

Scallop Enhancement:

A Literature Review with a Focus on Methods' Applicability in

Maine Waters

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Introduction

The Maine sea scallop fishery (*Placopecten magellanicus*) is known for its quality of product but has fallen off in landings in recent years (D. Morse, personal communication, August, 7 2008; Schick and Feindel 2005). Although primarily a secondary fishery for most participants, it serves as important additional income for its endorsed fishermen. Enhancement of the resource has recently come to the forefront of discussion again. This review aims to collect and consolidate prevalent information towards this possibility to help rebuild the state scallop resource.

Culturing of animals comes in multiple levels of intensity, from simply the accumulation and protection of wild progeny to intense cultivation and quarantine (Minchin 2007). It is not a novel process, with a history that dates back to the pharaohs of Egypt and the Romans (Borgese 1980). The first recorded use of larvae for restocking occurred in Gloucester, Massachusetts in 1878 (Svåsand et al. 2000). This “blue revolution,” as Mikus termed it (1998), is responsible for the rapid increase in world scallop production from 200,000 t in the 1970s to 1.7 million t in 1996 (Bourne 2000). Although stocking is present in over 25 countries, few have been able to obtain consistent success in production, especially with species of scallops (Booth and Cox 2003; Bourne 2000). Many factors on the biological, social, and economic fronts contribute to these successes and trials. Although these factors can vary from region to region and between species, this review looks to point out the many commonalities among the different systems.

The sea scallop has many favorable characteristics that suit it for culture. It is a highly fecund species, especially compared to its bivalve relatives (Langton et al. 1987).

It filters its own food and thus would require little additional input (Young-Lai and Aiken 1986). It already has an established market and garners a high price for its meats, which, additionally, are rather insensitive to biological toxins like the paralytic seafood poison. It can be reared in depths that minimize user conflicts of use of the water column, thus easing social acceptance (Young-Lai and Aiken 1986). Enhancement techniques vary from extensive to highly intensive. Extensive techniques can include what are normally considered regulatory restraints, such as effort controls (Booth and Cox 2003). More intensive possibilities that tend to be most common include broodstock protection, bottom-seeding, net-rearing, and ear-hanging. The most intensive forms of culture include tank and open-water net culture. The focus here is on broodstock protection, bottom-seeding, and net-rearing with some limited references to ear-hanging, as these options tend to be the most widely used and more economically viable for scallop enhancement.

All techniques, however, have some basic requirements. Bull (1990a) cites that the four factors New Zealand has deduced over its years of trial-and-error include: the reliability of spat collection, survival rates of different release methods, factors affecting survival and yield and the ability to maximize these outputs, and finally what are the costs and justification of commercial enhancement. The ability to develop and apply technologies and then the capability to manage these new abilities are also two very separate aspects to any sort of culture or enhancement system (Drummond 2002). A successful operation also requires good growth rates, which are incorporated into the yield, and good product values, which are dependent on the market (Dadswell and Parsons 1991). Biological and technical capabilities need support from social, legal, and

political frameworks to be truly biologically and economically successful (Halvorson et al. 1999).

Spat

For any sort of seeding operation, the first major requirement is a steady supply of spat. Throughout the literature, this supply is one of the most limiting factors on the success of an operation (Goudey and Smolowitz 1996; Aiken 1984; Bull 1990a). These spat can be sourced from the wild via spat collection or from a hatchery. If spat can be successfully collected from the wild, this method drastically reduces costs. Norway, in its twenty years of developing *Pecten maximus* culture, has spent the majority of its funding on developing its hatchery, due to the poor success in wild spat collection (Magnesen 2007). Aiken (1984) noted that the success of one commercial scallop aquaculture endeavor in Canada over the other was the success in spat collection, which translated into the sale of 10,000 juveniles and 16,000 spat.

Spat collection is based on the natural tendency of larvae to settle before metamorphosis (Young-Lai and Aiken 1986). For wild collection bags must be set early enough to catch the peak settlement but late enough to avoid excessive fouling and settlement by other organisms. The Japanese solidified the collector bag design in 1965, variations of which have been the primary collector since that time around the world (Beal et al. 1999). They consist of an outer mesh, originally an onion bag, filled with a high-surface-area material, originally a cedar branch. Plastics like polyethylene and monofilament now make up these collection bags. There has been some work with single-line designs, using a material known as Biocord or Christmas tree rope, but the two-tiered design still dominates. Recent studies have also looked at improving the

efficiency of these bags, demonstrating that an increasing array of mesh sizes is more efficient than the traditional single mesh (Miron et al. 1996).

The other two main questions with collectors are in regards to where and when to set them. The “where” refers to not only the geographical latitude and longitude but also at what depths in the water column or in accordance with what features. Brand et al. (1980) suggest that spat collection tends to be highest in mid-water, although Thouzeau (1991) suggest that deeper collectors closer to the sea floor will have the highest settlement. Silva et al. (2007) also suggest that settlement is highest near the seafloor. The trade-off in increased collection with depth comes with the additional increased amount of fouling that often occurs (Thouzeau 1991).

The selection of depth can also depend on the properties of the water column. Pearce et al. (1996) showed that scallop larvae rarely penetrate the thermocline until ready to settle, thus suggesting that placement of settlement bags at the thermocline would take advantage of this behavior. They suggested that in well-mixed waters, bags should be placed near the bottom, and that fronts may also be an opportunistic area for spat collection. Pringle and Franks (2001) looked further at this association with the thermocline in reference to Georges Bank. The bank has weak cross-isobath flows but strong cross-isobath currents, creating a transport mechanism for particles that have a sinking behavior, like scallop larvae. They concluded that this mechanism, the asymmetric mixing transport that occurs with the various tides, gives larvae a method for passive movement up to a few kilometers. This mechanism becomes very weak where the pycnocline intersects with the gradient of the bank, thus depositing many of its riders

there and forming large, persistent beds. The barrier that the pycnocline creates along with the possibility of movement gives rise to this large collection area.

The geographical placement of the bags relates to the hydrodynamics of the region, which can be reflected in the physical placement of current scallop beds. Within the Gulf of Maine, Xue et al. (2008) and Steneck and Wilson (2001) found that lobster larvae tend to have highest settlement densities west of Penobscot Bay and lowest to the east. Their flow studies also indicated that transport was highly dependent on hatching location and the system's variability, with overall highest retentions occurring within the 50-m isobath.

Monitoring of these conditions, such as adult abundance, hydrodynamic variability in the system, along with spawning stages, helps to indicate the "when." Monitoring systems in Japan address these basic needs. The local scientific branch monitors abiotic conditions with an automated buoy system, along with surveying for larval abundances and sizes in the water column and gonadosomatic indices of the adult spawning population (Beal et al. 1999). This monitoring system gives accurate predictions of the peak settling times approximately one month in advance, giving fishers ample time to set their bags. This monitoring system is extremely costly though, coming in around \$3 million. Such monitoring has been attempted in New Zealand, with far less success than in Japan and not considered worth the high cost (Bull 1990a).

Hatchery production is an alternative to wild spat collection, especially when wild collection is unsuccessful. The higher cost and investment can make it a more difficult venture, but successful hatchery operations have occurred in Norway and Martha's Vineyard, US (Bergh and Strand 2001; Halvorson et al. 1999). Year-round production is

possible through conditioning, which can be achieved through use of sex steroids other hormones, or by inducing stress (Wang and Croll 2006; Halvorson et al. 1999). The transfer of these spat to the field then becomes an important aspect. Heasman et al. (2002) found that survival of spat was greater for those transported wet rather than damp. These spat are highly susceptible as they can not closer their valves completely, so dessication is a real threat (Christophersen 2000). Transport time along with handling should be kept to a minimum, although studies indicate that transport up to twelve hours with low mortality is possible in appropriate conditions (Christophersen 2000). Transporting spat is a factor with wild spat collection as well, as spat must be moved to an appropriate seeding or rearing site.

Site

The selection of the appropriate site is a factor in all forms of enhancement, whether closing a specific area or putting seed down on the bottom or in nets. Halvorson et al. (1999) suggest three broad categories as the basis for site selection: biological- areas that favor growth and survival; regulatory- areas available for shellfish culture given existing laws; existing uses- areas known to have no or fewer activities that would present user conflicts. Within the literature the primary emphasis is on the first category, the biological aspects or implications of the site. Scallops tend to aggregate rather than be randomly distributed (Stokesbury 2002), emphasizing the need for a good site selection but also narrowing the area that is needed.

The community generally associated with scallop beds is adapted to a dynamic environment, where oftentimes the most stable parts of that environment are the scallops themselves (Stokesbury and Harris 2006). These observations correlate well with

findings that scallops are associated with granule/pebble substrates and higher flow areas (Stokesbury 2002; Hatcher et al. 1993; Thouzeau et al. 1991; Langton and Uzmann 1989). Too high of flows, on the order of 13.5 cm/s can inhibit feeding by juveniles, which are more susceptible to high flows than adults (Wildish and Saunier 1992).

The hydrodynamics again play into site selection as they did with spat collection. Flows dominate the spatial distribution of beds, as even under intense harvesting this distribution tends to be constant (Sinclair et al. 1985). These flows also influence water temperatures and food availability, two major factors in the growth of scallops (Kleinman et al. 1996; MacDonald and Thompson 1985b). The movement of water along the coast enhances the non-linear interactions between the coastal complexity and persistence of circulation features. These features can help or hinder the growth and survival environment for scallops. For example, eddies tend to retain not only larvae but other food sources necessary for growth whereas turbulence tends to increase dispersal of these particles (Sponaugle et al. 2002). The success of the three large productive areas on Georges Bank is tied to the physical oceanography and the other influences on recruitment (Brand 1991; Sinclair et al. 1985).

Additional features of concern are the layout of the shore and the additional physical and chemical properties that occur due to the area and the circulation. Bourne and Brett (1984) indicated that areas with intricate and longer shorelines with protected areas would be good for culture conditions, especially if those areas had temperate water conditions and low risk of ice formation. Marine salinities are also important, as areas with low freshwater runoff tend to be more suitable (Bergh and Strand 2001; Larsen 2004). The depth of the water plays a role in the growth conditions regarding food

availability and other effects on reproduction, with a decrease in depth generally having a positive influence (Young-Lai and Aiken 1986; MacDonald and Thompson 1985b).

Site selection may also be one of the largest factors determining the levels of natural mortality that scallops will face. One of these sources of mortality is dispersion. Whether the scallops actually perish is not of concern to the bottom line, rather it is their loss to the fishery. Hatcher et al. (1993) found that both site and season had a significant effect on dispersal, with the open bay site having the largest dispersal after seeding. As the area of a site increases, the dispersion becomes less of a factor as the movement stays contained within the designated area (Barbeau and Caswell 1999). This consideration plays a larger role when seeding the bottom with juveniles. Although the circulation of an area can predict the overall general movement of particles, the current vectors are often poorly correlated with the dispersal of already-settled scallops (Barbeau et al. 1996). In these cases the movement of juveniles may be more due to swimming escape responses, from either too high of densities with each other or interactions with predators.

Mortality

Predation is the other leading cause of natural mortality. The two main predators of scallops are crabs and sea stars, and, perhaps in certain areas, lobsters. Predators can have two categories of responses to increased prey densities: aggregative or functional (Wong et al. 2005). Predators can aggregate, or increase their numbers, in response to increased prey levels, effectively concentrating the local predator population. They can also have one of three functional responses, whereby their feeding habits change either linearly, asymptotically, or sigmoidally with the increase in prey densities (Figure 1).

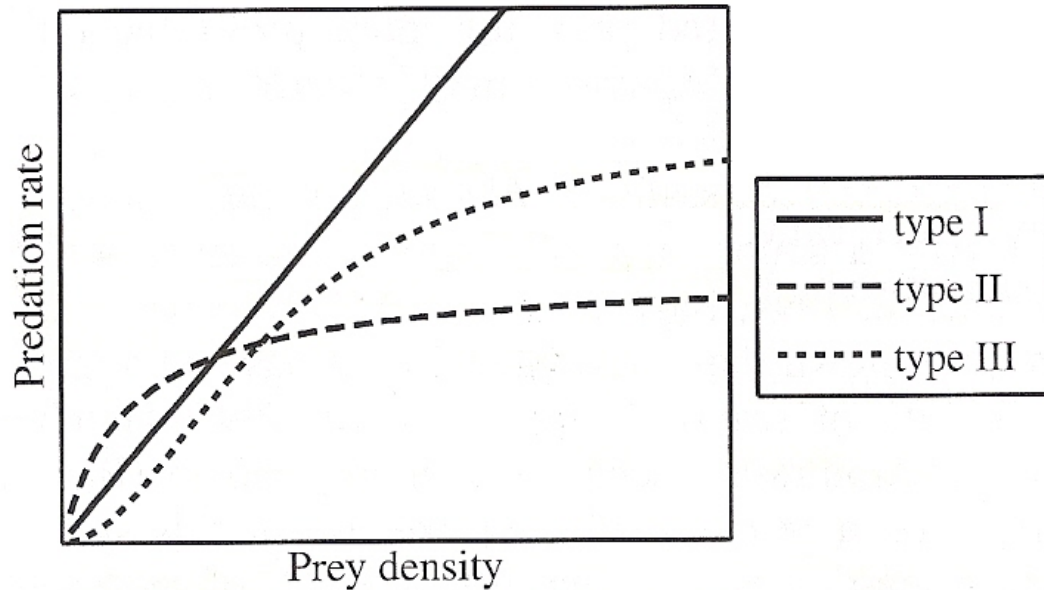


Figure 1. The three general predator functional response types (Wong and Barbeau 2006)

Crabs and sea stars differ greatly in their modes of attack, which gauges their success. Crabs are highly efficient foragers, moving rapidly and using their eyesight for quick ambushes (Barbeau and Scheibling 1994). In laboratory experiments crabs often show a Type II (asymptotic) response but a Type III (sigmoidal) response in the field (Wong and Barbeau 2006). Scallops' response to crab predation involves clamping shut (Barbeau and Scheibling 1994). This type of response is problematic for smaller scallops, whose shells have yet to increase in strength. Grefsrud and Strand (2006) tested the strengths of shells and found a three-fold increase in strength from age two (approximately 56 mm according to Dow 1969) to age five (approximately 104 mm according to Dow 1969). They recommended seeding scallops at least five to seven centimeters in shell height, in order to provide some protection against crab predation. Crabs, however, do show some ability to distinguish between cultured and wild scallops, as cultured scallops tend to have weaker shells. As it is the interaction rate that limits

crabs' foraging, lower densities are often helpful lowering mortality (Barbeau et al. 1994).

Sea stars are very different predators than crabs. Their method of attack is often much slower and based upon chemical stimuli that they receive from their surrounding environment (Barbeau and Scheibling 1994). They tend to show a Type III functional response and do the greatest damage at intermediate prey densities (Wong et al. 2006). Explanations for this middle-ground efficiency include that possibly high densities give conflicting stimuli whereas low densities lower the encounter rate. Scallops' response when contacted by sea stars is often to swim away. In fact, sea stars likely influenced the evolution of sea scallops, who are the most efficient bivalve swimmers (Caddy 1989; Brand 1991). In their interactions it is the probability of capture upon encounter that determines the success rate of sea star predation (Barbeau and Scheibling 1994). Sea stars are limited by their size compared to the size of their prey, often assumed to be a ratio of 1.5:1 (Dickie and Medcof 1963). Thus seeding larger sizes can be helpful to decreasing mortality (Barbeau et al. 1994).

Along with different densities and sizes, other tactics can possibly assist in decreasing natural mortality. Seeding right before low temperatures decreases both predator and scallop movement, thus lowering the levels of predation and dispersal (Barbeau et al. 1994). In Norway, Bergh and Strand (2001) and Strand et al. (2004) seeded scallops within aluminum fences on the bottom. These fences kept the most voracious predators, crabs, at bay, and slowed the dispersal of scallops and predation by sea stars. These fences would be appropriate for either broodstock protection or bottom seeding efforts. These fences increased survival from less than 5% after one year in open

areas to 89% within the fence. In all cases, besides fencing, an aggregative response by predators is often the hardest to combat as very large seedings or additional protective measures are needed to satiate the increased population (Wong and Barbeau 2006). Wong et al. (2005) attempted using an alternate prey species to give some protection to seeded scallops but concluded that the protection was only short-lived (less than one week) and that appropriate site selection would probably have a larger effect.

Growth

As size is one method of protecting scallops from predation, the growth of the individuals in the various settings should be known and considered for any sort of enhancement project. Within the early life history, McGarvey et al. (1993) identified three stages: the entire production of the fertilized egg, density-independent survival, and density-dependent spatfall and survival to age two. The production of the egg begins with the production of the gametes. Scallops can be sexually mature as early as age one or two, depending on the environmental factors (Naidu 1970; MacDonald and Thompson 1986a,b; Hart and Rago 2006). The reproductive contributions of scallops can be correlated to age or shell height and do not become significant until age four or five (Langton et al. 1987; Posgay 1979; Figure 2). MacDonald and Thompson (1988) found a latitudinal gradient in reproductive output, with southern populations producing more than northern populations. Barber et al. (1988) saw the same trend with populations from different depths, with shallower populations producing more eggs and having a higher reproductive investment. Both studies concluded that the difference was not genetic but rather environmental, specifically concerning food supplies. The more southern or shallower populations had a higher level of expendable reserves, which they put into

reproduction. The other groups of scallops lived under higher-stress conditions and were unable to allocate those reserves, as they either did not exist or needed to be used for maintenance or somatic growth. In the examination of stomach contents, Shumway et al. (1987) found that scallops from deeper waters (around 180 m) had mostly benthic phytoplankton in their guts with little to no surface-derived food, whereas shallower populations had a more even balance between the two sources. Even within the same population from year to year fecundity can vary up to two-fold depending upon changes in the water column (MacDonald and Thompson 1986 a,b, 1988).

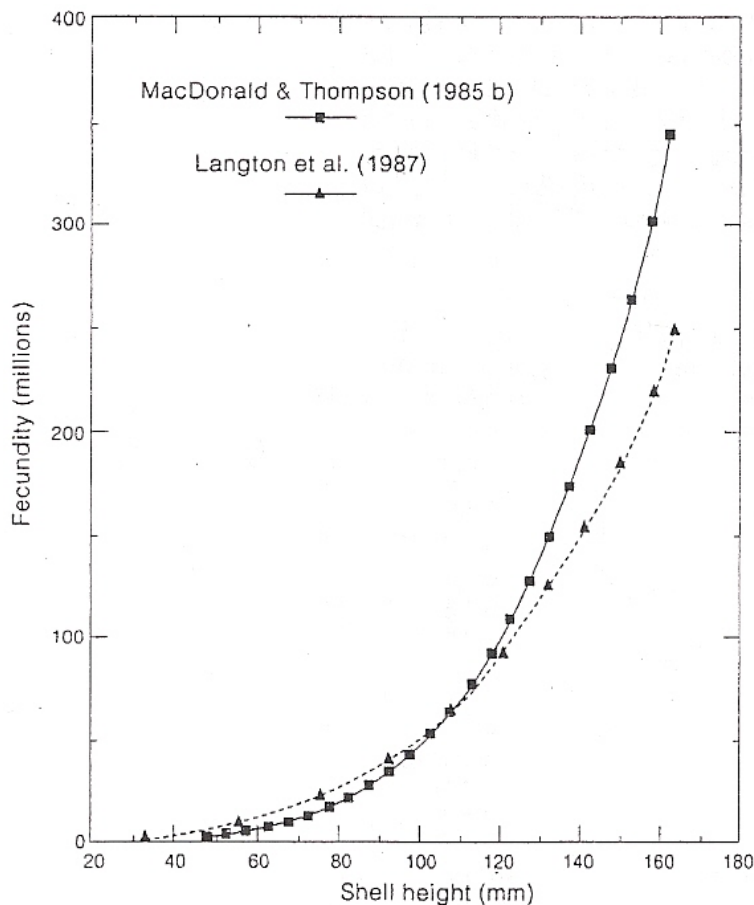


Figure 2. Two studies that compared shell height measurements to fecundity in millions of eggs. Both graphs show the exponential increase in fecundity with shell height. As a note, the MacDonald and Thompson 1985b samples came from 10-m deep at Sunnyside, Newfoundland. The Langton et al. 1987 samples came from a scallop population in the lower Damariscotta River, Maine, USA (McGarvey et al. 1992).

The differences in reproductive effort among populations translate into greater differences in reproductive success. Although Barber et al. (1988) found that the number of eggs decreased in stressed populations, the size and the assumed quality of the eggs did not. The difference in number, which can be up to a three-fold difference, decreases the likelihood of reproductive success with the broadcast spawning strategy. Also the synchrony of the release is another significant factor in successful propagation. The synchrony depends on the signaling cue and the population's response to it. Bonardelli et al. (1996) found that years with multiple spawning events had the least amount of synchrony, whereas years with single events had the greatest synchronization. They found that the signal to spawn depended on the scallops being physiologically ready to spawn and a large flux in temperature, associated with either a downwelling or fluctuations at above-normal temperatures.

Factoring into the success of a spawning event is also the distribution of the scallop population. Orensanz (1986) observed a megapopulation structure in tehuelche scallop populations in Chile, with several high density grounds among sparse areas with dense beds within those grounds. This species of scallop, however, tends to live in more-dense conditions, where density effects are often an issue. With *P. magellanicus* Hart (2001) saw a lack of density effects on growth in natural populations but rather observed only time effects in the growth of individuals and the population. This lack of density-dependent effects can be detrimental in certain culture techniques, due to food competition, such as in net-rearing (Côté et al. 1994). A patchy distribution is typical of pectinid species (Caddy 1989) and may represent a trade-off for the population between

aggregation for successful reproduction and the sprawling to decrease intraspecific competition for resources (Langton and Robinson 1990). The annual variability in spawning synchrony, food reserves, densities, and other environmental conditions, which affect the adult spawning population, all impact the success of the first stage, a successfully-fertilized egg.

The second and third stages relate to the pelagic larval period and the metamorphosis to a primarily-benthic lifestyle. The year-to-year survival of larvae is largely driven by the flow, in regards to where the flow carries the larvae and the conditions within those waters. Food availability and temperature tend to be the strongest factors not only during the larval stage but throughout the lives of scallops (Toro et al. 1995; Côté et al. 1994). Emerson et al. (1994) looked for a relationship between seston and growth but found that association to be inconsistent across trials. Current speeds, which relate back to flow and its properties and the movement of food, can also affect growth, as slower current speeds tend to inhibit growth compared to medium or high currents (Ferreira et al. 2007).

Spat are often present in high numbers in productive areas, with a higher probability of finding the elusive stock-recruitment relationship. For example, estimates from Georges Bank range on the order of approximately 100 quintillion eggs released each year (D. Hart, personal communication, August 12, 2008). Measurements of larvae are often lower, with estimates around 100-1000/m² on Georges Bank (Stokesbury 2002, D. Hart, personal communication, August 12, 2008). The high mortality that ensues between potential egg and recruitment to the bottom or the fishery is composed of many factors, including both abiotic and biotic factors. For the most productive region of

Georges Bank, the Northern Edge and the Northeast Peak, McGarvey et al. (1992) predicted that the chance of survival from potential egg to age-2 is on the order of 1.26×10^{-7} , or approximately 1 in 10 million. This probability reflects the difficulty of survival of a single egg becoming a settled scallop.

Most differences in survival and growth are attributed to environmental causes, as pronounced genetic differences have yet to be found. Fisher Owen (2008) found a disconnect between the eastern and western Gulf of Maine and high similarity between the western and offshore Gulf of Maine on Georges Bank. The connectivity of a population does not have to be high to maintain genetic differences, as it would take four times the mean age of the reproductive size multiplied by the population size for a neutral mutation to become fixed (Zouros and Gartner-Kepkay 1985; Volckaert et al. 1991). Thus genetic studies can only address the similarities on an evolutionary time scale and not an ecological time scale (E. Fisher Owen, personal communication, August 1, 2008).

Enhancement techniques

The three main techniques of focus here are broodstock protection, bottom-seeding, and hanging culture. These three techniques may be the most viable options for an initial enhancement attempt and are generally well-represented in the literature. They tend to be more extensive methods, especially when hatchery production of spat can be avoided. The following sections address the biological aspects of these techniques with economic and social aspects to follow.

Broodstock protection

The protection of broodstock builds its theory on the basis of two concepts: the presence of a stock-recruitment relationship and the stabilization of a metapopulation. If

an area has a stock-recruitment relationship, it makes sense to protect the spawning stock in order to preserve or enhance the population (Silva et al. 2007). Unfortunately, this relationship can not often be found, due to the disconnect that often lies between adult populations and the low success rate and dispersal of broadcast spawning (K. Stokesbury, personal communication, August 5, 2008). Despite the lack of this solid relationship, indirect evidence exists in many different populations. Hart (2006) observed that a higher density of adults can assist with the reproductive success of broadcast spawners. The clearest association between a stock and subsequent recruitment is often in regions with the densest and most consistent populations. On Georges Bank these areas correspond to the Northern Edge and the Northeast Peak, historical and current productive scallop grounds (McGarvey et al. 1993). Although no stock-recruitment relationship has been proven for Georges Bank (D. Hart, personal communication, August 12, 2008), McGarvey et al. (1993) noted that no years of low egg production aligned with high recruitment and that high-recruitment years only aligned with years of high egg production. Ito and Byakuno (1990), in their study of the highly successful Japanese cultured-scallop fishery, observed that the maximum number of spat per collector increased as the broodstock population increased. Thus, although this specific proven relationship has yet to be shown for populations of *P. magellanicus*, among other pectinid species, the indirect evidence and experience suggest that at best broodstock protection is a viable enhancement option and at worst a viable conservation strategy (D. Hart, personal communication, August 12, 2008).

The protection of part of the population inhibits the taking or disturbance of that portion in order to benefit the entire population. This process can involve the protection

of already-present or transplanted stocks. Transplanting of stocks is quite prevalent in bivalves, with oysters being the most mobile of all cultured species (Barber 1997). Transplanting involves two potential negative effects. The first is that transplanting involves the subtraction of one population to increase another, possibly creating user conflicts. The second negative involves the transportation and potential introduction of disease or invasive species. Barber and McGladdery (2001) specifically looked at diseases that affect bivalve species of the northwest Atlantic. They concluded that the two possible diseases for *P. magellanicus* were not significant threats or causes for concern, although the potential still exists for disease transfer or species introduction. They recommended that for within country movements and samples collected from open-water populations, a sample size of sixty animals will provide 95% confidence of detection of an infectious agent present at 5% prevalence in populations greater than one million individuals. This process could be used on a case-by-case basis for transfer requests. The actual process of transplanting is a two-stage approach, involving first establishing a high-density patch, and second, allowing and expecting larval cohorts from subsequent spawnings to settle (Arnold 2008).

Whether local or transplanted stocks, the area inhabited by the broodstock must be protected. This yield is effectively subtracted from the potential fishery yield over the period of the closure. For permanent closures to be economically and biologically productive, the enhanced recruitment from the population needs to make up for that lost yield above and beyond simply replacing it (D. Hart, personal communication, August 12, 2008). Hart's (2006) modeling study showed that rotational closures, whether systematic or pulsed, are more beneficial than permanent closures, as that yield within the

closure is only lost for a period of time. The study also indicated that closures, especially under high fishing mortality, not only increase yield but protect against both growth- and recruitment-overfishing, adding a level of precautionary management to the enhancement regime. Stotz (2000) observed enhanced recruitment in areas outside bay scallop (*Argopecten purpuratus*) aquaculture farms in Chile, an area that suffered from extremely high fishing mortality. The fisher-farmers work to maintain a standing stock of 95-218 million individuals in order to ensure continued good recruitment levels. The Japanese, who collect spat for grow-out, have determined that the optimal stock level for Mustu Bay is four billion individuals (Beal et al. 1999). This bay is just smaller in area than the three original groundfish closures on Georges Bank (Stokesbury 2002).

The groundfish closures on Georges Bank, which were initiated by emergency action in 1994, have been a key factor in the rebuilding of the United States sea scallop fishery. Landings have increase from 5794.4mt in 1993 to 22,575.3mt in 2006, with profits over \$300 million (NMFS-Stat Div 2007). These closures, which protected the broodstock populations within them, have had different effects on their respective regions. The closures on Georges Bank have not enhanced recruitment within or outside the closures, but have helped by allowing the scallops to grow larger and preventing recruitment- and growth-overfishing (Hart and Rago 2006, B. Hatcher personal communication, August 11, 2008). In the Mid-Atlantic, however, larval spillover has enhanced recruitment to the south. Multiple factors probably play into these observed differences, one of which may be the flow patterns. The flow on Georges Bank is a partly-closed or leaky gyre (Naimie et al. 1994). Coupled with the difficulty of following larval dispersal with so many outlet or retention points, the connection between the stock

and spillover can be more difficult to pinpoint (K. Stokesbury, personal communication, August 5, 2008; D. Hart, personal communication, August 12, 2008). The Mid-Atlantic can be described as a flow-through system, with the currents running primarily north to south (D. Hart, personal communication, August 12, 2008; Stokesbury 2002). While exit points do exist, due to the natural meanderings of currents and the interactions with the coastal complexity (Churchill et al. 2005), the overall trend of flow is unidirectional. These closures are a possible example to draw from in planning an enhancement effort of broodstock protection

The different circulation features of these areas highlight the necessity of selecting a good site. Within this decision is the decision of the scope of the desired effect. If the desire is to enhance a particular bay or other partially-enclosed site, selecting a site with good retention features along with appropriate water properties is necessary (Sponaugle et al. 2002). Using measurements, such as water residence times, can serve as good proxies in this decision process. For a flow-through coastal system, such as the coast of Maine, circulation studies have shown the disconnect that can occur at Penobscot Bay (Churchill et al. 2005; Pettigrew et al. 2005). This disconnect, however, should not be nearly so influential. These conditions tend to be absent during the fall and early winter months, when scallop larvae would be most prevalent in the water column. To enhance coastal retention of spat, Xue et al.'s (2008) work indicated that retention of particles is higher within the 50m-isobath. Beyond retention, shallower depths generally encourage enhanced growth and reproductive capabilities, both desirable results, often along with allowing easier monitoring of the site (Barber et al. 1988; Langton et al. 1987; Kleinman et al. 1996).

Along with site comes selection of appropriate populations to protect or to transplant and protect. Many studies observed phenotypic plasticity among populations, generally between inshore and offshore populations (Volkaert et al. 1991; Barber et al. 1988). These differences, although generally attributed to environmental and not genetic differences, have the potential to remain at least through the initial spawning years. To promote success, transplants should be from areas with relatively similar water properties, such as depth, temperature, and food supply. Transplants would also benefit from being full-grown adults, in order to lower mortality from handling and predation (Avendaño and Cantillánéz 2003; Christophersen 2000). Scallops can also be transplanted just prior to spawning, and with low transport stress, can be expected to spawn on schedule (Tettelbach et al. 2002). The individual fecundities within the scallop population can have a local effect on the reproductive success (Sponaugle et al. 2002). Choosing individuals from a population with known reproductive success and good spawning synchrony, as Posgay and Norman (1958) observed for Georges Bank scallops, can help the enhancement project be successful. Should there be a lack of wild scallops to serve as a broodstock population, Tettelbach et al. (2002) indicated that the reproductive investment of bay scallops (*A. purpuratus*) were equivalent to that of wild scallops, thus another viable source.

Other than oysters there have been few transplant studies of broodstock for enhancement purposes and none with *P. magellanicus*. Bay scallops show high success rates, in regards to survival and successful spawning. These studies involved transplanting between similar sites of adults, with short transport times and lower transport stress (Avendaño and Cantillánéz 2003; Tettelbach et al. 2002). These studies,

along with those that cite direct or indirect improvements in recruitment from broodstock protection, lend credence to the viability of this enhancement effort (Booth and Cox 2003; Hart and Rago 2006; Stotz 2000).

Bottom-seeding

Bottom-seeding can be considered the next level up in the range of culture techniques. This technique generally involves higher levels of labor and monetary investment than broodstock protection but comes with some increased benefits. The main benefit comes in theoretically increasing the survival of the spat. The process involves obtaining spat, whether from the natural population or a hatchery, and seeding these metamorphosed juveniles in favorable areas. After the individuals have grown to market size, they are harvested, generally by the same means as in a wild fishery. As the survival estimates of wild spat are around 1 in 10 million, the increased care of these collected spat presumably increases their survival and thus the output of the region (McGarvey et al. 1992). Many of the same factors play into the success of bottom-seeding operations as with broodstock protection, including site and seed selection, strategies to lower mortality, and success rates.

The first step in a successful bottom-seeding operation is the obtainment of spat. Hatchery production is far more expensive than wild collection and should be avoided if possible. Wild spat collection attempts date back to the 1930s when the Japanese began investigating scallop enhancement (Ito and Byakuno 1990), but successful ventures only began in the 1960s in Mutsu Bay. Previous attempts had used a single-layer design, either rope or a bag, with minimal success (Beal et al. 1999). In the 1960s experiments began using a double-layer approach, a high surface-area cedar branch within a mesh

onion bag. This design proved to be highly successful and since then has been the basis for spat collection.

The placement of these bags is the next hurdle. Recommendations generally include mid-range or deeper depths (C. Bartlett, personal communication, August 5, 2008), with higher collections often occurring at the pycnocline or just above the seafloor (Silva et al. 2007; Pringle and Franks 2001; Pearce et al. 1996). These higher catch rates need to be balanced against higher levels of fouling that also often occur closer to the seafloor (Silva et al. 2007). Geographically, higher spat settlement can be influenced by flows, having higher densities in some regions but not others (Xue et al. 2008). The timing of placement is also a factor, as setting them too early or leaving them out too long raises the probability of natural mortality from fouling, whereas setting them too late risks missing the peak settlement time and having overall low catch numbers (Young-Lai and Aiken 1986).

Once spat can be successfully collected, the appropriate placement of these individuals needs to be determined. As mentioned earlier, shallower seeding depths can increase growth, along with easing the monitoring ability of the seeded area (Barber et al. 1988; Langton et al. 1987; Kleinman et al. 1996). Predator populations play a large role in the success of bottom-seeding operations and thus should also play a larger role in the site-selection process. Crabs and sea stars, the primary predators, have the potential to decimate a seeded population (C. Bartlett, personal communication, August 5, 2008). Numerous trials have suffered devastating losses due to predators (Halvorson et al. 1999). Some operations have used fences with diver monitoring to successfully decrease predation levels, but these methods add costs and site restrictions (Bergh and Strand

2001; Strand et al. 2004). Barbeau et al. (1996) highly recommend selecting an area with all-around low predator populations, which involves an initial survey of proposed sites. Although it is an extra expense, appropriate site selection, in regards to predator numbers, can increase survival from less than 1% to 40% or higher (Halvorson et al. 1999; Hatcher et al. 1996).

Another aspect to bottom seeding that affects survival is the state of the seeded scallops. Studies have seen little difference between seeding 5 and 20mm shell height (SH) scallops (Bull 1990a), but there is evidence for greatly enhanced survival when seeding larger individuals. Barbeau and Caswell (1999) observed enhanced survival from less than 20% for small (5-20mm SH) scallops to greater than 50% for larger (50-60mm SH) scallops when coupled with low or intermediate predator densities. The Japanese harvest the spat from collectors at approximately 10mm SH and transfer them to an intermediate net-culture phase to reach 20-30mm SH (Beal et al. 1999). At this point the juveniles can be seeded or thinned for an additional intermediate net-culture phase in order to reach 50mm SH (approximately two years of age) and then seeded. These increased sizes have increased the Japanese success rate and thus profitability. With any size juveniles, Alban and Boncoeur (2008) noted in their study that it is necessary to protect the beds from disturbance after seeding.

Another major source of natural mortality other than predation is dispersal of seeded scallops out of the lease or protected area. As the area size increases, dispersal effects decrease, due to the definition of dispersal as moving out of the area (Barbeau and Caswell 1999). Different settings, such as an open bay site versus a constricted channel or a ledge, can influence the amount of dispersal (Hatcher et al. 1993). Lastly, the season of

seeding, mainly in relation to water temperatures, can affect levels of survival, dispersal, and growth. Seeding prior to a period of low water temperatures, such as in the fall, can decrease the amount of dispersal and predation, thus increasing survival (Barbeau et al. 1996). The negative aspect of this timing of seeding lies in the decreased growth experienced by the scallops, mirroring the natural seasonal growth cycle (Young-Lai and Aiken 1986).

These recommendations are simply suggestions to increase the probability of successful enhancement and do not guarantee an expected result. For example, the variability in scallop movement has yet to be resolved. Many studies have looked for connections between movement and current vectors, but the association is inconsistent. Carsen et al (1995) found correlations between the primary vectors and movement at their open bay site and between the secondary vectors and movement at their constricted channel site, but only during the fall. Barbeau et al. (1996) found no association between dispersal and current vectors during any season. Additionally, if predators display an aggregative response post-seeding, an area that may originally have had a very low predator population can increase substantially in predator density. Environmental factors, such as storm events, can obliterate a recently-seeded area (Halvorson et al. 1999). A lack of addressing potential user conflicts can lead to missing gear, both intentional and unintentional mishaps (Halvorson et al. 1999). All of these factors can negatively affect the success of a bottom-seeding operation, but successful operations, such as Mutsu Bay in Japan, the Bay of Brest in France, and Tasman and Golden Bays in New Zealand, exemplify the possible success and profitability of this enhancement technique.

Hanging culture

Hanging culture is by far the most labor- and cost-intensive of the three techniques presented here. Hanging can use suspended nets for rearing, such as lantern or pearl nets, or ear-hanging, by drilling and stringing the scallop shells and suspending them from long lines. Its costs can be upwards of 60% more than bottom-seeding (Morel and Bossy 2001), but again certain benefits in growth and survival exist. It is generally an economic determination whether the returns can offset the initial, additional costs.

The obtainment of spat is the same as for a bottom-seeding operation and is the first major obstacle of the process. Spat are then cultured further in multiple steps of thinning and net-rearing or on lines. Net-rearing and ear-hanging cultures often use an intermediate culture step, often using pearl nets (Dadswell and Parson 1991; Beal et al. 1999). The positioning of these intermediate nets is one key to good survival and growth. A good consistent food source and temperate water conditions accelerate growth (Lodeiros et al. 1998; Parsons et al. 2002). Both Parsons et al. (2002) and Lodeiros et al. (1998) indicated that a sufficient food supply could be a nearby finfish aquaculture facility, which are notorious for eutrophication issues. Depth of the nets also impacts the success, similarity as with collection bags, as fouling and decreased food sources can increase mortality while decreasing growth (Lodeiros et al. 1998; Cliché et al. 1997). The additional probability of fouling can increase the effort, as nets must be regularly cleaned, often twice per year (L. Davidson, personal communication, August 27, 2008). Weather events can affect the placement of successful nets. Nets should be buoyed to diminish the waves and storms from jostling the scallops within the nets or suspended from the lines (Aoyama 1989).

Within the nets or on the lines, the density of the individuals can affect growth and survival. Ito and Byakuno (1990) observed that too high of densities led to “biting” or “knifing,” whereby scallops end up piercing and damaging each other. These events causes soft- and hard-tissue damage to both parties. High densities also increase competition for food. Côté et al. (1994) ran two series of density experiments, one with all live scallops at different densities and one with “dummy” scallops, empty shells glued shut, to increase densities. The results indicated that it was food competition, and not space lost, that impacted growth of scallops. While appropriate density levels tend to be species- and site-specific, a good rule-of-thumb is 60% areal coverage as the upper limit that inhibits further growth (Parsons et al. 2002).

Although the costs for net-rearing or ear-hanging are much higher, the benefits of enhanced growth and survival may offset these costs. Studies have shown upwards of 30-40% enhanced growth in suspension than on the bottom (Emerson et al. 1994; Dadswell and Parson 1991). This level of enhanced growth can decrease time to the market by a full year (Aoyama 1989). Survival in suspension can be close to and surpass 90% (Parsons et al. 2002), with the biggest inhibitor being fouling. These advantages have potential to overcome the initial costs.

Costs

Enhancement, no matter the level of intensity, is meant to enhance economic growth. Thus, the costs and feasibility of any project need to be considered (Barber 1997). These costs include not only the materials and equipment needed but also the lease area, if necessary, and time and labor costs. Leasing of submerged lands is relatively ubiquitous in state waters throughout the United States with nearly one third of

submerged lands of coastal states privately leased or owned (Slade et al. 1997).

Generally, there are very few rights to restrict access of these areas to other users, but the costs tend to be an order of magnitude lower than terrestrial counterparts. The time, labor, and materials needed are all dependent on the technique used, the scale of integration, and the size of the operation.

Most studies concur that bottom-seeding is more economically viable than net-rearing or ear-hanging (Young-Lai and Aiken 1986; Bull 1990b; Halvorson et al. 1999). The SeaStead project out of Massachusetts, USA, specifically quantified the amounts for a 100,000 lbs/cycle bottom-seeding (Halvorson et al. 1999). It would require less than \$400,000 in start-up capital and would pay back the initial investment in four years. The operation would require the lease of an area approximately 150 acres (0.61 km²) and the use of a large scallop vessel three months of the year. They based those estimates on wild collection of spat and assumed sufficient levels of collection and juvenile survival. A similar operation with net-rearing was not projected to be economically viable, with start-up costs ranging from \$1-2 million. The New England Fisheries Development Association's sea scallop project calculated that the cost of rearing scallops in bottom cages was \$0.19/scallop off Truro, Massachusetts and \$0.42/scallop off New Hampshire, exemplifying the different monetary effects of site (Halvorson et al. 1999).

Bull (1990b), in his study of the New Zealand Challenger scallop enhancement, figured that the highest gross income of \$1,416,960 could be gained from a direct bottom-seeding operation, whereas the lowest gross income came from release after an intermediate culture period, figured at \$74,390. He assumed 15% and 30% survival, respectively, but noted that direct seeding becomes unprofitable with spat collection less

than 300 spat per bag or survival less than 5%. Penney and Mills (2000) modeled a net-hanging operation for a whole-scallop market, which requires scallops in the 55-65mm SH range. They determined that without vertical integration of the processing facility, none of the proposed farm sizes, ½ Million, 1M or 3M (seedstock per year), were economically viable. With vertical integration the 1M and 3M farms were viable, with payback on investments in 4.2 and 3.4 years, respectively. They also concluded that without an individual or family already being in the fishery, the ½ M farm, a family-owned or part-time size business, would never be economical. An economic assessment or model for a particular area and technique or range of techniques would be an important addition to the initial assessment of enhancement options.

Management

Jentoft (2000) remarked that community is the missing link in fisheries management. With the beginning of a new phase in fisheries, the “blue revolution” (Mikus 1998), comes the opportunity to assess the current and potential management schemes. In most cases of successful enhancement, such as the Japanese or New Zealand’s Challenger Scallop Co., the use of the industry to manage the rights and resource has been largely successful (Uchida and Makino 2008; Arbuckle 2000). The ability to be flexible and to empower and hold accountable those involved in the enhancement operation are essential to success (Mincher 2008). In addition the different enhancement techniques require different considerations when forming management options.

Self-governance can be a positive and enabling form of management. The objective of self-governance is to empower the stakeholders or industry to operationalize incentives to increase their value derived from the resource (Townsend and Shotton

2008). When self-governance groups with cooperation, a necessity, and property rights, an option, the potential lies for increased economic efficiency and social responsibility (Mincher 2008; Edwards 1994). Individual or cooperative quotas have the potential to increase the economic efficiency of the resource, outperform other options in a market economy, and set a hard cap on the resource (Edwards 1994; Repetto 2001). Both the New Zealand Challenger scallop fishery and the Japanese fisheries use a form of quotas to successfully manage their productive culture fisheries.

The New Zealand Challenger Scallop Co formed in 1994 as an alternative means of funding management and protecting stakeholders' rights (Yandle 2006; Mincher 2008). The various groups represent themselves through the New Zealand Sefood Industry Council Ltd or the Commercial Stakeholder Organizations (Harte 2008). With the authorization of the 1996 Fisheries Act, the government gained the ability to contract out management services to third parties. The Challenger Co is an example of one of those third parties and thus able to assist its shareholders with increased involvement in management. It also has the ability to assist the government in economic optimization of its management duties. The mandatory levy, which all shareholders must pay, avoids the problem of free-riders, identified by Olson (1965) as those who gain from a situation but do not contribute.

The New Zealand enhancement project with its self-governance effort under the Challenger Co has been successful. This success, however, took well over fifteen years to obtain, with enhancement trials beginning in the mid-1970s (Mincher 2008). The development of solid techniques and a good monitoring and management strategy have led to the current situation where enhancement is no longer needed but still an option on

the table. The Challenger Co has been successful at obtaining high levels of agreement on and enforcing its policies. Its method of shelving or holding quota until the end of the season has helped to prolong the season and maintain a steady and well-priced supply for the market. All recruitment indicators show a stabilizing and positive trend, conferring a level of economic and biological security to the fishery (Arbuckle 2000).

There are other cases of cost-sharing between the government and industry, such as the Joint Project Agreements between the Department of Fisheries and Oceans in Canada and the private industry. These agreements require a fishery organization that represents at least $\frac{2}{3}$ of the permit holders (Wilson 2008). While these agreements have increased the level of organization in the fishery and spread more costs to the stakeholders, its success as an entity other than cost-sharing remains elusive (Wilson 2008). These entities, for the most part, lack any real decision-sharing abilities and mainly provide a method of rent extraction (Kaufmann and Geen 1997). The policy of rent extraction, that those receiving a service should pay for it (Townsend and Shotton 2008), is not a negative aspect; however, in the case of the JPAs, rent extraction is the current limit to their capabilities. Canada's offshore scallop fishery, through its status as an Enterprise Allocation fishery, does obtain some decision-sharing capabilities (Stevens et al. 2008). This organization removed the derby aspect of the fishery back in 1986 and shifted to a cooperative arrangement with voluntary fishing stops and area avoidance of juveniles. The industry bears a good portion of the costs of the fishery, such monitoring and survey costs, but has gained additional capabilities in setting quotas. Stevens et al. (2008) declare it as being successful since the early 1990s.

The scallop enhancement effort in the Bay of Brest, France, took a similar cost-sharing route but through the collection of license fees (Alban and Boncoeur 2008). The enhancement effort began in 1983 with little success until the second half of the 1990s (Fleury et al. 2003). These successes and technical changes required institutional changes in the methods of management. The unique aspect is that the fishers introduced these changes, which increased their profitability and the fishery's sustainability (Alban and Boncoeur 2008). Licenses are issued on a yearly basis and are tied to a specific area that is open for fishing. These zones are the seeded beds and managed by quotas, whereas the enhanced natural beds are managed by input controls. As the success of enhancement and the quotas increased, the license fee increased proportionally. In 1994 before the enhancement success, the license fees were mainly ceremonial at only 70 euros per boat. With the increased quotas the fees rose to 5200 euros per boat by 2001, a 74-fold increase (Alban and Boncoeur 2008). Despite the large difference, fishers concluded that the license fee was worth the increased profitability within the fishery.

In these and other enhanced systems, the management of the fishery should address the biological indicators and the social implications of the policies. In the Bay of Brest, the license fees rose to historic highs, at first a relatively difficult aspect for fishers. However, the biological stability of the resource and the security to access it outweighed the initial high investment (Alban and Boncoeur 2008). In New Zealand the additional responsibilities and costs associated with the fishery prompted economization of these tasks (Mincher 2008). The government and legislative support helped the Challenger Co overcome issues of free-riders with the ability to impose a mandatory levy. In addition to overcoming free-riders, the legislation helped the company overcome enforcement issues,

as the entire group has a real monetary stake in the success of the operation before the fishing season even begins. Again, the increased biological stability and the quota management system conferred a level of resource-access security. Yandle (2006) noted that quotas, specifically individual transferrable quotas (ITQs), increase the perception of security rights along with increasing owners' willingness to participate in management. Voluntary participation by stakeholders is difficult to obtain, much less sustain, over multiple years. The need for additional perceived benefits is necessary to continue such involvement (Olson 1965).

Enhancement is a good avenue for voluntary participation by stakeholders and community members, especially in the initial, trial stages. With spat collection the community has an opportunity to help by preparing equipment and helping sort spat post-collection (Schick and Feindel 2005). Much effort has gone into making the setting of bags, nets, cages, or spat distribution amenable to normal fishing operations. The Westport Scallop project, which investigated the feasibility of offshore net culture, developed super lantern nets that were larger and more durable for setting from larger vessels (Goudey and Smolowitz 1996). Bottom-cage operations often use modified lobster traps, which are then easily set and checked off lobster boats along with the normal traps (Halvorson et al. 1999). The obvious downfall to volunteer-based programs is the uncertainty in the scope of involvement and results. Effort wanes when results do not show and the potential for "cold feet" increases (B. Hatcher, personal communication, August 11, 2008). Pectin UPM/MFU Inc., a non-profit organization managing a scallop enhancement project in eastern Canada, initiated its efforts in 1996 with volunteers (Davidson et al. 2001). However, the techniques of enhancement were

not mastered until 2001, when the company hired specific individuals to do the work instead of relying on volunteers. The benefits of an organized effort include consistency, accountability, and a different level of commitment to the project. A paid fleet of enhancement workers may be the more viable approach in a more intensive scheme, like bottom-seeding or hanging culture (D. Morse, personal communication, August 7, 2008).

The Japanese scallop enhancement, by far the most successful and oldest organized effort in the world, employs many of these practices. The Fishery Cooperative Associations (FCAs) represent the stakeholders and manage the fishing rights, which are guaranteed (Uchida and Makino 2008). The FCA employs specific individuals to set lines for spat collection (Beal et al. 1999). During the harvest a portion of profits go to the FCA with a majority of the profits from bottom-seeding funding the FCA's organization. The monitoring and science branch budgets are in the millions, allowing for accurate and precise information. Over the many years of effort, the scientific branch has set solid biological reference points for the standing stock and the level of enhancement (Beal et al. 1999; Aoyama 1989). Though good conditioning of the environment and techniques, the time to market has decreased, thus increasing the probability of a favorable return (Beal et al. 1999). The techniques for spat collection, net-rearing, ear-hanging, and bottom-seeding are the standards world-wide, further exemplifying their level of expertise. With limited access, secure rights, and a high level of buy-in, enforcement and monitoring are non-issues. The FCAs depend upon the government for information regarding spat collection times and locations and subsequent seeding and harvesting from the extensive monitoring program and science branch. The government, in return, depends on the FCAs to appropriately manage the user rights and access to the fishery

(Beal et al. 1999; Aoyama 1989). These combinations of factors have led to a successful and sustainable fishery, that collects greater than one billion spat per year and harvests greater than 400,000mt per year (Beal et al. 1999).

These examples of successful enhancement operations illustrate the economic, social, and biological feasibility of such efforts. The many hardships of these and yet-to-be-successful endeavors are good learning grounds for future projects. The first is time—the Japanese, the entrepreneurs in the field, took thirty to forty years to solidify their techniques, monitoring, and carrying capacity limits (Beal et al. 1999). New Zealand, Norway, and Chile learned from the Japanese but still took from fifteen to over twenty years to obtain considerable, sustainable harvests, during which time many trials and techniques failed (Bull 1990a; Magnesen 2007; Silva et al. 2007). The least amount of time recorded in the literature to successfully obtain increased population levels was that of *Pecten* Inc., which took approximately ten years (Davidson et al. 2001). Despite these successes fishers were still disappointed with what they believed to be a low output. Even the famed closures on Georges Bank and in the Mid-Atlantic took at least four years for the biomass within the areas to increase and an additional two to three years to see results of increased recruitment (D. Hart, personal communication, August 12, 2008). These efforts take time to perform pre-evaluations, solidify techniques, and harvest the results.

Another difficult aspect is planning for the responses to or effects of policies. With area closures, for example, these responses involve monitoring, enforcement, and the subsequent redistribution of effort into open areas (Bull 1990b; Brooke 2001). Inadequate monitoring and enforcement of boundaries leads to decreased yields (L. Davidson, personal communication, August 27, 2008); in addition, the lack of efficient

enforcement can lead to disenchantment of those involved in the effort. It is highly depressing for stakeholders to have an effort completely flop (C. Bartlett, personal communication, August 5, 2008), which can inhibit future involvement. Baskaran and Anderson (2005) noted that restrictive regulations can motivate politically-powerful groups to lobby for altered rights' distributions or regulations to obtain asymmetric wealth distribution. In such cases where a sacrifice is expected, this lobbying can be anticipated and must be addressed.

Included in these effects is the expected scope of the project. It is important that managers and stakeholders, if separate entities, determine the expected impact of a project prior to its implementation (E. Fisher Owen, personal communication, August 1, 2008). If a project is to affect an entire coastline, then the scale and involvement of the project must match this expected output. Small efforts may enhance limited areas but expecting such projects to bring back an area's population is unrealistic (D. Temple, personal communication, August 1, 2008). In such efforts the concept of fisheries self-governance is a strong and viable possibility. However, two potential misconceptions must be avoided. These include the belief that self-governance will spontaneously and entirely replace government regulation, and additionally that it can absolve the government of difficult decisions about restricting access (Townsend and Shotton 2008). The government can and must play a vital role in shaping these future endeavors. By providing a sound judicial system for enforcement violations and empowering self-governance, the government can promote industry stewardship (Baskaran and Anderson 2005). In addition, with the prospect of different products, such as roe-on or whole scallops, the government is a vital component to consumer safety and trust in monitoring

biological toxin levels (S. Feindel, personal communication, August 11, 2008). The government can be more than a necessary evil, providing a spring board for funding sources, organization, and a supportive beam for state- and self-enforcement.

Within cooperative projects it is essential to define roles, responsibilities, and expectations. Admitting to those involved what is known and unknown is one factor in managing expectations (D. Morse, personal communication, August 7, 2008). If expectations of future involvement and profits are never realized, disappointment develops, which can lead to future noninvolvement (Bull 1990a). It is also important to realize the different views of stakeholders. For example, dispersion and predation are both sources of lost profit in an enhancement operation. For fishers, they are the same, but biologists view them very differently (B. Hatcher, personal communication, August 11, 2008). Within the outline of expectations needs to be some method of differentiating benefits for those involved from those not involved with the project. Involved individuals will want priority access to the final products in exchange for their time and effort (Booth and Cox 2003). Many projects began on the grounds of nothing to divide or allocate, but allocation issues quickly come up, even during these early stages (Booth and Cox 2003; D. Morse, personal communication, August 7, 2008; L. Davidson, personal communication, August 27, 2008). However, restricting access to a public resource is not well-entertained by either stakeholders or the government without proper justification and proof of the advantages (NRC 1999). Possible, suggested solutions to this conundrum include: a modified or weighted lottery, local zone management and restrictions, hard quotas for different permit levels, community or organization quotas, and site-specific permits (Alban and Boncoeur 2008; C. Bartlett, August 5, 2008; L. Davidson, August 27,

2008; S. Feindel, August 11, 2008; D. Hart, August 12, 2008; D. Morse, August 7, 2008; and D. Temple, August 1, 2008 personal communication). During initial planning stages, it is helpful to keep all possibilities on the table until site- and species-specific reasons can remove them.

Conclusion

The concept of scallop enhancement is a viable one, as evidenced by the success in Japan, Chile, New Zealand, and other places (Beal et al. 1999; Silva et al. 2007; Bull 1990a). The many methods available all have varying factors to their success, including site- and species-specific conditions, initial costs, and effort required. Despite the evidence of success, many projects take at least ten years to be moderately successful, and far more time and effort is needed to show sustainable success (Davidson et al. 2001).

In light of these continued failures, it is prudent to remember that arrogance regarding man's ability to do better than nature can be misleading (B. Hatcher, personal communication, August 11, 2008). The aquatic environment is far more connected than our years of research understand. It is, however, that connectedness that can assist these efforts. Bivalves tend to be more sustainable in a cultured environment due to their ability to filter their own food and nutrients (Nunes et al. 2003). It is this ability that makes them ideal for pairing with traditionally unsustainable aquaculture practices, like salmonids, that provide a food source and already-present infrastructure to decrease the potential ecosystem impact of the operations (Parsons et al. 2002; Nunes et al. 2003; Ferreira et al. 2007). In such situations multiple benefits can be gained, thus it is important to keep an open mind when developing projects or new industries.

With any effort appropriate selection of site and methods along with stakeholder involvement or, better yet, initiation are important to the success of the project. Proper monitoring of results is essential for evaluating the current project's success and the viability or changes for future projects. The diffuseness of Maine's scallop fishery and limited state resources necessitate a cooperative management approach for the fishery (Schick and Feindel 2005). An industry-led, government-supported endeavor, with high levels of cooperation, would be an ideal situation for these projects.

Review

Spat

- Whether naturally-produced from protected broodstock or collected from wild or hatchery, a steady and semi-predictable supply is necessary for success.
- Japanese design is the rule for collectors.
- Deeper collections tend to have higher settlement, but by both scallops and other organisms.
- Changes in water mass, like the thermocline, may be good depths to set collectors.
- Larvae are in the water column on average 40 days, so hydrodynamics can play significant role in moving the larvae from original hatching site.
- Hatchery production has much higher costs than wild collection but may be a requirement if successful collection can not be accomplished.

Site

- Site selection one of largest factors once can secure a supply. Good flow rates needed for food supply.
- Good factors: protected; low ice formation; temperate water conditions; complex shorelines; low fresh-water runoff; shallower depths (<50-80m) generally better than deeper sites (>180m).
- Size of plot dependent on technique used: >50 acres necessary and one suggestion for 150 acres for bottom-seeding; broodstock protection needs to encompass area where laid down and anticipated dispersal; hanging culture only need the area where long-line set.

- In all situations culture area needs to negotiate area use with local- and already-present users to avoid/decrease conflicts.
- Low predator populations essential when seeding, as they can decimate a newly-seeded plot.
- Size of site needs to be determined, based on desired scale of results of operation.
- Dispersal can lead to an increase in area covered by seeded scallops by over 100-fold.
- Sites of 1km² still considered by many to be “small” site sizes.
- Closures on Georges Bank aggregations: Nantucket Lightship area: 260km², majority (80%) within 114km²; Closed Area I: most scallops (65.5%) located within 153km²; Closed Area II: greater distribution over area but, again, most (84.2%) within 109km²
- Mutsu Bay, Japan: total 1800km²; hanging culture: 50,000 hectares (=123,500 acres); bottom culture: 23,000 hectares (=56,810 acres)

Predation

- Predation and dispersion are the two leading causes of mortality.
- Scallops clamp shut when attacked by crabs, whereas their response is to swim away when contacted by sea stars.
- Generally, seeding at lower densities (0.5 versus 2/m²) can help reduce crab predation and larger sizes (35-55mm) can help reduce sea star predation. These low density levels, however, have to be assessed against economic sustainability.
- Fences on bottom can also help decrease crab predation.

- Seeding prior to colder water temperatures (in the fall) can reduce dispersion and predation.

Growth

- Reproduction of scallops correlated with age or shell height. Scallops can reproduce as early as age-1 but no real contribution until age-4 or age-5.
- Shallower depths help encourage greater growth due to larger supplies of food from both the plankton and the benthos. The decrease in food supply with depth reflects in reproductive output.
- Greater synchronization in spawning tends to lead to greater fertilization success. Generally see greater synchronization in shallower, more northern waters.
- Food availability and temperature tend to be largest factors to survival and growth throughout entire life.
- Predicted change of survival from potential egg to age-2 on Georges Bank is ~1 in 10 million.
- Most differences in growth among populations generally attributed to environmental, not genetic, effects.

Enhancement techniques

Broodstock protection

- Based on presence of stock-recruitment relationship, which is often very hard to find.
- Evidence from both Japan and Georges Bank indicate that a higher density and population of adults can lead to greater reproductive success and recruitment, although no relationship proven. Japanese try to maintain an

- Potential diseases identified for scallops not considered to be significant threats.
- Rotational, temporary closures tend to have higher yield than permanent closures.
- Transport stress needs to be kept at a minimum in order to preserve the transplanted stocks.

Bottom-seeding

- Successful obtainment of spat is a necessity for bottom-seeding success, along with appropriate site selection for young, vulnerable scallops.
- Where evidence of genetic similarity or differences exist, it is advisable to stay within those boundaries of similarity.
- Selecting a site with low predator populations can increase survival from <1% to >40%. Seeding larger animals can also increase survival.
- Seeding prior to low water temperatures can decrease dispersal and increase yield of seeded scallops.

Hanging Culture

- Hanging is more labor- and capital-intensive. Trade-off supposed to be in the percent survival and increased growth rates.
- The same necessity of obtaining spat exists as with bottom-seeding.
- Site selection involves more awareness of water-column conditions and circulation, rather than demersal predator populations.

- Density of scallops in nets negatively correlated with survival and growth.
The relationship is a result of competition for food supplies and the possibility of “biting” among scallops.
- Waves and storms can damage gear and scallops within the gear, so proper placement and care, including regular cleanings, needed.

Costs

- Project needs to be economically-feasible to be beneficial.
- Bottom-seeding more economically-viable than hanging culture, especially when considering a private investment. Broodstock enhancement easiest and cheapest but need to consider monitoring and enforcement costs.
- Bottom-seeding endeavor can requires only ~\$400,000 start-up costs, compared to \$1-2 million for hanging culture.
- For niche market of 55-65mm scallops, vertical integration is economically needed for survival.

Management

- Self-governance can be part of the solution to management but can not immediately replace government support or decision-making.
- Individual and community quotas have potential for increased economic efficiency and conservation incentives.
- New Zealand fishery based on quotas and management by the fishery’s organization, which contracts with the government.
- Japanese depend heavily on government science to know when to set and pull collectors and where to practice hanging versus bottom-seeding culture.

- In both cases a strong connection exists between government- and self-regulation.
- Enhancement can be a good avenue for community involvement, although hiring of paid individuals may be necessary for efficiency and dependability reasons.
- All successful endeavors took time, on the order of at least 10-15 years at the low end and over 30 years at the high end. Many endeavors (British Columbia, United Kingdom, Newfoundland) are still not consistently successful.
- The desired scope of the project and its results need to be identified early on, and methods for determining levels of success developed. Expectations must be clearly stated and managed.

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