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Volume 2

by

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PREFACE

Scallops are an important group of molluscs that have contributed to the affairs of man for many years. In the last century scallops have become economically valuable in many countries throughout the world. Natural stocks support large fisheries and aquaculture operations contribute to about half the world landings which amounted to over 875,000 tonnes in 1990.

International Pectinid Workshops have been held more or less biennially since they were first convened in Baltimore, Ireland in 1976. The purpose of these Workshops is to provide a forum for discussion of all aspects of research work being undertaken on scallops including, fisheries, biology and culture. The Workshops have attracted not only scientists but people from industry and resource managers. By design, Workshops have maintained an atmosphere of informality to encourage open and free discussion so that results of most recent research work can be presented and discussed by all attendees.

The 9th International Pectinid Workshop was held in Nanaimo, British Columbia, Canada from 22-27 April, 1993 and was attended by 150 scallop biologists and industry people from 17 countries. A total of 64 oral, 21 poster and 10 video presentations were made at the Workshop that covered seven fields: growth, physiology and nutrition, mortalities and disease, aquaculture, reproduction and recruitment, genetics, fisheries and general biology. This attests to the growing interest, number of people involved with scallop work worldwide and the ever increasing volume of information that is accumulating on scallops.

Papers from most Workshops have not been published, however, 47 papers presented at the 7th Workshop were published in a single volume and papers from the 8th Workshop have been submitted for publication. With the increasing worldwide interest in scallops, it was decided to publish papers presented at the 9th IPW. Authors were asked to prepare a six page summary of their paper for publication and this has been followed by some authors. Other authors preferred to publish a shorter paper or an expanded abstract since they plan to publish their papers in other venues. For those presentations where no paper was received, the abstract printed in the program is given so a complete record of papers presented at the Workshop will be available to the scallop community throughout the world.

The 9th International Pectinid Workshop could not have been held without the support of many agencies and these are listed on the following page. In particular we would like to acknowledge the assistance of the following organizations whose help aided in sponsoring the Workshop, assisted people to attend the Workshop and greatly aided in producing this publication: Department of Fisheries and Oceans Canada, Industry Science and Technology Canada, Natural Science and Engineering Research Council of Canada, Ocean Production Enhancement Network, Pacific Biological Station, Province of British Columbia Ministry of Agriculture, Fisheries and Food, and Technology Inflow Program (NRC). To all of our sponsors we extend our warmest appreciation.

Assembling this publication has been a time consuming task. We extend our warmest thanks to all who have assisted with the publication and to all the authors who submitted their papers. Because of the bulk of this publication it was decided to publish it in two volumes for practical considerations. The first volume contains the sections on General Biology, Mortalities and Disease, Reproduction and Recruitment and Genetics, the second volume the sections on Aquaculture, Fisheries and Growth, Physiology and Nutrition.

Neil F. Bourne, Barbara L. Bunting, Linda D. Townsend
Nanaimo, B.C.
April 1, 1994

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ABSTRACT

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RÉSUMÉ

Bourne, N. F., B. L. Bunting, and L. D. Townsend. 1994. Proceedings of the 9th International Pectinid Workshop, Nanaimo, B.C., Canada, April 22-27, 1993. Volume 2. Can. Tech. Rep. Fish. Aquat. Sci. 1994: 217 p.

Des ateliers internationaux sur les pectinidés ont lieu à tous les deux ans et constituent une tribune permettant une discussion libre et ouverte sur une vaste gamme de sujets concernant les pétoncles. Le neuvième atelier international sur les pectinidés a eu lieu à Nanaimo, en Colombie-Britannique (Canada), du 22 au 27 avril 1993; y ont participé 150 personnes venues de 17 pays. On y a présenté 64 communications, 20 séances d'affichage et 10 vidéos. Les présentations ont été réparties en sept catégories : croissance-physiologie-nutrition, mortalité et maladies, aquaculture, reproduction et recrutement, génétique, pêches et biologie générale. On trouvera dans la présente publication les articles ou résumés des communications présentées lors de ce neuvième atelier. Pour des raisons pratiques, ce document comporte deux volumes. Le premier volume regroupe les communications portant sur la biologie générale, la mortalité et les maladies, la reproduction et le recrutement, et la génétique; le second, celles portant sur l'aquaculture, les pêches et la croissance, la physiologie et la nutrition.

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AQUACULTURE

EXPERIMENTAL SCALLOP CULTURE USING HATCHERY-PRODUCED JUVENILES

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ABSTRACT

Due to the decline of king scallop, *Pecten maximus*, populations, the French and Brittany governments financed a program to re-seed scallop beds. Results of previous studies by IFREMER showed that regular spat production in the wild was insufficient to maintain adult stocks. In 1981, they began to produce scallop spat artificially in hatcheries. Later, a spat production program was organized that had three successive stages:

1. production (two months) of 2 mm postlarvae in a hatchery-nursery;
2. intermediate culture of juveniles from 2-30 mm in cages (six to nine months);
3. on-bottom growout for three years.

Scallops were dredged two or three years later when they were greater than 100 mm shell height and weighed 130 to 150 g each. Recapture rate was variable, 25 to 50% of estimated stock. In the immediate future, the rapid development of hatchery technology may lead to an increase in spat production and a decrease in costs. However, poor survival rate of spat when transferred to the sea is a limiting factor for production. Other limiting factors are mortality due to predation and dispersion, and the quality and availability of sites. At present, harvest is about 100 t of scallops from annual seedings. The problem is whether this type of production is economically viable without public financing. Production would have to finance the complete operation: about 0.10 FF (less than 2 cents) for postlarvae and 0.60 FF (10 cents) for juveniles, i.e. 15 to 20 FF/kg (3 or 4 US$) to produce scallops commercially, including harvesting costs. Groups of fishermen in conjunction with IFREMER have begun experimental scallop culture trials in other areas. Breton oyster farmers are also looking at the feasibility of scallop culture in conjunction with culture of the European oyster, *Ostrea edulis*, which also requires low culture densities and a three-year breeding cycle.

RECENT DEVELOPMENTS IN BAY SCALLOP, *ARGOPECTEN IRRADIANS*, CULTURE IN CHINA

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INTRODUCTION

A recent review of bay scallop, *Argopecten irradians*, culture and fisheries in Shandong and Liaoning Provinces, in the northern portion of the Yellow Sea (Bohai Sea), was conducted in March 1993. Several attempts were made to introduce the east coast United States bay scallop to China between January 1981 and December 1992. The first two attempts met with failure, but the third group of 120 scallops received on December 16, 1982, met with success. Twenty-six individuals of this third group survived and were subsequently conditioned and spawned in early 1983. A major scallop fishery has developed for several coastal areas in both provinces.

The Chinese have an indigenous species which is already cultured from hatchery seed. The Chinese scallop, *Chlamys farreri*, requires two to three years to reach 5-7 cm in size whereas the bay scallop, now cultured in China, normally requires less than ten months to reach a similar size. This was one of the principle reasons why the Chinese wanted to attempt culture of this species. It should be noted that the bay scallop (Fig. 1) which was introduced from the United States is hermaphroditic, whereas the Chinese scallop has separate sexes.

The successful introduction has led to substantial economic gain for some of the regional marine culture areas surrounding the Yellow and Bohai Seas. From the original 26 individuals which were first spawned in the beginning of 1983, the latest estimate of production for China was placed at 130,000 t live weight in 1992 (Fig. 2). Recent reviews have shown that scallop culture is now undertaken in many of the major areas as shown in Figure 3. The major producting areas are located on the east side of Liaodong Bay near the township of Jinzhou, Liaoning Province, in Laizhou Bay and the Qingdao-Jiaonan region of Shandong Province. Of these three areas, Laizhou Bay appears to produce the best growth in the bay scallop. It is postulated that the Laizhou Bay area, which is influenced by the Yellow River, has a range of salinities of 24-31 ppt. The slightly lower range of salinities coupled with a high nutrient load in Laizhou Bay from the Yellow River, appears to be better for cultivation of bay scallops.

A few comments about bay scallop culture and related issues are appropriate.

HATCHERIES

It appears that numerous hatcheries are present throughout the growing areas. As an example, there are approximately eight hatcheries near the township of Laizhou and 44 hatcheries in the Penglai-Yantai areas. There are 30 or more hatcheries around the Qingdao and Jiaonan growing regions.

All hatcheries follow a standard procedure and most grow three to five species and/or types of algae. One alga grown in all hatcheries is *Phaeodactylum tricornutum*, a larger diatom which is used for feeding broodstock that are being conditioned. It is also mixed with other algae for feeding larger scallop larvae. Also cultured is *Isochrysis galbana* and *Pyramimonas* sp., which are used primarily to feed the larvae. It should be mentioned that *I. galbana* has been brought from the United States, but its culture has apparently not been highly successful. It grows well under culture in 20 l containers; however, once it is put into the larger tanks for batch culture, it usually crashes. The Chinese stated they were able to isolate two strains of similar *I. galbana* from Haiyang County in Shandong Province (to the northeast of Qingdao). These two new strains proved to be easy to culture. One is a high temperature *I. galbana*, growing best at 30°C, whereas the other strain grows best a lower temperature of 20°C. Other types of algae such as *Chlorella* sp. are also used, but mostly cultured are the basic species noted.

Scallops are brought into the hatchery during March, when the temperature is still cold. The temperature of the water for broodstock is increased 1°C every one to two days until a temperature of 23°C is reached. Generally, round 15 m^3 cement tanks are used for conditioning adult bay scallops. Once the temperature reaches 23°C, an estimated 70-80 scallops are added per m^3 of tank space and allowed to spawn. When egg density reaches 50/ml in the tank, the adult broodstock are transferred to another tank for a second spawning. This second batch usually does not have as good larval development and/or survival, but sufficient larvae are obtained to make it economically viable. Usually after the second spawning the broodstock is placed in cooler water and slowly reconditioned for another spawning in 20 days. Again, survivorship from this third spawning is not generally as good as the first spawn, but it takes less time to condition them for the third spawning. The first spawning is the best. Generally broodstock are conditioned for spawning during the last week of March and throughout April.

NURSERY

When eyed larvae are observed in hatchery tanks, a special densely braided netting is placed in the tanks to catch the metamorphosing larvae. Ten to fifteen days later (depending on temperature), the netting is placed in a small mesh (0.4-0.5 mm) bag and hung on longline systems in the sea. One month later they are retrieved, washed, and the spat collected. Approximately 1000 spat are placed into a small mesh bag and hung out again on the longline system. The scallops are allowed to grow to 5 mm in these bags for 2.5 months, at which time they are large enough for commercial sales. Generally, spat are separated and thinned and held in bags at densities of 200-300 of the same size for another 20 days, until they reach a size of approximately 1.0 cm. In some areas they are then held in intermediate lantern nets with small mesh until they are approximately 2.5 cm, at densities of approximately 200 per compartment. On reaching 2.5 cm, the scallops are transferred to regular large mesh lantern nets (but with the same outside dimension) to give a density of 30-35 per layer and left until harvest. In some areas, no intermediate lantern nets are used, and cultivation goes through various size mesh bags until the scallops reach 2.5 cm before transferring them to the final lantern nets for growout to harvest size.

GROWOUT

Generally, when bay scallops are placed in the final lantern net for growout to harvest size, the only maintenance is periodic cleaning of the net or even changing nets if fouling is severe. The time from seed collection in April to the time of harvest in October-November is brief. Longline systems cover vast areas, e.g. in Shandong Province, over 35,000 MU (2350 ha) surface area is used for bay scallop culture.

NEW STOCKS INTRODUCED

Two new stocks of bay scallops were introduced in 1991 from the east coast of North America. One was from eastern Canada, which is presently being conditioned and spawned to produce an F2 generation. The other is similar to the original stock from Florida and will be used primarily in the southern part of China. No attempts have been made to interbreed the various stocks. The eastern Canada stock appears to have good potential for the region, since it appears to grow to a larger size. The Florida stock was found to be doing well under experimental conditions in Guangxi Province in southern China. The Florida stock has a faster growth rate and attains commercial size faster than stocks in the northern areas. A new hatchery is being built in Guangxi province to breed this Florida stock.

DISEASE CONCERNS

There are two concerns about the introduction of bay scallop stocks. First of all, although the original introduction was small, it is essential to maintain a great heterozygosity in order to sustain a fisheries of 130,000 t. Some recent evidence, i.e. survivorship of larvae in some hatcheries, may indicate reduced heterozygosity of broodstock. The second and main concern is called velum disease which occurs during culture of the larvae. Ciliary cells of the velum begin to slough off and the larvae die in mass. The cause of this disease is unknown, but it may be due to possible environmental problems related to hatchery practices, viral infestation, or other causes. Another concern is more frequent evidence of mantle recession in adults, where the edge of the mantle is pulled back from the edge of the shell. According to scientists, this condition usually results in poor larval success. It is unknown whether both conditions are related to genetics, environmental conditions, or viral diseases.

CONCLUSIONS

Bay scallop culture in China has obviously provided economic benefits for Shandong and Liaoning Provinces, but scallop growers are becoming concerned with the increasing evidence of larval mortalities. However, it is expected that scallop fisheries will continue to expand. One possible area for extension is polyculture, growing bay scallops with the Chinese marine white shrimp, *Penaeus chinensis*. It has been found that when bay scallops are grown on the bottom of shrimp ponds they reach a larger shell size in a shorter time than when cultured in the sea. Further, scallops grown in shrimp ponds tend to have a larger muscle, almost double in size, than when cultured in the sea. Faster growth rate and larger muscle size may be due to the high nutrient load in shrimp ponds.

Most other coastal provinces south of Shandong and Liaoning Provinces are experimenting with bay scallop culture. As a result of new introductions from eastern Canada and Florida, it may be possible to interbreed these stocks. However, it is recommended to proceed slowly with interbreeding until a better understanding of the discreteness of stocks is obtained through protein analysis.

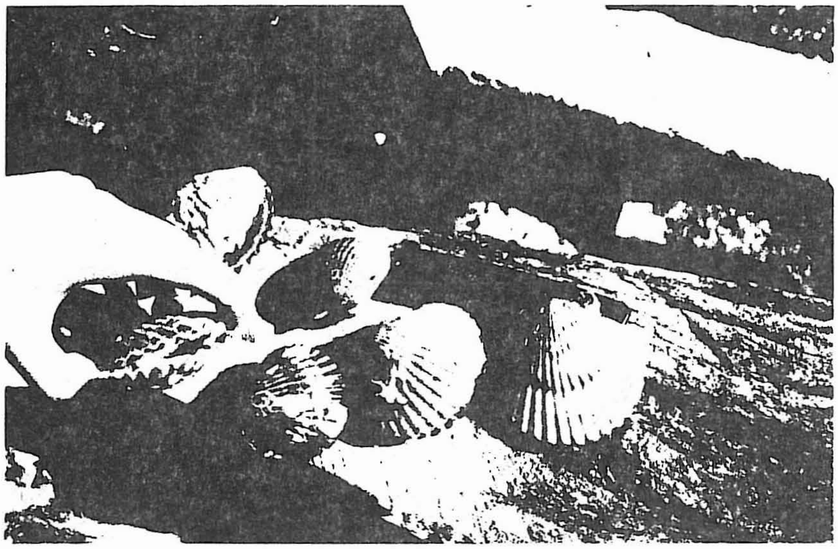

Fig. 1. Introduced bay scallop, *Argopecten irradians*, in Jiaonan, China.

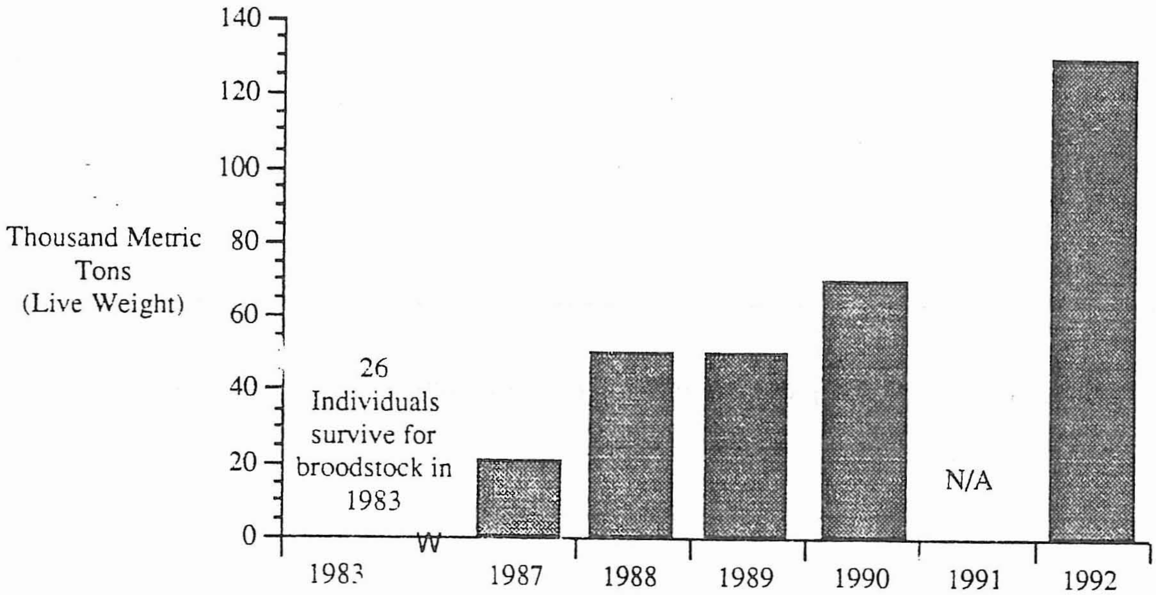

Fig.2. Production of bay scallops, *Argopecten irradians*, in China.

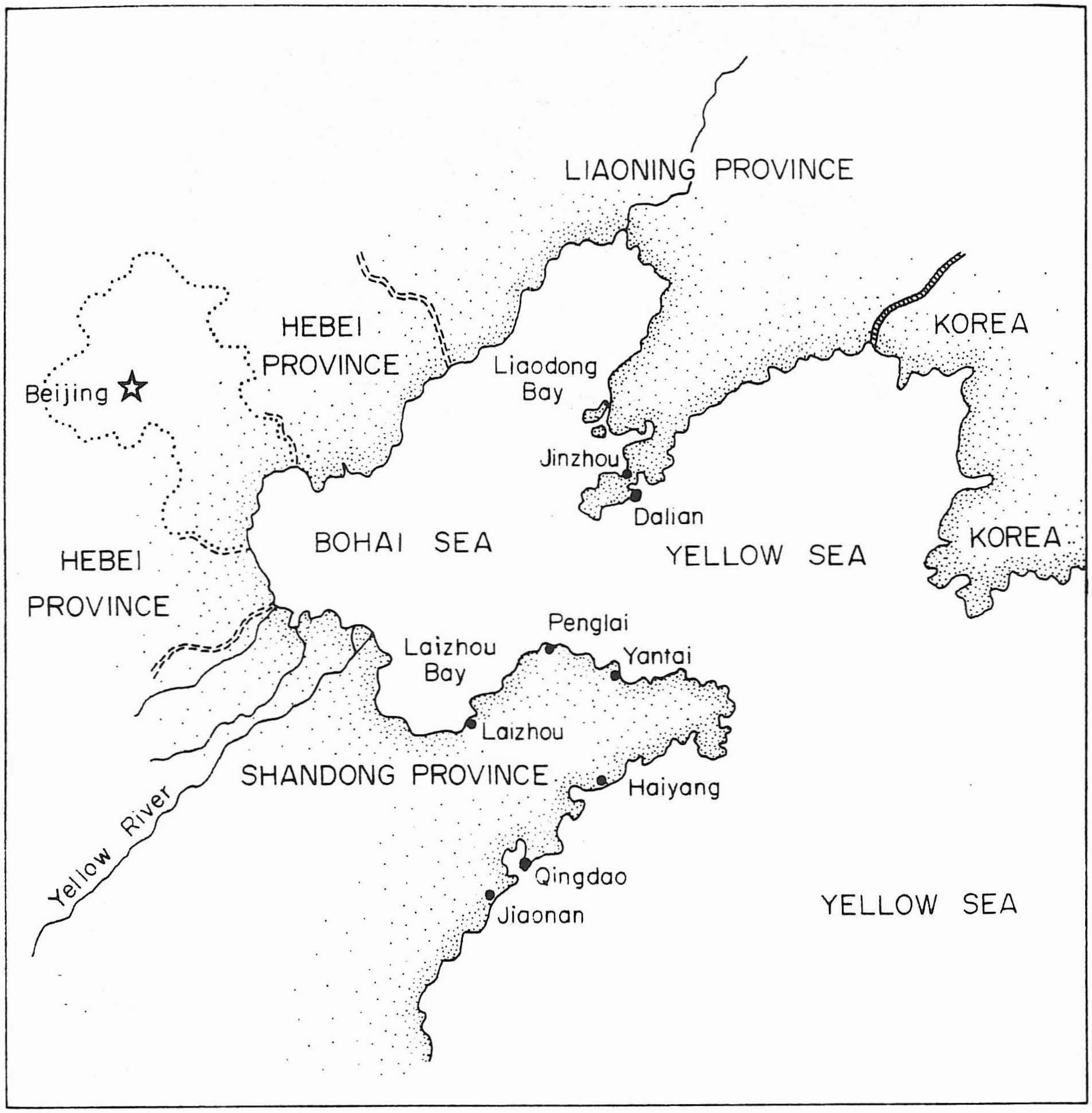

Fig. 3. Major bay scallop growing areas in Shandong and Liaoning Provinces of China.

OCEANOGRAPHIC CONDITIONS CONDUCIVE TO CULTURE OF THE JAPANESE SCALLOP, *PATINOPECTEN YESSOENSIS*, IN BRITISH COLUMBIA, CANADA

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ABSTRACT

The waters of Little Espinosa Inlet, located off the northwest coast of Vancouver Island, have demonstrated the highest growth rates and the best survival of hatchery produced Japanese scallop seed (1-3 cm) in British Columbia. This paper describes spatial and temporal changes in the water column properties of this unique oceanographic system, and discusses these conditions in terms of scallop growth and survival. A synopsis of important site selection criteria, based on the three year evaluation of our site, is also provided. It was found that site bathymetry plays an important role in maintaining water column stability and in ensuring that an optimum salinity and temperature environment is provided throughout the year at this site. Cold water entering over an outer sill (inlet mouth) during flood tides replenishes the lower water column water, while warmer water is withdrawn from the inlet across the surface during the ebb tide. At midsummer, the warmer surface water extends as low as 5 m (the upper zone in which our scallops were grown). Although plankton availability increased during this period, growth was retarded once water temperature reached 12.5°C. When temperatures exceeded 16°C, mortality increased. The sensitivity of the Japanese scallop to water column instability, particularly with respect to salinity and temperature, makes proper site selection essential for this species. Our success with culture of this species is directly related to the oceanographic conditions of the site.

INTRODUCTION

In the mid 1980's, the Japanese scallop, *Patinopecten yessoensis*, was introduced to the west coast of Canada through the Canadian Federal Department of Fisheries and Oceans (DFO). Given the extremely limited wild scallop fishery on this coast, it was decided that importation of a suitable culture species would contribute significantly to the shellfish culture industry on this coast. Employing all necessary quarantine and screening precautions with introduction of this species, procedures for hatchery production of seed were developed at the Pacific Biological Station in Nanaimo. These procedures have since been transferred to industry, and are presently employed by a single hatchery facility (Island Scallops Ltd.) located on the east side of Vancouver Island.

With the seed production aspect of Japanese scallop culture in British Columbia initiated and controlled by hatchery techniques, focus has now turned to growout phase of the culture process, and to identifying approaches and growing conditions which will optimize scallop growth while minimizing pre-harvest mortalities. In the spring of 1989, Aquametrix Research and Espinosa Mariculture initiated an independent study to examine the commercial feasibility of growing Japanese scallops off the northwest coast of Vancouver Island. The objectives of this study were to:

1 determine seed transportation mortality (from hatchery to growout site);
2. estimate timing and magnitude of mortality through the growth cycle;

3. explore husbandry techniques and procedures which might optimize scallop growth;
4. assess scallop growth characteristics in relation to the oceanographic characteristics of the growout site.

This paper includes a preliminary discussion of the results for objective 4, providing a description of our study site in terms its physical oceanographic characteristics, and a summary of how these site attributes contribute to the success of scallop growth and survival. A summary of these data is subsequently used to stress the importance of site selection and proper evaluation procedures for scallop culture growout on this coast. Presentation and discussion of the performance information (objectives 1-3) will be provided in future publications.

MATERIALS AND METHODS

STUDY SITE DESCRIPTION

Our foreshore study site is situated within the southern arm of Little Espinosa Inlet which is located along the northwest coast of Vancouver Island just north of Nootka Island. The site is within 5 km of the mouth of Esperanza Inlet, a comparatively large passage which faces southwest into the open Pacific and is therefore directly influenced by the coastal upwelling processes discussed earlier.

The southern arm of Little Espinosa Inlet is approximately 2 km long, 500 m in width, and is aligned due north-south. As the majority of storm tracks occur in a southeast-northwest or a southwest-northeast direction, our site never experiences the direct effects of wind. As the inlet is a relatively short body of water it does not provide adequate fetch for any build-up of wind-induced wave or swell motion through the site even if air movement occurs along a north-south vector.

Since the shallow entrance to Little Espinosa, approximately 10 m in depth, is 90° to the long axis of inlet, no significant wave swell, produced outside of the inlet system, can be relayed effectively through our growout site. Tidal currents across the mouth of the inlet reach 4-6 knots, and as a consequence the epibenthic communities within this area are rich with filter feeding macroinvertebrates, including a healthy population of rock scallops, *Crassadoma gigantea*.

At the north end of the south arm a very narrow and shallow passage separates our growout sites from the upper basin of Little Espinosa Inlet. Referred to as the Causeway, water movements through this opening come to a complete stop for only minutes during the change in tidal direction. As this passage, which is merely 5 m across and 2 m in depth, separates two relatively large bodies of water, the diurnal tidal fluctuations which must transfer water through the causeway typically result in tidal height differentials which create water movements of 800 cm/sec through this passage.

The shallow sills located at the mouth of Little Espinosa Inlet and at the causeway produce an isolated basin with an average centreline depth of approximately 55 m. The inlet is not sufficiently deep so as to support a stagnant, anoxic bottom environment as is so often found in many coastal fjords. With the exception of beaches situated on either end of this arm, the minimal littoral formations along the sides of the inlet, with relatively steep subtidal slopes, enhance installation of suspended culture systems along the foreshore.

STUDY DESIGN

In 1989 Aquametrix Research, in cooperation with Espinosa Mariculture, designed and initiated a study to examine the potential for scallop production at the Little Espinosa site. In addition to documenting growth and survival of scallop seed with depth, the continuing study has obtained information on the effects of growout density on culture success, and collected extensive information on spatial and temporal changes in oceanographic characteristics of this inlet system.

A monitoring program was established at one month intervals over the entire three year study. During each site visit, an oceanographic survey at four inlet centreline stations, plus one located outside of the inlet, included a water column profile of temperature, salinity, and dissolved oxygen. The continuous data-logging CTD used to accumulate this information was also deployed at each of the four stations during both the ebb and flood tides to establish movements of outflow and inflow water across the study site.

Oceanographic information obtained through this monitoring program was related to scallop growth and survival data, which was collected concurrently.

RESULTS AND DISCUSSION

OCEANOGRAPHIC CRITERIA

The Japanese have identified three basic site criteria which should be considered when attempting to grow *P. yessoensis*. These include:

1. maintenance of low-moderate water temperatures (7-10°C);
2. sustaining high water column salinity (>28 ppt);
3. minimizing movement, or motion, of the culture apparatus.

These general oceanographic characteristics, considered important to successful culture of *P. yessoensis* in Japan, can be readily employed in a gross water column evaluation of the British Columbia coastline to delimit specific areas capable of sustaining scallop culture. The coast of British Columbia, comprised of a variety of deepwater habitats including sheltered inlets, small and large embayments, exposed open foreshore, constricted high-current passages, etc., provides considerable opportunity for commercial scallop culture given the proper consideration of the site-specific oceanographic characteristics of each site.

Although gross spatial oceanographic information does give a general indication of regional differences in surface water temperatures, salinities and circulation patterns, it does not imply that it is a good site for the Japanese scallop. One must remember that this shellfish species is a deep water, epibenthic animal, and is therefore not adapted to the oceanographic fluctuations often represented in coastal surface waters.

STUDY SITE CHARACTERISTICS

Temperature-Salinity Profiles

As Little Espinosa Inlet is influenced only by seasonal inputs of freshwater, which are associated with winter rainfall events, the summer salinity profile, which reflects west coast conditions is vertically uniform and maintained at a high salinity of between 30 and 31 ppt. Summer temperature profiles indicate a distinct thermo-gradient, with warm surface waters gradually displaced with cooler waters at depth.

During winter months input of freshwater to the surface waters results in a concurrent reduction in both temperature and salinity. A thermocline and pycnocline corresponding to the freshwater lens which is created over the inlet's surface extends to approximately 3-5 m. Below this layer, salinity becomes vertically stable, again between 30-31 ppt, and temperatures are uniformly cool at between 7-8°C.

Analysis of data collected over diurnal tidal cycles suggests the presence of a density related circulation gyre through the inlet. On the flood tide, cool high salinity water entering over the outer sill sinks to the bottom of the inlet and maintains the stability and similarity of this lower water column with that of the outer coastal waters. During the falling tide the movement is primarily surface driven, with the warmer and seasonally less dense water moving seaward and over the outer sill. Within either side of the tidal cycle, deeper water is likely upwelled near the causeway and entrained within the surface waters at this point.

T/S Effects on Scallop Growth/Survival

Although salinity remained stable at between 30-31 ppt below approximately 4 m, temperature changed considerably throughout the water column, over the annual sampling period. Figure 1 summarizes the growth and survival data collected over two consecutive years for each of two distinct batches of scallop seed. For each experiment, the scallops showed an average, linear growth rate of between 5 and 7 mm/month. Retarded growth (RG), or deviation from this linear growth pattern, occurred during the summer months when water temperatures exceeded 12.5°C.

Slow growth was sustained above this temperature with no increase in mortality until such a time as water temperatures attained or exceeded 16°C. The percentage of mortality incurred is shown by the bars. Natural, "background" mortality of between 0.5 and 1.5% was typical of any sampling period during the year. However, when temperatures exceeded 16°C, mortalities as high as 17-21% were recorded.

Vertical changes in temperature and salinity represent seasonal events within coastal waters which can and should be closely monitored prior to deploying a scallop suspended culture system. Proper delimitation of pycnoclines and thermoclines within the site, as well as seasonal changes in the extent of the surface layer, will provide valuable information on the optimum placement of growout structures within the water column.

At our site, for example, down or drop lines have been established no closer to the surface than 7.0 m, thereby avoiding fluctuations in salinity and temperature associated with freshwater intrusion and summer heating. Placement of the longline backbone within the surface waters results in a periodic emersion in freshwater and a coincidental cleaning of any fouling which may develop on the surface on the line.

Motion

Motion, whether wind-induced or tidal current action, was not substantial at any time of the year at our site. During extreme outer coast storm events, the deflected winds through the inlet resulted in a surface chop of no greater than 0.5 m. In fact, unlike the Japanese growers, who culture scallops on submerged dampened longlines to minimize wave-induced motion, we have chosen to grow our animals on standard surface longlines which are much more easily handled.

Site selection and evaluation must define, *a priori*, what (if any) type of motion may influence the growout apparatus, and thus the scallops, at a site. Both tidal currents and wave-induced motion will most likely affect survival of these animals. Where wave-induced motion can cause vertical agitation of scallops, tidal currents pose a horizontal force which may cause significant bowing of the drop lines and result in a comparable stress, even if submerged lines are employed to mitigate wave action effects.

Quantification of climatological information and tidal activity through a potential culture site thus represent important site selection considerations for coastal scallop production. Use of Japanese anchoring systems and longline arrangements may not necessarily solve the potential problems of motion for this coast.

CONCLUSIONS

The sensitivity of *P. yessoensis* to temperature, salinity and motion have important implications to site selection. As suggested in the previous discussion, surveys for appropriate grow-out or production sites should be initiated within coastal regions known to provide these basic oceanographic requirements. Once a potential site is selected, one would be well advised to review all of the available oceanographic information for the site, and if such information in unavailable, to implement an independent seasonal survey to identify water column dynamics for the site.

Japanese scallops do not tolerate large deviations in either temperature or salinity. One should remember that this species occurs naturally on the bottom, in deep water. Conditions in these types of environments are generally more stable, and are not impacted by seasonal changes in temperature or in salinity as are surface waters.

Unlike many northern latitude regions of the world, the thousands of kilometres of convoluted coastline comprising British Columbia offer a choice of potential suspended scallop culture sites. The capability of these sites to sustain commercial production will depend largely upon initial site selection evaluations.

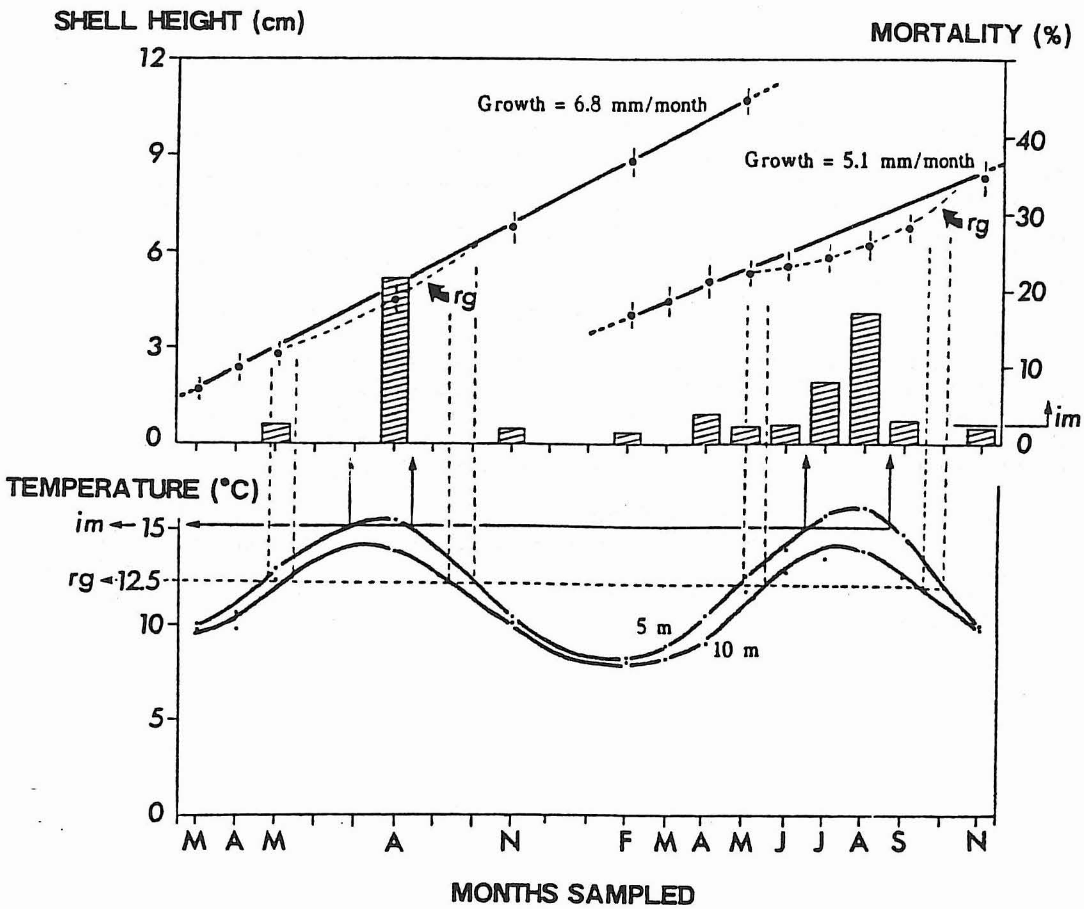

Fig. 1. Japanese scallop growth and survival with respect to water column temperatures at depths of 5 and 10 m. Two distinct seed batches demonstrate retarded growth rates (rg) at water temperatures above 12.5°C and show increased mortality (im) when temperatures reach and exceed 16°C. Growth is measured as shell height (cm) and mortality is expressed as a percentage.

EXPLOITING LIFE-HISTORY CHARACTERISTICS OF THE SEA SCALLOP, *PLACOPECTEN MAGELLANICUS*, FROM DIFFERENT GEOGRAPHICAL LOCATIONS IN THE CANADIAN MARITIMES TO ENHANCE SUSPENDED CULTURE GROWOUT

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ABSTRACT

Sea scallops on the Atlantic coast of Canada exhibit both annual and biannual spawning cycles depending on their geographical location. Populations with annual cycles normally spawn during late summer (August-September) and collected spat can be grown to commercial size (90 mm shell height, 15 g meat) in suspended culture in 33-36 months. Populations with biannual reproduction usually spawn both during early summer (June-July) and during fall (September-October). Spat collected from the early cohort can be grown to market size in 25-27 months while the late set requires 36 months for growout. Use of early spawning populations for spat collection or hatchery production will significantly reduce the growout period for this scallop. Strategies exploiting both population types would yield a steady supply of market size scallops for the farmer, especially if an assortment of end products were desired (i.e. 50-70 mm live markets, 120 mm roe-on).

SEED-RECAPTURE OF THE SCALLOP, *PECTEN MAXIMUS*, BY COMMERCIAL DREDGING IN THE BAY OF BREST DURING 1991-92

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ABSTRACT

A seed-recapture study of the king scallop, *Pecten maximus*, was part of a 10 year program that will end in 1993. As a result of previous work (Dao, presented at 8th. International Pectinid Workshop) two areas were selected in the Bay of Brest in 1989 to study the relationship between seeding and commercial harvest by dredging. The first area of 50 hectares was closed to dredging during the experiment. The second area, of 200 hectares, was seeded immediately after the fishing season in order to let the juveniles grow for the first months without any disturbance before commercial fishing began. Between May 1989 and April 1990, 1,035,000 juveniles of 25-30 mm were seeded to give a density of 1 scallop·m^{-2}. From November 1991 to February 1992, 40 t of cultured scallops were harvested, representing 40% to 50% of the total number of scallops on the grounds. Recapture rate of seeded scallops was 20.8% by number, but 6% of the remaining scallops after the fishing season were seeded scallops. Seeding operations were undertaken in several batches and variability between-batches was greater than the variability between-areas. Results of this work show that the two strategies can be used for further management of the resource and that improvement can be expected with better husbandry of early juvenile stages.

INTRODUCTION

Experimental seeding of juvenile king scallops, *P. maximus,* is part of a national research program that will end in 1993. The program developed technology for scallop aquaculture, through hatchery production of juveniles, intermediate culture of juveniles in trays set in rigid frames on the sea floor, followed by seeding at various sites in accordance with local enhancement strategies. Fishermen from the Bay of Brest and Bay of Saint-Brieuc have been involved in all these operations.

In the Bay of Brest, seeding was first undertaken to restock depleted stocks (Dao et al. 1985), but this goal was reviewed in 1988 after initial results showed low survival rates due to environmental disturbances in the experimental area. The new management objectives of this project were:

1 test scallop ranching by harvesting animals 2-3 years after bottom culture when they had achieved commercial size;
2. concentrate culture in the deeper parts of the Bay which are less sensitive to environmental disturbances;
3. compare two strategies for scallop enhancement management:
    a. seed an area and keep it closed to fishing during the entire experimental period;
    b. seed an area but subject it to regular harvesting.

In the second experiment, seeding occurred during the annual closed season in order to avoid disturbance from fishing gear during the first months following seeding.

MATERIALS AND METHODS

Before seeding, a survey was carried out on the different areas of the Bay using a dredge with an underwater video camera (Merrien 1980; Dao et al. 1985). In conjunction with fishermen, two sites were identified with sandy-mud substrate at a depth of 18 to 25 m: Le Caro and Roscanvel (Fig. 1).

At the first site (Le Caro) an area of 50 hectares was subjected to a restricted fishery. The opening for commercial fishing was restricted to hours and days in order to determine landings and fishing effort. At the second site of 200 hectares (Roscanvel) seeding occurred in early spring so that juveniles would reach a size of 50 to 70 mm before they were disturbed by fishing (two fishing seasons occurred during the experiment).

Two seedings were carried out at both sites to give a planting density of 1 juvenile$\cdot m^{-2}$:

1. Le Caro: 190,000 juveniles of 30 mm shell height in May and 295,000 in September 1989;
2. Roscanvel: 150,000 juveniles in May 1989 and 660,000 in April 1990.

During the experiments, regular sampling was undertaken by divers to assess biochemical condition and state of maturity of the scallops. Sampling also assessed any potential abnormal mortalities. After one year, density was estimated as 0.34 to 0.6 scallops$\cdot m^{-2}$.

At the time of harvest, fishermen completed logbooks giving information on species caught, daily catch and fishing site. Data return has been excellent (80%). Visual counts were made of the number of boats at the two sites and sampling was conducted at each landing port. Sampling was intended to determine the ratio of cultured and noncultured animals through identification of a stress ring layed down at seeding.

Two surveys of biomass were conducted at each of the two sites using an experimental dredge (small sized rings, video camera) before and after commercial fishing. This method is currently used in the Bay of Saint-Brieuc for stock assessment (Dao et al. 1985; Fifas 1991).

RESULTS

Results are presented in Tables 1 and 2. Buyers and consumers did not find any difference between wild and cultured animals.

LE CARO

This area was harvested for eight days in December 1991. After this period, it was determined that there was no difference in scallop density between the experimental site and the surrounding natural area and hence there was no reason to maintain the special closure regulation. Logbooks indicated that subsequent catches in January and February increased total landings by about 10%.

Total landings were estimated at 23 t, of which 66.5% by number and 64.3% by weight was from seeded scallops. This represents 51,300 individuals from the May seeding and 41,300 from the September seeding. This was confirmed by experimental dredging (39,700 and 45,300 individuals, respectively), which was similar to the reported composition. The difference in proportion of animals from the two seedings was due to discarded subcommercial sized scallops during the fishery (80% of scallops from the first seeding were commercial size, 60% of scallops from the second).

The two surveys produced similar data on survival rate. It was estimated that about 17,8000 scallops remained from the May seeding and 12,500 from the September seeding. Calculated biomass from experimental dredging before harvesting was 70% compared to the actual landings. This indicates some problems with the methodology for direct evaluation of biomass (efficiency of the dredge, area occupied by the animals). However, we can conclude that recapture rate of planted seed was 19% and the minimum survival rate was 26%.

ROSCANVEL

The seeding site was located inside the best fishing area in the Bay. Boats concentrated their fishing effort at the beginning of the season in this area and quickly found the exact position where higher yields could be obtained. It was estimated that the fleet remainded on the seeded area for the two first months and later fished the general "Roscanvel" ground. When the different landing and sampling data were combined, as was done for Le Caro, the number of recaptured scallops was estimated at 177,050 individuals (25 t).

As at Le Caro, only some of the scallops (46%) attained commercial size when the sampling survey was undertaken one month before the commercial fishery began. Growth continued during autumn and some animals just below the minimum commercial size that were discarded during the first part of the harvesting season would be captured later. This would explain the low number of scallops caught after the fishing season.

A better estimate of biomass was obtained at Roscanvel than at Le Caro because the bottom had a regular sandy-mud substrate and the dredge was more efficient on this type of bottom. The estimated number of scallops was 258,000 with 233,000 from the April 1990 seeding. This gave a survival rate of 32% and a recapture rate of 22%. Fishing effort was much higher here as seen by the number of scallops remaining after harvest compared with the May 1989 seeding at Le Caro.

The first seeding at Roscanvel gave poor results. This was due to methodology. Scallops were sown on another part of the bed at too low a density to give accurate results. Survival rate of 17% was estimated from survey results but sampling at landing ports in November and December indicated it was only 4.7%. The low number of scallops remaining after the survey suggests they were exploited late in the harvesting season. If only the April 1990 seeding is considered, the estimated survival rate was 35% by survey sampling and 31% from sampling landings and animals remaining on the beds, giving a recapture rate of 26%.

DISCUSSION

Evaluation of all biological parameters for successful bottom culture of scallops must be improved. This is a long term project that requires several technologies. A major problem encountered was estimation of the final area where the scallops were distributed. This is necessary in order to relate the sampling to biomass. Further, the precise efficiency of the dredge must be calibrated for each site and type of substrate. The size of the experiment in Le Caro was too small and gave excessive "edge effects".

However, the experiment did provide basic data for further economic analysis such as recapture rate during commercial fishing (Paquotte and Fleury 1994). Catch per unit effort cannot be determined at Le Caro since most of the tows were made partly out of the seeded area.

During fishing operations, the secondary effect of incidental capture of undersized scallops was discovered. It is known that scallops can be discarded and recaptured during harvesting, thus introducing a mortality due to additional stress. However, fishermen retain undersized scallops for personal use and release very small animals in other areas so they can catch them in the following fishing season. It would have been better in this experiment to delay fishing for one year, however, it was necessary to obtain results rather than wait and determine the optimum recpature rate.

CONCLUSIONS

The two seeding trials indicate that sea ranching of scallops was technically successful and could be undertaken for commercial harvesting. The average percent recapture was 21% but this could be increased to 25-30% with improvements in husbandry. Two growout seasons on the bottom is a short time in the Bay of Brest, and a third would be better and also increase biomass.

Results of the two harvest strategies did not differ greatly. Recapture rates for the two spring seedings were similar (27% at Le Caro, 25% at Roscanvel). However, fishing pressure was not the same. There were three years of growout at Le Caro with a large number of unharvested scallops and two years at Roscanvel and a high fishing effort. These differences caused an increase in the survival rate estimated from the landings: 36.5% against 30.1%, respectively. If this result is confirmed in future trials, the management benefits of closing a seeded area to fishing would be clearly demonstrated.

From the four individual seedings, we obtained various results showing the importance of husbandry and management during growout. There were more differences between seedings than between sites. This was probably due to a number of uncontrolled factors (stress during transportation, size at seeding, predation at different seasons, etc.). These will be investigated in the EEC Concerted Action experiment which started in June 1993.

At present, these results have convinced fishermen and local and regional authorities of the benefits of seeding and it will be continiued for the next three years.

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Table 1. Landings and recapture rate of scallops seeded at Caro and Roscanvel grounds, 1991-1992.

	Landings (t)	Mean Recapture Rate (%)
CARO	15	19
ROSCANVEL	25	22
Natural grounds	40 - 60	
Total	80 - 100	

Table 2. Number of scallops sown, recaptured, remaining, and percent survival at Caro and Roscanvel.

Seeded Juveniles (Number, date)		Number Recaptured	Number "Unfished"	Survival (%)
CARO				
190,000	May 89	51,300	17,800	36.5
295,000	Sep 89	41,300	12,500	18.3
ROSCANVEL				
150,000	May 89	7,050	? or 0	4.7
660,000	Apr 90	170,000	32,000	30.7

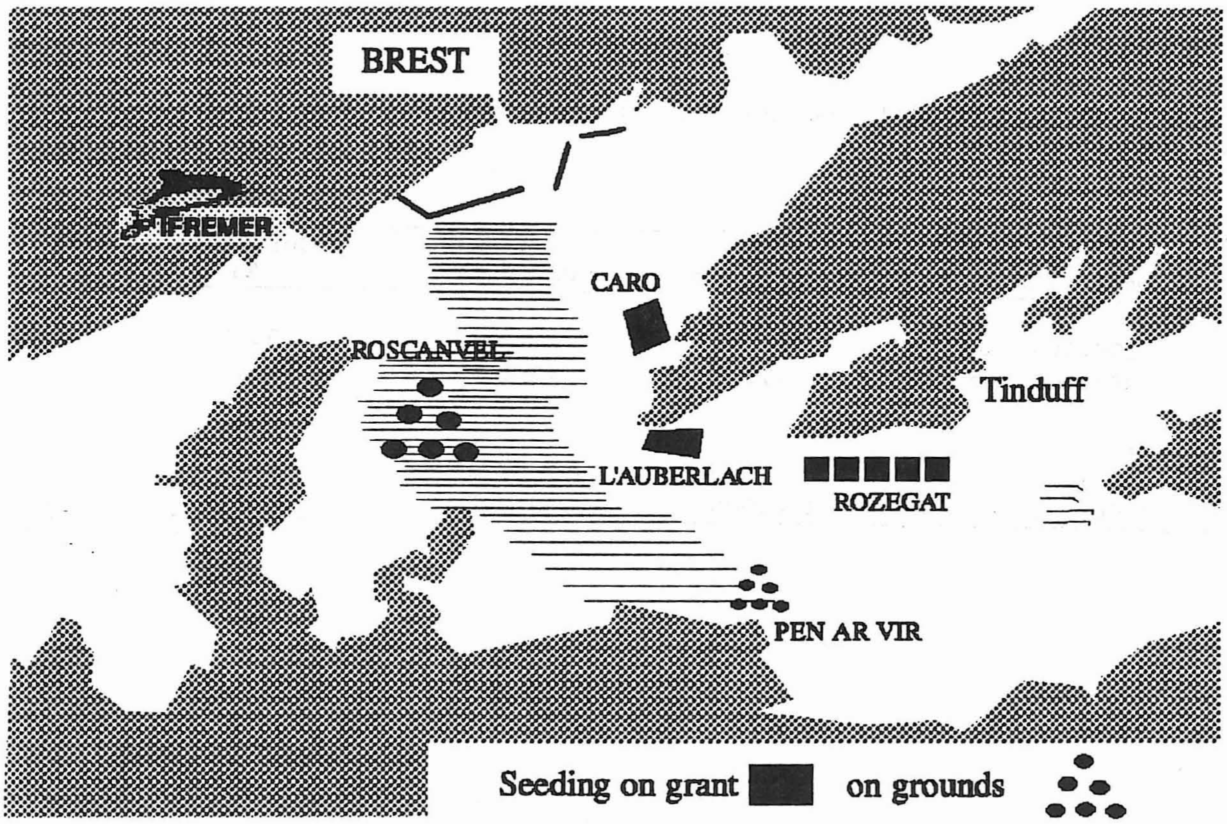

Fig. 1. Experimental seeding areas in the Bay of Brest.

INTRODUCTION OF NORTH ATLANTIC SCALLOP SPECIES AS A METHOD TO STIMULATE SCALLOP CULTURE IN THE PRIMORYE PROVINCE OF RUSSIA

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Scallops are valuable resource throughout the world and are harvested and cultured in many countries. Most world scallop production occurs in temperate waters between latitudes 30° and 55° where dense populations of large-sized scallops occur (Brand 1991). One of the largest species, *Patinopecten yessoensis*, is harvested and cultured in the northern part of the Sea of Japan. Production in Japan ranges from 260,000-280,000 t annually (Ito 1991) and about one fifth of this production is sold in the United States, realizing more than $100 million (US) per year. In contrast, production of this species from culture and illegal fishing operations on the inshore grounds in the Primorye Province of Russia, is scarcely 500 t per year, in spite of the fact that environmental conditions in Primorye and Hokkaido are essentially the same. The reason for poor production of cultured scallops in Primorye is that the government has stressed high seas fisheries and capture of natural stocks rather than investing in aquaculture.

Recently there has been a change in the direction of the economy in the far east part of Russia and development of aquaculture will be encouraged in the next two or three years. However, *P. yessoensis* is the only scallop species available for culture in this region. Culture areas for *P. yessoensis* are located in the upper shelf zone at depths of 5-30 m in bays and harbour areas which are exposed to wave action or are on the lee side of islands in Peter the Great Bay. Increasing industrial effluent is discharged into these shallow areas. Furthermore, the boundaries of culture areas are ill-defined. The grounds are readily accessible recreational activities, tourists and illegal fishing, and local authorities have little control over these activities. The lack of management of these inshore areas makes investment in aquaculture unattractive for the next five to seven years. It is doubtful if conditions will improve before 2005.

The lower part of the shelf from depths of 30-130 m is being subjected to increased disposal of domestic sewage. This lower zone is not subjected to fishing and is characterized by small variations in temperature and salinity and has stable currents that bring a steady flow of nutrients. The substrate of the lower zone is sand with a mixture of gravel and pebbles and is inhabited by macrobenthic species, including *Liocyma fluctuosa, Pododesmus macrochisma, Ciliatocardium ciliatum, Serripes groenlandicus, Turritella fortilyrata, Astarte borealis,* and other species. Three species of byssal-attaching scallops are found in this area, *Chlamys erythrocomatus, C. rosealbus* and *C. strategus*. These three species have a patchy distribution on the gravel-pebble and rock outcrop areas. Slow growth rate, erratic reproduction, small muscle size and problems with harvesting and processing make this group of scallops uneconomical for culture or harvesting compared with larger-sized free-living species. However, larger free-living scallops are absent from the lower shelf region in the Sea of Japan and also from the shelf area in the Sea of Okhotsk.

A comparison of environmental characteristics of the shelf area in Peter the Great Bay and the northwest part of Primorye indicates that environmental parameters in the lower area such as temperature, salinity, substrate, food and hydrodynamics are similar to areas inhabited by the giant scallop, *Placopecten magellanicus*, and the king scallop, *Pecten maximus*. These widely dispersed and commercially valuable species differ from *Chlamys* sp. in that they are larger and have higher gamete production and a faster growth rate.

The giant scallop, *P. magellanicus* (Gmelin, 1791), occurs on the shelf area of Canada and the U.S.A. from Cape Hatteras (36°N) in the south to Newfoundland (52°N)in north (Naidu 1991) at depths of 55-384 m in the south to 2-180 m in the north. The main fishing areas are between latitudes 40° and 45°N in depths of 10-100 m. The species is found on a wide range of substrates including dense silt, fine and coarse sand, gravel and pebbles mixed with boulders. Both juveniles and adults prefer substrates that have bottom current speeds of more than 0.3 m/s.

Gonadal devlopment begins in the first year at a temperature about 1°C and they are ripe during the second year when the scallop is 25-75 mm shell height. Spawning occurs generally in August-September but sometimes from September-December when bottom temperatures have increased to 8°C (Barber and Blake 1991). Average length of the pelagic larval phase is about 35 days at 15°C. Larvae frequently settle on the lower side of pieces of gravel (Thouzeau et al. 1991). Juveniles and some adults attach themselves to empty shells and pebbles with thin byssus. Giant scallops may live for 15-20 years at which time they are 150-180 mm shell height, but they grow to commercial size in 4-5 years. Optimum growth occurs at 10°C. Lethal temperature for adults is 20-24°C. Density of self-sustaining populations is between 0.6-8.8 individuals$\cdot m^{-2}$ (Orensanz et al. 1991). Commercial fishing is considered profitable when the density is more than 0.6 scallops$\cdot m^{-2}$. Predators include several species of fish, e.g. plaice, sea stars and crabs. At present the price for 1 kg of muscles is US $14-18.

The king scallop, *P. maximus* (L., 1758), inhabits shelf areas off the coast of the U.K., Ireland, France, Spain and West Africa (Brand 1991). The southern limit of distribution is approximately latitude 30°N and the northern limit is in the Shetland Islands (61°N) and on the Lofoten Islands (68°N). King scallops occur in depths from 3-183 m but maximum densities are between 20-50 m. The main fishing areas are found between latitudes 48° and 56°N. Larvae settle most frequently on substrates that are fine to coarse sand and gravel. The species is rarely found on silty substrate.

King scallops are hermaphrodites. They are sexually mature at 2-3 years after attaining a size of 50-80 mm shell height. Major spawning occurs in April-May with a second peak occuring in some areas (Barber and Blake 1991). Water temperature for spawning is 7-9°C (Strand and Nylund 1991) and 15-16°C (Ansell et al. 1991). Length of the pelagic larval stage is 21-33 days at temperatures of 15-18°C (Cragg and Crisp 1991). Maximum growth occcurs at temperatures between 4.5-10°C (Dare and Deith 1991). Juveniles lose their byssus when they are about 15 mm in shell height. Adults live in small pits in the substrate. King scallops live about 20 years but commercial size is attained in 5-6 years. Densities of self-sustaining poulations range from 0.01-5.6 scallops$\cdot m^{-2}$. At present the price for 1 kg of adductor muscles is US $15-20.

A comparison of the ecological and physiological characteristics of the north Atlantic species with the local *P. yessoensis* is of interest (Table 1). The main differences between giant and king scallops compared to *P. yessoensis* is growth rate and optimum temperatures for growth which are lower in the two north Atlantic species. Other marked differences are time of spawning, type of preferred substrate and type of food. Peak spawning of *P. yessoensis* is between the peaks for giant and king scallops, but food ratio of the north Atlantic species is broader than for *P. yessoensis* and involves some detrital material (Bricelj and Shumway 1991). Spawning temperature for all three species is similar. Optimum salinity, lethal temperatures, age, duration of the larval stage.and bathymetric requirements are of lesser importance for such deep water species and may depend on the local environment.

Considering these preqrequisite conditions, two areas of the Primorye shelf might be suitable for the introduction of giant and king scallops. One of these is Peter the Great Bay where the substrate in depths greater than 30 m is fine to coarse sand and the water column is well mixed throughout the year (Fig. 1). Bottom temperatures rise to 8-10°C during summer (Fig. 2). Total area that could be used to culture giant and king scallops is 380,000-400,000 ha. If scallops were cultured at a density of 0.2-0.3 scallops$\cdot m^{-2}$, production would be of 30-40 kg (whole weight) per ha. The entire area could produce scallops worth US $20-30 million per year even at the lowest current world prices. The second area that could be considered for introduction of giant and king scallops is northeast of Cape Povorotny (Fig. 3). This is an area of cold water currents where bottom temperatures rise to 5-6°C in summer and the smooth shoreline eliminates movement of large-scale water masses. As a result, the area for scallop culture could be considered as being the upper and lower shelf zone in which water depths range from 15-45 m. This area is affected alternatively by cold water intrusions and drift along the shore from the south. Bottom temperatures in this zone increase to 8-10°C in summer. The substrate is mostly gravel and pebbles. Populations of *P. yessoensis* here are low because of poor recruitment. This area could be used for introduction of giant scallops. The area available for culture between 15-50 m is 110,000-130,000 ha. With a minimum commercial density of 0.6 scallops$\cdot m^{-2}$ or a production of 90 kg (whole weight) per ha, an annual production of US $20-25 million could be realized.

Introduction of giant and king scallops in the Primorye area would involve a large project and include:

1. development of a hatchery to produce and grow juveniles;
2. transportation of juveniles to growing areas where environmental conditions, particularly temperature, are inadequate for spawning but would support growth (similar to culture of *P. yessoensis* in Japan and *Mytilus galloprovincialis* in China);
3. management of the fishery to increase densities to commercial levels;
4. export of juveniles to the shelf area of Sakhlain Island and the western part of the Sea of Okhotsk;
5. development of a processing industry that would establish an industry valued at US $100-120 million annually.

Introduction of these two scallop species could be achieved in several stages.

1. Experimental production of juveniles. Import 100-200 adult giant and king scallops from the north Atlantic under quarantine conditions. Adults would be acclimated and spawned and the larvae raised to maturity. Juveniles would be grown in cages and then placed out in experimental areas.
2. Commercial production of juveniles for growout. Continue to increase production of juveniles and extend the growout area. Export juveniles out of Primorye area to begin scallop culture in the northern part of the Sea of Japan, the Sakahalin Island shelf, the shelf of the Okhotsk Sea and the shelf of the east Korean Bay.
3. Establish the infastructure to manage the operation. Management would include restricting the area for harvest, quotas, limiting size of the catch, type of vessel and gear. It would also include sowing of juveniles and rotation of culture grounds.

Introduction of exotic species has been used in other countries, e.g. *P. yessoensis* is now cultured on the Pacific coast of Canada and in France (Cochard et al 1991), *Arogpecten irradians* was introduced a few years ago into the Yellow Sea area of China, *Crasssotrea gigas* is now cultured and of economic importance in the U.S.A., U.K., France, Spain, Australia and New Zealand. However, to insure there are no negative effects on the native benthos from such an introduction into the Russian area it is necessary to:

1. undertake a qualitative and quantitative inventory of existing benthos;

2. determine food production and competition for such resources in the intended areas for scallop culture;
3. continue such surveys after the introduction of giant and king scallops to determine if new benthic communities have become established.

None of this work should require a large amount of funding, particularly when the potential benefits are considered.

This project would be of interest not only to the aquaculture industry of Primorye Province but also to other countries where production of giant and king scallops occurs such as France, the U.K. and Ireland, where there is over 50 years experience in managing and fishing scallops. It would also be of interest to countries such as Canada, southeast Asia, the U.S.A., Japan and even Korea.

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Table 1. A comparison of characteristics of *Placopecten magellanicus, Pecten maximus,* and *Patinopecten yessoensis.*

Characteristic	Species		
	Placopecten magellanicus	*Pecten maximus*	*Patinopecten yessoensis*
Geographic area	36-52°N	30-68°N	38-52°N
Depth	2-381 m	3-183 m	5-25 m
Substrate type	gravel, pebble	fine-coarse sand, gravel	coarse sand, gravel
Temperature for growth	10°C	4.5-10°C	12-14°C
Temperature for spawning	8-11°C	7-16°C	12-14°C
Spawning period	August-November	April-May, August-November	June-July
Larval period	35 days	21-33 days	20-35 days
Culture cycle	4-5 years	5-6 years	3-4 years

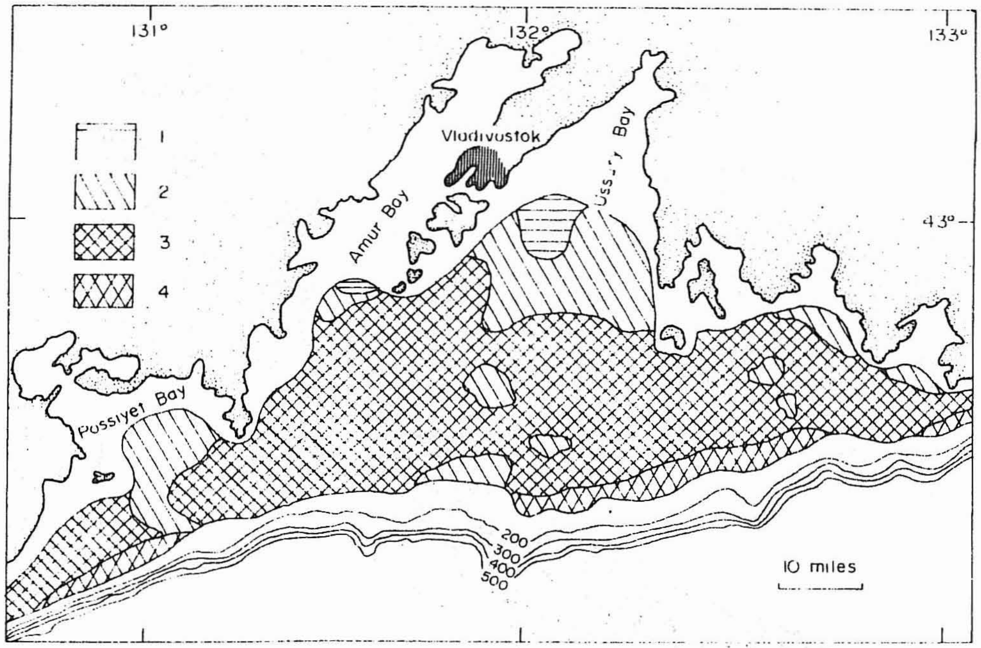

Fig.1. Substrate in the lower shelf area of Peter the Great Bay, Sea of Japan: 1, silt; 2, fine silty sand; 3, coarse sand; 4, gravel and pebbles.

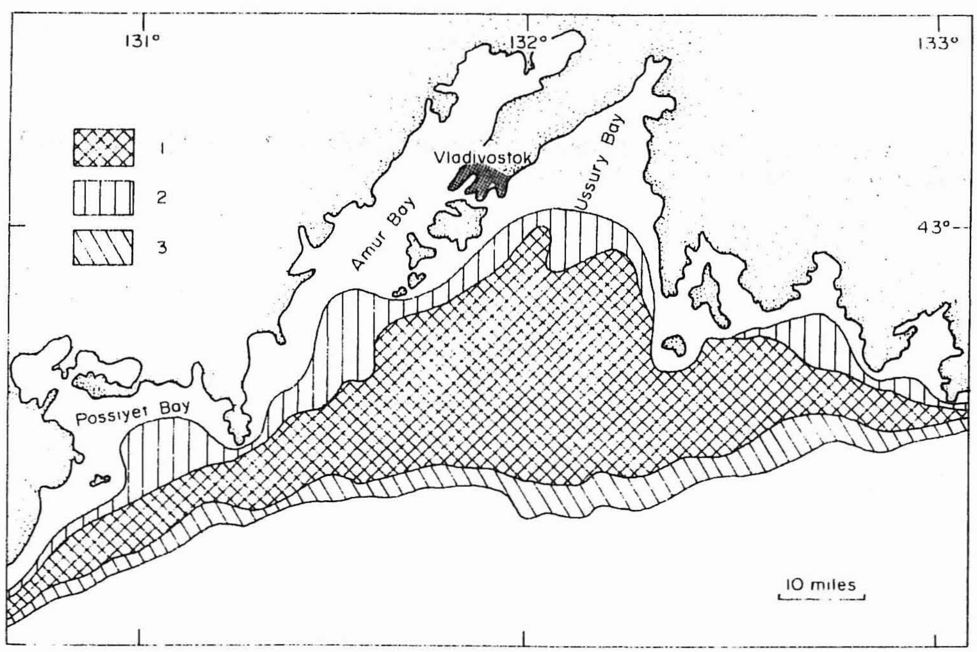

Fig.2. Bottom water temperatures during summer in the lower shelf area of Peter the Great Bay, Sea of Japan: 1, 4-8°C; 2, 2->8°C; 3, 3-<4°C.

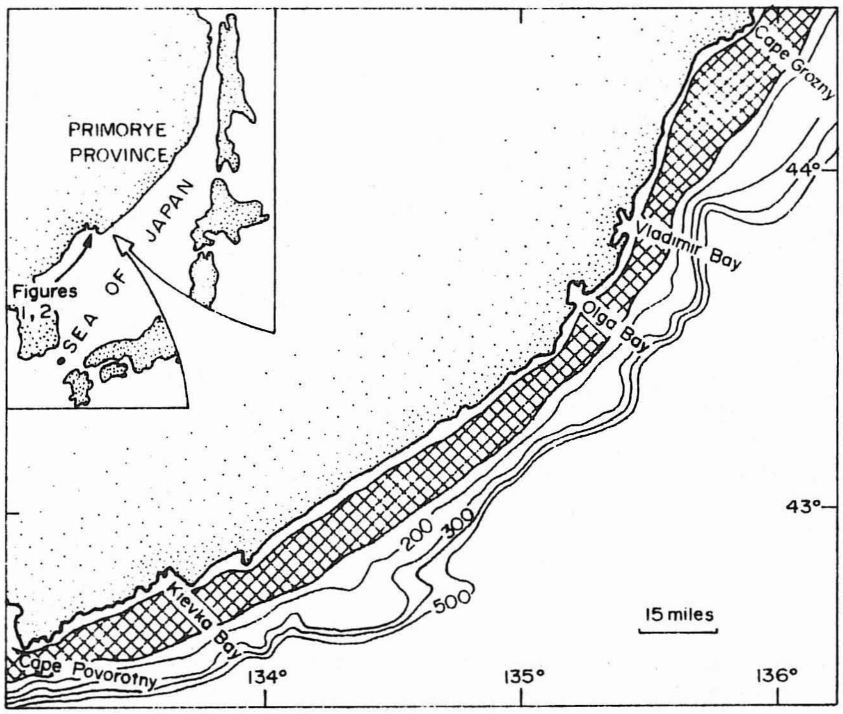

Fig. 3. Part of the lower shelf area between Cape Povorotny and Cape Grozny and its location in the Sea of Japan.

ARTIFICIAL SEED PRODUCTION AND CULTURE OF SCALLOPS IN SUNGO BAY

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ABSTRACT

Sungo Bay, at the eastern end of Shandong peninsula, is one of the most important mariculture areas in China. Scallop culture, initiated in the early 1970's, was mainly limited by seed supply. When several hatchery problems were solved in the late 1970's, more than 40 hatcheries were established on the bay, with an annual production of 1.5 billion seed of the native scallop, *Chlamys farreri*, and 300 million seed of the bay scallop, *Argopecten irradians*. Most bay scallop seed was sold to other cities because the lower water temperature of Sungo Bay is not sufficient for growth. However, most of the *C. ferrari* seed is cultured in the bay. The adequate seed supply and high economic return encouraged the mariculture companies to rapidly expand their scallop culture area with high culture densities. Now about 10% (more than 600 ha) of the total potential culture area in the bay is occupied by scallop culture, with total annual output of 10,000 t live weight. The remainder is occupied by *Laminaria* culture. Accompanying the rapid development of scallop culture were problems of reduced growth rate, extension of culture period, increased mortality, and decreased product quality. Local government agencies attempted to control the scale of scallop culture in the bay; however, growers were not inclined to reduce culture efforts. Recently, a new model of polyculture was introduced to understand these problems. The significant release of inorganic nutrients such as ammonium and CO_2 by scallops can be taken up directly by *Laminaria*, and the O_2 by-product of *Laminaria* photosynthesis may benefit the living environment of scallops. Meanwhile, the detrital yield from *Laminaria* is a potential food source for scallops. The mutual positive effect of polyculture on both scallops and *Laminaria* may be effective in obtaining optimal mariculture production in Sungo Bay.

KING SCALLOP FARMING IN FRANCE

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ABSTRACT

Due to fisheries management problems with natural stocks, production of king scallops, *Pecten maximus*, in France is developing more and more into a culture industry. Rearing techniques for king scallops are presented. Collection of wild spat is insufficient for the industry, and hence spat production must rely on hatcheries and nurseries using the following methods. Adults are conditioned using large quantities of food, larvae are reared in cylindrical-conical tanks, and postlarvae (metamorphosed larvae) are set in cylinders with mesh bottom. As in other molluscan hatcheries and nurseries, phytoplankton must be produced in large quantities. When spat are approximately 2 mm, they require too much phytoplankton to be held in nurseries. Hence spat are raised in cages in the open sea for six to nine months in two stages: "small mesh" cages (500 μ to 1.5 mm mesh size) are used for newly settled and early spat when the shell is thin (translucent), "large mesh" cages (5 mm mesh) are used when the spat lose their byssus attachment and the shells becomes thick (coloured). Survival rate is about 30% using this technology. Mortality occurs mostly at the beginning of the first phase and is due to stress at transfer and to the fragility of the thin shell. At 3 cm (< 1 year), the juveniles can be seeded on the open sea. Optimal density is about 10 to 20 scallops$\cdot m^{-2}$ (extensive culture). In intermediate culture, mortality occurs mostly during the first month. If undisturbed, scallops do not move from the depression they dig. Scallops are harvested by dredging two or three years later when they are larger than 100 mm and about 150 g in weight. The percentage of recapture is variable, from 25 to 50% on seeded sites. Scallop farming is increasing in France (≈100 t in 1992), however the two important causes of mortality, transfer to the open sea and seeding at 30 mm, must be solved to make the operation more economically viable.

DEVELOPMENTS IN THE INDUSTRIAL PRODUCTION OF SCALLOP, *ARGOPECTEN PURPURATUS* (LAMARCK, 1891), SEED IN SEMI-CONTROLLED ENVIRONMENTS IN THE NORTH OF CHILE

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ABSTRACT

During the last year, our production of scallop, *Argopecten purpuratus*, seed of marketable size has been raised to ever increasing levels. However, during the autumn-winter, seed production may be zero due to 100% larval mortality. Our success rests upon our operation and the management of certain parameters that explain our 1 million - 10 mm seed production per month. We start with the individual selection of potential breeders followed by a 10-day conditioning period. During this time, the scallops are fed a defined microalgae diet at 17°C. We spawn chosen individuals every 10 days. Spawning and fertilization are controlled and at 36 hours postfertilization, a D-larvae is obtained. At 20°C, settlement is induced in 17 days. The success rate of larval development is due to: the quality of seawater used; phytoplankton culture; periodic management of larval tanks; larval size selection; and the use of *Nannchloropsis* sp. and *Isochrysis* (Tahitian clone) as larval food. Metamorphosis and larval settlement are performed at constant temperature. Netlon nets used as settlement substrate are sent directly to the ocean. Taken together, all these factors explain the success of our seed production during the last year.

DISPERSAL OF SEA SCALLOP, *PLACOPECTEN MAGELLANICUS*, JUVENILES SEEDED ON THE BOTTOM OFF THE ÎLES-DE-LA-MADELEINE, QUÉBEC, CANADA

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ABSTRACT

Dispersal and predation of juvenile sea scallops are two important factors in culturing operations and restocking natural beds. Experimental seeding carried out in 1990 and 1991 off the Îles-de-la-Madeleine (Quebec, Canada) indicated a rapid dispersal of scallops over the bottom. In 1992, our objectives were to assess the importance of seeded scallop displacements, their predation mortality, and changes in the abundance of predators on a small scale and over a short period. In 1992, a total of 8,980 sea scallops, *Placopecten magellanicus*, of four size classes (≤35 mm, 36-50 mm, 51-70 mm and >70 mm) were tagged and seeded in a 30 m x 30 m quadrat. Systematic sampling was carried out by video and diving surveys. A few days before seeding, the density of indigenous scallops was estimated at 0.24 scallops/m^2. The density of seeded tagged scallops over time on the 30 m x 30 m seeding site dropped from 10 to 0.29 scallops/m^2 over the 44 day study. On the 50 m x 50 m area, including seeding site, the density change was less drastic, dropping from 3.6 to 1.0 scallops/m^2 over the same period. On the eight surrounding parcels (50 m x 50 m), the density increased noticeably from 0 to 0.13 scallops/m^2 between the beginning and the end of the experiment. Scallop dispersal was extensive and rapid. On day three, 70% of the scallops were still concentrated on the seeding site. On day nine, only 32% of the individuals were left, mainly concentrated in the southern part of seeding site, suggesting a displacement in that direction. On July 29 (day 25) the majority of the scallops had left the central parcel (50 m x 50 m), their distribution was fairly uniform, and the mean density was about 1 scallop/m^2. Displacement after 44 days was more than 60 m for 49% of the seeded scallops. Orientation of the displacements did not correspond with movement of the water mass during this period. Short term displacements seemed to be preferentially toward the south. Size structure of the scallops showed a strong decrease over time in the frequency of two size classes, ≤35 mm and 51-70 mm. The diving survey 44 days after the seeding revealed 1,150 dead scallops or parts of tagged shells on the seeding site, which is 12.8% of the total number seeded. Between July 1 (day 4) and August 17 (day 44) the predator density on the study site increased from 946 to 1,454 sea stars per 1000 m^2 and from 0 to 123 rock crabs per 1000 m^2. Distribution of the sea stars was, moreover, relatively uniform on the study site. At any rate, crab predation appears to be the most prominent since the diving observations revealed that 90% of the dead scallops had broken shells. The number of predators, sea stars and rock crabs, increased significantly after seeding.

EXPERIMENTAL CULTURE OF *PECTEN JACOBAEUS* (L.) IN THE ADRIATIC SEA

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ABSTRACT

Except for experiments carried out in France with *Pecten maximus* and *Patinopecten yessoensis*, no other scallop culture has been attempted in the Mediterranean Sea. In March 1991 a preliminary scallop culture experiment was started in an area 2.4 km off Venice in the Adriatic Sea using *Pecten jacobaeus*. Juveniles were cultured in lantern nets (Japanese type) and in plastic baskets (commonly used for oyster culture). Data on growth and mortality of juveniles held at different densities and under different environmental conditions showed this species has potential for culture. Similar trials undertaken during the same period on artificial reefs located about 240 km south showed high rate of scallop mortality during August 1991 when water temperatures were at their maximum (28°C). At present some fishery cooperatives in the northern part of the Adriatic Sea that are involved with mussel culture, are investigating the possibility of growing locally caught juvenile scallops on longlines.

Scallop culture has not been attempted in the Mediterranean Sea, except for experiments in France to culture *Pecten maximus* and *Patinopecten yessoensis* (Buestel et al. 1989). Recently experiments were carried out to determine the feasibility of culturing the "Great Mediterranean Scallop", *P. jacobaeus* L., a member of the family Pectinidae known locally as "capasanta" (Giovanardi et al. 1992). The work was carried out in collaboration with a mariculture cooperative at Cavallino (Venice) that has a leased area about 2.4 km offshore using juvenile scallops collected locally by beam trawls called "rapido". Dragging was concentrated on a bed of scallops southwest of Chioggia in an area off the Po River delta (Renzoni 1991).

On 13 March 1991, several hundred animals ranging in shell height from 40-75 mm were placed in Japanese lantern nets or plastic trays that are used in oyster farming and suspended depths between 5 and 10 m. Mortality due to transportation and handling on shore was negligible. Mortality was 17% in lantern nets and 4.5% in plastic trays a few days after seeding.

After 204 days of culture, total mortality in the lantern nets was 43.1%, shell height in the largest size increased from 3.1 ± 1.5 mm to 14.1 ± 3.8 mm, depending on the size at the time of seeding. Total mortality in the plastic trays was 63.3% with mean increases in size ranging from 13.4 ± 3.9 mm to 28.4 ± 4.4 mm. Although no procedures were taken to prevent encrusting organisms from settling in trays, no fouling sufficient to cause damage to the scallops was observed until October 1991. However, in the following year (February 1992) fouling became severe and required manual cleaning of affected animals.

Seeding density was one factor that affected growth and mortality. In the period from March to October (Fig. 1), a good relationship was observed between mortality and density ($r=0.83$, significant with $p<0.01$), when the scallops occupied approximately 60% of the floor area of the lantern net. During the period from March 1991-February 1992, greater growth was observed in the plastic trays than in the lantern nets (Fig. 2); however, this might have been affected by density.

Further observations are required to assess whether commercial scallop culture is feasible in this area. Experiments are needed to assess the effects of many variables that include environmental factors and culture methodology. Similar work carried out during the same period off the coast of Romagna (Central Adriatic) showed high mortalities, particularly in the month of August, which coincided with high water temperatures (up to 28°C). In this work low initial mortalities were observed in spite of a 24-48 h period between the time of capture and seeding in nets.

A small research project is now being undertaken by ICRAM in an offshore area in depths of 15-30 m, where lower water temperatures and less risk from fouling occur. Results will be compared with those obtained in the inshore areas.

Mention should also be made of occasional "experimental large-scale" rearing of juvenile *P. jacobaeus*, which are captured by the "rapido" and cultured by mussel farmers on longlines lcoated within five km of shore in the upper Adriatic, particularly in the Friuli region. Initial results have been encouraging, with good growth rates and limited damage due to fouling provided the culture system is monitored regularly. The situation is similar to that observed in the Spanish Atlantic area a few years ago (Roman 1991). The major problem is high water temperatures in summer that can cause mortalities.

It should be pointed out that commercial quantities of small *P. jacobaeus* can only be captured by the "rapido" in nursery areas. The impact of harvesting juveniles should be controlled for example by establishing a yearly harvest quota.

Present management regulations in the wild fishery include a size limit and temporary trawling closures. The size limit is difficult to control and there are significant landings of small scallops below the size of sexual maturity, particularly during periods when scallops are scarce. Although temporary closures have limited duration (usually 45 days in summer), they may have a beneficial effect on settlement of spat.

Overexploitation to the point of fishing out scallop beds has occurred periodically in this area, e.g. the disappearance last year of a bed from which juveniles from our present work were taken and the present exploitation of beds close to Croatian territorial waters. Because of this situation and fluctuations in environmental factors such as the abundance of the stock, its size and distribution, there is little possibility to collect seed using natural seed collectors. Areas where spat will accumulate are variable resulting from the complicated oceanographic conditions in the basin.

Culture techniques require improvement, i.e. locating culture operations in deeper and cooler waters. Some people have suggested introduction of exotic scallop species into the area which could be bred in hatcheries and which would tolerate high temperatures. Some attempts have been made in the Adriatic and others are planned. We think that because of the encouraging results with the native species, *P. jacobaeus*, it is worth undertaking biological studies of this species to determine the feasibility of production of juveniles in hatcheries. Then other culture methods could be studied after careful assessment of the cost/benefit ratio in terms of production and also impact on the environment.

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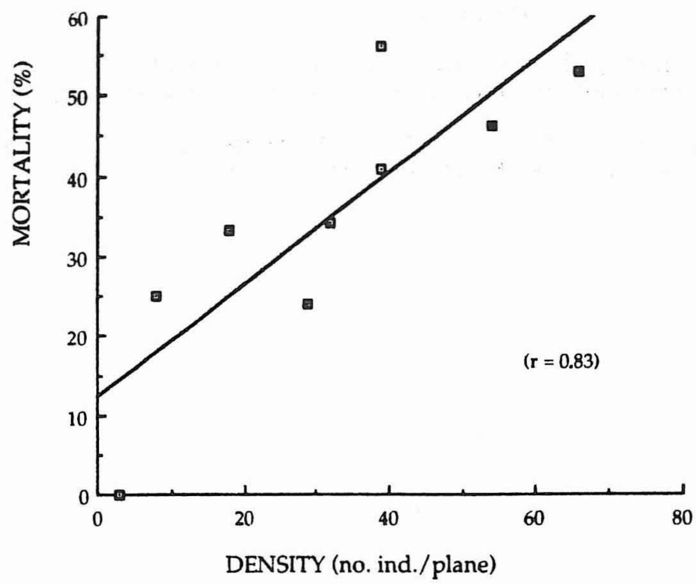

Fig. 1. Relationship between mortality and density in the lantern nets from March-October 1991.

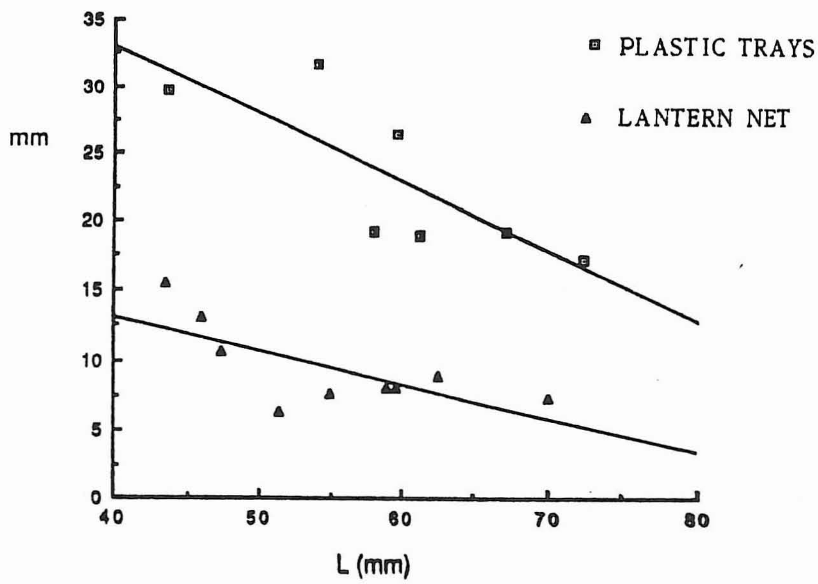

Fig. 2. Increases in size observed in the lantern nets and plastic trays from March 1991 - February 1992.

EFFECTS OF PREDATION AND COMPETITION ON SCALLOP, *PECTEN MAXIMUS*, SEABED CULTIVATION IN SAINT BRIEUC BAY: PRELIMINARY RESULTS

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ABSTRACT

Seabed cultivation trials with the scallop *Pecten maximus* have been undertaken since 1980 by fishermen's organizations from Brest and Saint-Brieuc in cooperation with IFREMER. Spat was produced in a hatchery at Brest and transferred to Saint Brieuc for intermediate culture. Batches were later divided equally between both scallop grounds for seeding trials with appropriate local strategies. In the Bay of Saint-Brieuc, harvesting began in 1986 by dredging, with recovery ranging from 0 to 25% of the seeded animals. These low recovery results did not agree with observations made by divers in the summer which showed good growth and survival after seeding and during growout. To obtain a better understanding of this problem, an experimental program was conducted between 1990 and 1993 on a reserve area of 110 ha close to commercial fishing grounds. Preliminary results were:

1 mortality during the seeding operation was generally low.
2. there was severe predation by the whelk (*Buccinum undatum*) which was very specific: exclusively in winter with large variability between years;
3. there was competition with the slipper limpet (*Crepidula fornicata*) when this species occupied more than 20% of the seabed. Scallop growth rate is then lower and the heavy *Crepidula* biomass changed the biotope and was a constraint during dredging. This species is increasing on scallop grounds;
4. other causes of mortality found in previous experiments in the Bay (bad weather affecting the sediment layer, predation by crabs) had no evident effect in this case.

INTRODUCTION

In the Bay of Saint-Brieuc, scallop seeding trials began in 1980 when evidence of this enhancement method was shown to be promising (Buestel and Dao 1979). Operations where difficult to initiate due to the lack of juveniles from local stocks. Introductions of spat from Scotland (1980) and Ireland (1982) were used. After 1984, the hatchery in Brest provided sufficient postlarvae and spat for the experiment.

The first results from the work were related to physiological behaviour at maturation and growth rate of different strains occurring on the same seeded area (Dao et al. 1985b). However, it was not possible to evaluate the survival rate.

Small scale experiments were attempted to determine the optimum size of the juveniles for seeding in a joint trial in the two grounds, Saint-Brieuc and Brest (Dao et al. 1985a). Survival rate was calculated after six months of free-living for animals 5 to 30 mm shell height (groups of 5 mm). Good results were obtained for juveniles above 15 mm, with survival rate increasing with the size at seeding. Predation was mainly by crustaceans, since there were no starfish in the Bay and octopus disappeared from the area in 1963. Competition between scallops and other fauna was not evident.

Following these encouraging results, larger scale seedings (100,000 to 1,000,000 animals) were conducted annually at different locations selected in collaboration with the fishermen's organizations of the Bay (Fig. 1). Results have been poor and late (1989 and 1990), and various explanations have been proposed to explain these phenomena.

1. Marginal quality of the sites chosen by the fishermen. As the seeding area had to be closed to the fishery for several years, the best fishing grounds were retained for commercial operations. Specific site problems included:
    a. Brehat site: sediment instability due to effect of bad weather on this poorly sheltered area.
    b. Le Palud site: sediment covered by crepidula (*C. fornicata*) which prevented scallops from recessing properly.
2. Logistic constraints for completion of the experiments, e.g. finding local boats for experimental recapture evaluations, fishing allowed only during the open season from November to April. Some seed was recaptured in two years time, which made survival rate difficult to evaluate.
3. Winter schedule of the biological team, e.g. the number of days of bad weather preventing field work on the boat and diving, and management of the local scallop grounds from 1986 to 1988 when several samplings were conducted to study abnormal winter mortalities (Le Gall et al. 1988).

A new program based on sampling by divers was developed with a strict fieldwork procedure in order to obtain data on the following subjects:

1. why were poor final results obtained after summer observations indicated great growth and survival during growout?
2. is the drift of juveniles important?
3. what is the predation level by crustaceans and other animals?
4. is there any difference in survival rate between areas with or without *Crepidula*?
5. is the growth rate similar under various conditions in the Bay?

MATERIALS AND METHODS

The area selected for the intensive diving program was "Les Comtesses", where optimum results were obtained previously. Part of the site was occupied by intermediate culture cages, which required periodic visits. The substrate was sandy-mud, well colonized by a natural population of scallops. Depth was 17 to 18 m at low tide (11 m more at high spring tide). The site was divided into four units (Fig. 2), with unit C further divided in two to account for culture equipment.

Seeding was carried out at an initial density of 5 to 10 individuals (30 mm shell height) per m^2, for a total of the following:

Unit C: 660,000 individuals in March 1990
Unit B: 640,000 individuals in July, 290,000 individuals in August 1990
Unit A: 828,000 individuals in July, 665,000 individuals in November 1991.

The total area covered was 110 ha. Diving was undertaken since it was the only way to sample every size of seed, especially during the early stage of seeding. Sampling was carried out inside a quadrat of 1 m^2 and the number of replicates was related to the size of the observed scallops. At 20 m depth, the area covered by a trained diver was 20 m^2 for scallops 30 mm shell height, and 50 m^2 for animals greater than 50 mm shell height. In accordance with other results, scallops were considered to be sedentary animals, although they are capable of some random movements but these do not affect the calculated density.

From a central mooring point, lines on the bottom were laid out north, south, east and west. Divers counted live animals, "fresh" dead ones (attached valves), separated shells, predators and estimated ground coverage by *Crepidula*. An initial dive seven days after seeding estimated mortality due to stress of transfer from intermediate to bottom culture. A second dive after 20 days evaluated mortality due to adaptation. Dives were made every month during winter and every two to three months for the remainder of the year to verify prior data.

The final biomass could not be evaluated by diving, consequently it was assessed by harvesting scallops with a dredge and developing a sampling program to discriminate natural from cultured animals. Cultured scallops were identified easily because of the additional stress ring created at the time of seeding. Results presented in this paper were deduced only from diving data, except for Unit C. Survival rate and mortality were calculated from the difference in local densities during successive samplings and must be confirmed by fishing operations at a later date.

RESULTS

MORTALITY DURING SEEDING

In all experiments, mortality during seeding remained low. As our understanding of intermediate culture progressed, some basic rules were developed to avoid overcrowding in the trays and stress during transfer of seed to the seabed.

SEASONAL SURVIVAL

Two periods were noticeable during the experiment: May to November and December to April. For the first period, survival was good for all sizes of scallop. Natural mortality was estimated at 5% corresponding to an annual value of 15 to 25% which is used for recruited animals in stock management (Dao et al. 1985a; Fifas 1991).

Winter survival rate was much lower and highly variable. Mortality was higher on small scallops during their first winter due to predation by crabs in shallow waters or near rocky areas, as well as by the whelk (*Buccinum undatum*). When it became evident that the whelk was a major predator, some complementary experiments were undertaken. Crabs, including the hermit crab (*Eupagurus bernhardus*), were more active predators of scallops 30 mm shell height or smaller (Fleury 1989) but whelk predation continued on scallops to 50 mm size. Predation did not totally explain the increase in mortality during the winter period. From 8-20% of the animals died at the end of the winter in late March and April; mortality at the beginning of spring growth has been classically observed in other bivalve species.

The cumulative evaluation of survival rate showed highly variable results of different seedings on an apparently identical area. Conditions during the first winter affected the success of seabed culture; early 1990 seeding yielded only average results, but results from the two other seedings are more promising.

The estimated survival rate in Unit C, which was harvested, was 25%. The recapture rate of 18% was corrected for dredging efficiency, because 10% of the animals were broken or unfished. The presence of *Crepidula* forced harvesting operations to terminate early there and increased the expected number of scallops left on the bottom.

PREDATION

Primary predation at all sites was due whelks. During the first experiment, this counted for the loss of nearly 60% of the animals in the first two months. To positively identify whelks as a predator, some whelks were placed in trays in intermediate culture cages with scallop spat: predation was effective and significant. The same observation was made in tanks. Scallops remained passive to whelks and were quickly eaten. During seeding surveys, test-trays with scallops but without whelks were monitored. In all cases winter mortality remained low (Tables 1 to 3).

Predation by whelks was highly variable from year to year. In the winter of 1991-92, whelks were not identified as the cause of significant predation. However, whelk predation corresponded to winter mortality and it appears to be a major component of seabed culture management in this area. As an unfished species in the Bay, the population is expected to remain on the grounds. The lack of scallop mortality can be attributed to the size of the scallops, which was too large for active predation.

Predation by whelks occurred during two short periods, in winter after Christmas and in March. There has been no study of the behaviour of this animal, which appears to be confusing. In south Brittany, it was not possible to show predation in tanks using the local whelk. However, the species is well known to be active in cold water which could explain predation in March at the lowest temperature of the year. Another possible factor is the physiological state of the scallops at the end of the winter, which makes them more vulnerable. Predation in January could have a further explanation: whelks could be active feeders before the spawning season in February.

COMPETITION

Scallop grounds in the Bay of Saint Brieuc were located on sandy-mud sediments at depth of 8 to 40 m, on homogeneous substrate with little epibenthic fauna. However, since 1975-78 there has been a gradual increase in dispersal and density of *Crepidula*. In a number of places the animals built up a continuous bed several centimeters in depth which reached a biomass of 15-20 kg/m^2. *Crepidula* is a filtering gastropod whose larvae settle on the shells of adults to form a chain of 10-12 animals. They also settle on scallop shells, and one scallop can carry several chains whose weight may equal the host. Thus, competition can be spatial and/or trophic, and may cause secondary effects since small crabs can find protection in the layer of live and dead shells. Mud can become deposited under this layer and become nearly anoxic. Infestation of an area can be very injurious to scallop seabed culture. For this reason it has not been possible to fully exploit the "Le Palud" site and recovery there has been only 4%. The effect of *Crepidula* during fishing operations is to fill the dredge very quickly, and much time is spent clearing the gear and separating *Crepidula* from the few scallops to be marketed (one hour fishing, two hours cleaning).

On the "Les Comtesses" site, the *Crepidula* population has increased considerably in recent years (Fig. 2). Experimental dredging was undertaken to reduce *Crepidula* populations in Unit A during the winter of

1989-90. A local effect on density was observed but it is doubtful if this operation could be extended to include all scallop grounds. Moreover, the stock on Unit C showed a decrease in growth rate: scallops required an additional year on the ground to reach the commercial size of 100 mm in length when *Crepidula* occupied over 20% of the surface.

CONCLUSIONS

These results on mortalities caused by whelks and *Crepidula* provide additional information for management of scallops in the Bay of Saint Brieuc. Mortalities observed during the first winter confirm the observations of Thouzeau and Lehay (1991) during the National Programme on Determination of Recruitment, where heavy mortalities of natural scallop recruits were observed. Results of this present work must be included in analysis of the economic feasibility of scallop culture (Paquotte and Fleury 1994). Financial profitability is realized when the recapture rate is 25 to 30% which apparently could be achieved by avoiding seeding during the short period of whelk predation. Ideally the scallops should attain a size of 50 mm by Christmas which requires seeding animals 25-30 mm from May to September.

Any further development of aquaculture, including the fishery, in the Bay of Saint Brieuc, depends on the spread of populations of *Crepidula*. It is estimated that up to 50% of the fishing grounds in the area may be occupied by this species and that its biomass for the entire area (including the adjacent bays of the Gulf of Norman-Breton) is about one million t. A five year program to investigate commercial use of *Crepidula* has begun.

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Table 1. March 1990 seeding of Unit C at "Les Comtesses" (Bay of Saint Brieuc).

	Evaluated mortality %	Whelk density no/100 m^2	Test-trays mortality %	Number of survival (index)
Seeding				100
27.03.90	25.0	40		
23.05.90	57.0	36	5	
06.06.90	60.0	-		40
06.08.90	1.6	0		
04.12.90	1.5	0		38
27.01.91	15.0	0		
26.02.91	0	0		
16.05.91	0	4		32
11.07.91	1.7	0		
17.09.91	1.0	0		
23.10.91	0	0		
02.12.91	0	0		31
06.01.92	0	0		
19.02.92	0	0		
03.03.92	0	0		
31.03.92	0	0		
22.04.92	10.0	0		27
12.05.92	0	0		
22.07.92	0	0		
Recapture 09.92				18

Table 2. August 1990 seeding of Unit A at "Les Comtesses" (Bay of Saint Brieuc).

	Evaluated mortality %	Whelk density no/100 m^2	Test-trays mortality %	Number of survival (index)
Seeding				100
17.09.90	5.0	0		
13.11.90	0	0	10	95
20.12.90	0.8	0		
20.01.91	20.0	30		
26.02.91	2.0	12		
13.03.91	1.0	4		
26.04.91	25.0	18	1	47
11.07.91	2.0	0		
18.09.91	0.5	0		
22.10.91	1.0	0		
04.12.91	1.0	0		44
03.01.92	0	0		
03.02.92	0	0		
02.03.92	1.0	0		
30.03.92	5.0	0		
14.04.92	2.0	4		40
12.05.92	1.7	0	2.5	
29.06.92	0.8	0		
22.07.92	0	0		
14.10.92	0	0		
09.11.92	0	0		
22.12.92	0	0		39

Table 3. July 1991 seeding of Unit B at "Les Comtesses" (Bay of Saint Brieuc).

	Evaluated mortality %	Whelk density no/100 m^2	Test-trays mortality %	Number of survival (index)
Seeding				100
10.07.91	1.5	0		
07.08.91	1.8	0		
04.12.91	1.0	0		95
02.01.92	1.0	0		
03.02.92	10.0	14		
02.03.92	0	0		
30.03.92	3.0	0		
14.04.92	6.0	0	2	76
11.05.92	0	0		
23.06.92	0.5	0	4	
19.10.92	0	0		
06.11.92	1.5	0		74

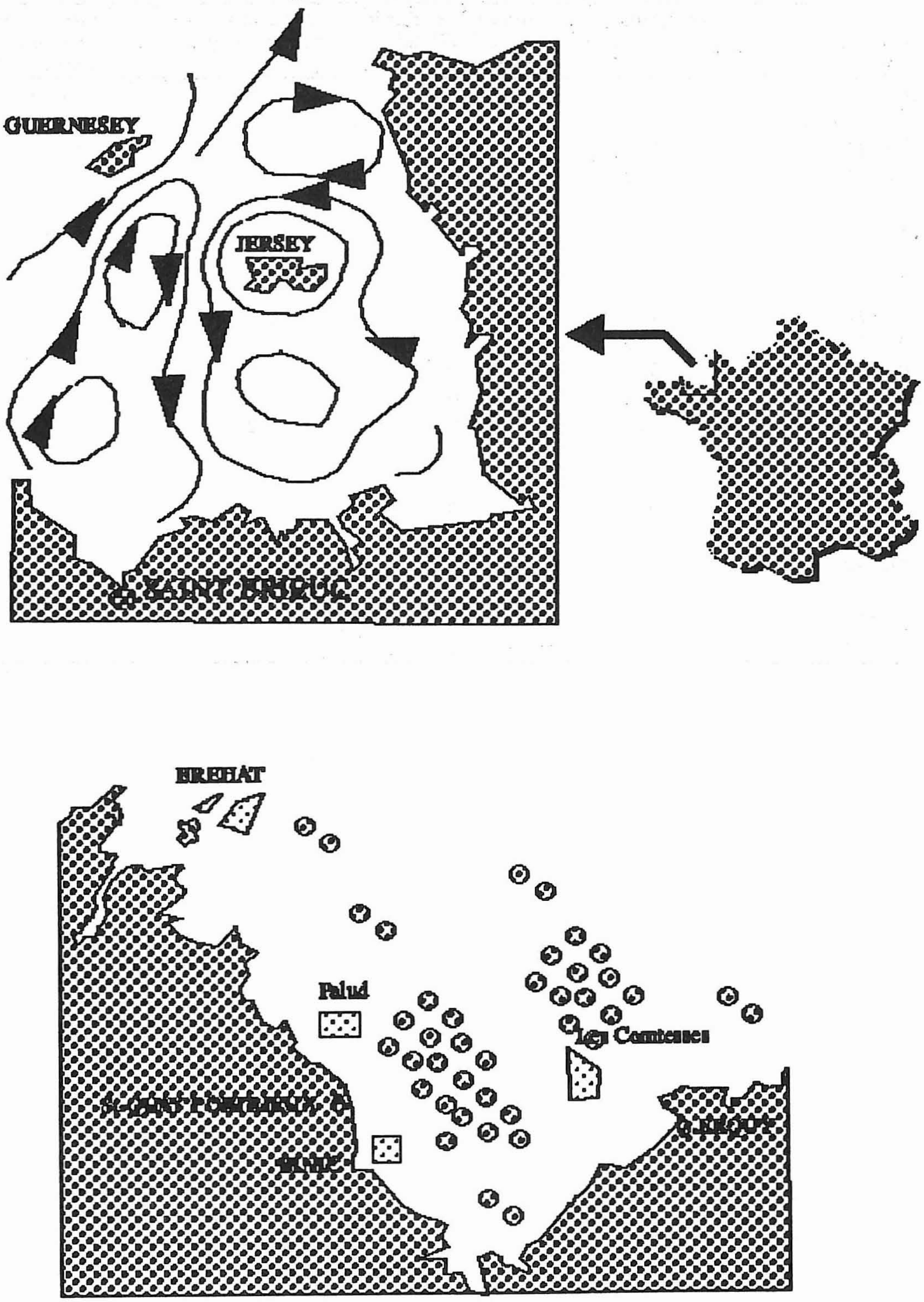

Fig. 1. The Bay of Saint Brieuc. Above - residual currents in the Norman - Breton Gulf; below - scallop grounds and seeding areas in the Bay of Saint Brieuc.

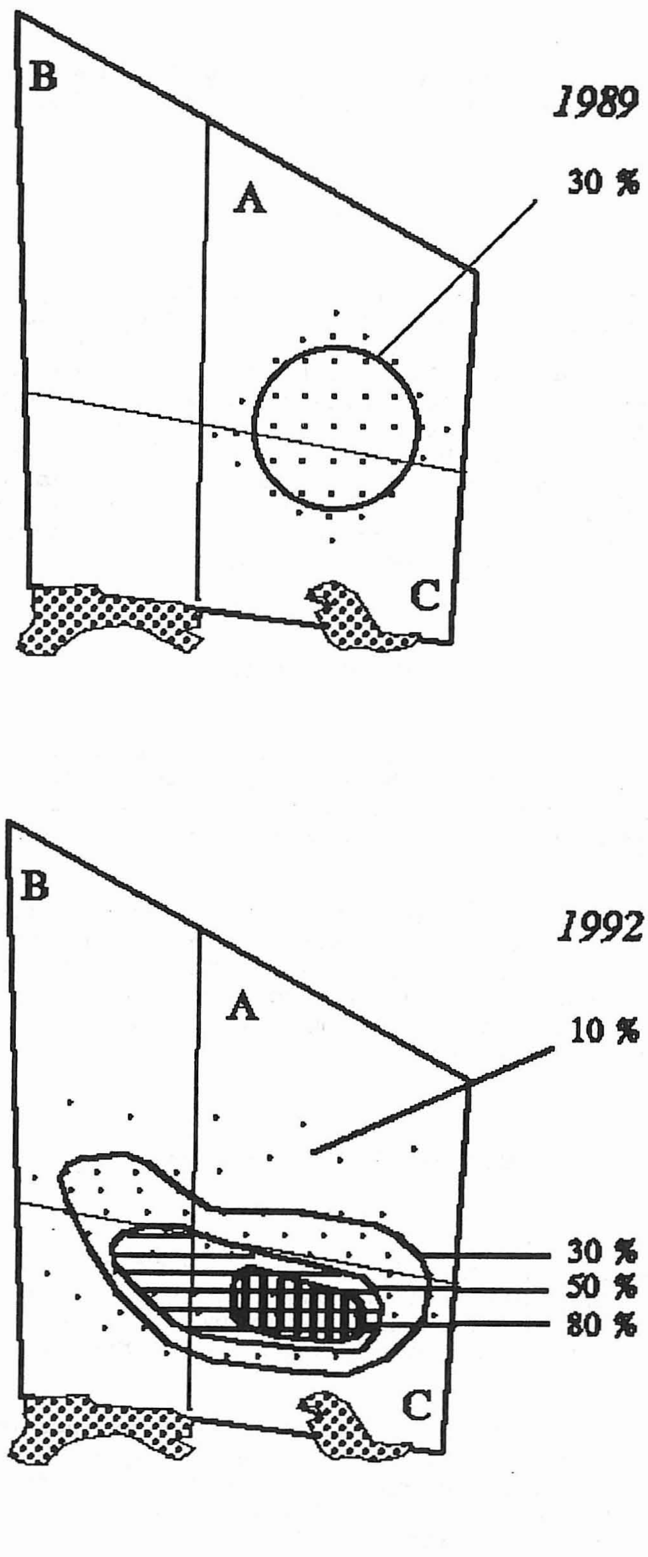

Fig. 2. Increase of *Crepidula fornicata* on the seeding area " Les Comtesses".

AN IMPROVED SYSTEM FOR MICROALGAE CULTURE

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ABSTRACT

A new type of unicellular algal culture system that can be used for large scale production is described. The system is composed of two culture containers for growing algae and a control rack which can adjust light intensity and temperature. The light intensity, temperature, and amount of aeration can be controlled to meet environmental requirements for various species of algae. As a result, algae can be cultured in all types of weather. Two years' testing has proven that many species of algae cultured in this system remain healthy, fast-growing, and do not crash easily. The production cycle is shortened in this system and less initial investment is required. Production is three to four times greater as that in concrete tanks, per m^3 of water, and production costs are reduced by 80%.

INTRODUCTION

The algal culture facility is a most important part of a bivalve hatchery. Adequate quantities of high-quality food must be available at all times for successful operations. Scallops feed on microalgae both as larvae and adults. There must be an adequate supply of food to maintain them in a healthy condition.

Concrete tanks are commonly used for large scale algal culture in bivalve hatcheries in China. The method is inefficient and tanks occupy considerable area. In addition, the cost is high. Algae grow slowly and crash easily in concrete tanks. A failure in the algal culture facility can be catastrophic to the hatchery. An improved system for microalgal culture was required for large scale production.

DESCRIPTION OF THE SYSTEM

The new system (Fig. 1) is composed of two culture containers and a control rack which can adjust light intensity and temperature. The amount of aeration can be controlled to meet environmental requirements for various species of algae. As a result, algae can be cultured in all types weather with this system.

The culture container is a sterile nylon-polyethylene bag. The outside of the bag is nylon, the inside is polyvinyl plastic. The size of the bag is 1.5 x 2.0 m, and holds about 1400 l of water. The bags are sealed and the inside is sterile. They can be inflated with air to form the required shape before they are filled with sterilized seawater.

The bags must be supported by a frame to maintain a rectangular shape and should be positioned so that the maximum distance from the light source is no greater than 20 cm.

Seawater can be sterilized by pasteurization. The water is heated to 80°C for a minimum of 30 minutes in concrete tanks, then cooled before it enters the bags.

Aeration is used in the system to provide CO_2 for photosynthesis and to mix the water. Air with CO_2 can be injected into the bags with the hatchery air system or by a small aerator.

EXPERIMENTS AND RESULTS

Experiments were carried out in 1989-1990 comparing algal production using the two systems. The results are shown in Figures 2 through 5.

GROWTH OF *ISOCHRYSIS* UNDER DIFFERENT CULTURE TECHNIQUES

Growth of *Isochrysis* is much faster in the improved culture system than in concrete tank culture (Fig. 2).

GROWTH OF *NITZSCHIA* IN SEMI-CONTINUOUS CULTURE

Algae cultured in the new system remained healthy, fast-growing, and remained in good condition for a long period of time. In concrete tanks, the algal cultures crashed readily.

GROWTH OF *ISOCHRYSIS* UNDER DIFFERENT LIGHT INTENSITIES

Light is an important factor for algal culture. Adequate light for photosynthesis is required for optimal algal growth. Fluorescent lights are used in the improved system and light intensity is controlled by a switch. The range of light intensity is 1690-8220 Lux at a distance of 10 cm from the light source. Usually, the system is placed in a greenhouse and natural light is sufficient to maintain the culture. If cloud cover is excessive, artificial light is used.

GROWTH OF *ISOCHRYSIS* UNDER DIFFERENT TEMPERATURES

Temperature is also a limiting factor for algal growth. The proper temperature must be maintained to maximize algal growth and temperature fluctuations must be kept to a minimum. Usually, algae should be cultured in a temperature controlled room. In our system, we use a special electric heater that heats the water. A monitor automatically controls the temperature for different species.

ACKNOWLEDGEMENTS

I thank the many people who have assited me in the algal culture program, and I thank to Dr. N. Bourne for his advice and assistance.

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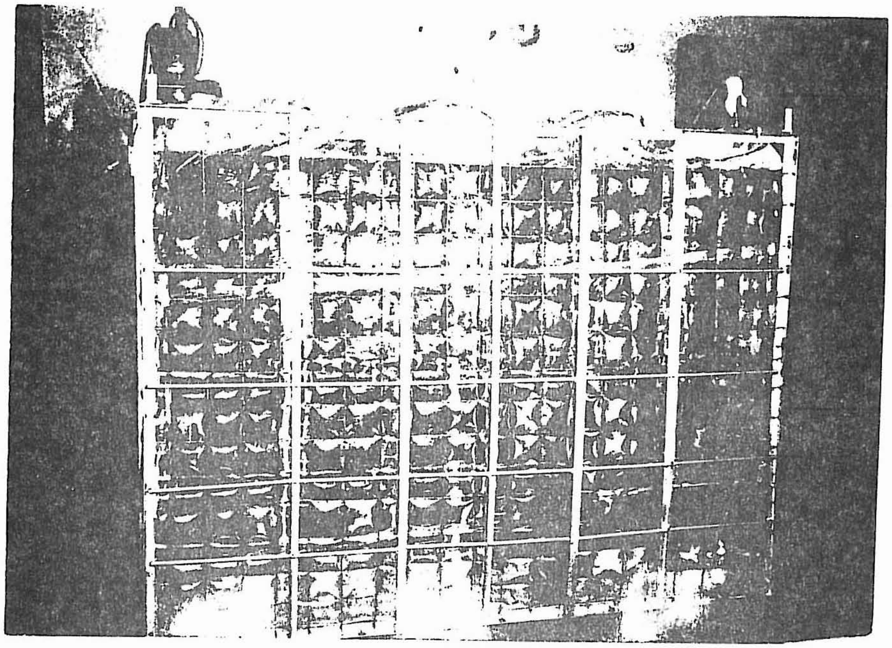

Fig. 1. a) Front view of the culture system.

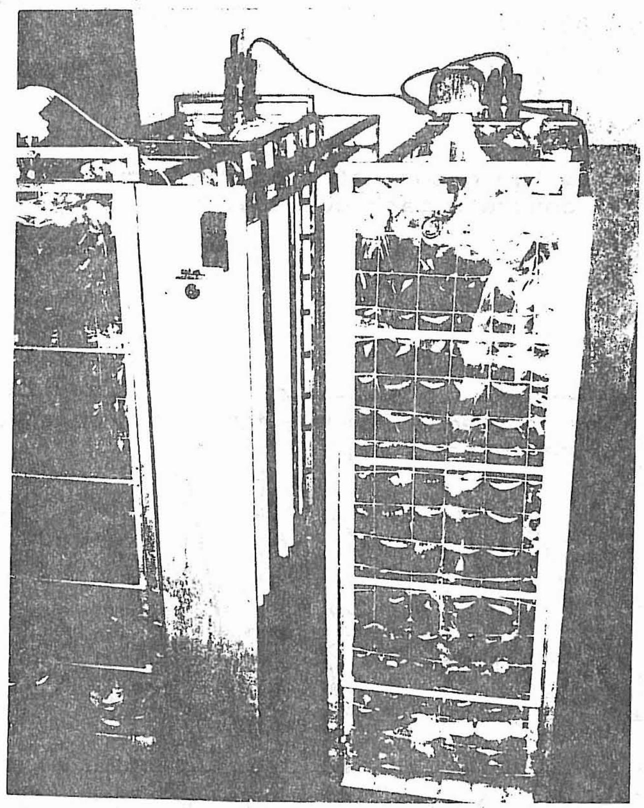

Fig. 1. b) Side view of the culture system.

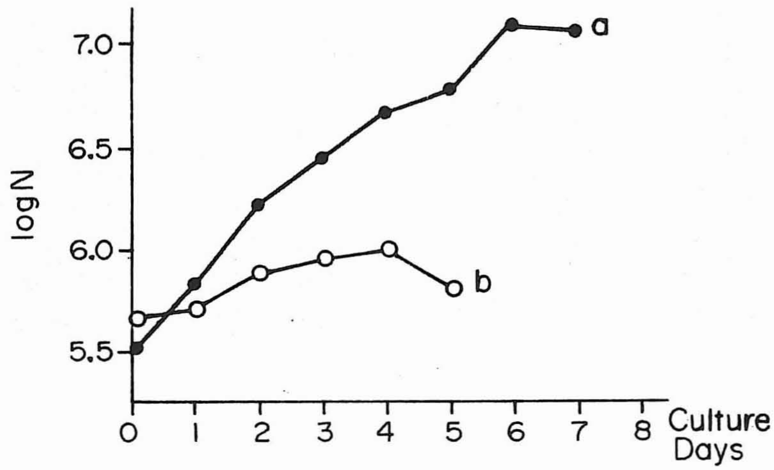

Fig. 2. A comparison of the growth of *Isochrysis* cultured in (a) the improved culture system and (b) concrete tank culture.

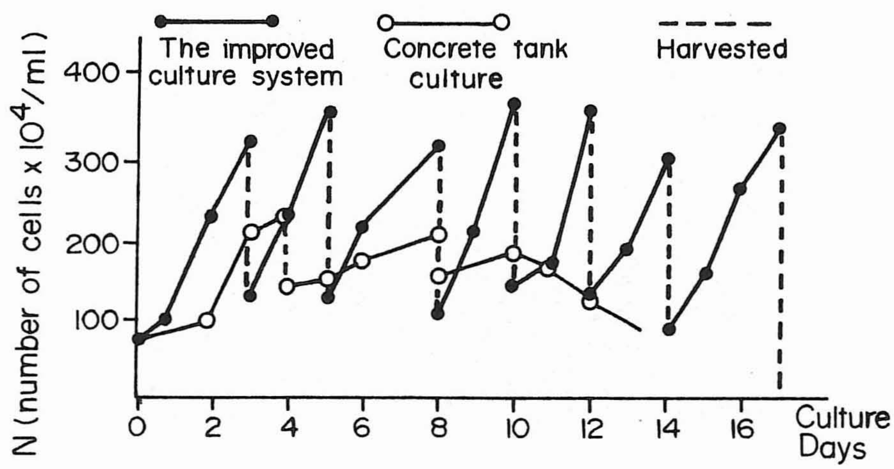

Fig. 3. Growth curve of *Nitzschia* in a semi-continuous culture. Light intensity 250-15,000 Lux; water temperature 10-18°C; pH 7.2-8.0; specific gravity 1.020.

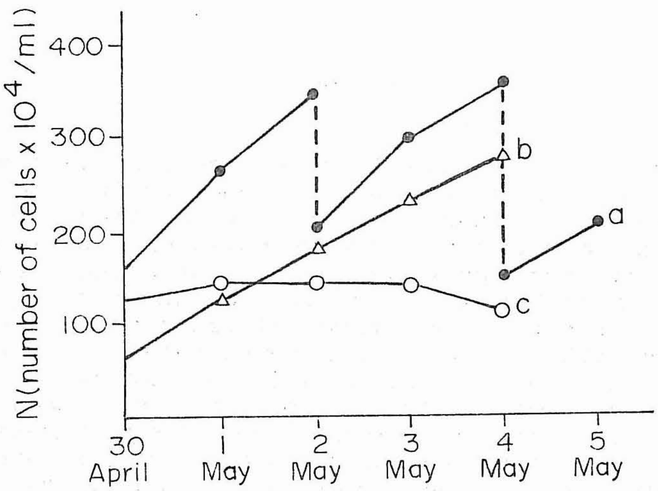

Fig. 4. Growth of *Isochrysis* under different light intensities: (a) controlled light intensity and (b) normal light intensity in the improved culture system; (c)normal light intensity in concrete tank culture.

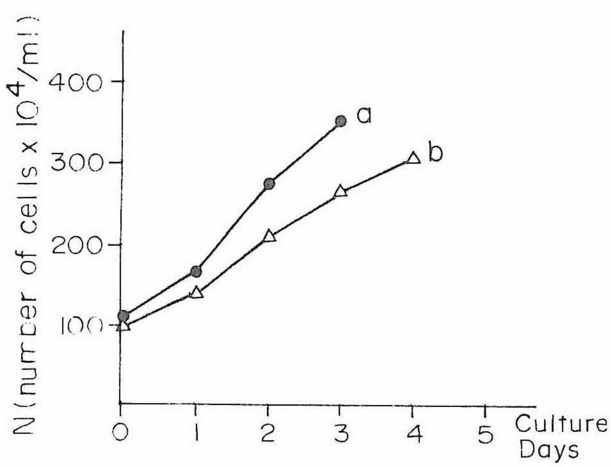

Fig. 5. Growth curve of *Isochrysis* under different temperatures: (a) controlled and (b) normal temperature in the improved culture system. Light intensity 2500-10,000 Lux; pH 7.2-8.0; Specific gravity 1.020.

CRAB AND STARFISH PREDATION OF THE SCALLOP *PECTEN MAXIMUS* (L.) DURING SEABED CULTIVATION

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ABSTRACT

Seabed cultivation of scallops is seen as a cost effective production method. Using this technique, the earlier stock can be moved from suspended cultivation to the seabed, the greater the economic gain. However, predation pressure is likely to be inversely related to scallop seeding size. Crab and starfish predation of juvenile scallops has been found to be an important factor in both cultivation and stock enhancement programs. In order to assess the relative predatory importance of crabs and starfish, laboratory trials were undertaken with locally occurring species. *Cancer pagurus* L. was the most voracious of the four crab species investigated. Size selective predation at rates proportional to the relative predator:prey size ratio was evident. All sizes of scallop from 3-9 cm (shell height) were predated. With respect to starfish, of the four species studied *Asterias rubens* L. was within the locality the most abundant predator, while *Marthasterias glacialis* L. was far less common but also preyed on the scallop. Size selective predation occurred, with predator size increasing in relation to prey size. Field trials have been undertaken as a comparison to the laboratory studies. Results are discussed in relation to optimization of seeding size and techniques.

INITIAL STUDIES IN THE HATCHERY CULTURE OF KING SCALLOP, *PECTEN MAXIMUS*

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ABSTRACT

The king scallop, *Pecten maximus*, was conditioned to spawn in the laboratory. Adult scallops (220 mm shell height) were held in groups of 10 on 1 cm aperture mesh trays containing substrate. Trays were supported off the bottom of 120 l fibreglass tanks through which unfiltered seawater, heated to between 11-16°C, flowed to waste at a minimum rate of 20 $ml \cdot min^{-1} \cdot scallop^{-1}$. Seawater temperature was increased by 1°C each week to a maximum of 16°C. Approximately 30 $l \cdot day^{-1}$ of an algal mixture containing *Tetraselmis suecica* and *Skeletonema costatum* were continuously dosed into the seawater. After 5, 11 and 12 weeks of conditioning, scallops were induced to spawn by thermal shock. Fertilized eggs were set up in 150 l of filtered, UV-treated seawater at 16°C and EDTA (1 $mg \cdot l^{-1}$) and chloramphenicol (2 $mg \cdot l^{-1}$) were added. Egg concentration was kept low at $50 \cdot ml^{-1}$ to prevent abnormal development. After 72 h, percentage recovery to "D" larvae (100 μ) was estimated and ranged from 10.1-58.3%. Larvae were reared in seawater treated as above, and fed a mixture of 50 $cells \cdot \mu l$ of *Isochrysis galbana* Parke and 50 $cells \cdot \mu l$ of *Chaetoceros calcitrans* Takano. Water and food were exchanged at 48 h intervals. At 100 μ, larvae ingested 200 algal $cells \cdot d^{-1}$, increasing to 3000 $cells \cdot larva^{-1} \cdot d^{-1}$ at the commencement of metamorphosis (240 μ). Metamorphosis was reached after 20-25 days depending on temperature. Larvae (>50% eyed) retained on 170 μ mesh were encouraged to settle using three methods:

1. larvae were placed in 15 cm diameter perspex tubes with 170 μ nylon mesh bases and grown on in a 170 l downwelling system;
2. 10 cm diameter, 30 cm long perspex tubes were filled with black, nylon filament netting and placed in 150 l larval bins;
3. larvae were placed in specially constructed 170 μ nylon mesh baskets (50 x 24 x 30 cm) and reared in 150 l larval bins.

A total of 30,000 (8.0%) spat survived metamorphosis, but only 2,000 (8.3%) reached a minimum planting-out size of 10 mm.

SHALLOW WATER BAY SCALLOP, *ARGOPECTEN IRRADIANS*, CULTURE IN VIRGINIA

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ABSTRACT

Culturing the bay scallop, *Argopecten irradians*, in the shallow waters (<3 m) of Virginia, U.S.A., has been investigated since 1990. Particular attention was paid to early nursery phase and final growout technology. The use of land-based upweller nursery systems for juvenile (>1 mm shell height) growth to field planting size resulted in growth rates of 0.3 mm shell height per day. Growout technology using polyethylene trays, plastic mesh cages and either multi-tiered or single tier racks was studied. While market-sized animals could be obtained within seven months of spawning using any of the gear combinations, the most viable culture option appears to be plastic mesh cages on single tier racks.

INTRODUCTION

In the mid-1960's the bay scallop, *A. irradians*, was identified by scientists of the Virginia Institute of Marine Science (VIMS), Wachapreague Laboratory, as having culture potential for Virginia waters. It was considered to be suitable for marine aquaculture because of its high market value, high level of consumer recognition and acceptance, its variability in availability due to natural population fluctuations and a rapid growth to market size. In addition, hatchery techniques for spawning and rearing larvae were successfully demonstrated.

Castagna and Duggan (1971) documented the biological feasibility of rearing bay scallops from egg to market size within the span of 8 to 10 months. However, they identified a major impediment to further culture development. Duggan (1973), reiterated by Castagna (1975), noted that better handling and holding methods were needed for expanded growout ventures.

An additional constraint to development was perceived to be unfavourable economics of producing bay scallops for the shucked meat market. At the time Castagna and Duggan conducted their investigations, only the adductor muscle of the bay scallop was utilized. It is still felt that U.S. culture of bay scallops for a shucked product is not economically feasible, in light of the large volume of imported bay scallop meats that annually enter the U.S. Recently, however, interest has developed in using the entire animal, similar to oysters or hard clams. These animals command a premium price and make the economics of culture much more favourable.

With this renewed interest in bay scallop culture, a project was begun to demonstrate growout methods for Virginia waters. From the outset, the traditional lantern net technology for grow-out was not considered immediately feasible, primarily due to regulatory uncertainty surrounding the permitting of large numbers of lantern nets in Chesapeake Bay. Instead, a rack and tray system was investigated which could utilize the abundance of shallow water available in Virginia.

This paper will review the progress in the development of techniques for shallow water (less than 3 m water depth) culture of the bay scallop in Virginia waters. To be discussed will be spawning, onshore nursery procedures and efforts at field growout, including stocking density investigations.

MATERIALS AND METHODS

The VIMS, Wachapreague Laboratory was utilized for spawning and growth of post-set bay scallops to over 1.0 mm shell height. Broodstock initially came from a line of animals maintained at the Laboratory since the 1970's. These animals represent a hybridization of the three subspecies of *Argopecten* (*A. i. irradians, A. i. concentricus* and *A. i. amplicostatus*) and have been shown to grow well in Virginia waters (Castagna, Pers. Comm.).

For spawning, no artificial conditioning was employed. Ripe animals, as identified visually based upon gonad colour, were placed into a spawning trough and induced to spawn using standard procedures of temperature manipulation. Following the initiation of spawning, fertilization was allowed to occur within the trough. Periodically, spawning trough water was drawn down and eggs collected on a 25 μ screen. Eggs were washed through a 153 μ screen to remove debris, subsampled and counted.

Larvae were raised in static water tanks and fed "brown" water, natural water that was passed through a 10 μ bag filter. Just prior to the initiation of settlement, larvae were transferred to troughs fitted with vertical inserts. The inserts served as surface area for attachment of the post-set animals. Following settlement, troughs were supplied with flowing seawater filtered through a 50 μ bag filter.

After the animals exceeded 1.0 mm shell height, they were transferred to the onshore upweller nursery system of a commercial hard clam culture facility (Cherrystone Aqua-Farms) located on the Bay side of the lower Eastern Shore of Virginia, near the town of Cape Charles. This location also served as the final field growout site for the project.

Approximately 10,000 bay scallops were placed in each 46 cm diameter upweller cylinder. Flowing, unfiltered seawater (salinity 27 ppt) was supplied at the rate of 15 l per minute per cylinder. Outflow drains had to be screened to prevent the escape of scallops. The cylinders were drained and flushed with fresh water daily to remove accumulated silt and debris. The scallops were sampled weekly and measured for shell height as an indication of growth. Once over 75% of the animals exceeded 8 mm shell height, they were graded and field planted.

In 1990, bay scallops were field planted in polyethylene trays originally designed for hard clam culture. The trays measured 112 cm by 79 cm by 8.9 cm with solid side walls and 4 mm square perforations over the entire bottom. Once scallops were placed into the trays, plastic mesh with 4 mm mesh openings was snapped into place across the top using special clips that ran the entire length of the sides. No attempts were made to control the stocking density at this time. Trays were deployed either directly onto the bottom or were placed onto cinder blocks to be held off-bottom.

For 1991, racks were constructed of 3.8 cm by 3.8 cm L-angle fiberglass reinforced plastic. Each rack was designed to hold three of the polyethylene trays secured by bungee cords. Racks were deployed into 2.0 m water depth (mean low water) so that the scallops would always be subtidal. Additionally, a single tier rack was constructed and installed in shallower water for a stocking density-growth study. Trays were stocked at three different densities: 513 per m^2, 797 per m^2, and 1026 per m^2.

Planting strategies for 1992 employed steel reinforcing bar racks (single level) deployed into 1.5 m of water depth using both polyethylene trays and plastic mesh cages (88 cm × 45 cm × 8 cm). Two stocking densities were initially used, 513 per m^2 and 1026 per m^2. However, once mean shell height of animals in the 1026 per m^2 gear exceeded 30 mm, half the gear was split into 513 per m^2 as well. This was done in an effort to evaluate alternative handling procedures at initial stocking. Additionally, when animals in mesh cages exceeded 30 mm shell height, they were removed from the original stocking cage which had a mesh size of 6 mm and placed into cages with larger mesh openings of 12 mm.

RESULTS AND DISCUSSION

In the interest of clarity and for chronological purposes, each year's results will be presented and discussed separately.

1990

This marked the first year of fieldwork and as such was used as a trial period so that preliminary questions could be answered. Little attention was paid to details other than would scallops survive and grow at the experimental site in the gear being tested. No attempts were made to quantify growth or survival. Field observations consisted of whether or not the gear was still in place, whether scallops were alive and how could the entire system be improved. Additional information was obtained regarding the use of downweller and upweller nursery facilities for seed production.

The use of downweller nursery systems for early juvenile (750 μ to 3 mm) bay scallops proved not to be workable; for one reason, the scallops grew too fast and actually overgrew the downweller cylinders. Additionally, the manpower required to maintain and clean the cylinders was excessive. The use of upweller cylinders for more advanced juveniles (over 2 mm) was acceptable, provided the water outflows were screened and enough surface area could be provided to the scallops for attachment. Using plastic mesh inserts within the cylinders, while increasing the surface area for attachment, made removing the seed very tedious. Rather than trying to provide additional surface area within an individual cylinder, using more cylinders was considered to be the more preferred option.

Subjective information indicated that the experimental site would support scallop growth, however changes must be made in the growout method being used. Problems identified with the tray system being used included excessive siltation should the tray rest directly on the bottom, poor water circulation resulting from excessive fouling or overcrowding, the need for a more manageable gear system and better information on stocking densities and logistics of animal management. This information was used to develop the experimental plan for the subsequent year.

1991

On April 16, 1991, 184 animals were used as broodstock for spawning at the VIMS Wachapreague Laboratory. Using standard bivalve spawning techniques 128,955,000 eggs were produced. The resultant larvae and post-set juveniles were cultured at the Wachapreague Laboratory until June 11, 1991, at which time they were transferred to the Cherrystone Aqua-Farms upweller nursery facility. Approximately 105,000 animals were equally divided among 10 upweller cylinders. At the time of transfer, mean shell height was 3.5 mm (S.D. 1.3, range 1.0 to 6.5 mm). Growth within the upweller cylinders was quite rapid; over a four week period, mean daily change in shell height was

0.2 mm. By this time all available surface area was being utilized. Scallops were overgrowing the cylinders and escaping into the upweller trough.

Three-tiered racks were deployed into 2.0 m water depth (mean low water) on July 16, 1991. A total of 17 racks were used. Deploying and securing the racks was labour intensive, requiring six men one hour for initial deployment and then four men an additional hour to secure the racks in the bottom.

Polyethylene trays were stocked with scallops on July 17, 1991, and secured to the racks using bungee cords. Three different sized animals were used (6 mm, 8 mm, and 12 mm), at three different stocking densities (513, 797 and 1026 per m^2). A total of 34,272 animals were deployed into 51 trays.

Five days later, racks were discovered tipped over with trays missing. Other racks were still upright, but had trays missing. Three problems were identified associated with the multi-tiered racks and polyethylene trays. First, the trays were semi-buoyant. The combination of little weight associated with small seed scallops and the bungee cord attachment could not counteract this buoyancy and trays escaped the racks. Secondly, at least for this site, the rack profile was too high in the water column, exposing the trays to excessive physical forces, contributing to lost trays or tipped racks. Finally, the actual water depth in which the racks were deployed was too deep to efficiently work and be sure that all racks and trays were secure.

A single-tier rack was deployed on July 25, 1991, in shallower water and stocked the following day with six trays, using the three densities as previously, two trays per density. Beginning in August, 1991, animals from the three stocking densities were non-destructively sampled biweekly and measured for shell height. Over the course of the entire sampling period, a Scheffe's Test for significant differences of shell heights between stocking densities revealed that the shell heights of animals stocked at 513 per m^2 and 797 per m^2 were significantly different (0.05 level) from 1026 per m^2. However, 513 per m^2 and 797 per m^2 animals were not significantly different from each other. These results corroborated the findings of Duggan (1973). As further subjective indication of overcrowding effects, the incidences of shell blunting or misshapen shells increased with time in the 797 per m^2 and 1026 per m^2 stocked trays.

On September 19, 1991, both 513 and 797 per m^2 animals averaged over 40 mm shell height. In concurrent work with restauranteurs in Virginia, 40 mm shell height was determined to be the minimum acceptable market size for whole bay scallops. Thus, in 1991 market-sized animals were available five months after spawning.

In actuality, animals for distribution to restaurants were not harvested until the last week of October, six months after spawning. However, at that time only 57% of the animals exceeded the minimum market size of 40 mm.

Table 1 presents the harvest data for the scallops that were grown in trays on the three-tiered racks. Several interesting trends are visible in this data. First, percent survival decreased beginning in January, 1992. This period coincided with the onset of severe winter storms with increased turbidity and associated high sediment loads. Trays harvested at this time had large amounts of sediment within the trays and many scallops were buried. Secondly, those trays with the highest stocking densities generally had lower percentages of market-sized animals. Note that on November 13, 1991, one tray with a stocking density of 1065 animals per m^2 had a marketable percentage of only 48.2, while a tray with a stocking density of 646 animals per m^2 had a marketable percentage of 83.8.

The activities during 1991 demonstrated a further need to refine the grow-out methods. The use of multi-tiered racks in 3 m of water was not satisfactory, both from an initial expense position (rack construction material cost US$6.56 per linear meter) and because of the difficulties in installing and maintaining trays.

1992

Spawning and nursery of juvenile bay scallops was conducted identically to the previous year. On April 28, 1992, 202 broodstock animals from the previous year's production produced 211,275,000 eggs. The resultant larvae were cultured at the Wachapreague facility. Only 54,000 animals over 1 mm shell height were transferred to the upweller facility for continued nursery. It is speculated that the cooler than normal spring water temperatures adversely affected bay scallop survival at the Wachapreague facility by slowing the growth rate of the scallops as well as reducing the available natural phytoplankton food supply.

Growth within the upweller system was again rapid. Over a three week period, mean daily change in shell height exceeded 0.3 mm.

Polyethylene trays and plastic mesh cages were deployed onto single-tier steel reinforcing bar racks on August 5, 1992. Five trays and five cages were each stocked at 513 animals per m^2; eight trays and seven cages were stocked at 1026 animals per m^2. Problems still occurred with the trays, even on a single-tier rack in shallower water. Some trays were lost. Additionally, because of the size of the tray and weight of the scallops as they approached market size, the trays became unwieldy for a single person to handle. The plastic mesh cages, on the other hand, did not move, allowed for good water flow and were easily handled by one person, even when full of market-sized animals.

The first harvest for distribution occurred on October 20, 1992, 175 days after spawning. However, only 75.5% of the animals stocked at 506 per m^2 exceeded minimum market size of 40 mm shell height and just 56.0% were market size from those animals stocked at 646 per m^2 (Table 2). Overall survival was excellent, ranging from a low of 94.8% to 100% survival within a tray. Early in the harvest season (November and December) those gears with the highest stocking densities had the lowest percentage of market size animals (51.4% and 76.0%); thereafter all densities produced high levels of market size animals.

Experiences from this year's activities demonstrated that growout technology using single-tier racks and plastic mesh cages was acceptable in terms of growth to market and ease of handling. Additional work is planned for the early stage nursery systems and setting of larvae in hopes of increasing survival.

SUMMARY

Continuing the work initiated in the early 1970's, this current project has corroborated earlier results. Spawning technology for bay scallops is well in place, with no difficulties in obtaining substantial numbers of fertilized eggs. Larval culture is relatively well-known, with acceptable survival to setting stage. Post-set juveniles still pose some problems in maintaining high survival rates to a shell height exceeding 1 mm.

Growth in upweller nursery systems of juveniles exceeding 1 mm shell height is excellent. Growth rates of 0.3 mm per day were obtained. At this rate, juveniles require only three weeks in this system before field planting size is reached. Space limitations can become a problem if juveniles remain in the upwellers too long.

Of the various field planting methods evaluated for shallow water Virginia conditions, the use of plastic mesh cages held off-bottom on steel reinforcing bar racks offers the most potential for commercial application. These cages allow for unrestricted water flow, are easy to secure to the racks, are easy for one person to handle, even when full of market-sized animals and are readily available, fairly inexpensively.

Field planting densities between 513 and 797 animals per m^2 appear to be the best utilization of space as measured by growth rate to market size and shell shape. Stocking density of 1026 animals per m^2 was too dense, resulting in reduced size and misshapened shells.

In Virginia, harvestable numbers of market-sized animals can be achieved within seven months of spawning using techniques described. Restaurants will accept animals over 40 mm shell height. However, for appearances sake, most likely the best market size is over 45 mm.

Finally, while there is considerable interest from commercial sectors in growing bay scallops, additional research must be done to fine tune the techniques for larval culture and growout prior to large scale expansion of the industry.

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Table 1. Harvest data for 1991-92 bay scallops grown in trays.

Harvest date (Days after spawniing)	Actual stocking density (#/sq m)	Number alive	Percent survival	Number >39 mm	Percent market animals
22 Oct 91 (189)	678	732	92.9	415	56.7
13 Nov 91 (211)	1065	1112	90.7	536	48.2
13 Nov 91 (211)	646	501	66.4	420	83.8
20 Nov 91 (218)	925	866	80.2	246	28.4
20 Nov 91 (218)	753	675	77.1	300	44.6
20 Nov 91 (218)	687	672	83.8	521	77.4
9 Dec 91 (237)	872	868	85.3	399	46.0
9 Dec 91 (237)	334	327	83.0	274	83.8
18 Dec 91 (246)	753	713	81.3	361	50.6
18 Dec 91 (246)	990	820	71.4.	490	59.8
18 Dec 91 (246)	850	605	61.2	399	66.0
20 Jan 92 (279)	408	423	88.1	378	89.4
28 Jan 92 (287)	818	787	79.7	568	72.2
28 Jan 92 (287)	484	498	89.2	437	87.8
28 Jan 92 (287)	732	607	71.2	260	42.8
28 Jan 92 (287)	990	632	55.1	337	53.5
3 Feb 92 (292)	506	404	68.2	339	83.9
3 Feb 92 (292)	258	125	42.3	111	88.8
3 Feb 92 (292)	936	469	42.8	328	69.9
2 Mar 92 (319)	516	205	33.3	203	99.0
2 Mar 92 (319)	1044	730	60.0	565	77.4
7 Apr 92 (355)	732	298	34.9	286	96.0
7 Apr 92 (355)	742	557	64.3	517	92.8
7 Apr 92 (355)	732	335	39.0	290	86.6
23 Apr 92 (371)	484	337	59.9	330	97.9
23 Apr 92 (371)	742	361	41.7	345	95.6

Table 2. Harvest data for 1992-93 bay scallops. Following the Actual Stocking Density, a "T" indicates a tray and a "C" means a cage was used for field grow-out.

Harvest date (Days after spawning)	Actual stocking density (#/sq m)	Number alive	Percent survival	Number >39 m	Percent market animals
20 Oct 92 (175)	506 C	204	96.7	154	75.5
20 Oct 92 (175)	646 C	257	94.8	144	56.0
6 Nov 92 (192)	344 C	140	98.6	127	90.7
6 Nov 92 (192)	452 C	189	99.0	170	89.9
6 Nov 92 (192)	570 C	238	95.2	181	76.0
6 Nov 92 (192)	764 C	313	97.5	161	51.4
1 Dec 92 (217)	506 T	421	100.0	389	92.4
1 Dec 92 (217)	979 T	805	98.4	612	76.0
1 Dec 92 (217)	527 T	439	99.1	401	91.3
1 Dec 92 (217)	420 T	336	97.4	307	91.4
6 Jan 93 (253)	624 C	256	98.5	232	90.6
6 Jan 93 (253)	678 C	278	98.6	246	88.5
6 Jan 93 (253)	366 C	151	98.7	145	96.0
6 Jan 93 (253)	613 C	356	99.2	235	91.8

PRODUCTION COSTS IN FRENCH SCALLOP CULTURE

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ABSTRACT

Methods of culturing king scallops in France (hatchery production of seed, intermediate culture in cages and extensive growout on the seabed) have been developing since 1983. A multi-step project analysis was carried out to estimate the economic feasibility of such culture. Since there is no market for scallop spat in France at the present time, the project analyzed the entire production cycle from hatchery to harvest. The project was based on a production of 150 t of marketable scallops, which represents the expected supply from culture activities in the near future. The software developed by IFREMER for the project analysis provided the main financial criteria, i.e. internal rate of return, potential earning power, cash requirements and a breakdown of production costs. The first simulations indicated scallop culture in France was profitable, but attention must be given to the cash flow because of the lack of income during the first years. Generally, it appears that regardless of rearing strategy a survival rate of 30% after sowing is required to expect economic viability when the ex-farm price of scallops is about US $3.60/kg.

INTRODUCTION

Development of king scallop, *Pecten maximus*, culture in France is supported by the French government and regional authorities of Brittany. Now that culture technology has been developed, the government requires information on the economic feasibility of scallop production. Work on improving the technical results continues, and IFREMER (the French Public Organization for Marine Research) has initiated an economic evaluation of scallop culture which takes into account production costs, pectinid market analysis, and social and legal constraints. The study of production costs presented here is based on a project analysis that allows prediction of both financial needs and the profitability of the activity.

Due to a lack of natural sources of seed and slow growth of *P. maximus* in hanging culture, French scallop farming is characterized by the production of postlarvae (2 mm) in a hatchery-nursery, intermediate culture of spat in cages in the sea (from 2 mm to 30 mm), extensive growout culture on the seabed (density $10 \cdot m^{-2}$), and dredging the scallops 2.5-3.0 years later when they reach a marketable size of 100 mm shell height.

As the technical methodologies are clearly defined and results are consistent, it is possible to accurately determine the requirements for equipment, manpower, etc. Only the rate of recapture from seed remains variable (20% to 50%). This has little influence on the size and amount of equipment and input required since this occurs at the end of the rearing cycle; however, the recapture rate influences revenues directly and thus can have a significant effect on the profitability of the operation.

MATERIALS AND METHODS

PROJECT ANALYSIS

Project Identification

The project was defined first by location, personnel, farming operations and production targets. These choices led to preparation of an annual schedule for the use of equipment and manpower (Fig. 1).

Estimation of Costs and Revenues

Secondly, it was necessary to assess annual costs and revenues for a 15 year period, a convenient time frame due to the length of the farming cycle (three years):

1. amount of initial investment, depreciation and renewal;
2. manpower and other operating costs;
3. stocks, yield and expected revenues.

A financial plan was proposed to meet the need for initial investment, taking into account the availability of subsidies and the legislation regulating debt.

All these figures were computerized on tablesheets for an automatic calculation of accounting data and cash position survey, with the help of PROJAQ, a software program we developed on the basis of Microsoft EXCEL (Fig. 2).

A breakdown of operating costs for different rearing stages was also carried out in order to obtain an analytical accounting and assess the cost of intermediate products (postlarvae and juveniles). This breakdown, like any other analytical accounting method, depended somewhat on arbitrary assumptions.

Financial Analysis

The third step was financial analysis, undertaken with PROJAQ from the computerized accounting data and other parameters beyond the control of the entrepreneur, such as survival rate during intermediate culture (as long as it did not greatly modify the size of the project), recapture rate from seed, market price of scallops and the interest rate (currently 8% in France). From these data, PROJAQ supplied within a few minutes:

1. the return on investment through the Internal Rate of Return (IRR) over 15 years. The IRR measured the rate at which the money would have to be invested elsewhere to get the same return as in this project. This step did not take into account either the financial plan of the project or the interest expenses. This analysis examined the project from the standpoint of the investor;
2. the project feasibility through monitoring the cash flow during the next 15 years in order to demonstrate potential problems and permit a revision of initial financial choices. The definitive financial plan was obtained after a succession of iterations carried out by PROJAQ. These elements are particularly important to the lending banker;

3. profitability of the activity and factors causing variation. The breakdown of costs of five main items (purchases, salaries, taxes, depreciation and interest expenses) is a good method to appraise the profitability of the activity according to different ratios, such as Operating Result/Turnover or Net Result/Turnover. These criteria represented the entrepreneur's point of view;
4. an analysis of costs through a breakdown of operating expenses and particularly of depreciation expenses during the rearing stages and the type of investment, in order to highlight relevant profitability issues and possible productivity gains. This breakdown would be helpful to the researcher in charge of improving culture technique.

Study of Variants

The last step in project analysis was the study of variants, which was partly modified due to results of prior analysis. These results led to new choices, for instance changing organizational structure, equipment or financial plan, and consequently led to a new project identification (return to the first step of the analysis).

THE ENTIRE SCALLOP FARMING PROJECT

Since there was no market for spat in France, and therefore no current price for either the 2 mm postlarvae or the 30 mm juveniles, the project analyzed the entire production cycle from hatchery to harvest, and was not based on purchase of spat. An integrated model was designed based on the predicted production over the next few years. Approximately 100 fishermen were considered to be involved in the construction of a hatchery, intermediate culture, and in management of extensive scallop seeding. The seeding area was assumed to be a 150 ha lease, of which 50 ha was seeded annually. It was estimated that the fishermen produced three batches of four million postlarvae, i.e. 12 million annually, yielding 4.2 million juveniles, then 150-180 t of marketable scallops three years later.

Investment

On the whole, it was assumed the project would require an investment of $1 million (U.S.). The primary investment costs were the hatchery (US $349,000), 57 frames and 2000 cages for intermediate culture (US $224,000), pumping station (US $153,000), land (US $73,000), on-land working station with tanks (US $67,000), and a 15 m dredging barge and dinghy (US $67,000). Part of this equipment was considered to be renewable after five, seven, or ten years, with renewal extended over several years when possible. Total depreciation was calculated at US $100,000 per year. The first investment could be partly supported by the E.E.C. and the regional government (up to 50% in Brittany at the present time) if the entrepreneurs could demonstrate professional ability and contribute 10 to 15% of the financing. The remainder was presumably financed with loans adjusted according to the first results of the financial analysis (feedback).

Salaries and Other Operating Costs

According to the production schedule, the project required six permanent employees; other operating costs were calculated from the real accounting of the Local Fishermen Committees. Operating costs (excluding depreciation) totalled US $320,000 per year, of which US $200,000 was required for manpower. Due to the lack of revenue during the first three years, these costs were considered to be financed by contributions from the partners and by bank loans with deferred payment. Again, the definitive financing choices were dependent on preliminary results of the financial analysis (feedback).

Output and Sales

The assumptions on farming output and sales were based on current data: survival rates of 25% in the nursery stage and 35% during intermediate culture, and seed recapture rates of both 25% and 30%. An average price of US $3.60/kg was adopted due to the presence of gonads which are desired in the French market. After a small harvest in year four, full production was considered to begin in year five with 150 t, valued at US $545,000 on a 25% recapture, and 180 t, valued at US $650,000 on a 30% recapture. Sales were generally considered to be greater than operating costs, but the question remained whether these were sufficient to cover expenses during the first three years and interest charges.

RESULTS OF FINANCIAL ANALYSIS AND DISCUSSION

RETURN ON INVESTMENT

The importance of investment as early as the first year and the lack of revenue during the first three years were the main reasons for obtaining an Internal Rate of Return less than 6.4% at 30% recapture, and a negative IRR at 25% recapture (Fig. 3). This result should not be considered as a death sentence for the project, however, but rather as an indication that this kind of activity is not likely to attract investors whose primary object is either a fast return on investment or a high internal rate of return.

FINANCIAL PLAN, CASH EVOLUTION AND PROJECT FEASIBILITY

Many investment costs have to be financed in year one, then renewed in years eight and fifteen. Operating costs must also be financed during the first three years. Therefore, the operation cannot rely on personal contribution and subsidies alone, but must resort to borrowing. The definitive financial plan was calculated by PROJAQ after several iterations. With these financial conditions, the evolution of the cash flow was very different for each assumption (Fig. 4). At a recapture rate of 25%, annual sales were not enough to meet the sum of operating costs and interest costs. The feasibility of the project was jeopardized at this price and with this method of financing. In contrast, at a recapture rate of 30% the cash flow remained positive during the first three years, due to the different loans, and seesawed around zero till year 11. From year 12 on, the operation started making a profit since most of the loans were repaid, and it was possible to repay the partner's contributions. The cash position in year 15 was enough to cope with renewal of investments without any new loans, but this position was not sufficient to permit any new development or diversification of the activity before year 15.

PROFITABILITY OF THE ACTIVITY

The ratio of added value was greater than 80% regardless of recapture rate. After taking the operating charges into account, the ratio of Operating Result/Turnover declined to 23% for a recapture rate of 25%, or 36% for a recapture rate of 30%. After including the financial expenses, the ratio of Net Result/Turnover remained at 21% if the recapture rate was 30%. This value appeared to be sufficient to conclude that the activity was profitable under these financial conditions. If the recapture rate was only 25%, however, financial expenses were so high that they led to a negative Net Result (Fig. 5).

ANALYSIS OF PRODUCTION COSTS

To better understand the way in which the project works and the factors affecting its profitability, it may be interesting to study it independently of financial expenses. This reduces the influence of the financial plan, which depends a great deal on the institutional context (subsidies) and on the overall economic situation (interest rates). As recapture rate in the range 25-30% had little influence on operating costs, this analysis is the same in both situations. The breakdown of costs in the three rearing stages (Fig. 6) shows the prevalence of the hatchery costs at more than 50%, while intermediate culture and growout represent about 25% each.

The repartition of costs among the different stages is somewhat arbitrary but allows appraisal of the production cost at each level:

1. US $0.02 per postlarva;
2. US $0.08 per juvenile (30 mm);
3. US $0.34-0.40 per marketable scallop according to the seed recapture rate (30 or 25%, respectively), i.e. US $2.30-2.80 per kg of whole scallop, or US $16.00-19.00 per kg of muscles (without gonads).

DISCUSSION AND VARIANTS

Such a financial analysis makes it possible to assess potentialities and the limits of scallop culture in France. The cost of the hatchery seems very important but because of technical constraints, it is not possible to reduce the number of employees, and because of financial constraints, it would be hazardous to look for economies of scale by increasing its size. As for intermediate culture, only a reduction of the price of frames and cages or a better control of spat survival may lead to a reduction of production costs.

Recapture rate of seed appears to be the key for increasing productivity, principally because it occurs at the end of the rearing cycle and brings added value. The existence of clear differences in the results of the financial analysis of this scallop farming project based on assumptions about the recapture rate emphasizes the importance of obtaining more reliable technical results during growout.

These preliminary results may also lead to the study of variants of the project in consideration of new rearing choices such as partial or total supply of wild spat, marketing of surplus postlarvae, or intermediate culture in cheaper frames. In these cases, the problems in terms of maintenance cost, depreciation, or longer rearing cycle (four years instead of three) required to increase income by raising larger animals, must be taken into account.

CONCLUSIONS

INTERESTS AND LIMITS OF FINANCIAL ANALYSIS AND PROJECT ANALYSIS

The design of PROJAQ makes it possible to assess all the effects of technical innovation, a modification of the farming method or change in biological standards in terms of production and financial results, for it takes into account the organization of production for the whole operation. It is a simulation tool which helps to distinguish results of different variants of the same project based on numerous criteria.

However, results of the financial analysis cannot be accepted as definite or absolute. Market uncertainty and risks inherent in dependence on the natural environment must be considered. These results should be regarded as elements to facilitate decision-making by investors, bankers, entrepreneurs, researchers or public policy-makers with respect to their own aversion to risk.

Finally, in the present economic context of extremely high real interest rates, very few projects may seem attractive strictly in terms of financial profitability. Agricultural and aquacultural projects are at a particular disadvantage because they need a long time for a return on investment. These high interest rates are also the cause of cash difficulties if biological results do not attain the norm, since bank charges continue in addition to interest expenses.

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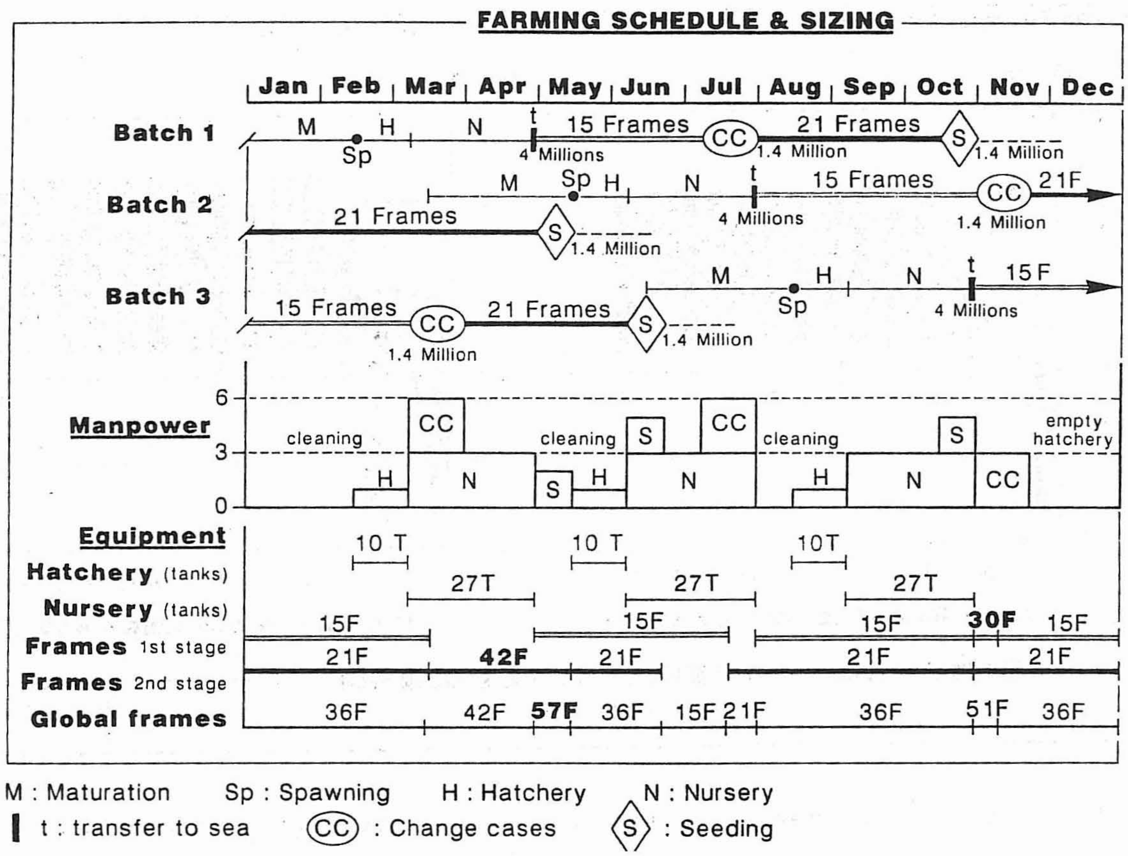

Fig. 1. Manpower and equipment sizing and farming schedule.

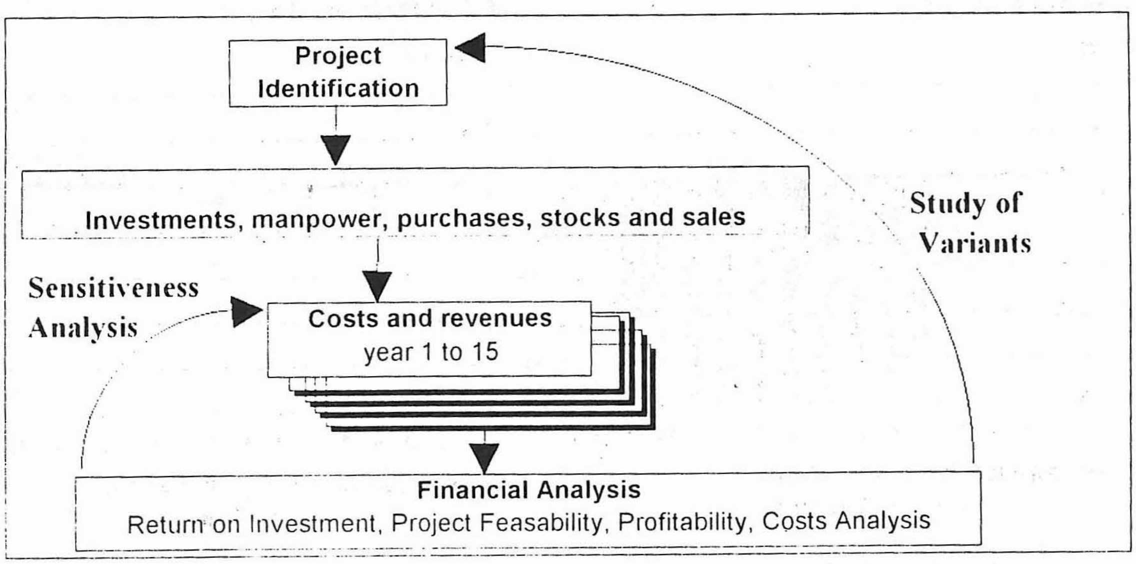

Fig. 2. PROJAQ software and project analysis method.

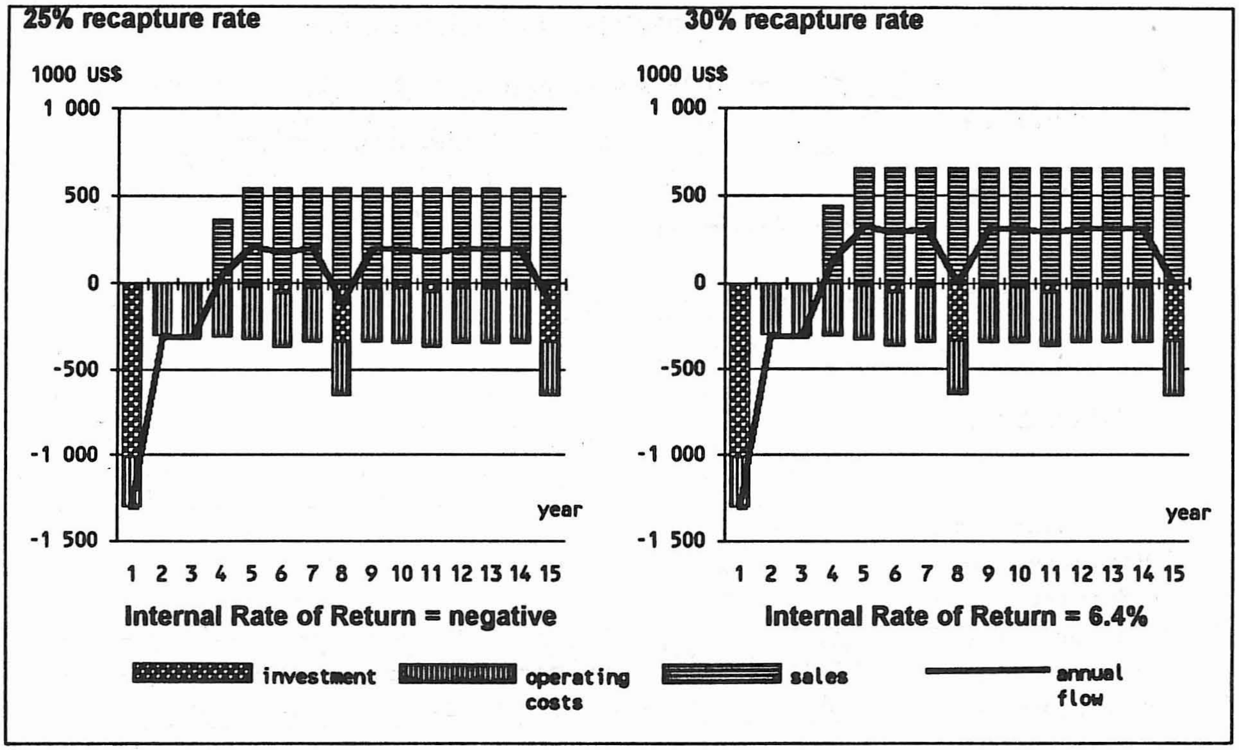

Fig. 3. Costs and revenues first estimation and return on investment.

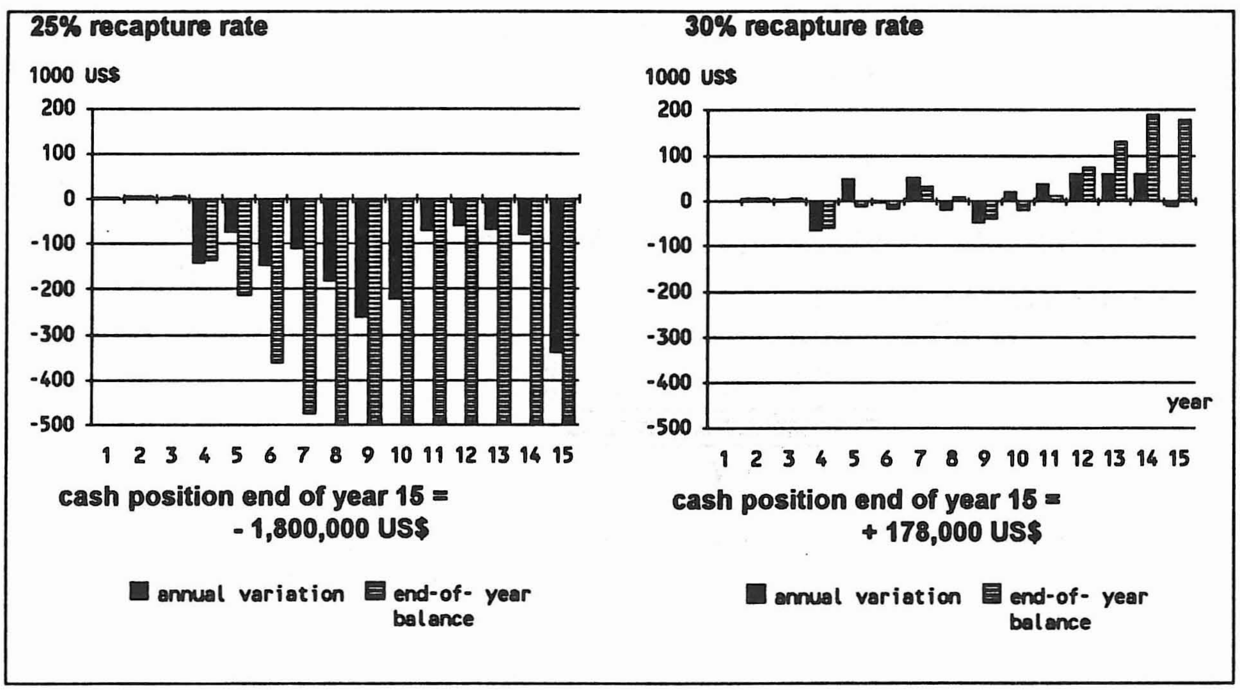

Fig. 4. Evolution of the cash position.

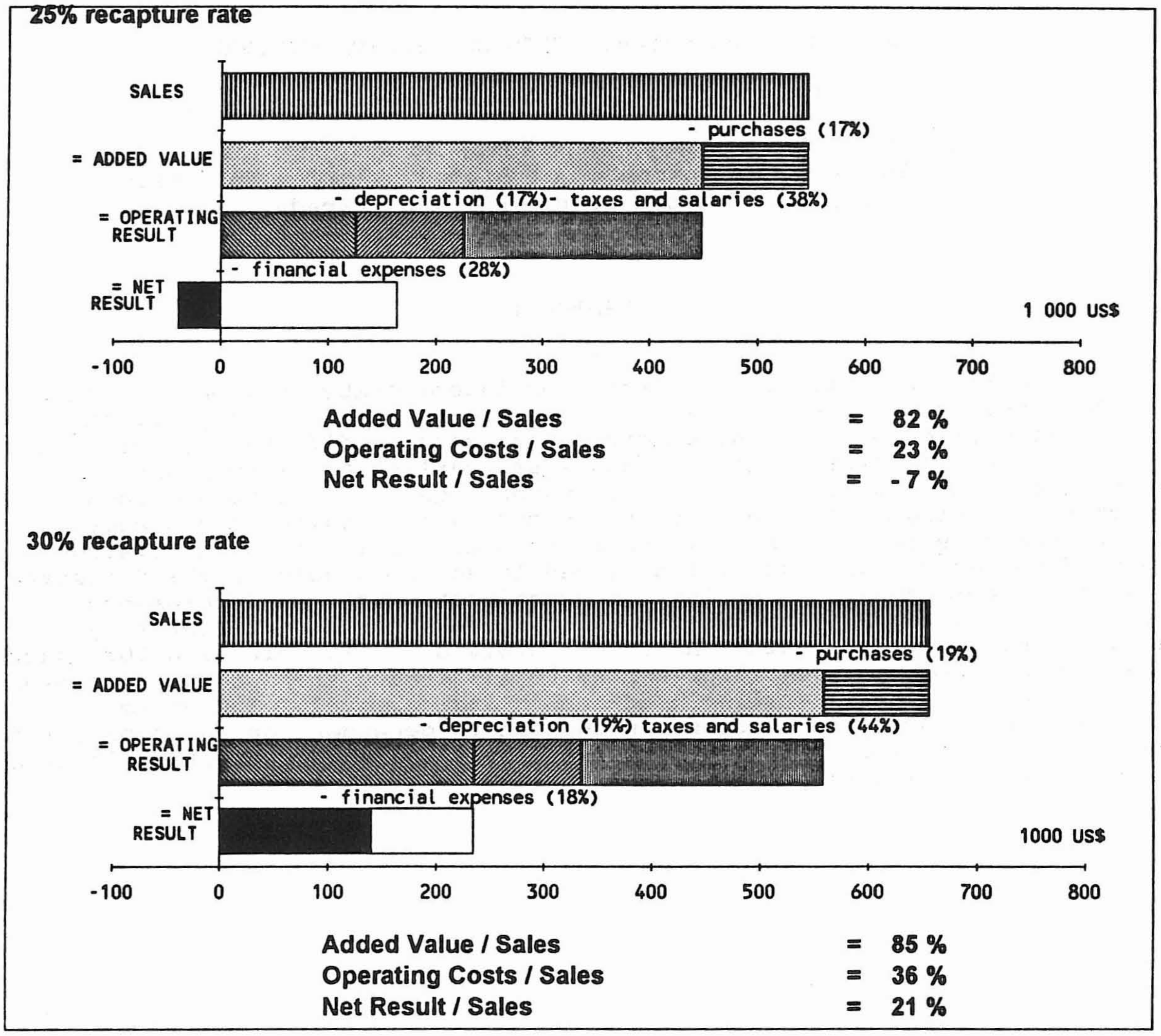

Fig. 5. Formation of the net result and profitability of the activity.

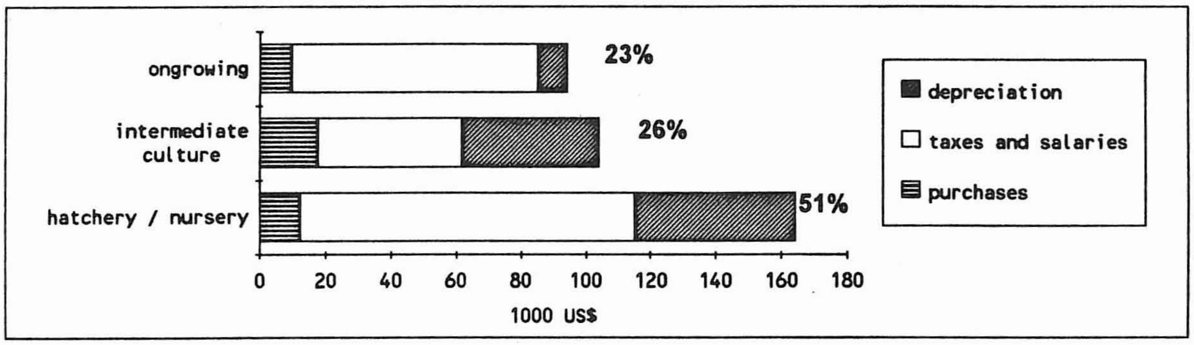

Fig. 6. Breakdown of production costs (without financial expenses).

STRATEGIES FOR INTERMEDIATE SUSPENSION CULTURE

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ABSTRACT

The traditional technology for intermediate scallop culture has been the pyramid-shaped pearl nets. In this experiment we compared the cost and handling time (loading and unloading) of several different types of net designs (square-base pearl nets, round-base pearl nets, lantern nets, superlantern nets, Shibetsu nets, and oyster cages). We also examined the effect of stocking density on growth and survival of juvenile sea scallops, *Placopecten magellanicus*, held in pearl nets and, using this information, we compared the growth and survival of juvenile scallops held in the different nets at the same density. An inverse relationship was found between shell growth and stocking density but overall survival was not influenced by density. A table summarizing the costs involved in producing 100,000 scallops held in the different nets is presented to illustrate the trade-offs between costs of nets, ease of handling, and growth and survival. The optimal strategy for intermediate suspension culture is dependent on net choice and stocking density, and is influenced by the overall growout strategy including final market product (e.g. whole vs meats only).

HISTORY AND STATUS OF SCALLOP CULTURE IN NORTH AMERICA

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ABSTRACT

Experimental scallop culture in North America began in the early 1970's with at least seven different species. Results from feasibility studies on the growout of scallops to market size with natural spat collection and hatchery produced seed indicate hatchery seed growout to be a more viable economic choice than natural spat collection. At least four commercial hatcheries now produce seed for the bay scallop, *Argopecten irradians*, deep sea scallop, *Placopecten magellanicus*, and the Japanese scallop, *Patinopecten yessoensis*. Other candidate species for culture currently under survey are the pink scallop, *Chlamys rubida*, spiny scallop, *C. hastata*, and the rock scallop, *Crassadoma gigantea*.

EXPERIMENTAL CULTURE OF MOON SCALLOPS, *AMUSIUM PLEURONECTES*, IN ULUGAN BAY, PALAWAN, PHILIPPINES*

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ABSTRACT

Growth rates were determined for scallops (35 to 75 mm valve height) held in pocket nets and lantern nets at varying densities. The Ford-Walford linear transform of the von Bertalanffy growth equation was used to correct for lower expected rates of ontogenetic growth in larger individuals and to allow quantification of food-limited stunting. Pocket nets allowed for greater growth of scallops than did the lantern nets at all stocking densities. The growth rates of scallops in pocket nets, nevertheless, was well below the growth of scallops in the wild. Clearance rates of Caribbean strains of *Isochrysis galbana* (*C-Iso*) and *Chaetocerous gracilis* (*C-Cg*) were determined for moon scallops, *Amusium pleuronectes*, in static chambers at 28°C. The scallops have a great capacity to filter both species of phytoplankton. Clearance rates were observed to range from 2.84 to 12.13 l/g·h dry weight ($4.7x10^6$ to $9.8x10^6$ cells/min or $1.3x10^8$ to $2.8x10^8$ cells/g·h) in pre-conditioned 70 mm animals. The threshold cell concentration for the beginning of pseudofeces production is less than 20,000 *C-Cg* cells/ml. The high rates of particle clearance and concomitant water transport by *A. pleuronectes* are adaptations to their native warm oligotrophic waters. These high clearance rates coupled with their habit of active swimming (>9 m/swim) may limit this species to low density bottom pen culture methods.

INTRODUCTION

The Asian moon scallop, *A. pleuronectes*, is found in southeast Asia from the Ryukyu Islands of southern Japan to Thailand and Indonesia (Habe, 1964). In the Philippines, moon scallops are caught throughout the archipelago in small-scale trawl fisheries (Llana 1983; DelNorte et al. 1988). A number of studies have focused on aspects of reproduction, recruitment, growth and mortality of natural populations of these scallops as they relate to the capture fisheries (Llana and Aprieto 1980; DelNorte 1988). The reported rapid growth of this species (≈two year life span), its relatively large maximum size ($H\infty$=106 mm), some promise in development of spawning and larviculture techniques, and its relatively high viscera and adductor muscle weights to shell weight ratio make this species attractive to study as a potential aquaculture prospect (Belda and DelNorte 1988; DelNorte 1991). One key aspect that makes bivalve molluscs attractive as a culture species in many developing nations is that they are filter feeders, utilizing naturally-occurring, low food chain phytoplankton and other suspended particulates (see Newkirk 1992 for a recent review). Concomitant with culture of filter feeding bivalves is the recognized effect of reduced growth with increasing stocking density (e.g. Eldridge et al. 1979; Eversole et al. 1990; Newell 1990). Because of this, it is of practical interest to determine optimum stocking densities as part of an economic feasibility analysis. The

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primary aim of this study is to evaluate the technical and economic feasibility of growout culture of *A. pleuronectes*.

Feeding rates of bivalves in relation to available food supply are an important factor influencing growth of animals in suspended culture (Incze et al. 1981). Thus a secondary aim of this study is to estimate the particle filtration rates of individual scallops.

MATERIALS AND METHODS

A. pleuronectes (ranging from 35 to 75 mm valve height) were caught by small-scale commercial trawlers in the Sulu Sea near Palawan, Philippines, and kept in buckets of aerated seawater while aboard the boats. After being brought ashore, scallops were transported in 500 ml capacity plastic bags (two to three scallops/bag) with approximately 200 ml seawater (34 ppt) and inflated to full capacity with pure oxygen. Bags were placed into styrofoam fish transport boxes with gel-ice packs for overland transport to the study site at Ulugan Bay, on the South China Sea coast of Palawan. Transport survival of scallops was near 100%.

The seawater of Ulugan Bay is oligotrophic (average >10 m Secchi depths), supporting fringing reefs beyond lightly exploited intertidal mangrove forests. During the growth study period, August to October 1991, salinity and water temperature averaged 34 ppt and 31°C, respectively. Variously sized and individually marked scallops were placed at varying densities (10, 20, and 40 scallops per 1140 cm^2) on shelves of lantern nets with exterior netting mesh of 4 mm. Larger mesh netting allows for nipping of scallop tentacles by grazing fish (Siganidae and others). Pocket nets with dimensions of 1 m x 1.5 m were constructed of 4 mm mesh outer nylon netting sandwiching an inner 25 mm mesh net. The pocket nets accommodated a total of 192 scallops (96/side). Both lantern nets and pocket nets were suspended at 2 m intervals from a 30 m subsurface longline set at right angles to the prevailing tidal currents. All gear were constructed of materials locally available in the Philippines.

Growth of individually marked scallops was determined on a monthly basis August through October. Data were analyzed by use of the Ford-Walford linear transformation of the von Bertalanffy growth equation.

Clearance rates were determined by using cultured Caribbean strains of *Chaetoceros gracilis* (*C-Cg*) and *Isochrysis galbana* (*C-Iso*) at 28°C in 30 l aerated static chambers. Prior to determinations of filtration and ingestion rates, scallops (≈70 mm valve height) were preconditioned for six hours in water containing 60,000 cells/ml. Clearance rates of 5 to 10 animals per experiment with two replicates were determined by monitoring depletion of phytoplankton from the medium by triplicate haemacytometer counts every 5-10 minutes. Rates were calculated by the equations of Jorgensen (1943) or Coughlin (1969), and expressed as ml/g·h or cells filtered per unit time. In some experiments, phytoplankton was added at 10 minute intervals in an attempt to maintain constant cell concentrations.

RESULTS

Growth studies suggest that *Amusium* is prone to density-dependant stunting or food limited growth when held in lantern nets (Table 1). Scallops held at low densities exhibited a growth check corresponding to transport and initial stocking; growth resumed at a reduced rate. Scallops held at the highest densities did not grow. Apparent maximum valve heights ($H\infty$), may be used as an index of the degree of food limited growth. Scallops held in pocket nets grew faster than scallops in lantern nets, but their growth was, nevertheless, lower than scallops in nature (Table 1). *Amusium* are prone to swim around the open space of lantern nets when disturbed; pocket nets allow individual scallops to be held in place.

Survival of scallops was high (>95% for all densities) during first month of the study. During the second month, mortalities were approximately 50% in the high density lantern nets. In December, freshets associated with the northeast monsoon lowered the salinity of Ulugan Bay to <25 ppt, killing all scallops.

At average phytoplankton densities of 60,000 cells/ml, filtration rates of 70 mm scallops were observed to range from 100 to 427 ml/min (2.84 to 12.13 l/g·h dry weight or (1.3×10^8 to 2.8×10^8 cells/g·h) (Table 2). The threshold cell concentration for the beginning of pseudofeces production is <20,000 cells/ml *Chaetoceros gracilis*.

DISCUSSION

The von Bertalanffy (1938) growth equation has been successfully applied to growth of bivalve molluscs (reviewed by Vakily, 1992). In a number of studies, von Bertalanffy growth parameters have been used to assess growth and production of bivalve populations in sites with varying hydrographic conditions or positions in the intertidal zone (Bayne and Worrall 1980; Broom 1982), as a means for assessing the impact of pollution on bivalve growth (Appeldoorn 1981), and as an indication of food-limited stunting in particularly dense wild bivalve populations (Rice et al. 1989). In this study we show that von Bertalanffy growth parameters may possibly be used as a tool for rapid assessment of growth and production potential for bivalves in off-bottom culture.

The particle clearance or filtration rates of *A. pleuronectes* are high in comparison to some other scallops. Bricelj and Shumway (1991) list the reported clearance rates from a number of species. Dry weight standardized clearance rates ranged from 0.145 to 31 l/g·h in various species of scallops. The only species with greater filtration rates than *Amusium* were *Chlamys opercularis* and *Pecten furtivus*. Although the reported values for particle clearance by *Amusium* are rather high, it is likely that the (60,000 cell/ml cell densities in the experimental chambers may have led to an underestimation of filtration rate in field conditions (Palmer 1980; Doering and Oviatt 1986).

We speculate that high particle filtration rates along with concomitant water transport rates by *A. pleuronectes* are an adaptation to warm oligotrophic waters. Scallops strongly compete for limited food resources. This presents an interesting challenge for those contemplating commercial culture of this species. Use of intensive (high stocking density) methods such as traditional lantern nets or pocket nets for growout appears to be unfeasible for this species. However, this does not rule out the possibility that larger-scale bottom enclosures with low stocking densities might be a viable culture method.

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Table 1. Walford analysis parameters.

	Theoretical (DelNorte 1988)	Lantern nets			Pocket net
		10/shelf	20/shelf	40/shelf	
y-intercept	7.831	6.494	2.151	0.762	4.968
slope (k in yr^{-1})	0.9261	0.9017	0.9664	0.9839	0.9336
intercept on y=x (apparent H∞ in mm)	106.0	66.1	65.0	47.3	74.8
correlation (r)	---	0.9914	0.9964	0.9966	0.9860

Table 2. Results of feeding studies.

	Isochrysis galbana (at 60,000 cells/ml) (n = 15)	*Chaetoceros gracilis* (at 60,000 cells/ml) (n = 58)
mean clearance rate (ml/min)	204.0	114.2
std. dev. clearance rate (ml/min	137.6	86.2
range clearance rates		
(ml/min)	108 to 427	100 to 344
(l/g·h wet wt)	0.46 to 1.84	0.43 to 1.48
(l/g·h dry wt)	3.07 to 12.13	2.84 to 9.77
mean clearance rate (10^6cells/min)	7.6	6.8
mean clearance rate (l/g·h dry wt)	5.80	3.25

OBSERVATIONS ON LARVAL DEVELOPMENT AND SETTLEMENT OF *PATINOPECTEN YESSOENSIS* IN HATCHERIES

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ABSTRACT

The influence of density on *Patinopecten yessoensis* larval development was studied during production of an F2 generation. Setting behaviour of *P. yessoensis* on PVC removable spat collectors, previously tested with *Pecten maximus,* was determined. Poor larval growth of *P. yessoensis* was observed at a larval density of $7 \cdot ml^{-1}$ and postlarval settlement occurred mainly on the bottom of the baskets, as has been observed with the king scallop, *P. maximus*. The PVC collector is not suitable for either species of scallop.

INTRODUCTION

Production of an F1 generation of *P. yessoensis* in France (Cochard et al. 1993) enabled initial experiments to be undertaken on the culture of this species in the Mediterranean (Buestel et al. 1989). In spite of high mortalities (Coatanea, Pers. Comm.) the broodstock was maintained in France. This was necessary because of difficulties encountered during its introduction into France and the potential for further investigation on the feasibility of culture of this species on the Atlantic coast, where scallop farming is of considerable interest.

In Britanny, the scallop industry is based on harvest of the king scallop, *Pecten maximus*. Low survival rates (20 to 50%) observed during transfer of spat to sea is the major problem for culture of this species (Fleury et al. 1993). High mortalities at this time may be due to removal of spat from setting tanks because mortalities during transfer of unattached spat have been low. A change in the setting techniques using removable spat collectors has been suggested as a method to reduce mortalities. Consequently, experiments with *P. maximus* showed that spat settled mainly on the bottom of the baskets (Robert et al., unpublished data).

The aim of this study was to determine the suitability of removable spat collectors for *Patinopecten yessoensis* and to compare setting behaviour of both species. Experiments were carried out while producing an F2 generation.

MATERIALS AND METHODS

LARVAL REARING

Sexually mature *P. yessoensis* were collected from the Bay of Brest (France) in April 1992. Spawning was induced in the laboratory by increasing seawater temperature from 11°C to 13.5°C. After incubation (72 h), veliger larvae were put in five 450 l cylindrical-conical tanks at densities of $1.5 \cdot ml^{-1}$ in four tanks and at $7 \cdot ml^{-1}$ for one tank. This higher density is used in culture of *P. maximus* larvae under our standard conditions. All larvae were reared in 1 μ filtered seawater, renewed at 48 h intervals, at a salinity of

33-34 ppt and a temperature of 15°C. Bacterial contamination was controlled by adding chloramphenicol (8 $mg \cdot l^{-1}$) and the larvae were fed daily on a mixed algal diet of *Isochrysis* aff. *galbana, Pavlova lutheri* and *Skeletonema costatum* to give a final concentration of 30 to 60 $cells \cdot \mu l^{-1}$. Larval size was determined on a minimum of 50 individuals per tank, every second day, by measuring the shell length converted to equal shell diameter by means of an image analysis technique as described by de Pontual et al. (1993). Mortalities were assessed by counting the number of dead larvae in a sample of 200 individuals from each tank under a profile projector (Nikon V12). After grading on a 150 μ mesh screen, mature larvae were transferred to setting tanks.

POSTLARVAL REARING

The postlarval rearing containers used were 100 l flat bottomed rectangular tanks paired and connected to the same seawater supply. Each tank was continuously supplied with 400 $l \cdot h^{-1}$ of 15°C seawater, filtered to 1 μ for the first 10 days, and then only sand-filtered at ≈50 μ. The seawater, enriched with 0.2 $l \cdot h^{-1}$ of phytoplankton (*Isochrysis* aff. *galbana, Pavlova lutheri, Chaetoceros calcitrans* and *Skeletonema costatum*) was homogeneously distributed from above to each tank by means of PVC removable drilled tubes, connected perpendicularly to the primary circuit. Five rectangular containers with a mesh bottom, whose mesh size corresponded to spat size (125 to 250 μ), were placed in each tank (Fig. 1). PVC baskets (45 cm long, 35 cm wide and 12 cm high, for a total water volume of 15 l) were used as a setting surface. In these containers, the setting surfaces were 1535 cm^2 for the bottom and 1600 cm^2 for the edges. Supplementary collectors, formed by crossed PVC sheets (the same material as the edges of the baskets) with a setting surface of 4648 cm^2, were placed in some of these baskets.

Pediveligers (950,000) were placed in five baskets, four of which (B1-B4) were equipped with additional collectors at a density of 190,000 (≈13 $larvae \cdot ml^{-1}$). Spat numbers were estimated six weeks later by counting the entire population on the collectors and by counting a sample of individuals settled on either 30 cm^2 on the bottom (30 squares of 1 cm^2 randomly selected) or 50 cm^2 on the edges. Spat size was estimated at the end of the trial by measuring the length (anteroposterior axis) of 100 individuals per treatment, under a profile projector. The experiment was undertaken from May to July 1992. Data were processed using Excel, Statview and Sigmaplot software.

RESULTS

LARVAL DEVELOPMENT

The average fecundity per female was low (5 million oocytes released) but development to the veliger larvae was high, 55%. The rate of abnormality was 10%. At lower larval densities, mortality was less than 5% until the end of the larval period. At higher densities, similar values were recorded during the first 10 days but then mortalities increased to 15%. Larval growth is shown in Figure 2. At the lower larval density, the increase in size was steadier with a daily length increment of 7 μ. In contrast, at the higher larval density, the growth rate declined from the 12th day onward which produced a difference in length of 50 μ on day 23. Consequently this brood was discarded before transferring larvae to the nursery. Excluding this brood, the average larval yield (number of mature larvae retained on 150 μ mesh screen compared to the initial number of veliger larvae) was high (65%).

SETTLEMENT ON REMOVABLE COLLECTORS

Spat survival rates and densities (number·cm^{-2}) are shown in Table 1. Low survival rates, less than 20%, were observed, with a high range of spat dispersal in the baskets with collectors representing a coefficient of variation of 23%.

Spat densities on collectors were low (Table 1). There was a difference at the 5% significance level in spat density between collectors, edges and bottoms of the baskets (Kruskal-Wallis test: H=7.038; P=0.0296) leading to the rank of classification shown in Table 2. Nevertheless, the average rate of collector settlement (number of spat on collectors compared to total number of spat), independent of the setting surface, was satisfactory (41.75 ± 6.00%).

No differences in spat size, at the 0.1% significance level, were noticed, at the end of the experiment, between spat settled on collectors (mean shell length = 1.51 ± 0.11 mm) and bottoms of the baskets (1.51 ± 0.13 mm).

DISCUSSION

It was impossible to rear *Patinopecten yessoensis* larvae at the same larval density as is used for *Pecten maximus*, 7·ml^{-1}. At a lower density, 1·ml^{-1}, a daily length increment of 7 μ was recorded, similar to that reported by Bourne et al. (1989). *P. maximus* reared at the same period but at the higher density of 7·ml^{-1} showed a similar growth with a daily length increment of 6.3 μ (Fig. 2). Larval overcrowding may explain the poor growth of *P. yessoensis* at the higher density, but this result may also be explained by underfeeding from day 12 onward, when the growth rate decreased. The potential amount of food per larva was constant during this experiment (4,500-9,000), whereas Bourne et al. (1989) recommended a higher ratio for older larvae (>12,000-20,000). Compared to *P. maximus, P. yessoensis* feeding requirements seem to be higher.

Low survival rates of spat were probably due to overcrowding and/or underfeeding. The setting density was 13·ml^{-1} whereas Bourne et al. (1989) recommended lower densities (<2·ml^{-1}). Under our standard culture conditions, *P. maximus* setting density is also lower, 6·ml^{-1}. The high spat mortality made interpretation of results difficult. Nevertheless, *P. yessoensis* appeared to settle mainly on the bottom of the baskets as was observed with *P. maximus* (Tables 3 and 4).

Consequently, in our postlarval culture system, these types of collectors are not considered effective for either scallop species. In future, we will focus on developing new techniques such as deeper raceways with recirculating systems and using new types of collectors such as Kinran which has been reported to be the best cultch (Bourne et al. 1989).

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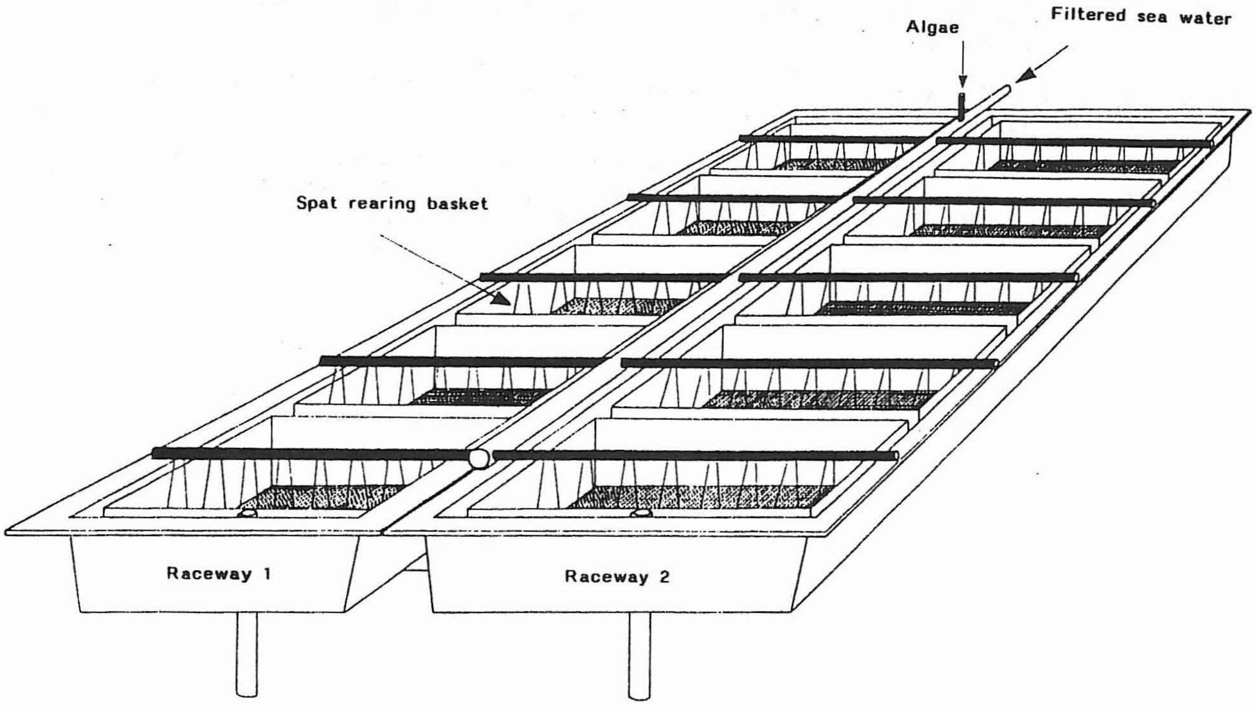

Fig. 1. Postlarval experimental unit.

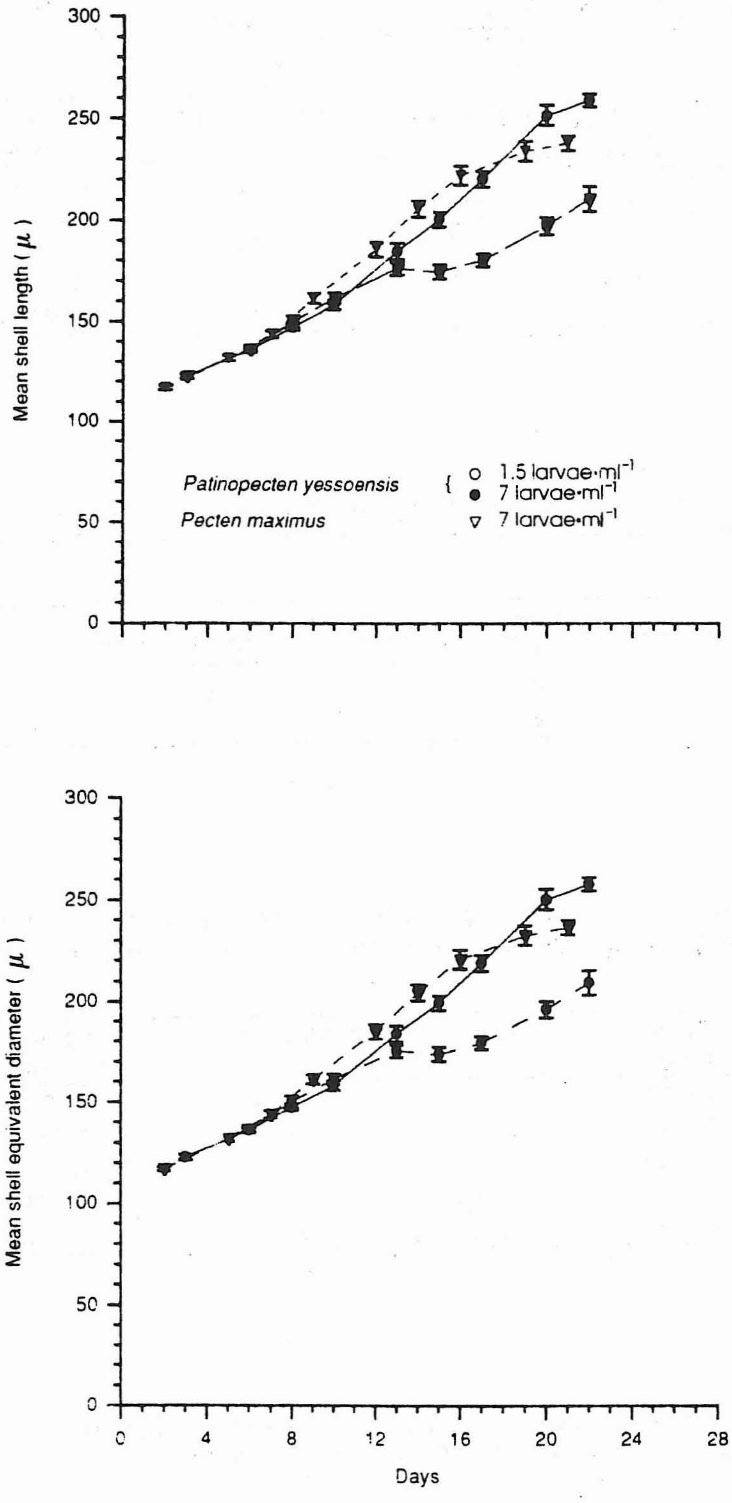

Fig. 2. Larval growth of *Patinopecten yessoensis* and *Pecten maximus* at different densities.

Table 1. *Patinopecten yessoensis*. Percentage survival of spat (number·cm^{-2}) on removable collectors (B1-B4), edges and bottom of the baskets.

	Survival rate	Collector	Basket edge	Basket bottom	Total
B0 (control)	17.50	*	7.38	14.00	10.62
B1	20.80	3.15	6.26	9.67	5.07
B2	15.70	2.79	2.26	8.60	3.83
B3	11.80	2.00	3.42	5.03	2.89
B4	16.20	3.05	4.80	5.87	3.96

Table 2. *Patinopecten yessoensis*. Kruskal-Wallis rank classification for density of spat on collectors, edges and bottom of the baskets.

	Count	Sum ranks	Mean ranks
Collector	4	13.00	3.25
Edge	4	25.00	6.25
Bottom	4	40.00	10.00

Table 3. *Pecten maximus*. Percentage survival and density of spat (number·cm^{-2}) on removable collectors (B1-B4), edges and bottom of the baskets.

	Survival rate	Collector	Basket edge	Basket bottom	Total
B0 (control)	39.20	*	9.60	15.53	12.50
B1	35.19	2.61	4.82	10.00	4.52
B2	38.24	2.65	7.14	9.43	4.91
B3	51.02	2.61	7.32	17.70	6.55
B4	45.80	2.72	5.14	16.23	5.88

Table 4. *Pecten maximus*. Kruskal-Wallis rank classification for density of spat on collectors, edges and bottom of the baskets.

	Count	Sum ranks	Mean ranks
Collector	4	10.00	2.50
Edge	4	26.00	6.50
Bottom	4	42.00	10.50

SPAT PRODUCTION OF THE SEA SCALLOP, *NODIPECTEN NODOSUS* (LINNAEUS, 1758), IN THE HATCHERY: INITIAL STUDIES IN BRAZIL

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ABSTRACT

The most suitable native species for the development of scallop culture in Brazil is *Nodipecten nodosus* due to its fast growth rate, large size and commercial value. The experimental production of spat of *N. nodosus* was achieved in the hatchery for the first time in Brazil. Broodstock was collected from a wild population at Arvoredo Island, Santa Catarina State, and maintained under laboratory conditions for five weeks prior to induction of spawning. Procedures for spawning, larval culture and settlement were modified from techniques used for other scallops. Viable gametes were released and fertilization was accomplished. Straight-hinged veligers (1.26×10^6) were present in the culture container after 22 hours. Eyed larvae were observed after 14 days. Settlement and metamorphosis took place on artificial substrates after 19 days. One set of collectors holding juveniles was transplanted to the sea 33 days after fertilization and another set was kept in the laboratory. The total number of spat produced was 2,286. Further research is needed before large scale culture work can be attempted. Detailed studies of physiology and reproductive cycle of broodstock, triggering of spawning as well as the larval and juvenile requirements are essential. These studies may allow an increase of spat production of *N. nodosus* in the hatchery as well as subsequent establishment of a new economic activity in coastal areas in the south of Brazil.

INTRODUCTION

The sea scallop, *Nodipecten nodosus* (Linnaeus 1758) (≡ *Lyropecten nodosus*), is the largest pectinid occurring in Brazilian waters (Rios 1985). According to Smith (1991) *N. nodosus* is found in the Caribbean and discontinuously as far south as Rio de Janeiro, Brazil. Commonly named the Lion's Paw, its colour varies from dark maroon-red to bright-red, orange, or rarely yellow (Abbott 1974; Abbott and Dance 1990). The depth distribution is reported to be from 35 to 150 m over sandy and calcareous algae bottoms (Rios op cit).

Landing statistics are not available for *N. nodosus* in Brazil; however, in Santa Catarina State the species is occasionally collected by divers, who sell the scallops in local markets. The prices vary from US$3.00 to US$5.00 each, depending on size and season. Not only are the adductor muscle and gonads consumed, but the shells are used also as curios.

Mollusc culture is a new activity in Brazil and only a few enterprises exist for growing mussels and oysters (Ostini and Poli 1990). Scallop culture is still non-existent and initial efforts to study its feasibility are taking place at the Federal University of Santa Catarina. The Marine Molluscs Culture Laboratory is an experimental hatchery designed to produce spat of *Crassostrea gigas* for artisanal fisherman in local communities as well as to develop new alternatives for aquaculture in coastal areas of Santa Catarina State.

A natural bed of *N. nodosus* was found at Arvoredo Island (Lat 27°17'S, Long 48°22'W), which is a Federal Biological Reserve. Adults larger than 170 mm have been collected in the lowest part of the sublittoral, in depths ranging from 6 to 30 m. The population distribution seems to be random and the density is too low to support commercial exploitation. Experiments to assess spat settlement in artificial collectors were carried out in the field for the last two years; however, the number of spat collected has been very low. The growth experiments with naturally collected spat indicate that they can exceed 10 cm total length within 12 month of culture (Manzoni and Rupp 1993). If viable scallop culture is to be developed in Brazil it will probably rely on hatchery produced spat.

Techniques to induce spawning and culture larvae and juvenile scallops have been presented by several authors: Bourne et al. (1989); Castagna (1975); Comely (1972); Costello et al. (1973); Loosanoff and Davies (1963); Sastry (1965); Velez et al. (1990); among others. However, no information was available for *N. nodosus* other than that of Coronado et al. (1991) and Velez (1987).

The objective of the present work was to determine the feasibility of producing spat of *N. nodosus* on an experimental scale in the hatchery.

MATERIALS AND METHODS

BROODSTOCK MAINTENANCE

Broodstock was collected at Arvoredo Island and transported to the laboratory. Fifteen scallops were placed in a 500 l tank provided with a system modified from the one described by Devauchelle and Mignant (1991), where the scallops were maintained for five weeks prior to spawning. Food was supplied daily and consisted of a mixture of at least two of the following species: *Isochrysis* aff. *galbana* (Tahitian variety), *Chaetoceros gracilis*, *Chaetoceros calcitrans* and *Tetraselmis tetrathele*. Concentrations were about 150,000 cells/ml per day. Water was changed every two or three days.

The temperature range during all culture phases was from 22°C to 27°C. Water was pumped from the sea, pre-filtered and passed through 5, 3 and 1 μ filters (FSW). The salinity was 31 ± 2 ppt.

INDUCTION OF SPAWNING

Nine individuals, showing the best gonadal condition by visual inspection, were used to induce spawning after scrubbing and cleaning the epifauna. A combination of techniques described by Chew et al. (1987) was employed. Broodstock was subjected to thermal stimulation and UV-irradiated FSW with the addition of hydrogen peroxide, after being immersed in high density of algae for one hour. Temperature was decreased from 25°C to 23°C and increased to 27°C at intervals of half hour for each 2°C. Broodstock was exposed to air for 15 minutes between each temperature change.

Spawning and fertilization procedures were accomplished after the methods of Bourne et al. (1989).

LARVAL CULTURE

Some of the fertilized eggs (1,440,000) were placed in a plastic bin containing 100 l of UV-irradiated FSW and gently aerated. The other eggs were used for various experiments.

Feeding consisted of *Isochrysis* and *Chaetoceros* in final concentrations varying from 3 to 5 x 10^4 cells/ml. Proportions ranged from 100% *Isochrysis* the second day to 50% of each species at 15 days. Water was changed every other day and larvae were retained on nylon screens ranging from 50 to 150 μ. Procedures for draining tanks, holding and counting larvae were similar to those reported by Bourne et al. (1989). No sorting of larvae was carried out and larval density was reduced by natural mortality.

Algae supplied as food was cultured in the Conwy media, modified with vitamins, in 5 l carboys as described by Walne (1979).

SETTING

Plates of polycarbonate and netlon filaments previously soaked in FSW were placed inside the culture container on day 15, one day after eyed pediveligers were observed. Water was changed daily so that water entered the tank at the same rate as it was drained by a siphon for approximately half an hour. This method avoided exposure of the settled larvae to air. The larvae retained on screens were replaced in the tank. Feeding consisted of 6 x 10^4 cells/ml until day 19 (70% *Chaetoceros*, 30% *Isochrysis*), and 8 x 10^4 cells/ml from day 20 to day 30.

NURSERY

After 33 days of culture, some of the polycarbonate plates and netlon containing settled juveniles were taken out of the setting tank and placed inside a 500 μ mesh nylon bag. This bag was transported to Arvoredo Island immersed in FSW, where it was hung on a longline at a depth of 8 m. Size and number of spat were estimated after a period of 38 days.

The other set of settled juveniles was kept under laboratory conditions for three more weeks, when the number and size of spat were estimated. Feeding during this period consisted of a mixture of *Isochrysis* (45%), *Chaetoceros* (45%) and *Tetraselmis tetrateli* (10%) at a final concentration of 100,000 cells/ml.

RESULTS

No mortality was observed in the five week period that broodstock was maintained in laboratory.

N. nodosus is a functional hermaphrodite having gonads with a reddish-orange ovarian portion and a white testis. All scallops that were conditioned for spawning released gametes. Spawning started 20 minutes after the temperature was increased to 25°C. Sperm was released initially and only two individuals subsequently released oocytes (3,000,000). A certain degree of self-fertilization was unavoidable.

The initial stocking density was 1,440,000 fertilized eggs in the culture container. By the second day there were 1,260,000 "D" shaped veligers (87.5% survival), and at the end of 14 days of culture there were 76,000 larvae (5.27% survival). As soon as setting began it was not possible to assess the number of surviving individuals.

Swimming trochophores were observed 12 hours after fertilization. Fully developed "D" shaped veligers were present after 22 hours at 27°C, and slightly protruded umbones were formed after 7 days. An eye spot and a rudimentary foot were observed after 14 days.

Individuals showing conspicuous dissoconch shells crawling over the collectors were observed by the 19^{th} day. Settlement and metamorphosis took place on both polycarbonate plates and netlon filaments.

Spat maintained in laboratory for a period of 52 days from fertilization reached an average size (anterio-posterior length) of 1.1 mm (± 0.39, n=30). The total number of surviving individuals was 1,660.

Spat transplanted to the sea 33 days after fertilization reached an average length of 5.16 mm (± 2.1, n=54) 38 days after transfer (71 days after fertilization). The number of surviving spat in the sea was 626; however, it was not possible to assess the initial number of transplanted spat.

DISCUSSION

Broodstock of *N. nodosus* was successfully maintained under laboratory conditions for five weeks when fed with a mixture of unicellular algae. However, it is unknown whether food supplied was of sufficient quantity and quality enough to fulfil nutritional requirements. Nor was it possible to assess gonadal maturation during this period, since no conspicuous changes were observed in gonad structure. The reproductive cycle of this species in the region is unknown, so it was not possible to determine whether broodstock was collected during the spawning season as would be desirable for conditioning.

Methods employed to trigger spawning in *N. nodosus* were a combination of different techniques used for inducing spawning in other molluscs. Prior to the present study several other techniques were used to induce spawning of scallops by the author, but they were not successful. Methods used here were sufficient to induce liberation of sperm, since all individuals released active sperm. However, only two individuals released oocytes. It is not clear whether the techniques employed inhibited liberation of oocytes or whether the conditioned scallops had ripe female gonads.

Larval culture of *N. nodosus* was found to be feasible using techniques similar to the ones employed for scallops in other hatcheries (Bourne et al. 1989; Illanes 1990). The high mortality observed during the larval period (93.9% from D-shaped veligers until the 14^{th} day) may be due to inadequate feeding, overcrowding or other factors such as handling or disease.

The pattern of embryogenesis and larval development was typical for scallops as described by Sastry 1965, Loosanoff and Davies 1966, Rose et al. 1988, among others.

Settlement took place on polycarbonate as well as on netlon. There was no apparent preference of one material compared to the other.

The culture of juveniles was undertaken in the laboratory as well as in the field. Further studies will be necessary to determine the best size of spat for transplanting to the field. An efficient nursery system must also be developed.

The total number of spat produced (2,286) is obviously too low for commercial purposes. However, considering the lack of biological knowledge and that this was the first attempt to induce spawning, rear larvae and culture spat of *N. nodosus* in Brazil, the results attained indicate that the species has a good potential for mariculture. A research program to study the biology of *N. nodosus* and to improve culture technology is needed if spat is to be produced at satisfactory levels.

CONCLUSIONS

The production of spat of *N. nodosus* was found to be feasible on an experimental basis in the hatchery. However, further research is needed to improve the methods and techniques before a large scale culture can be attempted. Detailed studies of the physiology and reproductive cycle of broodstock, as well as procedures to induce spawning, are necessary to permit production of gametes of desirable quantity and quality. Research into larval and juvenile culture conditions is also needed in order to reduce mortality and permit an increase in spat production. Further research into the culture and biology of *N. nodosus* may permit establishment of a new economic activity in coastal areas of South Brazil.

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MOVEMENT AND MORTALITY OF JUVENILE SCALLOPS RELEASED IN BOTTOM CULTURE TRIALS

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ABSTRACT

Tens of thousands of juvenile *Placopecten magellanicus* (10-25 mm shell height) have been seeded onto the seabed at three sites in tidal channels in Lunenburg Bay, Nova Scotia, and monitored for up to three years. The fate of the seeded populations varied significantly in terms of the type and magnitude of losses from the seeded areas and the relative importance of migration and mortality. The post-release dynamic was rapid in all cases, with losses of 30%, 75% and 95% during the first two weeks in the three sites. Variation between sites greatly exceeded that between seasons of seeding. The densities of predators within seeded areas did not increase markedly during the course of the seeding trials, but local populations of the crab *Cancer irroratus* showed a functional response to scallop density at the site with the highest mortality rates. Patterns of dispersion away from release sites are not simply reflected by hydrodynamics, due to the complexity of swimming behaviour. Small between-site differences in near-bed physics and predator fields at the time of seeding produce large variations in surviving population sizes, indicating that post-settlement processes contribute significantly to the great variability of scallop populations.

THE IMPACT OF HARMFUL ALGAL BLOOMS ON SCALLOP CULTURE AND FISHERIES*

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ABSTRACT

Harmful algal blooms occur worldwide and their associated phycotoxins are accumulated by filter-feeding bivalve molluscs. Since only the adductor muscle of scallops has been traditionally marketed, scallops are not usually included in routine monitoring programs. A renewed interest in marketing both whole and 'roe-on' scallops from various geographic regions along with intensified aquaculture ventures in areas prone to toxic blooms have provoked public health concerns regarding the safety of this resource. Our studies have focused on the sequestering and biotransformation of phycotoxins in scallops. Our results, coupled with a review of historic data, indicate that:

1. toxins are not distributed evenly throughout the scallop tissues, most toxin is usually concentrated in the mantle and digestive gland;
2. some scallop tissues, e.g. digestive glands and mantles remain highly toxic throughout the year;
3. toxicity varies considerably (±43.5%) between individual animals collected in the same area;
4. no correlations could be made between toxicity levels in gonadal tissue and any other tissues.

Scallop culture and commercial fisheries can thrive in areas prone to toxic algal blooms if only the adductor muscle is utilized. Safe marketing of 'roe-on' scallops is feasible only under strict regulatory regimes. Marketing of mantles or whole scallops poses a high risk to public health and should only be undertaken after extensive monitoring. Scallop mariculturists should be acutely aware of the potential risks associated with phycotoxins. Further, public health guidelines with particular emphasis on toxin levels in individual tissues is necessary if scallops are to be marketed whole or in conjunction with tissues other than adductor muscles.

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GROWTH OF THE SCALLOP *MIZUHOPECTEN YESSOENSIS* CULTURED IN THE COASTAL WATERS OF PRIMORYE PROVINCE, RUSSIA

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ABSTRACT

Growth of juvenile scallops, *Mizuhopecten yessoensis* (1.0-1.5 years old) after they were transferred from nursery-collectors to bottom culture grounds was studied using alternate seasonal markings of broad multidiurnal and narrow diurnal growth layers on the microsculpture of the surface of the shell. Growth rate of cultured scallops was similar to that of native (resident) scallops in all areas, but the initial body weight and shell height of juveniles from collectors was lower. Final size of cultured scallops was generally smaller than native individuals of the same age: 10-15 mm shell height if juveniles were seeded in May, and 20-25 mm if they were sown later, in August-September. If juveniles were planted early when they were 1.5 years old in October, then shell height of cultured and native scallops was similar. In some areas it is recommended that scallops be cultured until they are four years old before harvesting.

INTRODUCTION

M. yessoensis is the only scallop species cultured in Russia, in the coastal waters of Primorye Province in the northwestern part of the Sea of Japan. The main culture method includes collection of spat in nursery-collectors and rearing them in the same suspended collectors for one year, followed by transfer of juveniles to bottom culture grounds where they attain commercial size (100 mm), usually in two to three years. The purpose of this study was to determine growth of scallops after they were transferred from collectors to the bottom at age 1.0 and 1.5 years at different times of the year, and to compare their growth with that of native (resident) individuals inhabiting the same area.

MATERIALS AND METHODS

Growth rates were studied in scallops transferred in different years from collectors to the bottom in 14 areas situated along the south and east coast of Primorye Province. Planting usually occurred in May-June when the juveniles were one year old. Early sowing of six-month-old scallops was done in October in four areas. In two areas, sowing was delayed until August-September, the time when water temperatures were highest and salinities lowest. Samples of 30-50 cultured scallops were taken at one, three, and six months and after one and two years. The external surface of the upper valve of these scallops had a thin microsculpture with detectable elementary growth layers. Width and appearance of growth layers change seasonally (Silina 1978). One broad growth layer was formed every 5-7 days during the period from mid November-April when water temperatures were below 4-6°C, but a narrow layer was formed diurnally during the rest of the year. These layers differ in appearance and permit one to determine age and linear growth rate of each individual. When juveniles were transferred from collectors to the bottom there was a significant ring formed at the edge of the shell. This ring allowed us to distinguish between cultured and resident individuals, determine the year and season when transfer occurred and determine the age of the scallop when it was planted.

RESULTS

Scallops were usually transferred from collectors to culture grounds in May-June when they were about one year old. The microsculpture of the external shell surface of cultured scallops differed appreciably from resident animals. Scallops transferred in May-June had a narrower shell section (from the umbo) with broader winter growth layers than resident animals. The distinct shell breakage sign was found just across this section (Fig. 1a). Transferred scallops usually weighed less and were smaller in shell height by 10-15 mm than native scallops. This difference usually continued throughout the life of the scallops (Fig. 2a,b, 3a,c). It is believed that slower growth of scallops in collectors during winter and spring when the density is high affects growth unfavourably. Moreover, some growth inhibition resulted from shell breakage during transportation and sowing on the bottom. Growth of transferred scallops was further affected while the animals adaptated to the new habitat and regenerated new shell at the ventral margins.

On two culture grounds in the east of Primorye, scallops were seeded in both May-June and later in August-September, when maximum annual water temperatures occurred. The microsculpture of the scallops transferred to the bottom at the end of summer had numerous shell breakage signs prior to the main one formed during the planting. Both the first section from the umbo with multidiurnal winter growth layers, and the section formed in May-August, were narrower than the same sections in native scallops. Because of the long period when scallops were held under high density in collectors and unfavourable environmental conditions which weakened the scallops and caused a longer period for adaptation to the new habitat, scallops transplanted in August were smaller than those transplanted in May at the following autumn (Fig. 2b,c). Scallops transferred to the bottom at the end of summer were smaller by 20-25 mm shell height than native scallops (Fig. 2a,c). Their adductor muscle weight was less than 4 g (10 g in native scallops) when they were two years old, and only about 10 g (20 g in native sallops) at three years old.

Juveniles less than half a year in age were sown on culture grounds in south Primorye in October. Scallops of this age were usually 14-26 mm shell height because of the early warming of waters that occurs along the southern coast of Primorye. Almost all juveniles died when they were sown on gravel-pebble or mud substrates. Most juveniles that were more than 20 mm shell height survived well when planted on sand and mud-sand substrates. Signs of shell breakage were clearly observed in the microsculpture of shells of juveniles formed during the year that were sown in the autumn (Fig. 1b). After this mark, broader diurnal growth layers were observed. They were similar to multidiurnal winter layers in width, but not in appearance. The increase in growth rate was probably related to the change in scallop density when they were transferred from collectors to the bottom during the period of optimal environmental conditions. In autumn, shell height of seeded scallops was almost the same as native scallops (Fig. 3a,b). If the site where juveniles were collected had warmer water earlier than where culture occurred, then in the autumn juveniles from the collectors were larger than native scallops. In this situation, cultured scallops remainded larger than native scallops until they were 1.5 years old, but their sizes were nearly the same when they were two years old (Fig. 4).

DISCUSSION

Scallops usually reach commercial size (100 mm) at an age of three years under natural conditions along the coast of Primorye. The adductor muscle weight of scallops of this age ranges from 20 to 40 g depending on geographic location (Silina and Pozdnyakova 1986). Near islands in the south of Peter the Great Bay, scallops reach commercial size as two-year-olds and have a muscle weight of about 21 g. Because of environmental parameters, scallops sown as one-year-olds do not reach commercial size until they are three years old on the main culture grounds, particularly in cold-water areas. Since growth of the scallop muscle is fastest when they are two to four years old (10-17 g per year) and mortality of three to four-year-old scallops is minimal (Silina 1990), it is recommended that scallops sown as one-year-olds in such areas be cultured until they are four years old before harvest.

When early (autumn) transfer is made of scallops six months old, there is no need to extend the period of growth to commercial size. In years when the waters are warmed early to 8-10°C, spawning occurs earlier (Yamamoto 1951), and juveniles can reach a larger size than usual by the autumn. In years when environmental conditions are optimal for this species, early October transfer of juveniles with a shell height of more than 20 mm from collectors to bottom culture is recommended.

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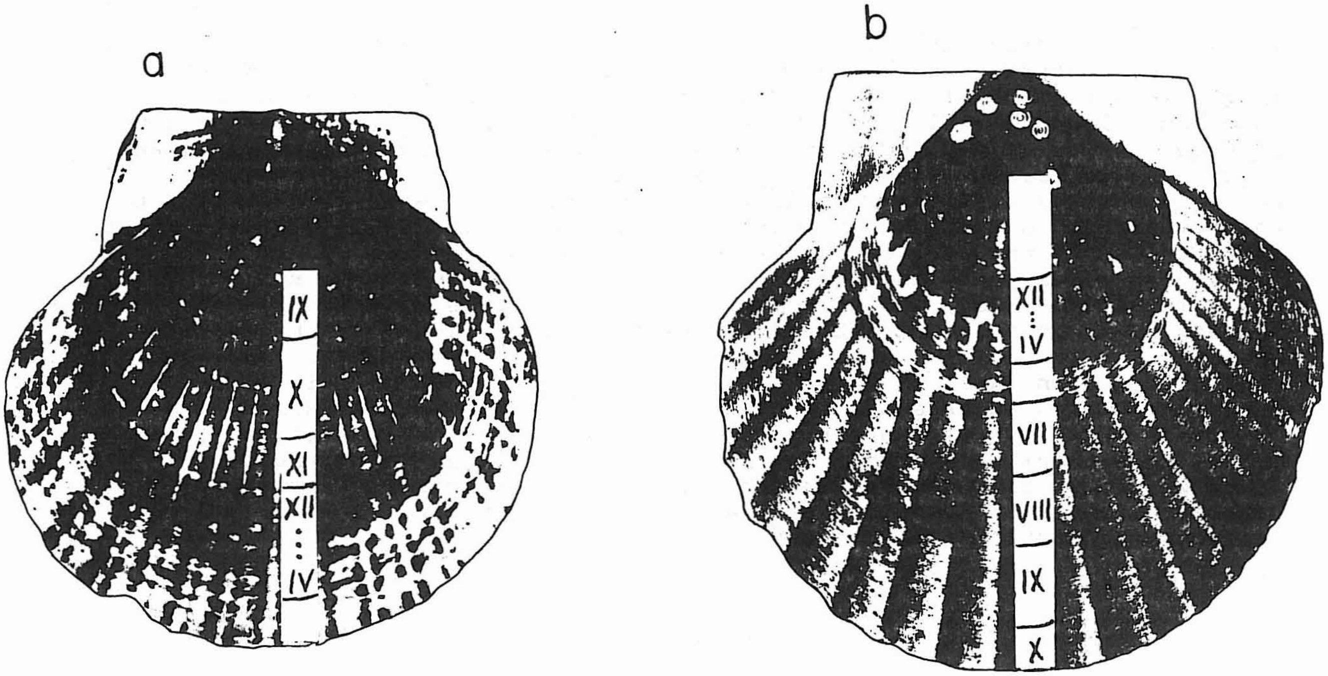

Fig. 1. Japanese scallop, *Mizuhopecten yessoensis*, transferred in May-June from nursery-collectors to the bottom at about one year old (a) and in October at less than six months old (b), x1.5.

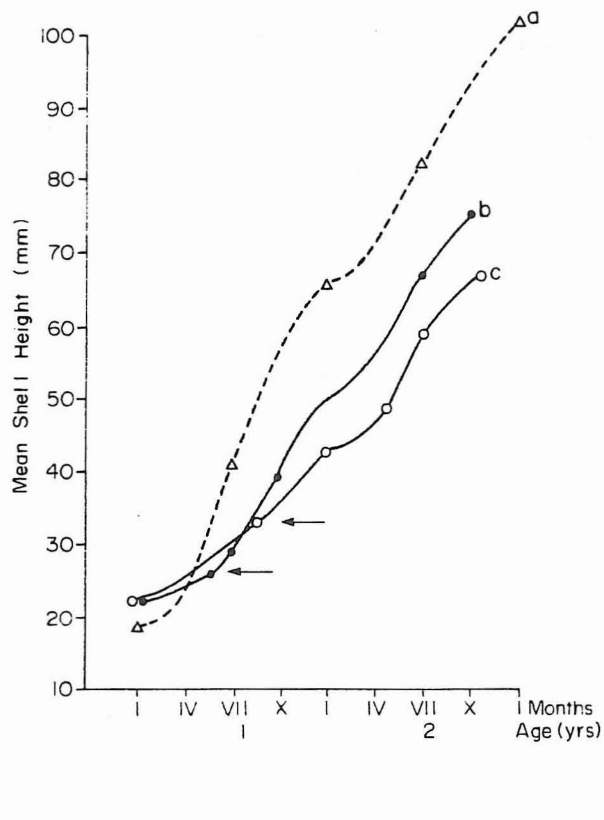

Fig. 2. Linear growth of the scallop *Mizuhopecten yessoensis*: a - native animals, b - animals transferred in May-June from nursery-collectors to the culture ground in the Gulf of Vladimira (the Sea of Japan) at about one year of age, and c - later, in August and September. Arrows indicate mean shell height of the scallops at time of transfer.

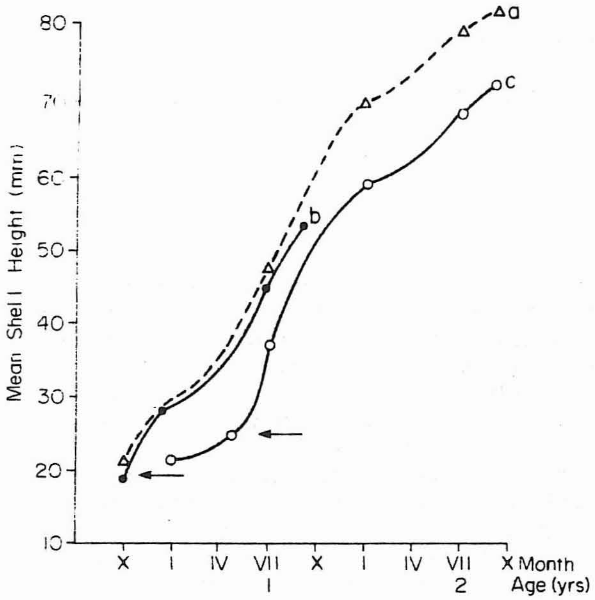

Fig. 3. Linear growth of the scallop *Mizuhopecten yessoensis*: a - native animals, b - animals transferred from nursery-collectors to the culture ground in Peter the Great Bay (the Sea of Japan) in October at less than six months old, and c - in May-June at about one year of age. Designations as in Fig. 1.

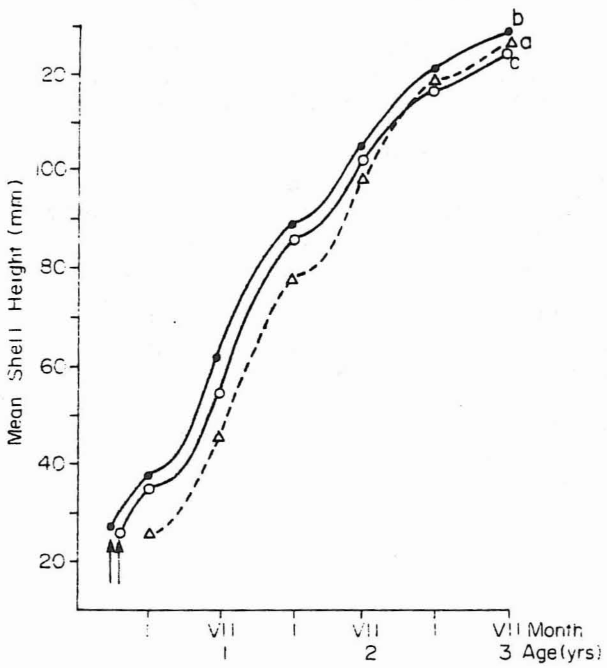

Fig. 4. Linear growth of the scallop *Mizuhopecten yessoensis*: a - native animals, b,c - animals transferred from nursery-collectors to the culture ground in Possjet Bay (the Sea of Japan) in October of different years when they were six months old. Designation as in Fig. 1.

AN INVESTIGATION OF TECHNIQUES FOR THE HATCHERY AND NURSERY REARING OF THE KING SCALLOP, *PECTEN MAXIMUS* (L.)

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ABSTRACT

A three-year investigation of the practical techniques involved in king scallop, *Pecten maximus*, spat production was carried out at a pilot-scale hatchery located in the Orkney islands. The investigation included all stages of hatchery and intermediate nursery culture, with the main emphasis on incubation methods, and on larval husbandry. Prophylaxis and vessel design during incubation were investigated as factors in normal development of three-day veliger larvae. It was found that use of chloramphenicol during incubation, and aeration of the incubation vessel, were detrimental to normal development. Successful spat production was achieved under this program, using a flow-through system to exchange water in larval and post-metamorphic spat culture vessels. A significant improvement in growth rate was attributed to the change in cleaning method from a more traditional drain-down, to this flow-through system.

INTRODUCTION

In Great Britain, cultivation of the king scallop is confined to Scotland, with the majority of activity being concentrated in the Highland region of the country. Scallop production remains relatively low at 59 t of production in 1992 (S.O.A.F.D., 1992). However, this species fetches a high price, and production has consistently increased since 1990, with a dramatic 55% improvement in production for the table market between 1991 and 1992.

To date, there has been no successful commercial hatchery production of king scallop spat in Great Britain, with which to supply growers. Scallop farmers are still reliant upon the natural spatfall for their raw material, and are consequently vulnerable to cyclical failures in recruitment, such as last occurred on a major scale in 1988.

The remit of the present work was therefore to investigate this species as a subject for commercial spat production. The duration of the project was three years, from September 1990 to September 1993, and included the design and construction phase of the hatchery and nursery facilities. The program was successful in its basic aim of enabling culture of scallop spat, and this paper identifies those aspects of husbandry that were found to be material to this success. Production of seed as a commercially viable operation has not yet, however, been achieved.

INCUBATION

Two aspects of the incubation process were considered under this program. The first of these was the use of antibiotics.

In this hatchery, incubation is carried out in treated seawater. Treatment consists of settlement, filtration to 10 μ through a sand filter, followed by filtration to a nominal 1 μ through a cartridge filter. The water is then heated to 17 ± 1°C, passed through a degasser a polishing 1 μ filter, and through an ultraviolet sterilization unit, before delivery to the hatchery. Development to veliger occurs within approximately 50 hours of fertilization at this temperature, at which stage feeding can commence, but it is established practice for the first feed and water change to be delayed until three days post-fertilization. Comparisons of the percentage of fertilized eggs retrieved at the first water change as normal, healthy D-veligers were made for eggs incubated in the standard treated seawater (control treatment), and in treated seawater containing 2 ppm chloramphenicol (experimental treatment.)

It was found in the two trials conducted that a higher proportion of normal larvae were retrieved from incubation without the antibiotic. Experimental and control populations of these two batches produced 51% and 61%, and 44% and 48% normal larvae, respectively. From these results, it was concluded that chloramphenicol may have a minimal inhibitory effect on embryogenesis, resulting either in zygote mortalities, or in abnormal development. In view of this finding, and the known disadvantages of routine antibiotic use, it is now the practice in this hatchery to incubate eggs without the use of antibiotics.

The second aspect of incubation to receive attention was the design of the incubation vessel, and the requirement for aeration. Two distinct systems were employed; a static, flat-bottom tray of 25 l capacity, and a cylindro-conical vessel of 600 l capacity, with a central aeration point. In each system, fertilized eggs were incubated at a density of 20 per ml.

In two trials, percentage development from fertilized egg to normal, healthy three-day D-veliger, was 51% and 28%, and 46% and 33%, in tray and vessel, respectively. These results suggest that turbulence during incubation has an adverse effect on normal development. Although shelled larvae are unexpectedly robust, the trochophore stage before shell development may be subject to mechanical damage. It was concluded from these trials that a higher percentage of fertilized eggs will develop normally to the early veliger stage, in a static system than in an aerated system. Egg density must be carefully controlled, as shown by Gruffydd and Beaumont (1970), and overstocking of eggs in a static system may equally result in abnormal development and mortalities, resulting from mechanical damage or localized oxygen deficiency.

Normal development from egg to veliger in the aerated system has varied between 30% and 50% during the scallop culture program. These values compare well with those quoted in the literature for Pectinid species, e.g. 21-28% (Cabello and Camacho 1976) and 10-15% (González and Román 1983.) Practically, it has been found that retrieval of larvae is much easier from the cylindro-conical vessels, which also represent a more efficient use of hatchery space than the trays. As such, incubation continues to be carried out in this hatchery in the aerated, cylindro-conical vessels, despite the apparent theoretical advantage of the static system.

LARVAL HUSBANDRY

A major part of this program was an assessment of the practical techniques of larval husbandry. *P. maximus* is cultured in this hatchery at around 17°C, and at this temperature, the duration of the free-swimming, planktotrophic phase of development is 30 to 35 days. During this phase, the larval diet consists of a mixture of three algal species, comprising one flagellate and two diatoms, fed at 50 cells$\cdot\mu l^{-1}$. The species generally in use are *Isochrysis galbana*, *Chaetoceros calcitrans* and *Thalassiosira pseudonana*. The method of feeding is an adaptation of that used by Bourne et al. (1989). The appropriate volume of each species, calculated on the basis of culture cell density and relative cell volume, is added at each water change on alternate days. Once the feed is distributed within the culture vessel, a sample of the water is taken, screened on a 45 μ mesh to remove larvae and debris, and a cell count taken using a Coulter Multisizer. On days in which there is no water change, a further count is taken, and the proportion of a full feed that has been consumed in the preceding 24 hours is returned to the vessel, in order to maintain the cell density between water changes. The data collected in this process were also used to calculate clearance rate in static culture systems, this parameter being used as a measure of larval health. In addition to clearance rate, increase in mean shell length, survival and rate of attainment of key developmental stages were used as indicators of larval vigour.

In the early stages of the program, water change in larval vessels was effected by siphoning all water out of the vessels, and retaining the larvae in the water column on a 45 μ mesh. The vessel was then cleaned with hypochlorite solution, rinsed and refilled. The larvae were graded on an appropriate selection of meshes, and returned to the vessel. It was found that this method produced a gradual mortality in the cultures after approximately the first week after incubation, followed by a sudden collapse, characterized by heavy protozoan infestation of dead and moribund larvae. Immersing the larvae in dilute hypochlorite solution and antibiotic baths failed to overcome this problem. During the 1992 season, a novel method of cleaning larval vessels was investigated. This involved setting up an outflow pipe on the side of the larval vessels, with a 45 μ or 64 μ banjo filter fitted to this pipe, to retain the larvae in the vessel. Clean treated seawater flowed into the vessel at a rate equating to outflow, such that the volume in the vessel remained constant. On alternate days, this method was used to change one and a half the total vessel volume, with the aim of producing a complete water exchange.

Two trials were carried out to compare these two cleaning techniques. Figure 1 shows the growth curves for experimental (flow-through) and control (drain-down) populations of these batches. Comparison of the regression coefficients of mean shell length on age shows that there was a significant difference at the 5% confidence level in slope of the control and experimental growth curves for both batches, indicating that larvae in the experimental populations had a significantly higher rate of growth. Clearance rate data showed considerable variability, but a pattern emerged of higher clearance rates in the experimental group than in the control. The increase in clearance rate around settlement was quite marked, and reflects the response to reduced feed level at this stage, as well as the higher feeding rate which occurs following metamorphosis, when the gill starts to function as a feeding organ, and ration increases to support increased somatic tissue and shell growth rates.

Spat production was also found to be affected by the cleaning technique used. In batch 14, survival from day three to post-metamorphic spat at day 73 post-fertilization was 0.10%. Of these spat, 83% were produced in the experimental system, and mean shell length of spat was 429 μ and 340 μ in experimental and control populations, respectively. In batch 16, the control population was discarded at day 37, at which time only 5% of the original population remained, and these larvae showed no signs of competency. Spat production in the experimental culture was equivalent to 0.21%.

From these trials, it was concluded that reducing the amount of disturbance during culture maintenance produces significant improvements in larval vigour, and in survival at metamorphosis. The precise effect of the drain-down procedure on larvae is not known. It is possible that feeding is interrupted, and does not recommence immediately on return to the culture vessel. This theory is supported by the observation that larval motility in the control populations was visibly less than in the experimental groups. It has also been suggested that draining down the culture vessels resuspends pathogenic surface-coating bacteria, with the risk of disease transmission being aggravated by holding the larvae at high densities while the vessel is cleaned and refilled.

Successful spat settlement has been achieved in three subsequent larval batches cultured on a flow-through water change regime, conclusively proving the efficacy of this method.

CONCLUSION

The hatchery has produced approximately 50,000 post-metamorphic spat to date, and survival of hatchery-reared spat in intermediate culture has been found to be high. Production of seed in viable numbers has yet to be achieved, but represents a realistic prospect in view of the material improvements made in larval husbandry techniques under this program.

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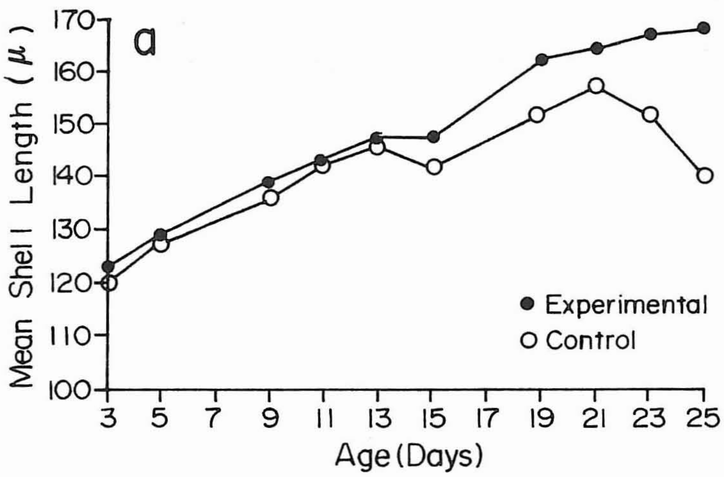

Fig. 1. Growth of *P. maximus* larvae maintained on flow-through and drain-down water exchange regime, batches 14 (a) and 16 (b).

THE DEVELOPMENT OF SCALLOP HUSBANDRY FISHING IN TASMANIA THROUGH TECHNOLOGY TRANSFER FROM HOKKAIDO

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ABSTRACT

The Scallop Enhancement Research Project between the Tasmanian government and the Japanese Overseas Fishery Cooperation Foundation ran from 1987 to 1990. Contracted Tasmanian oyster hatcheries were unable to produce sufficient spat for large scale experiments. Wild spat collection of commercial scallops *Pecten fumatus* Reeve was sufficient to demonstrate that intermediate culture of scallops was necessary for survival of scallops 'reseeded' or sown on the seabed. Hanging culture by lantern cage could produce marketable scallops (80 mm shell length) 18 months from spatfall. Survival rates of sown scallops were 60% after one year. These results were encouraging so a new project, the Scallop Enhancement Project, commenced in 1990 to take the Project into its pilot commercial stage. Earhanging of scallops and sowing after intermediate culture are now the major activities of the fledgling industry. A fishermen's company was set up to develop the industry along Japanese lines. The Project thus became a sociological as well as an economic and biological experiment. Areas of seabed which provide fastest growth for scallops do not always have the best survival rates. Storms seem able to bury scallops in shifting sand causing large mortalities within a few days. Scallops from the area with the highest survival rate had the lowest meat yield.

IMPROVED TECHNOLOGIES FOR SEED MANAGEMENT IN THE NORTH OF CHILE: FROM METAMORPHOSIS TO 20 MM

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ABSTRACT

The economically viable hatchery production of, on the average, two million *Argopecten purpuratus* seed from six producers during the last high season has been possible due to the development of new improvements on existing technologies to handle the seed from metamorphic larvae until the 20 mm size range. The life cycle of scallops from metamorphic larvae is completed in the open ocean and therefore, it is a necessary condition to monitor seed status to obtain a suitable number of physiological robust seed. Our production-related decisions are made by the enforcement of at least twice per week diving regime. The complexity of natural variables in the water column makes almost impossible the use of efficient management diving-independent schedules. Also, it is economically unwise to predict the outcome of a particular batch of seed without a detailed weekly ecoanalysis of seed condition. The most frequent causes of mortality or loss of seed are: detachment, excess sedimentation, predation and bad handling.

INTRODUCTION

The present paper is based on experience of seed management in the Third Region of the Atacama Desert in northern Chile at 27°N. The Region has a straight coastline of over 300 km. Here, upwelling of deep water, rich in nitrates and phosphates, occurs frequently. This phenomenon, together with others, makes this zone high in primary productivity.

Aquaculture began less than 10 years ago and today the only shellfish that is being cultivated on a commercial scale is the Ostion del norte, *A. purpuratus*. This species, the only scallop in northern Chile, is a functional hermaphrodite and has a rapid growth rate of 1.5 years to reach commercial size of 90 mm (at 20 to 40 scallops per kg). There are 15 operating centers of aquaculture in the region with 1,250 hectares of concessions. Five of these centers have hatcheries.

A small part of the scallop seed for the industry comes from natural collection. At the last high season, the natural collection increased drastically; this may be due to the increase in the number of scallops in the bay.

In 1990 the Atacama region produced 400,000 cultured scallops. In 1992 the production was 9.2 million. In 1995 we expect a production of 250 million scallops.

Currently, about 400 people work in scallop culture in the zone and we expect that by 1995 it will increase to 3,000. The third region of Atacama produces nearly 35% of the scallops of Chile.

At the moment, scallops are cultured in suspension systems in lantern nets. Bottom culture is presently under study.

One of the common problems in our industry in Chile has been the high mortality that occurs in the seed stage, from metamorphosis to 20 mm. We have found that understanding this mortality is related to periodic underwater observation. Analysis and discussion of the principal causes of seed mortality is the theme of this paper.

This paper does not have a bibliography because the information comes from observations made during at least 2.5 hours of diving, twice a week, by the author, for more than eleven years in seed management.

MATERIALS, METHODS AND DISCUSSION

The most frequent causes of mortality or loss of seed are:

1. detachment;
2. excess sedimentation;
3. predation;
4. poor handling.

By itself, density is not a problem, but together with any of these four factors, mortality will increase as density increases.

DETACHMENT

In our systems, scallop larvae are set on Chilean netlon and then after some growth they are sent to sea. Detachment is a problem in seed from postlarvae of 250 μ up to 1.5 mm shell height. If they fall off the netlon, they will pass through the outer mesh bag. The critical moments are:

1. when the netlon is put into the bags, when the scallops can be knocked off;
2. during transport to sea, when they can be exposed to air for too long;
3. during cleaning, when they can be knocked off or exposed to excessive movement.

Solution

Scallops knocked off during bagging can be resettled on netlon, the detachment caused during transport can be minimized by reducing exposure to air. The detachment caused during cleaning can be avoided by careful work.

Discussion

About half of the seed will fall off within seven minutes of exposure to air. If the seed is transported to the sea without exposure to air, about 90% will survive to 10 mm. We grow the seed in Chilean netlon until 15 to 20 mm and good production is 4,000 seed per netlon.

EXCESS SEDIMENTATION

Massive mortality due to excess sedimentation occurs in a short time: the time that it takes for mortality to begin depends on the density of seed and on the quantity of sediment trapped by the external mesh. These mortalities are due to low oxygen and/or increases in waste products from the scallops, produced by poor renewal of the water in the nets. If measures are not taken in time the mortality is always more than 50% at high densities.

Solution

The mortalities caused by sedimentation disappear with periodic cleaning of the mesh, at least twice a week. This cleaning is done by a diver who, after cleaning the outside mesh, takes the container by both ends and quickly changes its position, renewing all the water inside.

Discussion

The cleaning must be done by trained divers, hopefully by biologists, not only for the cleaning but also because this is the only time that a person can detect the problem in time. The netlon and mesh bags used for natural collection should be handled this way.

PREDATION

Predation inside the culture systems is basically by crabs, *Cancer* and *Pilumnoides*, which enter the nets as larvae and grow more rapidly than the scallops.

Solution

The crabs must be removed from the systems when they begin to prey on the scallops. This could be done during the routine cleaning by divers or during the handling of the seed. Normally the crabs start by eating each other and later the largest begin to eat the smallest scallops.

Discussion

Periodic inspection by divers is the key, the same as with sedimentation problems. When the diver finds an abnormal mortality inside a container, he must find the crab intruder.

POOR HANDLING

Handling seed to reduce density normally produces high mortalities. This is basically due to cuts created in soft parts which are then attacked by bacteria.

Solution

Handling must be kept to a minimum and when necessary, we have discovered that keeping the seed with shells closed during emptying and filling the containers reduced mortality drastically. A very important factor is the speed at which the seed is placed in the new container and final position on the raft or longline.

Discussion

All the handling is done at sea, on a raft or boat, and the seed is never exposed to air for more than 10 seconds except when it is being measured for the new containers. When the wind starts blowing and begins to agitate the water and the boat, we stop handling and we terminate the job.

CONCLUSIONS

In determining a solution to the mortality and loss of seed, problems must be identified by observations made underwater by a trained diver. Seed cannot be managed with a pre-established schedule, but to the contrary, the decisions must by reviewed daily, based on the diver's periodic observations. The best seed management avoids seed handling.

SCALLOP FARMING IN IRELAND - AN INTERACTIVE COMPUTER BASED TRAINING PACKAGE

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ABSTRACT

Scallop farming is Europe's fastest growing shellfish mariculture species with about 300 t per annum currently harvested between Scotland, France and Ireland. Unfortunately, information on the best husbandry and technology is not freely available in this rapidly evolving industry. This project aimed to bring together widely dispersed information into one easily accessible training package which could also be updated as the industry evolved. An interactive computer program was the ideal vehicle to fulfil these aims. The result was a user friendly package which required about £6,000 ($9,600) of hardware in order to construct it and a further £10,000 ($16,000) to produce the software. Trials involving postgraduate aquaculture students have demonstrated that the information can be easily accessed and assimilated in 40-60 minutes.

INTRODUCTION

The National Aquaculture Development Centre (NADC) was established by the Zoology Department of University College Cork in 1989. It has three main areas of operation: Research, Consultancy and Training. The training activities center around two postgraduate courses in Aquaculture - an M.Sc. which lasts 18 months and a Higher Diploma in Applied Science (Aquaculture) which is for one academic year (9 months). In addition the NADC runs short specialist courses of two to three days. These are typically funded by the European Community (EC) or grant aided by the Irish Higher Education Authority. Recent examples of some of these courses are shown in Table 1.

All the existing training material at the NADC involved time commitments of from three days to 18 months on the campus which is not always feasible especially for employees on remote fish farms. Self-paced learning is a well proven alternative to full time courses and the new generation of computers and software has considerably speeded up the creation of teaching material. Obviously some form of financial backing was required in order to explore the possibilities of this new technology. There are various grants administered by the European Community (EC) which support training activities. These include ERASMUS (transnational student exchange), COMETT (personnel exchange and short training courses) and FORCE (vocational training). The latter program was felt to be the most appropriate from which to obtain funding for this project.

THE FORCE PROGRAM

The EC FORCE program (Formation Continuee en Europe) aims to promote continuing vocational training for employees in the workplace. In this way the employees learn at their own pace without the need for time off from work. The program places a strong emphasis on new developments in education and therefore distance learning training methods such as video, computer conferencing, electronic white boards and interactive multi-media computer programs are a priority.

In 1990 The Zoology Department, University of Aberdeen (Scotland, U.K.) coordinated an application for a pilot project to the FORCE program. Its main partners were The NADC (Ireland) and DIMITRA, a non-profit Information, Training and Development Institute for young people (Greece). The project was entitled "Continuing Vocational Training in the European Aquaculture Industry" and each country had State development agencies, growers organizations and a number of working fish farms as collaborative partners These enterprises were vital for determining the outputs of the project and for testing the end product.

MATERIALS AND METHODS

Each of the three partner countries carried out a survey of their own fish farming industry to establish their immediate training needs and priorities. High on the list of subjects, about which aquaculturists wanted to know more, was "New Species". In particular scallop farming was frequently mentioned as an alternative source of income for mussel farmers. This species had also been proposed, in Scotland, as a possible area of diversification for salmon farmers. Altogether about 300 t of the scallop *Pecten maximus* are farmed between Ireland, Scotland and France but information on how best to farm it is not easily available. It therefore seemed the ideal subject for an interactive computer based package. Various other projects were also funded by the FORCE program (Table 2).

RESULTS

Scallop information was sourced from published literature and the various Pectinid Workshop Abstracts (1975-1993). In addition scallop farmers in Ireland and Scotland were canvassed for their views on husbandry and management. Equipment suppliers gave information on design, availability and price of scallop ongrowing gear and government agencies advised on appropriate technology transfer from scallop farming countries such as Japan. Finally pictures for illustrating the text were obtained from existing collections of transparencies and histology slides held by the NADC.

At present the scallop training package consists of 15 main "screens" at 100 words per screen. There are also 20 customised diagrams and 15 photographs to accompany the text. The program is organised in a logical progression from the availability of seed (juveniles) to final ongrowing and marketing. It operates through "Windows" and is "Mouse" driven. The trainees can access any part of the package via an Index and move forwards or backwards at their own pace. The time taken to cover the contents thoroughly would be 40-60 minutes. One of the special features of the package is: the use of Hypertext to allow "hidden" information which can be accessed by clicking the "mouse" on highlighted words. There are also timed diagram sequences which illustrate a progressive action such as scallop swimming. It contains full colour reproduction of transparency and video images.

DISCUSSION

The development of the package including familiarisation with programming techniques, preparation of the script and diagrams and finally the synthesis of the interactive program took about 9 man-months. The equipment (hardware plus software) necessary to produce interactive multi-media programs (Table 3) costs about IR£6,000 (US$9,600). If you were to start producing the software from the beginning (i.e. source material, write script, produce graphics and film visual material), an interactive computer package could cost from £5,000-10,000 (US$8,000-16,000). However if customers can provide a lot of this information themselves then the cost could be as little as £2,000 (US$3,200).

The package has been well received both in Ireland and abroad. Trials are just starting with three levels of students. At third level institutes it will be used with postgraduate students training for site biologist and management positions. The second category are the skilled technicians in training on post secondary certificate and diploma courses. Finally its most important application will be with trainee farm operatives both on the farm and on short vocational courses.

We are about to obtain the software (Microsoft's *Video for Windows*) which will enable users to play back video sequences without having to purchase extra video hardware. In addition the use of Kodak's *Photo CD* will allow us to achieve and access high resolution photographic quality images and sound can be incorporated using an audio card (*Soundblaster* type).

Table 1. Details of recent short training courses run by the National Aquaculture Development Centre.

Title of course	Date	Participants
New technology in the Shellfish Hatchery	April 1991	40
Turbot farming workshop	Sept. 1992	60
Aquaculture and the Environment	April 1993	45

Table 2. Projects funded by the EC FORCE program at the National Aquaculture Development Centre.

Subject	Media
Scallop farming in Ireland	Interactive computer program
The effective feeding of fish	Interactive computer program
Basic fish husbandry	Video
Depuration of shellfish	Interactive computer program

Table 3. Equipment required for the development and delivery of the program.

Hardware (development)	an IBM compatible, 486, with 256 colour display and 8 Mb memory.
	Screen Machine digitiser (to capture images from video and transparencies)
	dedicated camcorder eg.*Tamron Fotovic* to transmit the analog transparency image to the digitiser.
Software	*Windows 3.1*
	Microsoft Visual Basic Programming System for Windows
	Graphics program (e.g.*Corel Draw*)
Hardware (delivery)	IBM compatible, 386 or 486, 256 colour display, 4Mb memory
Software	*Windows 3.1*

NOWHERE TO HIDE? PREDATOR IMPACT ON SEEDED SCALLOPS

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ABSTRACT

Predation remains the major obstacle to the on-bottom cultivation of scallops in many regions. Small scallops are most vulnerable and so expensive intermediate culture is employed so they can out grow their predators and achieve a "refuge in size". Small scale seeding on a commercial scallop ground indicates that the starfish *Asterias rubens* (L.) and the crab *Cancer pagurus* (L.) may be able to overcome this refuge under certain conditions. Replicate grids laid out on the seabed 25 m below LAT, were seeded with three-year-old *Pecten maximus* (L.), mean shell length 92.3 mm (S.D. = 5.3 mm), at a density of 9 scallops$\cdot m^{-2}$. Monitoring of the grids and the immediate locality was carried out by divers over a nine month period. Starfish density within the grids increased from zero at seeding to more than $1 \cdot m^{-2}$ in 24 hours, and greater than $1.5 \cdot m^{-2}$ after 48 hours. This rapid aggregation was followed by a gradual disaggregation although after two months the density of *A. rubens* was still five times that of the locale at the time of seeding. *C. pagurus* was seen only occasionally but damage to recovered shells suggested that it was responsible for up to 45% of scallop mortalities. Characteristic chipping of the shell margin suggested that the scallops were close to the upper prey size limit of *C. pagurus*. Scallop mortality, expressed as a percentage of those scallops that could be accounted for, was 86%, despite their large size at reseeding. However, at the termination of the experiment 58% had been lost from the area monitored by divers, presumably due to predation and dispersal. Assuming complete survival or mortality of those scallops unaccounted for, the range of potential survival is from 6% to 64% after 286 days. The high predator-induced mortality was considered to be an invasion of the scallops' size refuge proposed in the literature. It is suggested that the size-selective feeding behaviour of both the major predators was modified by frequent encounters with large sub-optimal prey, to the point where the usual bias towards smaller, more easily handled prey was overwhelmed. Similar behaviour has been reported for *A. rubens* and *Carcinus maenas* feeding on *Mytilus edulis*. The rapid predator aggregation was a taxic migration mediated by the chemical signature of the reseeded scallops, possibly enhanced by stress-related products given off as a consequence of the reseeding itself. The slow disaggregation of *A. rubens* was due to a return to random foraging as the prey density fell, and the chemical attraction declined. The implication is that without effective predator clearance prior to reseeding, modification of predator behaviour by the presence of weakened scallops at high density, may result in a size refuge being breached and lead to early catastrophic losses of stock.

FISHERIES

ESTIMATING ABUNDANCE ON NORTH IRISH SEA SCALLOP, *PECTEN MAXIMUS* (L.), FISHING GROUNDS

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ABSTRACT

Catch per unit effort values (CPUE: scallops per meter dredge width per hour) calculated for a sample fleet are used to estimate density and stock size for populations on seven important fishing grounds around the Isle of Man in the 1987/88 and 1988/89 fishing seasons. These population estimates are compared with Petersen estimates of stock size obtained from tagging experiments. Likely sources of error for the two methods are considered and the use of commercial CPUE as an index of stock abundance in this fishery is discussed.

INTRODUCTION

There is an important fishery for the scallop *Pecten maximus* (L.) in the North Irish Sea, based on the Isle of Man. The fishing season runs from 1 November - 31 May and a minimum legal landing size of 110 mm shell length is enforced. Commercially exploitable densities of scallops occur on a number of more-or-less distinct fishing grounds (Brand et al. 1991). The scallop populations on each ground have different rates of growth, recruitment, fishing mortality and natural mortality (Mason 1957; Murphy 1986; Allison 1993). Stock assessments and fishery management must therefore take this spatial variability into account.

Since 1981, a detailed study of the population dynamics has been carried out on different fishing grounds based on catch and effort data from commercial fishermen's logbooks, research vessel surveys and a series of tagging experiments. This paper compares population stock size estimates for seven major fishing grounds in the 1987/88 and 1988/89 fishing seasons made by two methods: from scallop density estimates based on commercial catch per unit effort (CPUE) data and by Petersen single census estimates from the tagging experiments.

MATERIALS AND METHODS

The seven fishing grounds investigated are shown in Figure 1; those nearest to the Isle of Man are generally the most heavily fished and have the longest history of exploitation.

Complete catch and effort statistics are not available for the fishery but detailed information is collected for a sample fleet, based on logbooks recording daily fishing activity, completed on a voluntary basis by vessel skippers. The logbooks provide details of the size and power of the boat, gear specifications and daily records of the number of hours fished, the catch in bags of scallops (plus an estimate of the number of scallops per bag) and the area fished. The areas can be recorded as Decca co-ordinates or as the reference number of a grid square. The grid is based on five Nautical mile (9.26 km) squares, constructed from the lines of latitude and longitude, starting at 54°N and 5°W.

Seasonal CPUE values (number of scallops caught per hour's fishing per meter width of dredge) have been calculated from the logbook data for each five Nautical mile grid-squares since 1981/82. The calculated CPUE values are means, weighted by fishing effort, of the winter season's fishing of the sample fleet, which represents 24-34% of the Manx registered fleet.

Density of commercial size (>110 mm shell length) scallops is given by:

$$\text{Density} = \frac{\text{CPUE / Gear efficiency}}{\text{Distance covered in 1 hour fishing}}$$

Distance covered in one hour fishing was calculated assuming a mean towing speed of 1.5 Knots (2.78 $km \cdot h^{-1}$) (Murphy 1986). A value of 20% was chosen for gear efficiency, based on published estimates (Rolfe 1969; Gruffydd 1974; Chapman et al 1977; Mason et al 1982). It is assumed that gear efficiency is the same on all grounds.

Estimates of stock size for each fishing ground were obtained by multiplying the density estimates by the area of the grid-squares from which the CPUE data were obtained (25 Nautical $miles^2$ or $8.5857 \times 10^7\ m^2$ per grid-square).

Scallops were tagged and released on the seven grounds in July 1987 and again in June 1988 (Allison 1993) as part of a large tagging experiment designed to estimate mortalities using Ricker's two-release method (Ricker 1975; Seber 1982). The tag returns are used here, together with sample fleet catch data, to calculate estimates of population stock size for the grid-squares over which tagged scallops were distributed, using the Petersen or single census method (Ricker 1975):

T is the number tagged, corrected for tagging-induced mortality and tag loss. Total catch (C) per fishing ground was estimated from sample fleet catches and

$$\text{Stocksize} = \frac{(T+1)(C+1)}{(R+1)}$$

the ratio of tag recaptures by the sample fleet to tag recaptures by the whole fleet (R). Non-reporting of recaptures was considered to be negligible (Allison 1993).

RESULTS

Trends in sample fleet CPUE for the seven grounds over the period 1981/82 - 1991/92 are shown in Figure 2, with separate plots for each grid-square within the ground. CPUE was comparatively high on all grounds following good recruitment in 1983/84 but has fallen steadily since then and become homogeneously low in all areas. The values calculated are generally very similar and follow the same trends in adjacent grid-squares within the same fishing ground and in contiguous grounds like Peel Head and Bradda Head. This suggests that annual recruitment to the populations and exploitation are generally evenly distributed over at least the area of each fishing ground.

The densities and stock size estimates for each ground in the 1987/88 and 1988/89 fishing seasons, calculated from sample fleet CPUE data, are given in Table 1. Mean densities were slightly higher on the offshore-south grounds, compared with the very heavily exploited inshore-west grounds, but the differences were very little, ranging between three and five scallops per 100 m^2 on all grounds. Stock size was between 2.8 and 11.6 million scallops with very similar estimates for the two seasons on all grounds. The calculated densities and stock sizes are highly sensitive to the chosen values for gear efficiency and towing speed. If gear efficiency of 30% and towing speed of 2 knots (3.71 $km \cdot h^{-1}$) is used in the calculation (both within the range of possible values) the density and stock size is half that calculated in the table.

The Petersen estimates of stock size based on tag returns (Table 2) are, in general, considerably lower than those calculated from CPUE (Figure 3). The only instances in which the stock size estimates are comparable are for the southeast Douglas and H/I-sector fishing grounds in the 1987/88 season. Both Petersen and CPUE-based estimates for these grounds are based on very small catches by the sample fleet. Estimates for grounds where sample fleet catches were high and large proportions of tag-recaptures were made by the sample fleet lead to Petersen estimates of stock size that are generally two to three times lower than the CPUE-based estimates, except for The Targets ground (and The Chickens in 1987/88) where the difference is even greater.

DISCUSSION

In calculating density and stock size from commercial CPUE data, we make the basic assumption that CPUE is proportional to abundance. This is equivalent to assuming that fishing mortality is proportional to fishing effort (Gulland 1963). In order for these relationships to apply, each scallop within a five Nautical mile grid must be equally vulnerable to capture within a fishing season.

Several authors have contended that CPUE does not reflect abundance in scallop fisheries (reviewed in Caddy 1989 and Orensanz et al. 1991). They argue that fishermen do not fish at random, but exploit patches within a fishing ground, fishing each patch until density drops to some threshold level, when the fishermen move to another patch. Given this sequential pattern of patch-depletion, stock size is not reflected by CPUE. However, the spatial extent of the Isle of Man fishing grounds is generally very small and the boundaries of each reasonably well-defined. Boats usually tow for one to two hours before hauling the gear so that any high-density patches within a fishing ground are not perceived by fishermen, especially as overall densities are very low. If patches within a fishing ground are not detectable by fishermen during normal fishing activity, then they cannot be a determinant of fishing strategy. Under these conditions, Orensanz et al. (1991) concede that changes in CPUE can reflect changes in abundance.

Murphy (1986) showed that scallop CPUE declines significantly through a fishing season on the major Isle of Man grounds, with the declining CPUE reflecting declining abundance as the predominant recruit year-class is fished down. For the major fishing grounds, where the patterns of change in CPUE are so consistent between adjacent grid-squares, it therefore appears reasonable to assume a relationship between CPUE and abundance. This relationship can be assumed to be density-independent, as gear performance is not affected by scallop density (which is too low to cause dredge-filling), but the relationship may vary between fishing grounds due to substrate-specific differences in gear efficiency, such as those shown recently by Dare (1993). The densities calculated from a single gear efficiency value of 20% for all grounds may therefore be subject to some bias but they fall within the range of densities reported for other commercially fished *P. maximus* populations (Orensanz et al. 1991). Recent surveys of inshore fishing grounds around the Isle of Man by divers have also produced similar, very low, estimates of density (MacDonald 1993; U.A.W. Wilson, pers. comm.).

Errors in the estimation of density from using an incorrect value for gear efficiency, or mean towing speed, will result in some error in the estimates of stock size calculated from commercial CPUE but these are additionally dependent on the assumed value for the area covered by each ground and this could be a major source of error. The actual areas commercially exploited on each ground are well known to fishermen, but not to scientists, as many of the grounds have never been surveyed in sufficient detail. For most grid-squares it appears that fishing activity only occurs over relatively small proportions of the square, so stock size estimates, based on the total area of one or more grid-squares, will be overestimates. This overestimation is likely to be greatest where the fishing ground is located around the intersection between several grid-squares.

The tagging-based estimates of stock size will also be subject to some error, due to violation of the assumptions required for tagging experiments (Ricker 1975; Jones 1979), to the low numbers of tag returns from some grounds and to the necessity of obtaining total catches by extrapolation from a sample fleet that is not equally representative of the total fleet on all grounds. However, care was taken to account for the known sources of error with the tagging and the stock size estimates are unlikely to be severely biased.

The Petersen estimates of stock size on the Bradda Head ground in 1987 and 1988 are of the same order of magnitude as previous estimates of stock size on this ground, based on tagging experiments carried out in 1953 (Mason and Colman 1955), 1966 (Gruffydd 1972), 1982/83 and 1983/84 (Murphy 1986). These estimates of stock size, derived independently of CPUE data, accord well with the historical changes in CPUE on this ground (Brand et al. 1991). This again suggests that CPUE is a reasonable index of abundance for grounds where the spatial extent of the stock is the same over long periods of time.

In conclusion, it would seem that the large discrepancy in stock size estimates between the two methods of estimation is most likely due to the invalidity of the assumption that the CPUE (and therefore scallop density) applies to the whole area of the grid-square. For the traditionally fished grounds such as Bradda Head, which are persistent in their location at a fairly small spatial scale and where changes in CPUE are likely to reflect changes in overall abundance, the spatial extent of each fishing ground need only be determined once before CPUE can be converted to abundance, without incurring the bias resulting from the assumption that scallop grounds cover the whole of the five Nautical mile squares from which CPUE data are reported. CPUE could thus be used to provide annual abundance estimates for major grounds without the requirement for an expensive annual research-vessel survey. For fishing grounds where the spatial extent of the stock is more variable, CPUE is not such a reliable index of abundance and cannot be used in this way without annual survey data. Improved estimates of gear efficiency and towing speed would also enhance the accuracy of conversion of CPUE to stock size.

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Table 1. Stock size estimates for Isle of Man fishing grounds, calculated from CPUE values for the sample fleet of commercial fishing boats. Each grid square is 5 Nm^2 (85858756 m^2).

Fishing Ground	No. Grid Squares	CPUE (scallops·m^{-1}h^{-1})	Density (scallops·100 m^{-2})	Stock Size (scallops x 10^3)
1987/8				
The Targets	2	19.69	3.54	6,081
Peel Head	1	18.15	3.26	2,803
Bradda Head	1	17.86	3.21	2,758
The Chickens	2	27.40	4.93	8,462
Port St. Mary	1	24.27	4.37	3,748
H/I Sector	3	24.95	4.49	11,559
S.E. Douglas	2	21.67	3.90	6,693
1988/9				
The Targets	2	15.48	2.78	4,781
Peel Head	1	17.68	3.18	2,730
Bradda Head	1	18.83	3.39	2,908
The Chickens	2	24.37	4.38	7,527
Port St. Mary	1	24.53	4.41	3,788
H/I Sector	3	24.34	4.38	11,276
S.E. Douglas	2	24.35	4.38	7,521

Table 2. Stock size estimates for Isle of Man fishing grounds. Petersen single census estimates of stock size calculated from tag returns. T - number tagged (corrected for tag loss and non-reporting); R_s - number returned by sample fleet; R - number returned by the total fleet; C_s - sample fleet catch; C - total fleet catch.

Fishing Ground	T	R_s	R	C_s	C	Stock size (scallop $x10^3$)
1987/8						
The Targets	524	66	219	47,381	157,219	376
Peel Head	541	32	134	79,540	333,074	1,344
Bradda Head	490	87	187	147,133	316,251	828
The Chickens	417	93	183	381,081	749,869	1,708
Port St.	703	44	178	137,404	555,862	2,195
Mary	715	1	29	19,387	301,223	7,426
H/I Sector	759	6	77	51,924	666,358	6,568
S.E. Douglas						
1988/9						
The Targets	374	21	66	27,973	87,915	498
Peel Head	428	39	120	90,445	278,292	992
Bradda Head	458	69	102	161,815	239,205	1,074
The Chickens	518	66	227	332,625	1,144,028	2,610
Port St.	649	54	181	156,036	523,010	1,875
Mary	594	11	31	73,476	207,069	3,967
H/I Sector	753	12	70	44,276	258,277	2,778
S.E. Douglas						

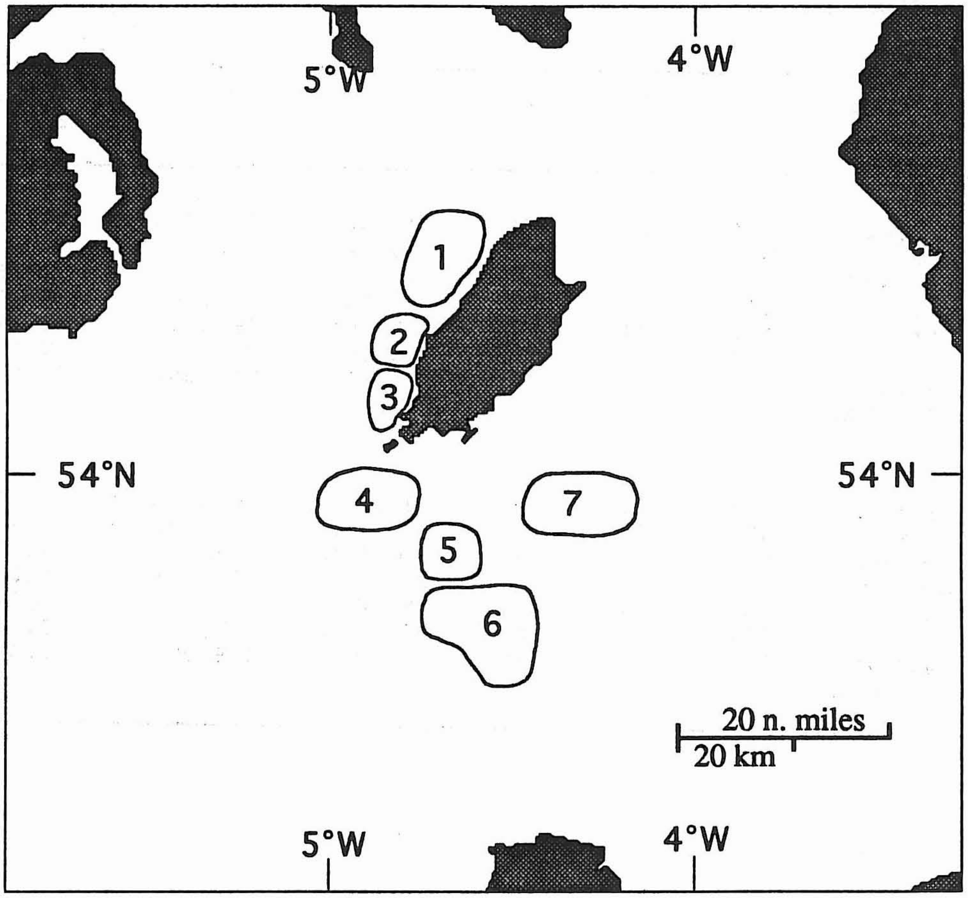

Fig. 1. The seven scallop (*Pecten maximus*) fishing grounds in the North Irish Sea around the Isle of Man investigated in this study. 1 - The Targets; 2 - Peel Head; 3 - Bradda Head; 4 - The Chickens; 5 - Port St. Mary; 6 - H/I Sector; 7 - S.E. Douglas.

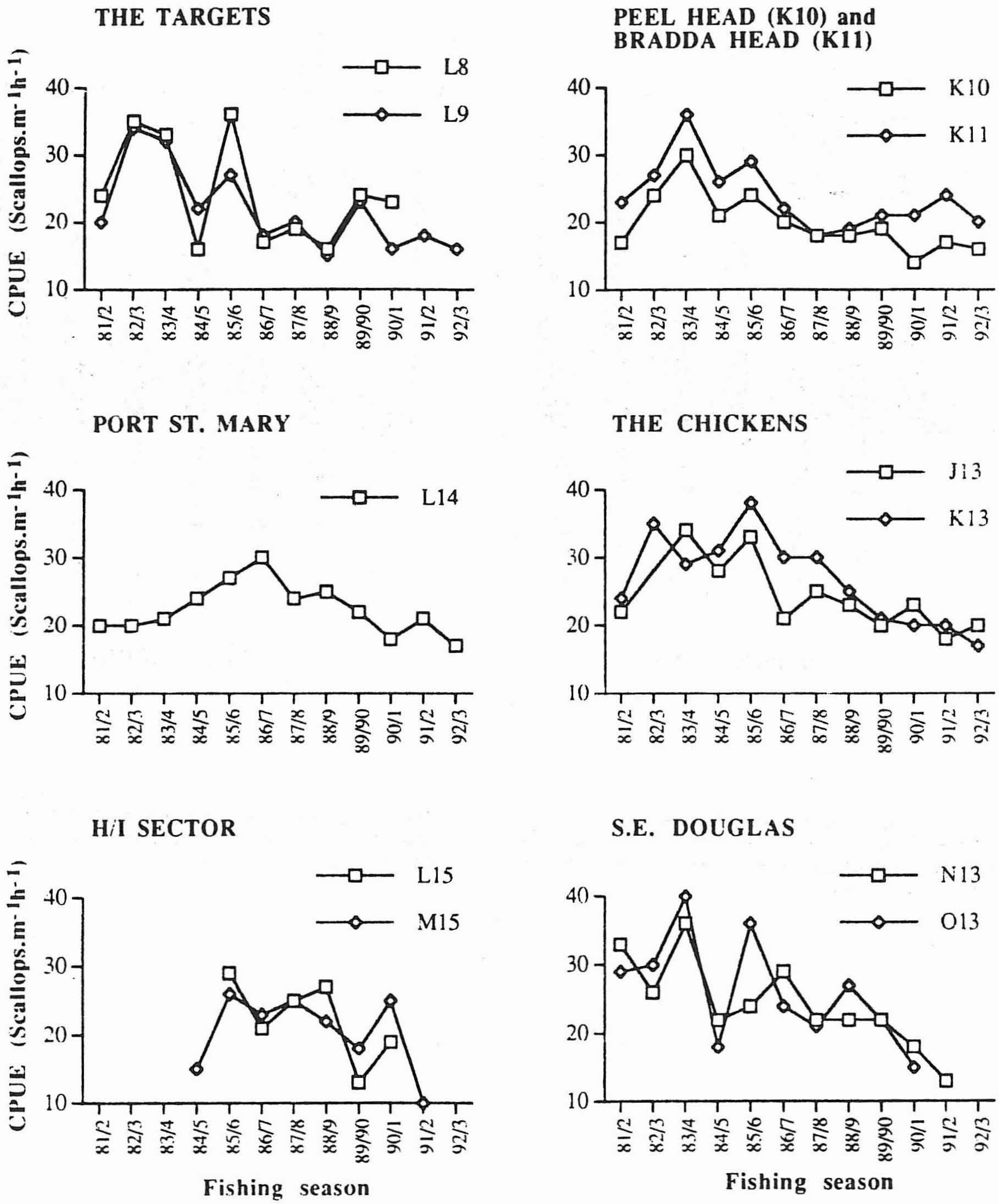

Fig. 2. Sample fleet catch per unit effort (CPUE: scallops$\cdot$m$^{-1}\cdot$h^{-1}) on major Isle of Man fishing grounds, for 1981/82 to 1992/93 fishing seasons. CPUE values are plotted for each five Nautical mile grid-square covered by the fishing ground (except H/I Sector where only two of the three grid-squares are shown). Each grid-square is identified by an individual code.

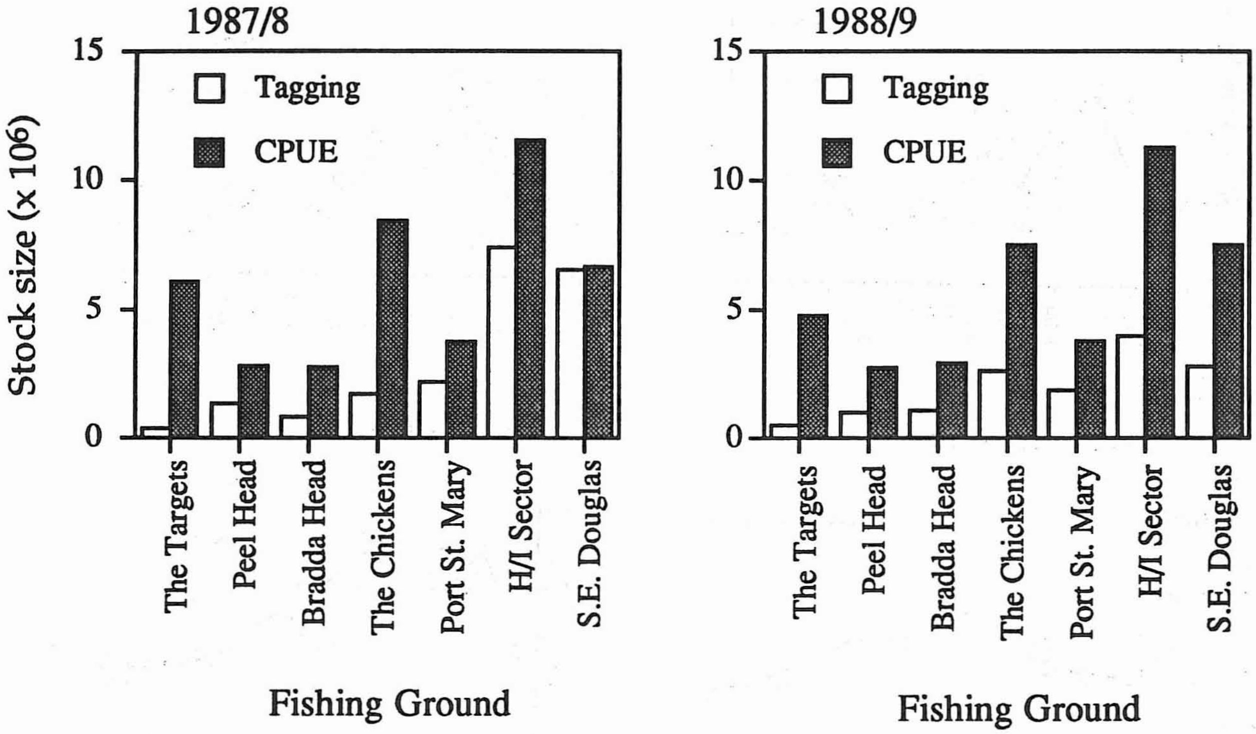

Fig. 3. Stock size estimates for major Isle of Man scallop fishing grounds calculated by two methods: from tag returns and total catches (Tagging) and from density estimates based on commercial Catch Per Unit Effort (CPUE).

ENHANCEMENT AND MANAGEMENT OF NEW ZEALAND'S "SOUTHERN SCALLOP" FISHERY

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ABSTRACT

The progress of management of New Zealand's "Southern Scallop" Fishery, from a largely unregulated wild fishery through a period of strict management controls and finally to a seeded and rotationally fished "farming" operation, is traced. Current methods involve a dual strategy of seeding spat caught inside Japanese type collector bags and dredging up and transplanting juvenile scallops which have off migrated from the outside of collectors. The scale of the operation has expanded rapidly since the first trials in 1982 and in the 1991/92 summer involved the setting of 300,000 collector bags which enabled a release of approximately 1.2 billion spat. Seeded stock is now contributing significantly to the yields from the fishery with an estimated 40-50% of the 1992 landings of approximately 700 t meat weight being of seeded origin. The rotational fishing system introduced in 1989 involves the subdivision of the fishery into a number of sectors which are managed on a three year rotation of seeding, ongrowing and then harvest to "economic extinction". The system has given significant advantages to both planning and efficiency of seeding and harvesting operations, but there is as yet an insufficient time series of data to allow assessment of its effectiveness as a way of maximizing productivity from the area or minimizing indirect fishing mortality and disturbance of the seabed through dredging. A system of individual transferable quotas was introduced to the fishery in 1992 as a means of securing rights for existing fishers, providing incentive for the industry to fund an ongoing seeding operation and providing a means of access for new entrants.

HISTORY OF THE FISHERY

The fishery for the New Zealand scallop, *Pecten novaezelandiae*, began in 1959 in the Nelson/Marlborough area at the top of the South Island. This area, now known as the Southern Scallop Fishery, remains the main scallop producer for the country although other fisheries for the species have since developed along the east coast of the North Island and at the Chatham Islands (Fig. 1).

Dredging within the Southern Scallop Fishery was initially restricted to a few known beds in Tasman Bay and effort was limited by local market demand. At this time scallops were shucked at sea and the fishery was largely unregulated. Within the first ten years, however, controls had been introduced establishing a minimum size (4", later 100 mm), restrictions on number and size of dredges and an annual five-month closed season (February-July).

During the early 1970's catches increased dramatically to reach a peak of nearly 10,000 t shell weight in 1975, but during the following five years suffered a dramatic decline (Fig. 2). As a result of concern about declining catches, controls on the issuing of new permits were introduced in 1977 but despite a reduction in boat numbers from 245 in 1976 to 98 in 1979, the decline continued and the fishery was closed for two years in 1981.

Following its reestablishment in 1983, the fishery was held under tight control. Boat numbers were held at 48, the season length was shorted to only two to three months, and restrictions were put on daily and seasonal landings. Fishing intensity was limited by restricting fishing to daylight only hours and five days a week and the 100 mm size limit was strictly enforced. At the same time the N.Z. Ministry of Agriculture and Fisheries in conjunction with the Overseas Fishery Cooperation Foundation of Japan embarked on a joint project aimed at trialing the feasibility of enhancing the scallop beds through release of spat caught in collector bags.

Yield during the 1980's ranged from 1640 to 2938 t but landings in excess of 5000 t were made in 1991 and 1992. These higher landings were partly the result of a particularly strong natural spat settlement in the 1988/89 summer, but there was also a significant contribution from the seeded beds. Prospects for the following two years are for a further significant increase in landings with the major contribution being from seeded stock.

There have recently been a number of major initiatives in the management of the Fishery including establishment of a large scale seeding program, introduction of a rotational fishing strategy, and allocation of fishing rights by individual transferable quota. These are described in the sections below.

ENHANCEMENT OPERATIONS

Trials carried out between 1983 and 1986 on the release of scallop spat caught in synthetic mesh spat bags showed that the system gave an excellent return on investment (Bull 1988). As a result a large scale annual spat collection and seeding operation is now carried out in Golden Bay and Tasman Bay.

Between late November and mid December (early summer) spat catching longlines are placed in close proximity to areas that are due to be seeded. Each line carries in excess of 2000 collector bags and in the 1991/92 summer a total of 142 such lines were set (Figure 3).

By early March the collector bags usually contain between 1000-3000 spat of 8-20 mm per bag. The bags are then removed and the spat seeded out onto the chosen release site at a density of $4\text{-}6 \cdot m^{-2}$. A 26 m self-propelled barge is used for most longline work and smaller 12-15 m scallop boats are used for distributing the scallop spat over the grounds. In 1992 approximately 111 km^2 of seabed was seeded in this way.

As well as obtaining a settlement within the collector bags spat often settle on the outside of the bags and on the floats and ropes and when these eventually release themselves they fall to the seabed to form dense beds of juvenile scallops. By winter (June-August) these young scallops have reached 25-50 mm shell height and are big enough to be dredged for redistribution using a modified dredge with fine mesh codend. These juvenile scallops can be used for topping up any areas where the earlier release using spat directly from collector bags has been unsuccessful and for seeding on grounds which may be unsuitable for the release of small spat because of the existence of crabs or other predators.

In 1992 approximately 200 million young scallops were released by the transplant method giving a total release for the year of approximately 1.2 billion spat.

The percentage of seeded spat which survives to harvest is highly variable but an average of 15% for spat released directly from collector bags and 30% for those recovered from the seabed by dredging is probably being achieved (Bull 1988).

MANAGEMENT OF ANNUAL HARVESTS

In 1989 a system of rotational fishing and subsequent reseeding was introduced to the fishery. Under this system the fishing grounds in Golden Bay and the inner part of Tasman Bay are each divided into three sectors which are fished on a three-year rotation. Each year market sized scallops ($\geq$ 90 mm) within the open sectors are fished down to minimum economic density and the following autumn these sectors are restocked through the enhancement program. They are then kept closed until their third year when they are again fished.

There is not yet a sufficient time series of data to allow assessment of the effectiveness of rotational fishing as a way of maximizing productivity or minimizing indirect mortality and disturbance of the seabed through dredging. However the system has given significant advantages to planning and efficiency of both seeding and harvesting operations and it is intended that it will be introduced to other parts of the fishery as the scale and extent of the seeding program expands. These areas are currently managed by either irregular rotational fishing of wild stocks (outer Tasman Bay) or annual fishing under a TAC restriction (Marlborough Sounds).

In 1992 a system of transferable quotas was introduced to the fishery as a means of securing rights for existing fishers, providing incentive for the Industry to fund an ongoing seeding operation, and providing a means of access for new entrants. During a five-year phase-in period existing fishers (along with a 10% Maori allocation) have an equal share of the first 640 t (meat weight) available each year and the Government tenders out on a one-year lease basis any additional stock that is available (Fig. 4). It is hoped that by 1997 there will be a better understanding of the potential long term productivity of the fishery and at this point it is intended that any quota available above the 640 t already allocated will be tendered out on a permanent basis. All holdings will then be converted to proportional holdings, which will vary from year to year in accordance the availability of stock as determined by preseason surveys.

FINANCING AND MANAGEMENT OF ENHANCEMENT OPERATIONS

During the first three years of the trials, funding of the project came from the N.Z. Ministry of Agriculture and Fisheries and the Overseas Fishery Co-operation Foundation. Sale of product from plots seeded during this time financed the next three years. In 1989, fishers agreed to finance the enhancement operations through a levy on their annual catches in exchange for access to existing stocks and some guarantee of future rights in the fishery.

Current operations are financed through this system. The Ministry of Agriculture and Fisheries manages the funds through a trust account, organizes the operational side of spat catching and seeding operations, and carries out relevant research. All at sea work, however, is done using chartered commercial vessels (usually scallop boats or mussel farm barges) and Industry have direct input into management of the scheme through their representation on the Southern Scallop Advisory Committee which has been set up for the purpose.

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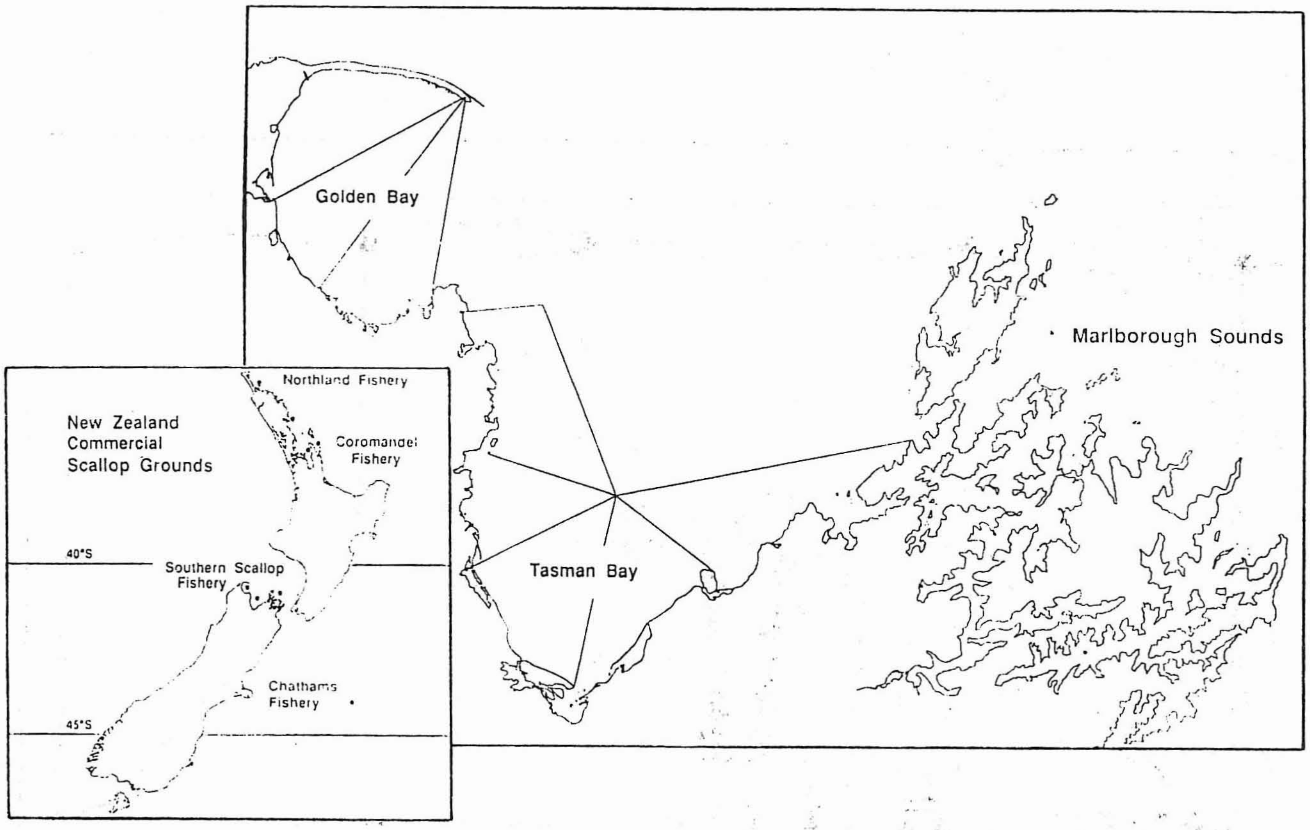

Fig. 1. Southern Scallop Fishery and rotational fishing zones.

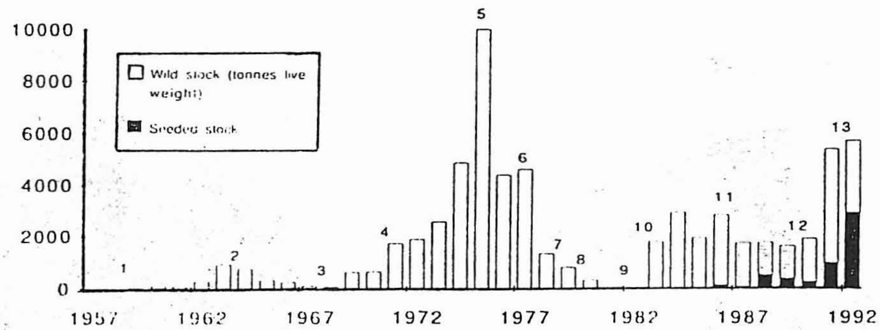

Fig. 2. History of landings and management changes in the Southern Scallop Fishery. Changes introduced: 1 - fishery commenced; 2 - 4" size limit; 3 - closed season 15 Feb - 14 Jul; 4 - geared restricted to two 8 ft dredges per boat; 5 - daylight only fishing; 6 - five-day week; 7 - controls on boat numbers; 8 - size limit removed for 1979/80 seasons, season shortened; 9 - fishery closed 1981/82 seasons; 10 - scallop enhancement program; 11 - first harvest of seeded stock; 12 - rotational fishing, size limit reduced from 100 to 90 mm; 13 - ITQ system.

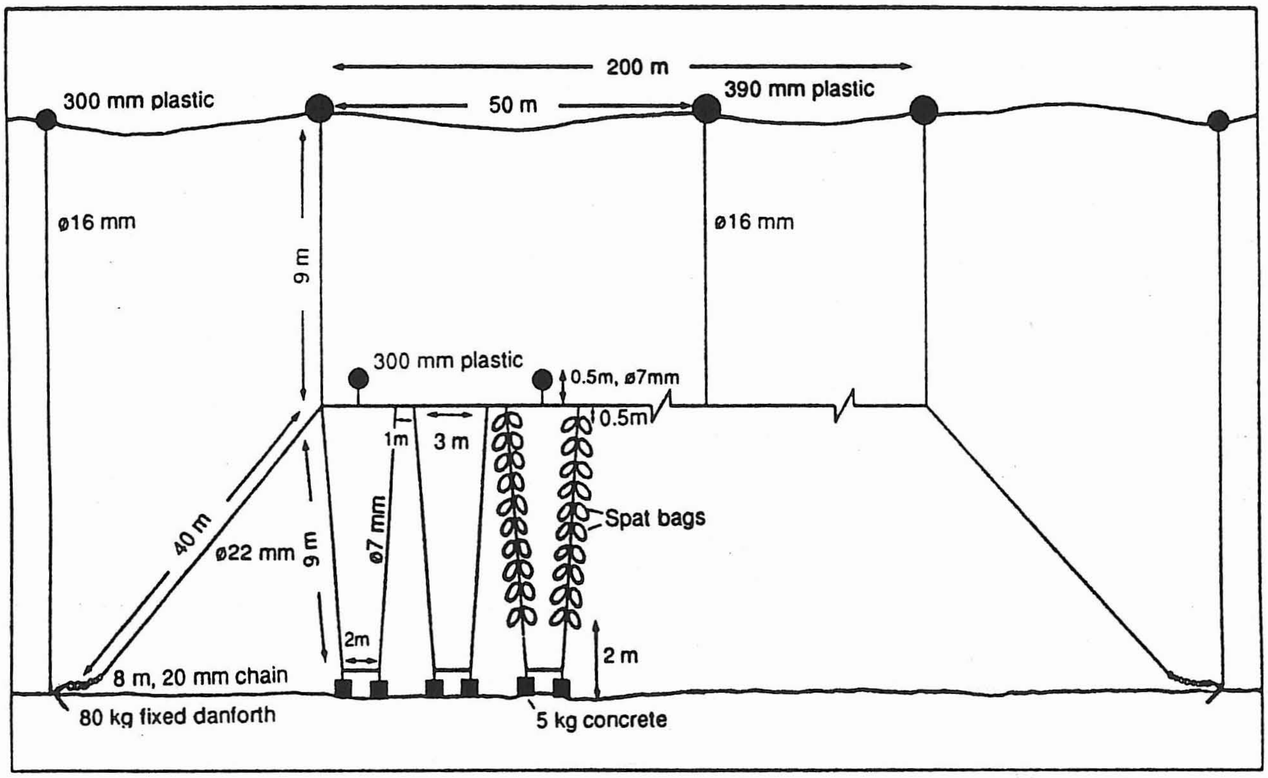

Fig. 3. Design of spat catching longline.

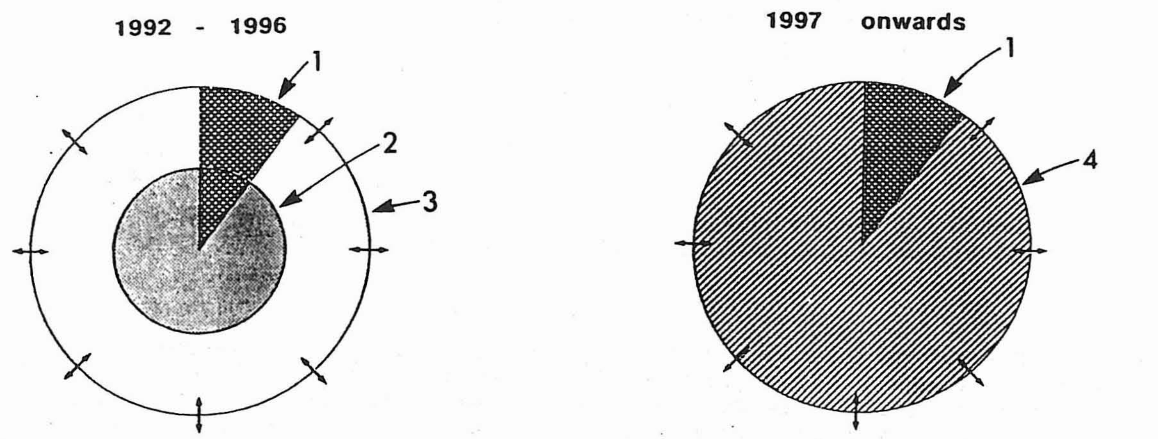

Fig. 4. Diagram of resource allocation system. 1, Maori share = 10% annually available stock; 2, allocated to historical fishers and Maori in 1992 as ITQ (sum = 640 t); 3, available on annual lease basis from crown (quantity dependant on pre-season survey); 4, allocated proportional ITQ.

THE USE OF DREDGE EFFICIENCY FACTORS FOR ESTIMATING INDIRECTLY POPULATION COMPOSITION AND ABUNDANCE OF SCALLOPS, *PECTEN MAXIMUS* (L.)

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ABSTRACT

In the western English Channel fishery for *Pecten maximus*, the direct assessment of true scallop abundance and population structure from dredge samples is not feasible due to gear inefficiency and mesh size selectivity. These problems can be overcome by measuring dredge efficiency *in situ* for each 5 mm size-class of scallop, and calculating a set of size-specific efficiency conversion factors (ECFs). Application of the ECFs to observed dredge catch size compositions on the same fishing grounds then permits the likely size structure of the sample stock to be derived. Its age structure is obtained by use of an age-height key. The procedures are illustrated with data from a study site in the fishery off south Cornwall. These have provided far more realistic estimates than hitherto of pre-recruit abundance relative to fishable scallops, and of population trends, in this stock.

INTRODUCTION

In molluscan fisheries the reliable estimation of total abundance and population density (animals per unit area) of each age and size-class are essential for understanding population dynamics and for improving management of stocks. Intertidal populations of bivalve molluscs such as mussels (*Mytilus edulis*), cockles (*Cerastoderma edule*) and various clams present rather few problems because usually they can be sampled and mapped directly using efficient methods (e.g. Hancock and Urquhart 1965; Walker and Nicholson 1986). For offshore bivalves, however, comparably reliable data are seldom obtainable directly from remote sampling by grabs and dredges, particularly on coarse substrates.

Scallop (*P. maximus*) stocks present acute survey and sampling problems in British waters because of their deep water (25-100 m) distribution, naturally low population densities, frequent occurrence on gravels or rougher bottoms, and their recessing (cryptic) behaviour on softer sediments. These factors, singly or in combination, preclude the effective use of grabs, SCUBA divers or underwater cameras in many fishery areas around the British Isles. Moreover, the toothed dredges used in the fisheries, and research modifications thereof, are highly size selective and especially inefficient at capturing juvenile scallops (Chapman et al. 1977; Mason et al. 1979; Dare et al. 1993a). Information on scallop populations therefore has been restricted to dredge indices of relative abundance and mainly for the larger (adult) component only.

This poster-paper outlines an approach being developed to circumvent these problems when assessing an important scallop stock in the western English Channel. Some preliminary results are presented which illustrate how more realistic estimates of actual population structure and abundance can be obtained from dredge catches by making allowances for gear inefficiency.

MATERIALS AND METHODS

Scallops in the fishery off south Cornwall have been sampled each summer, 1984-1992, during stock surveys using a research vessel or a commercial fishing boat. Both commercial (large mesh) dredges and research (small mesh) dredges were towed side-by-side over a 20 x 10 km grid of stations on an inshore ground at 50-60 m depth. Substrates comprised fairly uniform shelly sand and fine gravels.

The commercial dredge consists of a triangular frame with a mouth opening 75 cm wide and ≈14 cm high, a spring-loaded toothbar with nine teeth, and an 88 cm long bag with steel belly rings (8 mm thick, 75 mm internal diameter, 95-100 mm space between rings), and a netting back of 75 mm mesh. The teeth are 80 mm long (new) with 70 mm spacing between them. The toothbar's effectiveness, especially on rougher ground, depends upon the compression in the springs; this is regularly checked and 'fine-tuned' during dredging. This gear catches scallops mainly above minimum legal size, MLS (100 mm shell length; 88 mm height). To sample small (pre-recruit) scallops the above gear was fitted with finer and heavier mesh bellies and backs: belly rings of 40 mm internal diameter with 55-60 mm inter-ring gaps, back netting of 35 mm mesh.

The efficiency (E) of each dredge type was assessed during 1983-85 on these grounds by means of two mark-recapture experiments (details in Dare et al. 1993a, 1993b). In both experiments, the size-specific efficiency was calculated for successive 5 mm size-classes of scallop. The first experiment determined the efficiency of commercial dredges at catching the larger (85-105 mm shell height) scallops near or above minimum legal size. Efficiency conversion factors (ECFs) were then estimated for successive 2 mm size groups from the curve fitted by eye to these data; where ECF = 1/E . In the second experiment, the efficiencies of both gear types at capturing juvenile (pre-recruit) scallops of 45-85 mm shell height were compared directly by simultaneous tows. For each gear, the data were fitted by log-linear regressions, from which values of E (and hence ECF) could be obtained for successive 2 mm size groups over the range 45-85 mm. Values for 25-44 mm animals were then derived by extrapolation.

In order to keep ECF values minimal, a composite approach is adopted which utilizes the relative efficiencies of the two gears. For scallops <85 mm, the more efficient small mesh dredge values of ECF are applied, whereas large mesh ECF values are used for scallops larger than 85 mm. This switch corresponds to the point at which relative efficiencies become reversed such that small mesh dredges become consistently outfished by large mesh dredges when catching the larger scallops (see later). This procedure thus converts observed catch size compositions (biased by gear inefficiency) into less distorted estimates of the population structure. Knowing the area of seabed sampled by the dredges during a given tow length, we then estimate the number of animals actually present per unit area. Lastly, population age structure is constructed by applying an age:height key to the derived size composition; age is determined from the microgrowth (striae) patterns on the flat, upper shell valve (Dare, in press).

RESULTS

DREDGE EFFICIENCY

The observed relationships between dredge efficiency and scallop size are shown for each gear in Figure 1 (from Dare et al. 1993b). As expected, small mesh dredges were markedly more efficient than large mesh commercial gear at catching pre-recruit, especially <70 mm, juveniles.

However, the performance of the two gears converged with increasing scallop size and became similar at 80-85 mm, close to the minimum legal size.

Over the 45-85 mm size range, the two data sets are fitted by the log-linear regressions:

small mesh: $\log_{10}y = 0.0365\,x - 3.8661$ ($r = 0.8842$, 6df, $P<0.01$)
large mesh: $\log_{10}y = 0.0477\,x - 4.9724$ ($r = 0.9829$, 6df, $P<0.01$)

where x = shell height (mm)
y = efficiency E, expressed as logit E/(100-E)

Results for 85-105 mm scallops captured by commercial dredges are shown separately (Fig. 1). The eye-fitted curve suggests an asymptotic efficiency followed by a downward trend in efficiency with the largest size-groups - a feature also reported for this dredge design in a Scottish fishery (Chapman et al. 1977; Mason et al. 1979).

EFFICIENCY CONVERSION FACTORS

On the Cornish study area the range of ECF values thus derived from the conjunction of large and small mesh data is given by the following examples:

scallop size (mm)	25	45	83	95-100
ECF	909	167	7.5	3

APPLICATION OF ECFS TO CATCH DATA

To illustrate the conversion procedure, the original catch data from the July 1992 dredge survey of 25 stations are used. Figure 2 shows, for each gear type, the observed abundance of scallop size-classes expressed as numbers caught per 100 m^2 of seabed swept by the dredges, i.e. a measure of catch per unit of effort (CPUE). As usual in our surveys, commercial dredges caught virtually no scallops smaller than 75 mm whereas small mesh gear sampled the population down to 29 mm. The smallest scallop ever caught here during our summer surveys measured 19 mm.

The 'reconstituted' or predicted scallop population size composition and density are given in Figure 3, and its age structure in Figure 4. The very low abundance (1.3 per 100 m^2) of fishable scallops, four to eight years old, was the residue from heavy fishing activity two to three years earlier. The pre-recruit sector of this stock, mainly one to three year old juveniles, is estimated to have been nearly 30 times as numerous (36.7 per 100 m^2) as the fishable scallops. Most were one year olds, with two plus three year olds being about eight times as abundant as the fishable component.

The absence of very small (<29 mm) scallops reflects a natural gap in the size composition in midsummer as well as the inefficiency of even small meshes at these sizes. In July, spat from the current year's spawning (still in progress) would be less than 5 mm while the smallest individuals from the previous year-class have grown to 20-25 mm (MAFF, unpublished data).

By combining transformed catch data from successive July surveys, the year-class strength, survival and overall population trends can be followed (Fig. 4). Results for 1984-89 are still to be added to those shown for 1990-92.

DISCUSSION AND CONCLUSIONS

This exploratory application of dredge efficiency conversion factors to survey vessel catch data has provided, for the first time, an indication of the likely structure of the scallop population in a British fishery. The procedure is laborious, especially as it requires *in situ* experimental measurements of gear efficiency and this is markedly substrate dependent (Dare et al. 1993a). Use of the same survey vessel, and a standard dredging protocol, are also advisable.

The 'reconstituted' population structures are in broad accord with theoretical expectations although the very low gear efficiency and correspondingly high ECF values for very small scallops may mean that the relative abundances of one:two year olds can be estimated less confidently than those of older scallops. Nevertheless, for fishery management purposes, the ability to obtain more realistic estimates of pre-recruit (two plus three year old) abundance relative to fishable stock is considered to be a major improvement in stock assessment techniques for *P. maximus*.

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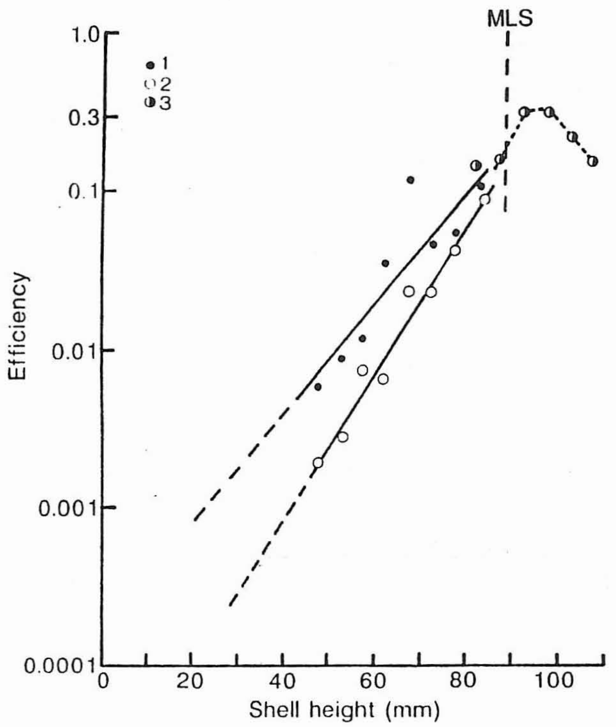

Fig. 1. The relationship between dredge efficiency (E) and size of *Pecten maximus* for large mesh commercial dredges (2,3) and for small mesh research dredges (1) working sandy-fine gravel grounds in the Cornish fishery. (The dashed curve is fitted by eye; MLS = minimum legal size.)

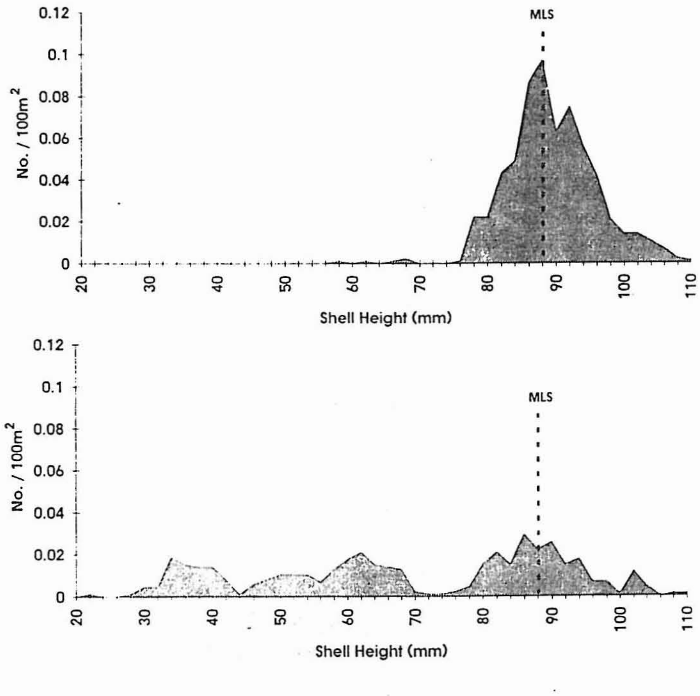

Fig. 2. Observed catch size compositions of *Pecten maximus* taken by large mesh dredges (above) and by small mesh dredges (below) on the Cornish survey area in July 1992. Relative abundances are expressed as numbers of scallops captured per 100 m^2 of seabed sampled (mean of 25 stations). (MLS = minimum legal size.)

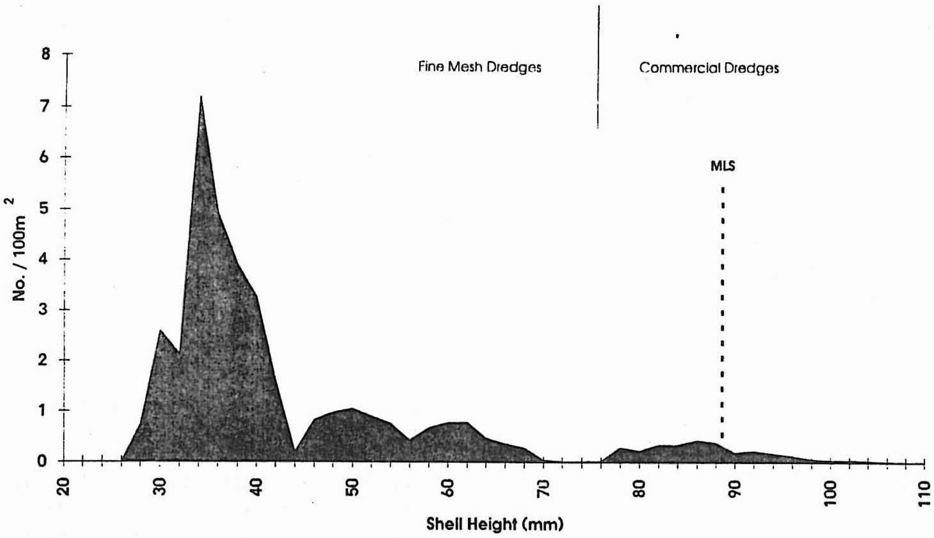

Fig. 3. The estimated population density and size structure of *Pecten maximus* stock, for ages one year and older, obtained by applying efficiency conversion factors to the catch data of Figure 2. (MLS = minimum legal size.)

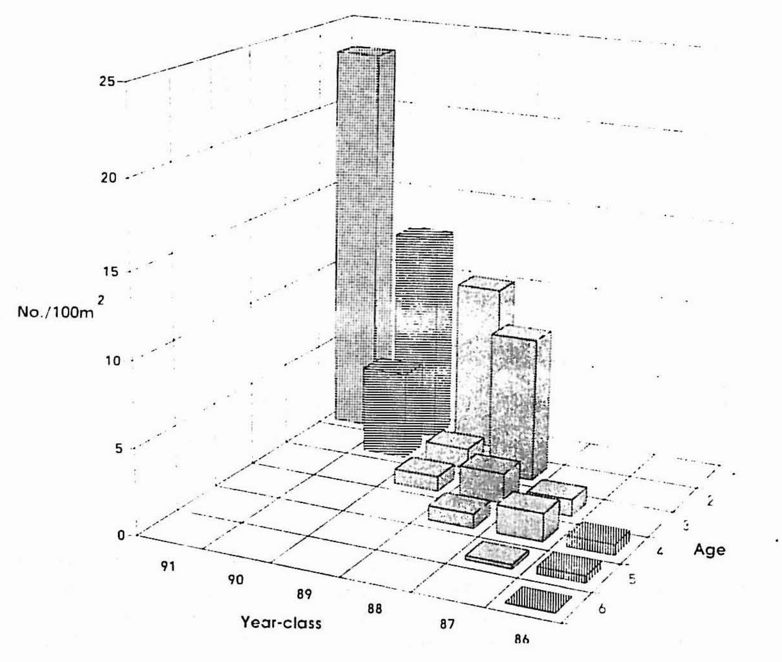

Fig. 4. Trends in the population age structure and density of *Pecten maximus* on the Cornish survey area over three successive summers, July 1990-92.

EMPIRICAL PREDICTIONS OF SCALLOP PRODUCTION: DEPENDENCE ON SAMPLING FREQUENCY OF OCEANOGRAPHIC PROCESSES

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ABSTRACT

By measuring a suite of oceanographic variables linked to scallop growth, predictions of stock production at a culture site can be calculated via empirical models. In addition to optimizing aquaculture management at established operations using estimates of carrying capacity, such models can be used to identify new areas where scallop culture should be successful. Empirical models can also reveal the predictive hierarchy of numerous environmental variables important to scallops, allowing the development of more general simulation models. Unfortunately, an examination of the literature indicates that truly predictive models of scallop growth are rare, a possible consequence of inadequate environmental sampling. Alternatively, the low predictive power may indicate that variables most important to scallop growth and survival are not being measured. By comparing empirical growth models based on high-frequency oceanographic probe data with those based on traditional sampling protocols, our objective was to resolve current discrepancies in scallop growth prediction. For one year, the effect of environmental sampling frequency on predictions of sea scallop, *Placopecten magellanicus*, production was evaluated by measuring monthly growth in conjunction with the monitoring of oceanographic variables at two frequencies. Temperature, salinity, current velocity and the concentrations of chlorophyll and total seston were measured every two weeks using direct water sampling, and hourly using *in situ* instruments (e.g. fluorometers, transmissometers and optical backscatter sensors). The study was conducted at a sheltered, muddy site and at a more exposed sandy site (both ≈6-8 m depth) in Lunenburg Bay, Nova Scotia. Scallops (≈30 mm initial shell height) were earhung on ropes attached within 2 m^2 frames constructed of PVC pipe. Each frame was suspended horizontally at 100 cm above the bottom, allowing several hundred scallops to be grown within a narrow depth range corresponding to the depth of oceanographic probes. In addition to measuring the shell height of 30 tagged scallops on each frame every month, five of the remaining scallops from each frame were subsampled for soft-tissue analysis. Regressions of shell height and soft-tissue indices allowed the estimation of monthly soft-tissue growth of the tagged scallops. Shell height generally increased from 30 mm in spring to approximately 80 mm one year later, confirming that cultured *P. magellanicus* grows at least twice as fast as natural offshore populations. Although soft-tissue growth trajectories indicated similar site-specific growth during most of the year, over-winter growth of muscle and other soft tissues at the ice-covered, muddy site was higher than at the sandy site. During the spring, however, scallops at the sandy site were able to convert the food supply from the spring phytoplankton bloom into tissue more rapidly than scallops at the other site, resulting in similar final tissue weights at each site. Site-specific growth differences were also apparent at other times, primarily when temperature or seston quality/quantity were different between sites. In early summer, enhanced growth was observed at the sandy site even though the muddy site exhibited warmer water temperatures, higher chlorophyll concentrations and higher levels of suspended particulate matter (SPM). During the fall phytoplankton bloom, chlorophyll and SPM concentrations were higher at the sandy site, yet scallop growth was higher at the other site. These and other observations of relatively low growth in high particle concentrations suggest that in Lunenburg Bay, scallops are not always food-limited and that high concentrations of SPM inhibit growth by reducing filtration efficiency or by dilution of SPM quality with inorganic matter.

Despite an intense effort to monitor those environmental factors thought to be responsible for changes in growth and survival, empirical models derived from stepwise linear regressions accounted for only 10-60% of the variation in scallop growth. For almost all site- and tissue-specific regressions, water temperature was the dominant predictor variable, with chlorophyll and SPM concentrations only marginally increasing the predictive power. In all cases, models constructed using high-frequency data from *in situ* instruments performed less favourably than those constructed from biweekly water sampling. Typically, the coefficients of determination estimated using the low-frequency models were twice those of the instrument models, a possible result of two factors. First, remote sampling with optical probes cannot resolve seston quality since variables such as total organic content and percentage carbon/nitrogen of the seston can only be estimated by filtering water samples. Second, the most relevant predictor variable may not be easily distilled from a lengthy data set produced from hourly measurements. Calculation of the mean SPM or chlorophyll concentration over a particular growth period is relatively accurate with this large data set, but a mean may not be the most relevant statistic to relate to growth. Chlorophyll data during periods of high current speed or high particle loading may be useless if scallops cannot feed efficiently at these times. By weighting food flux data based on other environmental variables, it may be possible to obtain an improved predictor estimate. At present, flume studies examining the feeding dynamics of scallops at different current velocities and particle loads are being conducted to determine the optimal weighting function to apply to field data.

GROWTH, RECRUITMENT AND MORTALITY OF THE PACIFIC CALICO SCALLOP, *ARGOPECTEN CIRCULARIS* (SOWERBY, 1835), IN BAHIA MAGDALENA, B.C.S., MEXICO

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ABSTRACT

Growth, recruitment and mortality were investigated in the Pacific calico scallop, *Argopecten circularis* (Sowerby, 1835), from Bahía Magdalena, Baja California Sur, México. Allometric relationships were defined by comparing different shell dimensions, body weight proportions, and total weight. Estimates of von Bertalanffy growth parameters were L_∞ = 81.19 mm shell height and K = 1.85 per year, with an approximate longevity of two years. Recruitment pattern suggested two settlement periods per year, with the greatest percentages occurring in May and July. The total mortality was Z = 5.11 in the bay. Some reasons for these variations and their implications are discussed.

INTRODUCTION

Traditional stock assessment methods work with age composition data. In temperate Pectinid species, such data are usually obtained through the counting of external growth rings recorded on shells. These marks are assumed to be registered annually, resulting from strong seasonal fluctuations in environmental conditions (Caddy, 1989).

In tropical areas, such drastic changes do not occur. It is very difficult, if not impossible, to use these kind of seasonal rings for age determination (Oberling 1964). Methods have been developed to use much finer structures, the so-called daily rings, but require special expensive equipment and much time, so they are not commonly used.

Fortunately, several numerical methods have been developed which allow the conversion of length frequency data into age composition. Such methods do not require the reading of rings on shells, and can also be used as a way of validation for age determinations made independently.

Growth, recruitment, and mortality patterns of tropical scallop stocks are not well understood. The aim of this work is to provide information of such population characteristics using a recently developed length-based method, the complete ELEFAN (Gayanilo et al. 1988). A comparison of growth parameters estimated by three different methods (including ELEFAN) is also done.

MATERIALS AND METHODS

Scallops were collected from the beds located in the central area of Bahía Magdalena (Fig. 1) at depths ranging from 4 to 20 m. Samples were taken by scuba diving or commercial divers and collected monthly in Bahía Magdalena from February 1989 to May 1991. The scallops sampled ranged from 45 to 82.9 mm. From each sample, the height of 50 to 55 scallops was measured to the nearest mm.

Growth parameters were estimated using the following methods:

1. the Complete ELEFAN Program, version 1.10 (Gayanilo et al. 1988), applied to the monthly composition of the population by sizes;
2. the Ford-Walford plot (Sparre et al. 1989);
3. the López-Veiga method (Ehrhardt, 1981), which estimates parameters with three age-lengths corresponding to the initial age (spat), the average age, and the age at maturity, using the same time interval between each sequential pair.

The three methods used assume that growth follows the von Bertalanffy (1938) expression:

$$L_t = L_\infty \; [1-e^{-k(t-t_0)}]$$

where L_t = length at age t,
L_∞ = maximum asymptotic length,
K = growth curvature parameter, and
t_o = the hypothetical age at size zero (years).

As a criterion with which to compare different growth parameter estimates, the standard growth index Þ' (phi prime: Pauly and Munro, 1984; Vakily, 1990) was employed as a measure of overall growth performance (Sparre et al., 1989). This index is defined as:

$$Þ' = 2 \log (L_\infty) + \log K$$

Total mortality (Z) was obtained by a length-converted catch curve estimated by the empirical relationship derived by Pauly (1987). The recruitment pattern was obtained with the estimated growth parameters by projecting the length-frequency data backward onto the time axis. This calculation was done through the routine contained in ELEFAN II program (Gayanilo et al. 1988). Normal distribution patterns in recruitment were identified according to Soriano's method.

RESULTS

A von Bertalanffy growth curve was fitted (Fig. 2) and the estimated parameters were L_∞ = 71.63, K = 1.40 per year and t_o = -0.5192. The equation obtained was:

$$L_t = 71.63 \; [1 - e^{-1.40(t+0.5192)}]$$

Using the López-Veiga method and the average shell height of monthly samples, the following values observed were used as estimates: L_o = 0.3 mm, L_{t1} = 59.15 mm and L_{t2} = 71.87 mm. A von Bertalanffy growth curve was fitted (Fig. 2) and the estimated parameters were L_∞ = 75.37 mm, K = 2.29 annual and t_o = -0.0017. The equation obtained was:

$$L_t = 75.37 \; [1 - e^{-2.29(t+0.0017)}]$$

The best fitting growth curve estimated by ELEFAN I (Fig. 2) had the parameters: L_∞=81.19 mm and K = 1.85 per year (Fig. 3). The estimate of the asymptotic size was 82 mm.

$$L_t = 81.19 \; [1 - e^{-1.85(t+0.0002)}]$$

Table 1 shows the values obtained used to select the best combination of K and L_∞ values resulting from the population data.

Values of Þ' obtained by all methods were similar. These values were: Þ'=3.85 (Ford-Walford; Beverton and Holt), Þ'=4.11 (López-Veiga) and Þ'=4.08 (ELEFAN I).

Maximum longevity of the species was approximately two years. Catch curve analysis was used to derive total mortality (Z), which was estimated to be 5.11 (Fig. 4).

Recruitment occurred throughout the year, showing a bimodal pattern, with one major pulse in May and a minor pulse in July (Fig. 5).

DISCUSSION

There is little information about growth rates of a natural scallop population (Baqueiro et al. 1981) and only some known in artificial culture situations (Tripp-Quezada 1985; Hernández-Llamas 1989).

The growth parameters for *A. circularis* estimated by ELEFAN I (L_∞ = 81.19 mm, K = 1.85 per year), by the Ford-Walford plot (L_∞ = 71.63, K = 1.40 per year), and by the López-Veiga expression (L_∞ = 75.37, K = 2.29 per year) are generally similar, considering the mathematical model behind the von Bertalanffy equation implies that lower values of L_∞ are always associated with higher values of K and conversely (Pauly and Munro 1984; Vakily 1990).

Using the different estimates obtained by the three methods applied here, ELEFAN I gave very similar values of Þ' (phi prime). The values of Þ' were estimated using values of L_∞ and K of 81.5 mm and 1.85 (per year). These values were used as standards to compare the Þ' values derived from ELEFAN I, Ford-Walford, Beverton and Holt method (Þ'= 3.85), and the López-Veiga formula (Þ'= 4.11).

Several authors applied different length-based methods with algorithms using similar assumptions about growth patterns. The parameters of the von Bertalanffy growth equation were estimated, mainly from size-frequency data, for three experimental areas under culture conditions in Bahía Magdalena. Tripp-Quezada (1985) reported growth parameters during an 11 month size increase expressed as: K value was 5.99 per year, using size compositions between 5 to 45 mm. Suspension culture of the scallop was carried out at Ensenada de La Paz. Hernández-Llamas (1989) reported growth parameters during a 12 month size increase expressed as: K values ranged from 3.67 to 6.35 per year, using size compositions between 10 to 50 mm.

The different estimates mentioned above showed the culture trials to be density-dependent. Similar growth curves (see Fig. 2) were estimated for Bahía Magdalena.

According to their estimates, lower values of L_∞ are always associated with higher values of K (Pauly and Munro 1984; Urban 1991). Pectinids can be partitioned in groups according to their life patterns: for large-sized (80-248 mm), relatively long-lived (>12 years) species, including *Pecten* spp. and *Patinopecten* spp., values of L_∞ are higher and K are lower (0.09-0.72 per year); for medium-sized (60-100 mm) species with maximum life span usually less than 10 years, including *Chlamys* spp., L_∞ is lower and K is higher (0.50-2.10 per year); for small-sized (45-80 mm) species, specimens older than 2 years are rare and include *Argopecten* spp., which also have high values of the K (0.70-2.10 per year) and low L_∞ (Orensanz et al. 1991).

The semi-tropical scallop *Amusium pleuronectes* has a medium-sized shell, attaining about 80 mm length. This species occurs in the Philippines. Del Norte's (1991) use of the von Bertalanffy-based ELEFAN I program yielded estimates of growth parameters equivalent to L_∞ = 106 mm shell height and K = 0.92 per year, with an approximate life for the species of 2 years like the life span of *A. circularis*.

The estimate of annual mortality rates (Z) from Bahía Magdalena was 5.11 (Fig. 4). Estimates of Pacific calico scallop mortality from the literature are scarce. Del Norte (1991) estimated total mortality (Z) for the Philippine scallop population. With the ELEFAN II program, the values obtained ranged from 7.2 to 4.8. The method for the estimation of mortality (Z) has been criticized, because it has tended to overestimate Z when growth is seasonal (Pauly 1990).

Recruitment of *A. circularis* is reported to be quite variable between years and areas (Baqueiro et al. 1981) and the evidence from the Bahía Magdalena sampling supports this. Recruitment at Bahía Magdalena appeared to occur annually, from at least 1989 through 1991, with a bimodal pattern. A similar recruitment pattern is shown by *Amusium pleuronectes* studied in Philippines, consisting of one major pulse and one minor pulse (del Norte 1991). The calico scallop, *Argopecten gibbus*, exhibits two spawning periods each year, occurring only when environmental conditions are optimal and not every year. However, the fall spawning appears to be important to the maintenance of the commercial stocks into the spring and summer months (Moyer and Blake 1986).

For *Argopecten circularis*, the recruitment pattern is correlated with the bottom water temperature of Bahía Magdalena. Recruitment intensity during the year of typical tropical stocks shows a pattern with two peaks in May and July (Fig. 5).

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Table 1. Growth Parameters obtained by the application of ELEFAN in Bahía Magdalena (ind. > 45 mm). Values of the growth index Þ' and mortality coefficient.

Parameters from 1989-1991	
Growth	
K (per year)	1.85
L_{∞} (mm)	81.19
t_o	-0.002
C	0.9
WP	0.3 (April)
Rn	0.18
Standard growth index	
	4.0861
Total mortality	
Z	5.11

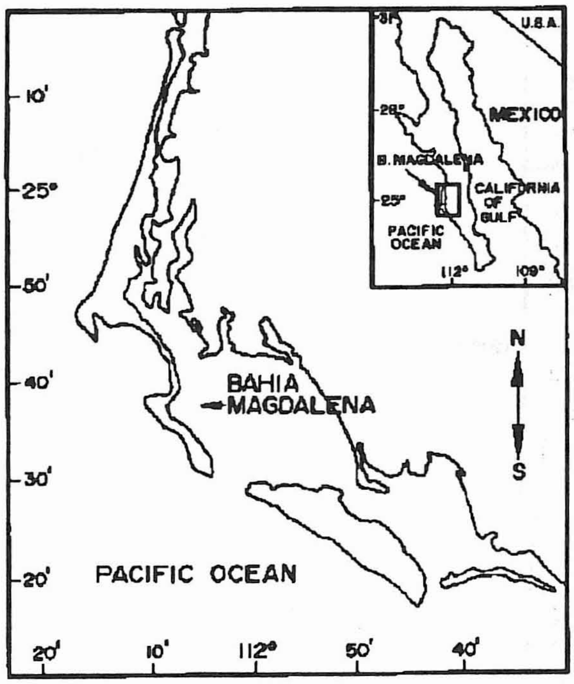

Fig. 1. Location of the scallop study grounds in Bahía Magdalena, B.C.S., Mexico.

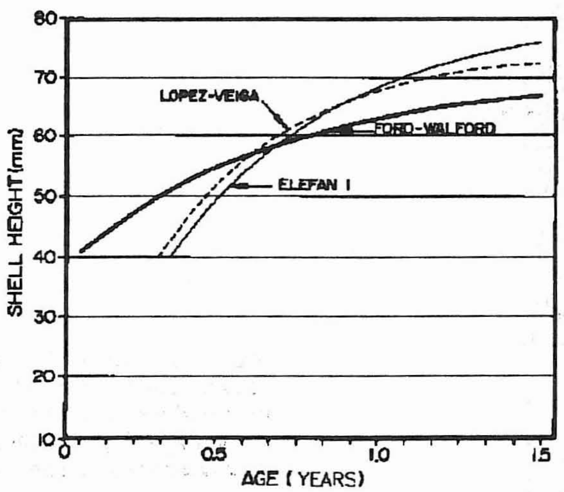

Fig. 2. Growth curves of *Argopecten circularis* for stocks in Bahía Magdalena. Ford-Walford, López-Veiga and ELEFAN I.

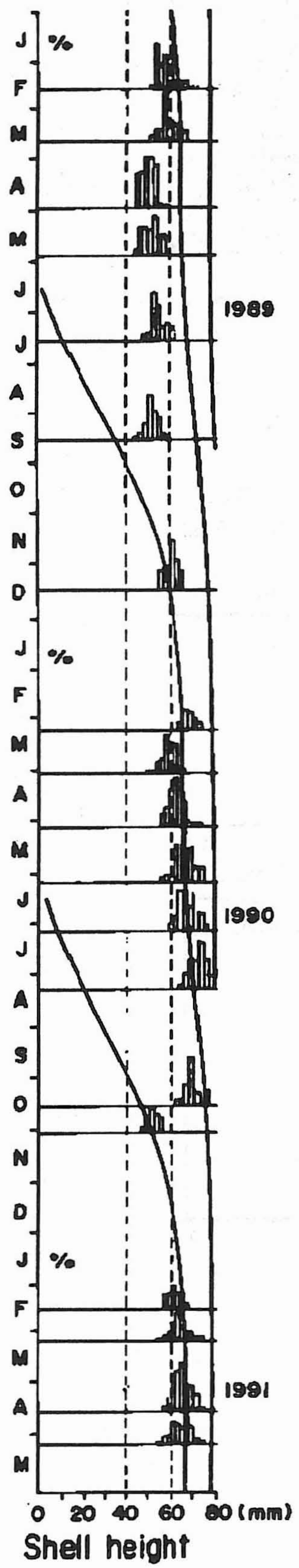

Fig. 3. Monthly length frequency distributions of *Argopecten circularis* with growth curves estimated by ELEFAN in Bahía Magdalena, from 1989 to 1991.

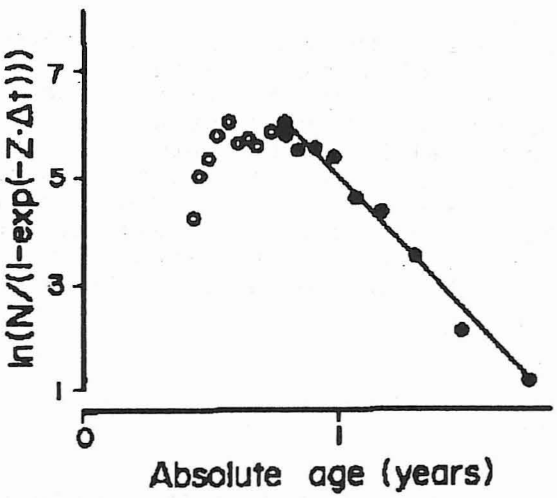

Fig. 4. Length-converted catch curves for Bahía Magdalena, from 1989 to 1991.

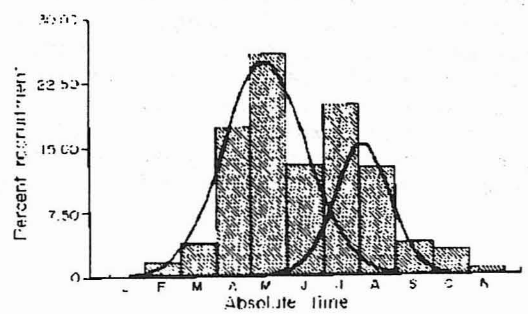

Fig. 5. Recruitment pattern in Bahía Magdalena, from 1989 to 1991.

SEASONAL CHANGES IN SOMATIC AND REPRODUCTIVE TISSUE WEIGHTS IN WILD POPULATIONS OF *PLACOPECTEN MAGELLANICUS* IN THE BAY OF FUNDY, CANADA

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ABSTRACT

A 22-month study on seasonal changes in sea scallop somatic and reproductive tissue weights was carried out on a commercial scallop bed in the Bay of Fundy, Canada. Over this time-frame a strong seasonal pattern was observed in both the weight of the adductor muscle and gonad for a standardized shell height. Gonad weight increased from April through to September, when spawning occurred. After spawning there was a 30-40% increase in adductor muscle wet weight. These patterns are modeled using sine curves. The adductor muscle is the only part of the sea scallop from the Bay of Fundy which is sold commercially. Such pronounced changes in meat weight have obvious implication to yield optimization and the application of fisheries models to the management of this species.

INTRODUCTION

The inshore scallop fishery in the Maritime Provinces, Canada, is a competitive fishery which exploits a number of contiguous beds in the Bay of Fundy (Kenchington and Lundy 1993). Historically, commercial catches have been variable, however recent landings have been well over 2000 t of adductor muscle or "meats" per annum (Fig. 1). Fluctuations in yearly landings reflect a lack of consistent recruitment on the larger beds located on the easterly shores of the Bay (e.g. Kenchington and Lundy 1992).

One means of maximizing income in years when fishable biomass is low is to harvest the scallops at a time of the year when the meats are in their best condition (Connor 1978). Thompson (1977), Jamieson (1979), Robinson et al. (1981), Serchuk (1983), Gould (1983) and MacDonald and Thompson (1986) have all reported marked seasonal variation in adductor muscle weight in various populations of *Placopecten*. The weight of the adductor muscle is related to the annual cycle of gametogenesis and spawning (e.g. Robinson et al. 1981). During gametogenesis (January - August) the muscle provides an energy source for gonad development (Ansell 1974; Faveris and Lubet 1991). During this period the weight of the adductor muscle decreases. The extent of this weight change and the post-spawning recovery period has not been documented on the commercial beds in the Bay of Fundy.

As part of an ongoing program at the Department of Fisheries and Oceans, Canada, aimed at maximizing the economic yield from the Bay of Fundy scallop resource, seasonal variation in somatic and reproductive tissues was studied over a 22-month period on a commercial scallop bed off Digby, Nova Scotia.

MATERIALS AND METHODS

The most persistent of the larger inshore scallop beds is the scallop bed off Digby, Nova Scotia (Fig. 2). This bed is divided into two zones, an "inside" zone which is closed to fishing from May to October, and the rest, referred to here as an "outside" zone, which incorporates the remainder of the bed and which is fished year-round. Large numbers of scallops occur on this bed at depths of approximately 60 to 100 m.

Scallop samples were collected aboard the *Brannetelle*, a commercial 54' Digby scallop dragger owned and operated by Vance Hazelton, Hazelton Fisheries Ltd., Digby. The expenses associated with the vessel were donated to the project by Mr. Hazelton. Four random locations were determined for each of the zones prior to sampling. Seventy-two scallops were randomly collected from each tow. The wet weight of the adductor muscle, gonad and soft parts (mantle and other organs) were recorded to 0.00 g. Sampling dates are given in Table 1. All weights in each tow were standardized to a 115 mm shell height using regressions calculated for each tow.

RESULTS

Seasonal changes in the adductor muscle and gonad weights for each zone were described by sine curves (Table 2). The annual cycle observed in the adductor muscle was almost perfectly out of phase with that of the gonad (Fig. 3a,b). As the gonad weight increased, adductor weight decreased. Only two periods of the sine curve were sampled. During the first year for the inside fishing zone there was a 33% increase (8.4 g) in adductor muscle weight calculated between the June and November collections. During the second year an 18% decrease was noted between the June and August samples. Spawning took place in late August and by late September adductor muscle weight had increased 27%. By November of 1992 the muscle had increased a further 12% in weight. Thus the overall post-spawning increase in adductor muscle weight was at least 33% in 1991 and 39% in 1992.

Conversely, the wet weights of the soft parts did not change significantly through the annual gametogenesis cycle. Linear models with non-significant slopes best described these data sets.

DISCUSSION

The annual cycle of weight changes in the gonad and adductor muscle can be modeled by sine curves. These curves are not to be construed as a mechanistic explanation of a biological phenomenon, at least with respect to the gonad. Although spawning may be an intermittent process in any one individual, Bay of Fundy populations generally have only one main spawning period (Parsons et al. 1992). After spawning the gonads will be empty and their weight will decline abruptly. The sine curve cannot reflect this change. However, as a means of modelling gonad weight change over several years, the sine curve can be an effective model. As the time of spawning shifts between years, and is protracted in some years (e.g. Faveris and Lubet 1991), the sine curve becomes a useful model in predicting weight changes. Such models have particular application to calculations of catch-at-age in this species. Age is determined from the commercial catch, which is landed as shucked meats, by regressions of meat weight against shell height, and age against shell height based on research samples. This study has dramatically confirmed the report of Serchuk (1983) on the relationship of meat weight at shell height. Seasonal variability in scallop meat weight at shell height must be considered in calculations of catch-at-age or in determining yield or meat count measures.

Weight increase in the adductor muscle would appear to be a rapid process, with a 27% increase noted one month post-spawning. The 33-39% increase in adductor muscle weight after spawning, observed for different sized animals at different depths, is greater than the yearly growth increment of animals greater than five years of age (Table 3), and is consistent with changes observed from shallow waters in the Gulf of Maine (Robinson et al. 1981), Newfoundland (Thompson 1977) and the Northumberland Strait (Jamieson 1979). Meat yield from this resource could be optimized by fishing scallops in the post-spawning period from late September through to January. In the case of older animals yield could be increased by 25% over the annual growth increment. The fishing season associated with the Inside Zone off Digby was recommended by the fishermen to provide fishing grounds close to port which could be safely exploited in the winter months. Coincidentally the fishing season in this zone (October 1 - May 31) will ensure that meat yield per scallop is maximized, especially during the first half of the season.

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Table 1. Sample dates, raw and standardized (115 mm shell height) mean adductor muscle weights, (± s.d.) for the Inside and Outside Scallop Fishing Zones off Digby, Nova Scotia, Canada.

Date	Zone	Mean adductor weight (g)		Standard Deviation	n
		Standardized	Actual		
Apr 9, 1991	Inside	22.88	22.77	5.28	215
	Outside	19.65	17.06	4.59	288
May 6,1991	Inside	23.76	25.86	5.77	288
	Outside	19.17	16.57	3.96	288
Jun 19, 1991	Inside	21.76	23.92	5.84	283
	Outside	18.61	15.66	3.96	288
Nov 7, 1991	Inside	28.93	33.57	6.84	288
	Outside	24.30	23.04	4.92	271
Mar 31, 1992	Inside	24.52	29.97	5.53	264
	Outside	20.41	20.23	4.80	197
May 4, 1992	Inside	24.93	30.68	6.48	269
	Outside	19.78	20.18	4.96	288
Jun 6, 1992	Inside	22.19	28.23	7.43	278
	Outside	17.80	15.75	6.13	288
Aug 11, 1992	Inside	18.24	22.42	7.37	288
	Outside	16.22	13.30	6.96	288
Sep 21, 1992	Inside	23.11	27.37	8.56	288
	Outside	21.36	19.28	7.13	288
Nov 10, 1992	Inside	25.38	32.27	9.94	264
	Outside	21.85	20.42	7.55	264
Jan 7, 1993	Inside	24.25	30.58	10.40	284
	Outside	22.15	18.90	8.42	288

Table 2. Fitted sine curves calculated from the mean wet weights obtained from 11 *Placopecten* samples (n = 72) collected over a 22-month period from each of two fishing zones in the Bay of Fundy. Y is the tissue weight, x is the sampling date in days from the first of January, 1991. All correlations are significant at $\alpha = 0.05$.

TISSUE	ZONE	FITTED SINE CURVE	CORRELATION (r^2)
Adductor muscle	Inside	Y = 24.0 + 2.8 Sine (x + 1.4)	0.45
	Outside	Y = 20.6 + 2.8 Sine (x + 1.7)	0.71
Gonad	Inside	Y = 6.7 - 6.3 Sine (x + 1.4)	0.78
	Outside	Y = 5.6 + 5.1 Sine (x - 1.7)	0.74

Table 3. Annual wet weight growth increments of the adductor muscle of *Placopecten magellanicus*. Calculated from data presented in Kenchington and Lundy (1992).

Age (yr)	Adductor wet weight (g)	Weight after 1 yr (June to June)	Weight increase (g)	% Increase
2	0.68	2.28	1.60	235.29
3	2.28	4.69	2.41	105.70
4	4.69	7.57	2.88	61.40
5	7.57	10.62	3.05	40.29
6	10.62	13.60	2.98	28.06
7	13.60	16.37	2.77	20.37
8	16.37	18.85	2.48	15.15

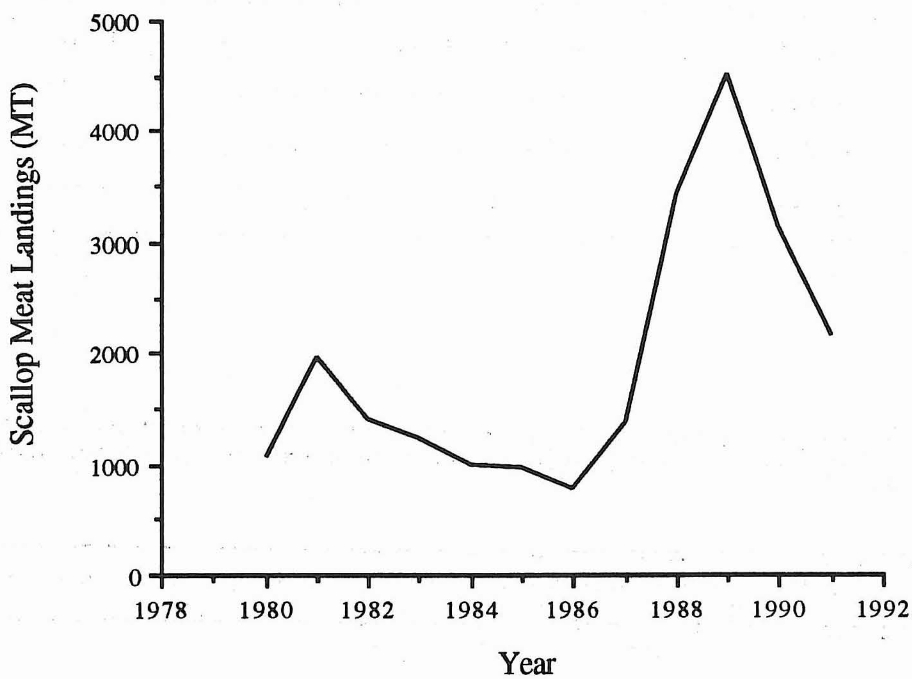

Fig. 1. Scallop meat landings (t) fished in the Bay of Fundy above latitude 43°40′ from 1980 to 1992.

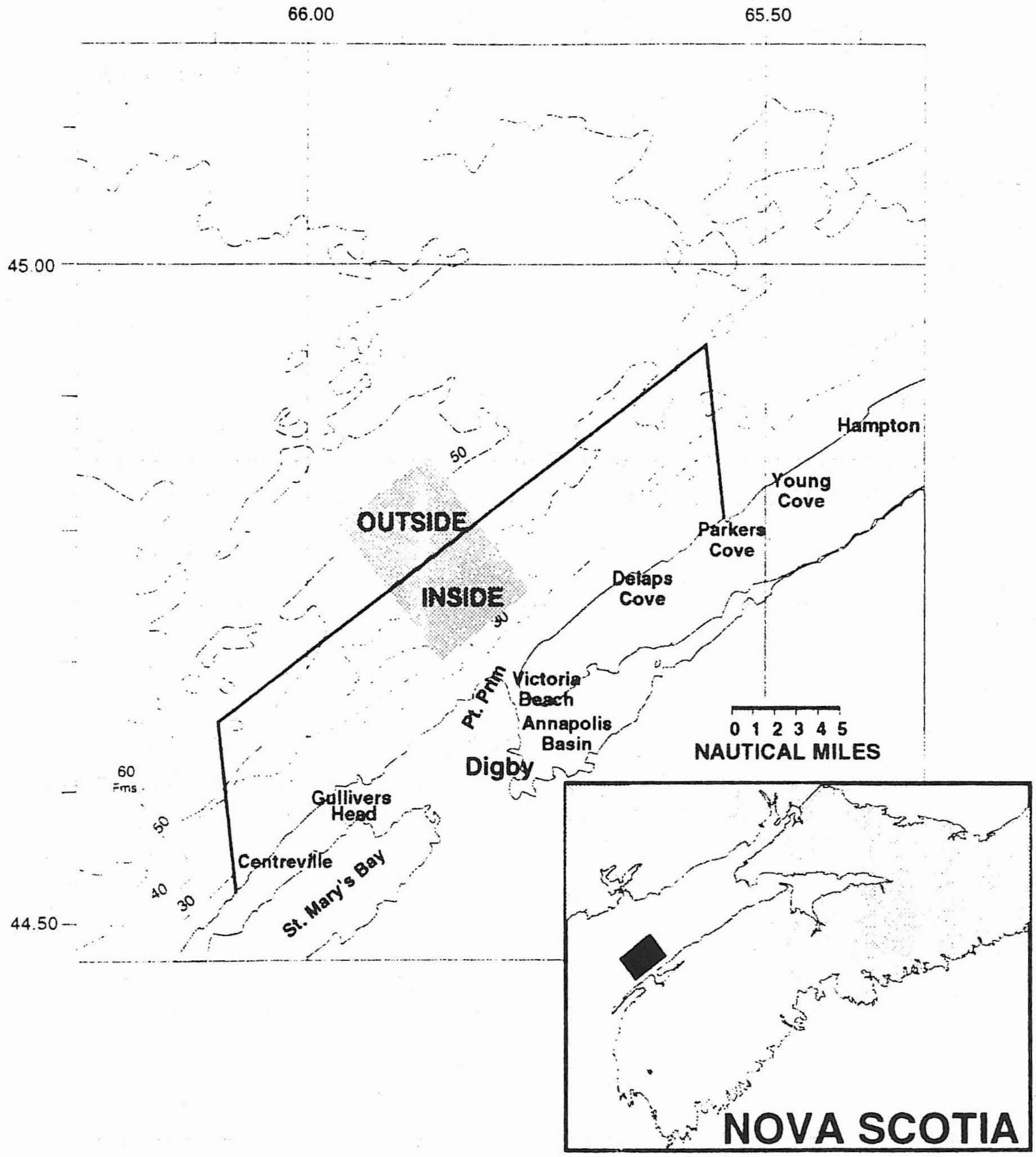

Fig. 2. Study area in the Bay of Fundy showing the 'inside' fishing zone.

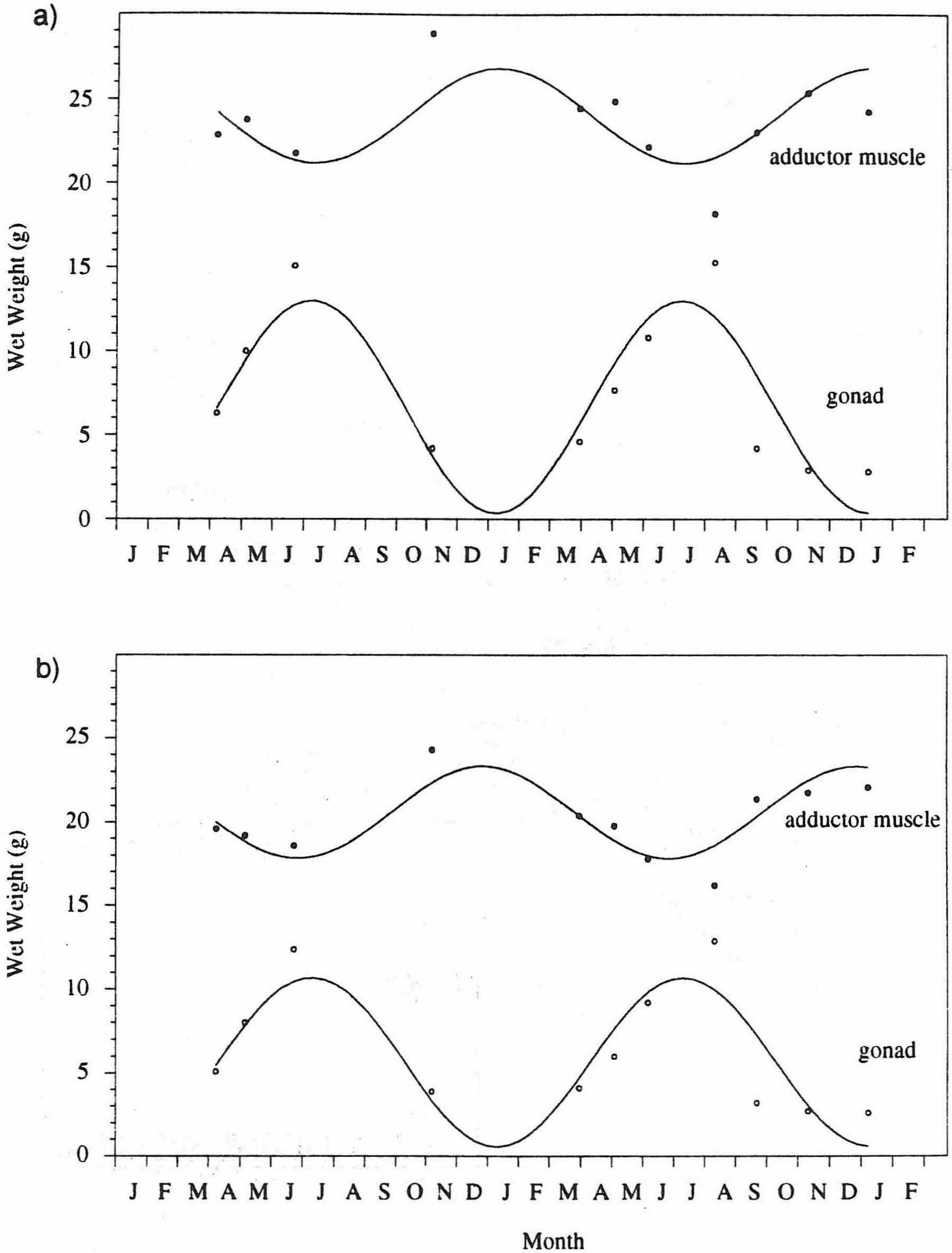

Fig. 3. Mean wet weights of *Placopecten* adductor muscle and gonad of a standardized-size (115 mm) scallop with fitted sine curves (see Table 2) calculated separately for the a) 'inside' fishing zone and b) the 'outside' fishing zone (Fig. 2).

TECHNICAL EFFICIENCY, BIOLOGICAL CONSIDERATIONS, AND MANAGEMENT AND REGULATION OF THE SEA SCALLOP, *PLACOPECTEN MAGELLANICUS*, FISHERY

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ABSTRACT

Achieving social and economic efficiency in a fishery requires that production be technically efficient. Yet, technical efficiency is rarely examined for a fishery. Utilizing detailed trip-level data and information about resource conditions obtained from routine sampling, a translog stochastic frontier production or catch-effort model is specified and estimated for a panel data set reflecting production activities for ten Mid-Atlantic sea scallop, *Placopecten magellanicus*, dredge vessels. Results obtained from statistical estimates are shown to contain considerable information about technical efficiency. Technical efficiency is shown to depend upon the mix of controllable inputs such as days at sea and crew size and uncontrollable factors such as resource conditions, individual product yields, and food availability. Last, we illustrate that two regulations currently under consideration by the management authorities should increase technical efficiency in the U.S. sea scallop fishery.

INTRODUCTION

Fisheries management primarily focuses on efficient resource utilization and conservation. Efficient resource utilization, however, requires that production be technically efficient or consistent with the best-practice frontier (Fare et al. 1985). Alternatively, production must be maximized given input levels and the technology. Achieving technical efficiency (TE) in fisheries, unfortunately, may be difficult because of varying resource and environmental conditions. These are non-marketable inputs for which services cannot be acquired by vessel captains in the market place. In addition, achieving technical efficiency may be complicated by inadequate information about the parameters that define and influence technical efficiency.

Studies on technical efficiency (TE) in fisheries have been limited (Comitini and Huang 1967; Hannessen 1983; Hilborn 1985). TE has most often been defined in terms of catch per unit effort or average product or by a technical efficiency parameter as in Strand et al. (1981). Alternatively, TE has been defined in terms of the proportion of fish that could be harvested by a particular type of gear (e.g. a catch of 25 out of 100 possible fish would yield an efficiency estimate of 25%). This latter type of efficiency measure is a partial measure in that it only reflects the potential efficiency of the gear; it does not indicate the potential efficiency of the producing unit. All of these approaches impose a deterministic framework; they do not accommodate noise, measurement error, or random shocks beyond the control of the production unit.

In this paper, we illustrate a stochastic approach for estimating and examining technical efficiency (TE) in a fishery. Using a panel data set reflecting production activities for a sample of sea scallop dredge vessels operating in the Mid-Atlantic, a stochastic translog production function is estimated. Following Green (1980) and Jondrow et al. (1982), TE is estimated for each trip and vessel. Estimates of TE are subsequently summarized and examined relative to days at sea and crew size, stock abundance, meat yield, reproductive activities, and food availability. TE is further examined relative to an annual days at sea per vessel restriction and a crew size limit; these two regulations are currently being considered by the New England Fishery Management Council (NEFMC), the U.S. agency responsible for managing the fishery.

Results of the analyses indicate that excessive labour is one major factor contributing to inefficiency in the sea scallop fishery. This result is not
surprising given that the fishery is labour intensive. Technical efficiency (TE) is also found, however, to closely follow changes in meat yield which in turn closely follow changes in gonad weight and food abundance. Maximum TE is shown to occur immediately after the spring spawn while minimum efficiency occurs subsequent to the fall spawn. Technical efficiency is also found to be quite variable but predictable given information on biological factors or resource conditions. Finally, analyses indicate that limiting the days at sea per vessel per year and crew size will increase technical efficiency in the short-run.

MATERIALS AND METHODS

METHODS

Technical efficiency (TE) is a measure of the ability to produce the maximum output given the level of inputs and the technology. Efficiency is a relative concept in that the production performance of one producing unit is compared to the production performance of a best-practice input-output relationship; efficiency is measured in terms of the deviations of individual vessels from this best-practice frontier.

In contrast to the widely used deterministic frontier, we consider the best-practice frontier as stochastic with two error terms. One error term is assumed to be normally distributed with a mean of zero and a constant variance; this error term captures measurement error and random exogenous shocks beyond the control of the producing unit. Another error term which is one-sided may be introduced to represent technical inefficiency.

Following Aigner et al. (1976, 1977) and Meeusen and van den Broeck (1977a, b), the stochastic frontier production or catch-effort function may be written as follows:

$$Y_i = h(X_1, X_2, \ldots, X_N; A)u_i \qquad (1)$$

where $i = 1,\ldots,M$, Y_i is the output of the i^{th} vessel, X_j $(j = 1,\ldots,N)$ is the j^{th} of N inputs, A is a vector of parameters, and u_i equals the exponential value, ϵ, raised to power of the sum of two independent error terms, ϵ_{1i} and ϵ_{2i}.

The sum of the two independent error terms equals the disturbance term, ϵ_i. ϵ_1 is a symmetric normally distributed error term which allows for random variation of the production function across vessels and reflects statistical noise, measurement error, and exogenous shocks beyond the control of the producer. ϵ_2 is one-sided and non-negative and represents technical inefficiency relative to the stochastic frontier (Jondrow et al. 1982). ϵ_2 must be greater than or equal to zero. If $\epsilon_2 = 0$, production lies on the stochastic frontier and is technically efficient (TE = 1); if $\epsilon_2 > 0$, production lies below the frontier and is technically inefficient ($0 \le TE \le 1$). We follow convention and assume ϵ_2 has a half-normal distribution (Green 1992a; Jondrow et al. 1982).

The symmetric error, ϵ_1, is independently and identically distributed as $N(0,\sigma_{\epsilon1}^2)$. The non-negative error, ϵ_2, is distributed as the absolute value of the normal distribution, $|N(0,\sigma_{\epsilon2}^2)|$ (i.e. half-normal). The variance of ϵ equals the sum of the variances of ϵ_1 and ϵ_2. If the ratio of variances $\sigma_{\epsilon2}^2/\sigma_{\epsilon1}^2$ exceeds one in value, production is more likely to be dominated by technical inefficiency. The closer the ratio is to zero, differences between observed and frontier output are more likely associated with random factors.

Estimating TE of the individual firm (TE_i) requires estimation of the non-negative error term (ϵ_2) and decomposing the error ϵ_i into the individual components, ϵ_1 and ϵ_2. Jondrow et al. (1982) offer a decomposition method:

$$E[\epsilon_{2i}|\epsilon_i] = (\sigma_{\epsilon2}\sigma_{\epsilon1} / \sigma) [(f(\epsilon_i\delta/\sigma)/(1-F(\epsilon_i\delta/\sigma)) - (\epsilon_i\delta/\sigma)] \quad (2)$$

where f() and F() are the values of the standard normal density function and the standard normal distribution function estimated at $\epsilon_i\delta/\sigma$ and $\delta = \sigma_{\epsilon2}^2/\sigma_{\epsilon1}^2$. The expected value indicates the TE of firm i relative to the practices of the best fishing vessels; the closer TE_i lies to 1 (0), the closer (further) the TE of firm i lies to the best-practice frontier.

THE TRANSLOG STOCHASTIC PRODUCTION FRONTIER

The catch-effort relationship is specified by a translog stochastic production frontier:

$$\begin{aligned} \ln Y_{it} = {} & \alpha_0 + \alpha_1 \ln DA_{it} + \alpha_2 \ln L_{it} + \alpha_3 \ln S_{it} + \Sigma_{j=1,3} \beta_j D_j + \beta_4 DR \\ & + \tau_1 (\ln DA_{it})^2 + \tau_2 (\ln L_{it})^2 + \tau_3 (\ln S_{it})^2 + \tau_{12} \ln DA_{it} \ln L_{it} \\ & + \tau_{13} \ln DA_{it} \ln S_{it} + \tau_{14} \ln L_{it} \ln S_{it} + \Sigma_{k=2,12} \Gamma_k D_k \ln S_{it} \\ & + \Sigma_{k=2,12} \Theta_k D_k (\ln S_{it})^2 + \epsilon_{it} \end{aligned} \quad (3)$$

where i and t index individual scallop vessels and trips, respectively. The variables are landed scallop meat weight (Y_{it}) by the i^{th} vessel on the t^{th} fishing trip, days at sea per trip (DA_{it}), crew size (L_{it}), resource stock size (S_{it}), annual dummy variables for 1988 through 1990 (D_j), dummy variable for dredge size (DR = 1 for 13 foot dredge and zero otherwise), and dummy variables for the months of February through December (D_k). The parameters to be estimated are α_i (i = 0,...,3), β_j (j = 1,2,3), τ_k (k = 1,2,3), τ_{1l} (l = 1,2,3), Γ_m (m = 2,...,12), and Θ_m. The disturbance term, ϵ_{it}, is assumed to be comprised of a normally distributed error (ϵ_1) and a half-normal distributed error (ϵ_2).

DATA

Information on production activities and vessel performance were obtained for ten scallop dredge vessels operating in the Mid-Atlantic between 1987 and 1990. Settlement sheets or trip-level financial summaries provided detailed data on landings, days at sea, and crew size. All vessels were constructed between 1979 and 1987 and all were steel hulled. Vessel size ranged from 24.4 to 27.4 m. Three of the ten vessels had lower horsepower engines, and therefore, pulled smaller dredges (3.96 vs 4.57 m). All vessels had two radars, Loran C, and plotters. The ten vessels made 581 trips between January 1987 and December 1990.

Information on stock size was obtained from data regularly collected as part of a Virginia Institute of Marine Science sea scallop monitoring program (Schmitzer et al. 1991; Kirkley and DuPaul 1991). Stock abundance per vessel per trip was calculated in terms of the geometric mean of baskets of scallops caught per hour by approximately 36 vessels fishing the same area during the same period of time and using the same dredge size; baskets of scallops caught per hour were only for the last tow that a group of vessels regularly make for research purposes. Meat yields were calculated as the average weight of meats obtained from 90-94 mm shell height sea scallops. The gametogenic cycle was previously determined in DuPaul et al. (1989), Schmitzer et al. (1991), and Kirkley and DuPaul (1991). Food abundance or availability was measured by stomach weight of 90-94 mm scallops; however, stomach weight data were not temporally consistent with the data used to examine technical efficiency. Collection of stomach weight data only began in November of 1990.

RESULTS

Equation (3) was estimated by maximum likelihood procedures available in LIMDEP 6.0 (Green 1992b). Most of the parameters were statistically different than zero at the 5% level of significance; estimates are omitted from this paper but are available from the authors. For the purpose of assessing the estimated stochastic frontier model, the adjusted R^2 was calculated for the ordinary-least-squares regression ($R^2 = 0.845$).

The ratio, $\delta = \sigma_{\epsilon 2}/\sigma_{\epsilon 1}$ was 1.28 and statistically significant at the 1% level of significance (t-statistic was 8.98). Therefore, the discrepancy between observed and frontier output was dominated by technical inefficiency rather than by random factors beyond the control of the captains. This result suggests there is scope for expanding production and increasing TE.

DISCUSSION

Higher technical efficiency (TE) was associated with higher landings and days at sea per trip. Approximately 80% of the trips had TE coefficients between 0.70 and 0.90. In general, minimum or least efficient production was associated with vessels having trips less than 14 days and very low crew sizes (six to seven). Low efficiency appeared to be associated with low individual meat yields and low resource levels.

A consistent linear association between efficiency, input levels, and resource conditions was not evident from the analysis. Neither Pearson nor Spearman Rank correlation coefficients indicated a linear relationship. The lack of a consistent pattern suggests that captain's skill and unknown biological and environmental factors may be important determinants for explaining TE.

Crew size, however, may be a very important determinant of TE. Too much or too little labour could very well contribute to inefficient production. Utilizing information obtained from eight trips at sea between 1991 and 1992 in which the time it takes to shuck scallop meats over extended periods of time was recorded, crew sizes necessary to process 39.65 and 44.05 meats per 500 g of scallops were estimated and compared to observed crew sizes. These are common size scallops harvested at sea. Paired t-tests were used to assess whether or not observed crew size equalled minimum crew sizes required for shucking 39.65 and 44.05 meats per 500 g scallops and the average of the two.

The most efficient vessels had observed crew sizes equal to the average of crew sizes required to process 39.65 and 44.05 meats per 500 g scallops. Vessels with minimum efficiency had observed crew sizes equal to the crew sizes required to process 44.05 meats per 500 g scallops; thus, the less efficient vessels had surplus labour. Surplus labour may occur because of family ties and kinship relationships or an error by the captain in determining labour needs.

The most discernable pattern between efficiency, catch, days at sea, number of crew, and resource conditions was exhibited on a monthly basis. Average TE appeared to closely follow vessel performance and resource conditions (i.e. high stock abundance and high TE and low abundance and low efficiency). Maximum efficiency occurred in June, when scallops have just completed their spring spawn (Schmitzer et al. 1991). High technical efficiencies also occurred between March and May when scallops spawn and meat yields are high. Production was also found to be efficient in August when meat yields are high. Minimum TE occurred between October and January when meat yields and stock abundance are minimum and sea scallops spawn and begin gonadal development.

Equality of mean TE between months could not be examined by the usual analysis of variance (ANOVA) since TE had a half-normal distribution. Equality of mean TE between months was tested and rejected by Kruskal-Wallis tests (1987-1990: chi-square with 11 degrees of freedom equalled 36.87; 1987: chi-square with 11 degrees of freedom equalled 41.51; 1988: chi-square = 33.32; 1989: chi-square = 27.26; 1990: chi-square = 34.65). Pairwise Kruskal-Wallis tests of the equality of efficiency between months did not indicate a clear consistent pattern in TE. Significant differences were detected between May and September (chi-square = 25.3), May and December (chi-square = 10.14), May and November (chi-square = 20.58), June and October (chi-square = 10.14), June and November (chi-square = 8.17), and June and December (chi-square = 8.19). Significant differences were also found between January, March, April, May, July, August, October, and September (i.e. January vs. September and October vs. September).

Examination of efficiency and biological conditions on an annual basis suggested a relationship between TE and resource conditions. Regressions of TE against stock abundance, gonad weight, meat yield, and these variables squared were found to be statistically significant for 1989 and 1990 (1989: $F_{6,11} = 7.23$; 1990: $F_{6,11} = 6.56$). TE increased as stock abundance and meat yield increased; gonadal weight did not appear to be a significant explanatory variable except during 1990. This latter result may be because gonadal weight and meat weight are redundant variables (i.e. meat weight changes as gonad weight changes). Kirkley and DuPaul (1989) and Schmitzer et al. (1991) have shown, in fact, that meat weight changes in response to changes in spawning events.

Analysis suggests that stock abundance and meat weight affect technical efficiency. In addition, since changes in spawning events affect meat yields, it appears highly probable that changes in the gametogenic cycle affect technical efficiency. Gametogenesis and meat yields also appear to closely follow food abundance as measured by the weight of stomach contents. Although data on stomach weight are only available for 1991, there appears to be a relationship between meat yield, gonadal weights, and stomach weights. Gonadal and meat weights tend to increase and decrease as stomach weights increase and decrease.

Analyses, thus far, indicate that technical efficiency is affected by economic and biological conditions. Policies designed to promote efficient resource conservation, therefore, need to consider the potential interactions between technical efficiency and associated economic and biological conditions. The New England Fishery Management Council (NEFMC) has proposed that crew size be restricted to nine individuals to limit total harvest and prevent excess harvesting of small scallops. The Council has also proposed restrictions on days at sea per year per vessel. Assessing the likelihood of these regulations to accomplish their goals will require considerable detailed knowledge of technical efficiency and the importance of biological and economic conditions.

Utilizing the information obtained from eight at sea experiments in which crew size required for given harvest levels was estimated, it was determined that production levels for only 63 out of 581 trips between 1987 and 1990 would have been affected by restrictions on crew size. Relative to production during 1990, landings would have been reduced for only 4 out of 132 trips. A nine man crew limit would only marginally restrict total catch and reduce fishing mortality relative to observed levels; however, it would improve technical efficiency.

Based on an assumed proportional relationship between fishing mortality and fishing effort (days at sea), the NEFMC has proposed reducing the annual number of days at sea a vessel may fish. Analyses in Kirkley and DuPaul (1992) have shown that an annual restriction of days at sea will likely cause vessels to stop fishing between October and January when harvests, meat yields, and economic returns are low. This is also a period when scallops spawn, food availability is low, and TE is minimum. In this case, TE should increase in response to a restriction on days at sea. Technical efficiency over all ten vessels and months between 1987 and 1990 was 0.74. If the vessels curtail fishing between October and January, TE increases to 0.77 or by approximately 4.1%. Moreover, gains in TE occur while overall harvest levels decline and spawning occurs.

Efficacious regulatory policy will have to consider the effects on input and output levels and technical efficiency as well as the relationship between technical efficiency, the gametogenic cycle, and food abundance. Failure to recognize these linkages could result in inadequate regulatory policies, particularly those policies designed to promote social and economic efficiency. Relative to the proposed restrictions on days at sea and crew size, technical efficiency should increase while harvest levels decline.

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THE ALASKAN SCALLOP FISHERY AND ITS MANAGEMENT

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ABSTRACT

The commercial fishery for weathervane scallops in Alaska began in 1967. Harvests totalled 761 t of shucked meats in 1968 and 840 t in 1969. During the ensuing two decades (1970-1989), landings averaged just 266 t annually. It was commonly held that the Alaskan scallop fishery was self-regulated by economics. Management was based on a set of passive regulations. In the early 1990's, this previously insignificant and sporadic scallop fishery began to change rapidly. Landings increased to 675 t in 1990 and 821 t by late 1992. This is the highest harvest since the initial "fishing up" period on virgin stocks. Shifts in effort to previously unfished or lightly fished areas accounted for part of the increase. Despite these shifts, reports of the dominance of small scallops in catches were received. Conservation concerns included local depletions of scallop stocks and crab bycatch. To address conservation and allocation issues, the state of Alaska developed an interim management plan. The plan has five objectives:

1. to ensure long-term viability of scallop populations;
2. to minimize adverse effects of gear on habitat and other species;
3. to conduct steady-paced fisheries that provide long-term socioeconomic benefits;
4. to maintain resource availability to subsistence users;
5. to conduct research to increase knowledge for future management decisions.

Management measures designed to achieve these objectives include registration requirements, gear specifications, harvest limits, fishing seasons, onboard observers, efficiency controls (crew limit and ban on shucking machines) and bycatch caps. Additionally, a federal fishery management plan that limits effort is being developed in an attempt to avert over-capitalization.

INTRODUCTION

The weathervane scallop, *Patinopecten caurinus*, fishery in Alaska provides an interesting case study of a minor fishery that rapidly emerged to the fore of state and federal fishery management arenas. Although the fishery was passively managed for more than two decades, it has recently been the subject of deliberations of the Alaska Board of Fisheries (BOF) and the North Pacific Fishery Management Council (NPFMC). The fishery now requires more active management by the Alaska Department of Fish and Game (ADF&G). Several issues account for the increased attention paid to this fishery. These include a sharp rise in landings, conservation concerns, bycatch issues, and fears of over-capitalization. Whereas the current fishery remains small compared to other major fisheries in Alaska, these issues pose challenges to management agencies that operate with limited data under tight fiscal constraints.

In this paper we provide a synopsis of this fishery and its associated management challenges. Specifically, we:

1. summarize the biology and life history of weathervane scallops;
2. review the history of the Alaskan fishery;
3. provide insights into recent fishery developments;
4. characterize the management response to these changes.

OVERVIEW OF BIOLOGY AND LIFE HISTORY

The primary pectinid harvested in Alaska is the weathervane scallop, *P. caurinus*. Sporadic attempts have been made to harvest the pink scallop, *Chlamys rubida*, arctic pink scallop, *C. pseudoislandica*, and spiny scallop, *C. hastata*. Because *Chlamys* species account for little of the overall landings, only the weathervane scallop is considered here.

Weathervane scallops are distributed from Point Reyes, California, to the Pribilof Islands, Alaska (Foster 1991). In Alaska, highest densities exist off Yakutat (Cape Spencer to Cape St. Elias), Kodiak Island, Dutch Harbor and in the Bering Sea (BS). In Alaska, weathervane scallops have been found in intertidal waters and to depths of 300 m (Foster 1991), but they tend to be most abundant between depths of 45-130 m on beds of mud, clay, sand, and gravel (Hennick 1973).

With rare exception (Hennick 1971), the sexes are separate. Most weathervane scallops become sexually mature at about 76 mm shell height (SH) generally reached by age three in Alaska (Haynes and Powell 1968; Hennick 1973). Although age at maturity may vary, size at sexual maturity appears to be invariant with latitude (Bourne 1991). Gonads of mature males are creamy white, whereas those of mature females are pink or orange-red (Haynes and Powell 1968; Robinson and Breese 1984).

The spawning season varies with depth (MacDonald and Bourne 1987) and latitude. Spawning occurs from mid-January to July off Oregon (Robinson and Breese 1984; Starr and McCrae 1983), from mid-April to mid-June in the Strait of Georgia, British Columbia (MacDonald and Bourne 1987), and from June to early July in Alaska (Hennick 1970).

External fertilization takes place after release of gametes into the sea (Cragg and Crisp 1991). At 14°C, fertilized eggs of weathervane scallops develop to the veliger larval stage by 72 h and metamorphosis to the juvenile stage is completed within about 30 days (Bourne 1991). Metamorphosis includes loss of the velum, development of an operational gill system, and commencement of filter feeding (Cragg and Crisp 1991).

Weathervane scallops are long-lived; individuals of ages >20 years have been collected from the Strait of Georgia (Bourne 1991) and some to age 28 in Alaska (Hennick 1973). Such long-lived species experience high annual survival (Hoenig 1983), but estimates of instantaneous natural mortality are unavailable for weathervane scallops.

Scallop growth varies significantly among beds and geographic areas. Based on von Bertalanffy growth estimates (Kaiser 1986), weathervane scallops from Marmot Flats off the northeast side of Kodiak Island grow faster (131 mm SH at age four) and achieve larger asymptotic sizes (l_∞ = 190 mm SH) than those from Cape St. Elias to Cape Fairweather in the eastern Gulf of Alaska (91 mm SH at age four; l_∞ = 144 mm SH). The largest recorded Alaskan specimen measured 250 mm SH and weighed 340 g (Hennick 1973).

HISTORY OF FISHERY

Despite periodic assessment surveys beginning in 1953, a fishery for scallops did not begin until 1967 (Haynes and Powell 1968). One year later the fishery became fully developed when 19 vessels made 125 landings totalling 761 t of shucked meats and reached its peak in 1969 with 157 landings totalling 840 t (Fig. 1). Harvests off Kodiak and Yakutat accounted for 99% of these early landings in these two years.

By 1970 participation dwindled to seven vessels and this new fishery began to change. Landings declined to 422 t in 1971 and to 198 t in 1975. Whereas catches from the early fishery were dominated by old scallops (seven$^+$ years of age), landings had shifted toward younger ages (two to six years old) by the early 1970's as older scallops were cropped from previously unexploited stocks (Hennick 1973). From 1973 to 1977, the average landing per trip declined (Kaiser 1986). Less than three vessels participated in the fishery during 1976-1979 (state of Alaska confidentiality requirements prevent reporting their catches). No scallop fishing occurred in 1978.

Kaiser (1986) reported that the scallop industry supported several exploratory cruises to increase landings during 1974-1978 with little success. In addition to reduced stocks, fishing area restrictions and inflationary operating costs contributed to the fishery decline (Kaiser 1986). As a result, converted halibut, crab and shrimp vessels exited the scallop fishery and only the more efficient east coast-type scallop vessels remained. Typically, the latter were 24-27 m in keel length and towed two 3.7-4.9 m dredges (Kaiser 1986).

In the 1980's, the weathervane scallop fishery received renewed interest, in part due to increased exvessel prices. Average price increased from $3.39/kg in 1977 to $8.04/kg (U.S.) in 1980 (Fig. 2A). Prices peaked in 1983 ($10.36/kg) and averaged $7.84/kg during 1985-1989 (Fig. 2A). When adjusted for inflation (scaled to 1991 dollars) using the gross domestic product implicit price deflator, prices paid to scallop fishers declined from $13.20/kg in 1980 to $9.00/kg in 1989 (Fig. 2A). Overall, during the 1980's an average of nine vessels (Fig. 1B) delivered 265 t (Fig. 1A) worth $2.15 million annually (Fig. 2B). Unlike the 1970's when Kodiak and Yakutat accounted for 93% of the landings, during the 1980's 33% of the landings were taken from Dutch Harbor and other areas such as Southeast Alaska, Cook Inlet, Alaska Peninsula, and BS (Fig. 1A).

Recently, significant increases in harvest occurred. During 1990-1992, two of the four highest annual landings ever were recorded. In 1990 nine vessels made 144 deliveries that totalled 675 t (Fig. 1A,B). By late 1992, landings approached 821 t, which is the highest harvest since fishing on virgin stocks peaked in 1969. ADF&G received anecdotal reports that small scallops had composed larger portions of the harvest despite other reports that scallop fishers had moved to new areas or marginal beds to maintain catches. Landings data reveal geographic shifts in effort. In 1992, 95 t were landed from previously unfished beds off Prince William Sound (Shirley 1993). Likewise, a shift from inshore to offshore grounds accompanied a record harvest of more than 460 t off Yakutat.

FISHERY MANAGEMENT

In the 1970's and 1980's, it was commonly held that the weathervane scallop fishery was self-regulated by economics. The fishery was small, and conservation and allocation issues were rare. Not surprisingly, a set of passive regulations (e.g. gear restrictions, closed areas to protect crabs, and fishing seasons) were promulgated by the state of Alaska via fishing permits (ADF&G 1993; Kruse et al. 1992). Commensurate with this management style, little biological and fishery data have been collected aside from annual landings since 1967, and sporadic surveys and onboard observations during the early years of the fishery (e.g. Haynes and Powell 1968; Hennick 1973).

Now, the view of self-regulating, sustainable scallop fisheries is debatable. It is not unusual for scallop fisheries to crash after relatively brief, intense periods of harvest (Orensanz et al. 1991; Starr and McCrae 1983; Renzoni 1991). Pectinids possess a range of life history traits from those that are long-lived (>12 years) and iteroparous to those that are short-lived (<three years) and semelparous (Orensanz et al. 1991). Because of their large size, longevity, and low natural mortality, weathervane scallops have attributes that tend to be associated with species that are most vulnerable to overharvest (Adams 1980).

At present, scallop fishery management involves a wide spectrum of complexities. Development of individual fishery quota programs for other Alaskan fisheries (e.g. halibut, *Hippoglossus stenolepis,* sablefish, *Anoplopoma fimbria*, and other groundfish) has motivated scallop fishers to maximize catches in anticipation that individual harvest histories may be used to assign future quota shares and limit effort. At the same time, fishers have expressed much trepidation about a perceived influx to Alaska of new vessels that are seeking new fishing grounds having failed to qualify for continued access to the Atlantic scallop, *Placopecten magellanicus,* fishery. Declining real prices (Fig. 2A) and limited stocks raise doubts about whether the Alaskan scallop fishery can remain profitable even without increased fleet size. Last, recent increases in scallop harvests, some from areas previously closed to scallop dredging, have alarmed crab fishers particularly concerned with potential impacts of bycatch on depressed red king crab, *Paralithodes camtschaticus*, and Tanner crab, *Chionoecetes bairdi*, stocks.

To address these issues, ADF&G developed an interim fishery management plan (Kruse et al. 1992). In creating the plan, ADF&G attempted to provide for cost effective collection of biological and fishery data that would promote management for resource conservation and sustained benefits to users. The goal of the interim plan is to maximize the overall long-term benefit of scallop resources to residents of the state of Alaska and the nation, while providing for conservation of scallop populations and their habitats. Within the scope of this broad goal, there are five objectives:

1. to ensure the long-term reproductive viability of scallop populations;
2. to minimize adverse effects of scallop gear on bottom habitat and other species;
3. to ensure the conduct of manageable, steady-paced scallop fisheries that promote long-term economic and social benefits;
4. to maintain resource availability to subsistence users;
5. to conduct fishery research to increase the information base for future management decisions.

In essence, seven management measures address these objectives. Foremost, the plan acknowledges a dearth of biological and fishery data. To help fill this void, industry-funded *onboard observers* are required aboard scallop vessels. Observer data will be used to prescribe annual catches based on regional stock productivity and to adjust area closures based on current crab abundance and distribution.

Towards objectives for biological conservation and sustainable fisheries, *annual harvest limits* were established for each traditional harvest area based on long-term average catches: 113 t for Yakutat, 23 t for Prince William Sound, 9 t for Kamishak District of Cook Inlet, 182 t for Kodiak, and 77 t for Dutch Harbor. The total from all traditional areas is 404 t. To provide for further exploration of scallop resources, harvests from non-traditional areas are allowed by fishing permits. The catches from these areas are not counted as part of the annual harvest limit.

The annual harvest is split equally into two *fishing seasons*: January-June and July-December. For 1993, this measure was largely motivated by a desire to collect some contemporary data via an observer program that began July 1.

To obtain more accurate data on origin of catch and to provide for orderly fisheries, new *registration requirements* require vessels to register for one of eight management areas before fishing in an area. The areas are Southeast Alaska, Yakutat, Prince William Sound, Cook Inlet, Kodiak, Alaska Peninsula, Dutch Harbor, and the BS.

Gear specifications were developed largely to address the biological conservation objective by minimizing the catchability of undersized scallops. Ring size is specified to be ≥10.16 cm, and restrictions are placed on the use of chafing gear, liners and ring modifications. No more than two dredges of maximum width 4.57 m may be used.

In 1993, the BOF established two *efficiency controls*: a ban on shucking machines and a crew limit of 12 persons. To a large degree, both measures were established to influence the average size of scallops culled from the catch. Without these efficiency controls, shucking machines and large crews can be used to economically harvest scallops much smaller than sizes associated with optimum yields.

Last, *bycatch caps* were set to limit incidental mortality of king and Tanner crabs. Generally, for healthy crab stocks that have directed commercial fisheries, the cap is set at 1% of crab biomass in the area where the fishery occurs. For depressed crab stocks in which the directed fishery has been closed, the cap is set at 0.5% of crab biomass.

ADF&G implemented the interim plan in 1993 and it remains in effect until a final plan is approved by the BOF. The BOF operates on a three-year meeting cycle, and they are next scheduled to address scallop management during spring 1994. It is anticipated that the BOF will take action on a final fishery management plan for scallops at that time. Because of a sense of urgency, in 1993 the NPFMC established a "control date" of January 23, 1993, to warn subsequent entrants that they may not qualify for this fishery in the future. A federal scallop management plan is being developed that would limit effort in an attempt to avert over-capitalization.

ACKNOWLEDGMENTS

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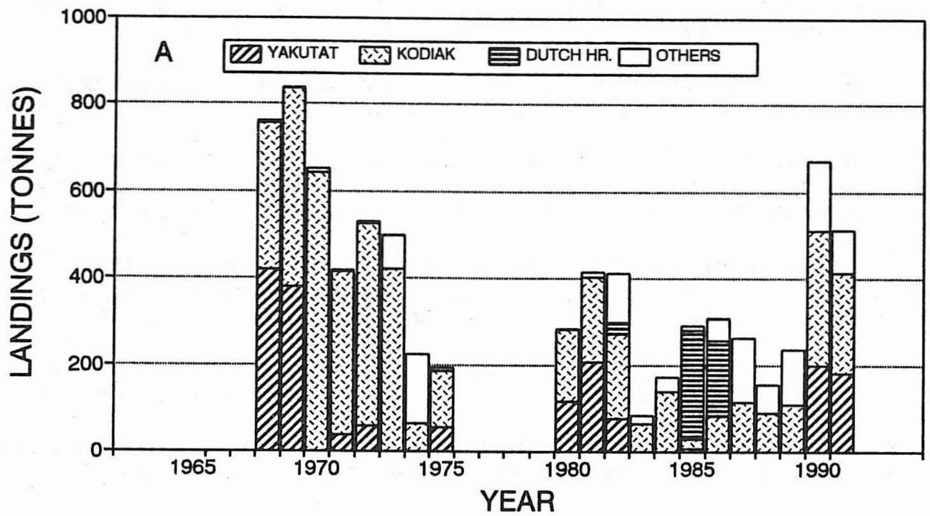

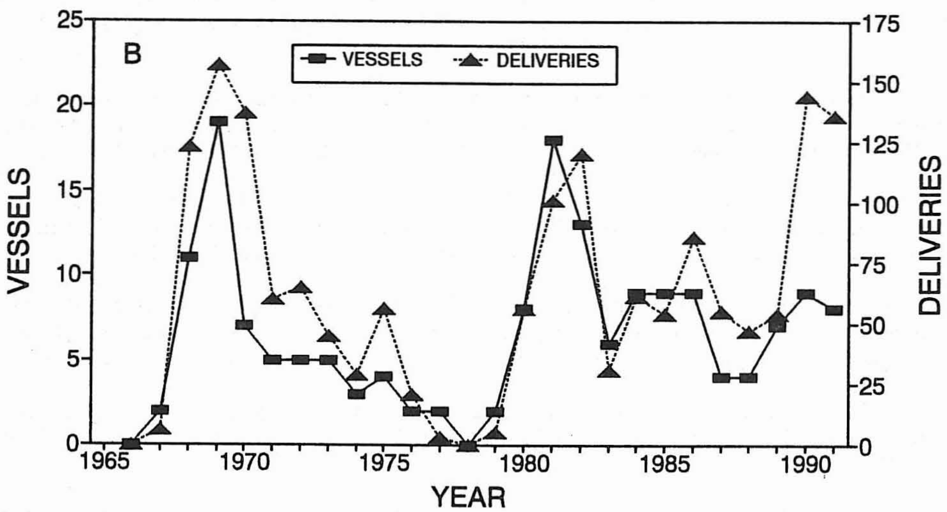

Fig. 1. (A) Landings (t) of shucked meats by harvest area and (B) total numbers of fishing vessels and deliveries in the weathervane scallop fishery in Alaska during 1967-1991. State of Alaska confidentiality requirements prevent reporting of harvests from <3 vessels. When individual regional harvests from Yakutat, Kodiak or Dutch Harbor were confidential, landings were lumped with other areas ("OTHERS"). Statewide landings were confidential in 1967, 1976, 1977, and 1979. Source: Alaska Department of Fish and Game, Division of Commercial Fisheries Management and Development, Juneau.

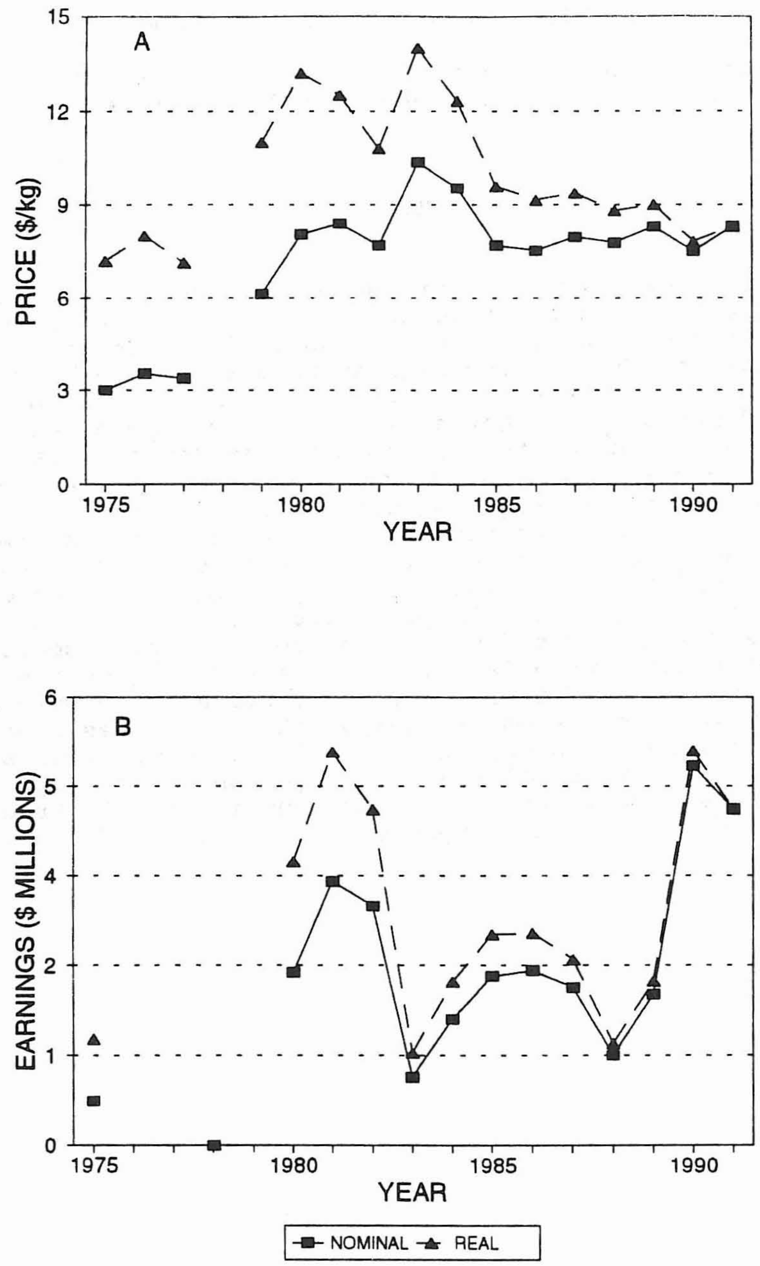

Fig. 2. (A) Weighted (by landings) average exvessel prices and (B) total gross earnings paid to weathervane scallop fishers in Alaska in terms of nominal (reported) and real (scaled to 1991 by the gross domestic product implicit price deflator) dollars during 1975-1991. Confidential data are not shown. Source: Alaska Commercial Fisheries Entry Commission, Juneau.

SPATIAL DISTRIBUTION OF THE GIANT SCALLOP, *PLACOPECTEN MAGELLANICUS*, IN UNFISHED BEDS IN THE BAIE DE CHALEURS, QUÉBEC

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ABSTRACT

Large and small scale distributions of the giant scallop (*Placopecten magellanicus*) were determined in two scallop beds near Port Daniel in the Baie des Chaleurs, eastern Canada. Large scale (km) distribution was strongly associated with substrates of gravel or gravel mixed with sand. Small scale (cm) distribution was contagious corresponding to a negative binomial distribution. Morisita's index confirmed the contagious spatial distribution and showed that clump size was approximately 1.13 m^2 in one bed and 4.50 m^2 in the other. The majority of scallops in both beds were within clumps. Small scale aggregation was not related to substrate type. Mature and immature scallops were significantly associated in the less densely populated bed but not in the more densely populated bed. This suggests that immature scallops moved nearer to adult scallops when densities were low. Both sexes were present in 79% of clumps of adult scallops. In both beds the sex ratio was 1:1 and scallops did not appear to seek out members of the opposite sex. In the two beds 91 and 75% of nearest neighbour scallop pairs were 100 cm or closer to each other. The short distance between scallops within clumps, the high proportion of clumps with both sexes present, and an average of three scallops per clump suggests high fertilization success within clumps. We suggest that the small scale aggregation of scallops is an adaptation to increase fertilization success, and if this is true, disturbance of these aggregations may decrease reproductive success.

DISTRIBUTION OF THE ICELANDIC SCALLOP, *CHLAMYS ISLANDICA*, IN THE NORTHEAST ATLANTIC

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ABSTRACT

During an Iceland scallop resource mapping survey in 1986, scallops were sampled by dredging at 1140 positions in waters off Jan Mayen, Bear Island, and Spitsbergen. In all three regions the scallop distribution was generally wide, but scattered, although beds with extremely high densities of scallops were found within each region. Factors such as shell height, age distribution, growth rates and relative weight of soft body parts varied among scallop populations from the different areas. The depth at which scallops were found tended to be shallower in the northern regions of their distribution than in the south. These differences may be caused by temporal and spatial variation in food availability and temperature. However, lack of information on abiotic and biotic environmental factors in the different regions makes it difficult to draw conclusions about possible environmental impact on the biology of the species. Scallop abundance was related to a qualitative description of surface sediment and the Iceland scallops were, as expected, mostly associated with substrates composed of gravel or empty bivalve shells.

GROWTH, PHYSIOLOGY AND NUTRITION

SHORT-TERM FEEDING EXPERIMENTS WITH *PECTEN MAXIMUS* AT VARIOUS ALGAL DENSITIES

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ABSTRACT

Interest in using seawater pond systems in the production of juvenile *Pecten maximus* raises the need for a greater knowledge of feeding of this species. In small ponds it is difficult to control algal density, which at times may reach values of 1000 cells/μl. A series of small scale experiments was carried out to investigate the effect of different algal concentrations (5-360 cells/μl) on individual filtration and feeding rates. Short term measurements (maximum 1 h) were made in a stagnant system. Three different size groups of scallops were used, with mean shell height of 30.9 mm, 41.7 mm and 57.4 mm (n=7). Each scallop was placed in a plastic tray filled with 3 l of filtered seawater. The food alga used was *Chaetoceros gracilis* (Bacillariophyceae). Mean seawater temperature in the experimental trays varied between experiments from 12.9°C (SD=0.6) to 14.3°C (SD=0.4). Results show the filtration rate, *m* (ml/min × g live weight), decreased at algal densities above 9-11 cells/μl for all scallop groups. The higher *m* at lower algal concentrations did not compensate for the decrease in algal concentration. Below about 40 cells/μl there was a sharp decrease in feeding rate, *Fr* (cells/min x g live weight). At any algal density both *m* and *Fr* decreased as the size of the scallops increased.

RESEARCH CONCERNING ENDOCRINE CONTROL OF GROWTH AND DIGESTION IN *PECTEN MAXIMUS*

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ABSTRACT

Research concerning the endocrine control of growth and digestion in *Pecten maximus* is performed according to several experimental approaches: research of bioactive molecules with *in vitro* and *in vivo* bioassays; research of peptide-like molecules using immunological probes; research using tools of molecular biology.

THE ROLE OF MUCUS IN PARTICLE TRANSPORT ON THE GILL OF *PLACOPECTEN MAGELLANICUS* (MOLLUSCA: BIVALVIA)

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ABSTRACT

In order to elucidate the role of mucus in particle transport on the gill in suspension-feeding bivalves, mucocyte distribution was examined on the frontal surfaces of two gill types known to differ in structure and function: the heterorhabdic plicate gill of *Placopecten magellanicus* (Pectinidae) and the homorhabdic gill of *Mytilus edulis* (Mytilidae). Mucocyte counts were performed on gills stained with Alcian blue and Periodic acid-Schiff (PAS) *in toto* and in histological sections. Functional correlates were obtained using recorded video endoscopic observations. A very clear separation of mucocyte types was observed on the *P. magellanicus* gill: mixed-secretion mucopolysaccharide (MPS) mucocytes were found mainly in the principal filament troughs, while acid MPS mucocytes were found mainly on the crests of the ordinary filament plicae (Fig. 1). This distribution corresponds to the functional specialization of these two sites as revealed by direct endoscopic observation: feeding (principal filament) and cleaning (ordinary filaments). A more uniform distribution and a broader range of MPS types was found for the *M. edulis* gill (Fig. 2), corresponding to the absence of anatomical specialization for the separation of feeding and cleaning functions in this species. Implications of these and further results are discussed in terms of theories of particle transport on the scallop gill in comparison with homorhabdic gills.

CONCLUSIONS

1. Division of labour on heterorhabdic scallop gill accomplished at two levels:
   a. anatomical (principal and ordinary filaments);
   b. biochemical (mixed vs acid mps).
2. Acid mps used in transport on "exposed" epithelia, mixed mps used in transport on "protected" epithelia.
3. Acid mps used for rejection (pseudofeces), mixed mps used for feeding.
4. No division of labour on homorhabdic mussel gill.
5. Much opportunity for research (e.g. composition of mucus associated with each function, energetics of mucus production under different feeding conditions, etc.)

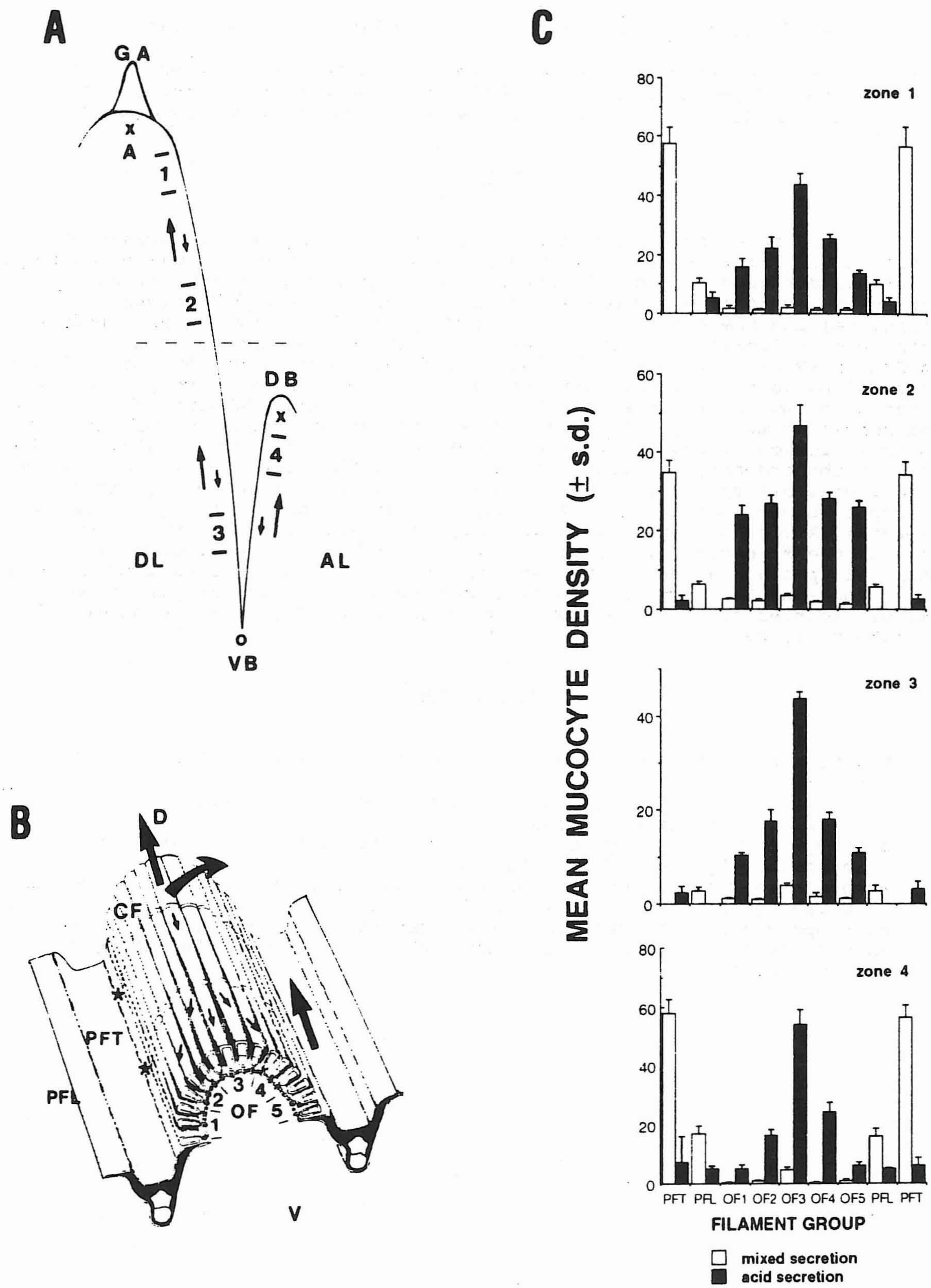

Fig. 1. *Placopecten magellanicus* gill. Particle trajectories, location of counting zones, and mean mucocyte densities.

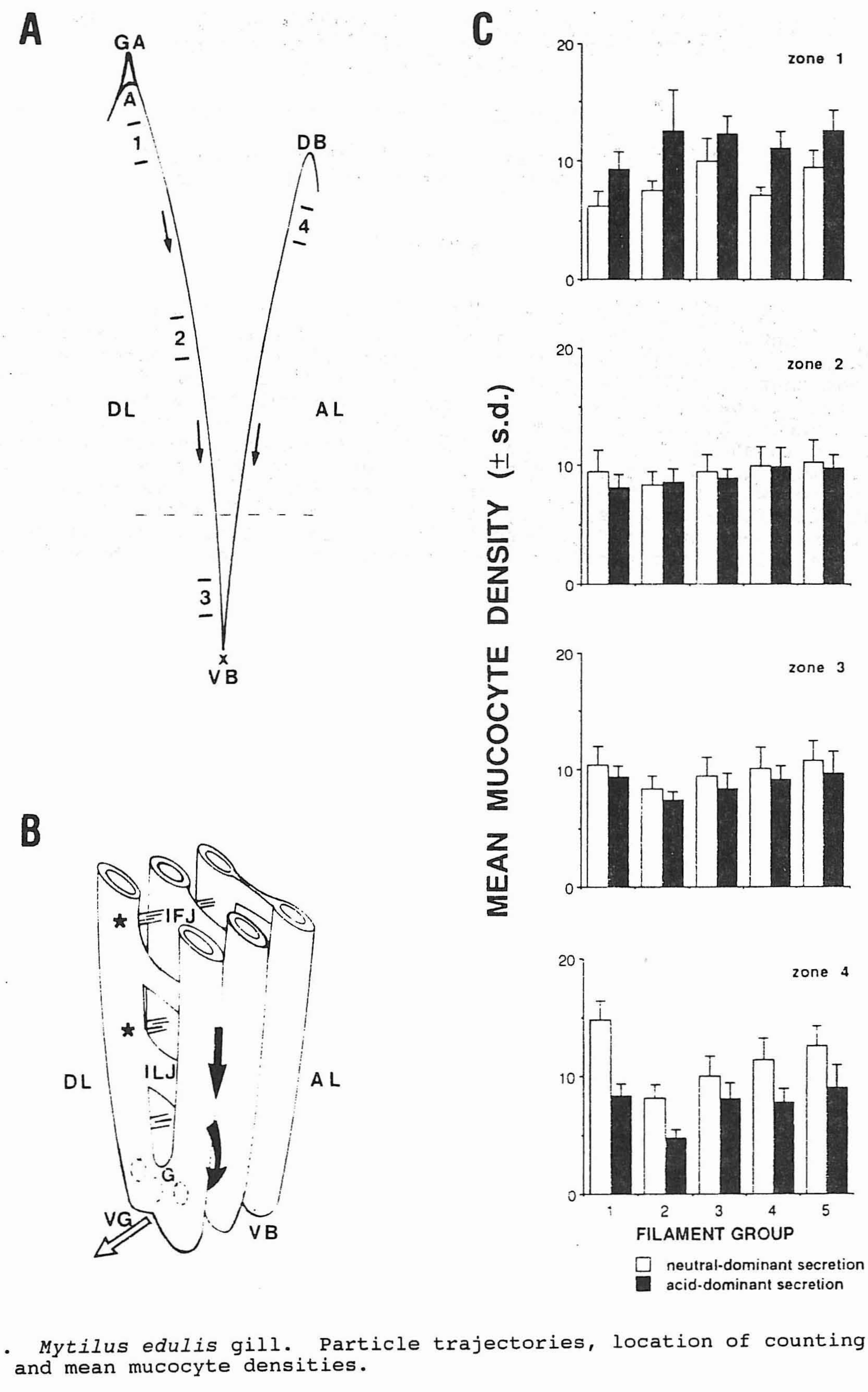

Fig. 2. *Mytilus edulis* gill. Particle trajectories, location of counting zones, and mean mucocyte densities.

IN SITU EFFECT OF FLOW VELOCITY AND ORIENTATION ON THE GROWTH OF JUVENILE GIANT SCALLOPS, *PLACOPECTEN MAGELLANICUS*, IN SUSPENDED CULTURE

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ABSTRACT

We experimentally investigated the effect of water velocity and scallop orientation on growth of juvenile giant scallops, *Placopecten magellanicus*, in suspended culture. The experiment was conducted at two locations characterized by different tidal current regimes in the Port-Daniel Bay, Baie des Chaleurs of eastern Canada. Our results show that pearl nets highly reduced the flow of water inside the net. Whereas this induced no difference in shell growth, there were significant differences in soft tissues indices (muscle and remaining tissue). However, the effect was reversed between the two sites, the effect of the pearl net being beneficial in high current velocities whereas harmful in low current velocities. Orientation in the current does not affect growth in high current velocities, but in low current velocities the exhalent opening facing downstream slightly favours growth.

THE GROWTH OF JUVENILE GIANT SCALLOPS, *PLACOPECTEN MAGELLANICUS*, IN SUSPENDED CULTURE IN THE BAIE DES CHALEURS, CANADA: INFLUENCE OF SPAT ORIGIN AND CULTURE SITE

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ABSTRACT

We compared growth in suspension culture of juvenile *Placopecten magellanicus* caught on artificial collectors with growth of other juveniles produced in a hatchery to experimentally determine the effect of contrasting environments. Experiments were conducted in the Baie des Chaleurs, the largest bay in the Gulf of St. Lawrence, eastern Canada. Our results suggest that the colder and more stable waters of the lower bay are more suitable for scallop growth than the warmer and more fluctuating waters of the upper Baie des Chaleurs, although food quantity and temperature appear to be more favourable. The lower concentration of suspended particulate matter at the mouth of the bay might explain this discrepancy. We also observed significant growth differences between wild and hatchery-produced scallops. The physiological condition of the scallops before they were stocked in pearl nets, rather than their origin, probably accounted for these differences. The better physiological condition probably translates into higher energy reserves that allow significant growth during winter.

PHYSIOLOGICAL COMPENSATION RESPONSES OF SEA SCALLOPS, *PLACOPECTEN MAGELLANICUS*, TO FLUCTUATIONS IN THE FOOD SUPPLY AND THE PRESENCE OF SUSPENDED INORGANIC MATTER

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ABSTRACT

The food supply of scallops residing in coastal and shelf environments is in a constant state of flux as particle types and concentrations are effected by an array of natural and human-induced processes. Suspension-feeding bivalves have been shown to employ several different physiological mechanisms and compensation strategies for optimizing growth under conditions of varied food abundance and nutritional value. The physiological responses of adult sea scallops, *Placopecten magellanicus*, exposed to a range of natural and simulated dietary conditions are presented and the endogenous capacity to compensate for exogenous controls on the food supply is discussed. Results from field and laboratory studies indicate that sea scallops regulate feeding activity (filtration rate and efficiency and pre-ingestive particle selection) in response to short- and long-term changes in the food supply; however, they do not appear to regulate food absorption on either time scale. Sea scallops are highly sensitive to the presence of low concentrations (<10 $mg \cdot l^{-1}$) of suspended clay owing to adverse effects on feeding rate and the low ability to selectively reject fine inorganic particles prior to ingestion. Larger inorganic particles appear to have less impact on sea scallop growth owing to a greater capacity to maintain high filtration rates while rejecting these particles as pseudofeces.

INTRODUCTION

Studies on the natural food available to suspension-feeding bivalves in coastal and shelf waters reveal considerable short- and long-term variations in the concentration, composition and nutritional value of seston (Berg and Newell 1986; Fegley et al. 1992). Long-term fluctuations are generated by the seasonal cycle of primary production. Short-term variations of similar or greater magnitude can occur through the resuspension of bottom deposits caused by tidal and wind effects. The stage of the tidal cycle in many coastal systems is closely correlated with the total concentrations of seston, chlorophyll *a* and particulate nitrogen owing to the resuspension of bottom deposits (Rhoads et al. 1984). Land-based erosion, bioturbation and anthropogenic activities (e.g. seabed dredging, coastal construction, ocean dumping, hydrocarbon exploration and production activities, and harvesting of fishery resources by trawls and dredges) can also alter the food supply by increasing the proportion of inorganic particles in the water column.

Since mineral particles dilute the nutritional value of suspended particulate matter available to suspension-feeding bivalves, any ensuing impact on tissue growth depends on the animals capacity to compensate for their presence. Endogenous factors that potentially influence energy acquisition in suspension-feeding bivalves include:

1. regulation of filtration rate in response to food availability and composition;
2. selective particle retention by altering the retentive characteristics of the feeding apparatus;
3 rejection of retained non-nutritious particles (pre-ingestive selection);

4. the selective absorption of particles (post-ingestive selection); and
5. variable absorption efficiency (Fig. 1).

The paucity of data on the capability of sea scallops, *P. magellanicus*, to regulate food uptake and utilization via these processes in response to variations in dietary conditions clearly demonstrates the need for further study.

The sea scallop is a major component of the Atlantic Canada fishery and the production of a high-value cultured product is currently in a developmental stage. Given the socio-economic importance of this fishery and the potential for aquaculture, there is a demand for information on the influence of environmental variables and anthropogenic stresses on scallop growth and survival. An important step in assessing the suitability of sea scallops and potential sites for culture is defining the species' environmental requirements. Local food conditions are a major factor in this assessment; however, the range of dietary conditions that scallops can cope with also depends on their endogenous capacity to control energy acquisition and compensate for apparent inadequacies in the available food supply, e.g. the presence of inorganic particles. This paper presents a brief synopsis of pertinent results from new and recently published studies conducted on the effects of a range of dietary conditions on the physiological components of scallop growth (feeding, digestion, respiration and excretion). Emphasis was placed on ascertaining the relative importance of various physiological mechanisms controlling energy acquisition and determining the influence of inorganic suspended solids on scallop growth.

MATERIALS AND METHODS

LABORATORY STUDIES

Sea scallops were collected by commercial dragger from offshore scallop beds off Nova Scotia and held in flowing unfiltered seawater. Animals between 98 and 102 mm shell height were selected for these studies, which were conducted at 15°C. Physiological measurements were obtained for scallops fed microalgal cells (spray dried *Tetraselmis suecica*) or seston (Bedford Basin unfiltered seawater) combined with different concentrations of suspended clay (bentonite), bottom deposits or particulate drilling wastes (cuttings from an oil well drilled on the Scotian Shelf). Feeding experiments were conducted using the flow-through feeding chamber technique described by Cranford and Gordon (1992). Retention efficiency (RE), the proportion of available particles of different sizes retained on the gill, was determined from Coulter Counter particle concentrations as $1 - C_t/C_c$, where C_t and C_c are the particle concentrations in the outlet of test (scallop) and control (no scallop) feeding chambers, respectively. Filtration rate, the volume of water cleared of particles per hour, was calculated by multiplying RE by the flow rate measured at the outlet of each feeding chamber. Ingestion rate was calculated as the product of filtration rate and the concentration of particles in suspension minus the pseudofeces production rate.

The ability of scallops to enhance the quality of ingested particles by selectively rejecting captured particles of low nutritional value was assessed from observed differences in the chlorophyll *a*, total organic matter (OM), organic carbon (POC) and nitrogen (PN) content of pseudofeces relative to the diet. Water samples and pseudofeces were collected from recirculating raceway tanks in which scallops were exposed to different diets for periods ranging from several days to two months. Particle selection efficiency was calculated according to Kiørboe and Møhlenberg (1981). Scallop feces were also collected and analyzed for the same constituents. The percentage of ingested food material (OM, POC and PN) absorbed by the digestive system, absorption efficiency (AE), was calculated according to

Cranford and Grant (1990). Absorption rates for each diet were calculated as the product of ingestion rates and AE.

Respiration and excretion rates were measured simultaneously for scallops sealed in stirred 1 l chambers. Water containing the desired particle suspension was pumped through each chamber for at least a 30 min acclimation period. Initial water samples were then collected, water flow terminated and the chambers left undisturbed. Respiration and excretion rates were measured simultaneously as oxygen depletion and ammonia production, respectively. Incubation times were set to provide reductions in oxygen concentration from initial values of less than 20%. Respiration and excretion rates are corrected with control incubations of each particle suspension.

Weight specific scope for growth was calculated for different diets from physiological rate measurements in terms of energy (SFG_E), carbon (SFG_C) and nitrogen (SFG_N) from the equations:

SFG_E (Joules$\cdot g^{-1}\cdot h^{-1}$) = Absorption - (Respiration + Excretion);
SFG_C (μg POC$\cdot g^{-1}\cdot h^{-1}$) = Absorption - Respiration;
SFG_N (μg PN$\cdot g^{-1}\cdot h^{-1}$) = Absorption - Excretion.

Diet organic content and respiration and excretion units were transformed to energy equivalents using conversion factors provided by Bayne et al. (1985).

FIELD STUDIES

Studies of bivalve feeding and particle absorption responses to short-term (hourly) tidal variations in the particle field were conducted in Lunenburg Bay, Nova Scotia, using a new approach for obtaining *in situ* time-series data (Cranford and Hargrave 1994). The method employed a sequentially-sampling sediment trap which was placed *in situ* on the seabed at 5.5 m depth. Scallops were placed over the mouth of the trap so that feces settled into a collecting funnel and into sample cups which rotated under the funnel at hourly intervals. Scallop deposition rates and the organic and elemental content of seston and feces were used to calculate ingestion and absorption rates.

RESULTS AND DISCUSSION

FILTRATION RATE AND EFFICIENCY

When sea scallops were fed a range of diets having different organic and elemental compositions (quality), they cleared particles from suspension at rates that were directly related to diet quality (Cranford and Grant 1990). Similarly, scallops responded to increasing concentrations of clay, added to algal cell and seston diets, by decreasing filtration rates (Cranford and Gordon 1992). The same study showed that scallops fed similar concentrations of natural seston and algal cells ingested the higher quality microalgae diet 80% faster than seston. These results support the observation that filtration models based on high quality algal monoculture diets can overestimate particle removal rates by bivalves in nature (Doering and Oviatt 1986). Results from field studies show that sea scallops seldom feed at full capacity (Fig. 2) but appear to regulate food uptake in response to tidal-induced changes in the food supply (Cranford and Hargrave 1994). Powell et al. (1992) reported that suspension-feeding bivalves in general exhibit two distinct rates of feeding and that the lower rate is a better predictor of growth.

Inorganic particle size appears to be an important factor influencing filtration rates in *P. magellanicus*. While low concentrations (>1 $mg \cdot l^{-1}$) of bentonite clay (2 μm mean diameter) caused a significant reduction in filtration rates (Cranford and Gordon 1992), resuspended bottom deposits and solid drilling wastes exceeding 10 $mg \cdot l^{-1}$ had no effect (Cranford, unpublished data). The latter diets were dominated by particles larger than 10 μm diameter.

P. magellanicus appears to have some capacity to alter both the minimum and maximum size of particles captured in response to changes in diet properties. Scallops fed a mixed diet of 1 $mg \cdot l^{-1}$ algal cells and greater than 2 $mg \cdot l^{-1}$ clay altered particle retention efficiencies such that the feeding apparatus retained 25% fewer clay particles (Cranford and Gordon 1992). The maximum size of particles effectively retained was also increased in response to the presence of clay (Cranford and Gordon 1992) and is presumably achieved through modification of the screening action of the guard tentacles.

Jorgenson's monograph on the biology of suspension-feeding bivalves (1990) concluded: "Water pumping and filtration efficiency are basically autonomous processes, reflecting physical properties of the filter pump, and they are not subject to physiological regulation at the organismic level, e.g., according to nutritional needs." Jørgenson claims that suspension-feeding bivalves feed at the full capacity of the pump and that any variations in food uptake by the organism are dependant on exogenous controls on ambient food particles, e.g. temporal variations in particle concentration and nutritional value. Several other bivalve physiologists have theorized that filtration activity is endogenously regulated to optimize ingestion for maximum energy gain (e.g. Bayne 1992). These authors propose that water processing rates are regulated depending on the quantity and quality of the ambient particle field according to some optimal foraging theory. Our results clearly support the latter theory by demonstrating that *P. magellanicus* controls filtration rate and efficiency in response to fluctuations in diet quality.

PRE-INGESTIVE PARTICLE SELECTION

Many suspension-feeding bivalves have the capacity to enhance the quality of particles consumed by rejecting particles of lower nutritive value as pseudofeces. While this mechanism can effectively compensate for fluctuations in the quality of the food supply (e.g. Newell and Jordan 1983), selection efficiencies vary widely among bivalves (Kiørboe and Møhlenberg 1981). Sea scallops fed mixed suspensions of algal cells and clay produced pseudofeces at a threshold clay concentration of 2 $mg \cdot l^{-1}$; selection efficiencies averaged 2.2 (ingested particles contained 2.2 times more organic matter than pseudofeces, Cranford and Gordon 1992). This is a relatively low degree of selection compared with other suspension-feeding bivalves (Kiørboe and Møhlenberg 1981). Sea scallops displayed higher selection efficiencies (averaged 5.6, SD = 1.4) when the diet contained larger inorganic particles (15 μm) than when clay (2 μm) was present. This suggests that the capacity to reject inorganic particles is affected by particle size.

ABSORPTION

Studies show that some filter-feeding bivalves can acclimate digestive processes to significantly increase absorption efficiency (AE) and improve utilization of readily available food sources (reviewed by Bayne 1992). Studies conducted in our laboratory using a wide range of diets show that sea scallop AE's are highly correlated with diet organic content (Fig. 3). Experiments were conducted to investigate the capacity of sea scallops to acclimate (increase) AE in response to a decrease in diet quality. During a 12 day exposure to elevated levels of suspended clay, AE actually decreased (Fig. 4). Similar results were observed for exposures lasting up to two months (Cranford, unpublished data). Scallops placed *in situ* in Lunenburg Bay also did not exhibit evidence of digestive compensation for short-term (hourly) fluctuations in food quality (Cranford and Hargrave 1994). As in laboratory studies, AE varied in direct proportion with changes in the elemental and organic content of seston.

SCOPE FOR GROWTH

Calculation of the energy, carbon and nitrogen available for growth from physiological measurements (scope for growth, SFG) provides insight into the impact of increasing concentrations of suspended clay on sea scallops (Fig. 5). SFG increased at low clay levels ($<0.5\ mg \cdot l^{-1}$) but decreased rapidly as concentrations increased. Zero growth is predicted at clay concentrations between 6 and 10 $mg \cdot l^{-1}$. As observed by Grant and Cranford (1991), energy and carbon SFG calculations may overestimate growth if nitrogen is limiting. Long-term growth studies in which scallops were exposed to clay levels of 0, 2 and 10 $mg \cdot l^{-1}$ for two months are in good agreement with these SFG calculations, e.g. no growth and extensive mortalities at 10 $mg \cdot l^{-1}$ and no impact at 2 $mg \cdot l^{-1}$ (Cranford and Gordon 1992).

STRATEGY FOR OPTIMIZING ENERGY ACQUISITION

There is considerable variability in the capacity of bivalve species to cope with turbidity. Silt appears to stimulate feeding activity, improve the utilization of algal cells and enhance growth in some species while having adverse effects on others (Cranford and Gordon 1992). This can probably be attributed to morphological and physiological differences that allow the adoption of different strategies for maximizing energy gain in response to reduced diet quality. Confronted with elevated concentrations of clay particles in the food supply, *P. magellanicus* maintains a constant ingestion rate by reducing filtration rate and increasing pseudofeces production (Cranford and Gordon 1992). Since lower filtration rates reduce the rate of organic matter capture, the success of this strategy hinges on the ability of the animal to effectively enhance the uptake and absorption of organic matter via pre- and post-ingestive compensation mechanisms. The low tolerance of sea scallops to suspended clay stems from the decreased filtration rate, the low capacity to sort and reject clay particles prior to ingestion and an inability to increase absorption efficiency. Sea scallops are more effective at maintaining high filtration rates and selection efficiencies when confronted with larger inorganic particles and, as a result, are more successful at compensating for their presence.

Bivalves that do well in high turbidity areas appear to maintain constant filtration rates over a wide range of particle concentrations and alter pseudofeces production rates to maintain a constant ingestion rate. The efficient selection of organically rich particles maintains organic ingestion constant (Iglesias et al. 1992). This may be coupled with a capacity to adjust digestion to optimize food absorption (Bayne 1992). The evolution of different strategies for controlling energy acquisition may allow each species a competitive advantage under different environmental conditions, e.g. turbidity. Sea scallops are clearly best adapted to coastal and shelf waters with low suspended particle concentrations, especially clay-sized particles. Scallops in general appear to exhibit higher weight-specific filtration rates than other bivalves fed similar diets (Møhlenberg and Riisgård 1979; Powell et al. 1992), an advantage that may allow them to be more competitive under conditions of limited food availability.

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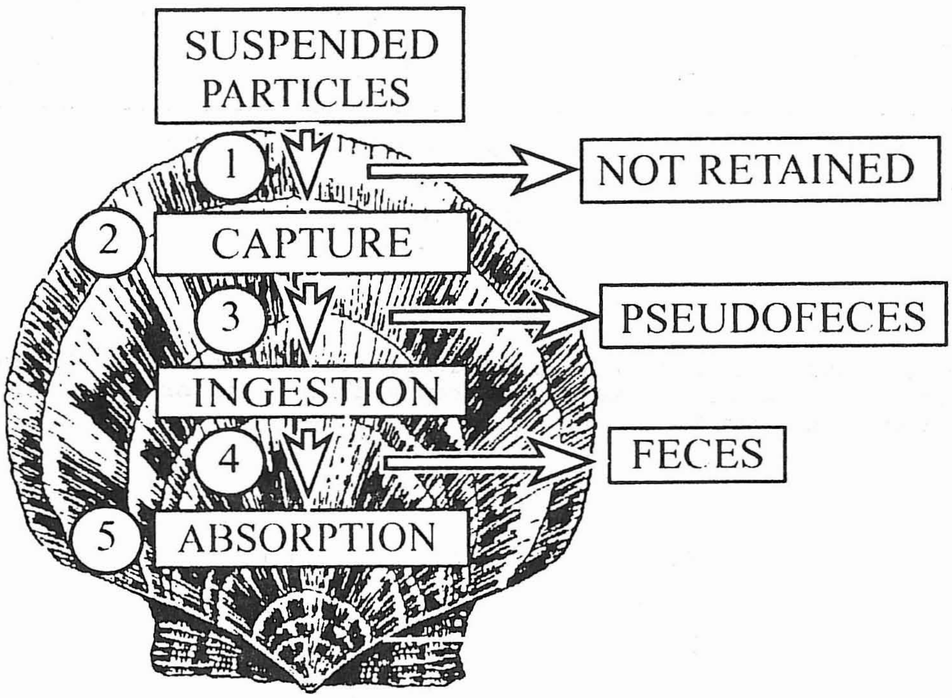

Fig. 1. Flow diagram of the processing of particles by sea scallops. The numbers designate the sites of potentially important regulatory processes described in the text.

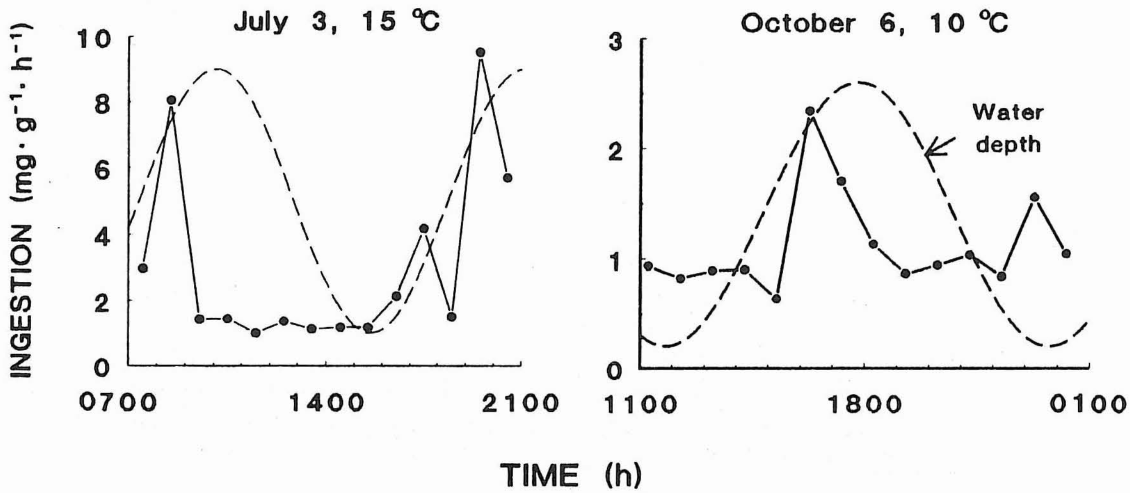

Fig. 2. Weight standardized ingestion rates measured hourly in Lunenburg Bay using the *in situ* time-series sediment trap method. The broken line represents the tidal cycle.

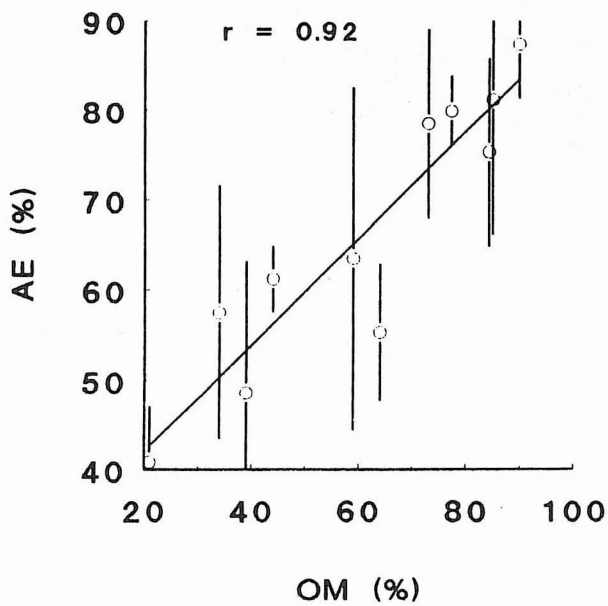

Fig. 3. Relation between absorption efficiency of organic matter by *P. magellanicus* and diet organic content. Values are means ± 1 SD.

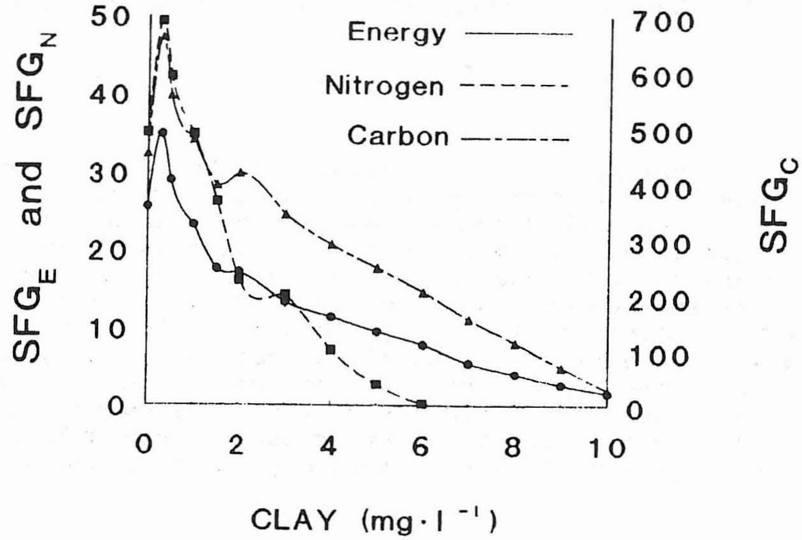

Fig. 4. Effect of clay on carbon ($\mu g\ C \cdot g^{-1} \cdot h^{-1}$), nitrogen ($\mu g\ N \cdot g^{-1} \cdot h^{-1}$) and energy ($joules \cdot h^{-1} \cdot h^{-1}$) scope for growth.

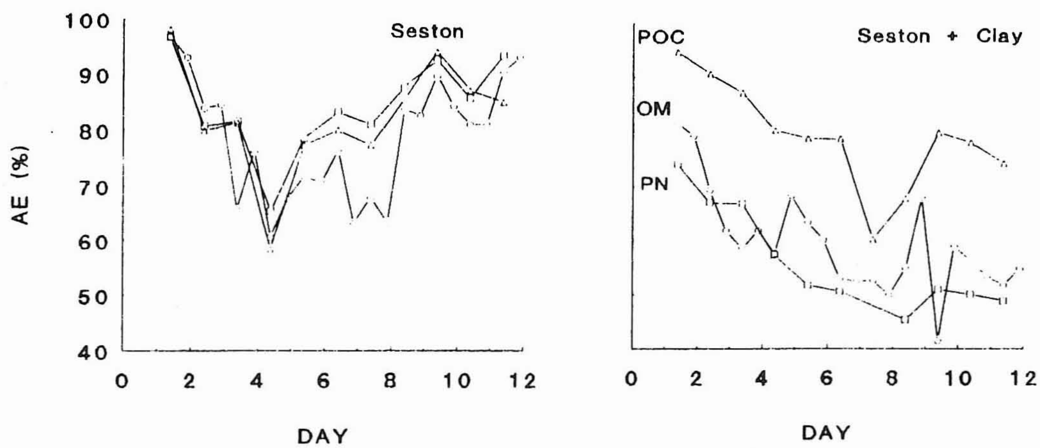

Fig. 5. Time-series of absorption efficiency of total organic matter (OM), carbon (POC), and nitrogen (PN) by *P. magellanicus* fed Bedford Basin seston alone (left) and with 2 $mg \cdot l^{-1}$ clay (right).

MOLLUSCAN REPRODUCTIVE PHYSIOLOGY PROGRAM AT IFREMER

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ABSTRACT

This program had two main goals: firstly, development of improved techniques for spawning and secondly, development of quality indices of gonads of spawning adults. Research directed towards improvement of spawning included experiments to determine the effect of external factors such as photoperiod, temperature and food on gametogenesis, as well as hormonal stimulation of spawning and optimal conditions for oocytes at fertilization. Research on quality indices included experiments to find a relationship between structural, biochemical and physiological characteristics of adults, gametes and embryos. The aim of this research was to obtain diagnostic information on the state of health of broodstock. Research has been undertaken to determine if a relationship exists between calcification and rearing conditions, sperm mortality, gamete oxygen consumption and density.

ACID BASE BALANCE IN THE SCALLOP, *PECTEN MAXIMUS* (L.), DURING EMERSION

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ABSTRACT

The acid base disturbances accompanying a 72 hour emersion at 10°C were studied in the scallop *Pecten maximus* (L.). Haemolymph samples, obtained directly from the heart, showed a rapid decrease in PO_2 during the first 2 hours in air. This was accompanied by an increase in PCO_2 and an associated reduction in pH. This acidosis continued throughout the emersion period and appeared to be unchecked, despite an increase in the concentration of haemolymph bicarbonate. Changes in concentrations of other haemolymph ions were also measured. The observed acidosis seemed to be exclusively respiratory in origin and this was supported by analysis which confirmed the absence of any significant quantities of organic acids in the haemolymph. The unusual features of this emersion response may be important in the inability of this species to survive relatively short periods of exposure in air. The significance of these results to the live transport of *P. maximus* and the development of the Scottish scallop industry are discussed.

FERTILIZATION PHYSIOLOGY: RESPIRATION RATE OF *PECTEN MAXIMUS* GAMETES

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ABSTRACT

The rate of fertilization of eggs of the scallop *Pecten maximus* is highly variable in hatcheries. In order to obtain more consistent fertilization rates a research program was initiated on gamete quality. Because gamete quality cannot be determined by macroscopic indices, we attempted to measure respiration rate of scallop gametes. With sperm, results showed that spermatozoa activity is synchronous with oxygen consumption which is generally high depending on season and origin of the sperm. The first analysis of oocytes indicates that respiration rate is also a measurable parameter.

SUSPENSION FEEDING IN POSTMETAMORPHIC JAPANESE SCALLOPS, *PATINOPECTEN YESSOENSIS* (JAY): IMPLICATIONS FOR NURSERY REARING

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ABSTRACT

In the early nursery phase of scallop culture, postmetamorphic juveniles are raised to a size of several millimetres. Typically this results in survival of only a small percentage of larvae which were induced to settle. Preliminary investigations into growth and survival of juvenile Japanese scallops, *Patinopecten yessoensis* (Jay), showed that major mortality often occurs at a size of less than 1000 microns in shell height. The objectives of this research were to investigate development of feeding structures, feeding mechanisms and associated changes in the filter feeding ability of early juvenile Japanese scallops from the time of metamorphosis until the juveniles measured two millimetres shell height. Three approaches were taken:

1. measurement of ability of postmetamorphic scallops to remove various species of phytoplankton from suspension and ingest a variety of particle sizes;
2. a description of the ontogeny of the feeding structures with emphasis on development of the ctenidia;
3. observations of the transport and capture of suspended particles by the filter feeding structures within the mantle cavity.

Feeding rates in postlarvae were determined with a series of flow through chambers through which seawater containing phytoplankton was pumped. Eight species of phytoplankton ranging between 2-10 μ in diameter over a range of concentrations between 10,000-50,000 cells per ml were used. Juvenile scallops were observed to clear all but the smallest, 2 micron diameter, species from suspension with maximum clearance rates generally observed at cell concentrations of 30,000-40,000 cells per ml. It is observed that filtration rates were extremely low from metamorphosis until a size of 400 microns shell height. Between 400 and 600 microns there was a sudden increase in filtration ability at all cell densities. Filtration rates increased slightly to 1000 μ and logarithmically between 1000 and 2000 μ shell height. These data suggest that juvenile scallops do not become efficient filter feeders until approximately 600 microns shell height. Analysis of the development of the ctenidia in postmetamorphic scallops was performed using scanning electron microscopy and light microscopy histological techniques. The filaments of each inner demibranch arose from three ctenidial buds present in the pediveliger. With initial formation of the dissoconch shell, the filaments increased in length, and ciliation increased along the lateral and then the frontal surfaces of the filaments. The filaments were connected at their distal ends by ciliated junctions. The paired demibranchs extended dorso-ventrally as they grew with new filaments arising as buds at the distal ends of the demibranchs. The ordinary filaments reached their maximum length prior to reflection when there were 8-9 filaments at approximately 600 μ shell height. Fine junctional cilia on the distal tips of the filaments meshed with those of the opposing demibranch, resulting in the mantle cavity being divided into infrabranchial and suprabranchial chambers. The primordia of the outer demibranch filaments were first observed at approximately 1000-1200 μ shell height. Growth and ciliation of the ordinary filaments of the outer demibranchs followed that of the filaments of the inner demibranchs. When

juveniles were approximately 2 mm shell height, the filaments of the inner and outer demibranchs were almost equal in size and degree of reflection with each demibranch having approximately 35 - 40 filaments. Adult structures such as folding (plication) of the demibranchs and filaments resembling principal filaments or marginal food grooves at the ventral margins of the demibranchs were not observed. Direct observations of feeding behaviour are important in understanding the processes by which particle capture occurs and by which feeding and particle selection is regulated. Observations of feeding behaviour were performed by tethering juveniles prior to 600 μ shell height in a flow through chamber and observing particle flow within the mantle cavity with video microscopy. Particles moved through the interfilamentary spaces into the suprabranchial cavity via the through currents and were not retained on the ordinary filaments. Particles were then directed orally towards the labial palps. Particles which arrived at the labial palps free in suspension were ingested or rejected. The juvenile gill prior to 2000 μ shell height was filibranchiate, homorhabdic and non-plicate and juveniles utilized unique hydrodynamic mode of particle capture. Morphological descriptions, particle clearance data and behaviourial observations suggest that until the formation of a simple functional gill apparatus at approximately 600μ shell height, *P. yessoensis* juveniles are unable to efficiently capture phytoplankton. Observed increases in particle clearance ability were associated with initial coordination and function of the 8-10 ctenidial filaments present. High mortality before 1000 microns may be the result of the inability of the juvenile to capture enough food to offset a reduction in energy to meet metabolic and growth requirements before the gills become effective. Survival through this early developmental period requires that energy reserves sequestered during larval growth are sufficient to support growth until the initiation of filter feeding at 600 μ shell height.

GROWTH OF JUVENILE SEA SCALLOP, *PLACOPECTEN MAGELLANICUS*, UNDER SUSPENDED AND FREE RANGE CULTURE CONDITIONS

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ABSTRACT

We tested the hypothesis that juvenile scallop growth was enhanced in suspended culture relative to bottom culture. Hatchery-reared sea scallops, *Placopecten magellanicus*, (22.2 ± 0.1 mm mean (±SE) shell height) were grown, unfettered on the seabed (6-9 m depth), and in pearl nets (6 mm mesh size) at a density of 100 per net, 3 m above the seabed, at two sites in Lunenburg Bay, Nova Scotia, Canada, from March 1992 to March 1993. Maximum and minimum mean (±SE) water temperatures were 15.5 ± 0.07°C and -1.7 ± 0.01°C in mid-summer and mid-winter, respectively. Particulate organic matter concentration, expressed as a percentage of total particulate matter, varied within 3.1% in late fall and 51.7% in mid-summer. Chlorophyll concentration ranged from 0.1 $\mu g \cdot l^{-1}$ in mid-spring to 4 $\mu g \cdot l^{-1}$ in late winter. Shell and tissue growth rates peaked in mid-summer and decreased to the lowest values in winter, although growth never stopped. Monthly measurements of shell heights (N = 100 approx.) made on individually-tagged scallops yielded overall mean (±SE) growth rates of 0.07 ± 0.003 $mm \cdot d^{-1}$ and 0.09 ± 0.004 $mm \cdot d^{-1}$, for suspended and bottom culture, respectively, at an open bay site, and 0.08 ± 0.003 $mm \cdot d^{-1}$ and 0.07 ± 0.004 $mm \cdot d^{-1}$, respectively, at an enclosed channel site. There were significant differences in shell growth rates between both sites and between both culture methods in most of the months (2-way Anova, $P<0.05$). Mean (±SE) final muscle dry weight, total soft tissue dry weight, and whole weight, also from monthly measurements (N=20), for suspended and bottom culture, were 0.44 ± 0.04 g and 0.56 ± 0.04 g, 1.01 ± 0.09 g and 1.22 ± 0.08 g, and 7.08 ± 0.44 g and 12.19 ± 0.63 g, respectively, at the open bay site. Significant differences were found between suspended and bottom mean final muscle dry weights, and also between suspended and bottom mean final whole weights (t-test, $P<0.05$), but differences in suspended and bottom mean final total soft tissue dry weights were not significant (t-test, $P>0.05$). Despite significant differences between environments, scallops growing on the seabed did not suffer reduced rates of shell and tissue growth.

IN SITU MEASUREMENTS OF BIVALVE SUSPENSION FEEDING: COMPARISON BETWEEN RATES OF MUSSELS AND SCALLOPS

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ABSTRACT

The objective of our project in OPEN (Ocean Production Enhancement Network) is to combine oceanographic data with studies on scallop, *Placopecten magellanicus*, physiology to produce an integrated production model for carrying capacity at aquaculture sites in Atlantic Canada. Little is known about the relationships between the quantity and quality of suspended food particles, scallop feeding activity and growth rates. However, there are data available on some of these relationships for the blue mussel, *Mytilus edulis*. Some of our studies were therefore designed to directly compare feeding responses in scallops and mussels. It is difficult to predict the animal's feeding response to the natural food supply, which consists of a complex mixture of organic and inorganic particles, from measurements of particle uptake made only in the laboratory. To measure feeding activity as realistically as possible we developed a new method to measure rates *in situ*. By continuously recording physical conditions and measuring food quality during our feeding studies, we are able to correlate observed differences in mussel and scallop feeding activity with fluctuations in environmental variables.

DAILY GROWTH RIDGES IN POSTLARVAL GIANT SCALLOP, *PLACOPECTEN MAGELLANICUS*

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ABSTRACT

Postlarval giant scallops, *Placopecten magellanicus*, were examined for daily growth ridges and growth rates by marking the dissoconch shell with Alizarin red dye. The surface of the left valve of postlarvae comprised concentric ridges, each consisting of a series of irregularly-shaped raised nodules. Ridges were clear and distinct in newly settled scallops between ≈0.25 to 2.0 mm shell height. The shell of postlarvae >2 mm was pigmented and ribbed and ridges were no longer distinguishable. Estimated age was significantly correlated with actual age, suggesting that growth ridges were produced daily, under the environmental conditions of Passamaquoddy Bay. Mean growth rate ranged from 32 to 57 $\mu \cdot d^{-1}$ and was proportional to size and age, but growth of individual scallops showed no coherence in their daily growth patterns. Short-term growth ridges in postlarval giant scallop can be used to determine age and can be applied to comparative growth, mortality, and recruitment studies of newly settled individuals <2.0 mm (≈40 days old, post-set). The high accuracy and precision of age determination for postlarval scallops differs from studies of short-term internal growth increments of bivalve shells and larval fish otoliths.

MICROALGAE AND BACTERIA IN REARING *PECTEN MAXIMUS* LARVAE

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ABSTRACT

Pecten maximus larvae fed monospecific diets of *Pavlova lutheri*, *Porphyridium cruentum*, *Rhodomonas salina* (3C), *Isochrysis galbana* (Clone T. Iso) and one species isolated from the pond of Argenton experimental hatchery, were cultured in similar media and at similar cell concentrations as those used to culture the standard mixture (*P. lutheri*, T. *Isochrysis*, *S. costatum*), except for *P. cruentum*, which could not be grown under these conditions, and the unknown strain from the pond. This unknown strain from the pond gave the best results in monospecific diets, as well as improving the results when added to the standard mixture. This might explain why better results were obtained raising larvae using this water compared to water from the open sea in the experimental hatchery (Samain et al. 1990). Vitamin and fatty acid composition of this strain is under study. Gelatin acacia artificial lipid microcapsules were fed to larvae to investigate fatty acid requirements. They were ingested and digested which permitted further studies. Vitamin transfer from algae to larvae was investigated and it was found that thiamine could be limiting under our conditions. Crude extracts of digestive tracts from *T. philippinarum* and *P. maximus* showed lysozyme activities. Bacterial strains isolated from rearing tanks, particularly vibrios, were digested better *in vitro* when added to these extracts than when added to egg lysozyme. Experiments with some of these strains labelled with C_{14} showed they were ingested and digested by larvae. Effects of these bacterial strains on larval growth when cultured under axenic conditions were either positive, neutral or detrimental. Vitamin content of bacteria that gave positive results will be studied. Chloramphenicol was found to be necessary during rearing cycles and acts to reduce the diversity of microflora and also to deplete production of bacterial exoenzymes.

TEMPERATURE EFFECT ON OXYGEN CONSUMPTION IN THE SCALLOP, *ARGOPECTEN PURPURATUS*

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ABSTRACT

The scallop *Argopecten purpuratus* is distributed along the Pacific coast from Nicaragua to Central Chile (12° 40' N to 36° 40' S), with commercially exploited natural populations occurring mainly in Peru and Chile. "El Niño" Event (ENE) 1982-83 produced a drastic decrease in most natural benthic shellfish populations in Peru; however, there was a huge increase in scallop populations which supported a brief intense fishery. The ENE of 1982-83 was characterized in Peruvian coastal waters by salinities of <34.8 ppt and temperatures near 30°C, together with low nutrient content and extremely low productivity but normoxic conditions in waters close to the bottom. The effect of the 1982-83 ENE was also strong in northern Chilean waters, but was much less evident in Central Chile (36° 40' S). The effect of temperature on the metabolism of the adult (shell size > 6 cm) *A. purpuratus* was examined at 8, 14, 18, 21 and 27°C in animals collected at Coquimbo (30° S) and Valparaíso (33° S). Results showed that scallops acclimated at 14°C behave typically as oxyconformers at PO_2 = 160-60 Hg, with greater metabolic rates at high temperatures and larger Q_{10} values (>3) in the 14-21°C temperature range. No differences in metabolic activity were observed between the two populations.

PRE- AND POST-METAMORPHIC CHANGES IN ENERGY OF THE JAPANESE SCALLOP, *PATINOPECTEN YESSOENSIS* (JAY)

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ABSTRACT

A mix of *Chaetoceros calcitrans* with *Thalassiosira pseudonana* (diet A) and these algae mixed with Tahitian *Isochrysis* (diet B) were fed to the scallop from d 17 to 89 post-fertilization. An assessment of the biochemical composition of mature pre-metamorphic larvae, immature pre-metamorphic larvae, and post-metamorphic juveniles of the Japanese scallop, *Patinopecten yessoensis* (Jay), provided information on the accumulation and expenditure of energy during scallop development, and an explanation for high mortality in post-metamorphic juveniles.

INTRODUCTION

Major anatomical change occurs in bivalves during embryogenesis and metamorphosis and survival beyond these developmental stages depends to a large extent on the stored energy reserves in the bivalves. During embryogenesis of *P. yessoensis* 49% of the energy originating in the eggs is lost, and of this loss 74% is expended on shell formation in the D-larva (Whyte et al. 1991). Reliance on reserves in the egg continues during early larval development when transition from endogenous to exogenous food occurs (Whyte et al. 1987). Accumulation of stored energy reserves in late larval development depends on the balanced content of macronutrients in the algal diets, and energy levels attained by the pre-metamorphic larvae reflect the nutritional value of the microalgae supplied (Whyte et al. 1989). These reserves in turn fuel the process of metamorphosis, the second major anatomical change, when disintegration of the velum limits locomotion and inhibits feeding by the scallop (Hodgson and Burke 1988).

Even when ontogenic cues provide for abundant settlement and metamorphosis, frequently less than 5% of early post-metamorphic *P. yessoensis* survive (O Foighil et al. 1990). Other cultured bivalves succumb to this common post-metamorphic mortality (Loosanoff et al. 1966; Castanga and Duggan 1971). Although energy reserves in pre-metamorphic larvae fuel the major anatomical changes during metamorphosis, a continued reliance on these reserves during post-metamorphic juvenile growth is required in the rock scallop, *Crassadoma gigantea* (Whyte et al. 1992). In this study on the Japanese scallop, *P. yessoensis*, the energy components in mature and immature pre-metamorphic larvae and in post-metamorphic juveniles, provides information on energy mobilization during and after metamorphosis that explains, in part, the high mortality in post-metamorphic juveniles.

MATERIALS AND METHODS

Chaetoceros calcitrans (Paulsen) Takano, *Thalassiosira pseudonana* (clone 3H), Hustedt Hasle and Heimdal, and *Isochrysis* aff. *galbana* Green (clone T-ISO; termed Tahitian *Isochrysis*) were grown as batch unialgal cultures. Seawater was enriched with nutrients based on the recipe of Harrison et al. (1980). The non-axenic cultures were maintained at 21 ± 1°C and irradiated continuously at 180 $\mu mol \cdot m^{-2} \cdot s^{-1}$ at the culture surface with full-spectrum fluorescent lamps (Vita-lite[R]). Tahitian *Isochrysis* was collected at the stationary phase of growth, above 6 x 10^6 cells·ml^{-1} and the other algae at a logarithmic phase, 0.8 - 5.0 x 10^6 cells·mlL^{-1}.

Conditioned adult *P. yessoensis* were induced by thermal shock (temperature raised by 6 - 8°C) to spawn in filtered seawater at 12°C. Larvae, from the same spawned parents, at the straight hinge stage (3 d post-fertilization) were added to fibreglass tanks (350 L) at a concentration of 1.50 - 1.75 larvae·ml^{-1}, and fed with equal numbers of *C. calcitrans* and *T. pseudonana* cells. Larvae at d 17 were screened, subdivided into group A that was fed diet A containing equal numbers of *C. calcitrans* and *T. pseudonana* cells, and group B that was fed diet B containing equal numbers of *C. calcitrans*, *T. pseudonana* and Tahitian *Isochrysis* cells. Total cell concentration of algae was increased progressively from 5 - 20 x 10^3 cells·ml^{-1} during larval development. A high proportion of premetamorphic larvae at d 21 post-fertilization exhibited signs of maturity and were fractionated into size classes using a 180 μ screen. Generally, mature setting larvae >250 μ diameter were retained and immature non-setting larvae <250 μ diameter passed the screen. Immature larvae were fed for a further 4 d and fractionated again into mature and immature larvae. This process was repeated for a further 2 d. Mature and immature larvae, collected at each fractionation were rinsed with cold aqueous ammonium formate (3.2%, w·v^{-1}) and freeze-dried for analyses. Group A and B mature larvae (5 x 10^6) were added separately to "setting" tanks (5400 L) containing suspended lines of artificial fiber cultch (Bourne et al. 1989). Diets A and B were supplied to the appropriate "setting" tanks and maintained at a replete level of 30 - 50 x10^3 cells·ml^{-1}, from d 21 to 89 post-fertilization. At intervals 6 lines of cultch were removed and exposed to air for 30 min to dry the byssal threads. The dried cultch on shaking released juveniles which were collected on screens, separated from extraneous material, such as empty shells, rinsed with cold aqueous ammonium formate (3.2%) and freeze-dried for analysis.

Analytical procedures used to measure insoluble ash, lipid, protein, and carbohydrate contents have been described in detail previously (Whyte et al. 1987). Energy conversion factors used for lipid, carbohydrate and protein were 35.24 kJ·g^{-1}, 17.16 kJ·g^{-1}, and 18.00 kJ·g^{-1}, respectively (Beukema and De Bruin 1979).

RESULTS

Larger larvae at d 21 exhibited signs of maturity - foot extension while swimming, development of primary gill filaments, and 10 μ eyespots - and were screened by size into mature and immature pre-metamorphic larvae. On d 21 group A and B mature larvae had the highest total energy, about 7.6 kJ·g^{-1}, of all the pre-metamorphic larvae (Fig. 1). Lower total energy in immature relative to mature larvae and the decline in total energy of mature larvae from d 21 to 27, reflected more variation in lipid than in protein or carbohydrate reserves. The lowest value, 5.6 kJ·g^{-1}, for d 27 immature larvae in group A, was considered to approximate the energy level at which larvae are unfit to undertake setting and metamorphosis. No consistent correlation was evident between protein energy, the major component, and age or degree of maturity of the larvae (Fig. 1).

Profiles of total energy in group A and B scallops from d 17 to 89 are presented in Fig. 2, with d 21 larvae represented by values for mature larvae. Total energy in group A and B larvae increased from d 17 to 21 at 0.2125 and 0.2300 $kJ \cdot g^{-1} \cdot d^{-1}$, respectively, suggesting that diet B provided more nutritional energy. As the scallop developed from pre-metamorphic larvae to juveniles the total energy levels declined. Energy loss at metamorphosis, d 21 to 26, for both group A and B larvae was 0.1700 $kJ \cdot g^{-1} \cdot d^{-1}$. A similar energy loss occurred in the two groups of post-metamorphic scallops during the next 7 d and losses continued at different rates to d 54 when values were again almost identical at 3.07 $kJ \cdot g^{-1}$ (Fig. 2). The period from d 26 to 54, considered early juvenile development, resulted in average losses of 0.1286 and 0.1314 $kJ \cdot g^{-1} \cdot d^{-1}$, from group A and B scallops, respectively. From d 54 to 68 energy levels in both groups became more constant at 3.05 ± 0.09 $kJ \cdot g^{-1}$. However, further energy depletion occurred to d 89 to provide group A and B juveniles with 1.93 and 2.39 $kJ \cdot g^{-1}$, respectively (Fig. 2).

Insoluble ash content indicated shell deposition that was corroborated by the constant increase in measured shell size during transition of larvae to juveniles. In group A pre-metamorphic larvae insoluble ash and total energy increased to d 21 indicating that the rate of tissue formation had kept pace with shell deposition (Fig. 3). Loss of total energy as organic matter, during and for about 21 d after metamorphosis, resulted in an increase in insoluble ash from 49 to 75% dry weight. After this post-metamorphic period ash levels were stabilized and together with total energy remained reasonably constant to d 68, which indicated formation and stabilization in body tissue during this period. Conditions in both rearing tanks were obviously not conducive to fast energy assimilation as the ash content continued to increase above 80% by d 89, with consequent loss of energy (Fig. 3). A similar total ash and energy profile was obtained from the group B scallops (Fig. 4), again indicating shell and tissue formation at late larval development, which was followed by dramatically changing then stabilizing profiles of ash (shell) and energy (tissue) that mirrored each other during development of the scallop after metamorphosis (Fig. 4).

Percentage changes in total energy levels between different developmental stages of the scallop fed different diets are presented in figures 5 and 6. The changes in energy during embryogenesis and early larval development were abstracted from two previous studies (Whyte et al. 1987; Whyte et al. 1991). Level of energy in D-larvae from these earlier studies was different, reflecting broodstock conditioning, and the value presented in figures 5 and 6 is an average for energy in D-larvae. However, the percentage change shown at these early developmental stages is accurately represented. Energy levels in group A scallops declined from 7.53 to 1.93 $kJ \cdot g^{-1}$ from d 21 to 89, and the loss was derived 47% from protein, 45% from lipid and 8% from carbohydrate catabolism. Similarly, from group B scallops the 5.21 $kJ \cdot g^{-1}$ loss during the same period was derived from catabolism of 55% protein, 39% lipid and 6% carbohydrate in the body tissue. At each stage of scallop development the gain or loss in total energy was represented by the percentage derived from protein, lipid or carbohydrate constituents (Figs. 7 and 8). During embryogenesis energy loss was derived 47% from lipid, 45% from protein and 8% from carbohydrate. Catabolism of protein accounted for 74% of the total energy lost during early larval development. The gain in energy by premetamorphic larvae fed diet A consisted of 49% lipid, 47% protein and 4% carbohydrate (Fig. 7). Metamorphosis resulted in the loss of 20% carbohydrate, 69% protein and 11% lipid, whereas early juveniles catabolized 4% carbohydrate, 44% protein and 52% lipid. The use of lipid as a source of energy continued in later juveniles with a loss of 48% lipid together with 38% from protein and 14% from carbohydrate (Fig. 7). Similar results were obtained for the percentages of component energy in the gain or loss of total energy by group B scallops at different stages of development (Fig. 8). However, the pre-metamorphic larvae fed diet B showed an anomalous decrease in carbohydrate that could not be explained. Of importance, was the substantial use of carbohydrate energy, 19%, to fuel the process of metamorphosis (Fig. 8).

DISCUSSION

Lipid and protein were the main energy reserves accumulated in maturing larvae of *P. yessoensis*, although the latter remained the dominant reserve. This was in accord with the accumulation of stored reserves during development of the larvae of the larviparous oyster, *O. edulis*, the rock scallop, *Crassadoma gigantea*, and earlier studies on the Japanese scallop (Holland and Spencer 1973; Holland 1978; Whyte et al. 1987: Whyte et al. 1989; Whyte et al. 1990a). The first batches of mature, larger-size-class larvae in both groups were the most energetically competent to enter metamorphosis at 7.5 to 7.6 $kJ \cdot g^{-1}$. Similar conclusions were reached on a study of pre-metamorphic rock scallops (Whyte et al. 1992) and supported the general practise in bivalve hatcheries of setting only the larger first-maturing eyed-larvae, as experience had shown that later maturing larvae were generally poor setters with low percentage of post-metamorphic survival. Lipid more precisely reflected the nutritional condition of the larvae than either protein or carbohydrate. This corroborated conclusions from previous feeding trials on larvae of rock and Japanese scallops (Whyte et al. 1989; Whyte et al. 1990b), and on the larvae of the oyster *O. edulis* (Ferreiro et al. 1990).

Development and growth of *P. yessoensis* from pre-metamorphic larvae to juveniles was accompanied by energy loss principally after metamorphosis and was independent of diet supplied. For 25-26 d after settlement group A and B *P. yessoensis*, *C. gigantea*, and *O. edulis* lost 61, 54, 58 and 82%, of their total energy, respectively (Whyte et al. 1992; Holland and Spencer 1973). The higher energy expenditure in early juveniles of *O. edulis*, relative to both scallop species, was supported by the high 51% loss of total energy only 48 h after the onset of oyster metamorphosis (Rodriguez et al. 1990). In addition, the higher energy demand by the oyster explains the preferential accumulation of lipid by the premetamorphic oyster larvae (Holland and Spencer, 1973).

Increase in insoluble ash by 35 and 32% in group A and B *P. yessoensis* 26 d after settlement was greater than the 25 and 27% increases in insoluble ash in *C. gigantea*, and *O. edulis* 25 d after settlement (Whyte et al. 1992; Holland and Spencer 1973). This increase in insoluble ash, or shell, during early juvenile development suggests an instinctive formation of shell which is un-impeded by total energy depletion for about 25 d after settlement. Energy required to deposit shell in *P. yessoensis* and *C. gigantea* scallops is substantial at 18.8 and 17.6 $kJ \cdot g^{-1}$, respectively (Whyte et al. 1990b; Whyte et al. 1991). An early juvenile with insufficient energy remaining after metamorphosis to withstand further depletion from unchecked shell formation, would quickly succumb to energy exhaustion and death. Rapid shell formation in early post-metamorphic growth, observed in both scallop species and in the European oysters, is probably a protective mechanism common to all bivalves. Changes in the overall energy levels throughout development of *P. yessoensis* from egg to juvenile were similar to those already established for the rock scallop, *C. gigantea* (Whyte et al. 1992) and elicit the following comments.

Embryogenesis, involving shell, tissue, and organ formation is fuelled by reserves in the egg that are derived from the parent. Conditioning of the broodstock is therefore vitally important to the nutritional quality and initial level of available energy in the egg. Subsequent energy loss in post-embryonic larvae illustrates the inability of the early developing larvae to assimilate exogenous food, even when adequate food particles are available, and imposes continued reliance on endogenous energy from the egg. Exogenous food particles are assimilated only at late larval development when energy reserves are accumulated prior to metamorphosis. Use of endogenous reserves during metamorphosis reflects the inability of bivalves to capture food particles during the 2 to 8 d period required to replace the larval feed organ, the velum, with the juvenile-adult feed organ, the gill (Holland 1978;

Waller 1981). Ingestion of food by post-metamorphic bivalves involves capture of the suspended food particles by the gill and their transport via cilia-transported mucus masses to the stomach (Beninger et al. 1991), where enzymes facilitate assimilation. Inefficiency in any or all of these functions would account for inadequate assimilation of food energy and a continued reliance on endogenous reserves accumulated prior to metamorphosis. Therefore, survival of post-metamorphic scallops is dependent, to a large extent, on the energy in the egg, the digestive efficiency of the pre-metamorphic larvae, and the food value of the algal diet supplied.

In both *P. yessoensis* and *C. gigantea* (Whyte et al. 1992) about 21 to 28 d after metamorphosis was required before food to energy conversion was sufficient to meet the metabolic demands of the growing juveniles. In *P. yessoensis* juveniles the energy assimilated from food particles must maintain the energy levels above an energy-competent survival threshold of about 1.5 to 2.0 $kJ \cdot g^{-1}$. Metabolic processes in living tissue generally involve lipid, carbohydrate, and protein constituents, usually in an integrated manner playing both structural and energy roles in the body. As yet, the percentage of each constituent playing a structural or energy role in scallops has not been clearly established. Thus, in this and previous *P. yessoensis* studies cited each constituent was converted to energy equivalents to provide a measure of the relative importance of each constituent at every stage of scallop development. The histograms (Figs. 7 and 8) clearly illustrate that lipid, carbohydrate and protein are associated with gains and losses in energy at all developmental stages of the scallop. Requirement for rapid energy to fuel the extreme anatomical changes during metamorphosis is provided by carbohydrate. Greater use of carbohydrate at this stage also spares lipid, the most efficient mode of energy storage, for the more prolonged energy requirement of post-metamorphic development. Assimilation of lipid by pre-metamorphic larvae is therefore a sound energy strategy, not necessarily for metamorphosis but for later development of the scallop.

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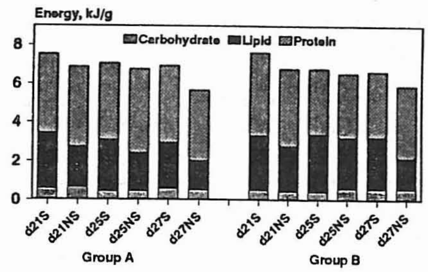

Fig. 1. Total component energy in two groups of setting (S, >250 μ) and non-setting (NS, <250 μ) larvae at different ages from post-fertilization (d) and fed diets A and B.

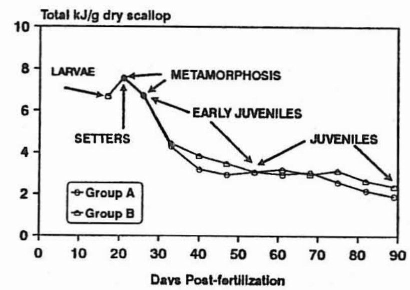

Fig. 2. Total energy in the scallop from larva to juvenile development when fed diet A and diet B.

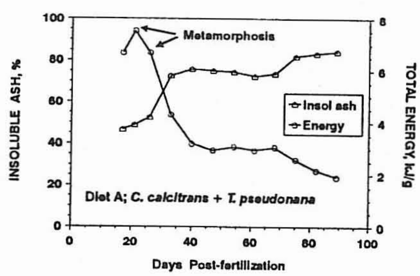

Fig. 3. Changes in the total energy and insoluble ash in the scallop (Group A) from larva to juvenile development.

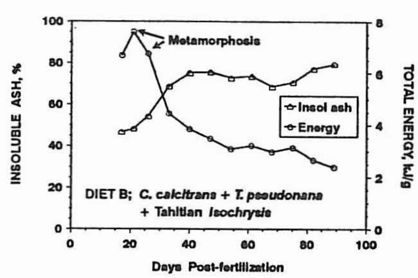

Fig. 4. Changes in the total energy and insoluble ash in the scallop (Group B) from larva to juvenile development.

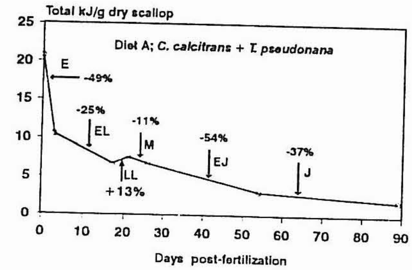

Fig. 5. Energy profile and percentage change in energy of the scallop at (E) embryogenesis, (EL) early larval, (LL) late larval, (M) metamorphosis, (EJ) early juvenle, and (J) juvenile stages of development when fed diet A.

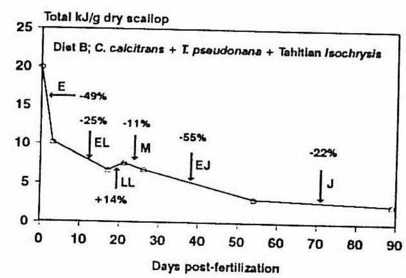

Fig. 6. Energy profile and percentage change in energy of the scallop at (E) embryogenesis, (EL) early larval, (LL) late larval, (M) metamorphosis, (EJ) early juvenle, and (J) juvenile stages of development when fed diet B.

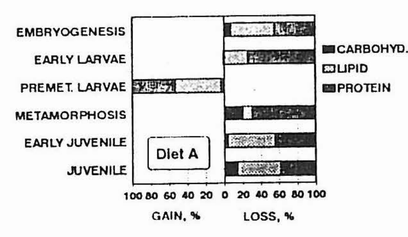

Fig. 7. Percentage of component energy in the total gain and loss of energy by the scallop at different stages of its development when fed diet A.

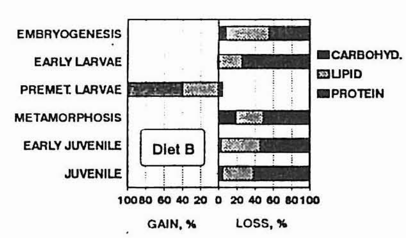

Fig. 8. Percentage of component energy in the total gain and loss of energy by the scallop at different stages of its development when fed diet B.