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Mussel Aquaculture in the Northeast

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Consumption of blue mussels (*Mytilus edulis* and *M. trossulus*) and use as fishing bait have long been supported in the northeastern United States by a small-scale fishery supplying largely niche markets. Mussels have been consumed since pre-colonial times and served as a ready supply of inexpensive seafood protein during wartime periods (1917 and 1942) in America (Miller, 1980). Markets for mussels expanded in the 1970s and 1980s leading to the introduction of mussel farming in the Northeast. The first U.S. mussel farm was established by Mr. Edward Meyers of Walpole, Maine, who in 1973 founded Abandoned Farm on a 5-acre (2-hectare) site in the nearby Damariscotta River. Other early mussel farms established in the 1970s included the 60-acre Blue Gold Mussel Farm on the East Passage of Narragansett Bay in the town of Middletown, Rhode Island and The Great Eastern Mussel Farm in Tenants Harbor, Maine (Hurburt and Hurlburt, 1980). Since these pioneering farms, others have become established in Maine, New Hampshire, Massachusetts and Rhode Island.

The process of mussel farming involves the collection of juvenile mussels ("mussel spat"), harvesting the spat and placing it into culture equipment and growing the mussels to market size for harvest and sale. In general, most of the mussel farms in the Northeast Region are of the off-bottom type in which mussels are grown on ropes either suspended from rafts, or strung on socking materials that are suspended from rafts or in either floating or submerged longline systems. Bottom culture of mussels occurs in Maine, using methods similar to those developed in the Netherlands and Germany, though most new efforts employ off-bottom mussel farming methods that produce a cleaner more uniformly sized product (Hurlburt and Hurlburt, 1980).

The aim of this NRAC fact sheet is to provide a general overview of the various mussel farming techniques as they are currently practiced in the Northeastern United States. References are cited that provide more in-depth information on particular production systems, and prospective growers are also encouraged to contact their local marine extension agent, aquaculture association, state marine fisheries agency, or the Northeast Regional Aquaculture Center.

Mussel farming systems

Mussel production can be generally categorized into suspension culture–where the mussels are grown in the water column–or bottom culture. As a general rule, suspension culture is more expensive in labor and equipment, but results in a product with high meat-to-shell ratio–often in excess of 50 percent–and less grit. Bottom culture has the advantage of lower cost, though more care is needed to provide a grit-free product, and meat yields are typically lower than suspension culture. The two basic suspension systems used in the Northeastern United States are rafts and submerged longlines, although floating longline systems are in common use in Canada.

Modern mussel **rafts** are constructed with steel I-beam main frames, wooden crossmembers, and large polyethylene floats. Most measure 40 feet square and are capable of supporting up to 400 droplines of roughly 45 feet-long each (Figure 1). Roughly 40,000 lbs. of mussels can be reasonably expected in an 18-month cycle from seeding to harvest. Raft systems are most appropriate for reasonably protected areas, in fairly shallow water. They have the advantage of providing a stable work platform, and the disadvantage of being susceptible to damage from heavy weather (Clime and Hamill, 1979).

Figure 1. Mussel raft: 40 square foot, with some dropper lines visible under the platform. Photo courtesy of Dana L. Morse, Maine Sea Grant.

Longline systems consist of a main horizontal line, anchored at both ends, with flotation along the center segment (Figure 2). Dropper lines are then suspended from the main line into the water column (Figure 3). Longline systems have the advantages of being adaptable to deeper waters, or more exposed sites, and can support high capacity and high efficiency. The disadvantage of longline systems is that they can be more difficult to deploy, particularly in deeper waters, and they often require larger work boats with specialized hauling gear (Lutz, 1985).

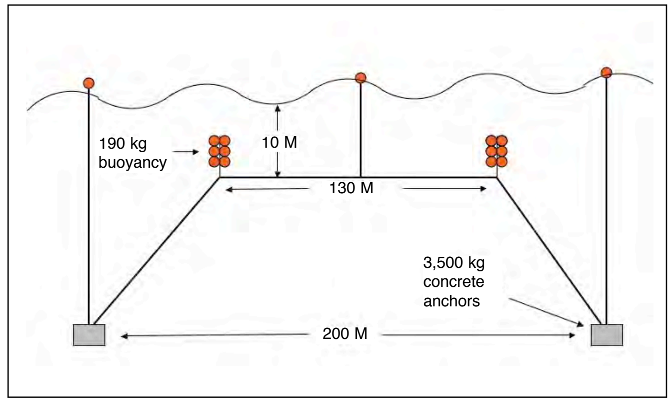

Figure 2. Diagrammatic representation of a submerged longline system used in offshore waters in New Hampshire. Diagram courtesy of Richard Langan, University of New Hampshire.

Bottom culture is an approach that uses reduced densities of mussels on the sea floor to achieve high growth rates and a good meat-to-shell ratio. A producer may locate an appropriate site and seed small mussels on to it, or may find an established bed, and use a strategy of thinning and dispersal to grow the product. Careful site selection is especially important, as the influences of temperature, primary productivity, siltation, predators and other competing organisms can have great effects on the crop. Bottom culturists avoid the capital and maintenance costs of growout gear, but must spend extra attention to quality, and generally experience lower meat weights than suspension culture methods.

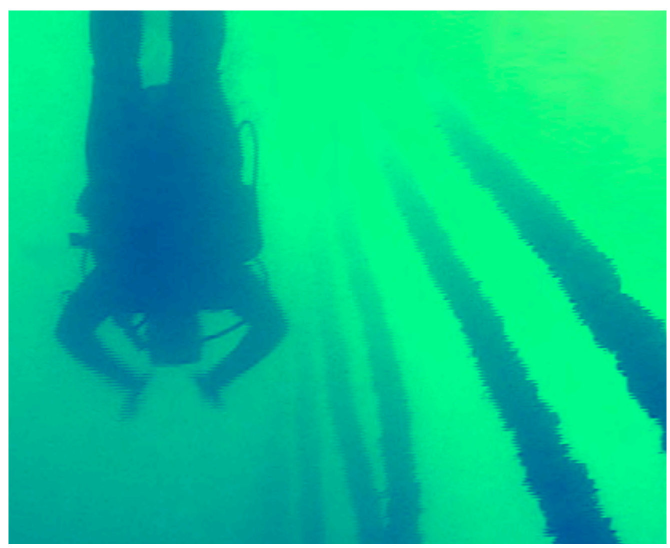

Figure 3. A diver inspecting dropper lines with mussels on a submerged longline system in New Hampshire. Photo courtesy of Richard Langan, University of New Hampshire.

Mussel spat collection

Unlike the practices of clam farming or much of the oyster farming in the Northeast that rely upon hatcheries for a source of seed, mussel farms rely upon the collection of setting mussels from the wild as their seed source. Mussels typically spawn in the late spring as water temperatures rise and develop for about two weeks as planktonic larvae in the water column. At the end of the larval period, the mussels settle and metamorphose into small juveniles known as spat. (For a more complete discussion of the reproduction and life history of mussels refer to NRAC Fact Sheet 210-2010.) In the Northeast Region, mussel spatfall typically occurs as an annual maximum between late April and early July and is largely dependent upon water temperature. However temperature alone is not the only criterion determining the time of mussel spawning; available phytoplankton in the estuary during the spring months also affects spawn timing (Newell *et al.*, 1982). Since maximum spatfall varies by location, it is most important as part of the mussel farming site selection process to evaluate spatfall timing and abundance by placing test collectors into the water during mid-spring or fall depending upon location.

An alternative to using spat collectors for predicting the timing of spatfall is to monitor the appearance of the mussel larvae in the water. This can be done by using a small 12-volt bilge pump (15 gpm) attached to a weighted line and lowered into the water (Figure 4). Water is then passed through a plankton net, with a mesh size of about 60µm. Such nets are available from an aquaculture equipment supplier. Water samples can be preserved in alcohol and stained with a few milligrams (a tiny pinch) of Rose Bengal aboard a boat, and the samples examined using a stereoscopic microscope for the presence of mussel larvae and other plankton. Rose Bengal is a biological stain often sold in 5g-quantities by biological laboratory supply companies. To make things simpler aboard the boat, it is recommended that before setting out to collect plankton samples, it is easiest to prepare sample transport bottles with 100mL of ethanol with the small pinch of Rose Bengal stain added (Figure 4). You can later examine the samples at your convenience in the laboratory using a stereoscopic microscope.

Identification of the mussel larvae and other plankton can be aided by appropriate guide materials (e.g. Loosanoff et al., 1966; Smith and Johnson, 1996). Your local aquaculture extension agent can help you get started if you choose to use this method of predicting spatfall timing in your area.

Originally, mussel spat collectors consisted of sections of frayed rope tied to rafts or floating longlines. There are now a variety of spat collector materials commercially available that consist of a rope core, with radially extended fibrous material or looped fibrous material. Spat collectors with looped fibrous material

Figure 4. Mr. Joseph Goncalo demonstrating the method of using a submerged 12-V bilge pump to obtain water samples for analysis of larval bivalves in the water column. Note the presence of a 1-liter glass sample bottle containing a pre-measured volume of alcohol to kill and preserve the mussel larvae and all the other plankton in the water sample. Photo by Michael A. Rice, University of Rhode Island.

generally collect mussel spat more effectively in waters with higher current speeds, but the fibrous collectors (also sometime known as a "Christmas tree" type collector) have the advantage of being able to be mechanically stripped of adherent seed mussels with lesser frequency of breakage losses.

The process of spat collection involves hanging spat collectors in the water just prior to the predicted maximum spatfall. Timing is critical, as deploying the collectors too late will miss the set, and deploying too early will allow fouling by other marine organisms that would compete with the setting mussels for space. Once mussels set they typically remain on the spat lines until they grow to become 1 cm (about 0.5 inch) long seed mussels at which time they can be stripped from the spat lines (Figure 5).

Figure 5. Freshly set mussels on a spat collector suspended from a floating longline. Photo by Michael A. Rice, University of Rhode Island.

One frequent question among those new to farming mussels is why the mussels cannot be simply left on spat collectors until they grow to market size. The answer is that mussel densities can be so high that they will be stunted because of competition for food resources, and if the set of spat is thick enough, the weight of the crowding mussels causes section or the entire mass of collected mussels to fall off and drop to the bottom. However, some of the seed 'dropoff' problem can be controlled by cross-pegging of spatlines (Figure 6).

Figure 6. Mussel seed on raft drop line, with cross pegs still visible. Photo by Carter Newell, Pemaquid Mussel Farms.

Mussel seed stripping and socking

Once mussel seed is available, it needs to be transferred to the growout lines – for either raft or longline production – in a step called 'socking.' This procedure allows mussels to attach (or 'knit') themselves to the load-bearing portion of the mussel line, by way of attachment by their byssal threads.

Once mussels reach about 1 cm (0.5 inch), the spat collectors are retrieved and the mussel seed is stripped from them. In small mussel farming operations, spat collectors may be typically about 4.5 m (15 feet) in length and the can be manually stripped of mussel seed by using some rugged gloves. For larger mussel farming operations there are a variety of spat line stripping machines that can be used either aboard a vessel or on shore as is convenient.

Socking can be accomplished by allowing mussels to fill the inner space of a long tube of socking material, or by wrapping the mussels and center line in a biodegradable material, such as cotton. For larger-scale mussel farming operations there is commercially available machinery, either to fill long lengths of cotton socking (ie; for continuous longlines), or to alternatively to wrap long dropper lines in cotton sheeting (such as for mussel rafts) (Figure 7).

Discontinuous longlines, with drop lines of 4.5m (15ft) or so, most often use polyethylene socking, whereas the continuous longlines and mussel rafts most

Figure 7. Mussel socking machine, manufactured by Aguin, used in mussel raft culture. Drop lines are fed under the hopper, and mussels are wrapped up against the line by cotton sheeting. The cotton sheet degrades, after the mussels have attached their byssal threads to the dropline. Photo courtesy of Carter Newell, Pemaquid Mussel Farms.

often use cotton socking or wrapping as socking material. Shorter drop lines can be created with the use of a socking table; essentially a hopper for seed mussels. At the bottom of the socking table is a pipe (the 'horn') of a diameter that snugly fits inside socking. Prior to placing mussels in the sock, a rope is inserted down the center of the sock to provide strength to bear the weight of the mussels as they grow. Mussels are then filled into the sock by running water into the socking table, which carries seed mussels into pipe and the sock, much as meat is forced into sausage casings in the sausage making process. For larger-scale mussel farming operations there are commercially available machinery to fill socks that can be in the hundreds of meters in length (Figure 8).

Figure 8. A shipboard continuous socking machine for seed socking of continuous longline droppers. Photo courtesy of Richard Langan, University of Hew Hampshire.

Once the mussel socks are suspended into the water either from rafts or longlines, the mussels will grow and eventually work their way through the netting holes in the socking material so that the socking material and its internal reinforcement rope are internal to the growing mass of mussels (Figure 9). In especially long mussel socks with lines in excess of 10 meters, the mass of growing mussels still can be heavy enough to rip away masses of mussels from the sock. To prevent mussel drop-off, socking pins, which are simply rigid plastic rods (about 20cm long and 1.5cm diameter) that are tapered at both ends, can be placed at two- to three-meter intervals to provide horizontal reinforcement to the mussel sock. Alternatively, socking collars (Figure 10) can be used. In this way the weight of the mussels is borne by either the socking pins or the socking collars at short intervals instead of the weight bearing down along the entire length of the socking tube.

Figure 9. A mussel sock after deployment showing mussels that have emerged from the sock. Photo by Michael A. Rice, University of Rhode Island

Figure 10. A typical mussel socking collar or anti-sloughing disk that is made of polypropylene plastic and is 20cm (8 inches) in diameter. Photo courtesy of Fukui North America

Problems occasionally encountered during growout

Among the various problems to be managed during the mussel growout process is losses due to predation. Refer to NRAC Fact Sheet No 2010-210 for a discussion of common predators associated with mussel farms. As stated earlier, mussel farms using on-bottom techniques are prone to greater predation losses to bottom-dwelling predators. However, mussel farmers engaged in on-bottom mussel farming use a variety of methods to lessen the impact of predators, including the use of crab traps.

Pests could include organisms such as barnacles, and solitary or colonial ascidians, also known as sea squirts. Sea squirts such as *Ciona intestinalis*, *Styela clava*, *Botryllus scholsseri, Molgula manhattensis* and *Botrylloides violaceous* can smother the crop, and make the gear too heavy to service. (Figure 11).

Figure 11. Sea Stars and other fouling organisms on a drop line from raft culture. Photo courtesy of Carter Newell, Pemaquid Mussel Farm.

For suspension growers, lifting culture lines and spraying with a 5 percent solution of hydrated lime mixed in seawater, followed by a short air-drying period, will help to control sea stars and crabs, and many fouling pests such as sea squirts. Bottom culturists need to use good site selection in limiting the impacts from fouling organisms, although in many cases, the other organisms existing on the sea bed can limit excessive fouling as well. Predator control for bottom culture is a mixture of seeding the correct size seed, good timing (seed when predators are less active, such as late fall or early spring), and occasionally trapping or using so-called 'starfish mops'.

On occasion, various mussel pests such as pea crabs and mussel pearls are problematic. In some locations such as Rhode Island, mussel farms are challenged by infestation of pea crabs that act to decrease the marketability of mussels. Pea crabs slightly affect the growth of mussels and may be a stressor, but their presence is more of a nuisance (Bierbaum and Ferson, 1986). At present there is no good means to control pea crab infestations other than to select sites that are less prone to infestations. Pea crabs are much less of a problem in Maine and other northern locations, but in these locations mussel pearls, resembling gritty grains of sand that can form in mussels, also reducing their marketability. (Lutz, 1980). Much like control of pea crabs, initial site selection to avoid areas where pearl formation is critical, but harvest of mussels prior to their reaching three-years of age is helpful in avoiding pearl formation.

Predation from diving ducks such as the Common Eider (*Somateria mollissima*) can be devastating to the mussel producer, certainly with the potential to wipe out an entire crop (Figure 12). Raft producers can use predator nets to surround the raft, whereas longline and bottom culturists cannot. The best control against duck predation is a personal presence by the farmer, to chase ducks away. Since a personal presence is often not possible on a daily basis, such as when weather does not allow it, producers may rely on a set of deterrents. Deterrents are best used in rotation and combination. Common approaches include the use of owl decoys, chasing the ducks off the site – sometimes using 'crackers' fired from a hand gun-like device, lasers (both over and under the water) or mooring an unmanned skiff on the farm. But the birds become accustomed to many of

Figure 12. A group of Common Eider ducks – *Somateria mollissima*. An adult bird can eat over 30% of its body weight in mussels per day, and eiders often collect in groups, called 'rafts' of several hundred individuals. Photo courtesy of Erick Swanson, Maine Cultured Mussels.

these methods rendering them useless over time, and the noise makers often do more to annoy the neighbors of the farms than they do to the birds! Sometimes floating netting material over the farms can exclude some of the ducks.

In recent years, the use of underwater acoustics has come into play, to keep ducks from feeling comfortable on the farm site, and to keep them from coming too close in the first place. Pioneering work in Western Europe has led to the adoption of underwater acoustic deterrents in Maine, and advances in this area are anticipated. By recording the sound of the specific chase boat used on the farm, and then constructing a device to periodically play the sound of that boat (and other sounds, typically in rotation), diving ducks can be kept reasonably at bay, without the producer being on site. Again, ducks will acclimate to this method if over used, but underwater acoustics can be a critical piece of an overall deterrent strategy (Ross *et al,* 2001).

Harvesting re-socking

In today's industry, harvesting requires speed and high capacity; much different from the harvests of years past, where fishermen employed long-handled rakes to fill a skiff or dory. Nowadays, harvesting on bottom sites is generally restricted to drags of various construction, such as the chain sweep drag used commonly in fisheries for scallops and urchins. Drags (commonly referred to as 'dredges') are high-capacity equipment, often up to 4m in width, and capable of catches in the hundreds or thousands of pounds. The harvest vessel may also be equipped with a tumbler, a cylinder of welded steel rod commonly mounted on the stern of the vessel, which allows small mussels, rocks and debris to be removed from the catch. Bottom-dragged mussels may then be purged in tanks or baskets for several hours to a few days, to allow sand and mud to pass from the mussel, prior to packaging and shipment.

Harvesting from rafts is most frequently done with a mast-and-basket arrangement; a large steel basket is lowered under the hanging lines of the raft a few at a time, and the basket is raised beneath them. The basket is hinged such that it opens like a clamshell, and mussel lines are allowed to drop to the floor of the work barge or vessel, ready for stripping and processing.

Longline harvesting is an efficient process. Most vessels, no matter what kind of longline arrangement (continuous or discontinuous), use a set of star wheels, to raise the backline of the mussel ropes to a good working height. At that point, continuous longlines can be cut from the backline and run through the mussel stripper. Single dropper lines can be cut by hand, and collected in a container. The function of the star wheel (one is driven, usually hydraulically, and the other is simply a roller) is to allow the vessel to pull alongside the backline and remain in proper position. By running the star wheel forward or backward, the vessel moves along the backline, without having to engage the propeller.

Processing: purging, declumping, debyssing and grading

Bottom-grown mussel producers will often include a purging step, where the mussels are placed into a large container or a tank, with a high flow of clean seawater pumped through the stock. The function of this step is to reduce the amount of mud and grit inside the mussel, leaving a cleaner product.

Regardless of culture type, the steps of declumping, debyssing and grading are virtually always taken prior to packaging. Each stage requires specialized equipment; these are often placed in series with conveyers in between, and are usually hydraulically operated. Hydraulics can employ vegetable oil in place of petroleum-based hydraulic oil, and this can reduce the negative impacts of leaks or spills. In recent years, processing machinery is often mounted on a floating barge, placed close to the production site.

First, a **declumper** is employed to reduce the groups of mussels down to individuals. Some growers replace the harder paddles inside the declumping unit with softer rubber paddles, to reduce the amount of breakage. The declumper needs to work at the proper angle and the proper speed, and it will take a little trial and error to work out the correct feed rate. The declumper should have a good output of single mussels (not still attached to one another with byssal threads), and should have a minimum of broken shells; less than 2 or 3 percent.

The **debyssing machine** uses a set of narrow cylinders that rotate counter to one another to grab the byssal threads (the 'beard') and pull them from the mussel. This leaves a cleaner and more palatable product, but also reduces shelf life somewhat, as the mussel is unable to close its' shell completely and will gradually lose the shell liquor. In many cases, the last step in processing is grading, so that the product has uniform size. Mechanical **graders** use rolling bars placed nearly parallel to one another, but with an increasing distance between them along their length. Mussels travel over the rolling bars, and the smallest mussels drop out first, based on the width of the mussel. Bins placed at certain distances along the length of the grader allow similarly-sized mussels to be retained together. At this point, when the original clumps of mussels have been separated into individuals, have had the beards removed, and have been grouped by size, they are ready for packaging.

Packaging and Shipping

Mussels coming from the production site and through the processing plant should be cooled as quickly as possible, to approximately 38^{o}F, to retard the growth of bacteria, and to achieve maximum shelf life–seven days. Depending on customer preferences, mussels are often packed into two-pound mesh or perforated plastic bags, or into larger quantities usually up to 20 pounds. Packaging should allow liquid to drain, and should be easy to handle. If individual bags are then consolidated, insulated, wax boxes with the company name, logo and other details should be used. Boxes that sag or leak are not satisfactory with many shippers, and the identifying marks on the box are beneficial in marketing and branding your product. Larger amounts may require the use of pallet-size insulated containers (Newell, 1990).

Selecting a site to culture mussels

Choosing a good site for farming mussels requires considerable local knowledge of the area as to its existing uses and an assessment of the area's potential for producing mussels. Among other things, this should include the availability of a steady setting mussel seed supply, as well as sufficient currents and phytoplankton (food) concentration to allow for rapid growth. The following factors should be considered when siting your mussel farm:

Speed of the current
Phytoplankton and other suspended food abundance
Water temperature
Water salinity
Exposure to wave action and storm surges
Sediment type
Water depth
Predators & pests, including excessive fouling potential
Frequency of occurrence of harmful algal blooms (HABs)
Occurrence of ice
Road access to the site (proximity to shore)
Security concerns
Sanitary water quality classification (approved, conditional, or prohibited)
Navigational concerns
Presence or absence of existing fisheries

It is often advisable to establish several small-scale experimental trial farming sites as part of a site selection procedure. A whole host of potential problems including lack of adequate seed set to conflicts with other users of the proposed aquaculture site can be discovered through farming trials.

A major consideration for the siting of any mussel farm is the availability of adequate food for the mussels and adequate current such that food (phytoplankton and particulate detritus) can be carried to the mussels and that the waste products from the mussels can be carried away. Considerable work has been done to correlate mussel food availability, current speed and the growth of mussels using various types of culture gear (Incze et al, 1991; Newell et al., 1998). In general mussel culture sites are best when there is in excess of 10 mg/L available particulate food in the water with average current speeds in excess of 30 cm/sec. Slower current speeds, however, could be offset by higher food concentrations in the water.

Most of the food for mussels consists of live phytoplankton cells in the water column, however, particulate detritus and some bacteria are also food for mussels. Available food for mussels can be measured in a variety of ways. Since all phytoplankton carry chlorophyll-a (chl-a) as a photosynthetic pigment, measurement of chl-a concentrations in the water is a good index of available food. Alternatively, samples of seawater of known volume from potential mussel aquaculture sites could be vacuum filtered using fiberglass filters with pore sizes of about 1 μm or less, then dried in a drying oven at 100^{o}C and weighed the ashed at 450^{o}C and weighed again to obtain an organic biomass measurement. If you are unfamiliar with some of the equipment or methods for determining food availability for mussels or how to make the water quality measurements, contact your state's aquaculture extension specialist for some assistance.

Not all phytoplankton is good for mussels. Certain types of algal blooms can be aging to mussel farming by posing a health threat to consumers (Jin and Hoagland, 2008). As part of the mussel farm site selection process, studying the history of official closures of your area to harvest of mussels can be a good indicator if the area is problematic and to be avoided.

A simple way of measuring current speed is to use a tethered current drogue (float), a measuring tape, and a stopwatch. Release the current drogue from a boat and note the time it takes to travel to extend the drogue tether to its full outstretched maximum. The current speed is then the length of the drogue tether divided by the travel time in seconds. So if, for example, the drogue traveled 1,000 cm in 40 seconds, its speed would be 25 cm/sec. Drogues can be complicated, or as simple as using an orange floating on the water surface.

You can measure temperature and salinity on your site using a thermometer and salinity refractometer or a hydrometer that can be purchased from an aquaculture gear suppliers. Another useful measurement is the overall water turbidity measured by a Secchi disk. The overall turbidity of water is affected by the amount of particulate material (including phytoplankton) in the water, so Secchi disk turbidity measurements can be an indicator of relative food abundance in the water. Make sure you record all of your observations at your sites. All of these data can help you understand the differences among your sites and the sites of other mussel farms, and give you insights into how varying water conditions affect mussel growth and productivity. If you are unfamiliar with some of the equipment or methods for determining food availability for mussels or how to make the water quality measurements, contact your state's aquaculture extension specialist for some assistance.

Planning a Business in Mussel Production

Shellfish aquaculture requires a broad range of expertise and ability, in everything from permitting and regulation to the production technology and husbandry itself. However, since mussel production nearly always relies on significant volume of product to be profitable, the prospective grower needs to be prepared especially in the areas of sales and marketing, equipment, and financing. Strong consideration should be given to developing a thorough business plan, and an accompanying marketing plan. In addition, appropriate capitalization is critical, to account for the known costs and to allow for the things that always take longer or cost more. Business planning outlines relative to raft culture and longline culture are available, to help in these exercises (Hoagland *et al.*, 2003; Anonymous, 1999).

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References

Anonymous. 1999. The Maine Guide to Mussel Raft Culture. Island Institute, Rockland, ME. 32pp.

Bierbaum, R.M. and S. Ferson. 1986. Do symbiotic pea crabs decrease growth rate in mussels? *Biological Bulletin* 170:51-61.

Clime, R. and D. Hamill. 1979. Growing Oysters and Mussels in Maine. Coastal Enterprises, Inc., Bath, ME 46pp.

Hoagland, P., H.L. Kite-Powell and D. Jin. 2003. Business Planning Handbook for the Ocean Aquaculture of Blue Mussels. Marine Policy Center, Woods Hole Oceanographic Institution. 32pp.

Hurlburt, C.G. and S.W. Hurlburt. 1980. European mussel culture technology and its adaptability to North American waters. Pp. 69-98. In: *R.A. Lutz (ed.), Mussel Culture and Harvest: A North American Perspective.* Elsevier, Amsterdam.

Incze, L.S., R.A. Lutz, and E. True. 1981. Modeling carrying capacities for bivalve mollusks in open, suspended culture systems. *Journal of the World Mariculture Society* 12(1):143-155.

Jin, D. and P. Hoagland. 2008. The value of harmful algal bloom predictions to the nearshore commercial shellfish fishery in the Gulf of Maine. *Harmful Algae* 7:772-781.

Lutz, R.A. 1980. Pearl incidence: Mussel culture and harvest implications. pp. 193-222. In: R.A. Lutz (ed.), *Mussel Culture and Harvest: A North American Perspective.* Elsevier, Amsterdam.

Lutz, R.A. 1985. Mussel aquaculture in the United States. Pp. 311-363. In: J.V. Huner and E.E. Brown. (eds.) *Crustacean and Mollusk Aquaculture in the United States.* AVI/Van Nostrand Reinhold, New York.

Miller, B.A. 1980. Historical review of U.S. mussel culture and harvest. Pp. 18-37. In: R.A. Loosanoff, V.L., H.C. Davis and P. Chanley. 1966. Dimensions and shapes of larvae of some marine bivalve mollusks. *Malacologia* 4:351-435.

Newell, C.R. 1990. A Guide to Mussel Quality Control. Maine Sea Grant Technical Report. E-MSG-90-1. 17pp.

Newell, C.R., D.E. Campbell, and S.M. Gallagher. 1998. Development of the mussel aquaculture lease site model MUSMOD©: a field program to calibrate model formulations. *Journal of Experimental Marine Biology and Ecology* 219:143-169.

Newell, R.I.E., T.J. Hilbish, R.K. Koehn, and C.J. Newell. 1982. Temporal variation in the reproductive cycle of *Mytilus edulis* L. (Bivalvia, Mytilidae) from localities on the east coast of the United States. *Biological Bulletin* 162: 299-310

Ross, B. P., Lien, J., and Furness, R. W. 2001. Use of underwater playback to reduce the impact of eiders on mussel farms. *ICES Journal of Marine Science* 58: 517–524.

Smith, D.L and K.B. Johnson. 1996. *A Guide to Marine Coastal Plankton and Marine Invertebrate Larvae.* Kendall/Hunt Publishing Company, Dubuque, IA. ISBN 0787221139.