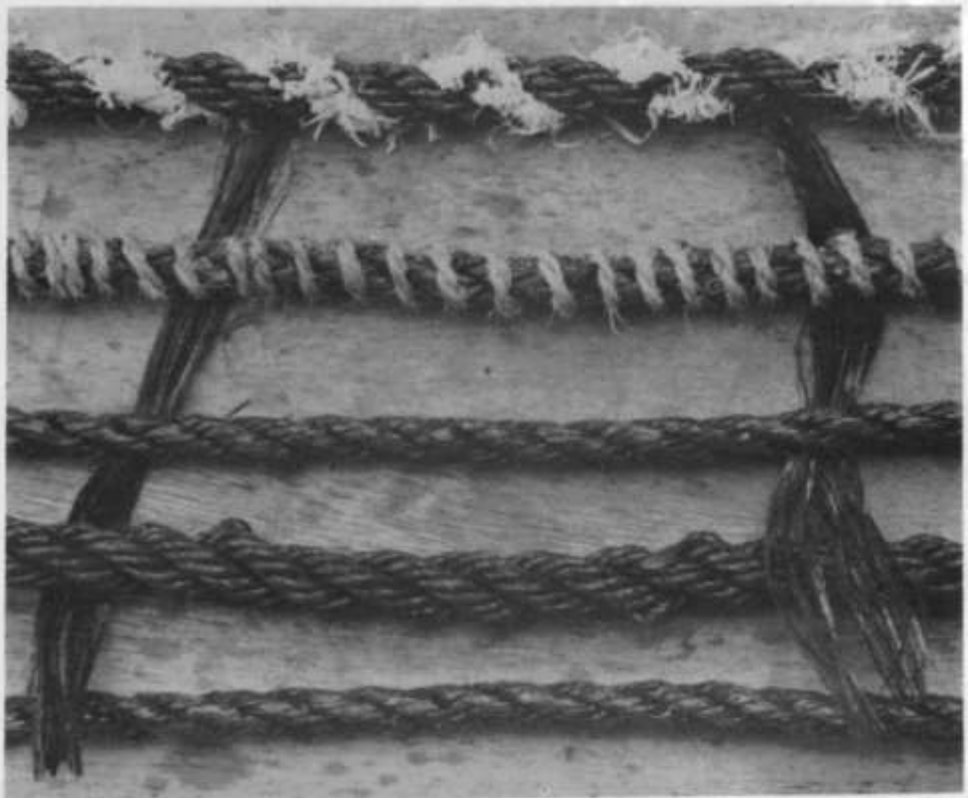


Fig. 61. Types of mussel spat catching/culture ropes used, all based on fibrillated film construction: (a) one rope lay wrapped with sacking offcuts; (b) wrapped with coir yarn; (c) with fibrillated film cross pieces; (d) soft lay; (e) firm lay.

62). Coir has excellent catching qualities but does biodegrade rather rapidly and is not a suitable support fibre. Coir is also prone to fouling which limits its effectiveness in seed catching 2-3 weeks after laying.

Another rope preparation procedure suggested is to intermittently place along the length of a culture rope (Fig. 61c) short segments of fibrillated film, the same material used for making film ropes. Test trials utilising this type of catching rope have shown excellent seed catching qualities, with an apparent low incidence of fouling organisms. Ropes of this type have been shown to maintain their "catchability" for 4-6 weeks. A newly developed catching rope shown in Fig. 61a utilising off cuts of sacking material has demonstrated good catching characteristics. The rope ready to use from the manufacturer is economically attractive as it requires no further labour in preparation.

Culture rope length is probably best determined by the mussel grower after evaluating and testing several rope lengths at his specific farm site. An arbitrary rope length of 5 metres is commonly selected but longer and shorter ropes have performed equally well.

Rope Weights

Rope weights are required for all cultivation rope types. This avoids chafing the young mussels from the ropes, caused by the tide flows through the farms. After 9 months or so when the mussels have gained sufficient weight, rope weights may be removed and used with the new season spat catching.

Fig. 62. Wrapping coir on ropes with electric motor. The rope opposite end is held with a ball bearing swivel hook and rubber strap.

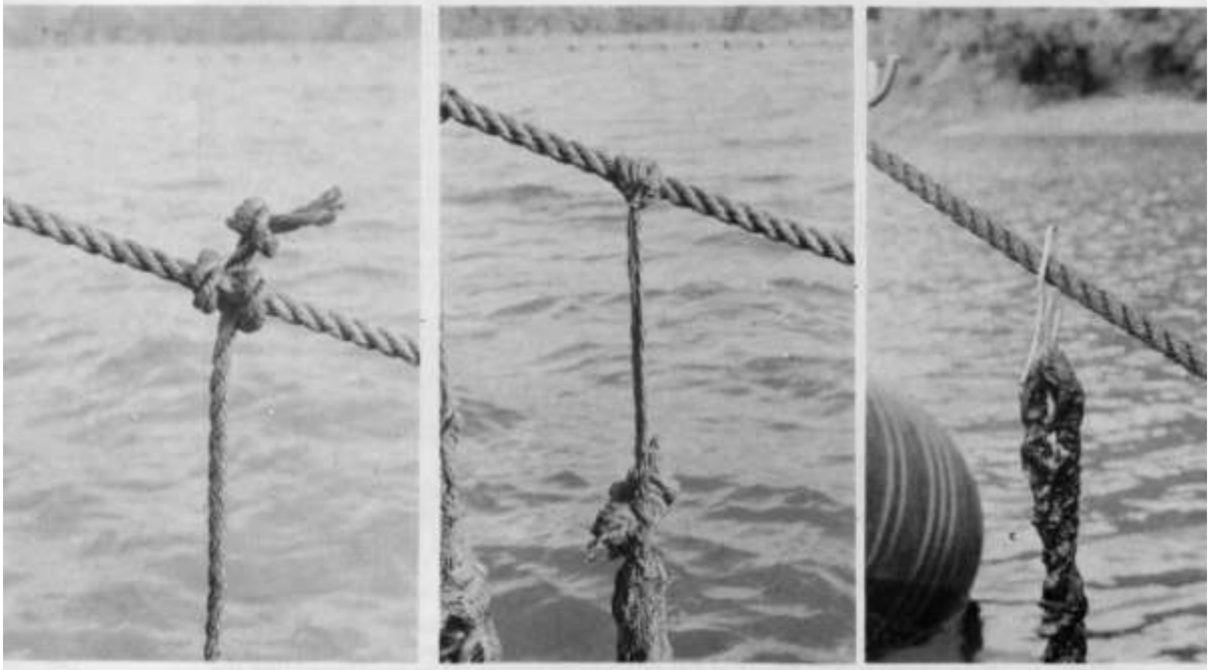


Fig. 63. Culture rope fastenings to long line main lines. (From Left) Tied directly to main line; with smaller rope attachment; stainless steel hook. To increase harvesting speed and reduce costs, culture ropes are best attached to the main lines with the smaller rope attachment (which is subsequently cut) or with the hook device as marine growth on the main lines make the untying of knots difficult.

The minimum weight required for most circumstances is .5kg (submerged) and is achieved with a 1kg concrete weight, most frequently made from 500ml cardboard milkshake containers (Fig. 64). For attaching the weight, galvanised, stainless or copper wire or even nylon or proplylene cord may be fixed in the concrete.

Fig. 64. Rope weights are usually poured in 600ml milkshake containers.

BOATS

Boat types to be used in mussel farming will be dealt with only briefly, as no universally accepted designs have yet appeared. The Ministry of Transport has basic guidelines and regulations which apply to boats servicing marine farms and these can be obtained from the Ministry of Transport.

A variety of boat types from 14ft aluminium and fibreglass runabouts to larger pleasure-type craft and commercial vessels, have proven adequate for developing the small farm. However, as the farm expands and the work becomes more demanding, larger and more specially designed boats appear essential.

A mussel grower intending to harvest from a boat will require a sizeable self bailing deck area for working and for hauling materials and mussels to and from the farm site. As grower's needs will vary the selection of petrol or diesel engines, planing or displacement hulls, etc., will be a matter of individual choice.

Fig. 65. A welded steel boat used for servicing long lines and harvesting mussels up to one tonne/day.

Fig. 66. *Simple hand winch used for partially lifting and servicing long lines.*

PRODUCTION

The ultimate productivity of a farm unit can be theoretically determined. This is by measuring the food organisms available to the mussels as related to the water exchange rates for a specific site, and the food conversion rates of mussels. However, in practice the production of a farm site will probably be largely determined by non-biological factors such as finance, labour committments, market outlets and social considerations in water use planning.

Unless a farm site is within a locality of poor water circulation, or is blocked out by several other developed farms, it is not foreseen within the near future that farms will be significantly limited in production by insufficient food availability for the mussels. Each grower does however, have many economic considerations and factors directly or indirectly influencing the scale and rate of development of his farming unit. Furthermore, one man's economic unit is not necessarily the same as anothers.

On biological considerations alone, such as the food availability it is conceivable that production within areas of intensive cultivation could exceed 50 wet weight tonnes per hectare per year. Since water exchange rates of areas differ considerably, production limits may prove to be higher or lower for specific sites.

Production of 75-115mm Mussels

For a developing farm carefully considering return from capital and expenditure, full utilisation of invested capital is important. Farm production considered only on invested capital is determined essentially by the investment in gross flotation, since flotation is the single most costly item in farm investment (excluding boat or service craft). A simplified example is of a uniform crop which matures at a point having used up 75 percent of the flotation, and once having reached a marketable size is subsequently harvested over a relatively short time. This would be very similar to many agricultural crops which are quickly harvested upon reaching maturity. This is shown diagramatically in Fig. 61 where A represents the maximum production possible from the invested flotation displacement of X kgs.

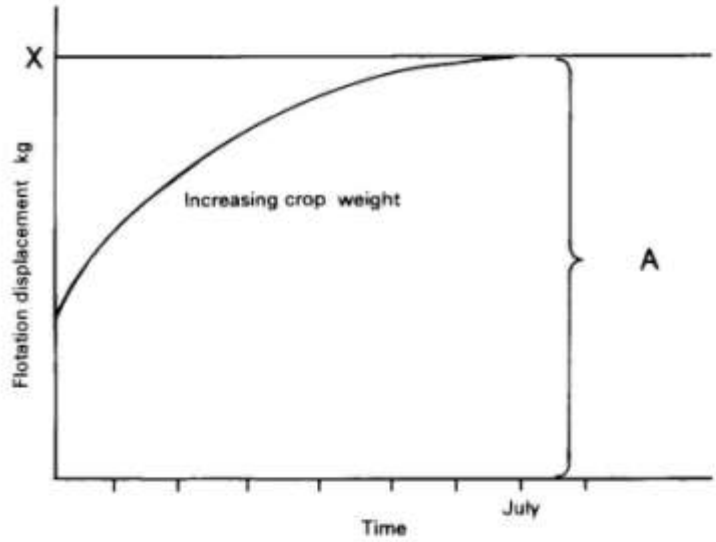


Fig. 67. Mussel production: (A) based on one point harvesting with regard to invested flotation (X).

An example based on the long line farming system (per 110m long line) as follows:

Flotation requirements – costs (approx. 1978)

Buoys – 43 at $50 each	$2.150
Surface lines, anchor lines, anchors, chain shackles, etc.	$1,050
440-4m mussel culture ropes	$ 700
	$3,900

Production (18 month cycle)

440-4 metre culture ropes at 300 mussel/metre

	44,000 doz
or approximately	34,000kg whole mussels

A more complicated production situation exists however where harvesting is extended over six months while maintaining a consistent mussel size, and exploiting the rapid growth of the mussels. Whereas the first production example is based on a uniform crop size achieved through uniform mussel seeding on ropes, harvesting over an extended period requires variable rope seeding which has the effect of regulating growth rates (Fig. 14). During the period of six months from May to November mussels will virtually double their weight and this second hypothetical farm could have the same net production as the first example but require only half the flotation. This is diagramatically shown in Fig. 68 where the same final production A is achieved with half the flotation (Y) as required in the first example (X).

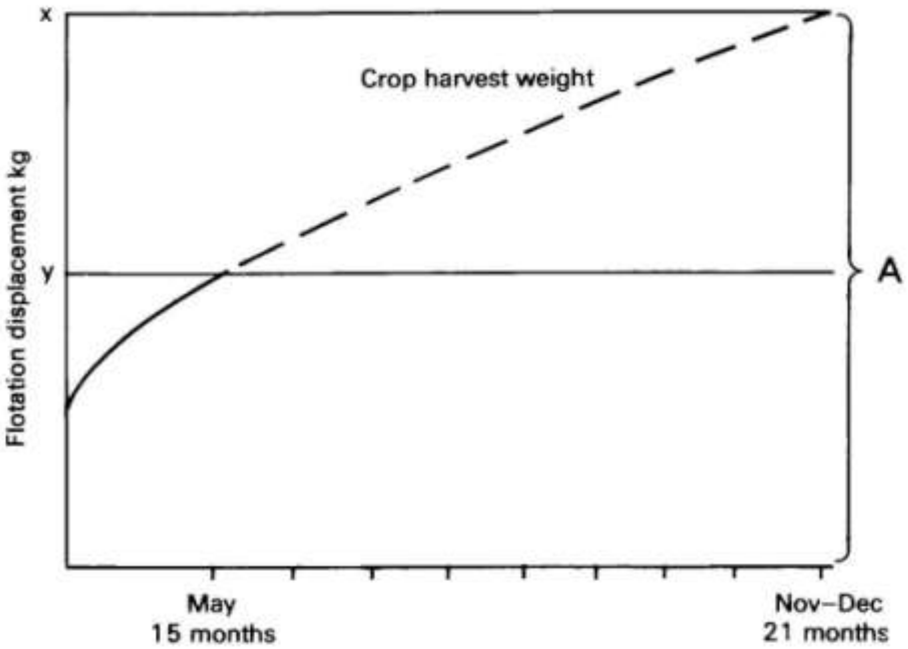


Fig. 68. Mussel production: (A) based on extended harvesting with regard to lower flotation requirements (Y).

As the crop weight progressively increases to the point where 75% of the flotation is used up or at about 15 months, harvesting is commenced and proceeds in a schedule which equals the growing mass of mussels. The final harvest of the heaviest seeded ropes may or may not require an increase in the harvest rate to harvest before the summer meat condition quality drop. This would be dependent on how early the ropes have been seeded and other factors specific to each farm site.

A 110 metre long line managed under this system would, instead of having floats spaced at 2.5 metres as the first example, have a float spacing at 5 metres although maintaining a similar 0.5 metre culture rope spacing. Each culture rope after being adjusted to a uniform mussel seeding along the entire length of approximately 100, 300 or 700 mussels per metre would need to be situated within the long line in the configuration;

etc - 700 (float) - 700 - 300 - 300 - 100 - 100 - 100 - 100 - 300 - 300 - 700 - (float) - 700 etc
(ropes as mussels per metre)

and could produce the following results (compare with the first example).

Flotation requirements/costs approx.

Buoys 23 at $50 each	$1,150
Surface lines, anchor lines, anchors, chain shackles, etc.	$1,050
440 – 4m mussel culture ropes	$ 700
	$2,900

Production (18 month cycle)

176 x 4 metre ropes at 100 mussels/metre	5,867 doz
176 x 4 metre ropes at 300 mussels/metre	17,600 doz
88 x 4 metre ropes at 700 mussels/metre	20,533 doz
	44,000 doz
	or approximately 34,000 kg.

In practice however, the mussel grower will probably find difficulty in precisely balancing up weight with flotation, and accepting the costs of maintaining a flotation surplus. Similarly, it may not be possible to as accurately manage rope seeding as in the examples, and production could be more or less a compromise of the two, with the harvest being conducted over several months. Also there is a danger when maintaining mussels of high densities of lowering their overall meat condition thus lowering meat recovery yields. Furthermore, there is the obvious complication of farmers attempting to unload the bulk of their crops within a relatively confined period and glutting the market or overburdening processing and storage facilities. This could result from the present situation of industry wide one point seeding and the relatively uniform rate of crop maturation.

As growers obtain experience in farm management and crop manipulation this potential problem could be avoided through an industry agreed production schedule.

Production of Mussels in excess of 115mm

Some growers may wish to produce mussels for the traditional larger fresh shell market 115-140mm which has to the present been supplied by the picking and dredge fisheries. Mussels grown to this size require 20-32 months of cultivation, depending on the rope seeding rates. Rope seeding at 150-250 mussels per metre should produce a mean harvest size at 130mm between 28-32 months whereas at seeding densities below 100 mussels per metre 130mm mussels are possible in 20 months.

Farm production based entirely on a two year harvest cycle obviously reduces the net production from the invested flotation. From the earlier calculation for a 43 float long line with an approximate 34,000kg per year production, if this line was simply harvested every other year, the net production is 17,000kg of mussels per year representing only 10,500 doz mussels (1.6kg per doz).

A relatively simple shuffle of floats does however improve the production without added capital cost. This is by shifting every other float from a second long line, which is to be seeded on alternative years, and retying them into the first line. This second line, which will not need the full flotation until well after the first year after seeding, will in turn receive the initial transferred floats as well as half of the original floats from the first line, after the first line is finally harvested. Production in this manner boosts the two year harvest to 51,000kg per line or an annual production of 25,500kg of mussels per year (instead of 17,000kg) representing some 15,900 doz mussels (instead of 10,500kg). The second example has a mean harvest size of 130mm as in the first example, but the average rope seeding is 214 mussels per metre versus 143 mussels per metre for the first.

These figures are again primarily an academic exercise, but nevertheless may have some application in farm management. Farmers may find it advantageous to carry some production through two years after possibly a poor seeding year, or as a normal procedure, if justified by a higher return per mussel.

HARVESTING

When to Harvest

Although it is premature to identify a consumer quality preference for mussels marketed in New Zealand, it is likely the grower will eventually schedule his harvest to meet consumer demands rather than his own preferred harvest schedule. The markets as they develop will undoubtedly specify both the acceptable shell size range and meat quality determined by appearance and fullness either in the raw state or after steam shucking or both. As the mussel crop as a whole is in constant change, not only affected by growth, but by seasonal changes in the body fullness, the grower needs to know the state of his crop. A method is suggested to standardise this procedure.

Meat Condition

Condition or "fatness" of a mussel is a term used to relate the body growth to shell growth. Although the more academic method is to measure the meat volume as compared to the shell cavity volume, it has been found with cultivated mussels that a simpler measurement of wet weight to total weight is equally valid. This suggested condition measurement is easily done at the farm site, which decreases the opportunity for error.

Therefore:

$$\text{Condition Index (CI)\%} = \frac{\text{wet weight of mussel meat (grammes)}}{\text{total wet weight whole mussels (grammes)}} \times 100$$

It has been found with cultivated mussels that the shells are relatively consistent in density and shape and are not a significant source of error in the calculation. Care should however, be exercised when weighing the whole mussels, making sure that surface fouling and excessive byssus lumps have been removed, and weighing should be done immediately at the farm site to assure no shell cavity water has escaped. Also when shucking the body, it is necessary to minimise tissue damage, and the meats should be weighed after draining any weeped tissue liquid which may result after standing for several minutes. The minimum number of mussels to be used should be no less than 25 and preferably around 50. Good quality kitchen scales will give reliable weight figures.

Reliability of the condition measurement will be dependent on the consistency of the procedure and on the ability to obtain representative samples of mussels to be harvested. It is advisable however, not to depend on condition figures obtained from several rushed samples without prior acquaintance with the procedure, as too often figures are misinterpreted as to their significance. It is also possible by using the data in the condition calculation to calculate and record the average mussel size. This is a size as determined by weight, but is easily converted to an approximate length measurement (Fig. 70).

$$\text{Average mussel size (grammes)} = \frac{\text{Total wet weight of mussels (grammes)}}{\text{Number of mussels in sample}}$$

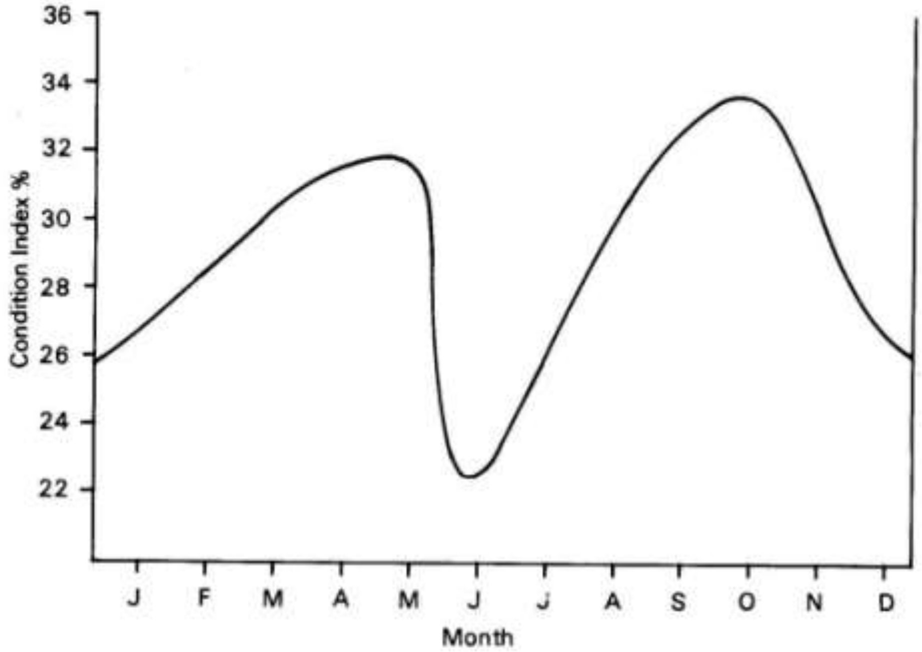


Fig. 69. Seasonal condition cycle as observed in Crail Bay for raft cultivated Perna determined by uncooked meat weight vs total weight. (Courtesy R. W. Hickman.)

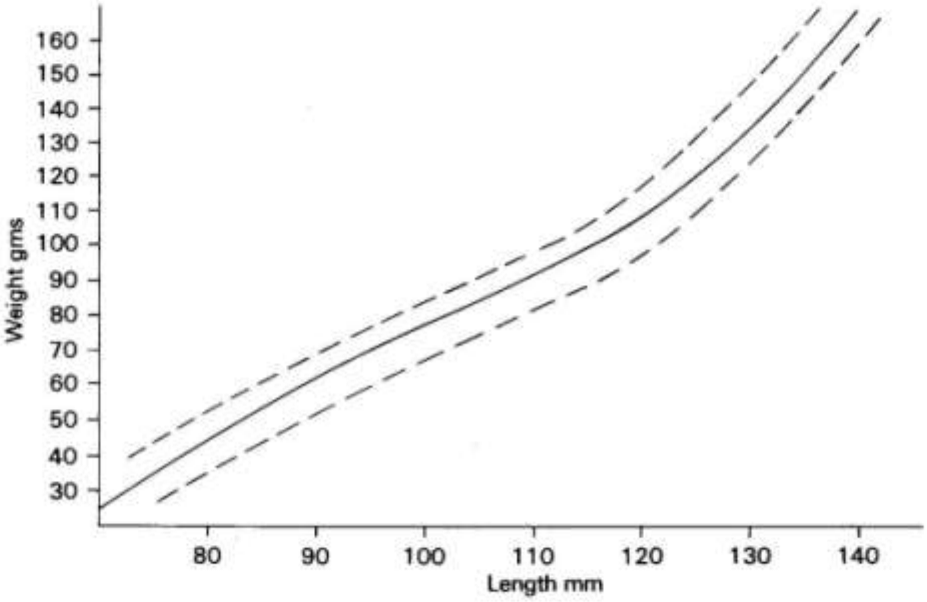


Fig. 70. Aprroximate weight-length relationship with raft cultivated Perna.

In some circumstances, such as communication with processors, condition may wish to be calculated from a steamed meat recovery as compared to the total weight. This is determined in a similar manner to the first calculation except that the mussels are immersed in a steam cooker (100°C) for five minutes, quickly cooled in cold water, and meats are weighed. Care should be taken not to overcrowd the mussels while steaming as the mussels are unequally cooked.

Steamed meat recovery is calculated:

$$\% \text{ recovery} = \frac{\text{steamed meat weight (grammes)}}{\text{total wet weight whole mussels (grammes)}} \times 100$$

The initial weighing for the total weight should again be done immediately at the farm site, although processors sometimes base their calculations after arrival at the premises. The shell cavity water drains from the mussels rapidly and accounts for a 10% weight loss in five hours. This will falsely increase the processor's meat recovery figures, but as bulk steaming generally is more severe than sample steaming, the net recovery is usually less than for the sample determination.

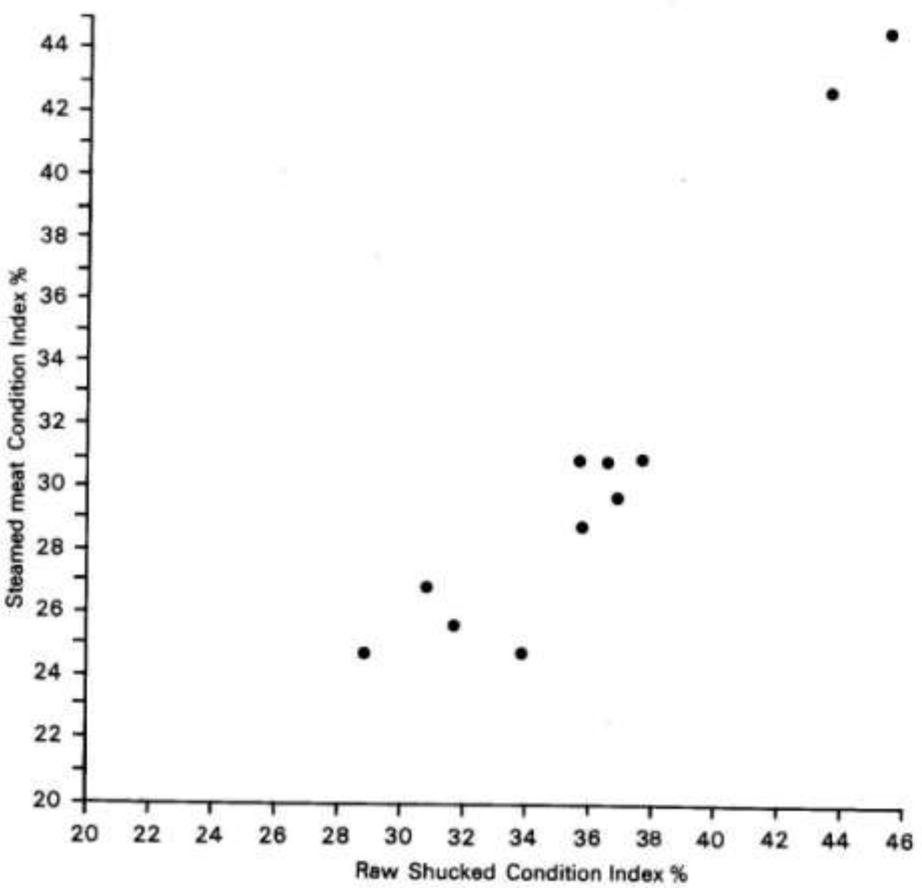


Fig. 71. A comparison of some sample determinations of raw shucked mussel meat to steamed meat recovery. (5 minutes @ 100°C.)

Fig. 72. A raft cultivated Perna near peak condition.

Harvesting and Service Vessels

Many methods will probably be employed to carry out harvesting, because of the differences in size of the farms and the different harvest schedules. Growers living in close proximity to the farm site and sending small weekly consignments to the live shell market will require less sophisticated harvesting techniques than other growers living some distance away and attempting to shift large tonnages over a relatively short period.

Contract harvesting may be advantageous for many growers. A marketing co-operative may prefer to undertake its own harvesting so that a regular supply is guaranteed.

Besides the physical act of lifting the mussel laden ropes from the water, the mussels may need to be separated into singles after being stripped from the rope and washed free of mud and clinging organisms such as barnacles, large sea squirts, etc. For small consignments it is possible this could be done by hand but for large quantities of mussels, some mechanical means need to be devised.

The grower who intends keeping his farming unit fairly low in production could, with the help of an inexpensive service vessel, (Fig. 73), quite successfully service his farm and harvest from a fairly small boat (18 – 25'). The larger producer however, or the grower intending to harvest his crop within a short period will need a larger harvesting vessel as part of the farming unit or obtain through contract to carry out the task (Fig. 74).

Fig. 73. (Top) Service catamaran used in conjuction with long line cultivation. (Right) Close up of working area.

Fig. 74. (Top) Harvesting with converted fishing vessel. (Middle) Harvesting barge. (Bottom) Catamaran harvesting vessel.

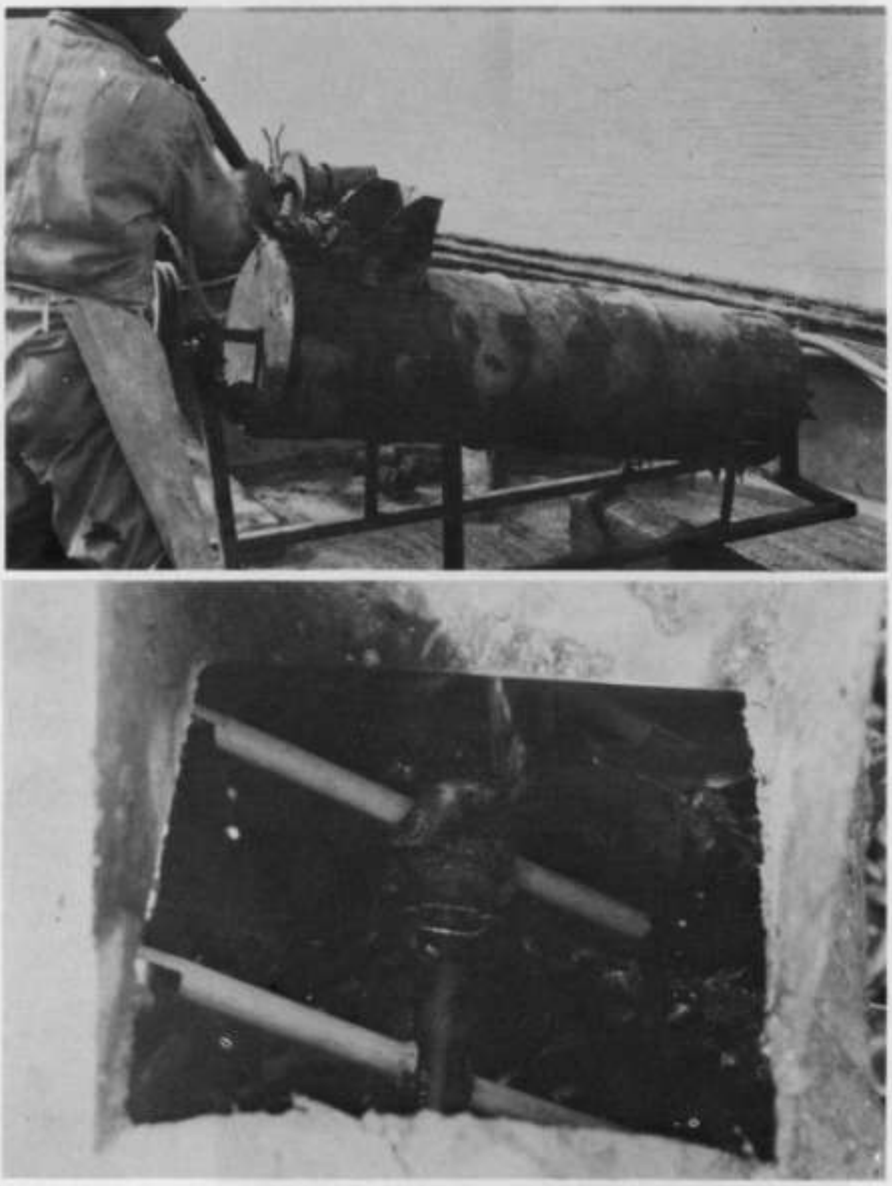


Fig. 75. (Upper) Simple washer and declumper for small lot harvesting. (Lower) Close up of centre revolving shaft.

LEASES AND LICENCES

APPLICATION PROCEDURE

The Marine Farming Act 1971, a consolidation of the Rock Oyster Farming Act 1964 and the Marine Farming Act 1968, makes possible the leasing and licensing of Crown foreshore and sea bed for the cultivation of shellfish, fish (with the exception of salmon and trout) and marine vegetation.

The application for leases and licences in the Marlborough Sounds is made to the Director-General, Ministry of Agriculture and Fisheries, Wellington, although the Marlborough Harbour Board, Marlborough Sounds Maritime Park Board and Marlborough County Council, have interests in the land and water use in the Sounds and are initially consulted regarding new marine farm application sites. Marine farm applicants are advised to become familiar with the provisions set out by the Marine Farming Act, and the functions of the various Government Departments administering the Act. The Town and Country Planning Act 1977 provides for the establishment of Maritime Planning Authorities and these are expected to play an important planning role affecting future developments.

PHYSICAL LAYOUT OF SITES

There are no hard and fast rules for setting out a marine farm site, although three hectare areas, rectangular, measuring 150m x 200m are commonly applied for (Fig. 76). With the 200m boundary parallel to shore and approximately 50m from low water mark, or where a minimum of 5m depth is obtained (MLW) the unit easily accommodates 110m long lines with the extended anchor lines or conventional raft structures.

Fig. 76. Typical long line farm layout with six 110 metre cultivation long lines.

As discussed in section "Water Quality", marine farms are sited in areas having basic requirements, in regard to depth, exposure, sea bed type, water exchange rates, and the proximity to port or service facilities. In few instances are all criteria met satisfactorily, which usually necessitates careful site development planning and the need to strengthen long line or raft structures and mooring arrangements, in relation to the sea conditions experienced.

Little knowledge is available regarding the maximum density at which a site may be developed with rafts or long lines as limited by food availability. As discussed in "Production" this may well be in most areas and instances just a secondary consideration while only in areas of poor water flow-through will farmers be noticeably limited because of poor food availability. Farm development however, should at least initially be cautious and long lines or rafts spacing be generous until on site evaluation be made as to growth rates, fatness, etc. For long lines an initial spacing of 20-30m between lines should be considered.

PERSONAL ORGANISATION (NOTE)

Each marine farmer must recognise the experimental nature of his own developing marine farm, and the need for careful evaluation of each attempted procedure. The regular keeping of a diary or notebook is essential to relate results either good or bad to earlier events so that a sound farm procedure may evolve. Any new untested procedure should be evaluated by small unit experiments and proven before large scale usage is undertaken.

Also a cost saving simple rule; never carry out tasks at the farm which can be accomplished at home. Many jobs may be easily done in the evenings which can help make time spent at the farm more productive.

ACKNOWLEDGEMENTS

Over the past six years mussel cultivation in the Marlborough Sounds has come from more or less an idea to the partial establishment of 50 marine farms and a further application of 150 marine farming licences. This rapid development is attributed to the input of many persons, but foremost, the pioneer mussel growers, whose enthusiasm has endured through repeated disappointments.

Without these people there would be no industry.

I gratefully acknowledge the input and assistance of the many persons contributing to the development of the mussel industry in the Marlborough Sounds and for information used in the assembly of this handbook.

I particularly wish to mention Mr John Meredyth-Young of the Fisheries Management Division, Ministry of Agriculture and Fisheries, for his dedication and assistance to the field study programme and contribution to the industry as a whole.

To Captain D. Jamison, Harbour master, and the Marlborough Harbour Board for their assistance to the Fishing Industry Board and support in the establishment of a Sounds mussel farming industry.

I wish to thank the Science Information Division of the Department of Scientific and Industrial Research, in particular Mr(s) Jeune and Phillips for preparation of the graphs and maps within the text.

For information on the biology of New Zealand mussels, I am grateful to Mr R. W. Hickman of the Fisheries Research Division for his observations of mussel growth and condition and the incidence of mussel parasites, to Dr B. Jones of the Fisheries Research Division, for his description of mussel parasites and diseases, to Mr R. Cooper of the Fisheries Management Division for his observations of fouling organisms and to Dr Climo of the Dominion Museum for literature assistance.

To Drs M. Dinamani and J. Cranfield, and Mr P. Chanley I am thankful for their critical comment in regard to the study programme and in particular for their photographing of mussel larvae and post larvae for this handbook.

I am sincerely grateful to Mr J. S. Campbell (General Manager of the Fishing Industry Board 1964-1976), and the Fishing Industry Board for direction, and for the generous financial support of the Marlborough Sounds mussel farming development programme.

R. J. Jenkins

READING LIST

Many journals occasionally publish articles on aquaculture and in particular mussel cultivation in the various localities around the world. In addition, there are a number of journals which are totally devoted to aquaculture topics. A few of these are:

Aquaculture
A technical journal published bi-monthly by Associated Scientific Publishers, Journal Division, P.O. Box 211, Amsterdam. The Netherlands.

Catch
A general fisheries and aquaculture magazine published monthly by the Information Services Division, Ministry of Agriculture and Fisheries, P.O. Box 2298, Wellington.

The Commercial Fish Farmer
A general aquaculture magazine published bi-monthly by the Commercial Fish Farmer, P.O. Box 4422, Manchester, New Hampshire 03108. U.S.A.

FAO Aquaculture Bulletin
A new digest of aquaculture published by the Fishery Resources and Environment Division, Fisheries Department, Food and Agriculture Organisation of the United Nations, Rome, Italy.

Fish Farming International
A general aquaculture magazine published quarterly by Arthur J. Heighway Publications Ltd, 110 Fleet Street, London EC4A2JL.

Marine Fisheries Review
A popular written journal on fisheries and aquacutlure published monthly by the National Marine Fisheries Service, available from the Superintendent of Documents, U.S. Government Printing Office, Washington, DC 20402.

New Zealand Journal of Marine and Fresh Water Research
A technical journal published quarterly and available from the Publications Officer, Science Information Division, Department of Scientific and Industrial Research, P.O. Box 9741, Wellington.

New Zealand Ministry of Agriculture and Fisheries, Fisheries Technical Reports
A semi-technical publication on specific topics related to fishing and aquaculture available from the Ministry of Agriculture and Fisheries, P.O. Box 2298, Wellington.

A few comprehensive books written on mussels or including sections on mussels and mussel farming are:

Aquaculture – The Farming and Husbandry of Fresh Water and Marine Organisms
By John E. Bardack, John H. Ryther, and William O. McLarney 1972. Wiley-Interscience, John Wiley and Sons, New York 868pp.

Farming Marine Organisms Low in the Food Chain
A Multidisciplinary Approach to Edible Seaweed, Mussel and Clam Production, by P. K. Korringa 1976. Elservier Scientific Publishing Company, Amsterdam, the Netherlands 264pp.

Marine Mussels : Their Ecology and Physiology
Edited by B. L. Bayne, Cambridge University Press 1976 506pp.

GLOSSARY

adductor (muscle)	– muscle responsible for shell closure.
algae	– simple marine plants ranging from planktonic single cell types to large leafy bottom attached varieties.
ascidians	– larger varieties referred to as sea squirts while some smaller appear as dense colonies in a gelatin like mass coloured red, yellow or purple.
byssus	– filaments made by many molluscs especially mussels to attach themselves.
cilia	– hairlike projections which create water currents by rhythmic beat.
coir	– coconut fibre.
conchyolin	– a horny substance found in molluscan shells.
condition	– a term used to relate body fullness of a mussel.
detritus	– a fragmented organic matter from decayed plants and animals.
exhalant aperture	– water discharge area of mantle.
fatness	– term applied to the plumpness or condition of a mussel, but having no relationship to the actual fat content.
fibrillated film	– polypropylene film sheet having been finely cut longitudinally.

gill	– filamentous or leaf-like organ used for respiration.
glycogen	– a food reserve material like starch in plants.
hermaphrodism	– male and female in same organism.
hydrographic conditions	– state of sea water (or fresh water) in reference to temperate, salt content, currents, etc.
hydroids	– colonial animals with filamentous appearance.
indigenous	– natural to an area, not introduced.
labial palps	– ciliated appendages around mouth which aid in feeding.
larva	– pre-adult stage and free swimming in the case of mussels.
mantle	– outer body tissue enclosing the body which secretes shell.
mesosoma	– a glycogen storage and reproductive organ in mussels.
metamorphosis	– a period of rapid transformation of larva to adult form.
nacre	– the iridescent innermost layer of a molluscan shell.
pericardial cavity	– cavity in which the heart lies.
periostracum	– horny outer layer of molluscan shells.
plankton	– floating or weak swimming plants and animals.
pseudofaeces	– material discarded by mussels having been entrapped with food material.
retractor muscle	– muscles associated with the foot of the mussel.
seed	– young mussels of a size suitable for transfer and use in aquaculture.
spat	– term usually describing very young settled mussels.
trematode	– flat worms sometimes parasitic with usually complicated life cycles.
valve	– in mussels the complete half shell.
veliger	– larval stage prior to adult metamorphosis characterised by the presence of a velum.
velum	– ciliated swimming and feeding organ found in molluscan veliger larva.