Municipal Shellfish Conservation Activity Summary

Tidal Bay Consulting, LLC

manomet

GPCOG
GREATER PORTLAND COUNCIL OF GOVERNMENTS

October 2021 | Rev 100621

Written by Madeline Tripp

Edited by Jessica Gribbon Joyce (Tidal Bay Consulting) and Marissa McMahan, PhD (Manomet)

Contributions by the Department of Marine Resources Bureau of Public Health and the Casco Bay Regional Shellfish Working Group Steering Committee

Cover photo by Madeline Tripp

Contents

Introduction

The clamming industry is a key part of Maine's culture, history, and economy, bringing in nearly $6.32 million in the Casco Bay region in 2020 and $18.31 million statewide.[1] However, the wild-harvest shellfish community is facing increasing pressure from the impacts of a changing climate, predation, and water quality. There are a number of strategies that municipal shellfish committees can use to address these challenges and manage their shellfish resources. Shellfish conservation activities cover a broad range of practices that address the unique concerns of a municipality. When selecting an activity, municipalities must consider their management goals, resources, volunteer support, and time constraints.

At the recommendation of the Casco Bay Regional Shellfish Working Group, this document summarizes the available information about conservation activities, with a focus on the two species co-managed by municipalities: soft-shell clams (*Mya arenaria*) and quahogs (*Mercenaria mercenaria*). It combines this with knowledge gathered from interviews with shellfish wardens and area biologists from the Maine Department of Marine Resources (DMR), and input from harvesters. Activities are grouped into the following sections: Stock Enhancement, Predator Mitigation, Pollution Source Identification, Data Collection, and Community Outreach. Each page includes information on the desired outcome, known effectiveness, timing and siting considerations, best practices, potential negative impacts, resources and equipment needed, number of volunteers, time investment, and permits needed for an activity. Most of these activities are ones that are currently being used in the Casco Bay region by municipalities, although many activities are also applicable statewide. Some activities include new techniques from recent studies that may be helpful.

This document is intended to be a tool for municipal shellfish committees to use when deciding which conservation activities will have the most beneficial impact on their shellfish management goals, while keeping in mind the constraints of their program. While the goals of any municipality likely include protecting or enhancing their wild soft-shell clam or quahog resources, different regions may also need to consider how varying levels of predation, pollution, or other challenges may affect the outcome of an activity. Some of the activities included in this overview may not have a direct biological impact on shellfish health, such as the activities in the Community Outreach section. However, these activities could increase public understanding and support of the shellfish industry and could serve to educate community members about the cultural and economic benefits of shellfishing, along with the ecosystem services that shellfish provide. Strengthening the connection between the shellfish community and the public may help municipalities address issues around intertidal access, conflicting uses, and the working waterfront.

Each municipality may find that certain activities work better on their flats than others, which is why it is important for towns to collect data before and after activities to measure the impact on their resources. This may include conducting a shellfish survey, sampling the sediment, or reviewing water quality data. Towns can then adjust activities based on this data and develop a management strategy that suits their needs. Any activity that involves putting materials out on the mudflats must also factor in time and volunteers to remove those materials at the end of the project to avoid debris. Time should also be allocated to secure any necessary permits for an activity.

This resource should serve as a starting place for municipal shellfish committees. Additional resources for each activity are included, but committees should consult with their DMR area biologist and other researchers, as applicable, for more details and assistance before undertaking a conservation project.

[1]Maine DMR, Commercial Landings Data (2020 data are preliminary): https://www.maine.gov/dmr/commercial-fishing/landings/index.html

Stock Enhancement / SEEDING

Species Benefitted	Soft-shell, Quahog
Description	Seeding typically involves purchasing cultured seed from a hatchery and distributing it in plots on the flat. This activity can be done in conjunction with predator netting to protect juvenile clams from predation while they are growing out. Purchased seed can also be overwintered to grow the juveniles out to a larger size before planting to increase the likelihood of survival.[1, 2]
Goal/Desired Outcome	Enhancement of formerly productive clam beds with juvenile clams to increase the harvestable population.
Known Effectiveness	The effectiveness of seeding with cultured clams has been documented by research by the Downeast Institute.[3, 4] Deploying netting on cultured clam seed can improve the survival rate from less than 10% to 70-80%.[3] To determine how successful seeding is, communities will need to conduct surveys before and after seeding activities.
Time and Siting Considerations	Clam survival can be maximized by planting in the spring (April-May) to allow the seed to grow out during the warmer season. Site selection is key to the success of seeding; juvenile clams have the highest survival rate in mid-intertidal heights in spots with warm waters, high salinity, high water flow, and algae and other microorganisms that clams feed on. Sites should also be monitored for predators such as green crabs, moon snails, and milky ribbon worms via trapping and surveys before seed is distributed.[1]
Techniques	Cultured seed can be purchased from a hatchery. In Maine, the Downeast Institute grows soft-shell and quahog seed, and Muscungous Bay Aquaculture offers quahog seed.[5, 6] It may be possible to import seed from out of state, but further requirements will apply under Maine DMR Chapter 24.[7] This would include obtaining a permit from DMR to import marine invertebrates.[8] Due to complexities of seeding and the permits needed, DMR should be consulted at every stage of a seeding activity. Seed can be grown out to a larger size to increase survival by using a floating upweller system (FLUPSY), a floating oyster bag, or a tidal upweller to overwinter seed purchased in the fall.[2] In the spring, seed can be dispersed onto the flat by hand. If using netting, the plot will need to be rectangular (typically 14 by 20 or 14 by 30 feet). Netting edges can be secured by digging a trench around the plot and burying the edge at least 6 inches beneath the sediment.[1] Nets should include up to nine 4 by 4 inch floats underneath to prevent sediment buildup and clam asphyxiation.[1, 9]
Potential Negative Impacts	If netting is used to protect dispersed seed and becomes loose or is not removed before winter ice, it can create debris.[1]

Resources/Equipment Needed	Time Input
Seed will need to be purchased, as well as any equipment needed if the seed will be grown out (floating bags, floating trays, or a tidal upweller). Costs for purchasing seed vary depending on the size; seed smaller than 1/4 inch will cost less initially but will need to be grown out, while seed from 1/4 to 1/2 inch can be planted directly.[1] According to a 2001 analysis, a million 1/4 to 1/2 inch seed can cost between $18,000-$25,000 and netting materials would cost between $1,411-$2,822.[9] Transportation for the seed and the volunteers will be needed, as well as buckets to carry seed, tools to cut netting, and zip ties to affix the floats.[1]	Seeding usually occurs during one low tide depending on volunteer availability and amount of seed. This activity will also require time beforehand to procure, transport, and prepare the seed and other materials.[1]
Permits Needed	**Volunteers Needed**
A Shellfish Transplant Permit Application should be submitted to DMR for each activity if a community is using seed under the 2 inch minimum size (the optimal planting size is 1/4 to 1/2 inches). If a community uses equipment (floating bags, floating trays, or a tidal upweller) to grow out seed in an area less than 400 square feet, then a Limited Purpose Aquaculture permit will be needed. Larger areas will need a Standard or Experimental Aquaculture permit. If a community is also installing predator netting, they must apply for a permit with the Army Corps of Engineers.[1, 10]	In order to distribute a million seed and deploy netting in one tide, at least twelve volunteers are typically needed.[1]

Stock Enhancement / TRANSPLANTING/RELAYING

Species Benefitted	Soft-shell, Quahog
Description	Transplanting is when wild seed clams are moved from one area of the flat to another to restock a once productive bed. While the effectiveness of seeding has been studied, there is little information on the impacts of reseeding transplanted clams. The techinques are similar, and seed can be grown out similarly to cultured seed.[1]
Goal/Desired Outcome	Enhancement of formerly productive clam beds with juvenile clams to increase the harvestable population.
Known Effectiveness	The effectiveness of transplanting wild juvenile clams has not been studied or documented as much as seeding cultured clams. Effectiveness will depend on the size of the seed and conditions of the site, including sediment type, temperature, tidal location, and the prevalence of predators such as milky ribbon worms and green crabs.[1] Netting could increase the survival rate, similar to cultured seed, but to determine how successful seeding is, communities will need to conduct surveys before and after transplanting activities.[3]
Time and Siting Considerations	Similar to cultured clams, wild transplants should be distributed in plots in the spring (April-May) to maximize survival. Site selection is key to the success of seeding; juvenile clams have the highest survival rate in mid-intertidal heights in spots with warm waters, high salinity, high water flow, and algae and other microorganisms that clams feed on. Sites should also be monitored for predators via trapping and surveying before seed is distributed.[1]
Techniques	Wild seed can be hand dug or caught by setting out recruitment boxes or astro-turf on the flats before a seeding event.[46] Planting seed from an area designated as Restricted by DMR's Shellfish Growing Area Program closes the receiving flat to harvesting for at least 60 days.[1] Setting out astro-turf on the flats to catch seed is a new technique that likely needs permitting from the Army Corps of Engineers.[1, 46]
Potential Negative Impacts	If netting is used to protect dispersed seed and becomes loose or is not removed before winter ice, it can create debris.[1]

Resources/Equipment Needed	Time Input
By transplanting wild seed, the cost of purchasing seed is avoided, but additional time and volunteers will be needed to dig and transport the clams. If applicable, netting materials would cost between $1,411 and $2,822.[9] Other materials needed include buckets to carry seed, tools to cut netting, and zip ties to affix the floats.[1]	Transplanting usually occurs during one low tide depending on volunteer availability and the amount of seed being planted. This activity will also require time beforehand to dig (usually during low tide), transport, store, and prepare the seed and other materials.[1]
Permits Needed	**Volunteers Needed**
A Shellfish Transplant Permit Application should be submitted to DMR for each activity if a community is using seed under the 2 inch minimum size (the optimal planting size is 1/4 to 1/2 inches).[44] If a community is also installing predator netting or using astro-turf to catch wild seed, they will likely need to apply for a permit with the Army Corps of Engineers.[2, 10]	In order to distribute a million seed and deploy netting in one tide, at least twelve volunteers are typically needed. Additional volunteers will be needed to dig the seed to be transplanted.[1]

Stock Enhancement / RECRUITMENT BOXES

Species Benefitted	Soft-shell, Quahog
Description	Clam seed is particularly vulnerable to predation due to its small size and fragility. Recuitment boxes are containers with solid sides and screen covering the open top and bottom of the container. These types of boxes are placed directly on the mudflat, and can be used to protect clam seed that settles within it from predation and to document the amount and size of seed settling in an area.
Goal/Desired Outcome	Catch and protect settling clam seed for growing out and studying seed recruitment patterns.
Known Effectiveness	Recruitment boxes have been shown to increase recruitment by as much as three times the typical recruitment rate of an unprotected mudflat. However, this method requires more active involvement over time.
Time and Siting Considerations	Clam seed usually settles on the mudflats any time from mid-May to mid-September. Recruitment boxes do not work as well on coarse or hard substrate because it tends to erode and expose the bottom of the flat. The boxes have been shown to recruit more seed when placed at lower tidal heights.[1]
Techniques	Recuitment boxes can be any wooden or plastic container with open sides. Usually, they are 1 foot by 3 feet and made of wood, with heavy duty screen attached on both ends. Some towns have also used plastic planter pots with screen covering openings on either end. These boxes are placed directly on the mudflat and secured, usually with 20 inch wooden lathes buried in the flat and then nailed to the box. If placed in a highly erosional evironment, the bottom screen should be replaced with a woven, UV-resistant polypropylene landscape fabric to prevent clam seed from slipping through the bottom screen.[9] Boxes cannot be used to grow out clam seed and cannot be left out an the flat indefinitely. At the end of the season, the clam seed should be removed for study and/or to be grown out with another technique.[1]
Potential Negative Impacts	If left on the flats too long, recruitment boxes could be damaged by ice and/or add to debris in the intertidal zone.

Resources/Equipment Needed	Time Input
Recruitment boxes can be made out of lumber or materials on hand (such as the plastic planters mentioned earlier). Heavy duty window screening is needed to cover the openings of the box, which can be found at many hardware stores. A method of securing the box is also needed, usually some type of lathe or dowel that can be buried 18 inches below the substrate and then attached to the recruitment box.[1, 9]	This activity requires time to build and install the boxes, as well as time to take the boxes up at the end of the season before the first frost.[1] Overall time investment depends on the type of box being contructed (wooden boxes will take longer than plastic planters), number and skillset of volunteers, and number of boxes being installed.
Permits Needed	**Volunteers Needed**
Towns need to have a general permit from the Army Corps of Engineers to put structures in the intertidal zone.[10]	If possible, volunteers with carpentry experience would be helpful to have. While the number of volunteers needed can be tailored based on the scale of the project, there needs to be volunteer commitment to deploy the boxes at the beginning of the season and take them up at the end of the season.

Stock Enhancement / SEASONAL CLOSURES

Species Benefitted	Soft-shell, Quahog
Description	Seasonal or conservation closures are when designated areas of harvestable flats are voluntarily closed to recreational and commercial harvesting by a municipality for a period of time. This management tool may be used to prevent overharvesting in a flat, to allow seeded clams to grow out to a legal size, or to rotate harvesting between several flats.[1]
Goal/Desired Outcome	Prevent overharvesting, allow juvenile clams (wild or cultured) to grow out to a harvestable size, and/or protect clams from being exposed to colder temperatures from winter harvesting.[1, 11]
Known Effectiveness	There is little research on the impact of conservation closures on soft-shell clams and quahogs, but flat rotation has been anecdotally successful in areas where predation is low. Some research suggests that conservation closures do little to address the damage of predation on shellfish populations.[12] Closures to allow shellfish to grow out are recommended after any seeding or transplanting activities. In a pilot study, seasonal closures during the winter have improved the survival of juvenile quahogs by limiting their exposure from digging during freezing temperatures.[11]
Time and Siting Considerations	Timing of the closure depends on the community's purpose, but flats are usually closed for a period of 6 to 12 months.[12] Flats with transplanted seed must be closed for 60 days after transplanting from a Restricted growing area. Some flats that do not ice over in the winter are closed to prevent winter digging.[1] A Conservation Closure form must be submitted to DMR at least 20 business days before the requested start date of the closure, and the municipality must advertise the closure at least 5 days beforehand.[13]
Techniques	Once the appropriate Conservation Closure form is submitted and approved by DMR, no further action is necessary. No forms are needed to reopen the area, as the end date is included in the request.[13] If municipalities want to measure the success of the activity, population surveys should be conducted prior to the closure and immediately before reopening.
Potential Negative Impacts	There are no known negative ecological impacts, but depending on the health of the flat and other flat closures, there may be an economic impact on harvesters.[1, 11]

Resources/Equipment Needed	Time Input
No equipment is needed.	A municipal staff or shellfish committee member will have to take time to fill out the one page form and submit it digitally or mail it to DMR.[13]
Permits Needed	**Volunteers Needed**
Towns must fill out a Conservation Closure form and submit it for approval by DMR.[13]	No volunteers needed.

Stock Enhancement / ROUGHING THE MUDFLATS

Species Benefitted	Soft-shell, Quahog
Description	Some communities use rakes to turn the sediment in their flats to increase oxygenation of the substrate and to increase roughness to encourage clam seed to settle in a certain area.
Goal/Desired Outcome	Increase oxygen in the sediment and rough up the surface of the mud to encourage clam recruitment.
Known Effectiveness	There is no known research on the effectiveness of roughing for increasing flat productivity or increasing oxygen levels, but anecdotal evidence suggests it could benefit oxygen levels in the sediment and clam spat recruitment. Soft-shell clams can be vulnerable to hypoxia, caused by a lack of oxygen in their tissues, while quahogs are relatively resilient in low-oxygen environments.[14]
Time and Siting Considerations	This activity can be done any time of year during low tide, as long as ice is not present. If the goal is increasing recruitment, it may be done in the spring before the spatfall.
Techniques	Volunteers can use clamming rakes to turn over the top few inches of the sediment.
Potential Negative Impacts	If the volunteers dig too deeply and expose any buried clams, this could increase clam vulnerability to predation or cold temperatures during the winter. [11, 15]

Resources/Equipment Needed	Time Input
Clamming rakes, gloves, and boots or waders.	The scale of this activity can be adjusted to fit volunteer availability. The area of flat that is turned or "roughed" can be as large or small as the group has time for.
Permits Needed	**Volunteers Needed**
Towns must indicate the activity on the Annual Shellfish Management Review form.	Any number of volunteers can participate.

Stock Enhancement / BRUSHING

Species Benefitted	Soft-shell, Quahog
Description	Brushing is a traditional recruitment strategy that involves putting boughs of spruce directly onto the mudflat to slow water currents and create eddies in order to recruit clam seed. Current research has not shown brushing to have a beneficial impact on recruitment because boughs can provide habitat to a soft-shell clam predator, the green crab.[16]
Goal/Desired Outcome	Increased recruitment of clam spat.
Known Effectiveness	Research conducted in Maine suggests that brushing does not have an impact on clam recruitment when compared with control sites. There are also data to support that the brush provides habitat for green crab recruits; more green crab recruits were observed in areas with brush as compared to control plots.[16] However, this activity has been traditionally used as a management technique and could foster a sense of stewardship and/or community among harvesters.
Time and Siting Considerations	Brush is usually put out on productive areas of the mudflat in May, before clam spat is dispersed, and is left out on the mudflat until the end of the season or never removed.[16]
Techniques	Boughs of spruce are cut, dragged out onto the mudflat, and placed in horizontal rows on the area of mudflat where recruitment is desired.[16]
Potential Negative Impacts	Areas of the mudflat that have brush have been observed to have higher numbers of green crab recruits. Brush may provide protective habitat for young green crabs and increase concentration of this predator near clam spat.[16]

Resources/Equipment Needed	Time Input
Spruce or pine boughs and a method to transport the boughs.[16]	Time input is minimal; it involves cutting the boughs, usually from a nearby area, and transporting them to the flat.[16]
Permits Needed	**Volunteers Needed**
Towns must indicate the activity on the Annual Shellfish Management Review form.	Depending on the scale of the project, this activity can take two or more volunteers.

Predator Mitigation / GREEN CRAB TRAPPING

Species Benefitted	Soft-shell
Description	Green crabs primarily feed on bivalves, like the soft-shell clam, which increases pressure on an already vulnerable population. The burrowing activities of green crabs can also cause erosion in ecologically important habitats, such as eelgrass beds. Consistent and targeted trapping can be a useful tool for monitoring and supressing invasive populations in low density areas, but practitioners need to consider timing, trap type, bait, temperature, and the lifecycle of the green crab to optimize the activity's impact.[1, 17, 18]
Goal/Desired Outcome	Assess size and distribution of green crab population near shellfish resources and supress population in low-density areas.
Known Effectiveness	With an intense, continuous, and consistent green crab trapping program, green crab populations may be managed or supressed but likely never eradicated. Without a continuous mitigation effort, green crab trapping may even increase green crab population levels due to the Hydra effect.[19, 20]
Time and Siting Considerations	Green crabs can survive in a wide range of temperature and salinity conditions (from nearly freshwater to high salinity). They can survive in a variety of habitat types with vegetated or non-vegetated substrates, including rocky or sandy shores, salt marshes, and lagoons. Juvenile green crabs can often be found in sheltered areas such as rockweed and eelgrass beds.[18] Green crabs are more likey to be caught during the warmer months due to higher activity, and are least active during the winter and while molting.[17]
Techniques	Depending on the amount of volunteers, time, and equipment available, green crabs can be caught by hand or using a variety of traps. Traps can be deployed for 1-3 days in any area where they will be submerged at low tide, with at least 10 meters of distance between traps. Typically, Atlantic herring is used to bait traps, but research supports that using Atlantic cod results in a higher catch per unit effort (CPUE). Short-fin squid is also associated with a higher CPUE.[18] Compost facilities that accept dead crabs are listed in the resources.[21]
Potential Negative Impacts	It is very unlikely to eradicate an invasive species once it is established. The ability of green crabs to adapt to a wide range of conditions, habitat types, and acceptable prey makes population control even more difficult. Trapping can be a useful data collection tool and population suppression strategy when done consistently, but sporadic trapping may actually cause population growth. A few studies support that trapping adult green crabs can increase the survival rate of juveniles by limiting adult cannibalism of juveniles.[19, 20]

Resources/Equipment Needed	Time Input
There are several types of traps that can be used to catch green crabs at different levels of development. Minnow traps can be used to catch juvenile crabs, while Fukui traps can target larger crabs. Research suggests that Fukui traps can be modified to increase CPUE by using sinker weights to increase the opening width of the trap.[22] The cylindrical Blanchard style trap has demonstrated high effectiveness, but is heavier and larger than the other traps. This style may be more suited to commercial crab trapping.[18] A list of green crab trap suppliers is available in the resources section.[45]	The scale of the activity can be adjusted depending on the amount of time volunteers are willing to commit by varying the amount of traps deployed. The amount of time needed includes baiting the traps, travel time to deploy the traps, travel time to locate and retrieve the traps, removal and documentation (if applicable), and disposal of the crabs.[1]
Permits Needed	**Volunteers Needed**
No permits are needed for individuals harvesting green crabs for personal use. Individuals harvesting green crabs for sale need to obtain a permit from Maine DMR. DMR issues Green Crab Exemption permits to municipalities that wish to conduct trapping or other green crab removal programs. This allows many individuals to participate under the umbrella of the municipality in green crab removal activities without obtaining green crab permits or submitting landings reports.[1]	The scale of trapping can be tailored for any number of volunteers.

Predator Mitigation / PREDATOR NETTING

Species Benefitted	Soft-shell
Description	Netting can be installed on areas of the flat that municipalities would like to protect from predators, such as the green crab. This technique can be used to protect newly settled clam spat, transplanted seed, or cultured seed. Netting has also been used to protect settling clam spat by creating eddies that slow water currents down.[1]
Goal/Desired Outcome	Protect juvenile clams from predation until they reach a mature size and potentially recruit wild clam spat.
Known Effectiveness	Several studies conducted by the Downeast Institute suggest that using netting to protect cultured, seeded clams from predation can be effective, depending on the location and site conditions .[12, 23, 24] Using netting to recruit wild clam spat is only effective some of the time. [1, 12] In one study, a finer netting resulted in a lower mortality rate from green crab predation.[23]
Time and Siting Considerations	Netting should be deployed at the same time as seeding or transplanting activities, which would normally be in the spring. If netting is intended to protect wild spat after it settles, then it should also be deployed in the spring before the natural spatfall.[1] When deploying materials on the mudflats, time will also need to be dedicated in the fall to remove the materials.
Techniques	Netting can be placed over plots of seeded or transplanted clams and secured by burying the edge 6 inches beneath the sediment. Plots are usually 14 by 20 feet or 14 by 30 feet, and should include up to nine 4 by 4 inch floats to prevent sediment buildup on top of the plot. The same technique can be used to provide a protected area for settling clam spat.[1]
Potential Negative Impacts	When using small-aperature netting, the smaller openings may contribute to less oxygen in the sediment and a slower growth rate for juvenile clams.[12] If not properly cared for or removed before winter, netting can contribute to marine debris.[23]

Resources/Equipment Needed	Time Input
Heavy duty, flexible netting is needed, as well as tools for cutting the netting.[12] Rakes can be useful to dig a trench around the placement area and bury the edge of the netting more easily.	The scale of the activity can be adjusted depending on the amount of volunteers and time that they are willing to commit. If this activity is in conjunction with seeding or transplanting, then it must be completed on the same day before high tide. When deploying materials on the mudflats, time will also need to be dedicated in the fall to remove the materials.[1]
Permits Needed	**Volunteers Needed**
A permit from the Army Corps of Engineers is needed to put out netting on the intertidal zone.[1, 10] A permit from DMR is also needed if undersized shellfish are seeded below the netting. See the section on seeding permits.	Netting activities can be tailored to the amount of volunteers available. However, if this is a part of a reseeding or transplanting activity, see those sections for volunteer needs.

Predator Mitigation / PREDATOR FENCING

Species Benefitted	Soft-shell
Description	Predator fencing is intended to serve a similar purpose to netting and protect juvenile clams from predation.[1] This involves erecting a frame, usually in a rectangle, and attaching flexible netting around the perimeter.[25]
Goal/Desired Outcome	Protect juvenile clams from predation until they reach a mature size.[1]
Known Effectiveness	An initial study in Freeport, ME, suggested that the survival rate of clams was no greater in fenced areas than in control plots. However, these studies were interrupted by a lack of structure maintenance and have not been published.[26]
Time and Siting Considerations	Predator fencing can be installed at any time from the spring through the fall.[26] There are no known studies on the impact of timing on effectiveness. When deploying materials on the mudflats, time will also need to be dedicated in the fall to remove the materials.
Techniques	A rectangular framing structure, usually made of wood, should be constructed to support plastic, flexible netting (4.2 mm aperature). Posts are driven into the flat, a cross beam is attached to the top, and then netting can be attached to the frame with zip ties or construction staples. This same technique can be applied to a linear fence across a cove. When the project is considered by the Army Corps of Engineers, there may be requirements for openings at certain intervals or other measures to minimize the structure's impact on intertidal hydrology.[25]
Potential Negative Impacts	Predator fencing must be maintained frequently (monthly or more) to prevent gaps in the netting, which can let green crabs in. It must also be maintained to prevent the structure from contributing to marine debris.[25]

Resources/Equipment Needed	Time Input
Lumber or another material for the frame is needed, as well as flexible netting and a fastener (zip ties or construction staples). Tools will be needed for digging in the posts and for screwing in the cross beam. One study used aluminum flashing at the top edge of the structure as another measure to prevent green crabs from entering.[25]	Depending on volunteer availability, the construction of the fencing could take a full day or more. Time should also be set aside on a monthly (or more frequent) basis to maintain the structure.[25]
Permits Needed	**Volunteers Needed**
Before construction begins, a permit application must be submitted to the Army Corps of Engineers.[1, 10]	Multiple volunteers with carpentry experience will be needed to transport the lumber out onto the flat and assemble the frame.[34]

Predator Mitigation / MOON SNAIL COLLAR COLLECTION

Species Benefitted	Soft-shell
Description	The northern moon snail (*Euspira heros)* and the banded moon snail (*Euspira triseriata*) are significant soft-shell clam predators that consume clams by drilling a hole in the shell and injecting digestive enzymes into the clam's tissue. One snail can consume an estimated 95 to 100 clams annually. Estimating snail populations in an area can be difficult because the snails bury themselves in the sediment and because they may migrate long distances in pursuit of clams. These snails have collar-shaped egg cases that can be removed before they hatch to control snail populations in an area.[1]
Goal/Desired Outcome	Mitigate the number of moon snails near productive shellfish beds.[1]
Known Effectiveness	There is little research that clearly demonstrates the effect of moon snail collar collection. However, this activity can help keep track of where moon snails may be feeding on clams since they reproduce near feeding areas. Young moon snails are planktonic, and adults migrate so frequently that collar removal may not prevent moon snail predation in an area.[1]
Time and Siting Considerations	Moon snails breed between April and September, so collar collection can only happen in these warmer months.[27]
Techniques	Volunteers can comb a flat for the sand collars during low tide. Collars may blend in since they are made of sand, but they are found on the surface of the sediment. Any collars that are collected should be disposed of.[1, 27]
Potential Negative Impacts	No known negative impacts.

Resources/Equipment Needed	Time Input
Buckets, gloves, and boots/waders may be needed for each volunteer.	Depending on the amount of volunteers and the area of flat to be covered, this activity could take an hour to the entire low tide cycle.
Permits Needed	**Volunteers Needed**
None.	Any number of volunteers can participate.

Predator Mitigation / MILKY RIBBON WORM CULLING

Species Benefitted	Soft-shell
Description	Milky ribbon worms (*Cerebratulus lacteus*) are another significant soft-shell clam predator. Some studies have shown that soft-shell clam mortality significantly increases as the presence of milky ribbon worms increases. The worms attack clams through the siphon and often leave no trace, so their impact can be difficult to measure. They can also vary their diameter, which increases their ability to bypass netting and other predator protection methods.[1, 28] Milky ribbon worm culling involves digging for and harvesting the worms, then either destroying them or using them for bait.
Goal/Desired Outcome	Mitigate the number of milky ribbon worms near productive shellfish beds.
Known Effectiveness	There is little research on harvesting or trapping milky ribbon worms. Clam-baited traps have been suggested as one way to avoid the breakage that may occur when digging for the worms, but more research needs to be done.[28]
Time and Siting Considerations	Culling milky ribbon worms can occur whenever clam harvesting is possible. There is not much research on when is the most effective time to cull.
Techniques	When harvesting milky ribbon worms, a rake can be used to dig out the worms. The entire worm must be removed gently to prevent breakage. The worms should be disposed of after harvesting.
Potential Negative Impacts	If milky ribbon worms are broken during culling, sections that are left behind may regenerate and create more worms. In order for culling to be effective, the entire worm must be removed.[28]

Resources/Equipment Needed	Time Input
A bucket, gloves, and boots/waders will be needed for each volunteer. A worm or clam rake may be used to dig the worms.	Time input is flexible and depends on the area that is culled and the amount of volunteers present.
Permits Needed	**Volunteers Needed**
None.	Any number of volunteers can participate.

Pollution Source Identification / DMR WATER QUALITY TESTING

Species Benefitted	All shellfish
Description	In accordance with the National Shellfish Sanitation Program (NSSP), Maine's Shellfish Growing Area Program must monitor and maintain certain water quality standards in areas where shellfish are harvested in order to minimize bacterial contamination and protect public health. Water quality monitoring is completed by the DMR's Public Health Program and trained volunteers at set sampling stations at least six times a year.[30] Additional pollution source identification can be beneficial to communities in order to address pollution sources and keep flats open to harvesting. Once pollution sources are identified, communities can take steps to reopen the flat.[29]
Goal/Desired Outcome	Routine testing for fecal coliform keeps Maine's public health program in compliance with the requirements of the NSSP and protects public health by preventing shellfish from being harvested from contaminated areas. These tests inform flat closures and indicate polluted areas that need remediation to be reopened to harvesting.[30]
Known Effectiveness	These routine tests performed by DMR are effective at identifying areas that are unsafe to harvest from, but further testing or investigation may be needed to find the pollution source.[30]
Time and Siting Considerations	This testing is organized by DMR and occurs six times per year at each designated station located within a shellfish growing area. Samples should be collected when there is at least 18 inches of water at the station, and must be kept cool until they can be transferred to the designated drop off location.[30]
Techniques	Sampling stations are grouped into random "runs" of 30 stations for volunteers to sample in a single trip. Water samples are taken for fecal coliform tests at each site, as well as temperature, salinity, GPS coordinates, and observations of the conditions. Water samples must be kept between 0-10 degrees Celsius until they can be dropped off at the designated drop off area and are tested within 30 hours.[30]
Potential Negative Impacts	No known negative impacts.

Resources/Equipment Needed	Time Input
All testing materials (cooler, thermometers, etc.) are provided by DMR for quality assurance measures, but volunteers should have transportation (vehicle or boat), above the knee boots, a first aid kit, a clock, and sampling sheets for each sample.[30]	A single run of 30 stations should be completed in a day, but the timing of that run will depend on weather and tide conditions.[30]
Permits Needed	**Volunteers Needed**
None, but volunteers must coordinate with DMR in order to have the samples processed.	Volunteers are needed who have completed the online application, reviewed the online powerpoint, and have received site certification by a DMR staff member. Usually at least 1-2 volunteers are needed to complete a sampling run. Shellfish license holders who are new to sampling will have to sample with a non-license holding volunteer for at least a year before they are able to sample alone.[31]

Pollution Source Identification / MICROBIAL SOURCE TRACKING

Species Benefitted	All shellfish
Description	Microbial source tracking (MST) can be used to identify whether the source of fecal coliform bacteria in a water sample is human, livestock, wildlife, or pets.[32, 35] This knowledge can aid municipalities in finding and addressing pollution sources, while minimizing the amount of testing needed to improve water quality management.[33]
Goal/Desired Outcome	This testing technique may help identify the source of pollution and give communities the data they need to remediate contaminated flats so that they can be reopened to harvest.[34]
Known Effectiveness	If proper procedures are observed, this pollution source identification technique can be an effective tool to help communities manage their water quality.[34]
Time and Siting Considerations	Samples should be kept stable between 0-10 degrees Celsius.[30] Volunteers should be aware of weather patterns and whether samples are collected during the wet or dry season, as this may impact the runoff from different sources of bacteria. If there are known or suspected pollution sources, samples should be collected upstream and downstream of each potential source.[36]
Techniques	Samples should be collected similarly to samples for the DMR water quality monitoring, and be marked with time, date, temperature, and sampling location. MST can use a molecular (DNA fingerprinting) or non-molecular (chemical) method to identify the source of bacteria. The molecular method compares genetic material in the sample to a library of know bacteria associated with different common species or groups. The non-molecular method identifies certain compounds that are associated with certain species or groups.[33]
Potential Negative Impacts	MST can be expensive, but there are no known negative impacts.[33]

Resources/Equipment Needed	Time Input
MST sample collection requires a cooler, sampling bags, a calibrated thermometer, a GPS unit for location tracking, sampling sheets, transportation, and any other safety gear needed for the data collectors. The cost of MST varies widely since it is a relatively new testing method, but the testing of each isolate (multiple can be extracted from each sample) ranges from $25-100 for molecular methods and $10-30 for non-molecular methods. There is little guidance on how many samples should be taken.[33]	Sampling time can vary depending on the number and distance between samples taken, from a few hours to a whole day. The samples must also be transported to the nearest MST capable facility. The Jackson Estuarine Lab at the University of New Hampshire is the nearest facility.[35] Contact Stephen Jones for more information at Stephen.Jones@unh.edu or (603) 862-5124.[37]
Permits Needed	**Volunteers Needed**
None.	One to two municipal staff or trained volunteers could take samples, as long as proper procedures are followed to keep the samples stable. The DMR water quality sampling method could be used as a framework.

Pollution Source Identification / FLUOROMETERS

Species Benefitted	All shellfish
Description	Fluorometers can be used to identify areas where septic systems have failed and may be leaching into the environment. Laundry detergents may conatin optical brighteners that can be detected by fluorometers, either with an onsite device or by collecting samples for testing with a lab-based fluorometer.[38]
Goal/Desired Outcome	This testing may help identify whether failing septic systems are contributing to fecal coliform bacteria levels in a flat, which can help communities address the source of pollution and remediate a contaminated flat.[38]
Known Effectiveness	If proper procedures are observed, this pollution source identification technique can be an effective tool to help communities manage their water quality.[38] More research needs to be done on the interference of dissolved organic matter in detecting optical brighteners. Organic matter in the water can hinder the ability of the fluorometer to pick up on optical brighteners, which could impact the effectiveness of this method as a tool for detecting failing septic systems.
Time and Siting Considerations	Water samples should be kept between 0-10 degrees Celsius and should be tested within 8 days of collection. Samples can be collected near areas where pollution is suspected, but time, date, temperature, and sampling location should be recorded. It may be beneficial to take samples over a time period of a few months.[38, 39]
Techniques	Water samples can be collected similarly to DMR water quality monitoring, and be marked with time, date, temperature, sampling location, and tidal conditions. Samples can be tested using a fluorometer, usually in a lab environment. The procedure may be adapted to the field. Detection is nearly instantaneous, the equipment used can be moderately expensive, no formal training is needed, and large numbers of samples can be analyzed in a short period of time.[38, 39]
Potential Negative Impacts	No known negative impacts.

Resources/Equipment Needed	Time Input
In addition to the water quality sampling gear listed in the previous testing methods, a fluorometer and a UV light are needed to perform analysis of the samples. A laundry detergent containing optical brighteners will be needed to calibrate the fluorometer. [39] Fluorometers typically range from $2,000-$18,000.[40]	Sampling time can vary depending on the number and distance between samples taken, from a few hours to a whole day. Using the fluorometer to test samples can take one to two hours.[39]
Permits Needed	**Volunteers Needed**
None.	One to two municipal staff or volunteers could take samples, and anyone could test the samples using the fluorometer, as long as proper procedures are followed.[38, 39]

Pollution Source Identification / WATER QUALITY SONDES

Species Benefitted	All shellfish
Description	Water quality monitoring sondes can help monitor certain water quality parameters in the field. Depending on the instrument, a sonde could measure: temperature, dissolved oxygen, turbidity, depth, pH, conductivity, and/or oxidation reduction potential. This can help communities monitor the health of their flats and could help collect additional data when performing other sampling methods.[42]
Goal/Desired Outcome	This testing can help monitor general water quality parameters that are important to understanding the health of the flat, and can help streamline other water quality sampling procedures by collecting background data quickly.[42]
Known Effectiveness	If proper procedures are observed, this can be an effective tool to help communities manage their water quality.[42]
Time and Siting Considerations	Water quality testing with a sonde can be performed anywhere there is moving water and at any time. Data can be collected and recorded on site.[42]
Techniques	The sonde is deployed into the water according to the device's instructions. The handheld device may log data or data may need to be recorded as needed.[42]
Potential Negative Impacts	No known negative impacts.

Resources/Equipment Needed	Time Input
Water quality sondes can be purchased at a wide range of prices.[42] Data sheets for recording location and data collected by the sonde may be needed, along with transportation and any safety equipment needed for volunteers.	Sampling time can vary depending on the number and distance between samples taken. The sonde can take readings in a matter of seconds or minutes.[42]
Permits Needed	**Volunteers Needed**
None.	It only takes one person to operate a water quality sonde.

Data Collection / SHELLFISH SURVEY

Species Benefitted	Soft-shell, Quahog
Description	Shellfish surveys provide a snapshot of the density and distribution of legally harvestable clams, or the "standing crop" in the area surveyed. It can provide data to inform management decisions, such as license allocations, and can indicate the health of a flat.[41]
Goal/Desired Outcome	Provides general data on the volume of harvestable clams in a flat to better inform management decisions.[41]
Known Effectiveness	If proper procedures are observed, shellfish surveying is effective at providing a snapshot of data on clam populations. Survey data collected over time can provide insight into long-term trends related to clam populations.[41]
Time and Siting Considerations	Surveys are generally conducted in the warmer months, and must be scheduled to follow the tide by either following the tide out or starting at low tide and working towards shore.[41]
Techniques	The plot distance should be determined based off of the size of the mudflat to be sampled (either 50 or 100 feet). Stakes and an appropriate-length rope can be used to measure the distance from each plot. At each plot, use a survey box to measure an area of 2 square feet. The designated digger(s) should remove all the clams possible from the area and the recorder should measure the clams and tally them by size using the shellfish survey data sheet from DMR.[41, 43] GPS location data and photographs may also be collected for each plot.[41]
Potential Negative Impacts	Shellfish should be handled gently so they are not damaged. After data collection, the clams should be reburied.

Resources/Equipment Needed	Time Input
Materials needed include: a map of the survey area, clipboard, pencils, data sheets, clam hoe, survey box, ruler, 50 ft. or 100 ft. rope, GPS (optional), compass (optional), camera (optional), and plot stakes or markers (optional).[41]	Depending on the survey area, it could take anywhere from one to four hours (which may be restricted by tide times).[41]
Permits Needed	**Volunteers Needed**
Notification should be provided to DMR on the Annual Review. Towns must have written authorization from the DMR Commissioner when surveying areas closed by DMR.[41]	Two or more volunteers trained in the DMR's survey methods are needed. At least one person should be the clam digger, and at least one person should record the data on the data sheet.[41]

Community Outreach / SHORELINE CLEANUP

Species Benefitted	All shellfish
Description	Shoreline cleanups involve removing debris along the shoreline that may wash into the intertidal zone. It addresses plastic pollution caused by littering, fishing gear, and other trash that may interfere with the health of the mudflat.
Goal/Desired Outcome	Keeps the intertidal zone clean and free from litter for all users, including harvesters and other community members.
Known Effectiveness	This activity has general benefits for the ecosystem by addressing litter and plastic pollution. It also may benefit the sense of community between harvesters and the general public by fostering the stewardship of a shared resource (the intertidal zone).
Time and Siting Considerations	Shoreline cleanups should occur in the warmer months when there is no snow or ice covering the shoreline and obscuring trash.
Techniques	Depending on the amount of volunteers and time, the cleanup can cover varying amounts of the shoreline. Volunteers can carry trashbags to remove litter and work together to remove larger pieces of trash (tires, etc.) as necessary. It may work best for the group to spread out and work systematically over the designated area. Trash should be removed to the local landfill immediately after the cleanup.
Potential Negative Impacts	No known negative impacts.

Resources/Equipment Needed	Time Input
Materials needed include: trash bags, trash sticks, protective gloves, and a method to transport trash to the landfill.	Depending on the area covered and the amount of volunteers, this activity can take anywhere from 30 minutes to all day.
Permits Needed	**Volunteers Needed**
None.	Any number of volunteers can participate.

Community Outreach / MUDFLAT FIELD TRIP

Species Benefitted	N/A
Description	Field trips to the mudflat are intended to education community members about the intertidal zone and the wild-harvest shellfish community. These trips can be organized for the general community or for school-aged children, and can include a tour of the mudflat, harvesting demonstrations, wildlife identification, and many other educational activities.
Goal/Desired Outcome	Educates the general public or school children about the ecological, cultural, and economic importance of the intertidal zone in their community, and fosters a sense of shared interest in the health of the mudflats.
Known Effectiveness	This activity has the potential to have community benefits by fostering a better understanding of working waterfronts and the importance of the intertidal zone among the participants.
Time and Siting Considerations	Field trips can take place any time of year, but may be safest and most enjoyable during the warmer months, when there is less danger of participants getting too cold or slipping on ice. Trips should be organized to areas with easy access from the shore and plenty of parking.
Techniques	This activity can be adapted to the needs, interests, and resources available to a community. Harvesters could demonstrate digging techniques, a local biologist or ecologist could talk about wildlife, or the shellfish committee could talk about conservation efforts by the town. If these trips are with school children, then the content and timing will need to be coordinated with the school and teachers.
Potential Negative Impacts	No known negative impacts.

Resources/Equipment Needed	Time Input
Participants should be asked to bring their own boots and/or waders, but extras should be on hand. Equipment will be needed for a shellfish harvesting demonstration and for any other activities.	This activity requires time to plan the itinerary, coordinate with schools or recruit participants, and recruit demonstrators/speakers. On the day of, time will be needed to transport participants to the site, set up for any activities, and clean up afterwards.
Permits Needed	**Volunteers Needed**
None. If shellfish harvesters hold a demonstration, then they will need to have licenses.	Any number of volunteers can participate.

Community Outreach / EDUCATIONAL CAMP

Species Benefitted	N/A
Description	Educational day camps can be organized for any age group, and can include a wide variety of activities based on the resources of the town and the talents of the volunteers. These camps can include a harvesting demonstration, educational talks by local scientists, harvesters, wardens, and/or harbormasters, shoreline cleanups, or clam-themed games and crafts.
Goal/Desired Outcome	Educates school children about the importance of clams, the intertidal ecosystem, and the working waterfront, and teaches them how to be good stewards of their community's resources.
Known Effectiveness	This activity has the potential to have community benefits by fostering a better understanding of working waterfronts and the importance of the intertidal zone among the participants.
Time and Siting Considerations	A children's camp will need to be during the summer months when school is out. Depending on the activities that are planned, there will need to be a sheltered area or indoor space to take breaks from the heat and/or do any planned indoor activities. If activities are planned out on the mudflats, then there will need to be transportation to the access point.
Techniques	This activity can be adapted to the needs, interests, and resources available to a community. Harvesters could demonstrate digging techniques, a local biologist or ecologist could talk about wildlife, or the shellfish committee could talk about conservation efforts by the town. There should be interactive activities for the children to engage with, such as crafts or games. Topics will need to be age-appropriate and tailored to the grade level of the children participating.
Potential Negative Impacts	No known negative impacts.

Resources/Equipment Needed	Time Input
Equipment will vary depending on the activities planned. If there are activities on the mudflat, participants should be asked to bring their own boots and/or waders, but extras should be on hand.	This activity requires time to plan the schedule, recruit participants and volunteers to supervise, and recruit demonstrators/speakers. Camps can last from a couple days to a full week, depending on volunteer availablility and interest. On camp days, time will be needed to set up for any activities and clean up afterwards.
Permits Needed	**Volunteers Needed**
None. If shellfish harvesters hold a demonstration, then they will need to have licenses.	Volunteers are needed to supervise the children (depending on age and the number of participants), to hold the demonstrations, and to organize the activities.

Community Outreach / HARVESTER Q & A

Species Benefitted	N/A
Description	A community question and answer session can be held with a panel of harvesters, the warden, and/or shellfish committee members to help educate the public on wild-harvest shellfish co-management and working waterfronts.
Goal/Desired Outcome	Educates the general public, including members of the town council/board of selectmen, about the ecological, cultural, and economic importance of the intertidal zone in their community, and fosters a sense of shared interest in the health of the mudflats. Provides space for community members to ask questions about the working waterfront and better understand the role shellfish harvesters play in their community.
Known Effectiveness	This activity has the potential to have community benefits by fostering a better understanding of working waterfronts and the importance of the intertidal zone among the participants.
Time and Siting Considerations	This event can happen any time of year, virtually or in-person. Scheduling should take into account the tides, if the event includes harvesters, as well as work schedules of the target audience. If the event is in-person, it should be held at an accessible, well-known location, such as the town hall, a park, or a local restaurant.
Techniques	This activity can be adapted to the needs, interests, and resources available to a community. Harvesters could speak individually or sit on a panel and take questions from the audience. Questions should be prepared ahead of time in case there is low participation from the audience.
Potential Negative Impacts	No known negative impacts.

Resources/Equipment Needed	Time Input
Depending on the size of the audience and the space, sound equipment may be needed. Seating will be needed for the speakers and the crowd.	This activity requires time to plan the itinerary, recruit speakers, and advertise the event several weeks beforehand. On the day of, time will be needed to set up and break down event materials.
Permits Needed	**Volunteers Needed**
None.	Speakers and event organizers will be needed, as well as volunteers to set up and break down the event.

References

1. *The Maine Shellfish Handbook.* (2020). Maine Sea Grant, the Maine Department of Marine Resources, University of Maine. https://seagrant.umaine.edu/wp-content/uploads/sites/467/2021/03/MaineShellfishHandbook_031021.pdf

2. McConkey, A.-J., & Linds, R. (2006). Seeding Soft-Shell Clam (Mya arenaria L.) Spat along the Eastern Shore, Nova Scotia. In L. D. Hiemstra (Ed.), *Aquaculture Canada* (Vol. 23, pp. 49–52). Aquaculture Association of Canada. http://aquacultureassociation.ca/wp-content/uploads/bsk-pdf-manager/2017/01/Aquaculture-Canada-2006-Proceedings-of-Contributed-Papers.pdf#page=50

3. Brian F. Beal, Chad R. Coffin, Sara F. Randall, Clint A. Goodenow, Kyle E. Pepperman, Bennett W. Ellis, Cody B. Jourdet, & George C. Protopopescu. (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. *Journal of Shellfish Research*, *37*(1), 1–27. https://doi.org/10.2983/035.037.0101

4. Beal, B. F. (2006). Biotic and abiotic factors influencing growth and survival of wild and cultured individuals of the softshell clam (Mya arenaria L.) in Eastern Maine. *Journal of Shellfish Research*, *25*(2), 461–474. https://doi.org/10.2983/0730-8000(2006)25[461:BAAFIG]2.0.CO;2

5. *Hatchery for Shellfish Production & Research.* (n.d.). Downeast Institute. Retrieved September 7, 2021, from https://downeastinstitute.org/hatchery/

6. *Muscongus Bay Shellfish Hatchery.* (n.d.). Muscongus Bay Aquaculture, Inc. Retrieved September 7, 2021, from http://muscongusbay.com/oyster-and-shellfish-seed-hatchery

7. Department of Marine Resources Regulations (13 188), Chapter 24: Importation of live marine organisms, 29. https://www.maine.gov/dmr/laws-regulations/regulations/documents/Chapter24_08102021.pdf

8. *Application for The Importation or Introduction of Marine Invertebrates and Algae.* (2016). Maine Department of Marine Resources. https://www.maine.gov/dmr/aquaculture/forms/documents/marineorganismpermitapplication2016.pdf

9. Beal, B. F., & Gayle Kraus, M. (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(1), 81–111. https://doi.org/10.1016/S0044-8486(01)00900-0

10. *U.S. Army Corps of Engineers General Permit.* (n.d.). U.S. Army Corps of Engineers. Retrieved September 7, 2021, from https://www.usace.army.mil/missions/civil-works/Regulatory-Program-and-permits/Obtain-a-Permit/

11. Wilkerson, E., Joyce, J. G., & Tetreau, C. (2020). *Exploring the effects of winter harvesting closures for Northern Quahogs (Mercenaria mercenaria) in Freeport* (p. 18). https://static1.squarespace.com/static/58b5a5a7cd0f6887943919df/t/5f7e19cdfe14454b9f35f0cd/1602099665070/Final_Report_Freeport+Quahog+Study_090420_v3.pdf

12. Brian F. Beal, Denis-Marc Nault, Hannah Annis, Pete Thayer, Heidi Leighton, & Bennett Ellis. (2016). Comparative, Large-Scale Field Trials Along the Maine Coast to Assess Management Options to Enhance Populations of the Commercially Important Softshell Clam, Mya arenaria L. *Journal of Shellfish Research, 35*(4), 711–727. https://doi.org/10.2983/035.035.0401

13. *Request for conservation closures form.* (2019). Maine Department of Marine Resources. https://www.maine.gov/dmr/shellfish-sanitation-management/programs/municipal/forms/documents/ConservationClosureNew8-29-193pages.pdf

14. Altieri, A. H. (2008). Dead zones enhance key fisheries species by providing predation refuge. *Ecology,* 89(10), 2808–2818. https://doi.org/10.1890/07-0994.1

15. Emerson, C. W., Grant, J., & Rowell, T. W. (1990). Indirect effects of clam digging on the viability of soft-shell clams, Mya arenaria L. *Netherlands Journal of Sea Research, 27*(1), 109–118. https://doi.org/10.1016/0077-7579(90)90039-J

16. Brian F. Beal, Sara F. Randall, & Kyle E. Pepperman. (2020). Comparative Field Trials to Examine the Efficacy of a Traditional Management Tool—Brushing—To Enhance Local Densities of 0-Y Class Recruits in the Soft Shell Clam Mya arenaria L. Fishery in Maine, USA. *Journal of Shellfish Research*, 39(3), 519–533. https://doi.org/10.2983/035.039.0303

17. Barry, P., Browning, M., Bryson, A., Fuchs, H., & Maipi, E. (2020). European Green Crab Mitigation in Whatcom County. *WWU Honors Program Senior Projects*, 19.

18. Butt, M. A. (2017). *Bait Selection Study of the Invasive European Green Crab (Carcinus maenas) in Newfoundland, Canada.* [University Centre of the Westfjords]. http://hdl.handle.net/1946/28681

19. Grosholz, E., Ashton, G., Bradley, M., Brown, C., Ceballos-Osuna, L., Chang, A., de Rivera, C., Gonzalez, J., Heineke, M., Marraffini, M., McCann, L., Pollard, E., Pritchard, I., Ruiz, G., Turner, B., & Tepolt, C. (2021). Stage-specific overcompensation, the hydra effect, and the failure to eradicate an invasive predator. *Proceedings of the National Academy of Sciences*, 118(12), e2003955118. https://doi.org/10.1073/pnas.2003955118

20. Green, S. J., & Grosholz, E. D. (2021). Functional eradication as a framework for invasive species control. *Frontiers in Ecology and the Environment*, 19(2), 98–107. https://doi.org/10.1002/fee.2277

21. *Green Crab Composting Facilities and Potential Buyers/Receivers.* (2014). Maine Department of Marine Resources. https://www.maine.gov/dmr/science-research/species/invasives/greencrabs/documents/compostingfacilities.pdf

22. Bergshoeff, J. A., McKenzie, C. H., Best, K., Zargarpour, N., & Favaro, B. (2018). Using underwater video to evaluate the performance of the Fukui trap as a mitigation tool for the invasive European green crab (Carcinus maenas) in Newfoundland, Canada. *PeerJ*, 6, e4223. https://doi.org/10.7717/peerj.4223

23. Munroe, D., Kraeuter, J., Beal, B., Chew, K., Luckenbach, M., & Peterson, C. P. (2015). Clam predator protection is effective and necessary for food production. *Marine Pollution Bulletin*, 100(1), 47–52. https://doi.org/10.1016/j.marpolbul.2015.09.042

24. Beal, B. F. (2015). *Clam Studies in the Fore and Webhannet River* (p. 51). University of Southern Maine Digital Commons. https://digitalcommons.usm.maine.edu/cbep-publications/194?utm_source=digitalcommons.usm.maine.edu%2Fcbep-publications%2F194&utm_medium=PDF&utm_campaign=PDFCoverPages

25. Beal, B. F. (2014). *Green Crab, Carcinus maenas, Trapping Studies in the Harraseeket River, and Manipulative Field Trials to Determine Effects of Green Crabs on the Fate and Growth of Wild and Cultured Individuals of Soft-Shell Clams, Mya arenaria* [Final report]. Downeast Institute for Applied Marine Research & Education. https://downeastinstitute.org/wp-content/uploads/2018/08/1_24-final-report-freeport-shellfish-restoration-project-b.-beal.pdf

26. *2014 Field Studies: Investigating the Cause of the Clam Decline.* (2020, August 17). Downeast Institute. https://downeastinstitute.org/the-cause-of-the-clam-decline/2014-investigating-clam-decline-freeport-maine-field-studies/

27. Tim, S. (2010, June 3). Moon Snails. *Tidepool Tim's Marine Life Blog*. https://tidepooltim.blogspot.com/search

28. Carter, J., & Moon, N. (2020). *Milky Ribbon Worm (Cerebratulus lacteus) Predation and Mitigation: A Review* (Anne Hayden, K. Kanwit, & A. Leach, Eds.). Casco Bay Regional Shellfish Working Group. https://static1.squarespace.com/static/6026cbaf8dfa6838a1b67b5e/t/602d912723d0e40d3cd9d8d8/1613599016981/MRW-Guidance-072820.pdf

29. Hillyer, G., & McGreavy, B. (2020). *Water Quality Decision Tree*. Maine Shellfish Learning Network. https://themudflat.org/water-quality-decision-support/

30. *Water Quality Monitoring Volunteer Guidance Document.* (2019). Maine Department of Marine Resources. https://www.maine.gov/dmr/shellfish-sanitation-management/forms/documents/WQ_Volunteer_SOP_2019.pdf

31. *Water Quality Volunteer Program Quality Assurance Training.* (2021). Maine Department of Marine Resources. https://www.maine.gov/dmr/shellfish-sanitation-management/forms/documents/WaterQualityVolunteerProgram_QATraining2021.pdf

32. Zimmer-Faust, A., Brown, C., Kaldy, J., Collura, T. C. M., Shanks, O., Rugh, W., Clinton, P., Stecher, J., Manderson, A., & Johnson, Y. (2018, May 22). *Patterns and sources of nitrogen and microbial contamination in a Pacific Northwest estuarine watershed*. UNC Water Microbiology, Chapel Hill, North Carolina.

33. *Wastewater Technology Fact Sheet: Bacterial Source Tracking.* (2002). United States Environmental Protection Agency. https://www3.epa.gov/npdes/pubs/bacsortk.pdf

34. Gyawali, P., & Hewitt, J. (2020). Faecal contamination in bivalve molluscan shellfish: Can the application of the microbial source tracking method minimise public health risks? *Occupational Safety and Health: Emerging Microbial Contaminants and Human Health Effects*, *16*, 14–21. https://doi.org/10.1016/j.coesh.2020.02.005

35. Jones, S., & Hillyer, G. (2020). *Microbial Source Tracking Technical Brief*. Maine Shellfish Learning Network. https://static1.squarespace.com/static/6026cbaf8dfa6838a1b67b5e/t/602eb0725ea41333e6b12c91/1613672562868/unh-mst-testing-brief-3.pdf

36. Gourmelon, M., Caprais, M. P., Ségura, R., Le Mennec, C., Lozach, S., Piriou, J. Y., & Rincé, A. (2007). Evaluation of two library-independent microbial source tracking methods to identify sources of fecal contamination in French estuaries. *Applied and Environmental Microbiology*, *73*(15), 4857–4866. https://doi.org/10.1128/AEM.03003-06

37. *Jackson Estuarine Laboratory.* (2019, February 26). University of New Hampshire: School of Marine Science and Ocean Engineering. https://marine.unh.edu/research-centers/facilities/jackson-estuarine-laboratory

38. Tavares, M. E., Spivey, M. I. H., Mciver, M. R., & Mallin, M. A. (2008). Testing for optical brighteners and fecal bacteria to detect sewage leaks in tidal creeks. *Journal of the North Carolina Academy of Science*, *124*(3), 91–97.

39. Burres, E. (2011). *Measuring Optic Brighteners in Ambient Water Samples Using a Fluorometer* (Standard Operating Procedure S.O.P. 3.4.1.4; p. 12). California Water Boards: State Water Resources Control Board. https://www.waterboards.ca.gov/water_issues/programs/swamp/docs/cwt/guidance/3414.pdf

40. Charles Hagedorn, Mike Saluta, Annie Hassall, & Dickerson, J. (2005, November). Fluorometric Detection of Optical Brighteners as an Indicator of Human Sources of Water Pollution, Part I: Description and Detection of Optical Brighteners. *Crop and Soil Environmental News*. https://www.sites.ext.vt.edu/newsletter-archive/cses/2005-11/part1.html

41. *Soft Shell Population Survey Field Guide.* (n.d.). Maine Department of Marine Resources. Retrieved September 8, 2021, from https://www.maine.gov/dmr/shellfish-sanitation-management/programs/municipal/forms/documents/SoftShellPopulationSurveyFieldGuide.pdf

42. *Surface Water Quality Monitoring: Water Monitoring with Portable Sondes.* (2021). YSI. https://www.ysi.com/applications/surface-water

43. *Sample Clam Flat Survey Datasheet. (*2013). Maine Department of Marine Resources. https://www.maine.gov/dmr/shellfish-sanitation-management/programs/municipal/forms/documents/samplesurveydatasheet.pdf

44. *Transplant/Relay Permit Application.* (2019). Maine Department of Marine Resources. https://www.maine.gov/dmr/shellfish-sanitation-management/programs/municipal/forms/documents/TransplantFormEdited8292019.pdf

45. *Green Crab Trap Suppliers List.* (n.d.). Maine Department of Marine Resources. Retrieved September 8, 2021, from https://www.maine.gov/dmr/science-research/species/invasives/greencrabs/documents/supplierslist.pdf

46. Bruno Myrand, Lise Chevarie, & Réjean Tremblay. (2012). Benthic Spat Collection of Softshell Clams (Mya arenaria Linnaeus, 1758) using Mats. *Journal of Shellfish Research*, *31*(1), 39–48. https://doi.org/10.2983/035.031.0105

CONTACT US

cascobayregionalshellfishworkinggroup.org/contact-us