Methods and Materials for Aquaculture Production of Sea Scallops (*Placopecten magellanicus*).

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Rationale and background

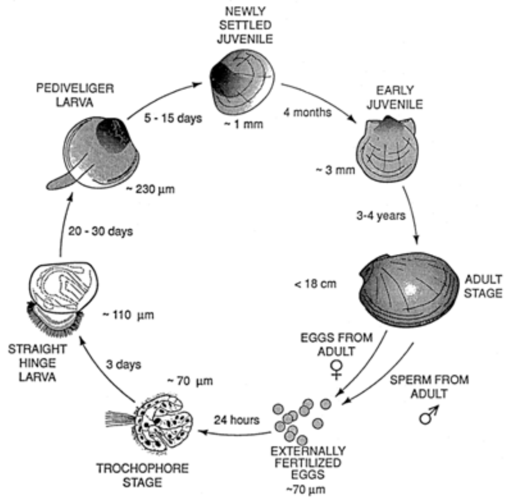
Sea scallops (*Placopecten magellanicus*) present an aquaculture opportunity in the northeast US, because of their high value, broad market demand, favorable growth rate, and the potential for adopting equipment and husbandry methods from established scallop production in Japan and elsewhere. The US market for scallop adductor muscles - or scallop 'meats' - is large: US landings averaged nearly $380M between 2000-2016, and in 2016, the US imported another 22,000 tons of scallops worth over $320M (Anonymous, 2019).

Despite the opportunities, the species has presented challenges, due to its preference for low-density culture, sensitivity to temperature and salinity, relatively short shelf life (for live product) and the careful handling required. 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.

Scallop biology

The range of the sea scallop extends from the Gulf of St. Lawrence to Cape Hatteras. *P. magellanicus* can live up to 20 years, and shell heights of roughly 9" (22cm) have been observed (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. Larvae undergo several developmental stages, before going through metamorphosis and settlement approximately 45 days post-fertilization. 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. Newly settled larvae are usually smaller than 250 microns (0.25mm) in size, and will grow slowly through the winter, becoming 5-10 mm typically by the following March-May.

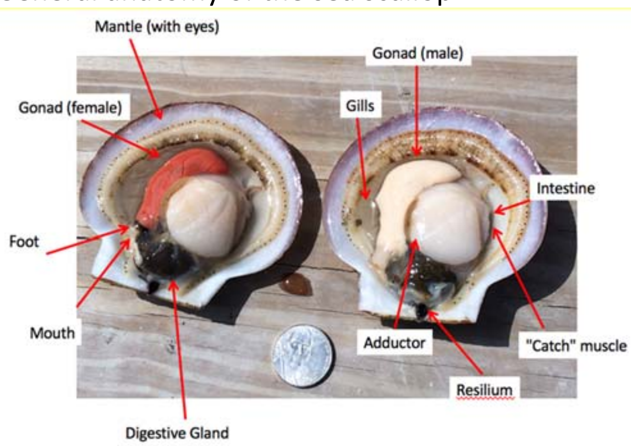
Figure 1.
Generalized life cycle of the sea scallop, *Placopecten magellanicus*. From Stewart and Arnold, 1994.



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 muscle, usually referred to as the 'scallop meat.' Adductor muscles gain in mass more quickly as the animal passes approximately 100mm in shell height (Hennen and Hart, 2012), so fisheries usually target larger individuals. The muscle itself is comprised of a larger segment, usually referred to as the 'quick' muscle and a smaller segment, the 'catch' muscle. The functions of each part differ; the larger segment is responsible for the rapid contractions used in swimming, while the catch muscle is slower-acting but keeps the shell closed for a longer time, principally as a defense against predation.

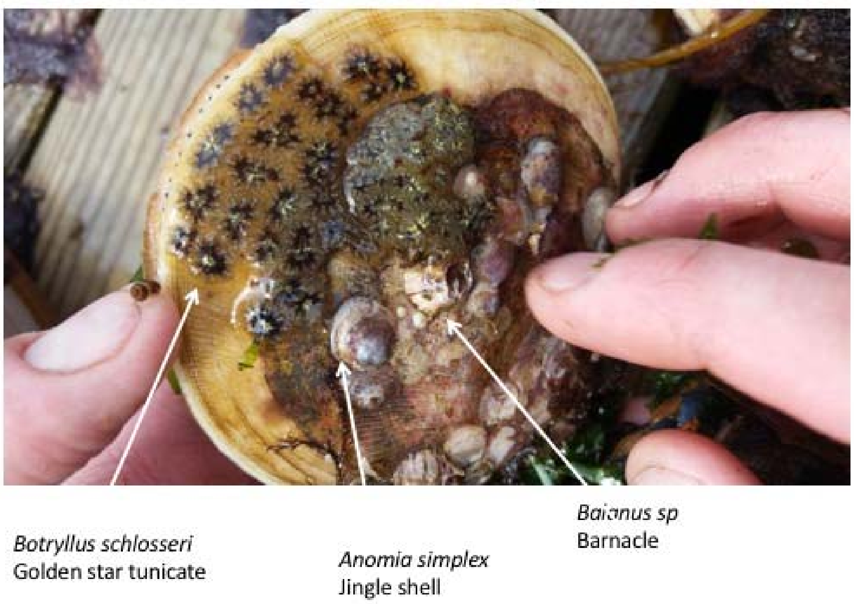
Scallops feed on phytoplankton and detrital matter, similar to other species of filter feeders like oysters and mussels. Flow rate impacts feeding ability, and rates above 10-20cm sec^2 (0.2 to 0.4 knots) can inhibit feeding (Wildish et al, 1987).

Figure 2.
General anatomy of the sea scallop



Scallops are subject to several pests and predators in the natural environment. Principal among these 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 (*Mya arenaria*), 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 using weights of various tissues - 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.



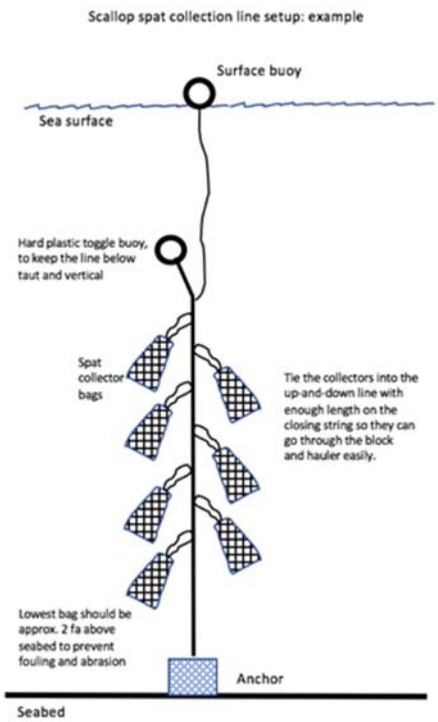
Spat collection

Scallop spat collection is a process of deploying a settlement substrate in places where competent larvae (those 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 having 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 more inexpensively (Morse and Cowperthwaite, in prep). 20-30 square feet of substrate per collector is common.

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; (Figure 5) bags are tied to the rope with the drawstring of the collector. 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 avoid the top 2-4 fathom of the water, because of the high fouling rates there, especially with mussels.

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, and then removing the settlement substrate and shaking the scallop free. It is oven handy to have a large container for this, such as a barrel or a large insulated container, as scallops will fly all over as they are 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 cold or hot days should be avoided where possible, so April-June is a common time-frame in Maine. Yields on good sites on the Maine coast should be above 1000 scallop per collector, with collections in excess of 10,000/collector possible.

A video on seed collection in Maine can be viewed at:
Seed collection: https://www.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 on to the growout stage.

Common nursery gear includes bottom cages, lantern nets, pearl nets, or suspended cages. Bottom cages have the advantage of remaining stable once they are 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 they 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. Scallops are typically set into nursery culture at 3mm-10mm shell height; removal from the spat bag allows juveniles greater access to food and flow, and more space.

Figure 6:
Scallops taken from a collector, showing a broad range in size

Photo: Bob Ware, used by permission

It is important to pay attention to stocking density when growing sea scallops; they will damage one another when grown too densely, as they will have the tendency to clamp down on one another's shells, damaging both the shell and the mantle in the process. At 5mm shell height, stocking density might be 100 scallops per pearl net or 200 per lantern tray tier, whereas by 20mm density might be 15-20 per lantern or 15-30 per lantern, and at 75mm, 5 per pearl net or 10-15 per lantern tier might be appropriate. Each site will vary; the above are only guidelines.

Note: at any phase, scallops are very sensitive to extremes in temperature and humidity. Make sure that your workflow minimizes air exposure and temperature swings; temporary holding tanks with flowing seawater, and sun shading are helpful. Unlike oysters, scallops will not tolerate fresh water rinses.

Growout
Many approaches are used in growing sea scallops, each with their own attributes and drawbacks. Depth, exposure, vessel size and handling capacity and other such details will be important to decide the correct option for each farm, and small-scale experiments may be necessary before scaling any operation. In all cases, take care to minimize the amount of time that scallops are exposed to air; they are sensitive to temperature changes, physical damage

and desiccation. Wherever possible, limit physical stress through shading, minimizing any kind of handling, and maximizing the time that the scallops stay in water.

Bottom Cages

Bottom cages vary in size and material, but 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. Left: oyster bags in a wire mesh rack. Right: Aquatrays™

Pearl Nets

Pearl nets are commonly used both for nursery and growout. They are inexpensive, and designed to be hung in strings, and are good at minimizing the action of high currents or surface waves. To minimize time spent in 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.

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

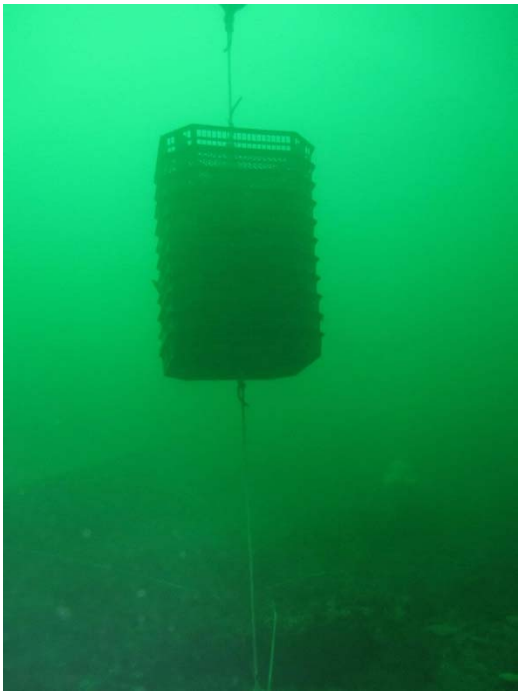
Lantern Nets

Lantern nets also come in a variety of mesh sizes, as well as differing number of tiers, square or round shape, and closure types (sewn, zippers, Velcro™, etc). Round lanterns are most common, and once the process of sewing shut has been mastered, becomes 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 have the advantage of ease of handling, so labor costs can be reduced.

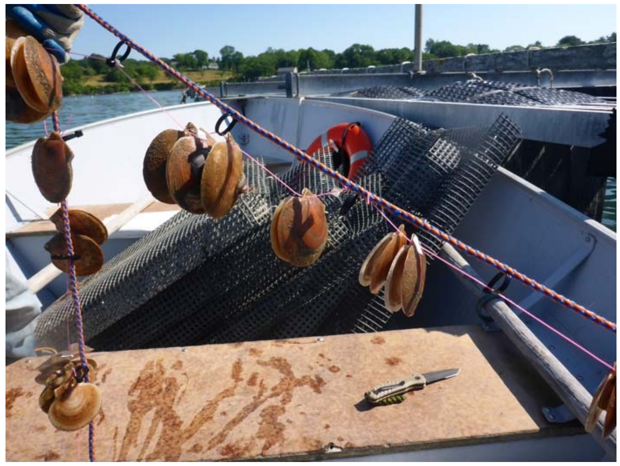
Figure 10:
Left: Dark Sea trays, as deployed from a longline. Photo: Fermes Marines du Quebec, used by permission. Right: a stack of Max-Flow trays, as hung from a raft.

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 method, using so-called '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.
Left: Scallops hung from age-pins. Right: scallops hung from loop cords

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. Turning a lantern net on its side lengthways and pressure washing the top half can be accomplished with the scallops still in the net; then the lantern can be rotated to gain access to the second half.

Longline design and materials

Longlines vary in length and materials but have some elements in common.

<u>Moorings and mooring lines</u>

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, but again must be matched well to holding power needed and sediment, and they will not prevent the longline from moving and tangling if they 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.

<u>Longline (or backline)</u>

Longlines are commonly of 24mm (1") diameter line; polypropylene is often used because of its 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 (34 kg) buoyancy are commonly used, sometimes in groups of three or more. Tension buoys function to 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.

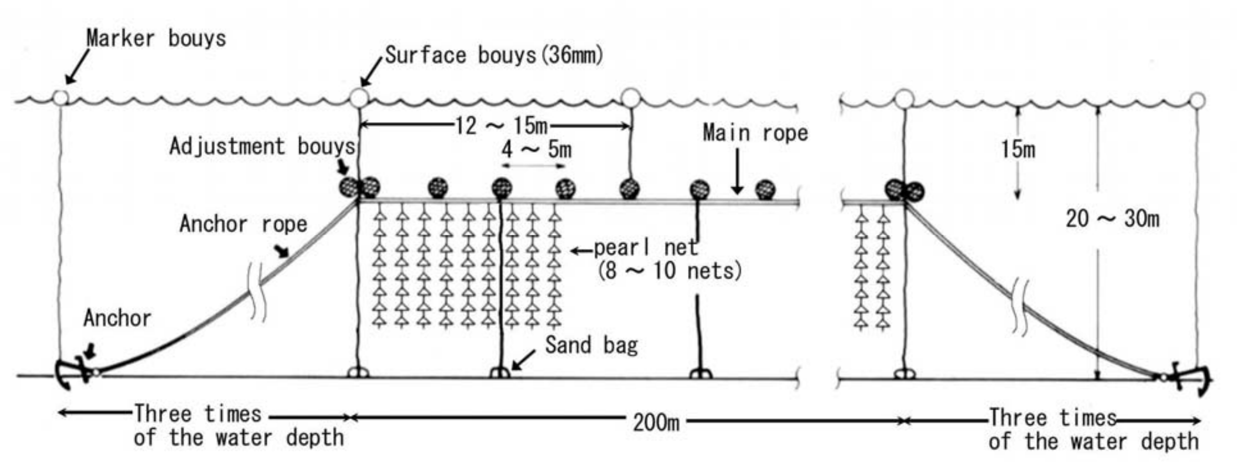
Compensation buoys

Compensation buoys maintain proper buoyancy along the line, and a generally horizontal profile. 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 compensation buoys, weighted droplines to the seabed are often used. Weights might be concrete, stone or even bags filled with sand; weight might range from 50 to 200 lbs.

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



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; frequency and degree of harmful algal blooms in the area, *et cetera*. Growers may find it helpful to list out the various considerations, and take notes about how one site compares to another, to help in decision-making.

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

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

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

Economic considerations and recordkeeping

As with any business, good recordkeeping is a 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 various time scales such as a month, a year, or several years at a time. The cash flow statement will give the grower a 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 and public health

US consumers are generally used 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, and it is impossible to tell without testing if scallop tissues are safe to eat. 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). It is absolutely critical that producers intending to explore markets for roe-on or whole scallops be in close contact with their state regulatory agency, to 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)	0	0	0	0	0	0	0	0	0	0	0	0	0	
Revenues														
Scallops whole														0
scallops meats														
Scallops other														
TOTAL REVENUES		0	0	0	0	0	0	0	0	0	0	0	0	0
Total cash available	0	0	0	0	0	0	0	0	0	0	0	0	0	
Expenses														
Fuel/Oil														0
Seed														0
Packaging														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)	0	0	0	0	0	0	0	0	0	0	0	0	0	

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