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Softshell Clam Culture: Hatchery Phase, Broodstock Care through Seed Production

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Introduction

Aquaculture of softshell clams (*Mya arenaria*), also called "steamer clams" (Figure 1), has grown steadily and is becoming a significant industry in New England. Successful spawning and rearing of softshell clams, like all bivalve mollusks, requires effort and experience. Considerable information exists for other commercially important bivalve species (e.g., Matthiessen 1989, Rice 1992, Conte *et al*. 1994, Hadley *et al*. 1997, Hadley and Whetstone 2007), some of which is readily transferrable to softshell clams. Culture techniques specific to softshell clams are not similarly well defined. Early work in Massachusetts by the pioneering Dr. David Belding during the first decade of the twentieth century focused on soft clam management and life history. His work remains the definitive treatise for this popular New England species and was recently republished by Cape Cod Cooperative Extension (2004). Ellis and Waterman (1998) developed a guide for public enhancement of softshell clam beds, which provides an overview of culture techniques. Examined in this fact sheet are specific aspects of softshell clam production during the Hatchery Phase and description of variations in management practices at three shellfish facilities: two in Massachusetts and one in Maine.

Figure 1. Market-size softshell clams ready for retail.

Softshell clam culture may be categorized into four phases: Hatchery, Nursery, Growout, and Overwintering. Phases are related to clam size, season and culture conditions. The Hatchery Phase includes conditioning and spawning broodstock, larval care through **metamorphosis** and culminates when post-metamorphoric clams are large enough to enter the Nursery Phase (Figure 2). In some facilities, the Hatchery Phase ends when clams are retained on a 1 mm mesh (about 2 mm **Shell Length**, SL); other facilities may rear clams in the hatchery until they are retained on a 1.5 mm mesh or about 3.2 mm SL. Duration of the Hatchery Phase varies as conditioning

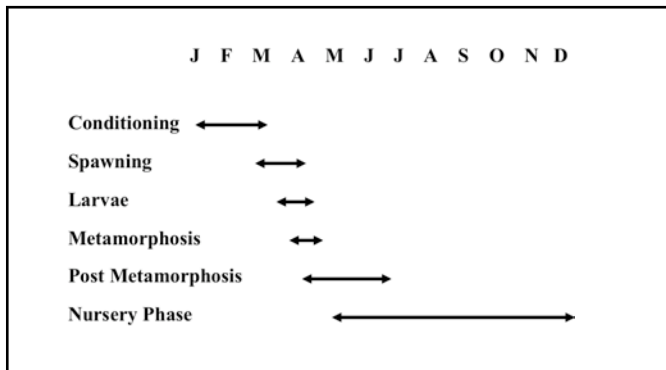

Figure 2. Schedule of Hatchery Phase activities by month from broodstock conditioning to stocking of juvenile clams in Floating Upweller Systems (FLUPSY) at the start of the Nursery Phase.

broodstock clams and development of larval clams is temperature- and food-dependent. Larval clams typically require six or more weeks from spawning to attain 2 mm SL.

Once clams are large enough to enter the Nursery Phase, they are removed from the hatchery and relocated to protected waters. Clams may be stocked and maintained in **upwellers**, moved into floating trays lined with window screening, or placed into sediment-filled containers. Regardless of system or technique employed, after clams attain or exceed 10 to 15 mm SL they are considered ready for release onto tidal flats, initiating the Growout Phase. In southern and central New England waters, most clams easily attain this size within the first growing season (May to November). In northern New England and Canadian waters, clams grow slower and it usually takes the entire growing season (June to November) for clams to reach 10 to 15 mm SL. Since November is considered too late to move clams to the field for growout, clams are transferred to bags and placed in cages, either in the field or in a facility for an Overwintering Phase (Beal *et al*. 1995). Clams too small or not needed for growout from southern New England waters are similarly overwintered. Survival of overwintered clams can be high, as much as 95%. Overwintered clams are ready for Growout Phase in the following spring.

Seawater Supply

Hatchery seawater requires filtration and thermal adjustment. At the Cat Cove Marine Laboratory (CCML) located in Salem, Massachussetts, seawater is filtered initially to 100 μm, then to 16 μm, and then **UV treated**. Ambient and thermally adjusted (to 15 ^{o}C) seawater is stored in reservoir tanks and gravity-fed to the Lab. Before addition to shellfish tanks, seawater is routinely filtered through a 1 μm mesh. Airblowers continuously aerate tank water. At the Downeast Institute (DEI) located on Beals Island, Maine, ambient seawater is filtered through a series of filters (100μm, 50μm, and 10μm) before it is warmed to the desired temperature using a furnace equipped with a heat exchanger. There are no reservoir tanks.

Broodstock: Acquisition and Maintenance

To ensure spawning success in the Hatchery Phase, a population of healthy adult softshell clams is needed. In early winter, broodstock clams are collected from local flats to maintain genetic integrity. Conditioning of clams commences within two weeks of their collection. The preferred size for broodstock is 40 to 70 mm SL, as they produce a larger quantity of eggs than smaller clams and spawn more readily than larger clams. Adult softshell clams live buried in sediments. When removed from sediments, clams gape and their condition deteriorates; clam survival and reproduction are negatively impacted. To simulate their natural environment and to preclude gaping: cages, socks, bands or sediments are used.

At CCML, broodstock clams are maintained in the sheltered tidal flats of Smith Pool, exposed to natural conditions. To facilitate access and retrieval, clams maintained in Smith Pool are housed in partially buried 19 L buckets. Each bucket has several dozen 6 to 10 mm holes in the top half, and the lower half is filled with local sediment (Figure 3). Clams 35 mm SL or greater

Figure 3. At the CCML broodstock clams are housed in buckets placed in shallow waters to facilitate access and maintenance when not being spawned.

are maintained at 12 to 14 per bucket. At any one time, approximately 150 clams are maintained in this manner. A back-up population of clams occurs naturally in the tidal pond.

At DEI, wild clams (55 to 70 mm SL) are collected each year from intertidal flats on Beals Island during late December. These are placed into "clam sandwiches," (Figure 4) and held indoors, in 700 L tanks supplied with ambient flowing seawater for two weeks prior to conditioning. The sandwiches are constructed of two pieces of vinyl-coated lobster trap wire (45.7 by 45.7 cm) and two pieces of extruded plastic netting of similar size (6.4 mm mesh). The pieces of wire form the outer portion of the sandwich, while the mesh netting forms the inner portion of the sandwich. Twenty to 30 clams are placed on the mesh netting that sits on top of one piece of trap wire. The other piece of mesh netting is then placed over the clams and the second piece of trap wire placed over the netting. The arrangement is as follows: 1) trap wire; 2) mesh netting; 3) clams; 4) mesh netting; and, 5) trap wire. Finally, nylon cable ties are used to cinch the two sides together, placing enough pressure on the valves of the clams to simulate burial in sediments. Approximately six "sandwiches", each with up to 30 clams, are used. Each "sandwich" can then be handled as a single unit (Figure 4). Softshell clams have been kept alive for a year in these "sandwiches".

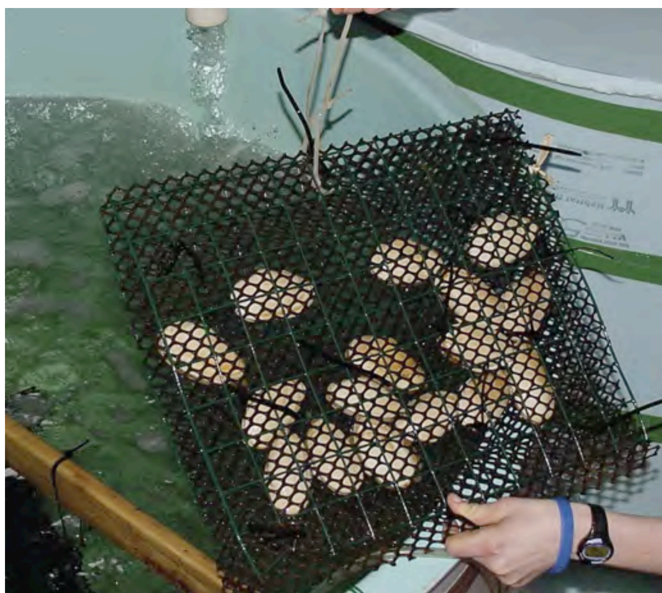

Figure 4. "Clam sandwiches" constructed of mesh materials are used to hold broodstock clams at DEI during the conditioning phase.

Broodstock: Conditioning and Maintenance in the Hatchery

In early January, conditioning of broodstock clams is initiated. At CCML, after relocation from Smith Pool to the hatchery, clams are cleaned and transferred to 15 cm long sections of 10 cm diameter PVC pipe filled with commercial grade 20/40 sand (approximately 0.6 mm in grain diameter) to about 2.5 cm from the top (Figure 5). Sand is retained by a 125 or 250 μm mesh glued across the pipe bottom, which permits water passage. Three or four clams (40 to 70 mm SL) are placed in a tube and 10 tubes are installed per holding tank (1,500 L working volume, static system). Up to three such tanks are concurrently set up and used. Clams are gradually warmed over 2 to 3 days from ambient water temperature, about 4 ^{o}C, to about 15 ^{o}C. Clams are maintained at 15 to 16 ^{o}C for 8 to 10 weeks.

Figure 5. Sand-filled PVC pipe is used to house broodstock at CCML.

Many species of microalgae can be used to feed clams (see NRAC Fact Sheet No. 160-1993, *Growing Microalgae to Feed Bivalve Larvae*). At CCML, *Isochrysis* sp. (T-ISO), *Nannochloropsis* sp. (UTEX 2341), and *Tetraselmis chuii* (PLY 429) are batch fed to tanks. Clams are fed as needed, usually once daily, with *Tetraselmis*, *Isochrysis*, and *Nannochloropsis* to approximate a target density of 75,000 to 100,000 *Isochrysis* cells per mL tank water (Table 1).

Broodstock conditioning tanks are cleaned two or three times weekly. The tank is drained of water. PVC tubes with clams are removed (Figure 6), cleaned on the outside and gently sprayed on the inside with fresh water until the discharge water vents clear. After the PVC tubes have been removed, the tank is sprayed with fresh water,

Table 1. Target densities for algae used to feed and condition softshell clams in tanks at CCML.

Algae	Target cell number per mL
Tetraselmis chuii (PLY 429)	3,000-8,000
Isochrysis sp. (T-ISO)	40,000-60,000
Nannochloropsis sp. (UTEX 2341)	20,000-35,000
Total	**75-000- 100,000**

scrubbed and cleaned with a bleach solution (2 to 5 mL dispersed in the residual 2 to 4 L of water that remains in the drained tank). A brush is used to scrub the tank bottom and sides. The tank is then rinsed with fresh water. Aeration tubing and pipettes used to circulate water are removed, rinsed and scrubbed in hot fresh water (48 to 50 ^{O}C). Aeration tubes and pipettes are replaced, tank filled with seawater filtered to 1 μm, and algae added to the target density.

At DEI, broodstock clams in their sandwiches are placed into 700 L tanks and filtered seawater is gradually warmed to 15 ^{o}C over three weeks. Clams are fed a mixed diet of *Tetraselmis maculata* (CCMP 897), *T. chuii* (PLY 429), *Chaetoceros muelleri* (CCMP 1316), *Isochrysis galbana*, *Thalassiosira weissflogii*, and *Rhodomonas salina* (CCMP 1319) in equal amounts for a total density of 75,000 cells per mL. Algae are dripped into the tank slowly so that there is a constant amount of food at all times. Regular cleaning (2 to 3 times per week) requires that clams in their sandwiches be removed from the tank (Figure 4). After removal, sandwiches with clams are sprayed with fresh water, cleaned using methods similar to those employed at CCML, and returned to the broodstock tank. Ceramic air stones are the only other objects in the broodstock tank. These are replaced with clean stones when each tank is cleaned.

Figure 6. Sand-filled PVC pipes with broodstock clams are removed and cleaned 1 to 2 times per week.

Broodstock: Spawning

There are two general methods of spawning clams: passive and active. **Passive spawning** is less management-intensive. Multiple clams are placed in a tank. Spawning typically occurs at night, and broodstock are removed from the tank the next morning. **Active spawning** requires more management, as individual male and female clams are identified and separated when spawning to ensure an appropriate sperm-to-egg ratio. Passive spawning can produce large numbers of larvae, but broodstock are likely to ingest larvae and not all eggs released are fertilized successfully (they may be either unfertilized or subject to **polyspermy**). In addition, with passive spawning it is impossible to document spawning success of individual clams and to ensure adequate genetic variability (e.g., it is possible that only one female or one male spawns in a passive spawn). These problems are remedied by active spawning.

At CCML, passive spawning is employed. The same 1,500 L tanks that held clams during conditioning are used. After a thorough tank cleaning, the batch of clams (10 PVC tubes, a total of about 30 clams) is returned to the tank which is gradually filled with 15 ^{O}C water. No **thermal shock** is used; temperatures are warmed gradually over several hours (approximately 1^{O}C per hour) until 22 to 24 ^{O}C is attained. An 1,800 watt heater will warm a 1,500 L tank at a rate of about 1^{O}C per hour. Generally, heaters are turned-on late in the day; clams are fed a broodstock dose of algae (Table 1) and left overnight. The next morning, seawater in the tank(s) is checked for presence of larvae. As a quick check, a flashlight is used to detect **trochophore** larvae. Larval presence and abundance is confirmed by volumetric samplings that are viewed microscopically. When larvae are detected, broodstock clams and PVC tubes are removed and placed into a separate tank gradually filled with 15 to 16 ^{O}C seawater filtered to 1μm. Larval clams are not disturbed or siphoned for 30 to 36 hours post spawn to allow for shell formation and hardening.

At DEI, passive spawning is also used, but the preferred method is active spawning. Both techniques use thermal shock to stimulate spawning. In passive spawning, sandwiches filled with broodstock that have been maintained at 15 ^{O}C for 6 to 7 weeks are cleaned and transferred to a 2,000 L larval tank containing 23 to 24 ^{O}C seawater. Sandwiches are placed into floating wooden trays lined with nylon window screen. One to two liters of algae are concurrently added. Spawning typically occurs at night, and the next morning broodstock are removed from the tank. At that time, the number of trochophore larvae is estimated by draining the tank completely and catching larvae on a 44 μm sieve. Throughout the draining event, sieve contents are frequently and gently transferred to a 19 L bucket. Several samples (e.g., 1 mL) are taken from the bucket to estimate trochophore abundance per mL.

In active spawning, clams are removed from the sandwiches and placed into a shallow tray containing 24° C seawater. Clams are watched carefully for a period of time that can take from 15 minutes to six hours. Typically, male clams spawn first. All spawning males are collected and placed into one bucket or dish and permitted to continue releasing gametes. As females spawn, each is removed from the shallow tray and gently placed into a 1 L glass bowl with seawater to facilitate observation. Females typically resume spawning after a few minutes. Eggs from a single female are collected and transferred to one 19 L bucket. This process is continued until all females that will spawn have done so. Typically from a batch of conditioned broodstock clams, only 40 to 60% will spawn at any given time. When done, sperm from all males is in one bucket and eggs from each female are in separate buckets.

Actual fertilization proceeds cautiously by placing a small amount of the sperm water (about 250 mL) into each egg-containing bucket. Visual inspection of the eggs using a microscope is the best method to determine whether fertilization has been successful. Fertilization is noted when a **polar body** forms, which occurs within 20 minutes after the egg and sperm contact. Eggs and sperm remain viable at room temperature for several hours, so if the percent of successful fertilization is low, it is possible to add small aliquots of sperm and increase fertilization success. Small aliquots are used to prevent polyspermy. Resultant fertilized eggs, 50μm in diameter, are poured through a 125μm sieve held over the larval tank. The sieve removes larger debris, while eggs pass into the tank.

An alternate approach used at the Eastham, Massachusetts Hatchery employs adult clams maintained in mussel tubing (25 mm mesh). *T. chuii* (1 L) is added to each bath. Clams and tubing are placed in one of two 30 L cylinders of water (Rubbermaid®). One cylinder is heated to 25 ^{o}C, while the other is cooled to 15 ^{O}C. Clams (25 to 30) in socks are alternately switched between the warm and cold baths at 45 minute intervals. After 8 or more cycles the clam socks are rinsed with fresh water and placed on a rack constructed of vinyl covered wire mesh suspended near the top of a 1,000 L conical tank filled with 1 μm filtered seawater heated to 20 ^{O}C. Clams are left to spawn overnight. The rack, socks and clams are removed the following morning and clams are returned to the conditioning tank. Water exchanges and clam sieving begin on the second day after the spawn and follow procedures employed by CCML and DEI. Spawns of up to 30 million trochophores have been observed.

Larvae: Maintenance and Care

Bivalves transition through several larval stages from trochophores (duration of 12 to 24 hours) to **veligers** (duration of 8 to 14 days) before they become **pediveligers** (duration of 2 to 6 days) (Figure 7) and are ready to undergo metamorphosis into tiny **benthic** clams**.** Metamorphosis from **planktonic** larvae to

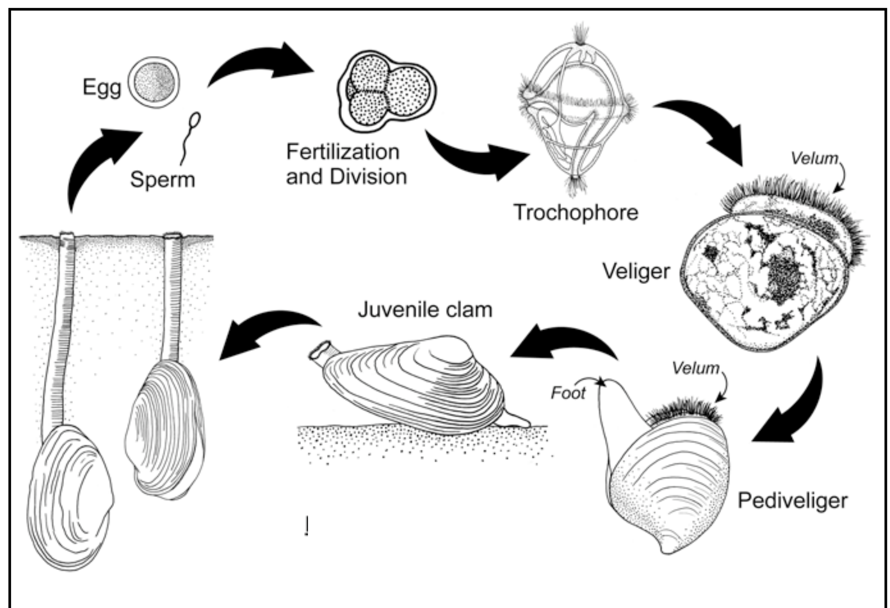

Figure 7. Life cycle of the softshell clam, *Mya arenaria.*

benthic clams can be delayed if appropriate (soft) substrate upon which to settle is lacking, food is reduced, and/or water temperature is low. Larval clams may be maintained successfully in **continuous flow** or **static systems**. In a continuous flow system, water and algae are added continuously; the discharge pipe is screened to prevent loss of larvae. In a static system, water is exchanged completely at least three times per week and algae are added in batches as needed. Both CCML and DEI employ a static management system.

At CCML, larval clams are siphoned from broodstock tanks 30 or more hours after spawning, when clams are in the "D-shaped" veliger stage. Siphoned water is passed through 150 μm and 35 μm mesh sieves to separate larvae from debris. Larvae are retained on the 35 μm nylon mesh and transferred to a larvae holding tank. Target stocking density is about 10 larvae per mL. Larvae require limited, but gradually increasing amounts of algae the first 2 to 3 days of life. *Isochrysis* and *Nanochloropsis* are added concurrently with larvae introduction. Initial target densities are 30,000 to 40,000 cells per mL and 5,000 to 10,000 cells per mL, respectively. Feeding rates are gradually increased to 50,000 to 70,000 cells per mL and 15,000 to 30,000 cells per mL for *Isochrysis* and *Nanochloropsis,* respectively. *Tetraselmis* is not used as it is too large for planktonic clams to ingest. To prevent overfeeding, larvae less than 5 or 6 days old are usually fed half the target density of algae on days with no water exchange. After 6 to 7 days as larvae, the full target density of algae is added whether or not water is exchanged.

Two types of larvae holding units are used at the CCML; 190 L conical bottom tanks and 500 L sloped bottom tanks (Figure 8). Both tank types are cylindrical and made of fiberglass. At any one time, half of the tanks are used for holding larvae. The remaining tanks have been cleaned, filled, warmed and are ready to receive larvae. Larvae are collected with a 35 μm sieve and transferred to a clean tank, three times a week (e.g., Monday, Wednesday, Friday). Clams are sieved, as tanks are drained by siphon and afterwards cleaned. Cleaning involves spraying tap water, scrubbing and treating with bleach (2 to 5 mL per treatment), rinsing with hot tap water (approximately 50 ^{o}C) and air drying for 24 h before next use. Tanks are filled with seawater (filtered to 5 μm and UV sterilized). After filling, heaters (250 to 300 watt) are used to warm and maintain seawater at 21 to 24 ^{o}C and continuous light aeration is provided to circulate larvae gently through the tank. Slightly lower temperatures may promote slower growth without adversely impacting survival to metamorphosis. Temperatures below 16 ^{o}C, however, may preclude metamorphosis and cause larval mortality.

Figure 8. Cylindrical fiberglass tanks with sloped bottoms are used to hold planktonic larvae, which are transferred to other tanks by a siphon as illustrated.

Daily maintenance of larvae holding units includes monitoring and adjusting water temperature, observing clam number and health, and adding algae as needed. A flashlight is used to assess quickly the general condition and approximate abundance of planktonic clams. For more detailed assessment, a sample of measured volume is collected and viewed with a dissecting scope to quantify larval density and examine condition (e.g., life stage, mortalities, feeding). Starting at 8 days post spawn, a siphon and 150 μm mesh are used to separate larvae. Larvae retained by the mesh are transferred to setting tanks. Smaller larvae are returned to the larvae holding tank. The majority of clams from one spawn will be retained on the 150 μm mesh by 14 days post spawn.

While most larvae are managed to transition rapidly through the planktonic stage, some may be intentionally delayed to serve as replacements for losses that occur or to facilitate management. Larval metamorphosis is delayed in tanks by reduced feeding and lowered temperature. They are otherwise monitored and maintained the same as other larvae. After carrying capacity and/or production quota is assured, intentionally delayed larvae are discarded. Delayed larvae have been maintained successfully for 3 to 4 weeks post spawn. When transferred to increased temperature and food, they appear to develop and metamorphose normally.

At DEI, fertilized eggs develop in the larval tank if passive spawning is used, or develop after transfer to larval tanks when active spawning is employed. Regardless of whether passive or active spawning is employed, the larval tank is drained 24 hours after a successful spawning

and fertilization. A 44 μm sieve is used to collect and retain larvae (trochophore larvae are present with a small proportion of veligers). Target stocking density after transfer is 3 to 6 larvae per mL. Larvae are fed a mixed diet of two or three species of cultured microalgae (*Isochrysis, Chaetoceros*, and *Thalassiosira*) at a combined density of 35,000 to 55,000 cells per mL. This density is maintained throughout the entire larval cycle.

Larvae are reared in 2000 L flat-bottom fiberglass tanks. Before filling with seawater, tanks are cleaned with warm water, soap, and a mild solution of bleach. After rinsing, the sides of the tank and the bottom are sprayed with a povidone-iodine solution (a microbicide) per manufacturer's instructions. After five minutes, the tank is sprayed clean. Tanks are then filled with 24 ^{o}C seawater filtered to 1 μm and provided with gentle aeration. Larvae collected by the 44 μm sieve are placed into the tank.

Larvae: Metamorphosis

At CCML, **downwellers** are employed to hold larvae and promote **setting** (a). Two sizes of polyethylene silos (i.e., modified trash barrels) are used as downwellers that house metamorphosing clams. Large silos are 52 cm in diameter and small are 44 cm in diameter. The bottom of each silo is covered with 125 μm mesh, secured by Marine "Amazing Goop®" and a 1 cm wide tie-down to retain clams (Figure 9b). Inflow water is provided by **airlift** through a 5 cm PVC pipe secured to the silo by a 90° elbow, which both circulates and aerates water (Figure 9b). Four or five silos are housed per fiberglass tank (1,500 L and 1,000 L working volume). These "setting tanks" are filled with seawater filtered through 1 μm mesh. Water is maintained at 20 to 24 ^{o}C by 250 to 300 watt heaters. Silos are suspended and positioned by PVC pipe (2 to 2.5 cm).

Water flow to each silo varies over time; initially flow is set at about 300 mL per minute and then increased gradually to a maximum of about 1.5 L per minute, after 4 to 5 days. Water flow is managed to minimize turbulence, which can disrupt larvae and lead to clumping.

Larval clams are introduced to silos with the target density based primarily on surface area of the silo retention screen (about 200 larvae per cm^{2}) and secondarily on tank volume (1 to 2 larvae per mL). Larvae number is determined volumetrically. A reasonable, initial estimate of pediveligers retained on a 150 μm mesh is 300,000 clams per mL (wet packed volume). Algae are added daily to maintain a target algal density of 70,000 to 100,000 cells per mL and for the first time *Tetraselmis* is used (Table 2). Normally, one half to one times the initial algae quantity must be added to maintain the target density on days when no water change occurs. In a fully-stocked system, if algae consumption is less than normal, then poor larval health and survival may be indicated. Typically, metamorphosis occurs from 3 to 10 days after transfer to "setting tanks". Use of adult clams or water from units with adult clams may promote metamorphosis.

Three times each week tanks are drained, rinsed with tap water, scrubbed and cleaned with bleach (2 to 5 mL per treatment), sprayed with tap water, and immediately filled with seawater filtered to 1 μm. At the same time, the airlift delivery system (i.e., PVC piping, airstone or pipette, tubing) and heaters are removed, cleaned and rinsed. During tank cleaning, silos with

Figure 9a and b. Silos installed in fiberglass tanks are supplied with seawater by airlift pumps and used to hold larval clams during metamorphosis.

Table 2. Target densities for algae used to feed softshell clams in the CCML hatchery during metamorphosis.

Algae	Target cell number per mL
Tetraselmis chuii (PLY 429)	1,000-3,000
Isochrysis sp. (T-ISO)	40,000-70,000
Nannochloropsis sp. (UTEX 2341)	15,000-30,000
	Total 70,000-100,000

pediveligers are removed and clams are kept moist by spraying or submerging in filtered seawater. Cleaned silos are either returned to their original tank, which is subsequently filled with water heated to 20 to 24 °C or transferred to a previously filled second tank maintained at 20 to 24 °C. Temperature is maintained by 250 to 300 watt submersible heaters.

Recently, an alternate approach has been employed. Rather than continuously airlift water to the silo as a downweller, no water is directly added by airlift to the "static silo" (Figure 10 a,b). Instead, aeration agitates water in the tank, which indirectly circulates water to the silo (Figure 10 a). The technique, investigated by H. Lind in Eastham, Massachussetts, and subsequently employed at CCML has not been used extensively, but preliminary results are promising. Survival is more consistent and silos are noticeably cleaner. At CCML, pediveligers retained on a 150 μm mesh are introduced to static silos. Clams are maintained in the static system for a short time as they undergo metamorphosis. Commencing 3 to 6 days post transfer (day 12 to 20 post spawn), 180 μm mesh is employed to separate set and nearly set clams from those still early in metamorphosis. Clams retained on 180 μm mesh are transferred to an airlift downweller (Figure 9a,b). Pediveligers that pass through the 180 μm mesh are re-sieved on 150 μm mesh to separate debris from live clams and returned to static silos to complete metamorphosis. Sieving continues until most larvae have metamorphosed.

Handling of metamorphosis at DEI parallels closely procedures employed at CCML. Differences reflect system design, management considerations and personal preferences. For instance, at DEI, clam pediveligers, visibly identified by the presence of a foot exiting the shell, are transferred directly from the larval tank to 91 cm by 91 cm by 3.8 cm deep wooden trays lined with 125 μm mesh housed in 3000 L tanks (Figure 11). An air-lift system is used to generate seawater flow over the clams in the trays in the tank. Clams swim in the shallow water of each tray for 3 to 7 days before undergoing metamorphosis.

Clam: Post Metamorphosis

At 200 to 300 μm (0.2 to 0.3 mm) SL, clams have completed metamorphosis and are managed as part of the Hatchery Phase until they attain 2 to 4 mm SL, when the Nursery Phase starts. At CCML, post-metamorphic clams are separated and managed as **cohorts**, based

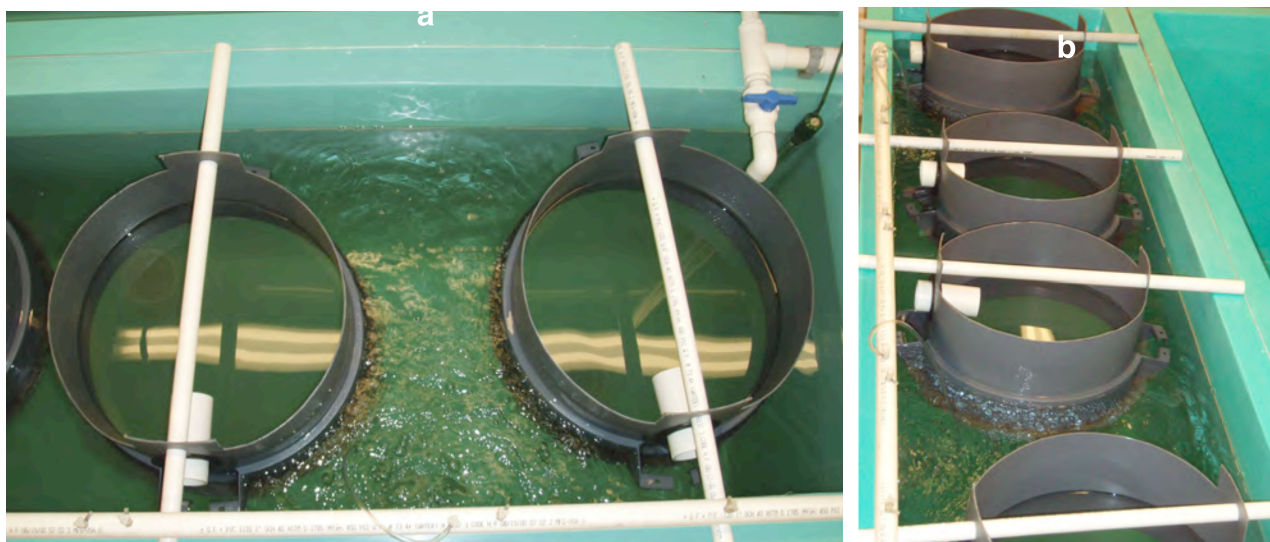

Figure 10 a and b. Silos used to maintain pre-metamorphic larvae without water flow have yielded good survival and cleaner silos. Note agitation of water between silos and calm water inside the static silos as well as the absence of water flow due to airlifts.

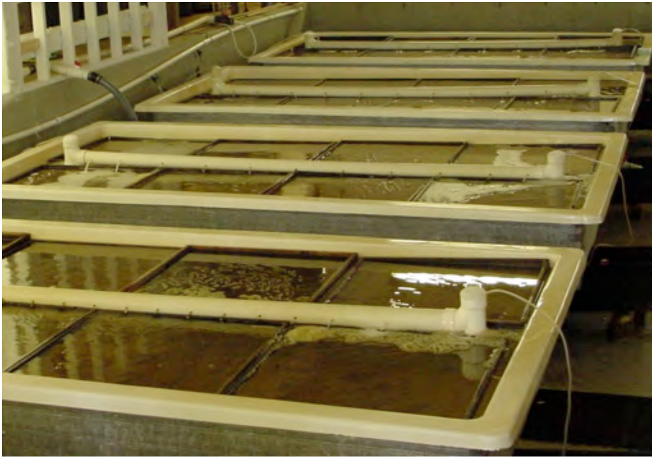

Figure 11. Tanks and wooden trays are used at DEI to facilitate metamorphosis of larval clams.

upon size rather than by date of spawn. Clams from multiple spawns are often combined and maintained as one cohort. Clams are maintained in the same downweller setup as used during metamorphosis (Figure 9a, b). The aperture of the silo mesh is increased as clams grow, from 125 μm used during setting to 250 μm and ultimately 500 μm. Silos are placed in tanks, where water is maintained at 15 to 17 ^{o}C and algae added 1 to 3 times daily to maintain a target density of 75,000 to 100,000 cells per mL (Table 3). Post-metamorphic clams from one silo are sorted and redistributed by size as needed. Sorting occurs 1 to 3 times per week for smaller clams (i.e., 300 μm mesh sieve) and once every 1 to 2 weeks for larger clams (i.e., 600 or 1000 μm mesh sieves; Table 4). Clams of similar size are quantified volumetrically and partitioned to silos at target densities: about 100 clams per cm^2 for 0.5 mm SL clams and about 50 clams per cm^2 for 1.0 mm SL clams.

Daily maintenance involves removal of silos, spraying with tap water and, if necessary, gentle scrubbing of silo walls, but not the mesh, to remove **feces**, **pseudofeces** and other material. Once each week, the airlift delivery system (i.e., PVC piping, pipette, tubing) is removed, cleaned and rinsed with hot tap water. Two to three times each week, tanks are drained, rinsed with tap water, scrubbed and cleaned with a bleach solution (2 to 5 mL per treatment), rinsed again with tap water and immediately filled with filtered, 15 ^{O}C seawater.

Table 3. Target densities for algae used to feed post metamorphic softshell clams in the CCML hatchery.

Algae	Target cell number per mL
Tetraselmis chuii (PLY 429)	3,000-8,000
Isochrysis sp. (T-ISO) sp.	40,000-60,000
Nannochloropsis sp. (UTEX 2341)	20,000-35,000
	Total 75,000-100,000

At CCML, when clams attain about 2 mm SL they are relocated to **Floating Upweller Systems (FLUPSYs)**, which constitutes the start of the Nursery Phase. To reduce the amount of resources and effort required, recently clams 0.5 mm SL or greater have been transferred to separate land-based upwellers that receive seawater filtered to 200 μm pumped directly from Smith Pool. Each upweller holds up to five silos maintained in a 1035 L tank (working volume). A continuous flow is provided to the tank at about 80 L per minute. Use of a land-based upweller shortens the time clams that are housed in the hatchery and provides a transition to the Nursery Phase.

At DEI, about 7 days after larval clams have metamorphosed within the shallow, floating trays (125 μm mesh), they are transferred to new trays with larger mesh (170 μm). Eventually clams are placed on trays with 500 μm mesh. Post-metamorphic clams are reared in the same trays and tanks until they reach 3 to 4 mm SL (Figure 11). At that point, they are placed in wooden trays lined with window screening in groups of 15,000 and relocated to a protected cove, which initiates the Nursery Phase.

Table 4. Clam sorting during Hatchery Phase at CCML. Days post spawn indicate when a specific sieve is first used. Size of clam in mm typically retained by a specific sieve in µm is indicated.

Days Post Spawn	Clam SL (mm)	Sieve size (µm)	Destination and silo mesh (µm)
1	0.1	35	Larval Holding Tank
8-14	0.2-0.25	150	Static Settling Silo (125)
12-20	0.25-0.3	180	Downweller Silo (125)
22-32	0.5	300	Downweller Silo (250)
29-46	1	600	Downweller Silo or Upweller Silo (500)
36-60	2	1000	Start Nursery Phase

Glossary

Active spawning – A method used to spawn clams where males and females are placed into separate containers and monitored as they commence spawning. Fertilization is controlled by mixing known ratios of sperm to eggs.

Airlift – A device used to aerate and circulate water. An airlift usually consists of a vertical cylinder (PVC pipe) submerged in water that transitions (PVC elbow) to a horizontal cylinder at or above the water line. Air is pumped into the submerged cylinder, as air rises up cylinder, it entrains water, and both exit out the horizontal section, establishing a flow of water.

Benthic – Relating to the bottom of a sea or lake or to the organisms that live there.

Cohort – A group of individuals in a larger population that are of similar age or size.

Continuous flow system – A system in which water and/or food is added continuously. For bivalve culture, algae used to feed clams is either dripped into or mixed with seawater that flows into the clam culture containers, to maintain a target density of algae.

Downweller – A culture container in which water is directed down through a layer of clams supported on a mesh screen of a silo. Typically this is accomplished via an airlift, and used at the pediveliger and early post-metamorphosis stage of clam culture.

Feces – Waste product from an animal's digestive tract.

Floating Upweller Systems (FLUPSYs) – Type of upweller that floats, typically resembling a dock or raft. Water enters the FLUPSY through the retaining mesh on the bottom of silos, it flows up through clams on the retaining mesh, and discharges into a center trough and exits the FLUPSY. Flow may be provided tidally, by a paddle wheel or submersible pump.

Metamorphosis – A complete or marked change in the form of an animal as it develops into an adult. In clam culture, metamorphosis generally refers to the period in which the veliger larvae gains a foot, becoming a pediveliger, then loses its swimming organ called the velum, and settles to become a miniature benthic clam. This period is stressful, and can result in elevated mortalities in the hatchery.

Passive spawning – A method used to spawn clams that are left in a common tank, males and females are not separated. Actual spawning may not be observed, but is usually detected by the presence of eggs and/or trochophore larvae in the water.

Pediveligers – Larval mollusks that have developed a small foot, which they extend beyond their shell and use to probe the bottom or sides of the larval tank.

Planktonic – References organisms, including algae and clam larvae, which float or drift in fresh or salt water. While some forms of plankton are capable of independent movement and can swim up to several hundreds of meters vertically in a single day, their horizontal position is primarily determined by currents in the body of water they inhabit.

Polar body – A tiny, non-functioning cell (less than10 μm) formed during the first meiotic division that eventually degenerates. It contains a nucleus, but little cytoplasm. (See photomicrograph in DaCosta *et al.* 2008).

Polyspermy – When more than one sperm fertilizes an egg, resulting in abnormal larval clam development.

Pseudofeces – The filtered, undigested material that is discharged because it is not food or the clam is full. The rejected particles are wrapped in mucus, and expelled out of the siphon. In a hatchery it can be a sign of overfeeding clams.

Setting – Term used by culturists for clams that are successfully going through metamorphosis.

Shell length – Measurement of a clam from its anterior end (siphon) to its posterior end (foot). In softshell clams this is typically the longest dimension.

Static system – Tanks that hold larvae through post-metamorphic clams without a continuous inflow of water. Water exchange is done periodically by a complete draining and refilling of seawater. Algae are typically fed in batches as needed.

Glossary *continued*

Thermal shock – The intentional warming and cooling of seawater to stimulate spawning. Usually the temperature change is 5 to 10 ^{O}C in less than half an hour.

Trochophores – The larval stage in bivalves that develops 12 to 20 hours after fertilization and lasts for 12 to 24 hours. They are 50 to 60 μm pear-shaped spheres surrounded by a girdle of cilia (fine hairs) with an apical tuft of cilia that is used to swim. Trochophores are equipped with a mouth, stomach, and anus. This is the developmental phase that precedes the veliger.

Upweller – A culture container in which water is directed up through a mesh, then through a layer of clams supported on the mesh and finally discharged. Typically this is accomplished with an external or submersible pump. Other methods of water movement include paddle wheels, air-lift, or tidal flow.

UV treated – Treatment of water with an ultraviolet light emitting bulb, usually housed in a clear glass tube, inside an opaque sealed cylinder. In aquaculture it is not used to completely sterilize, but rather to reduce pathogens and other undesired organisms. Its effectiveness is determined by flow rate and bulb intensity.

Veligers – Larval, planktonic mollusks with shells and a swimming organ called a velum, which is replaced by the siphon(s) once they become benthic organisms. This is the developmental phase that follows the trochophore.

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