Project Narrative

1. Project Goals and Objectives

This project responds to the Aquaculture category outlined in the Saltonstall-Kennedy (FY10) Program Priorities. Specifically, this proposal focuses on methods to enhance the wild sea scallop (*Placopecten magellanicus*) fishery in eastern Maine through the culture and wild collection of scallop juveniles, intermediate grow-out methods, predator prevention and control, and environmental protection and control in discrete bottom areas in eastern Maine. We propose to compare and contrast the efficacy of various culture techniques so that the information generated both in the hatchery and field can be used by fishers and managers who are considering stock enhancement measures to improve landings of this commercially valuable species in coastal areas of eastern and coastal Maine. Further, the project addresses exploration of a fisheries enhancement strategy that, if successful, could greatly increase sea scallop landings, benefiting the economy of Maine and possibly other Atlantic states in the future.

The effort proposed here fits nicely into the Saltonstall-Kennedy program's priorities and long-term goals. For example, the Magnuson-Stevens Act requires that NOAA, through the S-K program, undertake efforts to prevent overfishing, rebuild overfished fisheries, insure conservation, protect essential fish habitats, and realize the full potential of U.S. fishery resources. It further requires that NOAA take into account the importance of fishery resources to fishing communities; provide for the sustained participation of such communities; and, to the extent possible, minimize the adverse economic impacts of conservation and management measures on such communities.

The long-term goal of the proposed work is to increase production of sea scallops in the coastal fishery of eastern Maine, where, in 2007, 1.31 million pounds were harvested commercially, worth $1.27 million in dockside revenues. This production is nearly 90% lower than the twenty-two year average of 11.8 million pounds produced during 1980 to 2000 (**Fig. 1**). Recent landings are so low, that this situation prompted the Commissioner of Maine's Department of Marine Resources (DMR) to issue an historic, emergency rulemaking decision on February 4, 2009. At that time, DMR announced that the entire state of Maine would be closed to all scallop fishing through the end of the season. After hearings on the statewide closure, and in an effort to reach middle ground to address some of the fishermen's concerns, DMR modified its approach and instead established six "conservation closures" to "protect Maine's scallop resource due to the risk of unusual damage or imminent depletion of the scallop resource" (see: www.maine.gov/dmr/rulemaking/1110v2.pdf). Of the six areas closed, four were in eastern Maine (east of the Penobscot River, **Fig. 2**), and one included all of Cobscook Bay and the St. Croix River, the most productive sea scallop fishing ground in Maine in the past decade (Campbell, 2004). The reestablishment of marine fisheries, specifically the sea scallop industry, is critical to the survival of coastal communities dependent on these resources. The goals of the proposed research are directly supported by the S-K grant goals as well as NOAA's goals: to protect, restore, and manage the use of coastal and ocean resources through an ecosystem approach to management (NOAA Strategic Plan, 2000-2014).

The specific objectives are to determine:

1) economically prudent methods to generate sea scallop spat (i.e., wild spat

Figure 1.

Maine sea scallop landings and dockside value

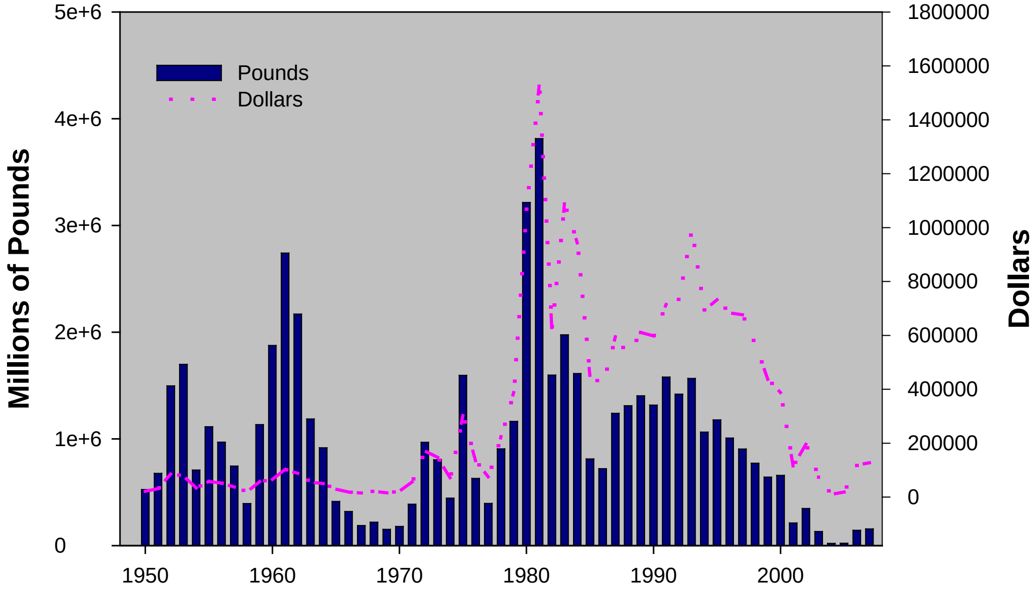
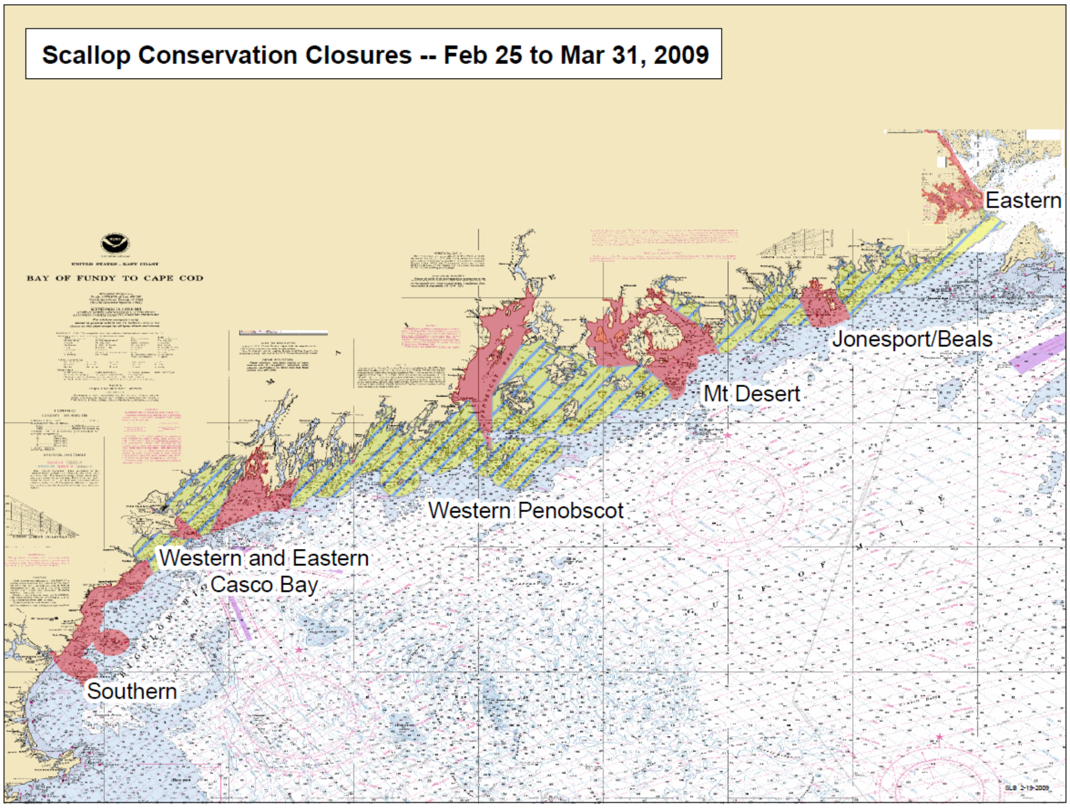


Figure 2.



collection using techniques that have been successful in Japan [Beal, 1999; Uki, 2006] and Canada [Davidson et al., 2005; Niles et al., 2005] vs. hatchery production [Culliney, 1974; Karney, 1996]);

2) effects of stocking density of wild/cultured scallop spat on growth and survival in two intermediate nursery culture scenarios;

3) how scallop planting size affects on-bottom growth and survival of sea scallop juveniles; and,

4) whether predator prevention and control methods or environmental protection and control methods (habitat modification) result in higher on-bottom growth and/or survival of scallop spat during the first ten months after seeding.

Review of previous work

This effort supports previous work with sea scallop fishermen conducted at the Downeast Institute for Applied Marine Research & Education (DEI) and funded by the Northeast Consortium (Beal et al., 2009). Fishermen from the Jonesport/Beals area identified two sites (≈ 1 km^2 that had once been commercially productive scallop habitat) that they wanted to close for experimental purposes. One area is in Mooseabec Reach (the area between Jonesport and the island community of Beals), and the other near Sheep Island (in the Eastern Bay). Using a rule-making process, the Maine Department of Marine Resources requested the Maine Legislature to create these closed areas for research purposes for three years beginning in May 2007. The areas chosen by fishermen: 1) were once highly productive areas that in recent years have become unproductive; 2) do not conflict with sea scallop harvesting or other fisheries, such as sea urchins, where dragging occurs; 3) are relatively easy to see from shore to minimize potential poaching; and, 4) are large enough to offset what poaching may occur. The areas are closed to dragging and diving. That is, fixed gear fishing (i.e., for lobsters) is not restricted in the closed areas. In 2010, we will work with local fishermen, the Maine DMR, and the state legislature to keep the areas closed to accommodate our research efforts.

Our research results determined that the best method to hold and transport sub-adults and adults (mean SH = 86.1; range = 40-120 mm SH) in the spring for up to 10 hours with animals held moist in fish totes stored on the deck of draggers out of the sun. The animals were used to seed bottom plots at both closed sites at 2.5 ind. m^{-2} using previously published accounts of sea scallop enhancement conducted in Canada (Barbeau et al., 1996; Hatcher et al.,1996). The fate of scallops was followed by divers on Days 1, 2, 3, 5, 10, 20, and 30. At the end of the trial, mean density (± 95% CI) in the plots at Sheep Island was 2.5 ± 0.63 individuals (n = 80), and 1.7 ± 0.50 individuals (n = 60) at our Mooseabec Reach site. After one year, these densities were unchanged. The work established that it is possible to move legal and large sublegal scallops safely to alternative bottom locations closed to all scallop harvesting. Although successful, this method has limitations. For example, we assume that bottom plots with enhanced densities of large scallops serve as spawner sanctuaries (sensu McKay, 1988); however, it is nearly impossible to determine the efficacy of this management scheme due to the size of scallop larvae and the amount of time that they remain in the plankton. It is unlikely, given nearshore hydrographic patterns in eastern Maine (Brooks and Townsend, 1989; Pettigrew et al., 2005), that spawning adults in one bed or single location are responsible for the juveniles that recruit to that bed or location. In addition, legal scallops that are harvested from open areas, and then transported to closed areas, are unavailable for the commercial harvest.

A second area of our research effort (Beal et al., 2009) examined the efficacy of collecting wild scallop seed using collectors similar to those used successfully in eastern Canada (Davidson et al., 2005; Cyr et al., 2007). Spat collectors (n = 1200), were deployed in shallow (< 10 m) and deep (20-30 m) water over a 10 km area in the Jonesport/Beals region on both eastern and western side of Great Wass Island (eastern Maine) during September 2007. In May 2008, 460 collectors were recovered (38.3% recovery rate) with an average of 2.7 ± 0.43 spat bag^{-1}. Another 1200 bags were deployed in late August 2008, and these were retrieved in May 2009 (n = 383 collectors, or a 31.9% recovery rate) with an average of 18.6 ± 2.04 spat bag^{-1}). In both years, more scallops settled into bags deployed in deep vs. shallow water, and scallops were significantly larger by several millimeters on the western vs. eastern side of Great Wass Island. Total number of sea scallop spat collected from the bags recovered in 2008/2009 was less than the number of scallops collected from a single bag in some Canadian studies (e.g., Davidson, 2005). These results suggest that larval supply may be the limiting factor in the eastern Maine coastal fishery.

Technical studies examining scallop aquaculture (patterns in the annual reproductive cycle of adults, spat collection, spat grow out, etc.) were conducted in the early 1990's in Cobs-cook and Passamaquoddy Bay (far eastern Maine and western New Brunswick, Canada, respectively) (Dadswell and Parsons, 1991, 1992a,b; Parsons et al. 1992, 2002; Parsons and Robinson, 2006). Scallop spat bags, similar to those used in the study described above and based on Japanese designs (Ito, 1990), have been used with moderate success. In Passamaquoddy Bay, average settlement varied annually from 100 to 400 spat per bag (Dadswell et al. 1988; Parsons 1989; Dadswell and Parsons 1991), and with a maximum settlement of > 3,000 spat per bag (Robinson et al., 1991, 1992). Annual, site-specific settlement rates varied by a factor of 2 to 3 (Robinson et al. 1999). In nearby Cobscook Bay, however, scallop spat collection over a three-year period (1998-2000) was relatively unsuccessful with less than 10 animals captured per spat bag (Beal, 2004). Once spat are collected at sizes < 10 mm in shell height (SH), intermediate culture occurs to in-crease the likelihood of scallop survival prior to bottom planting. Typically, pyramidal-shaped pearl nets (sensu Ventilla, 1982) or small mesh lantern nets (sensu Parsons and Dadswell, 1994) are used during this phase. The industry standard for stocking scallops in nets or other intermediate growout equipment (cages, trays, etc.) is not to exceed 33% of "floor coverage of the net" at the beginning of the growout cycle (Imai, 1977). Parsons and Dadswell (1994) evaluated handling and costs associated with eight different net configurations (pearl, lantern, shibetsu, etc.) and determined that cost, growth, and survival were highest in oyster trays (similar to VEXAR shellfish growout bags). Intermediate, or nursery culture, generally will result in animals between 40-60 mm SH after one year (Parsons et al. 2002).

We propose to determine the most effective method of producing sea scallop spat. We will investigate the cost per spat using both wild collection methods (see Grecian et al., 2001) and hatchery production. We will not develop new hatchery methods, but will rely on our own success in rearing sea scallops at DEI (Beal, 2002). Our previous investigations indicated a mixed diet of two species of flagellates (Class Prymnesiophyceae: *Isochrysis galbana* and *Pavlova pinguis*; CCMP 1323 and CCMP 609, respectively) resulted in highest survival to metamorphosis (**Fig. 3**) and fastest growth (**Fig. 4**). We will rely upon information from these investigations, as well as the work conducted by Hollett and Dabinett (1989), Harvey et al. (1997), Dabinett et al. (1999), Ryan (2000), and Milke et al. (2004) to rear scallop larvae and juveniles under hatchery conditions.

Figure 3. Survival of larvae of the sea scallop *Placopecten magellanicus* under different microalgal diet conditions (Beal, 2002).

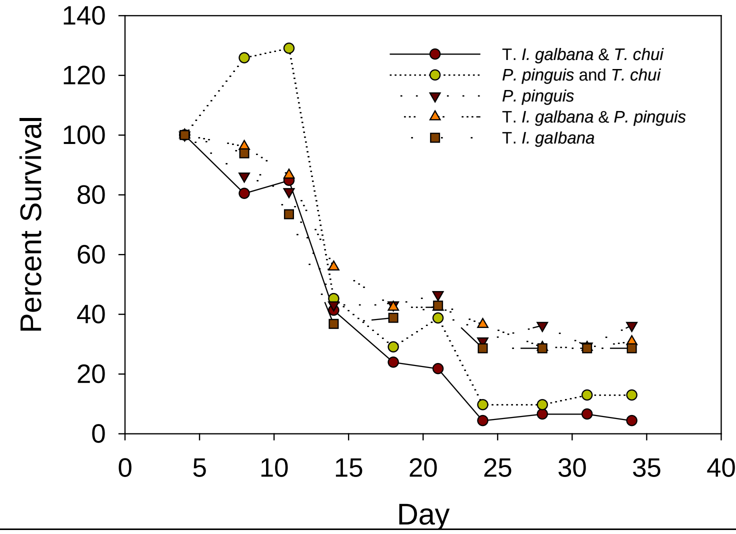
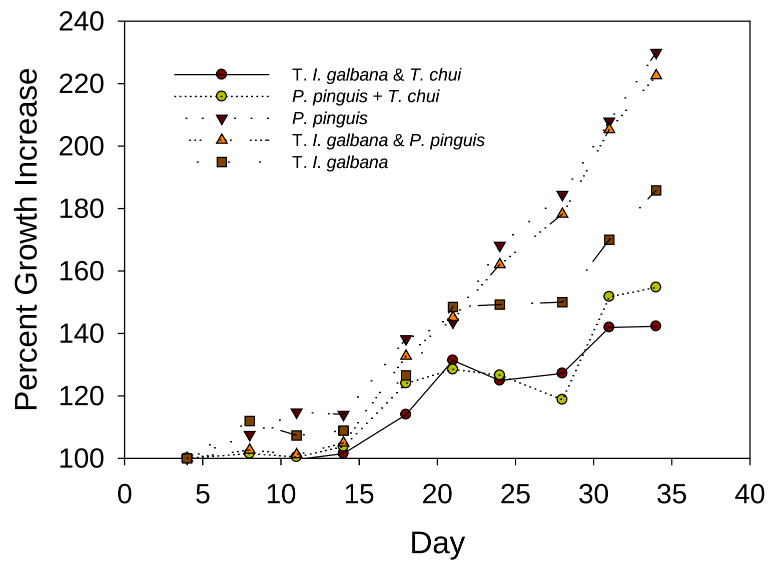


Figure 4. Growth of larvae of the sea scallop *Placopecten magellanicus* under different microalgal diet conditions (Beal, 2002).



Ultimately, we wish to enhance bottom areas with wild and/or cultured sea scallops, and will rely on published efforts conducted by Canadian scientists working in Newfoundland (Grecian et al. 2000), Nova Scotia (Carsen et al., 1995; Barbeau et al., 1994, 1996, 1998; Hatcher et al., 1996), the southern Gulf of St. Lawrence (Davidson and Têtu, 2000; Lafrance et al., 2003), and the Passamaquoddy Bay region of New Brunswick (Wong et al., 2003, 2005) with wild spat collected from spat collectors and from hatchery-reared individuals. Loss rates of individuals between 4-25 mm shell height (SH) seeded at densities of 250 ind. m^{-2} ranged from 90-99%, but resulted in a doubling of scallop abundance in the enhancement area (Hatcher et al., 1996). Losses were due to a variety of biotic and abiotic factors, with predation by sea stars (*Asterias forbseii* and *A. vulgaris*) and crabs (*Cancer irroratus*), and dispersal was due to predator presence and intraspecific competition for bottom space (Barbeau et al., 1996). In Nova Scotia, temporal variation in abundance and distribution of sea stars and crabs did not coincide with seeded scallop numbers, implying that predators increased their feeding rate (functional response) rather than increasing numerically (Barbeau et al., 1996). Sea scallops may reach a size refuge from sea star predation, but even adult scallops remain vulnerable to crab predation (Elner and Jamieson, 1979; Barbeau and Scheibling, 1994).

Scallop growth rates typically vary with site, season, and water depth due to variations in food and temperature (Bricelj and Shumway, 1991; Emerson et al., 1994). Hatcher et al. (1996) followed the growth of scallop juveniles in Lunenberg Bay, Nova Scotia for 13 months beginning in November 1990. Animals increased an average of 35 mm SH, or 0.09 mm/day. Shell growth was fastest in mid-summer and slowest in winter (Kleinman et al., 1996) at that same site. Barbeau et al. (1996) give recommendations for seeding bottom areas for enhancement projects: 1) seed large sizes of juvenile scallops to minimize predation by sea stars; 2) scallops should be seeded at low densities to counter functional response by crabs; 3) seeding should coincide with low seawater temperatures to minimize predation effects and lower dispersion; and 4) select sites that have low silt-clay levels, minimal wave action, and that are dominated by cobble substrates.

Recently, Wong et al. (2005) conducted a seeding|density experiment that we propose to partially replicate in our field studies. They used two different densities (5 or 68 scallops m^{-2}) of juvenile scallops (0 = 16 mm SH) that had been collected using spat bags and hand-seeded these to bottom plots. Scallop fate was assessed 1, 2, 4, 9, and 24 days after seeding. At the end of the experiment, there was no difference in the density of seeded scallops between treatments, and ca. 1 ind. m^{-2} was recovered in both density treatments. Losses from the seeded plots were due to both predator-related mortality and emigration. Their studies suggest that crabs may be attracted to an increased density of seeded scallops, and that a low density refuge from predation likely exists. In Hokkaido and Aomori Prefectures (northern Japan), scallop (*Patinopecten yessoensis*) stock enhancement on bottom grounds occurs one year after intermediate culture is initiated (Beal, 1999; Uki, 2006) when animals ≈ 40 mm SH, and coincides with active predator removal (sea stars) by fishermen (Ventilla, 1982).

2. Project Impacts

The anticipated impacts of the project on the fishing community are related directly to our ability to place significant numbers of wild and/or cultured sea scallop spat on the bottom and develop techniques to maximize their survival and growth. Ultimately, we wish to demonstrate methods that will enable fishers and managers to enhance the existing fishery and increase product yield. During that process, we will generate information about the efficacy of various production techniques that will allow us to move forward effectively and economi-cally. That is, our experimental approach to answering questions about scallop spat produc-tion and on-bottom culture will generate information that will make scallop management in Maine more effective. The impact of the work will be two-fold: first, we will enhance bottom areas and increase local production and new wealth in the fishery, and second, we will generate information about the efficacy of sea scallop enhancement in our area. The Maine Sea Scallop Advisory Council and its members have indicated their support for this work (see letters from Council members, Tim Harper and Dana Morse). They would like to understand more about sea scallop enhancement before making decisions about its general use as a viable management tool. The effort we are proposing will go far to help improve our knowledge about the role that enhancement can play in scallop management in Maine. Besides our recent field investigation (Beal et al., 2009), there have been a number of previous attempts to capture wild scallop spat along the Maine coast. Unfortunately, those efforts have not resulted in any published information or tangible reports. We have only anecdotal information about the success or failure of wild spat collection and subsequent seeding of bottoms with wild spat during the spring. The effort proposed here will take a careful, well-replicated approach to three facets of scallop enhancement that must all be examined closely prior to making longer-term decisions about the efficacy of this potential management tool. We will examine: 1) the relative costs associated with collecting wild spat vs. producing spat in a hatchery; 2) the necessity of intermediate growout of spat prior to deploying it to the bottom; and 3) the effect of scallop size, predators, and habitat on spat survival, growth, and migration.

The mission of the Downeast Institute is <u>to improve the quality of life for the people of downeast and coastal Maine through applied marine research, technology transfer, and public marine resource education</u>. Our organizational focus is to affect positively the livelihood of fishers and fishing communities through applied research projects. We have a variety of ways to make results of the project available to the public. First, our shellfish production and research facility at Black Duck Cove in the town of Beals is open to the public five days a week from 9 AM to 4 PM from 1 September through 14 May, and seven days a week from 15 May through 31 August. We welcome the public to the facility at all times it is open and staffed, and this is where much informal educational interactions occur with fishers and other interested parties. We have used the facility as a meeting place to plan various field activities associated with our Northeast Consortium project. In addition, we make presentations to the Maine Scallop Advisory Council about our work when we are invited (we have made two presentations in the past two years to this organization). We also make public presentations at the Maine Fishermen's Forum each March. Finally, we plan to publish results of our experimental efforts in peer-reviewed journals such as *Marine Ecology Progress Series*, *Journal of Experimental Marine Biology and Ecology*, *Fisheries Bulletin*, and *Journal of Shellfish Research*.

3. <u>Evaluation of project</u>

The criteria and procedures that we will use to evaluate the relative success of the project in achieving its objectives vary by objective. For example, we will assess the efficacy of wild scallop spat collection vs. hatchery production of sea scallop spat. To evaluate the success of this portion of our work, we will measure the number of spat we collect from the bags, and calculate a per-spat cost. This cost will take into account cost of gear, DEI staff time to prepare and deploy gear, cost of boat time and captain's time to deploy and collect gear, and the time it takes to process wild spat prior to releasing it to the bottom or placing it into a nursery for intermediate culture. Similarly, we will calculate a per-spat cost of hatchery-reared seed that will incorporate costs to condition broodstock (if necessary), chill seawater (temperatures must be less than 13-14^{o}C), and rear larvae and scallop juveniles to a size that is comparable to those collected from the spat bags or a size where individuals can be placed into intermediate culture (3-4 mm SH). In summary, we will assess the success of the first objective by comparing the real costs to generate spat using the two methods. One can argue that the comparison of costs per spat between hatchery and wild collection depends on the "luck" of the wild set in a given year; however, the collection of spat proposed here will be our third attempt in the Jonesport/Beals region since 2007. We will concentrate our activities in deeper waters and set gear in areas where we obtained the highest spatfall during 2007-2008 and 2008-2009. Information from the previous investigation (Beal et al., 2009) combined with the collection proposed here will ensure that the economic comparison between wild spat collection and hatchery production will not be based upon a single year data. We will have good estimates of interannual variability in spatfall in our area, and will use this information to help assess the most efficacious methods of producing spat for enhancement purposes.

We will use statistical analyses (Analysis of Variance, ANOVA) to evaluate the other three objectives. For example, in objective two, we will examine the best method to produce large scallops in an intermediate culture scenario. That is, we will place both wild and cultured individuals into floating trays, pearl nets, and into bottom cages at four densities. This will be a three-factor test with two levels of one factor (origin: cultured vs. wild spat), four stocking densities, and three levels of a third factor (bottom vs. suspended vs. floating culture). We will measure three fundamental, dependent variables – growth, survival, and biomass, and use statistical tools to help us evaluate objectively which of the 24 treatments (2 levels x 4 levels x 3 levels) maximize these dependent variables. Concomitantly, we will determine the cost-effectiveness of each treatment by regressing cost (dependent variable) associated with each treatment (e.g., cost per floating tray, net, cage, and the cost to deploy and collect trays, nets, and cages) on percent survival and growth per stocking density for each nursery scenario (independent variable).

In objectives three and four, we will design on-bottom trials in one of the scallop closed areas (Sheep Island) to determine the interactive effects of planting size, predator control, and environmental control on scallop growth and survival. Scallops of at least two sizes will be placed into caged or uncaged plots on hard bottoms (ledge) that are vegetated (kelp) or unvegetated (without kelp). Again, we will use ANOVA to assess the source of variation that explains the greatest amount of variation of the dependent variables, and then compare these biotic results to the costs associated with each treatment.

4. <u>Need for government financial assistance</u>

We are seeking financial assistance from the federal government because the scope of work is beyond the level that fishermen, local communities, and the Maine Sea Scallop Advisory Council can support. We have already been successful in attracting funds for a project that dovetails nicely with the one we are proposing here. That effort was supported by the Northeast Consortium, an association of four research institutions (University of New Hampshire, University of Maine, Massachusetts Institute of Technology, and Woods Hole Oceanographic Institution) that administers funding appropriated to the National Marine Fisheries Service for collaborative research on a broad range of topics including gear selectivity, fish habitat, stock assessments, and socioeconomics. We plan to use some equipment costs from a grant we recently received from the Maine Technology Asset Fund as match for this proposal. We received $93,575 for a variety of equipment that will be used for our mariculture enterprise at our Black Duck Cove facility, and plan to use the match associated with culture tanks, microscopes, dive tanks, and a compressor for this proposal.

5. Participation by persons or groups other than the applicant

This project will involve the fishing community in the Jonesport/Beals region of eastern Maine. Currently, we are working with commercial sea scallopers in this region, and personnel from Maine's Department of Marine Resources and Maine Sea Grant office. We have worked together to close two independent 1 km^2 areas of bottom in this region for scientific purposes. We have conducted research on sea scallops in these closed areas thanks to a successful grant through the Northeast Consortium (www.northeastconsortium.org). For the work proposed in this S-K request, we will hire boat captains to help us with two of the three research phases. First, we will have 100 independent lines and anchors with sea scallop spat bags (five per line, see below) to deploy in August 2010. This will require a day and a large boat (ca. 40-ft) to take all the gear to the study sites. The lines will remain in the water until the following May, at which time, we will hire a boat to help retrieve this gear. In addition, we will be moving gear (bottom cages) to one of the two closed areas to set up field trials to examine growth and survival of sea scallop spat. The gear is bulky and hard to manage without assistance from fishermen with their fishing boats. In addition, we will hire commercial divers to help deploy this gear on the bottom and to help us monitor the fate of the gear and its contents (the scallops) through time. It is crucial to the success of this project that local fishermen and divers be engaged in this research project. First, they receive financial support for their efforts. Second, they become part of the project and have a sense of ownership and stewardship for what is happening. Third, they discuss the project with other fishermen and divers, and through this network of friends and neighbors, word spreads through the local communities about the project. It has been our experience, too, that the more people who know about what is happening in their area, the less likely the chances are of inadvertent tangles with fishing gear and research gear.

Positive interactions with fishermen and the fishing community is the foundation of the Downeast Institute and its former incarnation, the Beals Island Regional Shellfish Hatchery (BIRSH). Since 1987, DEI and BIRSH projects involving public stock enhancement of softshell clam populations along the Maine coast with hatchery-reared seed have generated goodwill and created a wealth of knowledge about managing commercial populations of clams. Working with fishermen, managers, local elected officials, and the local schools to effect positive changes in marine fisheries is, fundamentally, why the Downeast Institute exists. Our proposal to develop a better understanding of some of the mechanisms that influence the dynamics of sea scallop populations in downeast Maine, and working side-by-side with the fishing community, is in keeping with DEI's mission.

6. Federal, state, and local government activities and permits

We are not aware of any Federal, state, or local government programs or activities that this project would affect, including activities requiring: certification under state Coastal Zone Management Plans; section 404 or section 10 permits issued by the Corps of Engineers; experimental fishing or other permits under FMPs; environmental impact statements to meet the requirements of the National Environmental Policy Act; scientific permits under the ESA and/or the Marine Mammal Protection Act; or Magnuson-Stevens Act EFH.

We are required to obtain scientific collection permits through the Maine Department of Marine Resources. These permits have been issued to the PI for the past 25 years without any difficulty. In addition, the DMR allows fishermen and other scientists working with the PI to be named on the collection permit. The permit allows the PI and others named to possess and transport commercial marine organisms of any size for scientific/research purposes. The permit is renewed annually. In addition, prior to May 2010, we will initiate with the help of our DMR colleagues, a rule-making activity to extend the length of time the current two closed areas near Jonesport for at least another three years. The areas will be closed to all harvesting that involves dragging, dredging, or diving.

7. Project Statement of Work

Objective 1: To determine economically prudent methods to generate sea scallop spat (i.e., wild spat collection using techniques that have been successful in Japan and Canada vs. hatchery production).

a) Project design

Wild spat collection

Sea scallops spawn naturally in eastern Maine from July through early September (Dadswell et al., 1988; Dadswell and Parsons, 1992a; Beal, 2004). Larval development to metamorphosis is temperature dependent (Culliany, 1974), but in the cool waters of eastern Maine, this planktonic phase takes about 40 days. Beginning the second week of August 2010, we will deploy scallop spat bags over hard bottom habitats near the southern end of Great Wass Island within 3-5 km of our Black Duck Cove facility at water depths ∃ 20 m. This effort will complement our recent trials (see above) by increasing the depths in which spat bags will be deployed. Because the fixed gear must remain in place during the latter portion of the lobster fishing season and throughout the winter/early spring when scallop and urchin draggers are working, we will employ a single line and surface buoy system that is anchored to the bottom using one or two cement blocks (depending on water depth) filled with cement. Five spat bags (sensu Pearce and Bourget 1996), 0.75 m long x 0.45 m wide with 1.5 mm aperture and stuffed with a piece of Netron®, a polyethylene material used to increase surface area within the bag, will be deployed along each line. The bottommost bag will be no closer than 3 m from the anchor, and bags will be spaced 2 m apart on each line. A Stryofoam float will be placed directly above the topmost bag to keep the line upright in the water column. The specific location of each line of bags will be recorded using GPS. We will deploy 100 lines (500 bags) over each of two depths (20-40 m vs. > 40 m) across ten separate locations within a specific depth (five lines x two depths x 10 locations per depth).

Lines and bags will be collected in April-May 2011 and taken to DEI's Black Duck Cove facility where they will be cleaned, and the number and size of scallop spat recorded for each line and location. We will use ANOVA to examine differences in mean number of spat $\cdot$ bag^{-1}; and mean SH (**Table 1**). Cost of gear, and the time to assemble, deploy, and collect it, as well as time to remove spat from the bags will be carefully measured to obtain a true cost per scallop individual. These data will be compared to the cost associated with producing sea scallop spat under hatchery conditions (see below).

Hatchery production

Typically, high natural variability (both spatially and temporally) exists with natural spat collection of sea scallops (Couturier et al., 1995). Therefore, we will compare costs of collecting sea scallop spat to the costs to produce spat under hatchery conditions. We have experience culturing sea scallop larvae at the Downeast Institute's research and production shellfish hatchery facility (Beal, 2002) using methods similar to those described by Karney (1996). We have found that a mixed diet (**Fig. 3**), similar to that described by Pernet and

Table 1. Analysis of variance table associated with the wild spat collection. Dependent variables: mean number of spat per bag; mean shell height per bag. Depth, Location, and Bag are considered fixed factors. Line is considered a random factor. The design is a completely randomized block design. Here, Line is considered the "block"; hence, there is no statistical test for this factor because line is unreplicated.

Source of variation	df	Mean Square Estimate
Depth (a = 2)	1	$MS_{Line(Location, Depth)}$
Location(Depth) (b = 10)	18	$MS_{Line(Location, Depth)}$
Line(Location, Depth) (c = 5)	80	no test
Bag (d = 5)	4	$MS_{Line \times Bag(Location, Depth)}$
Bag x Depth	4	$MS_{Line \times Bag(Location, Depth)}$
Bag x Location(Depth)	72	$MS_{Line \times Bag(Location, Depth)}$
Line x Bag x Location(Depth)	320	Residual error
Total	499	

Tremblay (2004), results in highest survival of both larvae and juveniles. To date, our methods have resulted in ≈ 35% of larvae reaching metamorphosis, and, because *P. magellanicus* is highly fecund (Langton et al.,1987), this larval survival rate can be offset somewhat by spawning large numbers of individuals.

Broodstock will be collected from shallow water sites around the Jonesport/Beals area beginning in mid-July 2010 through August 2010, when gonads are ripe and individuals can be induced to spawn using a combination of thermal shock and water agitation methods (Barber and Blake, 1991; Pearce et al. 1998). Should these methods fail, it is possible to induce spawning in *P. magellanicus* by injecting the ripe gonads with certain sex steroids such as estradiol (Wang and Croll, 2006). Fertilized eggs will be placed in gently aerated 1000-l larval tanks at temperatures between 13-15^{o}C at a density of 1 to 5 larvae ml^{-1} (Tremblay 1988). Seawater in the tanks will be drained every 2-3 days until larvae are competent to settle. Individuals will be induced to settle on shallow trays lined with 125-μ Nitex screens that are used routinely for bivalve culture at the Downeast Institute. Juvenile rearing will commence immediately afterwards in 2000-l rectangular tanks that receive cultured phytoplankton that drips continuously into the tanks. When scallop juveniles reach 3-4 mm SH, they will be counted prior to moving them either to an overwintering scenario (e.g., Beal et al., 1995) within the facility using ambient flow seawater, to an intermediate culture field nursery, or deployed in bottom plots (see below).

To compare the cost per scallop reared under hatchery conditions with the cost to gather spat using the collectors, we will carefully assess equipment costs, monitor electricity used, record staff time associated with broodstock maintenance, spawning, and larval and juvenile rearing. Ultimately, we will develop information about the cost-effectiveness of collecting wild spat vs. producing them in a shellfish hatchery. Although only a single year of effort to collect wild spat (August 2010 – May 2011) is included in this proposal, we have two previous years of information (2007-2008 and 2008-2009; Beal et al., 2009) about spat collecting with which to enhance our S-K data.

b) Responsibility for carrying out these activities
Drs. Brian Beal and Doug McNaught will be responsible for carrying out the wild sea scallop spat collection effort. Dr. Beal and the staff at the Downeast Institute will be responsible for the hatchery phase of spat production.

c) Major products and dissemination strategy for results
The goal of this portion of the proposed effort is to generate sea scallop spat for subsequent growth and survival trials in both a nursery setting and bottom plots where predators and environmental conditions are manipulated. The major product, then, are large numbers of sea scallop spat (500,000 to 1,000,000). We will learn which method (hatchery rearing or wild spat collection) proves the most cost-effective. We will disseminate results of this work through informal contact with fishermen who visit us either at the University of Maine at Machias or the Downeast Institute, by giving talks at the annual Fishermen's Forum in Rockport during late February and early March, by writing reports of the results and making them available at the Downeast Institute's web site: www.downeastinstitute.org, and by preparing manuscripts for publication in peer-reviewed fisheries/aquaculture journals.

d) Project milestones
Milestones for the wild spat collection include: 1) Acquiring all materials and preparing gear (two months: May-June 2010); 2) Deploying all gear (one day; mid-August 2010); 3) Collecting gear (one day; mid-May 2011); and, 4) Collecting spat from bags and recording number per bag and scallop size (up to one week; mid-May 2011). Milestones for the hatchery production of sea scallops include: 1) Acquiring broodstock from coastal waters around Beals and Jonesport (two weeks; July-August 2010); 2) Inducing broodstock to spawn (two weeks; July-August 2010); 3) Rearing larvae (up to two months, July-September 2010); Rearing juveniles (200µ to 4000µ SH) (up to six months, September 2010-January 2011); Overwintering juveniles (2000µ - 4000µ SH) (up to seven months, November 2010-May 2011); and, 4) Data analysis (one month; June 2011).

Objective 2: To determine effects of stocking density of wild and/or cultured scallop spat on growth and survival in several intermediate nursery culture scenarios.

a) Project design

We will examine the efficacy and cost-effectiveness of intermediate sea scallop culture because we anticipate that, like other bivalves that are used for stock enhancement or commercial purposes (e.g., soft-shell clams – [Beal and Kraus, 2002]; Manila clams – [Cigarria and Fernández, 2000]; bay scallops – [Lopez et al., 2000]), size-dependent juvenile mortality will occur. In fact, Barbeau et al. (1994) demonstrated that mortality rates due to sea star predation were greater on small (7-12 mm SH) vs. large (23-28 mm SH) tethered juvenile sea scallops. We will employ three intermediate culture designs for sea scallop spat from both origins (wild vs. hatchery-reared).

In the first scenario, spat (3-10 mm animals) at several stocking densities will be placed in shallow wooden trays (4-ft x 3-ft – 1.115 m^2) lined with window screening and taken to DEI's field-based nursery at Mud Hole Cove on Great Wass Island (44^o 29.13' N; 67^o 35.13' W). This four-acre area annually accommodates 400-500 similar size trays for nursery grow-out of cultured bivalves such as soft-shell clams (*Mya arenaria*), hard clams (*Mercenaria*

mercenaria), and European oysters (*Ostrea edulis*). Typically, 10,000-15,000 cultured bivalve seed (3 mm) are placed in each tray. For sea scallop culture, we will examine the effects of four densities – 1,000; 2,500; 5,000; and, 10,000 spat per tray. If sea scallop spat are each 10 mm SH, the first two densities are well below the generally accepted floor coverage (density based on area = areal coverage) limit of 33% for scallops (Ventilla, 1982; Parsons and Dadswell, 1992), and the latter two represent 35% and 70%, respectively, of floor coverage in the trays. If sea scallop spat are each 3 mm SH, all four experimental stocking densities are well below the floor coverage limit. We will employ fifteen replicate trays for each density and origin. Trays will be deployed in mid-May 2011 to coincide with the wild spat collection and the end of overwintering of the cultured scallops. Every attempt will be made to utilize the smallest size range of animals from both origins at the beginning of the trial in order that comparisons between the two are logical and unbiased. (Two origins x four densities x 15 trays/density/origin = 120 trays.) To reduce potential fouling of the mesh in each tray by macroalgae and other organisms, approximately 50 periwinkles (*Littorina littorea*) will be added to each tray. This method is effective in nearly eliminating macroalgal fouling of trays filled with clams or oysters (B. Beal, pers. obs.). Monthly visits to the nursery site will be made and relative growth and survival estimates recorded. Trays will be collected in mid-November 2011 when survival, growth, and biomass estimates from each tray will be taken.

In the second scenario, spat from both origins at four stocking densities (as described above) will be placed into bottom cages constructed of lobster trap wire (12-gauge; 1 ½-inch aperture) that will be deployed within the Sheep Island closed management area (44^{o} 31.05' N; 67^{o} 33.94' W; ca. 5.5 m at low tide). Cages, that are the same dimensions as the wooden trays used at the floating nursery (0.17 m^3, or 4-ft x 3ft x 0.5ft), will be lined on the inside with extruded, plastic netting (3.2 mm aperture) small enough to accommodate spat as small as 4 mm. Five replicate cages per treatment will be used (two origins x four densities x 5 cages/origin/density = 40 cages). Cages, with scallop spat and 50 periwinkles each, will be placed on hard bottom in mid-May 2011 using SCUBA and will be collected in mid-November 2011. Two cement blocks filled with cement will be placed on two of the four corners of each cage to anchor it in place. Bi-monthly monitoring using SCUBA will occur to assess how well the bottom cages stay positioned during the grow-out period.

Survival from each tray or cage will be estimated by randomly examining three 20 g samples from each. The percentage of dead scallops (animals without soft tissue) to living scallops will be an estimate of mortality. We will perform separate analyses for the interactive effects due to origin and stocking density for each nursery location (**Table 2**). Overall mean growth and survival will be compared between the two nursery locations.

In the third scenario, we will use suspended pearl nets (sensu Parsons et al., 2002), as these have been used with good success in Passamaquoddy Bay and elsewhere in the Canadian Maritimes (Parsons and Robinson, 2006). We will use side loading, square base nets (34 cm x 34 cm) with a floor area of 0.116 m^2. For this experiment, we will use 3 mm aperture nets because we will be stocking the nets with spat from the collectors and hatchery. We will use four stocking densities: 100, 250, 500, and 1,000 ind. net^{-1}. Nets will be suspended from long lines in vertical groups of four (each group will be considered a block and a particular density will be assigned randomly to one of the four vertical positions).

Table 2. Analysis of variance table associated with growth, biomass and survival of wild and cultured spat at two nursery sites near Beals, Maine. **a)** Floating trays located at Mud Hole Cove on Great Wass Island; **b)** Submerged cages located within a 1-km^2 area near Sheep Island that is closed to dragging and diving through a rule-making procedure with the Maine Department of Marine Resources. Wooden trays lined with window screening will be used at Mud Hole Cove whereas wire cages with extruded mesh inserts will be used at the Sheep Island nursery. Three 20 g random samples from each tray|cage will be taken to estimate percent survival. The shell height (SH) of twenty spat from each tray|cage will be taken and the mean SH/tray|cage used in the analysis.

a) Survival – *Floating Trays*

Source of variation	df	MS estimate
Origin (Wild v. Cultured)	1	$MS_{Tray(Origin,Density)}$
Stocking Density	3	$MS_{Tray(Origin,Density)}$
Origin x Density	3	$MS_{Tray(Origin,Density)}$
Tray(Origin, Density)	112	MS_{Error}
Error	240	
Total	360	

Growth/Biomass – *Floating Trays*

Source of variation	df	MS estimate
Origin	1	MS_{Error}
Stocking Density	3	MS_{Error}
Origin x Density	3	MS_{Error}
Error	112	
Total	119	

b) Survival – *Submerged Cages*

Source of variation	df	MS estimate
Origin (Wild v. Cultured)	1	$MS_{Tray(Origin,Density)}$
Stocking Density	3	$MS_{Tray(Origin,Density)}$
Origin x Density	3	$MS_{Tray(Origin,Density)}$
Cage(Origin, Density)	32	MS_{Error}
Error	80	
Total	119	

Growth/Biomass – *Submerged Cages*

Source of variation	df	MS estimate
Origin	1	MS_{Error}
Stocking Density	3	MS_{Error}
Origin x Density	3	MS_{Error}
Error	32	
Total	39	

Each long line will hold four sets of four pearl nets, with two groups of four nets assigned to wild spat, and two groups assigned to cultured spat. The bottommost net will be approximately 2m above the bottom in Mud Hole Cove. We will deploy ten long lines (N = 160 pearl nets). The data will be analyzed as a completely randomized block design (**Table 3**).

Once again, we will track costs associated with gear, deployment, and collection for each of the nursery grow-out scenarios to create information about the cost-effectiveness of each on a per scallop basis.

b) <u>Responsibility for carrying out these activities</u>

Dr. Brian Beal will be responsible for carrying out the field trials involving the floating trays, and Dr. Doug McNaught will be responsible for trials involving the submerged nursery.

Table 3. Analysis of variance table associated with growth, biomass and survival of wild and cultured spat in pearl nets at a nursery site near Beals, Maine. Nets will be arrayed in three groups of four from each of ten long lines. Stocking densities of 100, 250, 500, and 1,000 ind. net^{-1} will be randomly assigned to nets within each group of four. Three 20 g random samples from each net will be taken to estimate mean percent survival. The shell height (SH) of twenty spat from each net will be measured, and the mean SH per net used in the analysis. Origin and Stocking Density are fixed factors, whereas Groups (of long lines) and Blocks nested within Groups are considered random factors.

Source of variation	df	MS estimate
Group	9	$MS_{Block(Group)}$
Block(Group)	10	no test
Origin	1	$MS_{Group\ x\ Origin}$
Stocking Density	3	$MS_{Group\ x\ Density}$
Group x Origin	9	$MS_{Origin\ x\ Block(Group)}$
Group x Stocking Density	27	$MS_{Density\ x\ Block(Group)}$
Origin x Density	3	$MS_{Group\ x\ Origin\ x\ Density}$
Group x Origin x Density	27	$MS_{Origin\ x\ Density\ x\ Block(Group)}$
Origin x Block(Group)	10	no test
Density x Block(Group)	30	no test
Origin x Density x Block(Group)	30	no test
Total	159	

c) Major products and dissemination strategy for results

The goal of this portion of the proposed effort is to generate information regarding the growth and survival of sea scallop juveniles in floating, suspended and bottom nursery habitats. We are interested in the interactive effects of scallop origin (Wild vs. Cultured) and stocking density per container. Ultimately, we wish to place scallops of at least two different sizes in bottom plots to assess growth and survival for stock enhancement purposes (see below, Objectives 3 & 4). The major product, then, is large numbers (550,000 from trays and 74,000 from the pearl nets in Mud Hole Cove, and 185,000 from nursery grow-out trials off Sheep Island). These trials will yield information about which method(s) proves the most cost-effective both in terms of percent survival and growth. We will disseminate results of this work as described above.

d) Project milestones

Milestones for the nursery phase: 1) Acquiring all materials and preparing gear (two months: March-April 2011); 2) Deploying all gear (two weeks; mid-May 2011); 3) Monitoring trays on a monthly basis to estimate relative growth and survival (June-November 2011); 4) Monitoring submerged cages on a bi-monthly basis to estimate relative growth and survival (June-November 2011); 5) Retrieving trays and cages and estimating growth and survival (three weeks; November 2011); and, 6) Data analysis (one month; January 2012).

Objectives 3 & 4: To determine how planting size affects on-bottom growth and survival of sea scallop juveniles; and, whether predator deterrence and environmental measures (kelp habitat modification) result in higher on-bottom growth and/or survival during the first ten months after seeding.

a) Project design

We will assess both objectives simultaneously in the field within the 1-km^2 closed area near the town of Beals (Sheep Island). Beginning in mid-May 2011, we will deploy several extra floating trays and bottom cages at Mud Hole Cove and Sheep Island, respectively (as described above), to ensure that enough scallop juveniles are available for this portion of the project (n = 6,000; see below). To determine the interactive effects of planting size, predator exclusion, and habitat type on juvenile sea scallop survival and growth, we will use a factorial design. Beginning in mid-August 2011, we will harvest sea scallop juveniles from the trays and cages, and we anticipate that two separate sizes of scallops will be available (small = 6-8 mm SH; large = 10-12 mm SH). At that time, animals within these two size classes will be added to three types of bottom plots in areas with and without kelp (*Laminaria* spp.). We will employ full and partial cages as well as uncaged/control plots. Full cages (as described above – 0.17 m^3) will have six sides to deter large predators, and be lined with a plastic, extruded netting (3.2 mm aperture) to retain scallops. Partial cages will have five sides (no top), and will be lined with the same extruded netting. These cages are designed to allow predator (e.g., *Carcinus maenas*, *Cancer* spp., *Homarus americanus*, *Asterias* spp.) access, while reducing sea scallop migration. Cages will be held in place using two cement blocks filled with cement that are attached to two of the corners. Open, or control, plots will be the same planting area (1.1 m^2). Each will be delineated with a 1.1m^2 PVC quadrat (½-diameter) with holes drilled along each side so that it will sink and remain submerged. The corners of each quadrat will be held in place using cement weights at two of the corners. All scallops naturally occurring in each of the open plots will be counted, measured, and removed from the area prior to establishing the experimental density, and these data will be used to establish initial density and size-frequency distribution of the local population. The plot design (full and partial cages vs. open plots) will allow us to assess the relative importance of sea scallop loss due to predation vs. migration. In addition, by deploying the experiment in two habitats, we will test whether potential environmental controls (i.e., prey refuges; see Sih, 1987) will lower the probability of encounter between predators and sea scallop juveniles and/or reduce migration rates.

Five replicates of each treatment (a = 2 scallop sizes; b = 3 plot types; c = 2 habitats; total = 12) will be deployed using SCUBA. Scallops will be seeded into each bottom plot at a density of 100 m^{-2}, which is in the range of seeding densities used in Canadian studies by Hatcher et al. (1996) and Wong et al. (2005) for similar sized scallop juveniles from field trials conducted near Lunenburg, Nova Scotia, and Passamaquoddy Bay, New Brunswick, respectively. To understand better the nature of migration from the plots, 30 scallops from each plot (N = 30 x 60 = 1800 individuals) will be tagged using plastic bee tags (2.6-mm diameter, 0.02-mm thickness, 0.0014 g, Steele & Brodie Ltd., Hampshire, England) in the laboratory (after Barbeau et al., 1996). Plots and cages will be monitored 3-4 times during the first week, and then irregularly through the fall and winter as weather permits. All cages and open plots will be sampled in June 2012. Cages will be removed from the bottom and the contents of each examined in the laboratory. Two divers will hand-pick all scallop juveniles (dead and alive) from the open plots and place these into pre-marked bags that will be examined in the laboratory. Percent survival and growth from each experimental unit will be estimated. Depending on numbers retrieved from the plots, we will measure thirty animals at random from each cage and open plot. Survival and growth data will be analyzed using ANOVA (Table 4). (We plan to re-establish bottom cages after the June 2011 sampling when predation rates are expected to increase with increasing seawater temperature, but this activity would be outside the 24-month period of the grant.)

Table 3. Analysis of variance on mean growth and survival of two sizes of sea scallop juveniles (November 2010 - June 2011). Animals (100 m^{-2}) will be deployed in three types of plots (full cages, partial cages, and open plots – 0.17 m^3) on the bottom in two habitats (kelp vs. no kelp) within a closed fishery area adjacent to Sheep Island (Beals, Maine). The fully factorial design is a completely random one with each factor fixed. n = 5.

Source of variation	df	Mean Square Estimate
Scallop Size	1	MS_{error}
Plot Type	2	MS_{error}
Size x Plot Type	2	MS_{error}
Habitat	1	MS_{error}
Habitat x Size	1	MS_{error}
Habitat x Plot Type	2	MS_{error}
Size x Plot x Habitat	2	MS_{error}
Error	48	
Total	59	

b) Responsibility for carrying out these activities

Dr. Doug McNaught will be responsible for carrying out the field trials, while Dr. Brian Beal will be responsible for obtaining field gear and providing support in both the field and laboratory.

c) Major products and dissemination strategy for results

The goal of this portion of the proposed effort is to learn how scallop size, along with predators and habitat type interact to influence growth and survival of sea scallop juveniles. This information will be used to generate information about the potential for enhancing sea scallop stocks in eastern Maine. The major products will be information about size- and habitat-specific scallop migration, growth, and survival. We will disseminate results of this work as described above.

8. Participation by persons or groups other than the applicant

We have been working closely with several groups interested in sea scallop management for the past two years. Initially, we were approached by scallop fishermen in the Jonesport/ Beals area who wanted to collaborate on a field-based project to close bottom areas that were once productive scallop grounds to all dragging and diving activity. They wanted us to help them determine if these areas could be enhanced with animals dragged from open bottoms or with scallop spat that was collected as described above. This Northeast Consortium-funded project has been completed (Beal et al., 2009). In addition, we are working with staff from the Maine Department of Marine Resources (DMR) and with the recently established Maine Sea Scallop Advisory Council. In fact, several of the fishermen we worked with on the Northeast Consortium project are council members. We intend to continue working closely with local fishermen and members of Maine's DMR on this project. Fishermen will be hired on a daily basis so that they can help us deploy and tend gear, as well as remove gear from the water at the end of the various field trials. These individuals will see firsthand our results. DMR staff will be invited to join us in the field and are always invited to assist in the laboratory/hatchery.

9. <u>Project Management</u>

The project will be organized into three major activities: 1) procuring sea scallop spat and juveniles (wild spat collection vs. hatchery production); 2) intermediate culture of sea scallops in field-based nurseries (four stocking densities assigned to bottom cages, suspended nets, and floating trays); and, 3) field trials to determine interactive effects of sea scallop size, predator exclusion, and habitat on growth and survival.

The overall project PI will be Dr. Brian Beal, Professor of Marine Ecology; University of Maine at Machias, and Director of Research at the Downeast Institute. Dr. Doug McNaught, Assistant Professor of Marine Biology will be the co-PI on the project.

Overall Timetable and Milestones

	2010						**2011**												**2012**					
Activity	**J**	**A**	**S**	**O**	**N**	**D**	**J**	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**	**O**	**N**	**D**	**J**	**F**	**M**	**A**	**M**	**J**
Wild Spat Collection			x	x	x	x	x	x	x	x	x													
Broodstock Collection / Conditioning	x	x																						
Larval Rearing		x	x	x																				
Spat Rearing			x	x	x	x																		
Overwintering Cultured Spat					x	x	x	x	x	x	x													
Intermediate Culture Field-based Nursery											x	x	x	x	x	x	x							
On-bottom Field Trials														x	x	x	x	x	x	x	x	x	x	x
Final Report																								x

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