

**Bay Scallops in Massachusetts Waters:
A Review of the Fishery and Prospects for Future Enhancement and Aquaculture**

Prepared by

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for

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&
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INTRODUCTION

Bay scallops (*Argopecten irradians irradians*) have long been a commercially important species in Massachusetts waters, making natural fluctuations in their abundance cause for conversation and concern. Many fishermen historically have depended on abundant scallop harvests to provide their yearly income, only to be disappointed or devastated when the scallop abundance has not matched expectations. Bad years have followed good ones, and good years have followed bad ones. It is unclear why a poor set may follow an abundant harvest year, since a high yield in one year suggests enough adults should exist to sustain the population prior to harvest. Similarly, no one knows where an abundant set comes from following years of low harvest when presumably few adults are present to provide seed. These observations suggest variation in the characteristics of a scallop-producing area may have far-reaching implications for scallop populations.

The virtual disappearance of scallops from large geographic areas is not novel to Massachusetts waters. In the 1950's and 1960's, Marshall conducted studies on the Niantic River, CT. His early work included, "An abundance of bay scallops in the absence of eelgrass" (1947), which was completed shortly after the eelgrass blight of the 1930's. He continued his work in the Niantic through the 1970's. By 1981 when Stewart et al. worked in the Niantic River, few scallops remained, and most work focused on restoration. Today there is only a remnant population of scallops in the Niantic River. Similarly, Sisson (1970) stated that scallop production in Rhode Island peaked in 1955, with harvest declining an order of magnitude by 1958, and nothing since. Russell (1973) suggested there was not a sufficient density of scallops to lead to a resurgence of the Rhode Island population. Peconic Bay, New York also was devastated with the occurrence of the "Brown Tide", a monospecific bloom of the alga *Aureococcus anophagefferens* (Sieburth et al., 1988). Except in pockets on eastern Long Island and at the most easterly harbors, natural bay scallop populations have virtually disappeared. Researchers and managers have been actively pursuing seeding programs since 1987.

The Southeast Massachusetts Aquaculture Center (SEMACE) became concerned about scallops when they realized low harvests had been the norm in Massachusetts waters in recent years and may indicate a continuous trend in many areas— even among normally productive towns including Nantucket, Edgartown, and Chatham. To determine whether this

trend was real, and if so, why it was occurring and what could be done to prevent future scallop declines, SEMAC contracted Sandra L. Macfarlane to

1. gather pertinent background information relative to the scallop harvest in towns within the region served by SEMAC;
2. summarize current scallop management strategies used by each Town; and
3. provide a comprehensive review of published research, grey literature, progress reports, and other pertinent documents, along with inputs from local and regional experts who may have insight into the current status of scallops in Massachusetts waters.

Ms. Macfarlane was an appropriate choice to perform this work, having twenty-three years of Massachusetts municipal experience working for the Town of Orleans as Shellfish Biologist/Conservation Administrator. Her experience included investigations into scallop habits and life history, shellfish management issues, hatchery/nursery operations, and effects of land use on marine systems.

The goal of this effort was to search for clues regarding the environment for scallop growth and survival Massachusetts waters by answering several specific and pervasive questions: What constitutes suitable habitat for bay scallops? Are current environmental conditions amenable to scallop recovery, or are scallops so sensitive to existing environmental perturbations that they cannot sustain a wild fishery without substantial culture techniques? If conditions are suitable, would active propagation efforts restore stocks to historic levels or substantially increase them from current levels? If conditions are unsuitable, can they be improved? Have restoration strategies and techniques proven affective (what types and where)? Are anthropogenic factors in some way (directly or indirectly) to blame for the scallop decline?

These questions are of primary importance because bay scallops represent a “way of life” in Massachusetts that is fast disappearing. Scallops are important commercially on a local level but they are also extremely important for recreational harvest. They represent a socio-economic link with the land and water that is a primary reason many people live in the region. Capuzzo and Taylor (1982) state that scallops are an important economic resource for the towns on Cape Cod, Martha’s Vineyard and Nantucket, MA. Shumway and Castagna (1994) state that “while this species represents only a minor component of US commercial

fisheries, it is extremely important to local economies.” As shellfish managers and scientists are well aware, while bay scallops may not be a significant addition to global scallop harvest, they are a very important economic and social consideration in Massachusetts. Restoration programs may ultimately be the principal method of continued harvest.

SCOPE OF WORK

- Task 1:** Compile and annotate a bibliography of the published bay scallop research relevant to the concept of bay scallop aquaculture – private and community based (Appendix A).
- Task 2:** Compile a bibliography (not annotated) of references on the effects of anthropogenic contaminants in the environment on bay scallop physiology and survival (Appendix A).
- Task 3:** Attempt to identify and characterize bay scallop aquaculture efforts reported in the “grey” literature, including progress reports, final project summations, and other information (Appendix A).
- Task 4:** Compile a summary of current management strategies and attempted/on-going restocking efforts for bay scallops within the region.
- Task 5:** Conduct interviews with bay scallop researchers, local shellfish managers, and harvesters to discuss anecdotal observations, develop a historical perspective on bay scallop stocks, and estimate local productivity.
- Task 6:** Compile the catch records for bay scallops (by town) within the southeastern Massachusetts area for the past twenty-five years and relate these catch records to actual population estimates within the region,
- Task 7:** Prepare a final report including the above information by March 15, 1999.

APPROACH & FINDINGS

Literature review & annotated bibliography (Appendix A)

In reviewing the literature, it became clear that work carried out on shellfish throughout the world (even if not specifically on bay scallops) may have a bearing on how

Massachusetts attempts to restore scallop populations. As a result, several general groups of documents proved to be critical references and are cited accordingly, including summary documents (books) and proceedings of the International Pectinid Workshops and Australasian Scallop Workshop. For example, the books by Shumway (1991), and Shumway and Sandifer (1991) were often cited because of their importance to the focus of this project, and their contents have been reproduced herein on a macroscopic scale. The International Pectinid Workshops began as loosely organized groups of people getting together to share ideas and experiences regarding scallop research. Through time, the meetings became more formalized and abstracts were published. Most of the early abstracts specify that they cannot be cited without permission of the author. These abstracts are listed to demonstrate the nature of past research rather than as citations per se, and some of the proceedings contain abbreviated papers that are longer and more detailed than abstracts. The Australasian conference occurred once and was an important contribution to the global picture. Only papers of particular importance to this project are included among the references to workshop documents.

Another source of information that was particularly valuable was the Indexed Bibliography of the Bay Scallop (*Argopecten irradians*) published by the National Marine Fisheries Service (NMFS) in 1987. Throughout the Bibliography (Appendix A), I have annotated specific works that I thought were particularly relevant to the project. These annotations centered primarily on papers dealing with restoration projects, natural recruitment, population studies, and field observation studies.

It must be emphasized that any literature review or bibliographic compilation of this nature will not include every piece of documentation ever written. These documents and others from the published and “grey” literature (but not including newspaper accounts or similar references), however, comprise more than 300 entries in Appendix A. Taken in their entirety, the references listed herein provide an overview of the natural history of the bay scallop and its relevance for culture. Most importantly, by reviewing the work of others on other species of scallops, we can glean information that may be germane to assessing and managing bay scallops.

Bibliographic categories & content descriptions

The Bibliography (Appendix A) is segmented into several components: bibliographies, books, papers and reports, miscellaneous information, and newspaper articles. These sections have been further divided into six subject categories as follows:

1. **Overview**—natural history, fisheries, bibliographies, general information.

Notable among these are the monographs by Risser (1901), Belding (1910), Gutsell, (1931), Robert (1978) and Fay et al. (1983). Because of the short life span of the bay scallop, all authors noted frequent periods of low density within the scallop's range, regardless of the actual species.

2. **Local and regional efforts**—restoration projects (including gear, methods, nursery culture), recruitment, population studies, field observations of scallop habits.

Recruitment failure—Several authors note the boom and bust nature of scallop populations and have speculated about the reason. Recruitment failure has consistently been mentioned due to a variety of factors including predation. Russell (1973), Sisson (1987), Sarkis (1991), Peterson and Summerson (1992), Wenczel et al. (1992), Mattei (1995), Minchin (1995), Slater (1995), Peterson et al. (1996), Cropp (1998) and Arnold et al. (1998) specifically mention the lack of broodstock as a major reason for recruitment failure. Sisson (1987) offers an explanation to the lack of scallops following a high production year. He says that juveniles can be food-limited and if they are, they will produce smaller offspring with fewer gametes.

Spat collectors— Effort has been expended over the past several decades to increase scallop production throughout the world. While the species may differ, the methods described in the papers can be useful to Massachusetts's efforts. In 1977, the National Marine Fisheries Service published a translation of a Japanese document detailing culture efforts in Japan. The book is called *Aquaculture in Shallow Seas* and it contains a section on scallop culture (pp. 288-364). One of the primary methods described for obtaining large numbers of scallop seed was the use of spat collectors, described in detail. From that beginning, many authors from around the globe have used spat collectors, most of them successfully. The only caveat seems to be that there must be enough broodstock in the area of the collectors to be successful.

Use of spat collectors has been reported by Buestel and Dao (1979-France), Kelley (1981-Nantucket), Franklin et al. (1983-England and Wales), Peyton et al. (1987-Alaska), Roman and Cano (1987-Spain), Dare and Bannister (1987-England), Dao and Buestel (1991-France), Peña et al. (1991-Spain), Sarkis

(1991-Bermuda), Dadswell and Parsons (1991-Atlantic Canada), Ambrose et al. (1992-NC), Tettelbach and Wenczel (1993-LI, NY), Dadswell and Parsons (1993-Atlantic Canada), Minchin (1995-British Isles), Parsons et al. (1995-Canada), Chauvaud and Thouzeau (1995-France), Bull (1995-New Zealand), Wang, (1995-China), McDonough and Roberts (1995-Ireland), Pereira and Molina (1997-Chile), Felix-Pico et al. (1997-Mexico), Cropp (1998-Tasmania), Ito (1998-Japan), Coleman (1998-British Columbia) and Arnold et al. (1998-FL).

Most spat collectors have been used for species that inhabit deeper waters rather than the shallow-dwelling bay scallop. Therefore, spat collectors are typically attached to ropes hanging from long lines. Materials used for the bags and the interior media used to collect spat were tested at various locations with varying results. Because some of these references are abstracts, conclusions are not always given. What is clear, however, is that the method of transferring the seed from the bags to an intermediate form of culture is labor intensive. If the bags are successful, hundreds of small scallop seed per bag can be obtained through these methods. Wang (1995) states that thousands of spat can be collected if there is enough broodstock available.

Once spat has been collected, some researchers have planted the seed freely on the bottom while others have used an intermediate culture generally consisting of some sort of hanging culture. Following the Japanese example, many researchers have used pearl and lantern nets, cages with mesh “envelopes” or other similar gear while others have used the ear hanging technique (holes drilled through the shell and the scallop is attached to a hanging rope by another “string” substance).

Nursery methods—Descriptions or mention of nursery methods can be found in Castagna et al. (1971-VA), Castagna and Duggan (1972-VA), Duggan (1973-VA), Buestel and Dao (1979-France), Claus, (1981-review paper), Kelley (1981-Nantucket), Franklin et al. (1983-British Isles), Capuzzo (1984-MA), Peyton et al. (1987-AK), Heffernan et al. (1988-GA), Karney (1991-MA), Dadswell (1991-Can), Peña et al. (1991-Spain), Fleury et al. (1991-France), Sarkis (1991-Bermuda), Dadswell (1993-Can), Caisey et al. (1993-France), Chew and Fusui (1993-China), Dao et al. (1993-France), Fang (1993-Japan), Fleury et al (1993-France), Giguère and Cliché (1993-Québec, Can), Giovanardi (1993-Adriatic Sea), Oesterling and DuPaul (1993-VA), Rice et al. (1993-Philippines), Thomson (1993-Tasmania), Fontana (1993-Chile), Barber and Davis (1995-ME), Minchin (1995-British Isles), Felipe et al (1997-Venezuela), Cropp (1998-Tasmania), McLoughlin et al. (1998-Australia), Bull (1998-New Zealand) and Ito and Byakuno (1988-Japan). The list shows the widespread global use of these nursery methods for growout of scallops. It was interesting to note that Belding used mesh cages early in this century in Massachusetts waters and while modified, they are still being used.

It is unknown whether all methods described in these papers are adaptable to bay scallop culture in Massachusetts, but there are several methods that probably

have not been tried, particularly those requiring deep water that may not be available near scallop producing areas.

Flow-through raceways—A series of papers were published by researchers at the Milford, CT laboratory of the National Marine Fisheries Service who evaluated the use of flow-through raceways for land-based nursery culture. These papers include Rhodes and Goldberg, (1978), Rhodes and Widman (1980), Rhodes et al. (1981a), Rhodes et al. (1981b), Rhodes et al. (1982), Widman et al. (1983), and Rhodes and Widman (1984a & b). Prior to the development of upwellers described in *Nursery Culture of Bivalve Molluscs* (1981; see books), raceways provided a method for high density grow-out.

Free planting—Throughout the literature there are references to free planting. Regardless of species, location, or primary predator, scallops do not survive well planted unprotected in the field at small sizes. While not conclusive with all possible permutations of size and time of transplant for bay scallops, it appears that predation is high on scallops transplanted at anything smaller than 40 mm shell height with 40 mm being preferable as the minimum size (Tettelbach, 1979 and Tettelbach and Feng, 1986). Slightly smaller stock can be successfully planted depending on other factors such as time of year and water temperature.

While planting directly on the bottom is an attractive method of enhancement because of the obvious lack of labor intensity required, intermediate culture is an essential element for the successful culture of scallops. Robinson (1995) states that there are very few examples where skipping the intermediate nursery step has been successful and he cites France and Japan as those examples. In both cases, there was thorough bottom preparation prior to free planting including predator removal and the projects have been massive endeavors in both countries. Those who have tried free planting with varying success are Russell (1971-RI), Castagna and Duggan (1972-VA), Gaucher and Lee (1972-CT), Buestel and Dao (1979-France), Morgan et al. (1980-CT), Stewart et al. (1981-CT), Dao et al. (1993-France) and Silina (1993-Russia). The primary reason for lack of success with free planting is predation from a host of predators including crabs, starfish and drills among other organisms.

3. **Field studies/natural habitat**—feeding, nutrition, predation, and mortality.

Eelgrass—Researchers have looked at the natural habitat of scallops to answer questions about their habits and their surroundings. Eelgrass is an important component of bay scallop existence. Marshall (1960) noted that the fishery of the Niantic River, CT began with the decline of eelgrass in the 1930's and Flanders Bay in Peconic Bay, LI, NY is noted for producing scallops in the absence of eelgrass (Tettelbach pers. com.). However, most populations of bay scallops rely heavily on eelgrass for attachment and refuge. Ambrose et al. (1992) gives a comparison of recruitment in collectors in and near eelgrass while Pohle et al. () describes the role of eelgrass as a refuge for juvenile scallops. Papers by Short et

al. (1991 and 1998) and Short and Burdick (1996) suggest anthropogenic coastal structures such as docks and piers may limit the extent of eelgrass beds.

Nutrition/feeding—In addition to phytoplankton in the water column, Davis and Marshall (1961) discussed feeding mechanisms including the utilization of benthic diatoms as a primary food source. Alber and Valiela (1995 and 1996) looked at organic aggregates in detrital food webs and suggested that this source is important for scallops.

Predation—Predation is also an important topic mentioned by many authors in their discussions of field nursery methods. Stewart et al. (1981) and Tettelbach (1985) as well as Barbeau et al. and Bricelj et al. (1995) all give accounts of scallop predation. The index of *Scallops: Biology, Ecology and Aquaculture* (Shumway ed., 1991) lists 5 references to predation and 54 references to predators. Minchin (1991) looked at predation in relation to sowing size of scallops and found that “scallop survival is better when sown close to the maximum capabilities of crabs in that area” and Auster and Malatesta (1991) found that prey size can be reduced as a result of predator interaction because of escape mechanisms used.

4. **Culture methods**—hatcheries, feeding, nutrition, and larval studies.

Hatchery culture has been used for bay scallops for decades. The early papers on hatchery development have not been included in this work. The papers by Castagna (1975) and Castagna and Duggan (1971), however, give detailed descriptions of methods used specifically for bay scallops. Karney (1991) describes a solar-assisted hatchery on Martha’s Vineyard used to supply scallops for five towns on Martha’s Vineyard. Hatcheries have been used for introductions of non-native species in several areas around the globe such as the introduction of the Japanese scallop *Patinopecten yessoensis* in France (Cochard et al. 1991). Recirculating systems were attempted 20 years ago (Epifanio 1976) but were not overly successful. Researchers at the Milford, CT laboratory are evaluating four separate types of bio-filtering media (Wickfors et al., 1998). Mann and Taylor (1977 and 1981) describe the growth of bay scallops in a waste recycling aquaculture system. Environmental parameters affecting reproduction, larvae and newly set juveniles have all been studied either in hatcheries or as a result of hatchery production.

Useful diagrammatic sketches of culture techniques can be found in a number of references including *Aquaculture of Shallow Seas* and *Nursery Culture of Bivalve Molluscs*. Specific papers, notably Mottet (1979), Peyton, (1987), Bull, Ito, Coleman (Australasian workshop 1998), and Bull (1995) are particularly practical.

5. **General biology**—growth and reproduction (including gametogenesis), experimental survival studies, genetics, salinity/temperature tolerance, and other environmental parameter studies based on laboratory experiments.
6. **Environmental perturbations/management**—pollutants, anthropogenic interaction.

Management issues are tackled in several papers including Capuzzo (1984), an often cited document containing abstracts from a workshop held at Woods Hole Oceanographic Institution. Morgan et al. (1980) asks some of the same questions as the current work and could be useful for further research. Russell (1973) is one of the most comprehensive seeding trial papers presented and delves into management questions throughout the document.

One of the most interesting papers, from a management perspective, was written by J.D. Thomson (1998 – Australasian conference) about Tasmania and discusses issues that are directly applicable to wild fisheries in Massachusetts.

Data from managers, fishermen, and researchers (Appendix B)

A survey questionnaire was distributed to 32 towns, two biologists and the State Shellfish Biologist from the Massachusetts Division of Marine Fisheries. A total of 25 responses were received representing 22 municipalities, 2 biologists (Martha's Vineyard Shellfish Group and Water Works, Westport) and 1 State Biologist (Appendix B). The responses from the state biologist were broad-based, and direct answers to the survey questions could not be quantified. Hence, his opinion was included in the analysis of subjective answers and interviews.

Survey Results

Survey Rationale—Harvest statistics from the Massachusetts Division of Marine Fisheries showed a widespread decline in scallop resources and a precipitous decline that occurred over the entire region in the mid 1980's with no substantial recovery. A major goal of the survey, therefore, was to ascertain whether there were common explanations for this apparent phenomenon.

Survey considerations—Aside from name of respondent, town, and length of time in office, the survey asked questions about observations that may have a bearing on the status of scallop populations. Respondents were also asked to note problems not identified through the survey and suggest other possible explanations for the decline in scallops.

Eelgrass—Since eelgrass is the major species of attachment (shelter) for juvenile scallops, and the eelgrass blight of the 1930's resulted in widespread

decline of the species, it is possible that recent declines in scallop abundance may be related to eelgrass loss.

Eelgrass loss can be caused by disease, (Short, F.T. and D.M. Burdick 1996; Short, F.T. et al., 1988; Short, F.T. et al. 1991), boating activity (Short et al. 1993), or coastal eutrophication (Short, F.T. and D.M. Burdick, 1996). Thus, questions dealing with epiphytic or macrophyte growth on eelgrass could discern links to coastal eutrophication. For example, rafts of floating eelgrass during the summer could result from motor boat activity, or be the result of wasting disease, and nutrient loading in estuaries may be reflected in changes in sediment composition, frequency of plankton blooms, and subsequent eelgrass loss.

Anthropogenic alterations—Many towns on the Cape and Islands have experienced tremendous growth in the last 30 years. This series of questions asks if the growth was on or near the water, within a mile of shore, and/or conversions from summer cottages to year round houses. Development and growth have been linked to nutrient loading which has been linked to water quality degradation and shellfish habitat decline by numerous studies (see *The Ecology of the Waquoit Bay National Estuarine Research Reserve*, 1996, M. Geist ed.).

Bacterial contamination—While scallops can be harvested from areas closed to harvesting of other species, bacteria in scallop areas may be a problem. High counts of fecal coliform bacteria are a sign of degraded water quality. Additionally, marketing whole scallops or “roe on” could be a problem if scallops were grown in waters of high fecal coliform bacteria.

Shell morphology—State law requires that scallops exhibit a “raised annual growth ring” to be harvested because this ring is assumed to delineate the end of the first year of growth. Early studies (Belding 1910), however, noted the inconsistent nature of this relationship between shell morphology and age among scallops in Massachusetts waters.

Normally, the raised ring is relatively easy to determine; the shell has a definite raised ridge and often shows a distinctive color change. Sometimes, however, a small raised ring can appear relatively close (~6 mm) to the hinge. These scallops are the result of a late spawning event where they did not have enough time to grow much before the onset of winter. They grow the following spring, but often they do not spawn. These scallops stop growing in the fall, put on a second ring the following spring, and spawn naturally. They often have so much energy expended in this spawning event that they do not live much past the summer and are generally unavailable for harvest. If they are harvested the first season with only the “ring at the hinge” there is a good chance that they did not contribute to the broodstock. If they also are the predominant type of scallops harvested, the following year’s set could be jeopardized.

A second shell-type problem is the occurrence of large seed that do not exhibit any growth ring. These are the result of a successful early spawn where there was ample food available for fast growth throughout the summer and fall. Because of their relatively large size, fishermen often assume these scallops will not survive to spawn the following summer, while they are already economically valuable the first season. If these scallops are harvested prior to spawning, however, the following season's set may be endangered (Macfarlane, 1991).

Restoration efforts—Individual towns have engaged in restoration efforts, and the survey included questions designed to identify methods and their success.

Survey analysis—Survey responses came from the following geographic areas for a 71% response rate.

- **Cape Cod:** Barnstable, Brewster, Bourne, Chatham, Dennis, Eastham, Falmouth, Mashpee, Orleans, Provincetown, Wellfleet, and Yarmouth.
- **Islands:** Nantucket, Chilmark, Edgartown, Oak Bluffs, Tisbury, and West Tisbury.
- **Buzzards Bay:** Dartmouth, Fairhaven, Marion, Westport.

The survey was based on observations. Respondents were asked if they had noticed specific changes over time in their respective area. Many respondents used a check mark indicating a positive response. When responses approached 50%, it was indicative of a trend.

Eelgrass—Responses to questions dealing with eelgrass, sediment changes, predators, and possible nutrient loading showed definite trends. In particular, these responses suggested eelgrass is declining (70%), epiphytic growth on remaining eelgrass is increasing (67%), and macrophytes are increasing in eelgrass beds (48%). Moreover, 17% of respondents reported seeing rafts of eelgrass as early as June while 22% and 44% saw them in July and August and 39% reported seeing rafts in September.

Rafts of eelgrass in early summer is not a positive sign of eelgrass health, and any scallops attached to eelgrass during the summer in such locations is in danger of being washed up on the shore with eelgrass rafts. This was interpreted as a disturbing tendency.

These data also suggested abundance of crabs increased (with 57% of respondents indicating such a trend), while respondents thought conch and starfish may be decreasing. Birds were most often cited as the type of animal that is increasing in abundance.

Anthropogenic alterations—Effects of urbanization were reported throughout the region. 65% of respondents indicated anthropogenic development affects the water as well as land (78%). Effects of urbanization may not be realized in estuaries for decades after development, given the sandy soil conditions of this region (see *Buzzards Bay Comprehensive Management Plan*, *Cape Cod Commission Regional Policy Plan*, *Pleasant Bay Resource Management Plan*, *The Ecology of the Waquoit Bay Estuarine Research Reserve* and others). Land on and near the water has already been saturated with development in many areas so that no new homes are possible. Accordingly, 26% of respondents said no new houses were being built on the water and 22% said that development was not taking place within a mile from the water.

The most static area with regard to urbanization was Buzzards Bay, while the Cape and Islands were more dynamic. The conversion of cottages to year-round homes has long been a concern with respect to nutrient loading since the increased usage of homes as a result of the conversions may as much as triple nutrient inputs to coastal waters. Respondents indicated that such conversion is widespread in this region (83%).

Many respondents reported a change in sediment from hard to soft (48%), but few reported a change from soft to hard (4%). Respondents also noticed increased phytoplankton blooms (44%) and an increase in motor boat activity (87%), with a concomitant increase in boat size (61%). Inlet dynamics have changed according to a number of respondents where 57% is a result of natural occurrence, 22% from dredged channels and 9% from jetties, seawalls or other structures.

Bacterial contamination—Fecal coliform has not been a major problem in scallop areas, and fishing areas have not been closed as a result (74%).

Shell morphology—Shell morphology was listed as an observed occurrence. Many towns have seen either large seed (48%) or ring at the hinge seed (57%) or both. They have allowed harvesting when appropriate (61%) (when a visible ring is present, regardless of position on the shell, or when seed have washed up on shores) and have not seen an enforcement problem (57%), but did not see a set the following year or the next year (44%).

Restoration efforts—A majority of the towns have been engaged in scallop restoration efforts (65%). They use hatchery stock almost exclusively and all of them broadcast the seed. However, 80% provide the intermediate nursery link first through cages (80%), upwellers (33%) and suspension nets (27%). They have used spat collectors (73%) and for the most part have found them to be successful. When not successful, they attribute the failure to fouling and lack of broodstock as the primary reasons. Many of the towns use volunteers successfully (39%) and 44% use the schools. Private scallop aquaculture is not well established (22%).

Towns of the region have been actively involved in restoration efforts (65% as noted in the survey results), and all respondents reported using hatchery-produced scallops for enhancement programs. In addition, 80% of respondents use nursery culture as a first step in enhancement. The literature points out quite convincingly that broadcasting scallops smaller than ~25 mm shell height, regardless of time of year, is relatively fruitless (most will perish). Those planted between 25-40 mm may survive if transplanting is carried out when the water temperature has cooled sufficiently, but survival is greatest if scallops are 40+ mm at transplant time. Transplants without predator control is risky at any time but especially if the seed is small and/or the water temperature is high. Nursery culture and predator control are time-consuming and labor intensive activities. Almost half of the towns have used volunteers.

Martha's Vineyard Shellfish Group—The Martha's Vineyard Shellfish Group has been in the forefront of municipal scallop aquaculture and scallop research for over 20 years, providing seed scallops to the towns on Martha's Vineyard. They have perfected hatchery techniques for their particular operation and routinely produce millions of juvenile scallops. They have also found that the number of scallops they can raise is not sufficient to supply what is needed to actually repopulate all of Martha's Vineyard and have, therefore, integrated their hatchery production with field enhancement techniques.

They have used various types of nursery culture methods and have found, like many others, that the culture is labor intensive but worthwhile. They have used cages, mesh "envelopes" in rack structures, and assorted hanging culture techniques. They have deployed spat bags and have created spawner sanctuaries in some areas. They have used burlap bags for small scallops to grow protected until the burlap disintegrates, giving the scallops a chance to grow in the wild, free of predation until they are large enough to survive. They have experimented with genetic tracing, producing orange, purple, striped and other shell colorations.

They have free-planted stock or have given stock to the towns to free-plant and have found that survival is variable. As a result, they have turned to "spawner sanctuaries" whereby adults are placed in cages with spat bags surrounding them to catch the set of the adults. This approach seems to make sense for bay scallops since the literature points to numerous successes with spat bags if there is broodstock in the area.

Westport Water Works Program & Shellfish Department—The most intensive use of volunteer labor is the Water Works program, where the community is actively involved in helping to solve problems of degrading water quality as a community activity. There is currently no other town that matches Westport for aggressive restoration efforts, both from the Water Works Project and the Westport Shellfish Department. They have deployed hundreds of spat bags, and

cages and conducted transplants. While no where near the pre-'86 harvests, there has been a small rise in landings. The project has evaluated methods of spat collecting, material and methods of filling the bags as well as methods of deployment. They have modified their program to include spawner sanctuaries and have found that certain sites can be used repeatedly with good results. In this case, they collect spat in the bags and place the seed in cages. All the scallops remain in the cages until they spawn, after which the Shellfish Constable plants the scallops in the wild fishery. Most importantly, the educational benefit of a community-based effort cannot be overlooked, and a value cannot be placed on this additional benefit.

Peconic Bay, NY—The largest restoration project for Bay Scallops has taken place in Peconic Bay, NY. Reports by Wenczel et al. (1992) and Smith and Tettelbach (1996, 1997) provide insight into the restoration effort of Peconic Bay. These papers include problems encountered, vagaries of nature, amount of effort required to re-establish spawning populations (especially when faced with the specter of a threat like brown tide) and the difficulty in rearing scallops in a cost-effective manner. This series of papers also gives an account of the sociology behind such restoration programs that have some community support.

Additional comments—Additional comments included noting potential problems such as leaking boat oil; an increase in number of I/O boats; use of TBT bottom paint, MBTE gas additives, CCA treated lumber, lawn care products and general chemicals; increased road runoff; presence of sewage treatment plants; increased abundance of Codium, Enteromorpha, limpets, and barnacles; overfishing; “mung slime” (common term of biological fouling with unknown, unidentified, or unrecognizable species of organisms); and predation.

The survey results suggest a decline in water quality throughout the region that may be a gradual reflection of increased urbanization or may be tied to other issues that are not yet clear. Other possible explanations suggested for the decline in scallops included weather patterns (warmer winters, change in water temperatures, ozone depletion, too much fresh water), loss of year class, lack of broodstock, brown tides, increased sedimentation, and increased predation. One respondent suggested that dry summers followed by cold winter with ice results in scallop loss. Another respondent made the observation that, rather than changes in water quality, there may be a more general and as yet unexplained pulse phenomenon that occurred around 1987 (a time of scallop decline throughout the region). In any case, from the number of respondents and the thoughtful responses, it is clear that scallops are an important issue in Massachusetts.

Furthermore, it seems consistently clear that widespread eelgrass loss is a potentially major source of scallop decline in the region. Scallops, which rely so heavily on eelgrass for the early stages of life history, do not do well in the absence of eelgrass. There are instances where eelgrass reportedly has not been

the key habitat for scallops. In Massachusetts, however, eelgrass and scallops have been intricately linked, with past declines largely related to wasting disease and present loss largely due to increased anthropogenic use of the water and adjacent lands, or a combination of both factors.

Interviews

In addition to the surveys above, personal interviews were conducted with the following individuals.

Managers—Mike Hickey, Frank Germano and Gerry Moles (Massachusetts Division of Marine Fisheries); Dave Fronzuto and Tracy Curley (Nantucket Marine Department); Alan Marcy (Dennis Natural Resources Department); Karin Tammi and Wayne Turner (Water Works Group, Westport); Ed Rhodes, Aquaculture Coordinator (National Marine Fisheries Service, Washington, DC) Jim Widman and Ron Goldberg (National Marine Fisheries Lab in Milford, CT).

The Massachusetts Division of Marine Fisheries (DMF) stated that natural significant populations of scallops showed up this fall (1998) in several offshore areas of Vineyard Sound and Buzzards Bay. There is no explanation of why, but there is hopeful speculation that the lengthy lack of scallops may be turning around. They had no explanation of the apparent region-wide decline in the 1980's either but were well aware of the scope of the decline. DMF also conducted a joint project with Taylor Sea Farms, a private company that provided seed scallops for transplant at three sites in Massachusetts waters. The report has not been issued, but the project was not as successful as had been hoped. Divers observed severe predation within 24 to 48 hours after transplant of ~25 mm seed.

The Nantucket Marine Department has used a hatchery, as well as culture techniques, for very small juvenile scallops. They are conducting numerous studies with respect to scallops and scallop habitat throughout the island. They are using spat bags, cages, hanging culture and spawner sanctuaries. They are very concerned about the lack of scallops since it provides such economic benefit to local residents. However, they also acknowledged that older fishermen admit that scallops have always been considered a bonus, not a stable way to make a living. Fishermen understood the variable abundance and rather than trying to change the cycles, they learned to live with them. They were always ready for scallop season but were ready to hang up their drags if the season did not produce the anticipated crop.

The National Marine Fisheries Service Milford, CT Laboratory conducted scallop research during the 1980's (results are published in papers by Rhodes, Widman and Tettelbach) much of it having to do with raceways as a means of juvenile culture. They also used pearl and lantern nets in their experiments. They have recently gone back to studying scallops after a hiatus of several

years. Currently, they are working with the technology associated with recirculating systems and automating algae production (see Wickfors, 1998).

Public aquaculturists—Rick Karney (Martha's Vineyard Shellfish Group); John Aldred (East Hampton, NY Shellfish Hatchery).

The Martha's Vineyard Shellfish Group is the longest continuous scallop producer in Massachusetts (see section on restoration above). They have observed many changes in the ponds of the Vineyard over time and have witnessed substantial development throughout the island. Their work has had widespread exposure throughout the international shellfish community, and Rick Karney is often cited as a valuable source of information regarding scallops.

The East Hampton (NY) shellfish hatchery produces oysters (*Crassostrea virginica*), quahaugs (hard clams) (*Mercenaria mercenaria*) and bay scallops (*Argopecten irradians irradians*). They are short staffed to do both hatchery work and nursery culture and, thus, cannot devote much time to field analysis. As a result, Mr. Aldred expressed concern about lack of recovery of transplanted seed.

Researchers—Dr. Steve Tettelbach, Dr. Sandra Shumway, and Dr. Maureen Krause, (Southampton College); Kim Tetreault, Gregg Rivara, and Chris Smith (Cornell University Cooperative Extension); Dr. Mark Luckenbach (Virginia Institute of Marine Science).

Southampton College had several scallop researchers on staff. Dr. Sandra Shumway is the current editor of the *Journal of Shellfish Research*, the official journal of the National Shellfisheries Association and has also edited two of the books noted in the bibliography of this project (Appendix A). Dr. Shumway recently relocated to the University of Connecticut, Avery Point. She questions the cost effectiveness and viability of restoration projects in general and especially those in areas with specific adverse conditions. Dr. Maureen Krause performed electrophoretic work that demonstrated that approximately 25% of the scallops in Peconic Bay (in the year of the experiments) originated as hatchery stock. Dr. Stephen Tettelbach worked at the NMFS Milford, CT laboratory prior to obtaining his position at Southampton College. He has been the person most associated with the scallop transplants in Peconic Bay and believes that scallop transplants are an important and integral component of a valid scallop restoration program.

Cornell University Extension is one of the partners in the Peconic Bay Scallop Restoration Project. They have devoted considerable time, funds, and energy into the program and believe, despite the problems, that it is necessary to restore the scallop to Peconic Bay (see papers by Smith, Smith and Tettelbach, and

Wenczel). Prior to the incidence of brown tide, the bay supported fishermen and produced over 300,000 lbs. meats.

Virginia Institute of Marine Science has a different dilemma. They have a small population of mixed breed scallops and are investigating the feasibility of creating a fishery. They are interested in the Massachusetts and Peconic Bay experiences, especially with respect to future costs of a fishery development program.

Scallop Harvests (Appendix C)

Appendix C includes a table of harvest statistics for each of the towns in Southeast Massachusetts and graphs that depict the total for four geographic regions (Fig. 1) and the state as a whole (Fig. 2). From the mid-80's there appears to have been a steady decline in scallop harvests throughout Southeast Massachusetts, including normally productive towns such as Nantucket, Chatham, and Edgartown. The "Brown Tide" occurred in Peconic Bay and Narragansett Bay at the same time, and it was also a time of active harmful algae blooms (Gary Wikfors, personal communication.)

Data on scallop harvests of the 1960's are relatively poor. In fact, data of the 1950's were so inconsistent that they were virtually useless for work of this type. Early shellfish managers used qualitative terms such as "good, banner, poor, bad", etc. to denote the type of crop. Because the harvest records prior to 1965 are poor, we have no way of determining the crops prior to 1965. From 1965-1969, harvests were low relative to later years but were about equal to the period of 1987-1992. Following the graph (Figs. 1 and 2), one might interpret the data as indicating a cyclic abundance and the 1990's represents a low end of the cycle. The literature, however, does not suggest such a cyclic abundance, and the data set does not cover a sufficient period of time to discern whether this pattern is real, but the concept is interesting enough for speculation.

Problems surfaced with the data gathering that require amplification. First, the scallop harvest season spans two calendar years. Records for a particular year, therefore, are actually the prior year's year-class and this needs to be taken into account when discussing specific years. Second, the nature of scallop habitat is such that an individual community can have several different scallop-producing areas. One area may be productive, however, while

another is not. These factors complicate the question of why there are or are not scallops in a given year.

DISCUSSION

Several major points can be made from this project covering a range of subjects.

Historical perspectives on Massachusetts scallops

1. Scallops are noted for high variability in abundance; highly productive years can be followed by low productivity and vice versa.
2. Scallop-producing areas within the same town can exhibit wide variability of abundance in any given year because localized differences exist between bodies of water in the same town.
3. Statistics do not give the full picture, and the harvest season spans two calendar years but one year class.
4. The statistical harvest record is too incomplete and inconclusive to determine if the variability has any cyclic pattern. Relatively good records span only 30 years.
5. In those 30 years, however, there has never been such an extensive or lengthy decline throughout the region.
6. Some as-yet unexplained event might have occurred in the mid-1980's to create a decline in the abundance throughout the scallop-producing areas. Though not identified at the time, there is growing suspicion that Massachusetts waters was host to the brown tide organism *Aureococcus anophagefferens* but not in the concentrations of Peconic Bay, NY or Narragansett Bay, RI.
7. Belding (1910) noted shell morphological variability by regarding when scallops set and what the raised rings actually mean with respect to time of birth. He also noted problems in the fishery with both large seed that did not spawn prior to harvest season and those with a small raised ring at the hinge.
8. Predator/prey interactions have been noted for many years but the actual predator assemblages may have changed; starfish were mentioned in early papers, crabs have been more recent and changes could result from unintentional introductions of non-native species.

9. Scallops have been a “fall-back” position for employment when abundant; fishermen several decades ago did not count on the availability but fully utilized the species when it was advantageous to do so while fishermen currently expect and anticipate banner years often.
10. Eelgrass declined in the 1930’s due to a disease. A similar disease affects eelgrass in some Massachusetts waters. Eelgrass is also declining as a response to land use and specifically nutrient enrichment directly tied to land development.
11. Enhancement programs in towns such as those on Martha’s Vineyard, Nantucket and Westport show positive results although the harvest statistics do not show the same level of success (except for Martha’s Vineyard).
12. Deeper waters off Falmouth and Martha’s Vineyard experienced high yields in 1998-9 and were among the few areas to support scallop populations during this year.
13. While Nantucket is often referred to as having the highest yields, Martha’s Vineyard consistently exceeded Nantucket and has greater habitat acreage (Belding, 1910). Clearly, the islands taken together are the principal scallop producers.

Field observations (various species)

1. Scallops, regardless of species, generally do poorly if free planted at a size smaller than 40 mm with a preferred size closer to 45 mm unless specific care is exercised to remove all predators within planting areas.
2. Scallops can set in areas devoid of eelgrass but prefer eelgrass as the setting media.
3. Scallops may set in spat bags with assorted media material if there is sufficient brood stock in the adjacent area. Spat bags deployed in and around eelgrass may show a higher number of settled larvae in bags outside eelgrass beds because eelgrass is the preferred habitat.
4. Cages filled with seed scallops deployed in the spring can have a set nearby and the method is especially visible to track if there are spat bags deployed.

5. Spat bags themselves cannot provide the amount of scallops necessary to repopulate a region but can certainly add to the population and can be used to collect seed for the next year's spawning.
6. Scallop mariculture is labor intensive.
7. In large plantings, a survival rate of 30% is considered acceptable. That figure gives some idea of the scale at which scallop programs have been reported. Financial considerations have not been mentioned except in reviews that look at private aquaculture ventures.
8. Most scallop culture occurs in deep water. Very little of the literature uses shallow water habitats for the experimentation.

Future Directions

1. The response of the towns to this survey indicates a strong interest in bay scallop restoration. Most managers recognize the economic boon to a town that has, sporadically or consistently, sets of scallops within its borders. The interest engendered from this project may spill over to cooperative projects among towns.
2. The financing of enhancement programs is problematic. The former state aid to cities and towns was to be used for shellfish propagation but often was shifted to the General Fund of a municipality and for that primary reason (among others), the state discontinued the program. A competitive grants program was initiated within the past 5 years that requires towns to submit proposals. Credit is given to projects that are cooperative. Shellfish projects generally require several continuous years and successful propagation programs can be conducted yearly with proper funding. Shellfish enhancement must have stable funding in order to be successful. Even for a species with a two year life expectancy, a program cannot be mounted with all the attendant requirements if funding is questionable.
3. Even with restoration projects outlined below, restoration will be slow and costly. Spat bags can attract hundreds of seed if there are adults in the area but they have to be removed and cared for by some method. The amount of seed recovered in spat bags probably will not repopulate entire areas. Spawner sanctuaries that use seed from spat collectors that are held over in the winter and used for spawning stock may

be the key to mass production by keeping adults in a relatively confined area.

Determining best areas for spawning sanctuaries will take time.

4. To determine the best management practices for areas most affected by harvest, scallop population structure and dynamics should be determined. DMF, the towns, and extension programs could work jointly to evaluate areas that have high numbers of either large seed or ring-at-the-hinge seed. If either type of seed is prevalent, whatever decision is made relative to harvest should be carefully monitored for future sets and population structure.
5. The strong interest in scallop restoration indicated in survey responses from various towns suggests joint restoration projects may be feasible and beneficial.
6. Volunteer labor is likely to be essential to restoration projects. Hence, both need and availability of volunteer labor should be evaluated prior to project inception.
7. To facilitate sharing and standardizing data collected by towns conducting restoration projects, The Barnstable County Shellfish Advisory Committee may wish to consider establishing a forum to encourage and maintain communication.
8. State and local data gathering methods need to be clearly defined and consistent to facilitate statistical analyses.
9. Scallop restoration programs will fail if land use issues are not addressed in the long term.

Suggestions for restoration projects

1. Given the success of spat bags (with broodstock in the waters), a modest program could be initiated using this technique.
2. Spawner sanctuaries (using caged seed until ready to spawn) in conjunction with spat bags is a relatively low cost method to begin a continuous restoration process and could be utilized in several towns simultaneously, given the ready availability of brood stock.
3. Hatchery stock that is not large enough to plant freely must be held in containers until the size exceeds predator preference even if it means overwintering.
4. Spawner sanctuaries, if used, rely on overwintered seed to produce the broodstock. The literature, however, is relatively sparse with references to overwintering. Hence,

assessment of various methods and locations are necessary to determine the efficiency and overall success of overwintering methods.

5. Towns that have areas that could be used for overwintering (that do not ice up) could work together with those towns that do not have such areas.
6. Joint efforts could be made to test alternative and new methods for scallop nursery culture, described in the literature, and adapt them to Massachusetts conditions.

CONCLUSIONS

There has not been such a widespread or lengthy decline in scallop harvests as in the past 30 years in Massachusetts. Reasons for the decline are speculative, but something may have happened in the mid-80's that precipitated the current situation. Over 50% of the affected communities in Massachusetts responded to a survey indicating the seriousness with which the towns view problems associated with scallops.

Culture techniques do exist and have been used successfully in Massachusetts and elsewhere with a variety of scallop species. These positive experiences suggest bay scallop abundance may be enhanced through active restoration programs. Since so many Massachusetts towns are already involved in some form of restoration, the future for this species appears bright although the restoration effort will be costly, labor intensive, and time consuming.

SEMAC wanted to have the background information to guide scallop management efforts. With this report in hand, SEMAC, MA DMF, and Massachusetts towns can decide on the appropriate courses of action for restoration of this important species.

ACKNOWLEDGMENTS

This document could not have been accomplished within the timeframe allotted without the assistance of many individuals, to whom I am very grateful.

Mike Hickey, Frank Germano, Gerry Moles, and Neil Churchill of the Massachusetts Division of Marine Fisheries provided harvest statistics, current mariculture status and a Massachusetts perspective. Rick Karney and Marcus Bradley, Martha's Vineyard Shellfish Group, provided documents and valuable insight into the scallop as it relates to town managed resources. Dr. Sandy Shumway (who made her extensive collection of published research available for perusal and copying), Dr. Maureen Krause, and Dr. Steve Tettelbach, Southampton College, provided expertise on several aspects of scallop biology and on-going projects. Jim Widman, Ron Goldberg, Dr. Gary Wickfors, and Dr. Tony Callabrese, National Marine Fisheries Service Laboratory, Milford, CT provided technical material and an historical perspective of scallop research as conducted at the laboratory. Respondents of the surveys, and those I interviewed personally, provided important viewpoints with respect to local and broader contexts. SEMAC and specifically Dr. Dale Leavitt, Bill Clark, and Bill Burt offered encouragement and counsel throughout the project. Special thanks go to Dr. Bill Walton for shepherding the manuscript to publication and to Dr. Ruth Carmichael for applying her patient editing and formatting skills to the final document. My thanks to all!

APPENDIX A

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Chapter 1: Evolutionary relationships among commercial scallops (Mollusca: Bivalvia: Pectinidae).

T.R. Waller

Chapter 2: The Biology of Scallop Larvae

S.M. Cragg and the late D.J. Crisp

Chapter 3: Functional Anatomy of Scallops

Peter G. Benninger and Marcel Le Pennec

Chapter 4: The Structure and Function of Scallop Adductor Muscles

Peter D. Chantler

Chapter 5: Physiology: Energy Acquisition and Utilization

V. M. Bricelj and S. Shumway

Chapter 6: Physiological Integrations and Energy Partitioning

R.J. Thompson and B.A. MacDonald

Chapter 7: Reproductive Physiology

Bruce J. Barber and Norman J. Blake

Chapter 8: Neurobiology and Behavior of the Scallop

L.A. Wilkens

Chapter 9: Diseases and Parasites of Scallops

R.G. Getchell

Chapter 10: Scallops and Pollution

Edith Gould and Bruce A. Fowler

Chapter 11: Scallop Ecology: Distribution and Behavior

A.R. Brand

Chapter 12: Genetics of Scallops

A.R. Beaumont and E. Zouros

Chapter 13: Population Dynamics and Management of Natural Stocks

José M. Orensanz, Ana M. Parma and Oscar O. Iribarne

Chapter 14: Fisheries and Aquaculture

Three European Scallops: *Pecten maximus*, *Chlamys (Aequipecten) opercularis* and *C (Chlamys varia)*

Alan D. Ansell, Jean-Claude Dao, and James Mason
Spain

G. Roman
Scandinavia
G. Jay Parsons, Michael J. Dadswell, and Eva Marie Rodstrom
Italy
Aristeo Renzoni
Yugoslavia
Drago Margus
Greece
Joseph J. Lykakis and Marie Kalathakis
China
Yousheng Lou
Philippines
A.G.C. Del Norte
Australia
D. Gwyther, D.A. Cropp, L.M. Joll and M.C.L. Dredge
New Zealand
Michael F. Bull

Sea Scallop: *Placopecten magellanicus*

K.S. Naidu

The Calico Scallop, *Argopecten gibbus*, Fishery of Cape Canaveral, FL

Norman J. Blake and Michael A. Moyer

Fisheries and Aquaculture of the bay Scallop, *Argopecten irradians*

Eastern United States

Edwin W. Rhodes

West Coast of North America

N. Bourne

Mexico

E.F. Felix-Pico

Argentina

José M. Orensanz, Marcela Pascual and Miriam Fernández

Chile

Rodolfo Navarro Piquimil, Leandro Sturla Figueroa and Oriana Cordero Contreras

Japan

Hiroshi Ito

Soviet Union

V.Z. Kalashnikov

Nursery Culturing of Bivalve Molluscs: Proceedings of the International Workshop; Feb. 24-216, 1981. Ghent, Belgium Claus, C., N dePauw and E. Jaspers (eds.), 1981. European Mariculture Society Special Publication No. 7, 394 pp.

This book began national interest in the technique known as “upwellers”, a staple of the mariculture industry today. In addition to the upwellers, the book contains papers from international mariculture practitioners and is wealth of information that is difficult to obtain from other sources.

Polluting for Pleasure by Andre Mele, 1993. W.W. Norton & Co., 500 Fifth Avenue, NY, NY, 10110. 224 pp.

This exposé of the boating industry is a chilling reminder of the environmental effects of our collective desire for speed and “fun” on the water. The book demonstrates through arithmetic analyses, the amount of hydrocarbons entering the water through the unregulated powerboat emissions. Mele offers solutions to the dilemma of powerboat operations in the US including chapters entitled “Good Energy”, “clean power” and “Low Resistance Boats”. This is one book that does not only identify the problem but equalizes the doom and gloom with positive suggestions for future directions.

The Ecology of the Waquoit Bay National Estuarine Research Reserve, 1996. M.A. Geist, Ed., Waquoit Bay National Estuarine Research Reserve, PO Box 3092, Waquoit, MA 02536, 123 pp.

Papers, reports, and abstracts

The following references have been categorized by subject matter, identified by superscripts next to author’s name to be more easily reviewed by shellfish managers. Annotations have been concentrated on those papers with a “2” superscript.

Overviews—natural history, fisheries, general information

Barber, B. and C.V. Davis. Potential for bay scallop aquaculture in Maine, U.S.A. 10th International Pectinid Conference, April 27-May 2, 1995, Jury’s Hotel, Cork, Ireland.

Authors reviewed environmental requirements as part of feasibility study for growing bay scallops in Maine. They stated that out of 1.3 million lbs. of shucked meats harvested in last 10 years, 50-80% came from Massachusetts. To test feasibility for Maine waters and assess growth at 2 sites, they used floating trays with mesh “envelopes” in cages

Belding, D.L. 1910a. A report upon the scallop fishery of Massachusetts, including the habits, life history of *Pecten irradians*, its rate of growth and other factors of economic value. Boston, MA: Special Report to the Commonwealth of Massachusetts Commission on Fisheries and Game. 150 pp., 118 figs.

Possibly the most often cited manuscript for scallops, especially bay scallops (*Argopecten irradians irradians* (Lamarck 1819)). One of earliest references that covers physiology, environment and fisheries. Large version contains plates of scallops, gear and additional tables.

Belding, D.L., 1910b. The scallop fishery of Massachusetts: including an account of the natural history of the common scallop. Boston, MA: Commonwealth of Massachusetts Commission on Fisheries and Game, Marine Fisheries Series No 3. 51 pp.

See above.

- Fay, C.W., R.J. Neves and G. B. Pardue. 1983. Bay scallop. Washington, D.C.: U.S. Dept. of Interior, Fish and Wildlife Service Species Profile FWS/OBS-82/11.12. 17 pp.
 Good overview of species, repeating Belding and building on literature from that time. Main food: benthic diatoms. Includes all environmental factors including turbidity.
- Franklin, A., G.D. Pickett, and P.M. Connor, 1983(?). The scallop and its fishery in England and Wales. Laboratory Leaflet No. 51, Ministry of Agriculture Fisheries and Food, Directorate of Fisheries Research, Lowestoft.
 Pecten maximus cultured. Paper gives biology of an animal that is fully mature at 3 years but has irregular spat sets. Group used spat collector bags (two types) – pictured.
- Gaucher, T.A., G.C. Matthiessen and C.A. Griscom. 1974. Aquaculture in New England. Kingston, RI: University of Rhode Island Marine Technical Report Series No. 18. 77 pp.
- Gutsell, J.S. 1929a. Natural history of the bay scallop. Ithaca, NY: Cornell University 38 pp. Dissertation.
- Gutsell, J.S. 1929b. Scallop industry of North Carolina. Washington, D.C.: Report of the U.S. Commissioner of Fisheries for the Fiscal Year 1928, Part 1, Appendix 5, Document No. 1043: 173-197, 11 figs.
- Gutsell, J.S. 1931. Natural history of the bay scallop. Bulletin of the U.S. Bureau of Fisheries, 1930, vol. 46, Document No. 1100, 1930: 569-632.
 Comprehensive manuscript. Mostly same information as Belding for physiology. He stated that it was unknown why scallops prefer grass and speculates that post-veligers find satisfactory conditions for survival only where vegetation affords suitable conditions. He suggests that gulls are an obvious predator in shallow water; starfish and oyster drills other predators – crabs are not mentioned. Extensive bibliography.
- Hanks, R.W. 1971. Minor species – bay scallops, razor clams and mussels. American Malacological Union Inc. Annual Report: 15-16.
- Jones, J.G. 1986. The puzzling life of the bay scallop. Maritimes 30(1) 14-16.
- Kopinski, E. 1978. A partially annotated bibliography of commercially exploited scallops (*Pectinidae*, Rafinesque 1815). FAO Fisheries Circular No. 716. 158 pp.
- Marshall, 1979. The unpredictable bay scallop. Maritimes 23(2): 12-14.
- Mottet, M.G., 1979. A review of the fishery biology and culture of scallops. State of Washington Department of Fisheries, Technical Report No. 39, May, 1979. PP 21-66.
 Good review of scallop culture; information on bay scallops is sketchy but author states that bay scallops provides only 2% of world landings. He makes interesting statement about irregularity of recruitment to scallop fisheries worldwide and all have boom-bust patterns. The habitat rarely supports a maximum scallop population. Paper includes good diagram of culture methods employed in Japan including wave shock absorbers. Paper also describes “ear hanging” method of culture.

Rhee, W.Y. History and status of scallop culture in North America. P. 77 (abs.). Rice, M.A., R.B. Rheault, M.S. Perez, and V.S. Perez. Experimental culture of moon scallops, *Amusium pleuronectes*, in Ulugan Bay, Palawan, Philippines. Pp. 78-83. 9th International Pectinid Conference: April 22-27, 1993, Nanaimo, B.C., Canada

Risser, J. 1901. Habits and life history of the scallop (*Pecten irradians*). Providence RI: State of Rhode Island and Providence Plantation Preliminary Report, 31st Annual Report to the Commissioner of Inland Fisheries: 47-55, 13 pls, 1 graph.

One of earliest documents of life history of scallop. Some aspects differ from Belding (see above) with respect to time of adding growth ring. Gutsell mentions difference between two authors. For Massachusetts, it does not matter whether growth ring is laid down because of feeding activity after winter or spawning activity.

Robert, G. 1978. Biological assessment of the bay scallop (*Argopecten irradians*) for Maritime waters. Halifax, Nova Scotia: Dept. of Fisheries and Environment, Fisheries and Marine Service Technical Report (Canada) No. 778. 13 pp.

Another excellent review of scallop biology. Paper prepared to determine if scallop culture was feasible for Canadian Maritimes and concludes that it probably would not merit much attention because of temperature.

Russell, H.J. Jr., 1971. A scallop success story. *Maritimes* 15(1): 12-14.

Sisson, R.T. 1970. Occurrence of bay scallop seed in Rhode Island, 1970. Providence, RI: Rhode Island Dept. of Natural Resources, Division of Fish and Wildlife Information Leaflet No. 32. 4 pp.

Peak production in 1955 @ 132,845 lbs.; next significant harvest in 1958 @ 49,506 lbs. and nothing thereafter. This author was looking for scallops as part of Russell's work; 1970 was good year for spawning and setting.

Shumway, S.E. and M. Castagna, 1994. Scallop fisheries, culture and enhancement in the United States. *Memoirs of the Queensland Museum* 36(2): 283-298.

Good overview of the fishery and some management problems of both bay scallops and sea scallops (*Placopecten magellanicus*). The authors state that for bay scallops, "while the species represents only a minor component of US commercial fisheries, it is extremely important to local economies." Authors review the problem in LI, NY with the alga *Aureococcus anophagefferens* that decimated the scallop population in 1985. The paper includes harvest statistics compiled by O'Bannon from NOAA statistics. The authors discuss enhancement projects stating that most projects use traditional hatchery technology that can supply sexually mature spawning stock throughout the year. They quote Rhodes who said that there are no profitable private scallop aquaculture companies in the US but that China has been very successful. They say that unexplained Chinese scallop mortalities are probably attributable to insufficient genetic diversity and that new broodstock was supplied by Canadian sources. For enhancement projects, they cite the Martha's Vineyard Shellfish Group as being the most successful using a solar assisted hatchery and nursery techniques including placing seed scallops in burlap bags that are added to the habitat slowly as the burlap bio degraded.

Thayer, G.W. and H.H. Stuart. 1974. The bay scallop makes its bed of seagrass. *Marine Fisheries Review* 36(7): 27-30.

Study compared bar dredges with rakes on bottom environments. Authors found that bar dredges uprooted eelgrass and oxidizes sediment to that recolonization may be impeded. Small scallops missing from dredged areas but not from raked ones.

Theroux, R.B. and R. L. Wrigley. 1983. Distribution and abundance of east coast bivalve mollusks based on specimens in the National Marine Fisheries Service Woods Hole collection. Washington, D.C.: U.S. Dept. of Commerce, NOAA Technical Report NMFS SSRF-768.

Thomas, F.B., W.A.B. Thomas, F.F. Busta and J.B. Moore. 1966. A study of the quality of North Carolina scallops. Raleigh, NC: North Carolina Dept. of Conservation and Development Special Scientific Report No 10 26 pp.

Thomson, J.D. Administrative, legal and sociological difficulties of scallop culture and enhancement. Pages 264-271. Proceedings of the Australasian Scallop Workshop, July, 1998, Taroom, Australia. M.L.C. Dredge, W.F. Zacharin and L.M. Joll (eds.), Hobart, Australia.

Author raises same questions of exclusive use of common or public domain as raised in Massachusetts. He mentioned recreational boat usage and thousands of objections from salmonid farms. They question whether enhancement is farming, fishing or ranching. He said there were voluntary agreements among fishermen that turned to greed and vessels fished at will over the beds causing considerable damage and then poached in closed areas. (Ed. Note: this paper is an amazing paper on the sociology of fishing and farming and was quite unexpected from another part of the world.)

Verrill, A.E. 1873. Report upon the invertebrate animals of Vineyard sound and the adjacent waters, with an account of the physical characters of the region. In Baird, S.F. (ed.) Report on the condition of the sea fisheries of the south coast of New England in 1871 and 1872, pt.1. Washington, D.C.: U.S. Commission of Fish and Fisheries: 295-778.

Verrill, A.E. 1900. A study of the family *Pectinidae*, with a revision of the genera and subgenera. *Transactions Connecticut Academy of Arts and Sciences* 1899, 10(1): 41-96; 6 pls.

Zuraw, E.A. and D.E. Leone. 1971. Status of the Niantic estuary for supporting a scallop fishery. Groton, CT: General Dynamics, Electric Boat Division Report No. U-412-71-078. 61 pp.

Local and regional restoration efforts

Aldred, J. Town of East Hampton (NY) Shellfish Hatchery 1998 annual report of operations and 1999 operating plan.

Hatchery grows oysters (*Crassostrea virginica*), hard clams (*Mercenaria mercenaria*), and bay scallops (*Argopecten irradians irradians*) and performs nursery culture as well. They have found that best spawner sanctuaries are those that are densely seeded in smaller areas for best spat retention.

Ambrose, W. G. Jr., C.H. Peterson, H.C. Summerson and J. Lin, 1992. Experimental tests of factors affecting recruitment of bay scallops (*Argopecten irradians*) to spat collectors. *Aquaculture* 108: 67-86.

Excellent account of use of spat collectors with respect to eelgrass cover. Collectors near but not in grass beds had equal or greater recruitment than inside grass beds. Higher recruitment found in grass beds with low shoot density and higher velocity than opposite. Seagrass supports more predators. Spat collectors increase settlement if suitable natural habitat is limited or if larvae take a long time locating suitable settlement site – the longer in the water, the greater risk of mortality. Best location to deploy collectors for maximum spat collection is likely to be near spawning populations of adults. Excellent paper and references.

Ambrose, W.G., Jr., E.A. Irlandi, 1992. Height of attachment on seagrass leads to trade-off between growth and survival in the bay scallop *Argopecten irradians*. *Marine Ecology Progress Series* 90: 45-51.

Paper suggests that there seems to be a small difference in growth between scallops attached high or low on eelgrass; those near the bottom grew faster but were preyed on the most suggesting the trade-off between growth and survival.

Arnold, W.S., D.C. Marelli, C.P. Bray and M.M. Harrison, 1998. Recruitment of bay scallops *Argopecten irradians* in Floridan Gulf of Mexico waters: scales of coherence.

Authors conducted surveys of adults at 4 study sites and tracked recruitment to those sites through spat collectors. At 2 stations, adults were sparse (<5/600m²) and at the other two, they averaged >25/600m². Authors found a positive relationship between number of adults and density of recruitment. Authors suggest that even in open areas, recruitment may be limited to geographically local habitats though the mechanism is not well understood at this point and authors suggest further research.

Arsenault, D.J. Ontogenic habitat shifts in a population of Iceland scallops, *Chlamys islandica* (O.F. Müller), in the northern Gulf of St. Lawrence. 10th International Pectinid Conference, April 27-May 2, 1995, Jury's Hotel, Cork, Ireland. (Mostly Abstracts)

Observations of scallops using refuges at small sizes to escape predation. Smaller seed was found in shallower water whereas larger ones were deeper.

Barbeau, M, R.E. Scheibling and B.C. Hatcher. Effect of predation on the dynamics of seeded scallop populations. 10th International Pectinid Conference, April 27-May 2, 1995, Jury's Hotel, Cork, Ireland. (Mostly Abstracts)

Surviving scallops from transplants of 5-30 mm sea scallops was 10% at 1 site and 1% at another. Effects seen in a few weeks. Large juveniles protected from sea stars but not crabs. Seeding at low temperatures lowers predation rates.

Barret, J., C. Mingant and R. Robert. *Patinopecten yessoensis* rearing in Atlantic conditions: preliminary results. Proceedings of the Australasian Scallop Workshop, July, 1998, Tarooma, Australia. M.L.C. Dredge, W.F. Zacharin and L.M. Joll (eds.), Hobart, Australia.

Authors conducted growth experiments of F2 generation juveniles using 4 mm mesh racks held on 30 cm “trestles”, 15 m below the surface. Preliminary results showed good growth and survival.

Bourne, N. and C.A. Hodgson, 1988. Scallop culture in British Columbia. Ministry of Agriculture Fisheries Information Bulletin 19, 7 pp.

Bulletin gives overview of program using hatchery seed from local broodstock, spat bags for nursery and then pearl and lantern nets for grow-out. Paper includes diagrams.

Bourne, N.F. Potential for scallop culture in British Columbia, Canada. 8th International Pectinid Workshop, Cherbourg, France, 1991.

Buestel, D. and J.C. Dao, 1979. Extensive scallop farming (1). The results of an experimental sowing. Contribution No. 624 of the Scientifico Department of the Oceanological Centre of Brittany.

French have been in forefront in scallop culture. This paper summarizes experimental sowing on the bottom after seed is grown in collectors to 16 mm. Paper details their methods including collection of juveniles from high density areas to use as broodstock, seed collected on artificial media and bottom preparation by physically grading the bottom to remove some of the marl and also remove predators. After bottom preparation, seed was sown directly on the bottom. Authors found that this size was too vulnerable for free planting. Project was done by the French government for commercial stocking.

Bull, M.F. Enhancement and management of New Zealand’s “southern scallop” fishery. 10th International Pectinid Conference, April 27-May 2, 1995, Jury’s Hotel, Cork, Ireland. (Mostly Abstracts)

Author reports that it was an unregulated wild fishery that led to strict management controls that led to seeded and rotationally fished “farming operation”. The deployed 300,000 collector bags that obtained 1.2 billion spat. Survival from spat bag to direct planting was 15%. Author includes good diagram of cooperative nature of project.

Bull, M.F. Lessons and mistakes from recent trials of methods for spat catching and grow out of scallops in New Zealand. Pages 253-263. Proceedings of the Australasian Scallop Workshop, July, 1998, Taroom, Australia. M.L.C. Dredge, W.F. Zacharin and L.M. Joll (eds.), Hobart, Australia.

Bull, M.F. New Zealand scallop enhancement project – cost and benefits. Pages 154-165. Proceedings of the Australasian Scallop Workshop, July, 1998, Taroom, Australia. M.L.C. Dredge, W.F. Zacharin and L.M. Joll (eds.), Hobart, Australia.

Author discusses project with large gear and large project. He gives good depiction of gear.

Caisey, X, P-G Fleury and G. Vincent. Experimental scallop culture using hatchery-produced juveniles. P. 2 (abs). 9th International Pectinid Conference: April 22-27, 1993, Nanaimo, B.C., Canada

Three stage process used: 0-2 mm – hatchery; 2-30 mm cages (6-9 months); on bottom (3 years). Limiting factors included poor survival rate of spat transferred to sea, mortality from predation and dispersion and quality of available sites.

Capuzzo, J.M. and R.E. Taylor, Jr. 1980. Preliminary investigations of local populations of the bay scallop, *Argopecten irradians irradians* (Lamarck). Woods Hole, MA: Woods Hole Oceanographic Institution Annual Sea Grant Report, 1978-1979: 26.

Project was aimed at looking at three specific problems: migration of adult populations, gonad development and time of maturation and growth of newly set scallops in Waquoit Bay, MA. Scallops were tagged to find out about travel distance. 20% found within 4 meters of transplant site; 9% at 200 yards toward bay entrance and 3% up to 0.25 mi.

Capuzzo, J.M., G. R. Hampson, and R.E. Taylor, Jr., 1983. Seeding program for the bay scallop: comparison of local bays, Falmouth, MA. Woods Hole MA: Woods Hole Oceanographic Institution Annual Sea Grant Report, 1981-1982: 5-6.

Authors speculate that factors for resource instability may include: loss of eelgrass and other epibenthic supports, loss of larvae from local bays by tidal flushing, biological interactions such as overcrowding, disease, parasites and predation, harvesting juveniles prior to maturation. Predators observed were blue and green crabs, oyster drill (starfish not mentioned). Mortality occurred after spawning with very high temps. Of 28-29° C.

Capuzzo, J.M., and R.E. Taylor. 1982. Seeding program for the bay scallop: comparison of local bays, Falmouth, MA: Woods Hole Oceanographic Institution Annual Sea Grant Report, 1980-1981: 13.

Authors state that scallops are an important economic resource for the towns on Cape Cod, Martha's Vineyard and Nantucket, MA. They suggest that the best locations for enhancement transplant projects include ones with stable physical and chemical conditions, high rate of productivity and low predator interaction. They observed that aside from predation, mortalities occurred post-spawning when temperatures were 28-29°C.

Capuzzo, Judith M.;1984. Bay Scallops Fishery: Problems and Management: proceedings of a workshop October 18, 1983; Woods Hole Oceanographic Institution, Woods Hole, MA. Woods Hole Ma: Woods Hole Oceanographic Institution Technical Report No 84-38. 35 pp.

Document is often cited and contains abstracts of work by Massachusetts shellfish officers and town biologists, National Marine Fisheries Service biologists and Woods Hole Oceanographic Institution scientists. Workshop was an open exchange of ideas and fostered communication between scientists and managers and contains a list of attendees. Document also includes a survey that asked questions about harvest and ways to improve the fishery that was completed by participants. Perceptions of respondents and analysis of the questionnaire was included in the document.

Carriker, M.R. 1950. Some recent investigations of native bivalve larvae in New Jersey estuaries. Proceedings of the National Shellfisheries Association 41: 69-74.

Observations of spawning activity of scallops in the wild in NJ. Finding animals ready to set was rare. Author conjectures that larvae stay together in “swarms”; maximum daylight concentration 1 m from surface but was higher during more current velocities and at night, more widely distributed over water column. Author speculates that this behavior may be a response to light.

Castagna, M. and W.P. Duggan. 1972. Mariculture experiments with the bay scallop, *Argopecten irradians* in waters of the seaside of Virginia. Bulletin of the American Malacological Union 37: 21 (Also Virginia Institute of Marine Sciences Contribution No. 411).

Authors used 25, 50, 75 and 100/ft² in density related experiments and found no difference in growth up to 27-28 mm; beyond that, they found a decrease in growth with each increase in density. They used cages, off-bottom floats and trays for experiments and planned to test the feasibility of direct seeding.

Castagna, M. and W.P. Duggan. 1973. Mariculture experiments with the bay scallop, *Argopecten irradians*, in the waters of the seaside of Virginia. South Florida Shell Club; 11(1): 5

Chauvaud, L. and G.Thouzeau. Experimental collection of benthic post-larvae in the Bay of Brest: settlement patterns in relation to spatio-temporal variability of environmental factors. 10th International Pectinid Conference, April 27-May 2, 1995, Jury’s Hotel, Cork, Ireland. (Mostly Abstracts)

Authors used typical collectors and collector plates deployed just off-bottom (6-25 cm.). They monitored for temperature, salinity, plankton and sediment. They were looking at other organisms that might compete with or predate on scallops.

Chew, K.K. and Z. Fusui. Recent developments in bay scallop, *Argopecten irradians*, culture in China. Pages 4-8. 9th International Pectinid Conference: April 22-27, 1993, Nanaimo, B.C., Canada

Expanded version of bay scallop story in China. Three attempts made to introduce scallops; two met with failure and the third was successful with 26 individuals that lived to spawn. Native species (*Chlamys farreri*) takes 2-3 years to reach 5-7 cm; *Argopecten irradians* takes 10 months to reach same size. Latest estimate of production was 130,000 metric tons live wt. The Chinese spawn the same individuals 3 times: condition to 1st spawn, remove to separate tank for 2nd and recondition for 3rd time. Eyed larvae placed in dense braided net for metamorphosis in a tank. 10-15 days later they go from mesh to bag then to long line for 2-5 mo. @ density of 200-300/bag of same-sized animals. Sometimes they are held in intermediate lantern nets @ 200.net. At 2.5 cm, they are transferred to lantern nets @ 30-35/layer and left until harvest. Problems included reduced heterozygosity, velum disease (ciliary cells slough off – cause unknown). Two new shipments arrived from Florida and Canada in 1991. They are moving toward polyculture with scallops in shrimp ponds.

Claus, C. 1981. Trends in nursery rearing of bivalve molluscs. In: Claus, C., N dePauw and E. Jaspers (eds.). Nursery culturing of bivalve molluscs: proceedings of the international workshop; Feb. 24-216, 1981; Ghent, Belgium: 1-33. European Mariculture Society Special Publication No. 7, 394 pp.

Coleman, N. Spat catches as an indication of recruitment to scallop populations in Victorian waters. Pp. 51-60. Proceedings of the Australasian Scallop Workshop, July, 1998, Taroom, Australia. M.L.C. Dredge, W.F. Zacharin and L.M. Joll (eds.), Hobart, Australia.

Cropp, D.A. On growing scallop culture in Tasmania, pp. 182-195. Proceedings of the Australasian Scallop Workshop, July, 1998, Taroom, Australia. M.L.C. Dredge, W.F. Zacharin and L.M. Joll (eds.), Hobart, Australia.

Project included using spat collectors made of black plastic sacks with 4-5 mm mesh filled with old monofilament. A high number of spat held for long time resulted in slower growth. Larger spat resulted in greater survival at planting. Smothering occurred with ascidian growth on collectors. They also used floating upweller made of aluminum that used an electric motor producing 600 l/m; there was worse growth with the upweller than other methods.

Cropp, D.A. and K.R. Frankish. Cost comparison of hatchery and naturally produced spat for the scallop *Pecten fumatus* Reeve. Pages 196-225. Proceedings of the Australasian Scallop Workshop, July, 1998, Taroom, Australia. M.L.C. Dredge, W.F. Zacharin and L.M. Joll (eds.), Hobart, Australia.

Low broodstock made catching naturally occurring scallop spat difficult. They examined costs for producing 15 million larvae and produced exhaustive production costs.

Cross, S.F. Oceanographic conditions conducive to culture of the Japanese scallop, *Patinopecten yessoensis*, in British Columbia, Canada. Pp. 9-14. 9th International Pectinid Conference: April 22-27, 1993, Nanaimo, B.C., Canada

Studies performed to determine optimum regime for Japanese scallops in British Columbia. Scallops do not tolerate large differences in temp., salinity or motion.

Dadswell, M.J. and G.J. Parsons. accelerated growth, increased meat yields and enhanced survival of the giant scallop (*Placopecten magellanicus*) grown in suspended culture: Implications for large-scale aquaculture in Atlantic Canada. 8th International Pectinid Workshop, Cherbourg, France, 1991.

Authors used spat collectors and put the seed in pearl nets. At 20-24 mo., they transferred them (after thinning several times) to ear hanging lines. At 36 mo., they were harvestable.

Dadswell, M.J., and G.J. Parsons. Exploiting life-history characteristics of the sea scallop, *Placopecten magellanicus*, from different geographical locations in the Canadian Maritimes to enhance suspended culture and growout. P. 15 (abs). 9th International Pectinid Conference: April 22-27, 1993, Nanaimo, B.C., Canada

These scallops can have an annual or biannual spawning event. If annual, they spawn in Aug/Sept and take 33-36 mo. to be harvestable. If biannual, they spawn in June/July and Sept/Oct. If early spawn used, they can be ready in 25-27 mo. If use both spawning times, a farmer can maximize his farm by having a steady supply.

Dao, J. and D. Buestel. Spat seeding and recaptures in France. 8th International Pectinid Workshop, Cherbourg, France, 1991.

Dao, J-C, J. Barret and M.L. Muzellec. Seed-recapture of the scallop, *Pecten maximus*, by commercial dredging in the Bay of Brest during 1991-1992. Pp. 16-22. 9th International Pectinid Conference: April 22-27, 1993, Nanaimo, B.C., Canada

Paper describes success with free plantings @ 25-30 mm where recovery was 25-27%. They used two management options- areas closed to dredging and seeded immediately after fishing activity. They concentrated on the deeper portions of the bay.

Dare, P.J. and R.C.A. Bannister. Settlement of scallop *Pecten maximus* spat on natural substrates off southwest England: the Hydroid connection, (Abs). 6th International Pectinid Workshop, School of Ocean Sciences, Marine Sciences Laboratories, Menai Bridge, Wales, UK, April 9-14, 1987.

Authors tried to assess distribution and abundance of newly set spat and juveniles using underwater TV and photography. Scallops (*P.maximus*) set on hydroids; scallops between 2-20 mm were not found in situ by any method.

Dreyer, W.A. and W.A. Castle. 1941. Occurrence of the bay scallop, *Pecten irradians*. Ecology 22(4) 425-427.

Paper contains discussion of eelgrass decimation and scallop disappearance. Authors traced recurrence of eelgrass and showed that recovery of scallops was slow. In large areas they found no more than 5 individuals and usually fewer.

Duggan, W.P. 1973. Growth and survival of the bay scallop, *Argopecten irradians*, at various locations in the water column and at various densities. Proceedings of the National Shellfisheries Association 63: 68-71.

Paper is an excellent account of survival and growth at varying densities and depth with good graphics of experimental design. Their design included scallops held at 1 and 2 m off bottom, 1 m below the surface and at the surface. Those held at 2 m off bottom probably exhibited better survival because of decreased wave action. Growth was equal at all depths with equal density; mortality decreased with increased depth except for those held 1 m off bottom; growth decreased and mortality increased with increased density.

Evseev, G.A. and V.Z. Kalashnikov. Introduction of North Atlantic scallop species as a method to stimulate scallop culture in the Primorye Province of Russia. Pp. 23-30. 9th International Pectinid Conference: April 22-27, 1993, Nanaimo, B.C., Canada

Discussion of introducing king and giant scallops to areas off Russia. Paper discusses requirements of all species listed. Introduction would be large project and would have to include a hatchery. Paper presents all the elements necessary for successful introduction and states that it could be done in stages. Paper could be used as checklist for wide scale enhancement program.

Fang, J-G. Artificial seed production and culture of scallops in Sungo Bay. P.31 (abs). 9th International Pectinid Conference: April 22-27, 1993, Nanaimo, B.C., Canada

Author states that 40 hatcheries produce 1.5 billion seed of *Chlamys farreri* and 300 million *Argopecten irradians*. 10% of the bay (600 hectares) occupied with scallop culture growing 10,000 tons live weight. Remainder of bay is *Laminaria* culture.

They are looking at mutual polyculture where inorganic nutrients such as ammonia and CO₂ from scallops are taken up by *Laminaria* and O₂ by-product may be beneficial to living environment of scallops. Detrital yield from *Laminaria* is potential food source for scallops.

Felipe, F.L., L. Cesar J.M., M. Francisco, J. Cote and J.H. Himmelman. Effect of sea waves on growth of tropical scallops *Euvola ziczac* and *Nodipecten nodosus* (L), in hanging culture in the Gulf of Cariaco, Sucre State, Venezuela. Pages 10-11. 11th International Pectinid Workshop, April 10-15, 1997, LaPaz, BCS, Mexico. Publ. Centro Interdisciplinaria de Ciencias Marinas, La Paz, Mexico, Abril, 1997.

Felix-Pico, E.F., A. Tripp-Quezada, J. Castro-Ortiz, G. Serrano-Casillof, P.C. Gonzalez Ramirez, M. Villahejo Fuerte, M Mazon Susstegui, G. Bojorquez-Verastica and Y.G. Lopez-Garcia. 10th International Pectinid Conference, April 27-May 2, 1995, Jury's Hotel, Cork, Ireland. (Mostly Abstracts)

Authors discuss catch restrictions during spawning and use of spat bags with good results.

Félix-Pico, E.F., A. Tripp-Quezada, J.L. Castro-Ortíz, G. Serrano-Casillas, P.G. González-Ramírez, M. Villalejo-Fuerte, R. Palomares-García, F.A. García-Domínguez, M. Mazón-Suástegui, G. Bojórquez-Verástica and G. López-García, 1997. Repopulation and culture of the Pacific calico scallops in Bahía Concepción, Baja California Sur, México. *Aquaculture International* 5: 551-563.

Authors used shrubs in onion bags as spat collectors; they found that fouling on the bags was necessary for good spatfall and therefore the bags needed to be deployed 2 weeks prior to finding larvae in the water. This was a large project of 550 lines containing 170,000 collectors. They found that intermediate culture was necessary.

Fleury, P., C. Halary, and J-C Dao. The intermediate culture of *Pecten maximus* in Brittany (France). 8th International Pectinid Workshop, Cherbourg, France, 1991.

Authors used small mesh (500µ – 1.5 mm) when scallops were translucent and larger mesh (5mm) when scallops were colored. They had 30% survival in 1st stage and 95% in second for overall survival of 30%

Fleury, P-G. J-C Dao, X Caisey and C. Mingant. King scallop farming in France. P 32 (abs). 9th International Pectinid Conference: April 22-27, 1993, Nanaimo, B.C., Canada

Authors describe hatchery process to 2mm. Small mesh cages, 500 µ to 1.5 mm used for early set. When shells are translucent, they are transferred to larger mesh (5mm) and are used until spat loses the byssus and shells become thick and colored. Survival is ≈30%; most mortality is through handling. 3 cm scallops are seeded in open sea @ 10-20/m². 2-3 yrs. later they are dredged and are >100 mm and 150 gm. Recapture has been 25-50% in seeded sites.

Fleury, P-G, C. Mingant and A. Castillo. A study of the reseeded behavior of reseeded scallops according to three seasons and to three different sizes. 10th International Pectinid Conference, April 27-May 2, 1995, Jury's Hotel, Cork, Ireland. (Mostly Abstracts)

Use of video camera showed interesting predation at night by small predators. Authors also found that best seeding time was spring.

Fontana, B.T. Improved technologies for seed management in the north of Chile: from metamorphosis to 20mm. Pp. 110-113. 9th International Pectinid Conference: April 22-27, 1993, Nanaimo, B.C., Canada

Paper presents problems and solutions to culturing large numbers of scallops. They used lantern nets for nursery culture. They found 4 frequent causes of mortality: detachment, excessive sedimentation, predation and poor handling. They offer solutions to each of the problems encountered.

Garcia-Esquivel, Z and V. M. Bricelj, 1993. Ontogenic changes in microhabitat distribution of juvenile bay scallops, *Argopecten irradians irradians* (L), in eelgrass beds, and their potential significance to early recruitment. Biological Bulletin 185: 42-55.

Hatchery scallops (10 mm) swam directly after release to gain vertical displacement. They also crawled upward and never downward. Most found at mid-canopy height, an adaptive behavior to escape predation. Between 14-29mm, they shift habitat to the bottom, over a 5 week period; swimming activity increases. Information helpful for field transplants.

Gaucher, T.A. 1972. Summary of progress report on program to reestablish the bay scallop in the Niantic River estuary. Prepared the Waterford-East Lyme (CT) Shellfish Commission. 2 pp.

Gaucher, T.A. and V. Lee, 1972. Progress report of the program to revitalize the bay scallop in the Niantic River estuary. Prepared for the Waterford-East Lyme (CT) Shellfish Commission 35 pp.

Fishery failed in 1965 and did not recover. Area was stocked with 4165 scallops using cages, bottom culture and Japanese hanging culture. Transplanted seed put in Japanese suspended cages at intermediate depths and bottom cages each had survival of >60%. Bottom cages scallops had thinner shells and shallower valves. Starfish was most abundant and destructive predator but crabs, scup and cunners also listed. Starfish preyed on caged animals. This was first large-scale hatchery transplant that they were aware of. Authors used quicklime to get rid of starfish that did not kill eelgrass unless in high concentrations that were not well mixed. Hatchery seed was used.

Giguère, M. and G. Cliché. Dispersal of sea scallop, *Placopecten magellanicus*, juveniles seeded on the bottom off the Îles-de-la-Madeleine, Québec, Canada. P. 34 (abs.). 9th International Pectinid Conference: April 22-27, 1993, Nanaimo, B.C., Canada

Four size classes from 35-70mm scallops (8,980 total) tagged and seeded in 30m X 30m quadrats and in 50m X 50m quadrats. Seeded area dropped from 10./m² to 0.29 in 44 days and 3.6 to 1 respectively. Surrounding area increased from 0-0.13/m². Displacement after 44 days was more than 60 m for 49% of seeded scallops. Highest decrease was with smallest animals and 12.8% counted as dead.

Giovanardi, O. Experimental culture of *Pecten Jacobaeus* (L.) in the Adriatic Sea. Pp. 35-38. 9th International Pectinid Conference: April 22-27, 1993, Nanaimo, B.C., Canada

Lantern nets and plastic trays (used in oyster culture) were used at depths of 5-10 m. Mortality after seeding was 17% in lantern nets and 4.5 in trays. After 204 days, mortality was 43.1% in nets and 63.5% in trays. Traditional spat collectors are not feasible for this species due to hydrographic conditions of the area.

Hernandez-Llamas, A. 1997. Management strategies of stocking density and length of culture period for the Catarina scallop *Argopecten circularis* (Sowerby): A bioeconomic approach. *Aquaculture Research*, 28: 223-229.

Economic model

Hickey, M.T. 1978. Age, growth, reproduction and distribution of the bay scallop, *Aequipecten irradians irradians* (Lamarck), in three embayments of eastern Long Island, New York, as related to the fishery. *Proceedings of the National Shellfisheries Association* 68:80-81 (abstract).

Heffernan, P.B., R.L. Walker and D.M. Gillespie, 1988. Biological feasibility of growing the northern bay scallop, *Argopecten irradians irradians* (Lamarck, 1819) in coastal waters of Georgia. *Journal of Shellfish Research* 7(1): 83-88.

Authors used pearl nets suspended from floating raft. Growth was continuous throughout the year but slower in January and February. A sheltered creek showed significantly greater scallop growth than an exposed site. They found high mortalities with bottom nets encrusted with bryozoans. Bay scallops survived and grew to harvestable size (50 mm) in a 200 day growing season; fouling was substantial problem and methods used were labor intensive.

Ito, S. and A. Byakuno. The history of scallop culture in Japan. Pages 166-181. *Proceedings of the Australasian Scallop Workshop*, July, 1998, Taroom, Australia. M.L.C. Dredge, W.F. Zacharin and L.M. Joll (eds.), Hobart, Australia.

Paper gives a good overview of the Japanese experience. The Japanese started scallop culture with pearl nets, lantern nets and spat collectors. The paper gives good diagrams of gear. Paper mentions mass mortalities through over crowding and suggests "shell biting" as a mechanism toward mortality whereby scallops break shells on other scallops as they attempt to close their shells. Scallops become deformed because of inability to secrete shell materials. There is a constant "leakage" of secreting fluid from the lesions results in significant waste of energy since scallops have open blood systems. Rough treatment and wave action also caused "biting" problem.

Karlsson, J.D. 1976. A study of stabilization of natural scallop populations by augmentation with artificially produced seed. Providence Rhode Island: Rhode Island Dept. of Natural Resources, Division of Fish and Wildlife Leaflet No. 44, 13 pp.

Kelley, K.M., (ed.) 1981. *The Nantucket bay scallop fishery: the resource and its management*. Nantucket, MA: Shellfish and Marine Dept., 108pp.

Author documents conditions in Nantucket for scallop habitat, fishery, management options, survival of different year classes, setting times, mass strandings, winter mortality and other salient features of the commercially important species. This document and its companion piece, "An update on the management of the Nantucket

bay scallop resource” are important documents for Massachusetts and are often cited. Both manuscripts were published by the author for the Nantucket Shellfish and Marine Department. Both documents are cited often and both contain an excellent “picture” of the scallop fishery and scallop habits and habitat.

Kelley, K.M. 1985b. An update on the management of the Nantucket bay scallop resource. Nantucket, MA Shellfish and Marine Dept. 43 pp.

See above

Kelley, K. and M. Ceely. 1980. Studies of bay scallops, *Argopecten irradians*, on Nantucket, 1979-80 season. Nantucket, MA: Shellfish and Marine Dept., 13 pp.

Marshall, N. 1947. An abundance of bay scallops in the absence of eelgrass. *Ecology* 28(3): 321-322.

Anecdotal account of scallops occurring where no eelgrass was present. Author offers suggestion that transplant of Long Island (NY) scallops may have been responsible for the “sudden rise” in the Niantic fishery.

Marshall, 1956. Studies of the Niantic River, Connecticut with special reference to the bay scallop, *Pecten irradians*. Report to the Waterford-East Lyme (CT) Scallop Commission. 37 pp., 2 appendices.

Marshall, N. 1960. Studies of the Niantic River, Connecticut with special reference to the bay scallop, *Aequipecten irradians*. *Limnology and Oceanography* 5(1): 86-105.

Niantic River fishery began with the decline of eelgrass and is well documented. Paper summarizes field data gathering including current, temperature, salinity, shell morphology (growth line) and discussion of possibility of third year growth that is prevented by regulations. He states that the life expectancy is 2 yrs. with ripening occurring in June and July. He emphasizes hydrographic features for habitat that includes: a high ratio of tidal volume to river flow, relatively shallow basin with high ratio of tidal volume to estuary volume at low water and circulation that can retain larvae.

Marshall, N. 1963. Mortality rates and the life span of the bay scallop, *Aequipecten irradians*. *Proceedings of the National Shellfisheries Association* 54: 87-92.

Marshall, N. 1964. Bay scallops as vigorous living filters. *Maritimes* 8(2) 11-13.

Mattei, N. Situation of pectinid aquaculture (*Pecten jacobaeus*) in Italy and some information on Italian pectinid fishery. 10th International Pectinid Conference, April 27-May 2, 1995, Jury’s Hotel, Cork, Ireland. (Mostly Abstracts)

This was a population study where author found that the species is becoming endangered through overfishing and trawling in Adriatic Sea. It grows faster than *Pecten maximus* and they are looking aquaculture to enhance the stock.

McDonough, N. and D. Roberts. Scallop spat collection techniques and settlement patterns: the potential of Strangford Lough, Northern Ireland for commercial scallop, (*Pecten maximus*), cultivation. 10th International Pectinid Conference, April 27-May 2, 1995, Jury’s Hotel, Cork, Ireland. (Mostly Abstracts)

Various outer and inner materials were tested for spat bags. Commercial spat collection was not feasible. Collectors with large mesh outer bag (onion bags) and substrate with increased surface area (netlon) was most efficient.

McLoughlin, R.J., P.C. Young and R.B. Martin. The growth and mortality of *Pecten fumatus* spat in collectors in Bass Strait: a preliminary study. Pages 241-252. Proceedings of the Australasian Scallop Workshop, July, 1998, Taroona, Australia. M.L.C. Dredge, W.F. Zacharin and L.M. Joll (eds.), Hobart, Australia.

Minchin, D. Some approaches to the cultivation and management of the scallop, *Pecten maximus*. 10th International Pectinid Conference, April 27-May 2, 1995, Jury's Hotel, Cork, Ireland. (Mostly Abstracts)

Review paper of methods used for cultivation. In one area, standard spat collector (onion bag) was not good; he used plastic box collectors and gave description. Author suggests leaving some areas as reserves for broodstock density to maximize fertilization. He also suggests using satellite imagery to find most suitable places for spat collectors.

Moore, J.K. and N. Marshall. 1967a. The retention of lamellibranch larvae in the Niantic estuary. *The Veliger* 10(1):10-12.

Larval distributions paralleled phytoplankton with respect to placement. Flood is more effective than ebb in transporting phytoplankton across shoals; water in flood may move across the bottom and ebb may move in surface waters. (Ed. Note: May be important consideration for asymmetric embayments where ebb is longer but weaker than flood).

Moore, J.K. and N. Marshall. 1967b. An analysis of the movements of the bay scallop, *Aequipecten irradians* in a shallow estuary. *Proceedings of the National Shellfisheries Association* 57: 77-82.

Interesting account of scallop movement suggesting it is in groups and not random. They found a N/S movement trend (tidal flow in the Niantic is N/S).

Morgan, D.E., J. Goodsell, G.C. Matthiessen, J. Geary and P. Jacobson. 1980. Release of hatchery-reared bay scallops (*Argopecten irradians*) onto a shallow coastal bottom in Waterford, Connecticut. *Proceedings of the World Mariculture Society* 11:247-261.

Good account of release of different sized juveniles: <35, 35-40, 40-45, >45. Confusing in parts because authors also talk about transplant of seed <22 and >24. In trials with smaller seed, 50% loss in less than 1 day for those <24 and 6 days for those >24. Some loss through dispersion; direct mortality of 20-54% of those >24 mm. Larger seed not evaluated. Authors state that scallop density may be direct function of predator pressure and unless predator management is practiced, hatchery-reared scallops will have little chance of survival in densities in excess of those occurring naturally. Paper also reviews other work on same problem and asks good questions for further study.

Oesterling, M.J. and W.D. DuPaul. Shallow water scallop, *Argopecten irradians*, culture in Virginia. Pp. 58-65. 9th International Pectinid Conference: April 22-27, 1993, Nanaimo, B.C., Canada

- Experiments to raise scallops to market size. Authors used polyethylene trays, plastic mesh cages and multiple or single tiered racks. Best results were with single tier mesh cages. Authors found unfavorable economics for shucked meat product. Paper included discussion of various methods and included problems encountered.
- Paquotte, P. and P.G. Fleury. Production costs in French scallop culture. Pp. 66-75. 9th International Pectinid Conference: April 22-27, 1993, Nanaimo, B.C., Canada
- Project based on production of 150t of marketable scallops. Profitable but poor cash flow in first 3 years. Survival rate 30% needed when ex-farm price is 3.60/kg. Good economic lesson and analysis.
- Parsons, G.J. and M.J. Dadswell. Strategies for inter mediate suspension culture. P. 76 (abs.). 9th International Pectinid Conference: April 22-27, 1993, Nanaimo, B.C., Canada
- Review of several net designs and effect of density on growth and survival. No conclusions given in the abstract.
- Parsons, G.J., S.M.C. Robinson, J.D. Martin and R.A. Chandler. Effect of substrate type and quantity on giant sea scallop spat settlement. 10th International Pectinid Conference, April 27-May 2, 1995, Jury's Hotel, Cork, Ireland. (Mostly Abstracts)
- Authors tested different substrate media within onion bags for spat collection and got 30-750/bag. No other results were given in the abstract.
- Peña, J.B, S. Mestre and A. Farias. Pectinid settlement on artificial collectors in Castellon, EST, Spain, in 1990. 8th International Pectinid Workshop, Cherbourg, France, 1991.
- Authors used 20m and 75m long line spat collectors set varied with depth; maximum @ 5m off-bottom. They found no relationship between growth and depth
- Pereira, L. and G. Molina. Development and present stage of the seed collection of the northern Chilean scallop *Argopecten purpuratus* (Lamarck) in Tongoy Bay, IV Region, Chile. Pages 18-19. 11th International Pectinid Workshop, April 10-15, 1997, LaPaz, BCS, Mexico. Publ. Centro Interdisciplinaria de Ciencias Marinas, La Paz, Mexico, Abril, 1997.
- Peterson, C.H., W.G. Ambrose, Jr. and J.H. Hunt. 1982. A field test of the swimming response of the bay scallop (*Argopecten irradians*) to changing biological factors. Bulletin of Marine Science 32(4): 939-944.
- Peterson, C.H. and H.C. Summerson, 1992. Basin-scale coherence of population dynamics of an exploited marine invertebrate, the bay scallop: implications of recruitment limitation. Marine Ecology Progress Series, 90:257-272.
- Extremely important paper that looks at lack of recruitment to large scale (entire basins) dynamics and lack of broodstock. Authors used spat collectors to estimate spatial and temporal patterns and introduced juveniles to low density areas. Authors state that echinoderm data (no citation) suggests that small distances on the order of a meter or less are sufficient to dilute sperm concentrations that cause huge declines in the percentage of eggs that are fertilized. In their discussion section they say that the goal of management intervention should be enhancement of spawning adults in

depressed populations. They discuss a loss of scallops due to a “red tide” episode in 1987-1988 that decimated the population. The following 3 years were lower than the previous 23 prior to '87. They suggest that there is a 5-12 year population recovery time. They state that their data suggest that managers might consider: closing the entire fishing season to enhance the number of adult scallops surviving the winter to reproduce in the spring, transplant adults well before spawning to reduce transplant stress, or and/or seed with hatchery stock or seed from spat collectors. The authors state that traditional thinking about harvesting adults is not germane since fishery occurs well after spawning and supposedly after recruitment.

Peterson, C.H., H.C. Summerson, R.A. Luettich, Jr, 1996. Response of bay scallops to spawner transplants: a test of recruitment limitation. *Marine Ecology Progress Series* 132:93-107.

Author introduces the paper with a philosophical discussion of restoration ecology. He suggests that restoration ecology is an emerging discipline that “places great demands on the basic science of ecology, demands that often quickly expose the limits of our ecological understanding. Restoration ecology requires sufficient knowledge of the processes that organize communities and limit population sizes to generate reliable predictions of the consequences of potential interventions proposed as restoration alternatives.” The author contends that because of our present “ignorance” about population and community controls in nature, there is a legitimate concern about intervention. The project developed and tested methods of 4 hr transport time of spawner scallops to reduce transplants mortalities. After spawner transplants, recruitment into natural seagrass communities increased by 568% vs. 34% in controls. The authors say that species (such as scallops) that exhibit great variability in recruitment in favorable sites in different years are the ones that exhibit recruitment limitation, which limits the power to detect the recruitment limitation in rigorous evaluation. In other words, natural systems are difficult to evaluate. The authors used 1 site for spat collectors and did not get a match between settlement on bags and in the natural seagrass and therefore could not confirm that the transplant was the cause of recruitment into the natural habitat. They suggest that they achieved the right prediction for the wrong reason.

Peyton, P., M Kaill, L. Hornig, and B. Osborne, 1987. Scallop spat collection study in Kodiak: preliminary results. Fourth Alaska Aquaculture Conference, November, 1987, Sitka, Alaska, pp. 43-53.

Good description of cooperative approach to increase amounts of “windowpane” scallops in Alaska. Paper gives good description of collector bags and how they were deployed. The bags were attached to dropper lines called “rens” and were hung off each longline. Each ren was 20 m in length with 20 bags/line. The bags were onion bags filled with netron mesh filler. 50 rens were weighted with 4 kg sinkers spaced evenly for a total of 100 bags/longline. Smaller gear included a single ren with a 30 cm float at the top anchored with a 50 kg sandbag and enough line for the float to be 5 m below the surface at low tide.

Pohle, D.G., V.M. Bricelj and Z. Garcia-Esquivel, 1991. The eelgrass canopy: an above-bottom refuge from benthic predators for juvenile bay scallops *Argopecten irradians*. Marine Ecology Progress Series 74: 47-59.

Scallops are especially vulnerable to predation because can't close valves tightly for long periods. Vertical attachment reduces susceptibility to predation; smaller animals crawl higher in canopy. Mud crabs can also climb in the canopy. Tettelbach found inverse relationship between size of scallop and vulnerability to crab predation but does not matter until scallops are about 40mm. Scallops greater than 35mm using swimming as escape mechanism.

Project Oceanology. 1981. Environmental factors which affect the size and geographical distribution of the *Aequipecten irradians* in the Niantic and Poquonock River estuaries. Report prepared under joint NSF-SSTP grants. 60 pp.

Rhodes, E.W. and R. Goldberg. 1978. The use of pumped raceway systems for the intermediate grow-out of hatchery reared bivalves. Proceedings of the National Shellfisheries Association. 68:85 (abstract)

Rhodes, E.W., R. Goldberg and J. Widman. 1981. The role of raceways in mariculture systems for the bay scallop, *Argopecten irradians irradians* and the surf clam, *Spissula solidissima*. In: Claus, C., N dePauw and E. Jaspers (eds.). Nursery culturing of bivalve molluscs: proceedings of the international workshop; Feb. 24-216, 1981; Ghent, Belgium: 227-251. European Mariculture Society Special Publication No. 7; 394 pp.

Use of raceways for intermediate scallop culture is reasonable but not economically feasible to grow to market size and method may prove more feasible for surf clams (*Spissula solidissima*).

Rhodes, E.W. and J.C. Widman. 1980. Some aspects of the controlled production of the bay scallop (*Argopecten irradians*). Proceedings of the World Mariculture Society 11: 235-246.

Authors describe raceway system for nursery culture of 5-25mm seed. Densities can be as high as 1.82 l/m² biomass, which equaled 2253/m² at the beginning and 226/m² at the end. Scallops did not grow below 15° C in spring but did grow down to 10° in fall. Water flow was 50 l/min; swimming behavior increased with increased density. Authors suggest raceways as intermediate between hatchery production and field planting.

Rhodes, E.W. and J.C. Widman. 1894a. Suspension culture methods for the bay scallop, *Argopecten irradians irradians*. Proceedings of the National Shellfisheries Association 76:17 abstract

Rhodes, E.W. and J.C. Widman. 1984b. Density-dependent growth of the bay scallop, *Argopecten irradians irradians* in suspension culture. Charlottenlund, Denmark: International Council for the Exploration of the Sea, CM 1984/K:18. 8 pp.

Lantern nets were used for nursery growout at density of 100-2500/m². Scallops grew to market size 50mm @ 750/m²; max current <_ knot @ 5-7m depth; mortality 15% @ 100/m²; 47% @ 2500/m²; no sudden mortality. *Mytilus edulis* was the principal

- fouling organism; shell deformities seen from overcrowding and generally precedes death (from Epifanio, 1976; *Aquaculture* 9:81-85).
- Rhodes, E.W. and J.C. Widman, and P. Boyd. 1981. Experimental evaluation of nursery and grow-out methods for the bay scallop, *Argopecten irradians*. Charlottenlund, Denmark: International Council for the Exploration of the Sea, C.M.1981/F:25. 14 pp.
- Rhodes, E.W., J.C. Widman and P. Boyd. 1982. Bay scallop mariculture – progress and prospects. U.S. Dept. of commerce NOAA National Marine Fisheries Service. Northeast Fisheries Center Newsletter, March-April 1982: 1-9
- Rice, M.A., R.B. Rheault, M.S. Perez, and V.S. Perez. Experimental culture of moon scallops, *Amusium pleuronectes*, in Ulugan Bay, Palawan, Philippines. 9th International Pectinid Conference: April 22-27, 1993, Nanaimo, B.C., Canada
- Authors discussed clearance and filtration rates and found it high compared to other scallops. Authors speculate that high clearance rate and concomitant water transport rates are an adaptation to warm oligotrophic waters. Traditional lantern nets appear to be unfeasible for this species.
- Robinson, S.M., J.D. Martin, C. Ross, G Parsons, G. Pay, and D. Bishop. 10th International Pectinid Conference, April 27-May 2, 1995, Jury's Hotel, Cork, Ireland. (Mostly Abstracts)
- Experiments on direct re-seeding techniques for scallop population enhancement.
- Authors state that there are very few examples where skipping an intermediate nursery stage has been successful. They looked for ways to enhance bottom settlement and used a bio-filter that resembled fuzzy rope that had long coarse filamentous strands. It was efficient but expensive.
- Roman, G. and J. Cano. Pectinid settlement on collectors in Malaga, S.E. Spain, in 1985, (Abs.). 6th International Pectinid Workshop, School of Ocean Sciences, Marine Sciences Laboratories, Menai Bridge, Wales, UK, April 9-14, 1987.
- Authors used 6 long lines at 1-15 m off bottom. Settlement was not found on recently immersed collectors; 15 days were needed. Collectors were efficient for up to 60 days; earliest deployed and deepest supported heaviest settlement.
- Russell, H.J., Jr. 1973. An experimental seed bay scallop stocking of selected Rhode Island waters. Providence RI: Rhode Island Dept. of Natural Resources, Division of Fish and Wildlife report 82 pp.
- One of the most comprehensive references with respect to seeding trials in the wild. It includes difficulties with obtaining enough seed from hatcheries (the paper was written in 1973). Paper describes areas, predators present, current speed, primary productivity. Author speculates that minor fluctuations in temperature may have disastrous effects on scallops especially if animals are already under stress from water quality problems. He states that low population levels are not of sufficient density to lead to natural resurgence of the fishery. Author suggests laboratory studies on field observations especially with respect to water quality issues in order to make the most efficient use of transplant stock.

Sarkis. Scallop Culture in Bermuda: A saga. 8th International Pectinid Workshop, Cherbourg, France, 1991.

Author relates that there was low initial stock density. They used spat collectors and retrieved 250 scallops that were put in pearl nets in the hopes of getting a population started.

Silina, A.V. Growth of the scallop *Mizuhopecten yessoensis* cultured in the coastal waters of Primorye Province, Russia. Pp. 99-103. 9th International Pectinid Conference: April 22-27, 1993, Nanaimo, B.C., Canada

Purpose of study was to determine growth of scallops after they were transferred to 14 areas from collectors at different times of the year. All of those planted on gravel/pebble or mud substrates at 14-26 mm died. Those >20 mm survived on sand and sand/mud substrates.

Silina, A.V. 1994. Survival of different size-groups of the scallop, *Mizuhopecten yessoensis* (Jay), after transfer from collectors to the bottom. *Aquaculture* 126: 51-59.

Author found that if planted under 18-20 mm, they are especially sensitive to unfavorable environmental conditions but reasonable success with 30-40 mm. He found that mud bottom was bad but muddy sand was reasonable and suggests size gradations for bottom type. These are large scallops that can grow to 180-200 mm.

Sisson, J.D. 1981. Variability in growth of juvenile bay scallops (seed) at selected areas in Nantucket Harbor, Nantucket, Massachusetts. In Kelley, K.M. ed. *The Nantucket bay scallop fishery: the resource and its management*, pp. 50-68.

Sisson, J.D. 1987. Density effects on growth and reproduction in the northern bay scallop, *Aequipecten irradians irradians*. Master's Thesis, University of Massachusetts, Boston. 120 pp.

Important paper that looks at the effect of density on future populations. Author correlates work by other authors regarding fecundity and size relationships. He states that high density areas (>80/m²) can induce abnormal development and that shell growth is density dependent. He further suggests that reduced growth in high density areas for juveniles can mean lower meat yields but can also lower probability of successful fertilization. He concludes that smaller seed produces fewer gametes and suggests thinning areas of high seed concentration. His suggestion has ramifications for answering the question of why large production years are followed by low production years.

Slater, J. Scallop spat collection in Mulroy Bay, Ireland, 1979-1994. 10th International Pectinid Conference, April 27-May 2, 1995, Jury's Hotel, Cork, Ireland. (Mostly Abstracts)

Spatfall intensity over 3 periods reviewed. First very little; 2nd low to 0 because of TBT; 3rd improved spatfall and improved water quality but imbalanced broodstock from very old (1st period) and very young (3rd period) with nothing in between. He states the obvious, that a fishery cannot be developed without broodstock.

Smith, C. and S. Tettelbach, 1996. Bay scallop restoration project in western Peconic Bay.

Authors review transplant program carried out in attempt to repopulate western Peconic Bay, NY after devastation of resource resulting from Brown Tide. In 1993, they transplanted 37,500 on Nov. 19. Few survived the winter. In 1994, they transplanted 50,000, many of which did survive and approximately 33-40,000 spawned the following year. They set out spat collectors and recovered 1900 on 3 collectors.

Smith, C.F. and S.T. Tettelbach, 1997. Restocking Bay Scallops: Final report submitted to the National Marine Fisheries Service.

Authors review program to restock Peconic Bay, NY with scallops (see above). Landings from Peconic Bay finally beginning to show signs of recovery with 270,000 lbs. Harvested in 1994 but recurring brown tide in 1991 and 1995. Approx. 220,000 were transplanted in Dec., 1994 and approximately 32% survived through March. Recruitment was minimal due to brown tide. Authors investigated effect of brown tide on spawning scallops held in nets and also investigated winter kill phenomenon. This program has been most intensive restoration effort for bay scallops within the Northeast US in terms of scope and duration.

Stewart, L.L., P.J. Auster and R. Zajak. 1981. Investigation on the bay scallop, *Argopecten irradians*, in three eastern Connecticut estuaries, June 1980-May 1981. Final Report to the U.S. Dept of Commerce National Marine Fisheries Service, Milford, CT. 34 PP, 26 tables, 25 figs. 27 pls., 3 appendices.

Exhaustive study of habits and habitats with filming used as primary recorder. Observation: when eelgrass dies off, some scallops <25mm are still attached which leads to interesting speculations regarding late sets. Predator/prey: at temps >8°C, *Argopecten irradians* can escape starfish but below that, they cannot move and are easy prey. At >7°, their mobility allows them to shed oyster drills.

Sumpton, W.D., I.W. Brown and M.C.L. Dredge. 1990. Settlement of bivalve larvae spat on artificial collectors in a subtropical embayment in Queensland, Australia. *Journal of Shellfish Research*, 9(1) 227-231.

Collector bags used in Australia for different species. Some bags did not work at all for some species but had great natural settlement later.

Sunderlin, J.B. 1976. Growth of shellfish in an artificial upwelling mariculture system. In: Valle, Juan Carlos (ed.) Proceedings of the international symposium on coastal upwelling; Nov 18-19, 1975; Coquimbo, Chile. Universidad del Norte, Centro de Investigaciones Submarinas: 25-42.

Taylor, R.E. 1981. Preliminary investigations of local populations of the bay scallop *Argopecten irradians* Lamarck in Falmouth, Massachusetts. *Journal of Shellfish Research* 1(1): 124 abstract

Tettelbach, S.T., 1986. Seasonality of factors responsible for mortality of the northern bay scallop. *Journal of Shellfish Research* (in press)

Tettelbach, S.T., P.J. Auster, E.W. Rhodes and J.C. Widman. 1985. A mass mortality of northern bay scallops, *Argopecten irradians irradians*, following a severe spring rainstorm. *The Veliger* 27(4): 381-385.

Authors documented severe mortalities near head of the river in shallow water and lesser mortalities further downstream in deeper water.

Tettelbach, S.T., C.F. Smith, J.E. Kalady, T.W. Arroll and M.R. Denson. Burial of transplanted bay scallops *Argopecten irradians irradians* (Lamarck, 1819) in winter. *Journal of Shellfish Research*, 9(1): 127-134.

Very good description of phenomenon seen as winter-kill in the field. Burial more prevalent in hollows and in muddy-sand substrate.

Tettelbach, S.T. and P. Wenczel, 1993. Reseeding efforts and the status of bay scallop *Argopecten irradians* (Lamarck, 1819) populations in New York following the occurrence of "Brown Tide" algal blooms. *Journal of Shellfish Research* 12(2): 423-431.

Very good overview of problems associated with re-seeding efforts in Peconic Bays after the occurrence of the "Brown Tide". Authors also noted *Polydora* infestation. Authors stated that even with Brown Tide, some of seeded scallops make it to spawn and some of those have made it also. Project is expensive, precarious and not cost-effective at this time. Peconic Bays produced _ of all landings and employed 400-600 people prior to Brown Tide.

Thomson, J.D., Fujimoto, T, Moriya, H., and Ikeda, T. Tasmanian scallop enhancement with *Pecten fumatus* (Reeve). Proceedings of the Australasian Scallop Workshop, July, 1998, Taroom, Australia. M.L.C. Dredge, W.F. Zacharin and L.M. Joll (eds.), Hobart, Australia.

Authors recount a joint project between Japanese Overseas Fishery Co-operation Foundation and the Tasmanian government. They used wild spat collection because hatcheries could not supply the demand. Intermediate culture used lantern cages and ear hanging (which was less capital intensive, took more time to harvest but produced broodstock. Scallops were also reseeded. Survival ranged from 11-60% three years after reseeded. Hanging culture is feasible alternative is survival of reseeded beds remains at low end. Seastar (*Asterias amurensis*) infestations were introduced to area in 1986 probably through ship's ballast and can be threat to success of scallop culture.

Thomson, J.D. The development of scallop husbandry fishing in Tasmania through technology transfer from Hokkaido. P. 109 (abs.). 9th International Pectinid Conference: April 22-27, 1993, Nanaimo, B.C., Canada

Intermediate culture necessary for scallops. Authors used hanging culture with lantern nets. For the second phase of their project, they used ear hanging techniques. They found that areas of fastest growth were not necessarily the ones with greatest survival.

Twomey, E., G.M. Burnell, A. Gillespie, and R. FitzGerald. Scallop farming in Ireland – an interactive computer based training package. Pp. 114-117. 9th International Pectinid Conference: April 22-27, 1993, Nanaimo, B.C., Canada

Paper describes a computer program that is basic training manual for European mariculture. Europe's fastest growing areas are in Scotland, Ireland and

- France. The program cost \$25 K to produce (and sounds like something SEMAC should obtain if still available).
- Walsh, D. 1981. Limitations and potentials of bay scallop (*Argopecten irradians*) culture in New England. *Journal of Shellfish Research* 1(1): 125-126 (abstract)
- Walsh, D.T., J.L. Madison, L.C. vanderhoop, G.L. Cook, J. Jeffers and D. Luce. 1978. The Wampanoag fisheries project: shellfish production improvement at Gay Head, Martha's Vineyard, Massachusetts. First Annual Report to U.S. Dept. of Commerce, Economic Development Administration, Technical Assistance Grant No. 01-6-01369.
- Walsh, D.T., J.L. Madison, L.C. vanderhoop, G.L. Cook, J. Jeffers and D. Luce. 1979. The Wampanoag fisheries project: shellfish production improvement at Gay Head, Martha's Vineyard, Massachusetts. Second Annual Report to U.S. Dept. of Commerce, Economic Development Administration, Technical Assistance Grant No. 01-6-01369-1. 60 pp.
- Wang Rucai, Liang Ying and Tian Chuanyuan. Study of factors affecting amount of semi-artificial seed collection of Farrer's scallop. 10th International Pectinid Conference, April 27-May 2, 1995, Jury's Hotel, Cork, Ireland. (Mostly Abstracts)
- Authors stated they used spat bags that were 40 cm long by 30 cm wide. Highest recruitment in 1975 was 290/bag; average density was >1,000/bag in 1984. 2,500 million market sized were harvested in 1984. In 1995, highest amount/bag was 4,500 and 130 billion were harvested in 1995. Good collection farm consists of clear seawater, little floating mud, 4-7 m transparency, 32 ‰ salinity and 20-40 cm/sec current velocity. There must be natural or cultured scallops nearby and the more broodstock, the more larvae. Optimum mesh for bags is 1.2 mm X 1.5 m; mesh too big 20 mm X 25 mm (Misprint? Should probably be 2.0 X 2.5 mm) will allow predation. Knowing the right time to set out the collectors is the crux of collecting seed.
- Wenczel, P., C. Smith and S. Tettelbach, 1992. Executive Summary: Planting bay scallops; results of reseeded bay scallops in the Peconic Bay New York 1986-1992. Final Report Submitted to: The New York State Urban Development Corporation, New York State Department of Environmental Conservation and County of Suffolk. 36pp.
- Good overview of problem in Peconic Bay, NY resulting from Brown Tide and efforts to re-establish scallop populations. Prior to incidence, 306,000 lbs. meats harvested @ 1.1 million (or 15-20% of US landings). Tourist industry devastated because "no one enjoyed recreational activities in coffee colored water". They established a 3-phase program: establish predator-free spawner sanctuaries, transplant natural set seed from NY or NE and purchase seed from hatcheries and purchase seed from hatcheries to plant after nursery grow-out. Authors suggest that lack of seed from other areas was due to region-wide decrease in bay scallops beginning in 1986. Paper gives description of methods to locate crabs and removal of starfish. Crabs that had been buried when surveys made caused highest mortality after transplant. Even with weekly monitoring, a significant % disappeared. Cage culture to overwinter seed @ 20 mm was unsuccessful.

Wickfors, G.H., J.C. Widman, S. Stiles, R. Robohm and A. Calabrese, 1998. New England bay scallops as a one season aquaculture crop. Marine Aquaculture: Emerging Technologies and Global Opportunities (Workshop Abstracts), University of Connecticut, Stamford, June 26-27, 1998.

Description of new recirculating systems with various removal techniques for bio-products. System uses heated seawater once and then recirculates it throughout the system. Accumulation of waste products from the shellfish is filtered using several different filtering methods and media. Paper also discusses algal cultures and automation procedures developed at the Milford Laboratory.

Experiments are being conducted using seaweeds species such as *Ulva* to further utilize waste products of shellfish (personal observation and discussion with Ron Goldberg).

Widman, J.C., and E.W. Rhodes, 1991. Nursery culture of the bay scallop, *Argopecten irradians irradians*, in suspended mesh nets. *Aquaculture* 99: 257-267.

Pearl nets were used. Authors found an inverse relationship between size and density as they affect growth. Survival in all treatment was 80% and unaffected by densities. Project was used to look as method as alternative to raceways. Scallops deployed at lower temps. May require longer time to acclimate before growth. No long-term observations made. Larger scallops were seen in nets closer to surface.

Widman, J.C., E.W. Rhodes, and P.A. Boyd 1983. Nursery culture of the bay scallop *Argopecten irradians irradians* (Lamarck) in suspended mesh enclosures. *Journal of Shellfish Research* 3(1): 104 (abstract)

Wolff, M., 1988. Spawning and recruitment in the Peruvian scallop *Argopecten purpuratus*. *Marine Ecology Progress Series* 42: 213-217.

Field studies/natural habitat—feeding, nutrition, predation, and mortality

Alber, Merryl, and Ivan Valiela, 1995. Organic aggregates in detrital food webs: incorporation by bay scallops *Argopecten irradians*; *Marine Ecology Progress Series*.; Vol. 121: 117-124.

Researchers tracked organic aggregates in detrital food webs and included diagram of suggested pathways for dissolved organic matter.

Alber, Merryl, and Ivan Valiela, 1996. Utilization of microbial organic aggregates by bay scallops, *Argopecten irradians* (Lamarck); *Journal of Experimental Marine Biology and Ecology*. 195: 71-89.

Bricelj, V.M., S.I. Bauer, S. Tanikawa-Oglesby, and F. Borrero. Growth and predatory mortality of juvenile bay scallops *Argopecten irradians irradians*, in Mid-Atlantic eelgrass meadows. 10th International Pectinid Conference, April 27-May 2, 1995, Jury's Hotel, Cork, Ireland. (Mostly Abstracts)

Davies, T.J., 1983. The influence of the epibenthic *Codium fragile* and *Crepidula fornicata* of the predation of the bay scallop *Argopecten irradians* by the sea star *Asterias forbesi* and the oyster drill *Urosalpinx cinerea*. Garden City, NY: Adelphi University. 52 pp. Thesis.

Davis, R.L. and N. Marshall. 1961 The feeding of the bay scallop, *Aequipecten irradians*. Proceedings of the National Shellfisheries Association 52: 25-29.

All food species listed were diatoms of two types; benthic diatoms predominated in stomach contents. Paper gives 4 possible explanations for feeding: 1. Raise food off bottom by shell flapping 2. Consume microfauna growing on upper shell valve surfaces 3. Feed directly from water over incurrent mantle opening and 4. Selective feeding for benthic and tychopelagic forms.

Halary, C., Y. Royer, J.P. Corlourer and J-C Dao. Effects of predation and competition on scallop, *Pecten maximus* seeded cultivation in Saint Brieuc Bay: preliminary results. PP. 39-50. 9th International Pectinid Conference: April 22-27, 1993, Nanaimo, B.C., Canada

Preliminary results of seeding effort: mortality generally low. Predation by whelks was exclusively in winter with large variability between years. Competition with slipper limpets resulted in lower growth rate. Crabs active with seed 30 mm or smaller; whelks preyed on scallops <50 mm.

Krause, M.K. and S.E. Shumway, 1997. A preliminary study of the effects of temperature and food availability on winter mortality and condition in the northern bay scallop, *Argopecten irradians irradians*. In Restocking Bay Scallops, final report submitted to the National Marine Fisheries Service. C. E. Smith and S. T. Tettelbach, 1997.

Lake, N.C.H. and C.L. McFarlane. Crab and starfish predation on the scallop *Pecten Maximus* (L.) during seabed cultivation. P. 56 (abs.). 9th International Pectinid Conference: April 22-27, 1993, Nanaimo, B.C., Canada

Marshall, N. 1970. Food transfer through the lower trophic levels of the benthic environment. In: Steele, J.H. (ed.). Marine food chains. Edinburgh: Oliver & Boyd: 52-66.

Ordzie, C.J. and G.C. Garofalo. 1980b. Predation, attack success, and attraction to the bay scallop, *Argopecten irradians* (Lamarck) by the oyster drill, *Urosalpinx cinerea* (say). Journal of experimental Marine Biology and Ecology 47(1): 95-100.

In laboratory experiments, out of 72.3 attacks by oyster drills, all led to success and death of scallops. Oyster drills were attracted by "scallop effluent" in situ.

Scheibling, R. and B.G. Hatcher. Movement and mortality of juvenile scallops released in bottom culture trials. P. 97 (abs.). 9th International Pectinid Conference: April 22-27, 1993, Nanaimo, B.C., Canada

Authors traced survival of small seed free planted at 3 sites. They found considerable losses in first 2 weeks and high variability between sites rather than between planting dates. They say that small variations in near-bottom physics can produce large variations in surviving populations and speculate that post settlement processes contribute significantly to scallop population variability.

Short, F.T., G.E. Jones and D.M. Burdick, 1991. Seagrass Decline: Problems and solutions. Coastal Wetlands, Coastal Zone 91 Conference-ASCE, Long Beach, CA, Pp 439-453.

Short, F.T. and D.M. Burdick, 1996. Quantifying eelgrass habitat loss in relation to housing development and nutrient loading in Waquoit Bay, MA. *Estuaries* (in press).

Short, F.T. and B.W. Ibelings and C. Den Hartog, 1998. Comparison of a current eelgrass disease to the wasting disease in the 1930's. *Aquatic Botany* 30: 295-304.

Shumway, S.E. and A.D. Cembella. The impact of harmful algal blooms on scallop culture and fisheries. P. 98 (abs.). 9th International Pectinid Conference: April 22-27, 1993, Nanaimo, B.C., Canada

Authors state that interest in "roe-on" scallops from various geographic locations has "provoked public health concerns". Authors found that toxins are not distributed evenly throughout scallop tissues but is usually concentrated in the mantle and digestive gland where it can remain toxic throughout the year. They found no correlation between toxicity levels in gonadal tissue and any other tissues.

Tettlbach, S.T. 1985. Temporal variability of crab predation on northern bay scallops, *Argopecten irradians irradians*. *Estuaries* 8(2B): 79A (abstract) No. 205.

Tettlbach, S.T., S.Y. Feng. 1986. Intensity of crab predation on northern bay scallops *Argopecten irradians irradians*: effects of prey size and predator assemblages on seasonal patterns. *Journal of Shellfish Research*. (in press)

Toner, R.C. 1974. Food preference and feeding of the bay scallop *Aequipecten irradians* Lamarck (1819). Boston, MA: Northeastern University. 100 pp. Dissertation.

Wilson, U.A.W. and A.R. Brand. Nowhere to hide? Predator impact on seeded scallops. P. 118 (abs.). 9th International Pectinid Conference: April 22-27, 1993, Nanaimo, B.C., Canada

Author describes infestation by starfish that were not present at time of seeding. Crabs only seen occasionally but accounted for 45% mortality. "Loss" included dispersal (58%). Author states that predators modified their behavior to get at larger than optimal prey and he suggests that the shellfish give off a stressed cue in addition to chemical signal as a consequence of seeding itself. Implication is that without effective predator clearance prior to reseedling, the presence of weakened scallops at high densities may result in a size refuge being breached to lead to early catastrophic losses of stock.

Culture methods—hatcheries, feeding, nutrition, and larval studies

Burle, E. and W.W. Kirby-Smith. 1979. Growth of the bay scallop, *Argopecten irradians* fed an artificial diet rich in protein. *Estuaries* 2(3): 206-208.

Castagna, M. 1975. Culture of the bay scallop, (*Argopecten irradians* Lamarck) in Virginia. *Marine Fisheries Review* 37(1): 19-24.

Detailed hatchery methods used at VIMS, Wachapreague lab.

Castagna, M. 1983. Review of recent bivalve culture methods. *Journal of the World Mariculture Society* 14:567-575.

Castagna, M. and W. Duggan. 1971. Rearing the bay scallop, *Aequipecten irradians*. *Proceedings of the National Shellfisheries Association* 61: 80-85.

- Castagna, M.A. W.P. Duggan and D. Garten, 1971. Spawning and rearing the bay scallop: VIMS laboratory method. Gloucester Point, VA: Virginia Institute of Marine Science, Marine Resources Advisory Series No. 5 3pp. (Also Virginia Institute of Marine Science Sea Grant Publication No VIMS-G1-71-001).
- Paper describes hatchery method, time and temperature of spawning, feeding and nursery culture in wood-mesh floats. Suspected mortality causes not investigated in this study but suspected causes included disease, parasites, over-crowding, smothering and senescence.
- Costello, T.J., J.H. Hudson, J.L. Dupuy and S. Rivkin. 1973. Larval culture of the calico scallop, *Argopecten gibbus*. Proceedings of the National Shellfisheries Association 63:72-76.
- Duggan, W.P. and M.A. Castagna. 1971. Studies on mariculture of bay scallop, (*Argopecten irradians*). In: Hargis, W.J., Jr. (ed.) Research on Chesapeake Bay and contiguous waters of the Chesapeake Bight of the Virginia Sea. Gloucester Point, VA: Virginia Institute of Marine Science Sea Grant Publication No. VIMS-Q-71-001:22.
- Epifanio, C.E. 1976. Shell Deformity among Scallops (*Argopecten irradians*, Lamarck) Cultured in a Recirculating Seawater System. *Aquaculture*, 9: 81-85.
- Epp, Jennifer, et al; 1988. Seasonal partitioning and utilization of energy reserves in two age classes of the bay scallop *Argopecten irradians irradians* (Lamarck); *J. Exp. Mar. Biol. Ecol.*, Vol. 121, 113-136,
- Flores-Briceño, B.L. Garcia, B.A. Trench, J.C. Véliz and R. Gonzales-Plaza. 9th International Pectinid Conference: April 22-27, 1993, Nanaimo, B.C., Canada
- Developments in the industrial production of scallop, *Argopecten purpuratus* (Lamarck, 1891), seed in semi-controlled environments in the north of Chile. P. 33 (abs.).
- Fordham, E.C. 1970. Scallop culture: hatchery rearing of the larval and juvenile stages of the bay scallop, *Aequipecten irradians*. Hartford, CT: Connecticut Research Commission, Grant No RSA-70-24. 25pp.
- He, B.S. An improved system for microalgae culture. Pp. 50-55. 9th International Pectinid Conference: April 22-27, 1993, Nanaimo, B.C., Canada
- Mann, R. and R.E. Taylor, Jr. 1977. Growth of the bay scallop, *Argopecten irradians* in a waste recycling aquaculture system. In: Ryther, J.H. and R. Mann (eds.). Bivalve mollusc culture in a waste recycling aquaculture system. Woods Hole MA: Woods Hole Oceanographic Institution Technical Report No. WHOI-77-59. 11pp.
- Mann, R. and R.E. Taylor, Jr. 1981. Growth of the bay scallop *Argopecten irradians* in a waste recycling aquaculture system. *Aquaculture* 24(1-2): 45-52.
- Report of pilot project; authors report high mortalities and shell deformities but offer no explanation for mortalities.
- Matthiessen, G.C. and R.C. Toner. 1966. Possible methods of improving the shellfish industry of Martha's Vineyard, Duke's County, Massachusetts. Edgartown, MA: Marine Research Foundation, Inc. 138 pp.

- Paper documents hatchery and post-set methods for four shellfish species including scallops. Field grow-out was not conducted for scallops.
- Millican, P.F. Initial studies in the hatchery culture of king scallop, *Pecten maximus*. P. 57 (abs.). 9th International Pectinid Conference: April 22-27, 1993, Nanaimo, B.C., Canada
- Robert, R., P. Miner, M. Mazuret, and J.P. Connan. Observations on larval development and settlement of *Patinopecten yessoensis* in hatcheries. PP 84-90. 9th International Pectinid Conference: April 22-27, 1993, Nanaimo, B.C., Canada
- Discussion of differences with *P. maximus* and *P. yessoensis* in hatchery.
- Rupp, G.S. and C.R. Poli. Spat production of the sea scallop, *Nodipecten dodosus* (Linnaeus, 1758), in the hatchery: initial studies in Brazil. Pp.91-96. 9th International Pectinid Conference: April 22-27, 1993, Nanaimo, B.C., Canada
- Paper looked at current production (low on spat collectors). First attempt to raise this species in hatchery in Brazil. Lost most of them at straight hinge stage.
- Sastry, A.N., N.M. Rhines and J.G. Jones. 1982. Food requirements for artificial conditioning of the bay scallop *Argopecten irradians* Lamarck to maturity. Final Report to U.S. Dept. Commerce National Marine Fisheries Service, Milford, CT. 41 pp.
- Taylor, J.E., B. Gunn, P. Williams and I. McNicholl. An investigation of techniques for the hatchery and nursery rearing of the king scallop, *Pecten maximus* (L). Pp. 104-108. 9th International Pectinid Conference: April 22-27, 1993, Nanaimo, B.C., Canada
- No successful commercial hatchery production. Most scallops around Highland areas of Scotland. In their hatchery they devised a new cleaning technique. A filter was placed on the outflow. Clean treated seawater flowed into the vessel at a rate = outflow; the volume remained constant. Method used every two days to change 1.5 total vessel volume to produce complete water exchange. It worked much better than traditional drain-downs for larvae.
- Tettlebach, S.T. and E.W. Rhodes. 1981. Combined effects of the temperature and salinity on embryos and larvae of the northern bay scallop *Argopecten irradians irradians*. Marine Biology 63(3): 249-256.
- Toner, R.C. 1975. The culture of phytoplankton for the feeding of the scallop *Argopecten irradians irradians* Lamarck (1819). Falmouth, MA: Marine Research, Inc. 48 pp.
- General biology**— growth and reproduction (including gametogenesis), experimental survival studies, genetics, salinity/temperature tolerance and other environmental parameter studies based on laboratory experiments
- Adamkewicz L. and M. Castagna, 1988. Genetics of shell color and patterns in the bay scallop *Argopecten irradians*. Journal of Heredity 79(1): 14-17.
- Auster, P.J. and L.L. Stewart. 1984. Compensatory growth in the bay scallop, *Argopecten irradians* (L). Journal of Northwest Atlantic Fishery Science 5(1): 103-104.
- Authors found that small first year scallops catch up in growth in second year in CT estuary.

- Barber, B.J. and N.J. Blake, 1981. Energy storage and utilization in relation to gametogenesis in *Argopecten irradians concentricus* (Say). *Journal of Experimental Marine Biology and Ecology* 52: 121-134.
- Discussion of cycle of gonad, mantle and adductor muscle with respect to energy storage and dry weights.
- Barber, B.J. and N.J. Blake. 1983. Growth and reproduction of the bay scallop *Argopecten irradians* (Lamarck) at its southern distributional limit. *Journal of Experimental Marine Biology and Ecology* 66(3): 247-256.
- Spawning is in conjunction with decreasing water temperatures; gametogenesis may be a function of available food and certain minimum temperature.
- Barber, B.J. and N.J. Blake, 1985. Substrate catabolism related to reproduction in the bay scallop, *Argopecten irradians concentricus*, as determined by O/N and RQ physiological indexes. *Marine Biology* 87:13-18.
- Barber, B.J. and N.J. Blake, 1985. Intra-organ biochemical transformations associated with oogenesis in the bay scallop *Argopecten irradians concentricus* (Say), as indicated by ¹⁴C incorporation. *Biological Bulletin* 168(1): 39-49.
- Barber, B.J. and N.J. Blake, 1986. Reproduction effort and cost in the bay scallop, *Argopecten irradians concentricus*. *International Journal of Invertebrate Reproduction and Development*, 10: 51-57.
- Bayne, B.L. 1976. Aspects of reproduction in bivalve molluscs. In: Wiley, M. ed. *Estuarine Processes: uses, stresses and adaptation to the estuary*. New York Academic Press: 432-448.
- Bonardelli, John C., Himmelman, John H. and Drinkwater, K. Relation of spawning of the giant scallop *Placopecten magellanicus*, to temperature fluctuations during downwelling events. 10th International Pectinid Conference, April 27-May 2, 1995, Jury's Hotel, Cork, Ireland. (Mostly Abstracts)
- Spawning usually associated with temperature fluctuations but authors found it was associated with downwelling events of warm surface waters. The downwelling of warm surface waters ensured that the gametes were released to water where fertilization was likely.
- Bricelj, V. Monica, et al; 1987. Comparative physiology of young and old cohorts of bay Scallop *Argopecten irradians irradians* (Lamarck, 1819): mortality, growth, and oxygen consumption; *J. Exp. Mar. Biol. Ecol.*, Vol. 112, 73-91,
- Bricelj, V. Monica, et al; 1987. Intraspecific variation in reproductive and somatic growth cycles of bay scallops *Argopecten irradians*; *Mar. Ecol. Prog. Ser.*; Vol. 36, 123-137,
- Bricelj, V. M., and M. K. Krause; 1992. Resource allocation and population genetics of the bay scallop, *Argopecten irradians irradians*: effects of age and allozyme heterozygosity on reproductive output; *Marine Biology* Vol. 113, 253-261,
- Cahalan, Jennifer A., et al; 1989. Effects of flow velocity, food concentration and particle flux on growth rates of juvenile bay scallops *Argopecten irradians*; *J. Exp. Mar. Biol. Ecol.*, Vol. 129, 45-60,

- Castagna, M. and P. Chanley. 1973. Salinity tolerance of some marine bivalves from inshore and estuarine environments in Virginia waters on the western mid-Atlantic coast. *Malacologia* 12(1): 47-96.
- Chipman, W.A. 1954. On the rate of water propulsion by the bay scallop. *Proceedings of the National Shellfisheries Association* 45:136-139
- Interesting set of experiments using radioactive plankton to trace rate of water over the gills; experiments showed rapid removal at beginning followed by leveling off and was function of time in suspension, not density of food.
- Chipman, W.A. and J.G. Hopkins. 1954. Water filtration by the bay scallop *Pecten irradians*, as observed with the use of the radioactive plankton. *Biological Bulletin (Woods Hole)* 107(1) 80-91. Expanded version of above.
- Clark, G.R., II. 1969. Shell characteristics of the family *Pectinidae* as environmental indicators. Pasadena, CA: California Institute of Technology. 101 PP Thesis
- Cooper, R.A. and N. Marshall. 1963. Condition of the bay scallop, *Aequipecten irradians*, in relation to age and the environment. *Chesapeake Science* 4(3): 126-134 (also University of Rhode island Graduate School of Oceanography, Narragansett Marine Laboratory Contribution No.72).
- Costlow, J.D., Jr. and W.W. Kirby-Smith. 1970. The effects of water current on the growth of the bay scallop, *Argopecten irradians* (Lamarck). Final report to the North Carolina Board of Science and Technology, Grant No. 279. 4pp.
- Authors found definite inhibition of growth at high current velocity >10 cm/sec. From -5 cm/sec, growth increased and reached a maximum. Separate experiment used pipes and a velocities <0.5 cm/sec, growth was rapid at the head of the pipe but not at the end and was particularly noticeable at higher temperatures (with implications for aquaculture). Scallops should be grown in relatively weak current <5 cm/sec with high volume of well-mixed water – approx. 1 gal/hr/animal at temp. 18-25°C for best growth.
- Crenshaw, J.W., Jr., P.B. Heffernan and R.L. Walker, 1991. Heritability of growth rate in the southern bay scallop, *Argopecten irradians concentricus* (Say, 1822). *Journal of Shellfish Research*, 10(1) 55-63.
- Paper traces genetic traits and selects for growth.
- Dodd, J.R. 1969. Effects of light on rate of growth of bivalves. *Nature (London)* 224(5219): 617-618.
- Duggan, W.P. 1975. Reaction of the bay scallop, *Argopecten irradians*, to gradual reductions in salinity. *Chesapeake Science* 16(4): 284-286.
- Jackson, D.L. and R.K. O'Dor. The role of gravity in the feeding and swimming mechanics of scallop larvae: results from microgravity experiments. 10th International Pectinid Conference, April 27-May 2, 1995, Jury's Hotel, Cork, Ireland. (Mostly Abstracts)

- Author suggests using space shuttle to test effect of gravity on 1 mm marine organisms.
- Kirby-Smith, W.W. 1969. Growth of the bay scallop *Aequipecten irradians* (Lamarck) as influenced by food concentration and temperature. *American Zoologist* 9(4): 1144-1145 (abstract).
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WHOI Sea Grants “Oceans Alive” Lecture Series Concludes with Presentation on the Westport Scallop Project

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APPENDIX B

SURVEY AND RESPONSES BY NUMBERS AND PERCENTAGES

SCALLOP SURVEY*

WE NEED YOUR HELP! As many of you are aware, the Southeast Massachusetts Aquaculture Center and the Barnstable County Extension Service have extended a contract to conduct a study of the bay scallops in Massachusetts. Declines throughout the region in the past decade, even in areas with a tradition of having at least some scallops to harvest, have been a cause for concern. The DMF has provided catch records that go back to the 1950's and although peaks and valleys of abundance are common, every region in Southeast Massachusetts has shown a decline. The reasons for this are probably many but a major focus of the current project is to try to find some common problems that may help to explain the lack of scallops in Massachusetts.

Please take a few minutes to respond to this survey. The study has a short time frame so we need your response as soon as possible but no later than **FEBRUARY 19, 1999**. Your answers will help all of us.

1. Name: _____
2. Town: (**N = 22, plus MVSG, Waterworks, DMF**)
3. How long have you been a shellfish officer? A. 1-5 years **26% (N=6)** B. 6-10 years **30% (N=7)**
C. more **39% (N=9)**

Please check and/or circle all that apply:

4. Have you noticed any of the following?
 - a. decline in eelgrass abundance **70% Y (N=16), 22% N, (N=5)**
 - b. increase in growth on eelgrass blades (slime, hair-like fuzz, colorful "pinwheels") **67% Y (N=12), 9% N (N=2)**
 - c. increase in seaweed within patches of eelgrass **48% Y(N=11), 22% N (N=5)**
 - d. rafts of floating eelgrass in 1. June **17% (N=4)**, 2. July **22% (N=5)**, 3. August **44% (N=10)**, 4. Sept. **39% (N=9)**,
 - e. increase/decrease in crabs (circle one if appropriate) **57% I (N=13), 9% D (N=2), 9% NC (N=2)**,
 - f. increase/decrease in other predators: starfish, oyster drills, moon snails, conchs, fish, birds **61% I (N=14), 13% D (N=3) most increase in birds; most decrease in conchs and starfish**
 - g. change in sediment _____; 1. Hard to soft **48% (N=11)**, 2. Soft to hard **4% (N=1)**,
 - h. change in inlet structure or dynamics (**N=13Y, 2N**),
 1. Construction (jettys, seawalls, etc.) **9% (N=2)**,
 2. Dredged channel **22% (N=5)**, 3. Natural occurrence **57% (N=13)** 4. When _____
 - i. increase in plankton blooms that turn the water an odd color or reduce water clarity **44% Y (N=10), 17% N (N=4)**,
 - j. increase/decrease in motor boat activity **87% Y (N=20), 4% N (N=1)**
 - k. increase/decrease in size of motor boats **61% Y (N=14), 9% N (N=1)**
5. If your town has had scallops in the past 10 years, has there been an incidence of:
 - a. large seed (no visible annual growth ring)? Yes **48% (N=11)** No **26% (N=6)**
 - b. "normal" sized with 1 ring within _" of the hinge? Yes **57% (N=13)**, No **17% (N=4)**
 - c. normal-shelled adult scallops mixed in with either a or b above? Yes **65% (N=15)**, No **13% (N=3)**
 - d. if yes, was harvesting allowed? Yes **61% (N=14)**, No **9% (N=2)**
 - e. if yes, was there difficulty in enforcing "growth ring" law? Yes **24% (N=6)**, No **57% (N=13)**

- f. were there many scallops the following year and year after? Yes 17% (N=4), No 44% (N=10)
6. Has your town grown substantially in the past 10 years in the following ways:
- houses built on the water? Yes 65% (N=15), No 26% (N=6)
 - conversion of summer cottages to year-round homes? Yes 83% (N=19), No 9% (N=2)
 - high development within a mile of the water? Yes 78% (N=18), No 22% (N=5)
7. Have scallop-producing areas been closed by DMF because of :
- fecal coliform bacteria? Yes 22% (N=5), No 74% (N=17)
 - rainfall closure? Yes 26% (N=6), No 57% (N=13)
 - other? Yes 9% (N=2), No 44% (N=11)
 - what was the cause for the closure? _____
8. Is there any other problem you have noticed not covered above? Please explain.
9. Can you think of any other possibility for explaining the lack of scallops?
10. Is there anyone in your town who might be appropriate to interview in person?
11. Who? (Name, address, phone)
12. Has your town engaged in scallop restoration projects? Yes 65% (N=15), No 17% (N=4)
13. If yes, did you **(based on responses to #12 above)**
- plant seed from a commercial/municipal hatchery?
 - broadcast 100% (N=15),
 - provide nursery culture first 80% (N=12)
 - cages 80% (N=12), b. upweller 33% (N=5), c. suspension nets 27% (N=4),
 - other 13% (N=2).
 - use spat collectors? 73% (N=11), Successful? Yes 73% (N=10), No (couched) 13% (N=1)
 - if unsuccessful, why? Fouling and lack of broodstock
14. Do you/have you used volunteers? Yes? (N=10), No? (N=7) Successful? Yes 39% (N=8), No 30% (back to full # respondents)
- if no, why? Can't coordinate
15. Have you used the schools for scallop (or other shellfish) work? Yes 44% (N=10), No 39% (N=9)
16. Are there any private scallop growers in your town? Yes 22% (N=5), No 52% (N=12)
- if yes, how many? 4 (N=3),
 - have they been successful? Yes 3 (N=3), No 1 (N=1)
17. Any additional comments?

Thank you very much for your cooperation.

Please mail this survey by **FEBRUARY 19, 1999** to:

Sandra Macfarlane
 P.O. Box 1164
 Orleans, MA 02653

***This document represents the actual survey distributed to municipalities, biologists, and managers in southern Massachusetts. N = number of respondents.**

APPENDIX C

SCALLOP HARVEST DATA BY GEOGRAPHIC AREA

Figure 1. Bushels of scallops harvested from the waters of Nantucket, Martha's Vineyard, Buzzards Bay, and all of Cape Cod between 1965 and 1997.

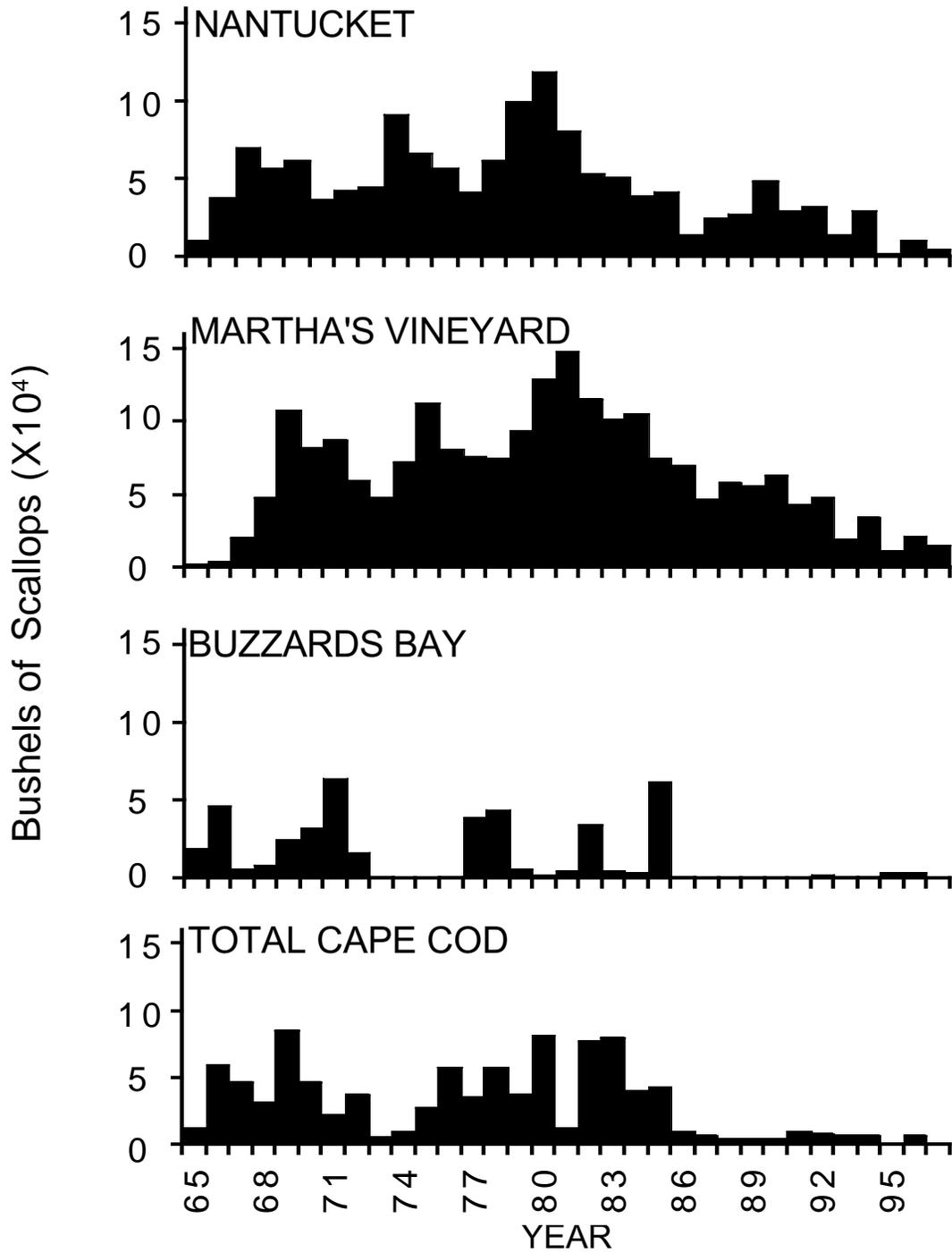
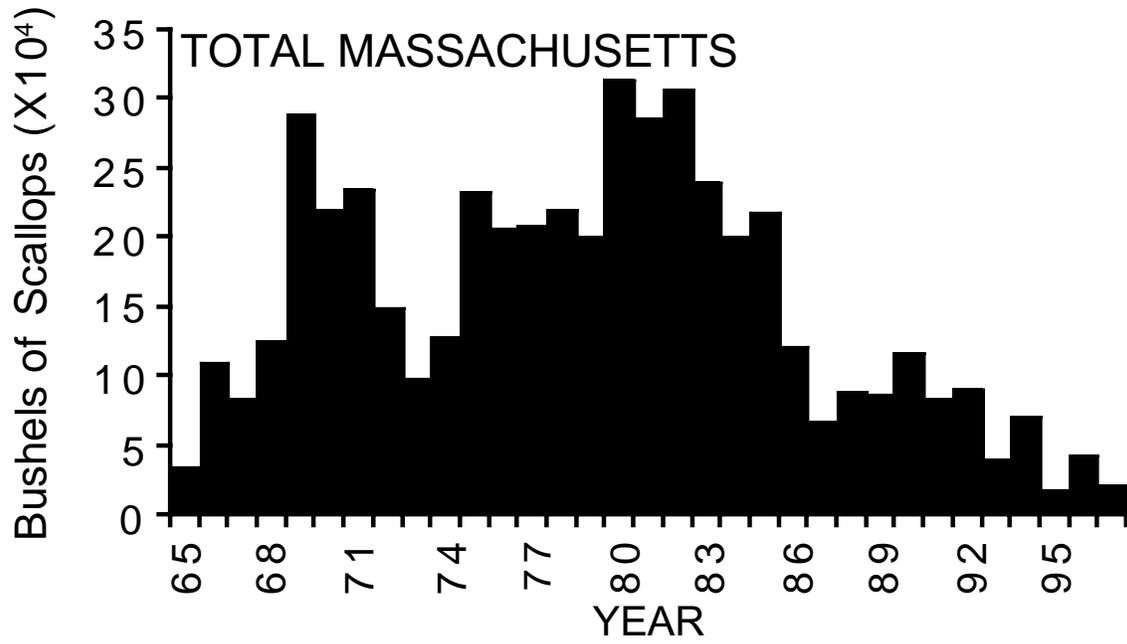


Figure 2. Bushels of scallops harvested from Massachusetts waters between 1965 and 1997.



APPENDIX D

ADDENDUM TO BIBLIOGRAPHY (1999-2004)

BIBLIOGRAPHY (1999-2004)

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