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A SUMMARY OF THE PROCEEDINGS OF THE HALIFAX SEA SCALLOP WORKSHOP,
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ABSTRACT

Tremblay, M.J. (editor). 1988. A summary of the Proceedings of the Halifax Sea Scallop Workshop, August 13-14, 1987. Can. Tech. Rep. Fish. Aquat. Sci. 1605: 12 p.

The proceedings of a sea scallop (*Placopecten magellanicus*) workshop which took place in Halifax, Nova Scotia on August 13-14 1987, are summarized. The workshop was of interest both to prospective aquaculturists and fishery biologists. Although sea scallops were the focus of the workshop, other scallop species were considered. The major subjects discussed were reproductive cycles, hatchery production, spat collection, grow-out, and the recruitment and stock structure of sea scallops.

RÉSUMÉ

Tremblay, M.J. (editor). 1988. A summary of the Proceedings of the Halifax Sea Scallop Workshop, August 13-14, 1987. Can. Tech. Rep. Fish. Aquat. Sci. 1605: 12 p.

Le rapport suivant contient un bref résumé des comptes-rendu d'un atelier portant sur le pétoncle géant (*Placopecten magellanicus*), qui a eu lieu à Halifax, Nova Scotia les 13 et 14 août 1987. L'atelier était intéressant à la fois pour les aquaculteurs potentiels et pour les biologistes travaillant dans le secteur des pêches. Bien que l'atelier ait porté sur le pétoncle géant, d'autres espèces de pétoncles ont été aussi discutées. Les thèmes principaux de l'atelier ont concerné: les cycles reproducteurs, la production en écloserie, le captage de naissains, l'élevage en mer, et le recrutement et la composition des stocks de pétoncle.

INTRODUCTION

The presence of a number of scientists in Halifax attending the Annual Meeting of the National Shellfisheries Association (NSA), and a Special Session on Sea Scallops (*Placopecten magellanicus*) within the NSA meeting, stimulated a two day workshop on sea scallops held on August 13-14, 1987.

Interest in sea scallops has grown substantially in recent years. From the perspective of the Atlantic fishery, sea scallops are among the most important shellfish. Scientific interest has recently focussed upon Georges Bank scallops, initially because of the Canada/U.S. boundary dispute, and subsequently because of proposed oil drilling on Georges Bank and the perceived vulnerability of the species. From the perspective of aquaculture, sea scallops show promise as a potential species along the Atlantic coast of Canada and the northeast United States. Sea scallops are indigenous, and the adductor muscle commands a high market price which could increase with a fresh, cultured product.

The workshop was organized as a series of panel discussions. A moderator chaired each session which consisted of 2 - 5 persons with experience in the topic of discussion. Although the species of prime interest was the sea scallop, other species (e.g. the bay scallop *Argopecten irradians*, the Japanese scallop *Patinopecten yessoensis*, and the Iceland scallop *Chlamys islandica*), were discussed where appropriate. The sessions are listed below in the order in which they took place.

1. Progress in the Hatchery Production of Scallops
Moderator: C. Couturier.
Panel: C. Blais, N. Bourne, S. Chapman, P. Dabinett.

2. Approaches for the Collection of Sea Scallop Spat
Moderator: J. Bonardelli.
Panel: M. J. Dadswell, K. S. Naidu.

3. Scallop Grow-out Strategies
Moderator: D. J. Wildish.
Panel: M. Gaudet, J. Grant, E. Rhodes.

4. Scallop Reproductive Cycles
Moderator: R. Thompson.
Panel: B. Barber, P. Beninger, J. Worms.

5. Scallop Recruitment and Stock Structure
Moderator: M. J. Dadswell.
Panel: K. Drinkwater, K. Fuller, R. K. Mohn, M. J. Tremblay, E. Zouros.

Although the workshop was videotaped, and the tapes were referenced extensively for this summary, no attempt is made here to reproduce the workshop verbatim. Instead, the document is organized by subject area, with less regard for the chronological order in which the discussion actually took place.

The idea for a scallop workshop arose from a series of informal meetings of sea scallop researchers working in the Halifax area. Both those meetings and the workshop were sponsored by the Biological Sciences Branch, Scotia-Fundy Region, Department of Fisheries and Oceans.

REPRODUCTIVE CYCLES

This subject was covered mainly in Panel 4. R. Thompson gave an introduction to the subject emphasizing the use and interpretation of various methods for the assessment of reproductive state. B. Barber gave a slide presentation of his work comparing the reproductive cycles of sea scallops in deep and shallow parts of the Gulf of Maine. P. Beninger presented a number of topics which require more research and/or careful consideration when interpreting scallop maturity data. J. Worms discussed some of the results of his study of scallop reproduction in the Southern Gulf of St. Lawrence. In addition, C. Couturier presented slides on his study of the relationship between scallop reproductive cycles and larval production in a hatchery environment.

Overview - Over most of their range, sea scallops have a discrete annual reproductive cycle. Major spawning tends to be in late summer and fall, with more southerly populations tending to spawn earlier. There is evidence of minor spring spawning in some areas. Scallops at different depths in the same geographic location may be out of phase. The scallop population on the Lower North Shore of the Gulf of St. Lawrence is unusual in that the major spawning occurs in July, the earliest reported complete spawning for the species.

There is also geographic variation in the timing of gametogenesis - in parts of Newfoundland, no gametogenesis occurs until the spring following spawning, while on the Lower North Shore of the Gulf of St. Lawrence, gametogenesis occurs during the winter. Timing in the Bay of Fundy appears to be intermediate, with some gametogenesis occurring after spawning, with a cessation over the winter.

Measurement of Reproductive State - A number of methods have been used to assess reproductive state. Among these are (i) Gamete Volume Fraction (G.V.F. = volume of gametes/total volume of gonad), (ii) Gonosomatic Index (G.S.I. = weight of gonad/weight of all soft tissues), (iii) Staging indices, and (iv) DNA content of gonad. All of these methods have their advantages and disadvantages and give different types of information. There is a move away from using staging methods alone as they are not precise enough to allow comparison between populations and years.

Nutrient Limitation of Reproduction - Sea scallops in a deep (~ 170 m) area of the Gulf of Maine did not spawn significantly over the course of one year. Only a few spent follicles and mature eggs were observed. It was suggested that reproduction in this population is nutrient limited. This population also showed slower growth of all body parts compared to the inshore population. R. Thompson noted that in general, sea scallops show much more conservatism in somatic tissue growth than in reproductive growth. Thus, most of the response to low nutrient conditions or stress is first apparent in reduced reproductive effort.

Occurrence of Abnormal Oocytes and Resorption Abnormal oocytes were noted in populations from Passamaquoddy Bay, the Gulf of Maine, the S. Gulf of St. Lawrence and coastal Newfoundland. Although there was some question as to whether such oocytes are in part an artefact of preservation, there was general agreement that abnormal oocytes are a real phenomenon, and that they are non-viable and likely to be resorbed. B. Barber felt that the resorption was evidence of continuous turnover of oocytes rather than the development of discrete cohorts of eggs which reach maturity and are released upon receiving an appropriate environmental stimulus. French studies of egg size frequency suggest that *Pecten maximus* produces discrete cohorts of eggs. Whether sea scallops actually differ from *P. maximus* with regard to egg turnover requires further study.

The resorption phenomenon has implications for both estimates of reproductive output in nature, and for broodstock conditioning. If the rate of resorption is high in some areas or seasons, fecundity estimates of sea scallops in nature may bear little relationship to the numbers of viable eggs actually released. As for broodstock conditioning, seasonal and nutritional factors affecting the rate of resorption will be of interest if maximization of the number of viable eggs produced per female is an objective.

Research Needs

- -frequency and significance of abnormal oocytes.
- -lipid/protein/carbohydrate metabolism as related to reproduction.
- -mechanisms of nutrient transfer to the oocyte.
- -the significance of maturation outside of the normal spawning period.
- -the reproductive strategies of sea scallops at the levels of population and individual.
- -endocrine control of reproduction.

HATCHERY TECHNOLOGY

This topic was covered almost exclusively in Panel 1. C. Couturier gave an overview of present methods, with emphasis on work done at Dalhousie University, Halifax, Nova Scotia. P. Dabinett then gave a slide presentation on techniques at the Marine Science Research Laboratory (M.S.R.L.), St. Johns, Newfoundland and was followed by N. Bourne, who related the rationale and techniques for the *Patinopecten* culture program at the Pacific Biological Station at Nanaimo, British Columbia. S. Chapman and C. Blais related their experiences with *Placopecten* in Maine and Rimouski respectively.

Broodstock for Spawning - Because broodstock is ripe in nature only at specific times of the year, the timing of spawning in the hatchery will be limited unless scallops are conditioned to spawn outside of their natural period by providing additional food. Work at Dalhousie University and M. S. R. L. has shown that scallops can be spawned throughout the year by conditioning, although the success rate varies. P. Dabinett reported better survival during the early larval stages when sea scallops were conditioned with cultured algae, particularly when they were left in nature long enough to take advantage of the spring algal bloom. For *Patinopecten*, there is a definite 'spawning window' of about 6 months. Outside of this period, spawning success is much reduced.

Spawning Techniques - Three main methods are in use of which the first is considered to be the least stressful and most reliable:

(1) Vigorous recirculation of sea water - Scallops are put in a shallow tray (~ 10 l), and the water recirculated at approximately 20 l per min. Scallops usually spawn within one hour.

(2) Thermal stimulation - Expose scallops to higher temperature (3 - 5°C above ambient) for short periods of time.

(3) Injection of serotonin (0.5 ml of 2 mM) into adductor muscle. Dependable, but more effort and cost.

At some labs methods (2) and (3) are combined.

Egg and Larval Rearing - Sea scallop eggs and larvae are usually reared at temperatures of 12 to 15°C in static systems. Water is usually filtered to remove particles greater than 1 to 2 *u*m, although S. Chapman found that double filtering of sea water through 10 *u*m bags was effective. At several hatcheries, seawater is treated with ultraviolet light and antibiotics to reduce the level of bacteria. P. Dabinett for example uses Neomycin sulphate during egg incubation, while Quebec researchers use antibiotics during the pediveliger and early post-metamorphic stages.

Sea scallop eggs (mean diameter of 68 to 72 *u*m) are incubated at 100 to 800 eggs cm^{-2}. Shallow trays appear to give the best survival.

The smallest shelled stage ('D' larva) is reached in 3 to 4 days, at a length of 100 to 115 *u*m. Survival to this stage ranges from 10 to 90% but is usually 50 to 60%. Once this stage is reached, larvae are transferred to containers ranging in size from 20 to 1000 litres. For *Patinopecten,* much larger tanks are in use - 5400 l. Initial larval densities are generally 1 to 5 larvae ml^{-1}. The water in containers is changed every other day or 3 times per week.

Larvae are fed a mixed algal diet at concentrations ranging from 20,000 to 50,000 cells ml^{-1}, depending on feeding frequency. A diet optimized for algal species and density has yet to be developed. Algal concentrations in use are generally regarded as *ad libidum* although the filtration rate of sea scallop larvae has not been studied. If culture conditions are good, the pediveliger stage can be reached in 20 to 35 days.

Metamorphosis and Settlement - The period of metamorphosis and post-settlement is when most mortality occurs. Many cultch materials, rearing systems, and chemicals have been tried with none proving 100% reliable. Cultch materials tried include shell material, fine mesh, monofilament gill netting, algae, Nitex™, and Kimram™ (fibrous cultch commercially available from Japan). Kimram™ gives the best results for *Patinopecten.* For the sea scallop, P. Dabinett found that Kimram™ was better than Nitex™, but no better than the tank surface.

Culture systems tried include upwellers, downwellers, stillwater, raceways, and slow water exchange. P. Dabinett has obtained settled scallops at densities as high as 1 per ml, 55 days after fertilization. His methods include the use of suspended containers with mesh on the bottom to which mature larvae are transferred. Chemicals tested to induce settlement include Gaba, L-Dopa, epinephrine, and red algal extracts. No consistent results have been obtained.

General Discussion - Although significant progress in sea scallop larval rearing is being made, reliable mass culture is not possible at present. It was suggested that because sea scallops are an offshore species, different culture conditions and water quality standards may be required compared with those developed for estuarine bivalves. The application of 'green thumb' modifications of these methods for the culture of sea scallops may be inappropriate. For this reason it may be necessary to do some basic work defining optimal conditions (e.g. temperature, rearing density, feeding level) for sea scallop eggs and larvae. A reliable technique for rearing larvae in small containers would be useful so that manipulation type experiments could be performed.

No obvious inter-annual differences in egg and larval viability have been observed for sea scallops, however good inter-year comparative data are not available. For *Patinopecten* the greatest difference in egg viabilty appears to be between seasons rather than between years.

The panel did not consider bacteria (*Vibrio*) to be a major cause of mortality in the larval culture of *Placopecten* or *Patinopecten*. P. Dabinett initially did extensive bacterial counts and found that numbers within cultures were lower than background levels where scallops were living. He thought ciliates may be more of a problem. N. Bourne reported that work at Nanaimo indicates that the Japanese scallop can survive in quite high concentrations of bacteria with no ill effect.

E. Rhodes described a diagnostic tool which he uses for judging the success of a particular larval batch - the growth curve. For healthy larvae it should be at least linear up to and through the point of settlement, perhaps with a slight pause at metamorphosis. If the growth rate declines well before settlement, this indicates problems exist with the culture.

Research Needs - There is a broad requirement for research in this area. Among the priorities are:

-reliable methods for achieving settlement and high post settlement survival.
-broodstock conditioning methods and the effect on larval and juvenile growth and survival.
-optimal rearing conditions.
-larval and early juvenile nutrition.

METHODS FOR THE COLLECTION OF NATURAL SPAT

This subject was discussed mainly in panel discussion 2. J. Bonardelli gave an overview of methods for the collection of scallop spat based on his experience in the Bay of Chaleur. Although contamination of collectors with the spat of iceland scallop has been a problem in the Bay of Chaleur, methods developed there are applicable to the sea scallop. M. Dadswell discussed his work in Passamaquoddy Bay and K. S. Naidu described his experience with scallop spat collection in Newfoundland.

Materials for Spat Collection - The substrate most used is monofilament gill netting, packed inside onion bags (500 g per bag). The gill netting can be new (expensive at ~ $6 per bag) or used. Onion bags are commercially available in Canada and Japan. Those available in Canada have larger mesh. In Passamaquoddy Bay smaller mesh onion bags have been used and M. Dadswell felt that a lot of spat would be lost after initial attachment if the larger mesh bags were employed. The larger mesh bags are used in the Bay of Chaleur, and spat counts after settlement and at regular intervals during removal indicate that such a loss does not occur there.

Although there has been a chance discovery of large numbers of scallop spat on a navigation buoy this is not a widespread phenomenon based on M. Dadswell's observations.

Deployment - If the substrate where collectors are to be placed has few large algal beds, spat collectors are strung from vertical lines. Where 'tumbling seaweeds' may foul collectors, the collectors are strung in such a way that they remain at least 2 m off the bottom.

Optimal Depth - Extensive work in the Bay of Chaleur indicates that in approximately 25 m of water, the best settlement observed was between 12 and 21 m. Reduced settlement was observed close to the surface and near the bottom.

Immersion Period - The immersion or soaking period prior to settlement appears to be an important consideration. In the Bay of Chaleur, collectors in the water 7 weeks prior to scallop settlement had 10 times as many spat as those in the water 3 weeks prior to settlement. This procedure is often referred to as conditioning the collectors.

Site Selection - Basic criteria for site selection in Newfoundland were learned from Japanese technicians in the early 1970's. Good sites tend to be small bays containing scallop beds with narrow sill entrances but with adequate inflow. If the bay has a gyre it may retain larvae and lead to consistently high settlement rates. Hydrodynamic considerations include placement of collectors perpendicular to the current direction, and in a location where larvae will be transported (if this is predictable).

Number of Spat per Collector - Number of spat per collector will vary widely with area, season, and year. Reported ranges for mean numbers of spat per bag were 30 to 40 on the Lower North Shore of the Gulf of St. Lawrence and 200 to 400 in Passamaquoddy Bay. In the Bay of Chaleur spat numbers were often higher, but a large percentage of the spat were Iceland scallops.

Starfish Predation - Predation by starfish within the collectors is a major problem in Newfoundland. In Passamaquoddy Bay, the problem can be overcome by placing collectors out after the peak in starfish settlement, which is usually earlier than the peak in settlement of scallop spat. Starfish predation in the Bay of Chaleur and the the Lower North Shore of the Gulf of St. Lawrence is not a serious problem. Lime has been successful in removing adult starfish from mussel beds in Maine, but the method would have to be modified considerably for use with collectors.

Removal of Spat from Collectors - This is one of the most labour intensive components of the spat collection process. Ideas posed as a solution included the use of a large trough and/or some type of mechanical shaker or roller which would allow scallops to fall through. If the scallop spat swim up (or at least detach), a current directed over the collectors may carry them downstream. Any method should try to exploit both scallop spat behavior and any morphological differences between the spat and other fouling organisms.

Research Needs

- -criteria for site selection.
- -optimization of all aspects of spat collection process - materials, timing and location of placement in water, depth, time of removal.
- -spatial and temporal variations in spat settlement.
- -procedures for dealing with starfish predation and fouling by competitors.
- -improved methods for removal of spat from collectors.

GROW-OUT METHODS

This subject was discussed mainly in panel 3, although much of the discussion from panel 2 extended to grow-out methods. In panel 3, D. Wildish introduced the subject, and was followed by E. Rhodes, who gave a slide presentation on *Argopecten* culture at the Milford Laboratory. M. Godin then summarized research on sea scallop culture on the Lower North Shore of the Gulf of St. Lawrence, and D. Wildish presented slides of the scallop grow-out project in Passamaquoddy Bay. Finally, J. Grant put forward some research requirements.

Bay Scallop (*Argopecten irradians*) Culture - Experiments on the bay scallop at the Milford Laboratory began in the mid 1970's. Initial bottom grow-out trials did not look promising, and subsequent research was directed at grow-out in suspended culture. Experiments were carried out to investigate the effects of temperature, density, and handling on bay scallop growth and survival. Bay scallops were hatchery reared and transferred to pearl nets at a size of 5 to 6 mm. Pearl nets were anchored to the bottom and buoyed up from there, rather than suspending them from surface buoys. Suspension from surface buoys leads to excessive movement of the pearl nets, which in turn leads to slower growth.

A temperature experiment showed that after a short period of acclimation, bay scallops reared in the hatchery at 20°C could be placed in the sea at temperatures of 5°C . Mortality was no higher than for scallops transferred later in the year, when temperatures were 10 and 15°C. This is a real advantage if hatchery produced spat are to grow to market size within one growing season.

Optimal stocking density for bay scallops in pearl nets is primarily a function of the desired terminal size. If terminal size is 15 mm, scallops can be stocked at 750 per pearl net. If a terminal size of 25 mm is desired, initial stocking density should be only 250 per pearl net. Abnormal shell development results if density is too high. This appears to be due to more swimming excursions (and therefore collisions) rather than to reduced food and/or oxygen.

After reaching a size of 25 to 35 mm, bay scallops were transferred to lantern nets for final grow out. At initial stocking densities of 20 per lantern net shelf, survival was 85%; at densities of 500 per lantern net shelf, survival was 55%. Growth of the shell and meat was also strongly related to stocking density. Excessive handling can also have detrimental effects on bay scallop growth and survival. At Milford, the approach to obtain harvestable bay scallops in a single grow out season is to put 5 mm hatchery raised spat in pearl nets in May, transfer them to lantern nets in July, reduce scallop density and remove predators from the nets in September, and harvest in November at a shell height of 50 to 60 mm. The minimum harvest size of 50 mm was reached with initial densities of 150 per lantern net shelf.

Sea Scallop (*Placopecten magellanicus*) Grow-out - Spat are usually transferred to pearl nets when scallops are 5 to 20 mm (6 months to 1 year in age). Other options are to leave the scallops in the collectors for a longer period, or in the case of hatchery reared scallops, transfer them to pearl nets at a smaller size. Both of these options have been tried on the Lower North Shore of the Gulf of St. Lawrence. There, small (0.5 to 1 mm) hatchery reared spat have been transferred to pearl nets and retained within by lining the nets with Nitex™ bags of 0.5 mm mesh size. Periwinkles are placed between the Nitex™ and the outer net to keep the Nitex™ clean. Once scallops reach a size of 40 to 60 mm, two options are available: growth in suspension or growth after relaying to the bottom.

Suspended culture may be in lantern nets or by "ear hanging" using Japanese blue cord or similar line. Most of the work in Canada has been with lantern nets although ear hanging has been tried on the Lower North Shore of the Gulf of St Lawrence and Port au Port Bay, Newfoundland. In Passamaquoddy Bay, an ongoing experiment of sea scallop growth in lantern nets versus bottom trays is in progress, with results expected at the end of 1988.

Growth rates in suspended culture are higher than on the bottom, but equipment costs are considerable (see section on Economics). Growth on the Lower North Shore of the Gulf of St. Lawrence is particularly rapid, where a size of 8 to 10 cm can be reached by the 3rd fall. An interesting aspect of culture in the Gulf of St. Lawrence is the possibility of harvesting in the winter through the ice. This may allow reduced transportation costs, with the added advantage of a seasonally high market price.

Bottom culture should be restricted to scallops which have reached a size which is sufficiently resistant to predation. Scallops smaller than about 40 mm may experience heavy predation mortality and losses due to scallops swimming out of the area may also be a problem. Bottom planting of 1 year old spat was attempted in St. Pierre, but few of the animals were retrieved. Careful choice of area and season may reduce such losses.

A characteristic of sea scallops which is very important to any consideration of bottom culture is their ability to move, particularly at a young age. This makes ownership rights tenuous at best and potential conflicts with the wild fishery may result. In Passamaquoddy Bay, M. Dadswell and others have observed scallops of 40 to 60 mm swimming extensively and perhaps undertaking migrations of at least a few kilometers. All agreed that scallops do move, but there was no consensus on whether or not scallops actually undertake directed migrations. Fences to keep scallops in (as have been used to keep predators out of oyster beds in Maine) may work but would be expensive. It was generally agreed that sea scallop culture on the bottom must be in bays which are tens of square kilometers in size - Passamaquoddy Bay for example.

A further consideration in bottom culture is the harvesting method to be employed. In Japan and France, conventional fishing drags have been utilized for this purpose.

Research Needs

- -criteria for site selection, with more consideration to hydrodynamics, e.g. rates of flushing and particle flux.
- -effect of such variables as temperature, salinity, stocking density, and handling on sea scallop growth and survival.
- -nutritional requirements in culture. Consideration should be given to the fact that scallops exist in the benthic boundary layer and therefore live amongst (and perhaps utilize) large quantities of non-living carbon as well as phytoplankton.
- -genetic selection studies. This is dependent on methods for routine breeding in the laboratory, but is necessary to develop suitable stocks for culture.
- -whether localized depletion of primary production can occur as a result of filter feeding.
- -fouling of rearing chambers.
- -control of scallop predators.

ECONOMICS OF SCALLOP CULTURE

This was a contentious issue and became part of the discussion in several of the panels. It was noted that when the value of individual animals is considered, sea scallops are not very highly priced. Assuming a meat weight of 20 gm (shell height of approximately 100 mm) and present Canadian retail price of $13 per kg, the price per individual scallop is about $0.26. Separate cost-benefit analyses have been done based on production costs in Newfoundland and in Quebec. Based on market conditions at the time of writing, the reports conclude that sea scallop culture can only be economic if spat are collected from the wild and culture is on the bottom rather than in suspension. In Japan suspended culture is still practiced, but there appears to be a trend towards bottom culture. This has also been the approach in France, where hatchery produced scallops (*Pecten maximus*) have been produced to seed the bottom for eventual harvest by the traditional fishery.

There were two major points made to counter the above rather pessimistic view. First, the market price for cultured sea scallops may well be considerably higher than for those caught via the fishery. This belief is based on a fresher product, and the distinct possibility of developing a market for whole scallops, as exists in France. Second, estimates of production costs based on the present technology may well be too high. Development of cost effective technology, from the hatchery stage to the grow-out stage, may greatly lower production costs.

There have been no cost-benefit analyses done for the culture of other scallop species in Atlantic Canada. The bay scallop appears to have potential and the experience of commercial pilot projects in the U. S. and in Canada will be of real interest.

POPULATION STRUCTURE AND RECRUITMENT

These topics were discussed mainly in Panel 5. M. Dadswell went over the major questions and possible approaches for answering them. E. Zouros then introduced some genetic approaches for examining population differentiation, noting their advantages and disadvantages. He then reported upon a study of allozyme frequencies in sea scallops. K. Fuller described an extension of this work, the use of mitochondrial DNA. J. Tremblay then described studies of the larval distribution of sea scallops within the Gulf of Maine area and their bearing on the question of population isolation. K. Drinkwater followed with a review of large scale environmental effects on scallop recruitment. Finally, R. Mohn spoke on models of sea scallop population dynamics from the viewpoint of the fishery manager.

Population Structure - Questions as to whether geographically defined scallop stocks (e.g., Georges Bank) are (1) self sustaining and (2) genetically distinct, continue to be difficult to answer unequivocally. It may well be that the two questions are not strongly linked.

Methods for the discrimination of scallop stocks include morphometrics and meristics, tagging, and analysis of allozyme frequencies by electrophoresis. The first method has not been attempted rigorously, even though scallops from different areas are readily distinguished by appearance. To what extent morphometrics, and population parameters such as growth and mortality rates, are determined by genetics or environment is not well understood. Transplant experiments and crossing individuals from different areas would be of interest in this regard, both to fishery biologists and to aquaculturists.

Tagging of older scallops has been carried out by the Department of Fisheries and Oceans and although most animals moved less than 10 km over 1 year, some moved considerably further. Smaller scallops (<50 mm) may have a greater capacity for movement and extensive numbers of these have been tagged.

The use of genetic markers (e.g., isoenzymes) will probably not be sufficient to determine whether two populations interact enough to replenish one another. Genetic markers are neutral and thus not subject to selection pressures. Therefore even if gene flow between populations is very low, it may be enough to prevent genetic differentiation. This is good in the sense that if differences in isozyme frequency are detected, the chances are high that the populations are non-interacting and therefore self sustaining. If, on the other hand, no differentiation is apparent, no conclusion can be made as to whether the populations are self sustaining. With this in mind, E. Zouros gave the results of a study of the frequencies of electromorphs at five enzyme loci in eight populations of sea scallops. The genetic distance between populations was relatively small and there was no evidence of genetic differentiation among the populations. A potentially more sensitive approach to the examination of genetic differentiation is to look at the level of mitochondrial DNA. K. Fuller related progress in her application of the method to *Placopecten*. The basis of the method is the variation among populations in mitochondrial DNA fragment size after digestion with various enzymes. This work is in progress and appears promising.

The larval distribution of sea scallops provides evidence to be considered in assessing whether significant exchange occurs between populations. The pelagic stage has the greatest potential to move large distances in a short period of time (30 to 50 days). Evidence from 1985 and 1986 suggests that the exchange between Georges Bank and Browns Bank is not extensive, since few larvae were found in the Northeast Channel. Even a small amount of exchange between Georges and Browns Bank is sufficient to maintain genetic homogeneity however. Thus the Georges Bank stock may well be self sustaining, even though the isoenzymes of scallops there are not distinct from surrounding areas.

Environmental Effects on Recruitment - There are several studies which argue for an environmental effect on sea scallop recruitment. Most of these have used temperature as an environmental signal. Direct and indirect mechanisms have been put forward to explain the effect of temperature on recruitment. Direct effects include scallop mortality resulting from exposure to water masses of high temperature. Indirect effects include the correlation between high water temperatures and the extent of closed circulation in the Bay of Fundy, which may lead to greater retention of larvae within the Bay.

A 9 year cycle in abundance of Bay of Fundy sea scallops, which has been described in the literature and related to the 8.9 year tidal period, was commented upon by several of the panel members. First, the 8.9 year tidal period is weak compared to others such as the 18 year tidal period. It is thus difficult to understand how it could affect recruitment to such an extent. Second, using the 9 year cycle, a major year class occurring in the 1980's was not explained. Third, R. Mohn reported that in his reanalysis of a time series of Bay of Fundy scallop catch data, he found evidence for both 9 and 18 year cycles, the 18 year cycle being the stronger.

The effect of Gulf Stream eddies on sea scallop landings on Georges Bank has been investigated by K. Drinkwater and R. Myers using 11 years of data. No effect could be found.

Biological Effects on Recruitment - Predatory control of sea scallop numbers at some early stage of the life history is a possibility. After several years of collecting scallop spat in Passamaquoddy Bay, M. Dadswell has observed that recruitment to the spat stage does not vary as much as might be expected if environment was a controlling factor acting prior to this stage. Spat numbers per bag have generally averaged between 200 and 400, which represents a much smaller range than that of year class size within Passamaquoddy Bay. Given that starfish have been observed to have a significant predatory impact within spat bags, recruitment may well be strongly affected by predation acting after settlement.

Variability in factors related to the prespawning and spawning period such as maternal condition, fecundity, egg viability, spawning synchrony, and the proximity of males and females during spawning, was implicated as affecting recruitment success. Data on such variability is sparse however.

Another biological mechanism which could influence recruitment is less obvious and is dependent only on the stock's age structure interacting with age related fecundity changes. R. Mohn, citing Botsford's work on Dungeness crab, indicated that if this was the case for sea scallops, a 4 or 8 year cycle would be predicted - less than the 18 to 20 year cycle now regarded as most important.

Research Needs - Population structure and recruitment are very broad subjects and many items could be listed here. Among the priorites are:

-causes of mortality during the first 1 to 2 years of life, and age by which year class size is determined.

-effect of variables related to pre-spawning and spawning on the recruitment process.

-movement/dispersal at larval and juvenile stages.

-genetic techniques of sufficient power to determine whether or not geographic populations are isolated as far as recruitment is concerned.

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