1. Proposal Narrative

    a. Background and rationale

Maine is the top producer of soft-shell clams, *Mya arenaria*, in the United States (NMFS, 2019); however, landings here have declined by 75% since the early 1980's (Fig. 1). The dwindling resource, and the loss of thousands of commercial harvesters (about 3,000 commercial licenses over that same period) threatens the very existence of what was once an iconic fishery (Beal et al., 2016, 2018). Nevertheless, the soft-shell clam fishery is, annually, the second or third most commercially important marine resource in Maine. Here, we propose to create a coast wide soft-shell clam monitoring program for 0-year class individuals (recruits) in three communities in each of Maine's three coastal regions (southwest; mid-coast; downeast). The program will accomplish at least three goals. It will: 1) increase visibility and public awareness for a fishery that is threatened by a dramatically changing marine environment; 2) create an extensive data set for shellfish managers to better understand factors that regulate the fishery by providing estimates of spatial and temporal variability for 0-year class soft-shell clams; and, 3) encourage participation and learning from a diversity of coastal residents including clammers, shellfish committee members, and other municipal officials as well as K-12 school children, their teachers, and parents.

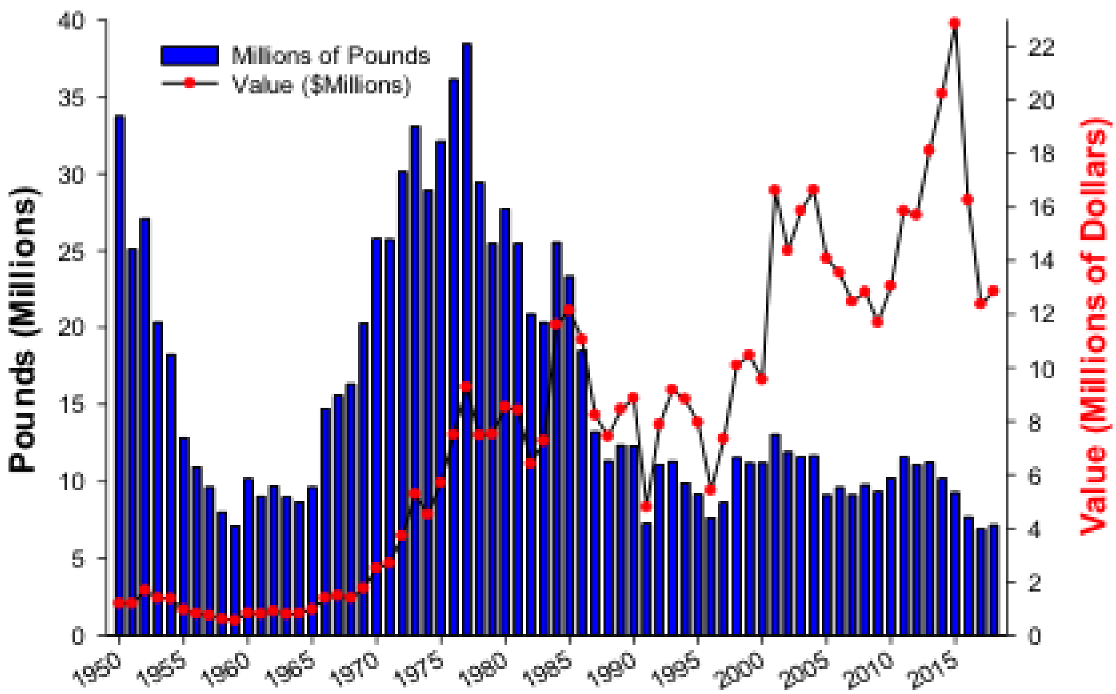

Figure 1: Maine Soft-Shell Clam Landings from 1950-2018 (ME DMR, 2018).

The PI has been studying biotic and abiotic factors that regulate soft-shell clam populations in Maine for the past 32 years. In 1987, he helped to establish the Beals Island Regional Shellfish Hatchery in the town of Beals as a University of Maine at Machias (UMM) project (Beal, 1988) to enhance intertidal mudflats with cultured soft-shell clam juveniles (seed). That program still exists today under the auspices of the Downeast Institute, a 501(c)(3) nonprofit organization that also serves, through a Memorandum of Agreement, as UMM's Marine Science Field Station.

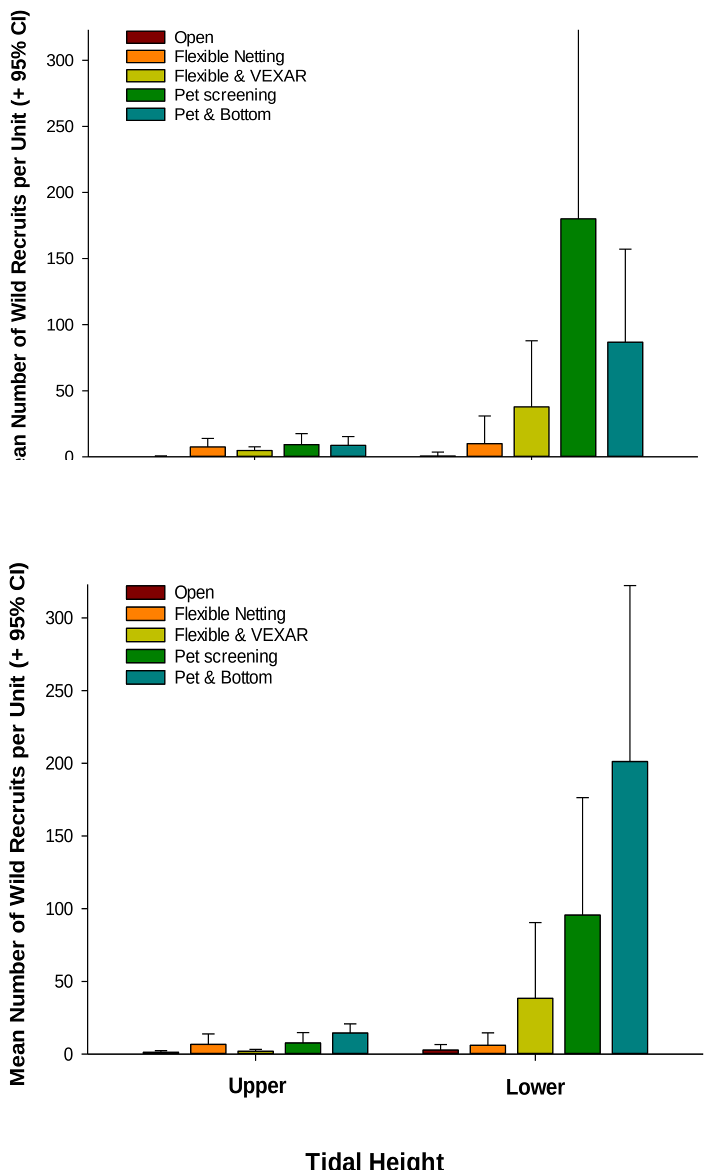

Figure 2: Mean number of 0-yr class recruits of *Mya arenaria* per experimental unit (area=0.01824m^2) at the Webhannet River Estuary (Wells, ME; top) and Fore River Estuary (Portland, ME; bottom). Units were deployed on 12-13 May and retrieved on 10-11 October 2014. "Flexible" refers to a plastic, flexible netting with a 4.2mm aperture. VEXAR is a hard, durable piece of extruded plastic with a durable piece of extruded plastic with a 6.4mm aperture (adapted from Beal et al., 2018).

The Downeast Institute (DEI) is Maine's first and only public shellfish hatchery. Much of DEI's research has focused on increasing the likelihood that our hatchery clams survive in the wild. So we have examined effects of various factors such as stocking density, transplant time of year, tidal position, predator exclusion, and sediment pH on survival and growth of clams (Beal et al., 2001; Beal and Kraus, 2002; Beal 2006a, b; Beal et al., 2016). While tidal position and predation appear to be the most important factors regulating populations of cultured individuals, it has become clear that these two factors also are paramount in controlling the distribution and abundance of 0-year class clams in a variety of intertidal habitats along the coast (Beal et al., 2016, 2018). That is, in our recent (past six years) examination of clam recruitment at numerous sites along the Maine coast from Cutler in the downeast region to Wells in the southwest region, we have found a strong association between tidal position, aperture size of predator exclusion netting, and the density of 0-year class soft-shell clams (Fig. 2).

In 2015, we scaled up our small experimental units (0.01824 m^2) to a rectangular unit (1-ft x 2-ft x 3-inches deep, or 30.5 cm x 60.9 cm x

7.6 cm deep; Figure 3), and began deploying these "recruitment boxes" on the surface of intertidal mudflats in the Harraseeket River Estuary (Freeport). Results showed unambiguously that compared to the adjacent, unprotected sediments, relatively high densities of *Mya* recruits occurred in the same areas, whereas in others few 0-class individuals occurred (Beal et al. 2018). We recognized the utility of the recruitment box to learn more about the dynamics of the early life history of soft-shell clams, and the importance of these results as a potential tool in locating areas of high seed production and perhaps, to predict future commercial or recreational densities of clams.

Figure 3: Left – recruitment box with Pet screening® (aperture = 1.7 x 0.9 mm); Upper right – deployment of six boxes on a mudflat in the Harraseeket River (Freeport, ME) in a 2 x 3 matrix with 1 m spacing between rows and columns. Lower right – recruitment box (deployed empty in early June 2018 in the St. George River Estuary – Thomaston, ME) that is filled with muddy sediments, and contains 1,875 wild soft-shell clam recruits (shell length range = 1.6 - 22.2 mm).

The proposed effort to establish a coast wide monitoring network for young-of-the-year soft-shell clams is akin to a larger effort (from Rhode Island to Maine) for postlarval settlement of American lobster, *Homarus americanus*, that began in 1989 (Wahle et al., 2004) with support from Maine Sea Grant, and continues to the present (Hunt et al., 2017). The American Lobster Settlement Index (ALSI) is an annual monitoring program that quantifies the pulse of newly settled lobsters. The value of conducting such a monitoring program to quantify lobster recruits is that, like other shellfish, the early life stage is crucial to understanding the strength of an individual year class, and is useful as a predictor of future trends in recruitment to the fishery

(The Wahle Lab, 2019). It is for these same reasons that DEI is proposing to set up a similar monitoring program to assess spatial and temporal variability of young-of-the-year soft-shell clams.

The ALSI uses both active (divers) and passive (postlarval collectors) to sample. Our proposal mirrors the ALSI passive sampling method for soft-shell clams as DEI's recruitment boxes also are passive, postlarval collectors.

Results of the sampling will show the relative strength of the 2020 and 2021 cohort at four spatial scales: 1) within site (16 boxes will be deployed per site that are spread out along the lower mid-intertidal in eight "blocks", or subareas); 2) within a community/shellfish program (there will be two intertidal sites within each community/shellfish program); 3) within a region (the coast will be divided into three regions from the southwest to northeast); and 4) between regions (southern, midcoast, and downeast).

Similar to the ASLI, there are many stakeholders who will be interested in the results of the sampling. Potential users of the information collected from the recruitment boxes include clammers, municipal shellfish committee members (local managers), biologists with the Maine Department of Marine Resources (DMR; state managers), K-12 students and their teachers, and members of the general public who wish to learn more about soft-shell clam ecology.

Maine has a system of managing its soft-shell clam resources cooperatively between the local community and the state through the DMR (McGreavy et al., 2018). Local and state managers may use the data generated from the passive collectors to make decisions about utilizing areas of relatively dense recruitment in future efforts to enhance local stocks with wild seed. That is, clammers can benefit by overwintering seed (Beal et al., 1995) collected each fall from the boxes followed by transplanting the wild juveniles to predator-protected plots in their community (Beal et al., 2016) the following spring.

This information could lead some communities to examine clam recruitment at other sites within their municipality, or scale-up boxes to commercial sizes (Beal, pers. obs.) followed by stock enhancement activities.

We intend for this work to be carried out well after the 2-yr grant funding (see below in section "d" under Outreach) so that communities can continue to observe and quantify temporal (annual) variability in cohort strength. Our dream is that this effort will continue indefinitely as the ASLI, and, we will work to locate additional sources of revenue beyond Sea Grant. One of the biggest strengths of this proposed work is that it does not require expensive and complicated equipment and technology to conduct. All essential materials are easily purchased at local hardware stores, and boxes can be easily constructed, especially by Mainers as our culture emphasizes being handy and self-sufficient. Once the knowledge and understanding of how to collect the data is transferred to the (possibly hundreds) of people who we will partner with in these coastal communities, they will be well on their way to being able to collect this data on their own. We will continue to coordinate the collection of data and see that it is easily accessible (sensu The Whale Lab, 2019).

For example, this proposal will engage K-12 teachers and their students. Some of the activities associated with this research will benefit public science education in several important ways: by engaging in the hands-on activities both during deployment and sampling, analyzing results (e.g., collecting data on everything from the diversity of organisms in the boxes, to the density and size-frequency of recruits), and presenting results in their town to their local shellfish committee and clammers. DEI encourages and works with classes to put together presentations to share their findings. To this end we have collected numerous letters from teachers who are interested in participating in this work.

The proposed research effort aligns with each of the five Maine Sea Grant strategic goals. Healthy Coastal Ecosystems: The project will demonstrate links between healthy ecosystems and resilient communities that will take action to ensure the long-term health of an important coastal resource. Recruitment box data, combined with results from sampling recruits in ambient (control) sediments at each site, will lead to important local conversations about the functions of the intertidal ecosystem followed by activities to sustain or improve clam harvests. Resilient Communities: The effort will increase awareness of the plight of the soft-shell clam fishery along the Maine coast, and lead communities to actively adapt to, and hopefully reverse the trend of, decreasing clam abundance and landings. The work will enhance the public decision-making process and assist communities in their efforts to value and preserve coastal and marine heritage. Safe & Sustainable Seafood: We recognize the importance that an environmentally sustainable and economically viable harvest of soft-shell clams means to Maine's coastal communities. The work proposed here will better inform local and state managers of the fishery by providing both regional and local data on clam recruitment. Decisions made by these co-managers to sustain or enhance the fishery will now include local recruitment data (heretofore not available) along with traditional population surveys. This will be an important addition to the management toolbox for this species. The research and extension services will improve coastal and marine resource monitoring and management by informing community, regional, and statewide management planning processes. Communities Preparing for a Changing Climate: Maine's marine environment is changing rapidly as a result of relatively recent rises in seawater temperatures in the Gulf of Maine (Pershing et al., 2015) with winters becoming much milder and shorter (Fernandez et al., 2015). These factors have resulted in an explosion of the invasive green crab population along the coast (McClenachan et al., 2015) with a concomitant effect of increased rates of predation on the smallest soft-shell clams (Beal et al., 2018). The work will support efforts to understand, communicate, and respond to climate-related changes while enhancing and expanding climate literacy and citizen science initiatives to increase understanding of the anticipated impacts of climate change. Environmental Literacy & Workforce Development: Creating a coastwide monitoring network for soft-shell clam recruitment will help support participation in citizen science and applied research activities and create an environmentally literate public that can use this new scientific knowledge to identify questions, draw evidence-based conclusions, and make well-informed management decisions about the health and economic vitality of their soft-shell clam resources.

b. Scientific approach/objectives

Goals To: 1) increase public awareness of problems within the soft-shell clam fishery that begin with the early life-history stages of this species; 2) create a long-term, coastwide monitoring network associated with soft-shell clam recruitment; 3) provide local and state managers with information that will lead to more informed decision-making and a healthier, more robust clam fishery; and, 4) align the work with Maine Sea Grant's Strategic Goals.

Objectives To: 1) determine spatial and temporal variability in soft-shell clam recruitment at two intertidal locations in three coastal communities within three geographic regions of the Maine coast during 2020-2021, and beyond; 2) engage learners of all ages and from a diversity of socio-economic backgrounds in the effort; 3) work with local and state managers to use data collected from this effort to better inform management decisions; and, 4) create sufficient interest and excitement in the coast wide monitoring network that communities and the local infrastructure (shellfish committees, clammers, K-12 children and teachers, and/or NGOs) will continue the effort beyond the Sea Grant funding cycle.

Questions to be addressed 1) How does soft-shell clam recruitment vary spatially and temporally along the Maine coast? 2) What effect does deterring both small and large predators have on clam recruitment density and size-frequency distribution in passive collectors (recruitment boxes) vs. ambient conditions (unprotected intertidal sediments)? 3) Can density of recruits from passive collectors be used to predict densities of clams that enter the commercial fishery? 4) How does diversity of other bivalves in passive collectors (both commercially-important – e.g., blue mussels, quahogs, oysters – and noncommercial) vary spatially and temporally along the Maine coast?

Hypotheses that will be tested in the research 1) Regardless of region, community, or location within a community, significantly higher densities of soft-shell clam recruits (0-year class individuals) will occur in passive collectors compared to densities occurring in ambient conditions (Beal et al., 2018); 2) Recruitment levels will vary as a function of geographic location with highest densities occurring in the southwestern region and lowest densities occurring in the northeastern region (Vassiliev et al., 2010); 3) Size-frequency distribution of clam recruits will be broader (more variable), with a greater number of larger (> 20 mm in shell length, SL) individuals occurring in the southern vs. the midcoast and northeastern regions because spawning occurs earlier in more southern areas of the Maine coast (Ropes and Stickney, 1965); and, 4) Green crabs, *Carcinus maenas*, the primary predator of soft-shell clam recruits, will occur more frequently and attain larger sizes in passive collectors deployed in the southwestern communities vs. the other two regions (B. Beal, pers. obs.).

c. Proposed research

We have invented a simple, passive collector that entraps sediment, soft-shell clams, and other species with planktonic early life histories (Fig. 3) that we have deployed annually since 2015 in the soft-bottom intertidal with numerous community partners (schools, municipal shellfish committees, local conservation groups, biologists with DMR, concerned citizens) from eastern to southern Maine. Results from a deployment of 120 passive collectors (i.e., recruitment boxes) in the Harraseeket River (Freeport, Maine) is described in Beal et al. (2018). Data generated from these efforts is critical in understanding how productive the intertidal ecosystem is in a particular area, especially when comparing results from the boxes to the unprotected, ambient sediments adjacent to the boxes. That is, comparison of clam densities from collectors vs. benthic cores taken from the ambient intertidal flat in the same location gives a realistic picture about site-specific clam predation rates.

We propose to learn about the nature of soft-shell clam recruitment variability (both spatially and temporally) by deploying boxes in three communities in each of three regions of the Maine coast (southwest, midcoast, downeast).

Within each community, and in coordination with the local shellfish program, we will choose two intertidal flats that are located 1-5 km apart, and place initially empty boxes on top of the mudflat surface prior to spawning (typically prior to mid-May; Ropes and Stickney, 1965; B. Beal, pers. obs.). Boxes will be placed in the mid-intertidal area, and are unlikely to conflict with clamming activities that are occurring in the cove or embayment, since most commercial clamming occurs at/near the upper intertidal zone (Beal et al., 2016). The boxes will remain anchored in place until November (well after spawning ceases) when they are removed from the flats. At that time, the contents of each box will be washed through a sieve with 1 mm screening.

To obtain information about clam recruits and larger individuals (as large as 85 mm) living in the unprotected (ambient) intertidal mud, 16 benthic cores (0.01824 m^2) will be taken in the same vicinity, but 2-5 m away, as the boxes on each flat in each community both at the time of deployment (May) and retrieval (November). Core samples taken in May will be used to establish site-specific baseline densities and size-frequency distribution of clams. Cores taken in November will be compared to the amount found in the protected recruitment boxes. This comparison is crucial because it will allow us to determine number of recruits that survive through the summer and early fall, and provide a realistic assessment of site-specific predation levels. In addition, both the May and November sets of core samples can be used by the local shellfish program as an accurate stock assessment of clams at the mid-intertidal of the cove.

We have examined specifically the potential unintended effects of the structure of the collector itself as well as the mesh netting in an experiment that examined clam recruitment in the boxes compared to recruitment in a variety of control units and from benthic cores (Fig. 4), so that we are confident that results from boxes represent effects due to the presence of predators and not potential physical effects (e.g., shading, water flow, temperature, sedimentation, pH, etc.) that can affect results and the interpretation of results (Posey et al., 2006; Alvarez et al., 2013).

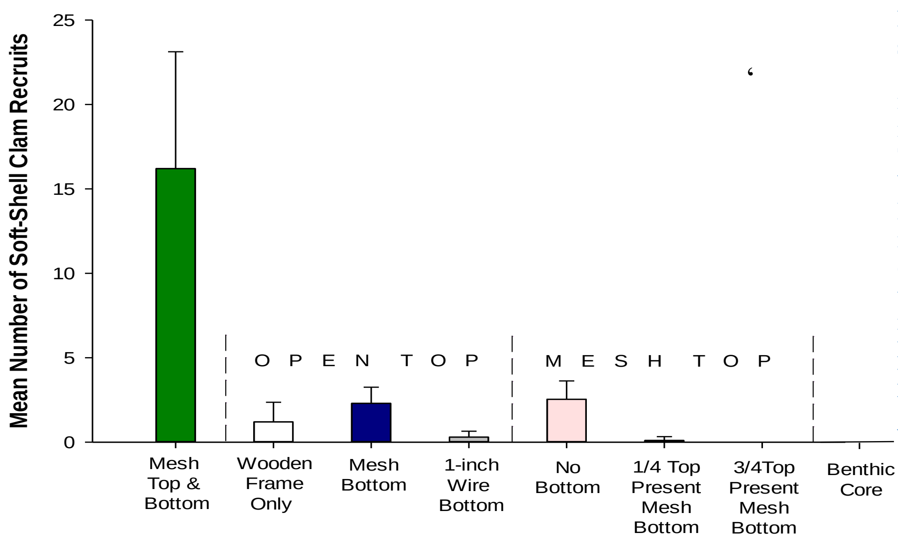

Figure 4: Mean number of the soft-shell clam recruits (+ 95% CI) in 1-ft x 2-ft x 3-inch deep recruitment boxes (Fig. 2). Mesh refers to Pet Screening. 'Mesh Top & Bottom' refers to a typical box, identical to what is proposed here. The remaining six treatments are various controls with open tops or mesh tops designed to permit either epibenthic and/or infaunal predators access. 29 May- 27 Oct. 2018 – Freeport, ME (n=10). In addition, 25 benthic cores were taken in the vicinity of the boxes in October.

The project will establish sites in nine coastal communities divided into three regions that are spread across the Maine coast (Fig. 5) so that a representative snapshot of spatial variability of soft-shell clam recruitment can be observed. DEI has carefully selected communities for the

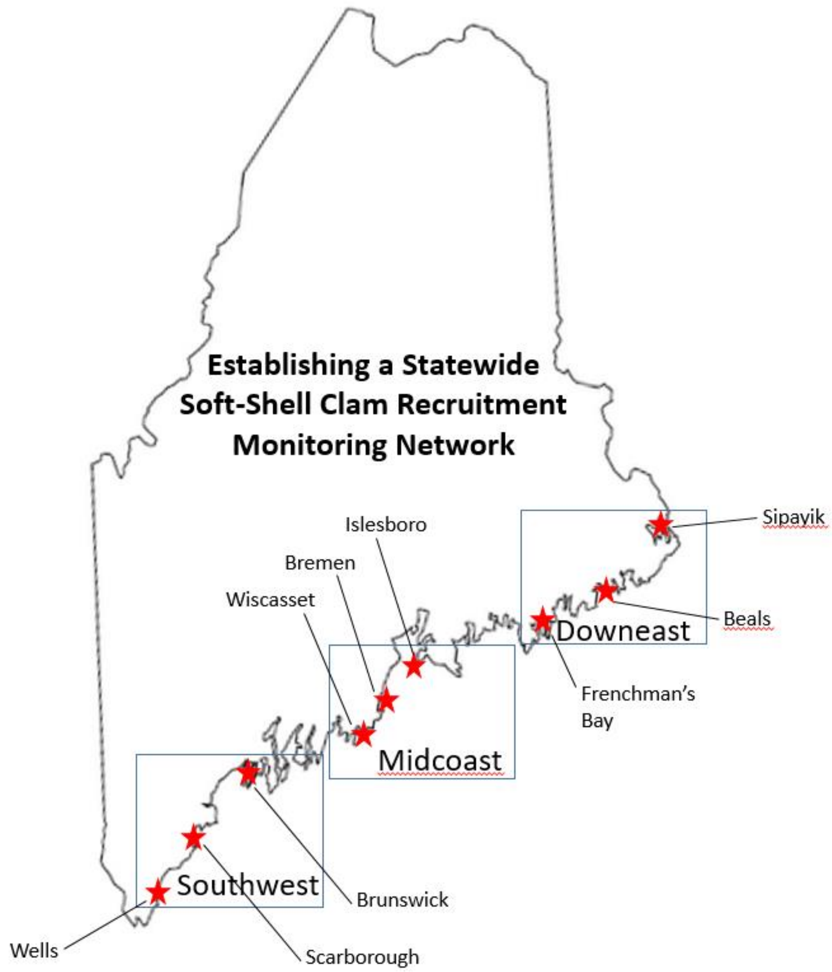

Figure 5: Map of Maine indicating the three geographic regions and nine coastal communities where the proposed soft-shell clam recruitment monitoring program would be established.

sampling sites with certain biological, ecological and social significance. For example. Sipayik's geographic characteristics make it a very desirable location for clam recruitment monitoring. It is the near the easternmost town in Maine and the US and is situated near the Canadian border. Its location on a peninsula in Passamaquoddy Bay means that tidal currents carrying clam larvae from Cobscook and Dennys Bays pass through this area. Fishing, including clamming is an important industry in this town that has 4,110 acres of intertidal habitat. The town of Beals is an island in another remote, highly-fisheries dependent town with 1,741 intertidal acres. DEI has been working to enhance K-12 science education with students from Jonesport and Beals for nearly a decade. Students have become very well versed in mudflat and intertidal biology and ecology, and would be a great assistance in collecting data from this area (see letter of recommendation from Beals Elementary School). The close proximity of the two Beals sites to

DEI improves accessibility to researchers (of all ages), which increases the likelihood that this sampling location will continue into the future. The remaining site in the downeast region, Frenchman's Bay, is a regional shellfish program encompassing the seven towns of Ellsworth, Franklin, Hancock, Sorrento, Sullivan, Trenton, and Lamoine. Recently, the clam stewardship committee has focused its efforts into collaboration across towns and shellfish sectors. The Frenchman's Bay shellfish program has over eight thousand acres under its jurisdiction. All the towns in the downeast region have unlimited commercial licenses available (i.e. no limited entry).

In the midcoast region, Islesboro is an island located in Penobscot Bay, a very important commercial fishing ground, and home to many fisheries-dependent communities. It has an unlimited amount of clammers and over 1,300 intertidal acres. The second town in that region, Bremen, is situated at the head of the very productive Medomak River. It has 45 clammers and over 1,000 acres where clams are commercially harvested. Wiscasset is situated on another important river and estuary, the Sheepscot. Wiscasset has 900 intertidal acres, 14 commercial clammers, and a public school that has worked previously with the PI on intertidal clam research (*Wiscasset Newspaper*, 2012).

In the southwestern region, the town of Brunswick is consistently one of Maine's top clamming ports, and last year (2018) clammers landed the second highest volume of clams in the state (over 524,000 lbs.). Their 2,250 intertidal acres supports 79 commercial license holders. In addition, the Brunswick Marine Resources Committee has established strong relationships with the local schools, and have a history of engaging students in intertidal projects. The second community, Scarborough, was the top clam-producing port in 2018, and, historically, also has been a top port for clam landings in the state. Scarborough has 48 commercial licenses, and about 1,000 intertidal acres. The third site, Wells, does not support commercial clamming, but it does have a shellfish management program with 106 recreational clammers. South of Biddeford, Maine no community sells commercial shellfish licenses; however we thought it important to sample in this geographic area so that our sampling sites spread most of the length of coast. DEI has conducted field experiments in Wells (Beal et al., 2018). Another benefit to the Wells site is that it is home to the Wells National Estuarine Research Reserve, which DEI will collaborate with (see letter of support).

Trials will occur in each of the nine communities in both 2020 and 2021 to observe temporal variability in clam recruitment. Recruitment boxes will be deployed each year during the second or third week of May (earliest in the southwest and latest in the downeast region) prior to the spawning season, which typically occurs after seawater temperatures have reached 10^oC (B. Beal, pers. obs.). To examine spatial variation within a community, two soft-bottom intertidal locations will be chosen based on conversations with the shellfish committee and clammers in each community. At each intertidal location, sixteen boxes will be deployed in eight blocks ($n = 2$) near the lower mid-intertidal. This tidal height was chosen based on two factors – first, recruitment appears to vary directly with tidal height – fewer recruits occur in upper intertidal areas with increasingly more towards the lower intertidal (Beal et al., 2018; Beal and Otto, 2019; B. Beal, pers. obs. in Islesboro and Thomaston, ME in 2019), and second, at most tidal flats, sediments become more muddy and harder to maneuver in at/near the low intertidal, so it will be easier for people who are not clammers to work in that area of the tidal flat. Boxes within a block will be separated by approximately 2 m. To examine within-location variability, blocks will be randomly placed at the same tidal height with 20-25 m spacing between adjacent blocks. This configuration allows examination of spatial variability at four different scales: regional, communities within a region, locations within a community, and blocks within a location (Table 1). The study will occur at the same locations each year so that temporal variability also can be examined. Because seawater temperature can affect recruitment both directly, including through a decrease in reproductive output (Philippart et al., 2003), and indirectly by changing predator-prey interactions (Freitas et al., 2007), we will deploy HOBO water temperature recorders at each of the 18 locations where recruitment boxes are established. This information will generate regional and location-specific trends in seasonal seawater temperatures, and will be used to examine potential correlations between temperature and recruitment rates (sensu Beukema and Dekker, 2014). Temperature recorders will be deployed in the spring at the same time as recruitment boxes. Data will be downloaded when boxes are sampled in the fall, and then re-deployed from November to the following March to record winter temperatures (Flach, 2003).

Table 1. Analysis of variance (ANOVA) will be used to examine mean number of soft-shell clam recruits at two intertidal locations within each of three communities in each of three coastal regions along the Maine coast (Fig. 5) over two years. All factors (regions, communities, locations, year) are considered fixed except blocks, which are considered random factors. The table shows the ANOVA skeleton and the expected mean squares based on the Cornfield-Tukey rules (Underwood, 1997). A_i = Region (a = 3), B_j = Year (b = 2), C_k = Community (c = 3), D_l = Location (d = 2), E_m = Block (e = 8), and n = 2.

Source of Variation	df	Expected Mean Square	F-ratio
Region	2	$\sigma^2_e + n\sigma^2_{BE(ACD)} + bcden\alpha_A$	$\div MS_{YxB(C,R,L)}$
Year	1	$\sigma^2_e + n\sigma^2_{BE(ACD)} + acden\alpha_B$	$\div MS_{YxB(C,R,L)}$
Region x Year	2	$\sigma^2_e + n\sigma^2_{BE(ACD)} + cden\alpha_{AB}$	$\div MS_{YxB(C,R,L)}$
Community(Region)	6	$\sigma^2_e + bn\sigma^2_{E(ACD)} + bden\alpha_{C(A)}$	$\div MS_{B(C,R,L)}$
Year x Community(Region)	6	$\sigma^2_e + n\sigma^2_{BE(ACD)} + den\alpha_{BC(A)}$	$\div MS_{YxB(C,R,L)}$
Location(Community, Region)	9	$\sigma^2_e + bn\sigma^2_{E(ACD)} + ben\alpha_{D(AC)}$	$\div MS_{B(C,R,L)}$
Year x Location (Community, Region, Location)	9	$\sigma^2_e + n\sigma^2_{BE(ACD)} + en\alpha_{BD(AC)}$	$\div MS_{YxB(C,R,L)}$
Block(Community, Region, Location)	126	$\sigma^2_e + bn\sigma^2_{E(ACD)}$	$\div MS_{error}$
Year x Block(Community, Region, Location)	126	$\sigma^2_e + n\sigma^2_{BE(ACD)}$	$\div MS_{error}$
Experimental Error	288		
Total	575		

In addition to counts and comparisons of clams both within the boxes and the adjacent cores, we will examine differences in clam size-frequency distributions within and between locations, communities, and regions using G-tests of independence (Sokal and Rohlf, 2012). This information will generate site-specific growth rates that local and state shellfish managers can use when making decisions about how long to extend conservation closures, when to harvest, and/or harvest rates.

d. Outreach

The goal of outreach is to effect change by having individuals, groups, or institutions use scientifically-based information when making decisions. Our effort includes working with a variety of groups within each of the nine communities. While we cannot ensure that all groups (clammers, shellfish committee members, DMR biologists, K-12 teachers and their students, local conservation organizations, etc.) will participate in each community, we have received enthusiastic support from the nine communities. Attached please find letters of support from the shellfish committees, DMR, schools, the Wells National Estuarine Research Reserve, and the Maine Clammers Association.

DEI is well-known within the state for its outreach and education programs. We have developed an approach to outreach that is inclusive and participatory (hands-on) in nature. For example, we worked with clammers, Town Council members, the Shellfish Conservation Commission, DMR biologists, and, to a limited extent, the middle school in the town of Freeport from 2013 to 2018 on a research project that was funded through both public (NOAA-SK, the University of Maine System, and the town of Freeport) and private philanthropic organizations (Sea Pact and Broad Reach Fund). That project examined potential factors that regulate the soft-shell clam fishery in that area (e.g., coastal acidification, predation, lack of competent settlers) in an effort to identify the cause of the soft-shell clam decline, as well as methods to adapt to a changing marine environment with the primary focus on fishery sustainability and enhancement. Each of the dozens of experimental field trials using predator-exclusion nets, fences, crushed shells, adult clams to encourage wild settlement of 0-year class juvenile clams, bloodworms as a bioremed-iator of native milky ribbon worms, etc. by design involved the fishing community. Many of these individuals helped to deploy and install gear, sample from the various experimental plots, and we processed the data together. This stakeholder-inclusive model is what we have in mind for this proposed project to establish a recruitment index for young-of-the-year soft-shell clams.

A major thrust of this effort will be to continue the process through time in as many communities as possible. Our hope is that the project not only will encourage the shellfish committees in each community to continue collecting data on soft-shell clam recruitment after the grant period, but that, working together with the local schools, this will become an annual event that provides opportunities for learning about an iconic fishery in Maine that could be replicated in other states that have an active recreational or commercial soft-shell clam fishery (e.g., each coastal state from New Hampshire to New Jersey). After this funding period, DEI is committed to search for additional funding to allow the program to continue, hopefully, indefinitely into the future. Our goal is for this effort to become a standardized network like the ALSI. Because we have observed a number of commercial bivalve species in the recruitment boxes (hard clams, *Mercenaria mercenaria*, American oysters, *Crassostrea virginica*, and razor clams, *Ensis leei*), especially those deployed in southern Maine, this technique and approach may be of interest to those wishing to examine dynamics of young-of-the-year bivalves in coastal states and communities throughout the U.S.

DEI will give presentations at scientific meetings and publications in peer-reviewed journals, and we understand that while Sea Grant considers these items important (and does encourage them), that these efforts are not considered outreach within the context of the Biennial Request for Proposals. Therefore, in addition, we intend to make results of the work available to the public within each community. We will compile the results from the sites across the states and print them in booklets for distribution to local shellfish committees and DMR.

In addition, location-specific presentations could be delivered by one of DEI's staff, or by clammers, K-12 students, and others who have participated in the project. As we have done in the past when working with local schools on field projects involving soft-shell clams, we will encourage K-12 teachers to have their students present results from their locations to the public at shellfish committee meetings or at other events, such as the annual *Maine Fishermen's Forum* that occurs at the beginning of March and that attracts fishermen and others interested in fisheries management to a 3-day event. For example, in each of the past two years, high school students from the towns of Searsport and Islesboro have presented information at the Forum about soft-shell clam recruitment from field studies they conducted with DEI and their shellfish committees. This public outreach and engagement creates not only a positive sense of place for students and community members, it also provides opportunities for STEM-related activities within the school and between the school, the community, and DEI. Outreach is a key ingredient in all facets of the proposed work, and we take very seriously our role in working together with community members and groups to effect decision-making based on the scientific information that all of us gather.

e. Educational impact

We plan to reach out to schools in each of the nine communities to invite them to participate. We have found that over the past decade more and more schools wish to incorporate hands-on activities into their curriculum, and this project is especially well-suited for a variety of learning levels. Typically, we contact one or two teachers, and explain the project to them. Once a school has committed to a project of this sort, one of us will go back and talk with those students who would be engaged about the life-history of the clam (we have a PowerPoint that demonstrates everything from spawning soft-shell clams and fertilization of eggs through the various planktonic phases and early settlement followed by growout to commercial sizes), as well as the particulars of the fieldwork. We have worked with teachers to develop curricula around particular projects, and DEI's Education Director, Colleen Haskell, has extensive experience in this field, and would be available as a resource to teachers along the coast.

PI-Beal is a professor of marine ecology at nearby University of Maine at Machias where he has taught courses in oceanography, marine biology, marine ecology, applied statistics, and experimental design and analysis for the past 34 years. Each fall, he teaches an undergraduate course (Marine Ecology – BIO 360) to juniors/seniors. During the fall of 2020 and 2021, students in that course will assist towns in the downeast region (Fig. 5) to remove recruitment boxes from the intertidal flats, help process samples, and count/measure recruits. These activities will become part of the regular coursework, and students will be required to produce a journal-quality manuscript of results from the three eastern communities. In addition, data from all nine communities will be analyzed (see Table 1) by undergraduates in his BIO/MAT 315 course (Experimental Design and Analysis for Biologists).

f. Literature Cited

Alvarez, M.F., Montemayer, D.I., Bazterrica, M.C., Addino, M., Fanjul, E., Iribarne, O., Botto, F. 2013. Interaction strength varies in relation to tidal gradient and spatial heterogeneity in an intertidal Southwest Atlantic estuarine food web. J. Exp. Mar. Biol. Ecol. 449:154-164.

Beal, B.F. 1988. Public aquaculture in downeast Maine: The soft-shell clam story. Proceedings of the Oceans '88 Conference, Baltimore, Maryland (31 October - 2 November 1988). pp. 980-983. doi: 10.1109/OCEANS.1988.794932. https://ieeexplore.ieee.org/document/794932.

Beal, B.F. 2006a. Relative importance of predation and intraspecific competition in regulating growth and survival of juveniles of the soft-shell clam, *Mya arenaria* L., at several spatial scales. J. Exp. Mar. Biol. Ecol. 336:1-17.

Beal, B.F. 2006b. Biotic and abiotic factors influencing growth and survival of wild and cultured individuals of the soft-shell clam (*Mya arenaria* L.) in eastern Maine. J. Shellfish Res. 25:461-474.

Beal, B.F., Coffin, C.R., Randall, S.F., Goodenow, C.A., Jr., Pepperman, K.E., Ellis, B.W., Jourdet, C.B., Protopopescu, G.C. 2018. Spatial variability in recruitment of an infaunal bivalve: experimental effects of predator exclusion on the softshell clam (*Mya arenaria* L.) along three tidal estuaries in southern Maine, USA. J. Shellfish Res. 37:1-27.

Beal, B.F., Kraus, M.G. 2002. Interactive effects of initial size, stocking density, and type of predator deterrent netting on survival and growth of cultured juveniles of the soft-shell clam, *Mya arenaria* L. in eastern Maine. Aquaculture 208:81-111.

Beal, B.F., Lithgow, C., Shaw, D., Renshaw, S., Ouellette, D. 1995. Overwintering hatchery-reared individuals of the soft-shell clam, *Mya arenaria* L.: a field test of site, clam size, and intraspecific density. Aquaculture 130:145-158.

Beal, B.F., Nault, D-M, Annis, H., Thayer, P., Leighton, H., Ellis, B. 2016. Comparative, large-scale field trials along the Maine coast to assess management options to enhance populations of the commercially-important soft-shell clam, *Mya arenaria* L. J. Shellfish Res. 35(4):1-17.

Beal, B.F., Otto, W. 2019. How acidic sediments and seawater affect interactive effects of predation on survival, growth, and recruitment of wild and cultured soft-shell clams, *Mya arenaria* L., along a tidal gradient at two intertidal sites in eastern Maine. Final Report to SEANET – Sustainable Ecological Aquaculture Network. 19 February 2019. 50 p. https://downeastinstitute.org/wp-content/uploads/2019/03/3_19_2019-final-report.pdf.

Beal, B.F., Parker, M.R., Vencile, K.W. 2001. Seasonal effects of intraspecific density and predator exclusion along a shore-level gradient on survival and growth of juveniles of the soft-shell clam, *Mya arenaria* L., in Maine, USA. J. Exp. Mar. Biol. Ecol. 264:133-169.

Beukema, J.J., Dekker, R. 2014. Variability in predator abundance links winter temperatures and bivalve recruitment: correlative evidence from long-term data in a tidal flat. Mar. Ecol. Prog. Ser. 513:1-15.

Fernandez, I. J., C. V. Schmitt, S.D. Birkel, E. Stancioff, A. J. Pershing, J. T. Kelley, J. A. Runge, G. L. Jacobson & P. A. Mayewski. 2015. Maine's climate future: 2015 update. Orono, ME: University of Maine. Retrieved from: https://digitalcommons.library.umaine.edu/cgi/viewcontent.cgi?article=1004&context=climate_facpub (accessed 20 May 2019).

Flach, E.C. 2003. The separate and combined effects of epibenthic predation and presence of macro-fauna on the recruitment success of bivalves in shallow soft-bottom areas on the Swedish west coast. J. Sea Res. 49:59-67.

Freitas, V., Campos, J., Fonds, M., Van der Veer, H.W. 2007. Potential impact of temperature change on epibenthic predator-bivalve prey interactions in temperate estuaries. J. Thermal Biol. 32:328-340.

Hunt, H.L., Wahle, R.A., Tremblay, J., Comeau, M., Sliva, A., Rochette, R. 2017. Spatial patterns of richness and abundance of benthic decapod crustaceans and fishes in the North-west Atlantic as measured by cobble-filled bio-collectors. Mar. Biol. Res. doi: 10.1080/17451000.2017.1296161. http://dx.doi.org/10.1080/17451000.2017.1296161.

McClenachan, L., O_Connor,G., Reynolds, T. 2015. Adaptive capacity of co-management systems in the face of environmental change: the softshell clam fishery and invasive green crabs in Maine. Mar. Policy 52:26–32.

McGreavy, B., Randall, S., Quiring, T., Hathaway, C., Hillyer, G. 2018. Enhancing adaptive capacities in coastal communities through engaged communication research: Insights from a statewide study of shellfish co-management. Ocean Coast. Manage. 163:240-253.

Pershing, A. J., Alexander, M. A., Hernandez, C. M., Kerr, L. A., Le Bris, A., Mills, K. E., Nye, J. A., Record, N. R., Scannell, H. A., Scott, J. D., Sherwood G. D. & A.C. Thomas. 2015. Slow adaptation in the face of rapid warming leads to collapse of the Gulf of Maine cod fishery. Science 350:809-812.

Philappart, C.J.M., van Aken, H.M., Beukema, J.J., Bos, O.G., Cadée, G.C., Dekker, R. 2003. Climate-related changes in recruitment of the bivalve *Macoma balthica*. Limnol. Oceanogr. 48:2171-2185.

Posey, M.H., Alphin, T.D., Cahoon, L. 2006. Benthic community responses to nutrient enrichment and predator exclusion: Influence of background nutrient concentrations and interactive effects. J. Exp. Mar. Biol. Ecol. 330:105-118.

Ropes, J.W., Stickney, A.P. 1965. Reproductive cycle of *Mya arenaria* in New England. Biol. Bull. 128:315-327.

Sokal, R.R., Rohlf, F.J. 2012. Biometry: The principles and practice of statistics in biological research. 4th edition. W.H. Freeman and Company. New York, NY.

Students head to clam flats. 2012. *Wiscasset Newspaper*. Retrieved from https://www.wiscassetnewspaper.com/article/students-head-clam-flats/5095.

Underwood, A.J. 1997. Experiments in Ecology: Their Logical Design and Interpretation Using Analysis of Variance. Cambridge University Press. Cambridge, UK.

Vassiliev, T., Fegley, S.R., Congleton, W.R. 2010. Regional differences in initial settlement and juvenile recruitment of *Mya arenaria* L. (soft-shell clam) in Maine. J. Shellfish Res. 29(2):337-346.

Wahle, R.A., Incze, L.S., Fogarty, M.J. 2004. First projections of American lobster fishery recruitment using a settlement index and variable growth. Bull. Mar. Sci. 74(1): 101-114.

Wahle Lab. 2019. American Lobster Settlement Index. University of Maine. https://umaine.edu/wahlelab/american-lobster-settlement-index-alsi/.