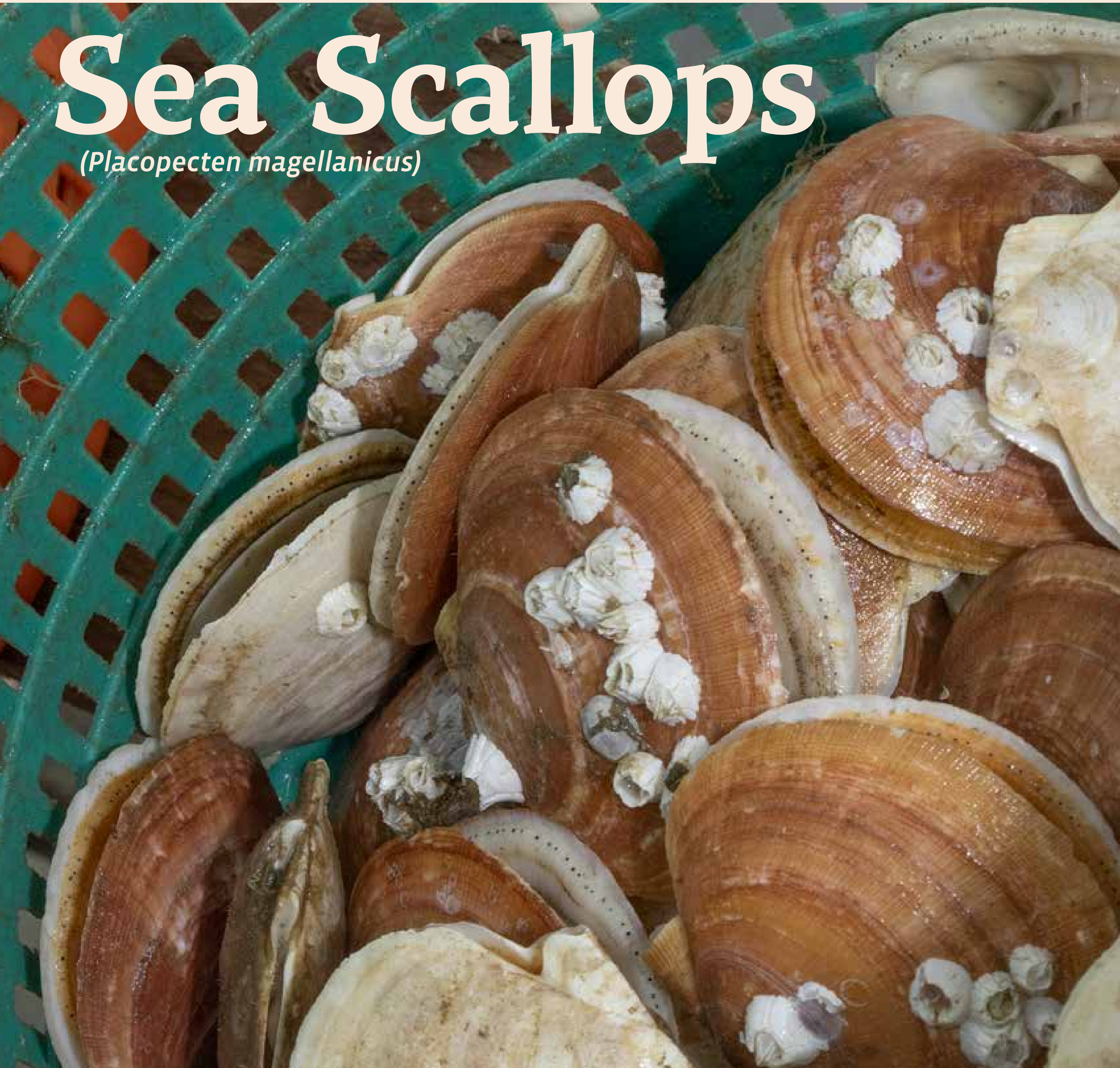
Methods and Materials for Aquaculture Production of

Sea Scallops

(Placopecten magellanicus)



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Rationale and background

Atlantic sea scallops (*Placopecten magellanicus*) present an aquaculture opportunity in the northeast US because of their high value, broad market demand, and favorable growth rate. Additionally, there is the potential for adopting equipment and husbandry methods from established scallop production in Japan and elsewhere. The US market for scallop adductor muscles, or scallop 'meats', is large: US landings averaged nearly \$380M between 2000–2016 (Anonymous, 2019).

Despite the opportunities, the species has presented challenges. Scallops prefer low-density culture, show sensitivity to temperature and salinity, have a relatively short shelf life (for live product), and require careful handling. The processes and equipment for scallop production in the northeast US continue to evolve. This sheet outlines the major processes, equipment, and considerations involved in scallop farming.

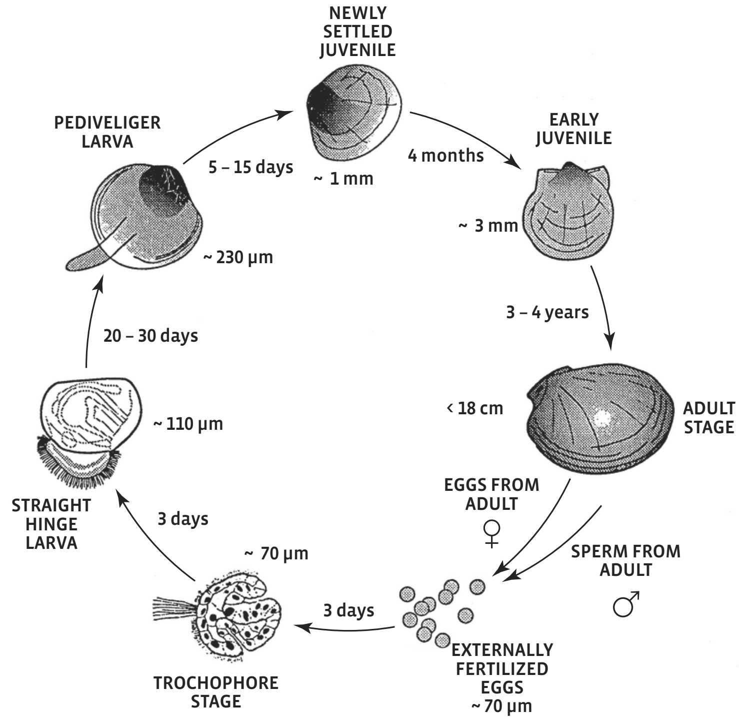

Figure 1. Generalized life cycle of the sea scallop, *Placopecten magellanicus*. From Stewart and Arnold, 1994.

Scallop biology

The range of the Atlantic sea scallop extends from the Gulf of St. Lawrence to Cape Hatteras. Individuals can live up to 20 years and grow in shell height to roughly 9" (22cm) (Hart and Chute, 1994). Sexes are separate, and individuals reach sexual maturity at age 2, although egg and sperm production is fairly low until age 4. Scallops are broadcast spawners, with sperm fertilizing the egg in the water column. In the Gulf of Maine, spawning occurs generally in July and August, with evidence of semi-annual spawning along at least part of the range (Thompson et al 2014). In Maine, settlement generally peaks during the last two weeks of September and the first week of October. Larvae undergo several developmental stages before going through metamorphosis and settlement at approximately 45 days post-fertilization. Newly settled larvae are usually smaller than 250 microns (0.25mm) in size, and will grow slowly through the winter, becoming 3–10 mm typically by the following March–May.

Sea scallops are active swimmers, especially when small, and can move 2+m during a single swimming event, although swimming becomes more inefficient over approximately 80mm (Dadswell and Weihs, 1990). The force for valve contraction during swimming is generated in the single adductor. The muscle itself is comprised of two parts: a larger 'quick' muscle that is responsible for the rapid contractions used in swimming and a smaller, slower-acting 'catch' muscle that keeps the shell closed for longer periods of time in part to defend against predation. Adductor muscles gain in mass more quickly as the animal passes approximately 100mm shell height (Hennen and Hart, 2012), and fisheries usually target larger individuals.

Scallops feed on phytoplankton and detrital matter, similar to other species of filter feeders like oysters and mussels. Flow rate, such as from tides and currents, impacts feeding ability, and rates above 10–20cm sec^2 (0.2 to 0.4 knots) can inhibit feeding (Wildish et al, 1987).

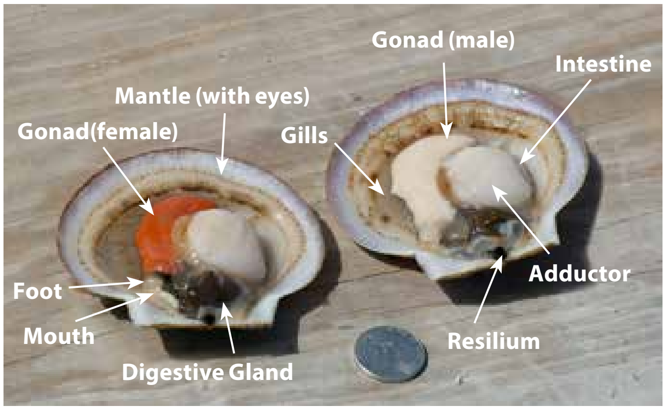

Figure 2. General anatomy of the sea scallop.

Scallops are subject to several pests and predators in the natural environment. Principal predators are sea stars (*Asterias sp.*), crabs (*Carcinus maenas*, *Cancer irroratus*, *C. borealis*) and lobster (*Homarus americanus*), though much of this predation can be reduced in culture and with proper attention to husbandry. Pests include fouling organisms like colonial and solitary tunicates, or 'sea squirts' (*Ciona intestinalis*, *Botryllus schlosseri*, *Botrylloides violaceous*, *Molgula manhattanensis*, *Styela clava* and *Ascidiella adspersa*), the hydrozoan *Tubellaria*, and settling shellfish such as blue mussel (*Mytilus edulis*), jingle shells (*Anomia simplex*), and barnacles (*Balanus sp*). Shell-boring polychaetes such as *Polydora websteri*, and boring sponges (*Cliona sp*) can cause damage to the shell and can reduce condition index—a measure of the overall health of the scallop, by comparing weight of tissues like the meat, roe, and viscera—when infestations become severe. Fouling by encrusting organisms is likely to be higher in suspension culture, such as ear-hanging, as compared to cages or nets, where the combination of filtration and scallop movement helps to keep the shells somewhat cleaner.

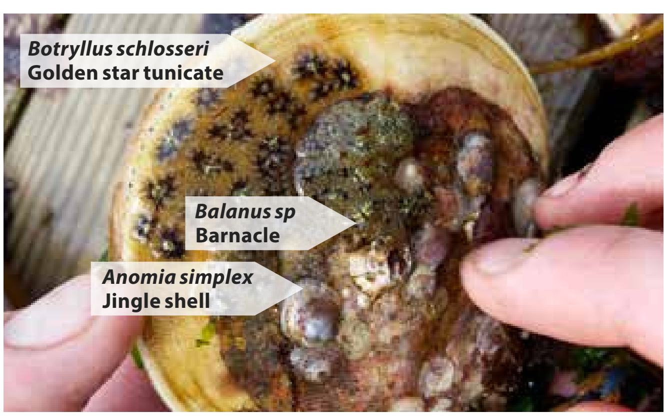

Figure 3. Some common fouling organisms on the right valve of an ear-hung sea scallop.

Spat collection

Scallop spat collection is a process of deploying a settlement substrate in places where larvae about to go through metamorphosis are present in high numbers. The standard gear was developed in Japan and has two principal parts: the spat bag and the substrate, or stuffing. The spat bag itself is about 0.6 m long and 0.3m wide, made of polyethylene mesh with openings typically 1.5 or 3.0mm in size. Inside the spat bag is the settlement substrate. Many materials have been tried, from monofilament gillnetting material to fuzzy rope for mussel farming, but polyethylene mesh is the industry standard. Netron™ is sold commonly by aquaculture suppliers in the Northeast US, although studies indicate that 1/4" agricultural netting (Industrial Nettings OV-7822) works as well or better, and and is less expensive (Morse and Cowperthwaite, in prep). Generally, each collector will hold 20–30 square feet of substrate.

Figure 4. Spat collector bags deployed by Nate Perry, Pine Point Oyster Company.

Collectors are usually deployed between the third week of September and the first week of October, and experience in Maine indicates that further offshore sites have better results than collection sites in rivers and in bays. Single lines of collectors are commonly used; bags are tied to the rope with the drawstring of the collector (*Figure 5*). Avoid setting bags within 2 fathoms of the bottom to keep the bags from collecting too much sediment or becoming damaged on the bottom, and the top 2–4 fathom of the water, where fouling rates are high.

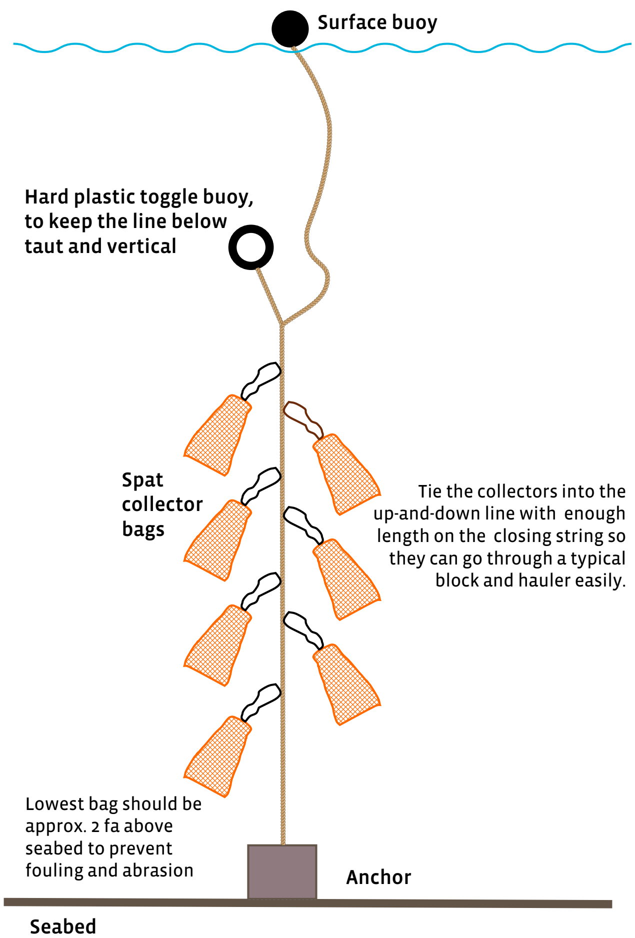

Figure 5. Typical spat collection line deployment.

Above the topmost bag, attach a hard plastic buoy to act as a toggle; this will keep the collectors oriented vertically as much as possible. A surface buoy and an anchor will keep the equipment in place, and will allow you and others to mark the location.

*Note: before engaging in spat collection, check on the regulatory requirements in your state about setting such gear.

Collector retrieval is a process of getting the collector line back aboard the boat, removing the settlement substrate, and shaking the scallops free. It is often handy to have a large container for this, such as a barrel or a large insulated container, as scallops will scatter when shaken off. Once the scallops have been shaken off, they should be transported to clean, circulating water as soon as possible. Retrieving collectors on very hot, cold or rainy days should be avoided where possible. April–June is a common time-frame in Maine. Yields along the Maine coast are often above 1,000 scallop per collector, with collections in excess of 10,000 per collector possible.

A video on seed collection in Maine can be viewed at: *youtube.com/watch?v=MWb9OJQ1uGI*

Nursery culture

Once scallops are removed from collectors, they are placed in nursery culture. The goal of the nursery is to efficiently grow scallops from their small size as juveniles to a size that they can either be sold as a specific product (such as half-shell) or sent to the growout stage. Common nursery gear includes bottom cages, lantern nets, pearl nets, and suspended cages. Bottom cages have the advantage of remaining stable once deployed, and can be constructed of materials common to aquaculture and the fishing industry, such as oyster bags and wire mesh. Lantern nets and pearl nets have the advantage of being light in weight and collapsible, so many can be transported at one time; they are the standard gear in scallop-producing countries and provide good protection with good water flow, but must be frequently maintained against fouling. Hanging cages such as Dark Sea™ trays or Max-Flow™ cages can be used as well, though will likely need a small-mesh liner to accommodate small scallop seed. Surface gear should be avoided, as too much movement by surface waves will reduce growth and increase mortality. Scallops are typically set into nursery culture at 3mm–10mm shell height; removal from the spat bag allows juveniles to have more space and greater access to food and flow.

Figure 6. Scallops taken from a collector, showing a broad range in size. Photo: Bob Ware, used with permission

It is important to pay attention to stocking density when growing sea scallops; they tend to clamp down on one another's shells, damaging both the shell and the mantle when grown too close together.

Stocking density is usually approximated by bottom coverage; treating the scallop as a circle, compared to the space in the net. 20–30% stocking density is common, but will vary by farm. Some examples at 20% stocking density are below.

Shell Height	Pearl Net	Lantern Net Tier
5mm	1,100	2,000
20mm	75	125
50mm	6	20
70mm	2	10

Each site will vary; the above are only guidelines.

Growout

Many approaches are used in growing sea scallops, each with their own attributes and drawbacks. Depth, exposure, vessel size, handling capacity, and other such details will vary for each farm, and small-scale experiments may be necessary before scaling any operation.

Bottom cages

Bottom cages vary in size and material, and can be scaled to the vessel lifting capacity. Oyster bags can be housed in wire mesh cages for an easy-to-handle option, or larger cages can be designed. Power washing or swapping fouled gear for clean will be needed periodically; just remember that scallops cannot be power washed or submerged into any sort of dip (hypersaline, hydrated lime, freshwater, etc) for fouling control.

Figure 7. Some typical examples of bottom cages. Top: oyster bags in a wire mesh rack. Bottom: Aquatrays™.

Pearl nets

Pearl nets are commonly used both for nursery and growout. They are inexpensive, designed to be hung in strings, and good at minimizing the action of high currents or surface waves. To minimize time spent sewing pearl nets shut, it's common to leave a section of the seam open; the weight of the line in water will help to keep the seam closed, and this will drastically reduce handling time in emptying and refilling each net. Fouled nets are usually emptied, and then taken ashore for cleaning, or dipped in a hot tank aboard ship. Several mesh sizes are available.

Figure 8. Pearl nets, strung together and deployed from a horizontal longline.

Lantern nets

Lantern nets also come in a variety of mesh sizes, heights (number of tiers), shapes (square or round), and closure types (sewn, zippers, Velcro™, etc). Round lanterns are most common and, once the process of sewing shut has been mastered, become fairly straightforward. Lanterns can be laid on their side so that the scallops fall to the bottom, and the top half of the net pressure-washed. The net is then rotated and the other half can be cleaned. This keeps the scallops safe from the blast of the pressure washer.

Figure 9. A lantern net being raised from a longline by Bobby Brewer (pictured) and Marsden Brewer; Stonington, Maine.

Suspension cages

(Dark Sea™, Max Flow™ cages)

Rigid cages can be used both as bottom cages or can be suspended by longlines. Their capital cost is typically higher than lantern or pearl nets, but they are easier to handle and can save money by reducing labor costs.

Figure 10. Top: Dark Sea trays, as deployed from a longline. Photo: Fermes Marines du Quebec, used by permission. Bottom: a stack of Max-Flow trays, as hung from a raft.

Ear hanging

Ear-hanging is a common technique for scallop production in Japan and other parts of Asia, though in the US it is still in the experimental phase. The process involves drilling a small hole (approximately 1.5mm) in the byssal notch of each individual scallop, and attaching the scallop to a dropline by means of a plastic pin or thread. The technique provides good access to flow and feed for each scallop, but equipment costs can be quite high, running into the tens of thousands of dollars. Two main approaches to ear-hanging exist. In the first, pairs of scallops are hung off of barbed plastic pins ('age-pins'), so that each individual hangs separately. In the second, 'loop-cord,' pairs or groups of scallops are hung from a thin nylon line that runs parallel to the drop line. The nylon line is tied off in segments so that if the line breaks only a few scallops will be lost. In this approach, the scallops are spaced directly next to one another.

Figure 11. Top: Scallops hung from age-pins. Bottom: scallops hung from loop cord

Husbandry and fouling control

Scallops are very sensitive to extremes in temperature and humidity. Make sure that your work flow minimizes air exposure and temperature swings; water baths and sun shading are helpful, especially on very hot, cold, or windy days. Unlike oysters, scallops will not tolerate fresh water rinses. Biofouling control can be accomplished through physical removal such as scraping or pressure washing, or by air-drying the equipment.

Longline design and materials

Longlines vary in length and materials but have some elements in common. Scallop longlines generally require 60 feet (18m) of depth or greater to function properly, and to accommodate nets and lines.

Moorings and mooring lines

Anchors for longlines include screw-type anchors, deadweights, and modified kedge-type anchors. Screw/helical anchors are easy to deploy, but should only be used where the sediment will definitely support the longline, as failure will lead to lost gear. Deadweights such as granite blocks may be more expensive, but will provide a measure of security as long as they are properly deployed and matched to the holding power needed. A modification of kedge anchors is used commonly in Japan and has been tried in Maine with some success. They must be matched well to holding power needed and sediment, and the longline may move or tangle if the anchors fail in heavy weather. Mooring lines are set commonly at 3:1 to 5:1 scope, with appropriate shackles and chain at the anchor end to provide seakeeping and to dampen shock loads.

Longline (or backline)

Longlines are commonly 24mm (1") in diameter and made of polypropylene, which has relatively low stretch. Longlines are submerged typically 10–25' below the surface to allow vessel traffic over the line and to place the culture gear below the zone of heaviest fouling.

Tension buoys

Tension buoys are attached where the mooring line joins the longline ends. Hard plastic, submersible buoys of 75lbs (34kg) buoyancy are commonly used, sometimes in groups of three or more. Tension buoys help maintain the shape of the longline and can help identify the end of the longline, although they are submerged most of the time.

Marker buoys

Marker buoys are placed periodically along the longline. Their purpose is somewhat to help maintain a level profile in the longline, but more to act as an indicator of when to add more compensator buoys, as the crop grows and becomes fouled over time. The marker buoys also alert mariners to the presence of the longline, and can be used to raise specific portions of the longline when needed.

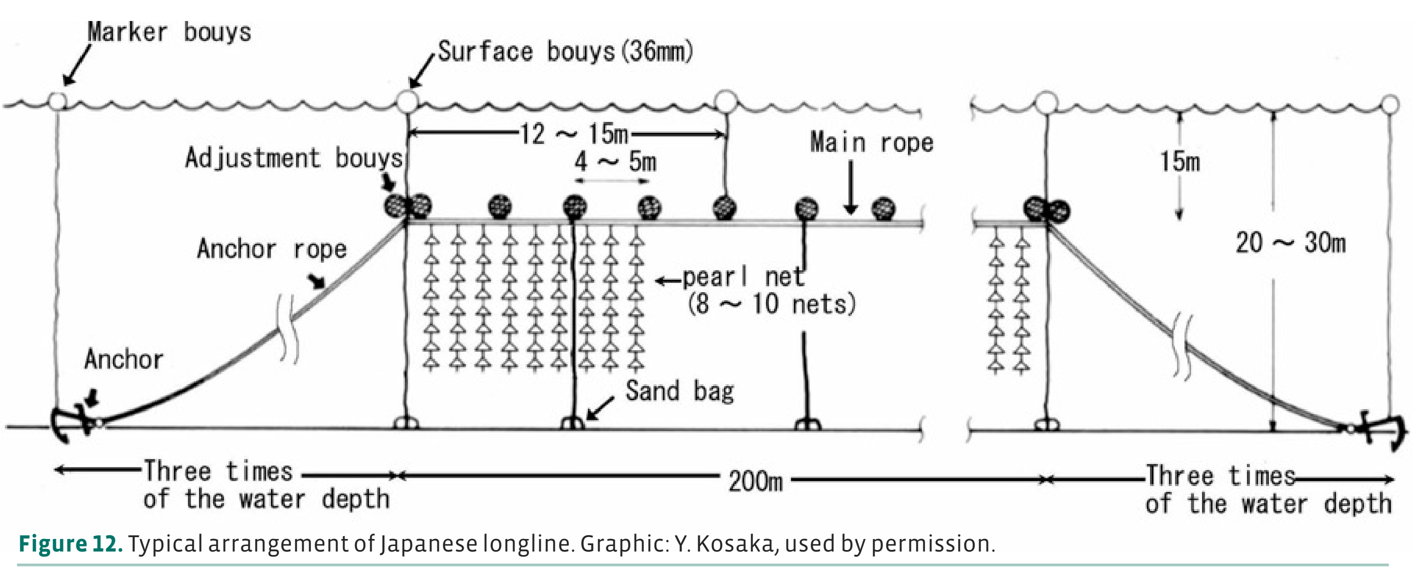

Figure 12. Typical arrangement of Japanese longline. Graphic: Y. Kosaka, used by permission.

Compensation buoys

Compensation buoys maintain proper buoyancy, and a horizontal profile along the line. There is a balance to be struck; too much flotation will bring the entire longline to the surface where it can present a navigation hazard, and not enough flotation will result in culture gear that might rest on the bottom, where it will abrade and allow predators to climb up the lines.

Longline weights

As a balance to buoyancy compensation, weighted droplines to the seabed are often used. Weights might be concrete, stone, or even bags filled with sand, and might range from 50 to 200 lbs.

Site selection

Site selection for any species is a critical decision, and the factors that influence this decision are complex. However, some of the basics that relate to scallop farming include the following: correct temperature and salinity; feed availability; ability to access the site; proper flow and exposure to extreme conditions; depth; presence of competing uses, such as fishing; seabed composition and ability of moorings to remain in place; type, degree, and seasonality of fouling; and frequency and degree of harmful algal blooms in the area. Growers may find it helpful to list out the various considerations and take notes about how one site compares to another.

	Minimum	Maximum
Salinity [1]	24ppt	36ppt
Temperature [2]	-1C / 30F	20–24C / 68–75F
Flow (cm/sec)	3–5 [3]	20–30 [4]

Figure 13. Salinity, temperature, and flow thresholds for farming sea scallops.

1.Mullen and Moring 1994 2.Petrie and Jordan, 1993 3.Wildish and Saulnier 1993. 4.Wildish et al. 1987

Economic considerations & recordkeeping

As with any business, good recordkeeping is key to financial success. Growers should prepare a business plan and cash flow projections as a necessary part of growing the farm. It is especially important to keep detailed notes; this documentation of capital and labor costs, husbandry observations, growth and mortality, and any potential returns will be indispensable raw material for a well thought out business plan. An all-weather notebook and a pencil are some of your greatest and most valuable resources!

A natural complement to the business plan is the cash flow statement, which can be created for a month, a year, or several years at a time. The cash flow statement will give the you chance to document revenue and expenses, and all growers to make reasonable guesses as to how revenue and expenses will change in the future. An example of a cash flow statement is given in Appendix I.

Scallop products, biotoxins & public health

US consumers are generally accustomed to eating only the adductor muscle of the scallop (scallop 'meat'), and this tissue usually accounts for about 15% of the total wet weight. Consumers elsewhere are more used to eating both the adductor muscle and the roe, or even the entire scallop. Greater utilization of the scallop helps to diversify products from scallops, and may bring greater return to the farmer. However, there are critical issues with respect to public health and seafood safety that cannot be ignored when considering these options.

Under no circumstances should scallop tissues other than the muscle be consumed, unless it has been part of an approved testing process overseen by appropriate authorities. Phycotoxins such as saxitoxin and domoic acid can build in scallop tissues to dangerous or deadly levels. Moreover, scallops can hold such toxins for weeks or months, and can be toxic even in the absence of a harmful algal bloom. (Bricelj and Shumway, 1998). Without testing, it is impossible to tell if scallop tissues are safe to eat. It is absolutely critical that producers intending to explore roe-on or whole scallop markets be in close contact with their state regulatory agency, and understand requirements and limits for such activity.

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Appendix I

Example of an annual cash flow statement

One-Year Cash Flow Projection

(Business Name)

Starting date	Mar-19
Cash balance alert minimum	

	Beginning	Mar-19	Apr-19	May-19	Jun-19	Jul-19	Aug-19	Sep-19	Oct-19	Nov-19	Dec-19	Jan-20	Feb-20	Total
Cash on hand (beginning of month)	5,000	20,000	20,000	20,000	20,000	20,000	20,000	20,000	20,000	20,000	20,000	20,000	20,000	
Revenues														
Lobster														0
TOTAL REVENUES		0	0	0	0	0	0	0	0	0	0	0	0	0
Total cash available	20,000	20,000	20,000	20,000	20,000	20,000	20,000	20,000	20,000	20,000	20,000	20,000	20,000	
Expenses														
Fuel/Oil														0
Bait														0
Trap replacement														0
Ice														0
Equipment														0
Labor														0
Licenses/permits														0
Vehicles														0
Nets and Gear														0
Repair Contingency														0
Dockage														0
Insurance- Hull, P&I														0
Insurance- Health														0
Fees														0
Taxes														0
Professional														0
GL Insurance														0
Utilities (electric)														0
phone														0
heat (propane)														0
shop supplies														0
Travel														0
Rent														0
Meals and entertainment														0
Miscellaneous														0
TOTAL CASH PAID OUT		0	0	0	0	0	0	0	0	0	0	0	0	0
Cash on hand (end of month)	20,000	20,000	20,000	20,000	20,000	20,000	20,000	20,000	20,000	20,000	20,000	20,000	20,000	

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