METHODS OF HANDLING AND SHEDDING BLUE CRABS, *Callinectes sapidus*

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INTRODUCTION

In 1940, Beaven and Truitt studied various aspects of the soft crab industry and made recommedations on the proper care and handling of peeler crabs. Similar observations were made by Newcombe (1945) in his discussion of the conservation of the blue crab.

In the past two decades, an increasing number of dealers have attempted to hold and shed crabs in some type of shore-based facility. Included are those who have abandoned the use of floats as well as those who are new to the industry. A wide variety of installations has resulted. Each operation possesses certain unique features, but is similar to all others in one or two aspects.

In a survey of the shedding industry in Maryland, Jachowski (1969) briefly reviewed some of the problems that can be encountered in a tank operation. Many of the concerns were similar to those expressed by Beaven, Truitt and Newcombe.

An all-inclusive check-list of pitfalls and specifications for handling and holding peeler and soft crabs is not available. This report summarizes the problems common to the soft crab industry and suggests guidelines for the installation of seawater systems for holding and shedding crabs. In many cases, specifications are not made because a system usually must be tailored to specific situations.

Many details related to the shedding of blue crabs in artificial surroundings must still be worked out, but some of the observations in this report may benefit those experiencing heavy losses in their shedding operations. These observations are also applicable to individuals who wish to establish inland markets for fresh hard crabs.

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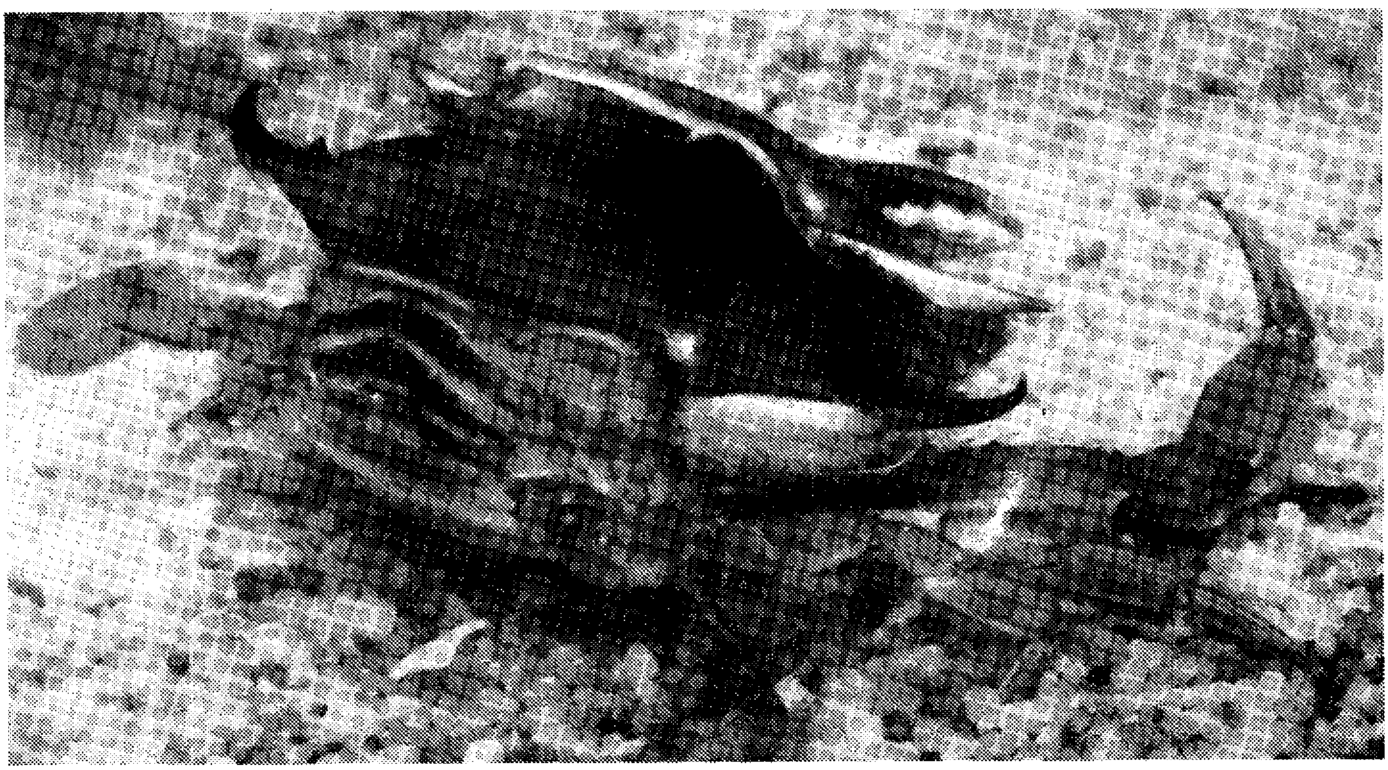


The blue crab increases in size by periodically shedding its hard shell. Once free of the outer shell, the "soft crab" expands to full size within fifteen minutes.

THE BLUE CRAB

The blue crab, *Callinectes sapidus* Rathbun, increases in size by periodically shedding its hard outer shell. When the crab completely emerges from the old shell, it has a new, soft, pliable shell, hence the term "soft crab". After shedding the outer shell, the crab expands to full size within 15 minutes, increasing in width approximately 25 percent before the new shell begins to harden.

Prior to the shedding stage, the new shell begins to form beneath the outer shell. As the new shell develops, it darkens and becomes visible through transparent parts of the hard skeleton. The color of the new shell is most readily seen in the last two sections of the swimming legs.

It is possible to estimate the length of time before the "peeler" will shed by observing the color of the new shell. A "white-rim" (green-sign crab) will not shed for another one or two weeks; a "pink-rim" will require three to six days, and the "red-sign" peeler will shed in one to three days. A "buster" is a crab that has begun to emerge from the old shell and should make the final withdrawal in a matter of hours.

Crabs shed from 18 to 23 times following the larval stages but become marketable as peeler crabs when they reach 2½ to 3 inches in width. Although it is the soft crab which is highly regarded as a gourmet item and forms the basis for the market, the increasing demand for the peeler crab as a bait for sport fishing has made it an integral part of the industry.

THE SOFT CRAB INDUSTRY

The soft-crab packing industry originated in Crisfield, Maryland in 1873. Since then it has spread into Virginia, Delaware, New Jersey, North Carolina, Florida, Mississippi and Louisiana. Although growth of the industry continues in the southern states, Chesapeake Bay remains the major source of soft crabs.

Shedding and soft-crab packing houses are located over a wide area of Chesapeake Bay but the packing center is still located at Crisfield. Of the 32 Maryland and Virginia counties listed in Fishery Statistics of the United States (1960) as having contributed to the production of soft crabs and peelers, Somerset County in Maryland, which borders on Tangier Sound, ranked highest with 2,230,700 pounds. Neighboring Accomack County in Virginia was second with a contribution of 587,600 pounds.

While the total Maryland catch for 1960 was listed at 2,788,000 pounds (nearly twice that of Virginia's 1,590,000 pounds), one must consider that Crisfield firms begin taking the catch of the western shore of Virginia and Tangier Island two or three weeks before soft crabbing is begun in Maryland. In addition, some of the Maryland soft crab catch is imported from Virginia.

Landings (4.2 million pounds) of peeler and soft crabs were valued at $1,639,000 to the Chesapeake fishery in 1969. Although the total value of the hard crab fishery for 1969 was larger ($5,374,000), the soft crab is worth considerably more per pound than the hard crab (56,654,000 pounds were required to bring in the $5.4 million ex-vessel value mentioned above).

Whereas the historical catch statistics for the past 40 years reveal fluctuations in the soft crab industry, the annual Chesapeake yield has always been somewhere between 2.5 and 8 million pounds. In most years the catch has been within the 3-to-5 million pound range.

CATCHING AND HANDLING OF PEELER CRABS

One source of soft crabs is the catch of crabs shortly after having shed. The majority of these crabs are taken by dip nets but also may be obtained by trotline and scrape, and more recently by peeler pound and peeler pot. However, the bulk of the soft crabs handled are obtained by the "shedding out" of peelers.

Studies by Beaven and Truitt on the distibution of peelers according to fishing gear and stage of molt indicate that the scrape and dip net caught fewer green crabs than did the trotline. On the other hand, trotline catches contained considerable numbers of green crabs, which do not survive well. Unlike the green-stage crabs, pink-sign to buster-stage crabs do not require food. Since crabs in shedding pounds are not fed, the green crabs suffer from malnutrition and eventually die.

The method of capture often dictates the way in which the peeler catch is handled from the time of capture to the time the crabs are placed in shedding facilities. Care and handling ultimately affect the percentage of peelers which survive and molt. Crabbing commences early in the morning and the crabs are not placed in the shedding floats or tanks until mid-afternoon. Frequently the necessary care is not provided to prevent losses in the peeler catch due to drying, excess heat, direct sunlight, overpacking and motor fumes.

Table 1. Comparison of soft crab yield in 5 days from dip-net and pot crabs.

Source	Purchased	Shed	Died	Alive not shed	Percent Mortality	Percent Molted
	Number of Crabs					
Dip net	450	149	217	84	48	33
Pot	450	72	361	17	80	16

Shallow containers would help prevent the problems of overpacking common to catches carried in the standard barrel. Covered boxes using moist eelgrass, burlap or some other means of producing shade and preserving moisture would also help protect the crabs. Live cars or wells, such as the type built into the boats of dip-netters, are highly effective in keeping the catch in excellent condition.

A dealer recently compared the soft crab yield from rank peelers purchased from dip netters and pot fishermen (Table 1). The comparison showed that survival through shedding was higher for crabs caught in dip nets than for those caught in pots.

Improvement in handling methods is by no means the only answer. The dealer must also take certain precautions if he is to obtain a successful yield. Some of the precautions mentioned below may be pertinent to both the dealer and the fishermen. The question of how the catch is to be handled and what will be accepted can be answered only by open communication between the parties involved.

When hard crabs are confined without food in the same tank or float with soft crabs they will feed on the soft ones and even destroy each other. To prevent injuries and cannibalism, the crabber can force the movable finger of the claw to the side until it is dislocated from its juncture with the claw. This practice, called "nicking", is satisfactory only if care is taken to prevent damage to the underlying muscle. Bleeding often results, causing swelling and blood clot formation in the joint which may lead to bacterial infection and death. This swelling often prevents the crab from pulling the newly-formed claws from the shed and often results in the death of the crab before it can slough the shell.

The figures of Beaven and Truitt indicate that nicking does not appreciably reduce the losses that occur if the claws are left intact. Binding the claws increases the survival of crabs in the floats but this method of protection is not practical, particularly for large-scale operations, because it takes too much time. Thus nicking is still the accepted method, but can lead to economic loss if it is not done carefully.

It is not economical to use green crabs as shedders since they require an extensive holding time and seldom survive the molting stage. Beaven and Truitt suggested that losses of shedding crabs would be reduced 80 percent by avoiding green crabs. They noted further that these crabs, if allowed to escape, may increase the general yield and contribute to a high level of brood stock.

THE FLOAT OPERATION

The commercial shedding facility most commonly seen today is hardly different from those existing at the time of the birth of the industry. The center of the operation is a wooden building ("shanty", "shedding house" or "soft-crab house") supported on pilings and surrounded by floats tied to stakes in the water. There are also sloping platforms onto which the floats may be hauled for cleaning and drying.

The floats are made entirely of wood, usually pine, and are of a basic design although variations are found in localized areas. They are often 3⅓ feet wide, 12 feet long and 18 inches deep.

The bottoms are made of close fitting 6-inch wide boards while the side and ends are constructed of vertically placed laths with ¼ inch spaces between them. A wooden shelf, 6 to 8 inches wide encircles the float about mid-depth. This wing stabilizes the float and helps buoy the float at a level preventing escape of the crabs. The narrow spacing of the lathing allows circulation of water over the crabs but prevents the entry of pests such as eels. Some variations known are widths to 4 feet and depths of 15 inches and 2 feet. A few dealers have installed screened covers to keep waterfowl and gulls out of the floats, but most floats are left uncovered.

Most float operations are located in shallow coves, harbors or inlets which are protected from excessive wind and wave action. These same locations, unfortunately, lack adequate currents, thus circulation and turnover of the water are poor. Without the proper turnover, waste products from the crabs accumulate and dissolved oxygen can be depleted.

The center of the float operation is a wooden building supported on pilings and surrounded by floats tied to stakes in the water.

These situations can become critical during long periods of low rainfall and high summer temperatures. Since the crabs are confined to the upper 9 to 12 inches of the water column (due to the inherent nature of the float construction) this exposure may become severe. At this depth, mortality in the floats can also occur from freshets or lenses of freshwater runoff from rainfall. However, of all the factors involved in the float operation, it was probably the desire for more convenience which led to the development of the shore based operation.

THE TANK FACILITY

Either the open or closed seawater system may be employed in a tank operation, depending on the location of the related facilities. The open system is commonly used in shedding operations situated within reasonable pumping distance of a natural supply of brackish water. The water is pumped into the tanks, passes through the system and is returned to the river or bay. The closed system involves the recirculation of a given volume of water within a tank or series of tanks. This type of operation is usually located in areas where it is impractical or impossible to pump from a natural water supply.

There are features unique to each of these systems but let us first observe their common components and the recommendations designed to make the systems functional.

BASIC COMPONENTS

Tank. The most common type of tank used in the industry today is one constructed of wood with outside dimensions of 4 ft. x 8 ft. x 9¾ inches. This size is generally derived from the basic sizes of the materials used. A 4 x 8 ft. piece of ¾ inch marine plywood forms the floor of the tank onto which are fastened sides of 2 x 10 inch pine (dressed size 1½ x 9 inches).

Smaller size tanks may be more practical for some operations. The tank mentioned above will hold 53 gallons of water at a 4-inch depth. A 4 ft. x 4 ft. x 10 inch tank would hold 30 gallons at the same depth. Wooden tanks are the easiest to construct, but certain precautions must be taken when they are selected for use.

Most soft woods are acceptable, but Stewart and Cornick (1964) found western red cedar to be toxic (poisonous) to lobsters. Redwood and Tennessee cedar extracts stained the lobster shells. Coating the wood is recommended to prevent leaching of such materials and to protect the wood from marine wood borers, surface fouling organisms and rot.

Since copper is potentially toxic to blue crabs (a sheet of copper placed in a tank of lobsters will kill them in 18 hours [Wilder, 1953]), any form of it should be avoided. This includes the copper-containing anti-fouling paint. One of the epoxy resins (GLUVIT)[1] is quite satisfactory. It not only waterproofs the wood, but seals the joints and is durable enough to be scrubbed. Pigments are available if coloring is desired. GLUVIT is much easier to apply than fiberglass cloth and resin, another alternative.

Reckeweg (1969) reported the use of a high-density 60/60 plywood[2] for tank construction. The plywood is impregnated and coated on both sides with a resin which makes it waterproof. Guidelines for tank construction are included in Reckeweg's paper, which also compares the cost of high-density plywood with standard exterior plywood covered with fiberglass cloth and resin.

Those who want to invest more money initially on permanent equipment should consider the construction of concrete tanks or purchase of gel-coated fiberglass tanks.[3] Concrete tanks will require a coating of non-toxic epoxy resin. Fiberglass tanks are relatively lightweight, yet quite strong, require no painting and, with reasonable care, outlast wooden tanks.

Shleser and Tchobanoglous (1973) designed a polypropylene tank with a sanitary surface and expandable compartments. The designers claim that the tank, used for lobster culture, costs one-fifth less than the fiberglass equivalent.

In any system, the drains or drain standpipes should be placed to promote a good circulation and turnover of water. Drains should be two to three inches in diameter and conveniently located for ease in emptying and cleaning the tank. Larger drains promote a smoother flow of water, but if the diameter is larger than the length of the crabs, it must be covered with a non-toxic screening such as VEXAR[4], available in a variety of mesh sizes. Metal screening should be avoided.

Tank support. There is no specific design required for tank support. Some dealers use trestles and saw-horses; some place the tanks on pilings. If a table is desired, it should be ruggedly built and reinforced according to the size of the tank it will support. Remember that a cubic foot of water (7½ gallons) weighs 62.4 pounds. The weight of a 4 x 8 ft. tank with 4 inches of water depth (53 gallons) is nearly 500 pounds.

Recommended is a table which stands 30 inches, constructed with six 4 x 4 inch legs bolted to an upper framework of 2 x 6 inch lumber. Additional strength is provided by an internal cross-bracing of 2 x 4 inch boards fastened to the 2 x 6 inch skirt.

For indoor display or holding purposes in an area where there will be little or no direct contact with corrosive salt water, a support frame of 2 x 3 x ¼ inch angel iron could be used as described by Stewart and Power (1965).

Pumps and plumbing. Careful thought should be given to selection of the correct pump for the job. Pump manufacturers provide directions and formulae so that the prospective buyer may make a decision on his own. It is critical that the pump and lines complement each other, and therefore it is advisable to consult a company engineer to select the most efficient combination for the job[5]. Some of the facts which must be known in order to apply the formulae are (1) vertical suction lift from water to pump, (2) the length of this suction line, (3) whether or not a strainer is employed on the suction line, (4) the vertical discharge head from the pump, (5) the length of the discharge line, (6) the number and type of fittings (elbows, tees, etc.) in the system, and (7) the desired rate of flow.

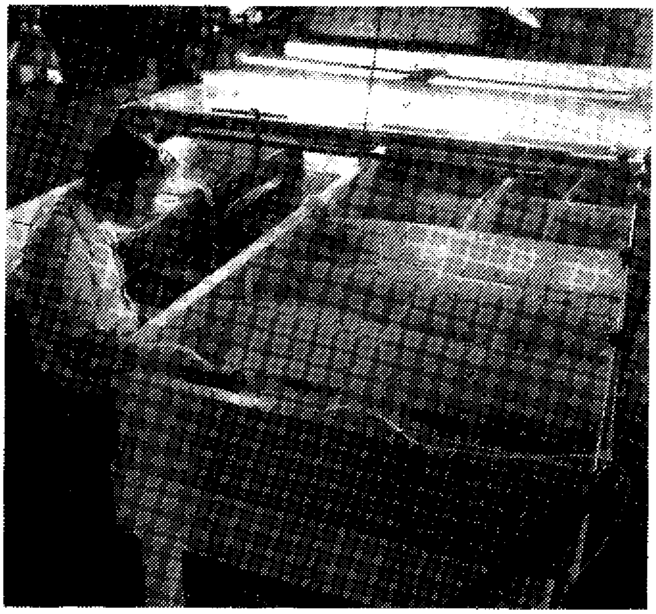
The size of the pump will depend on the volume of the overall operation. It is necessary, however, that a sufficient circulation and turnover of water be maintained in order to aerate (supply air to) the water and to remove poisonous waste products from the crabs. The higher the turnover, the better conditions will be for the crabs.

Recent results of research at the Virginia Institute of Marine Science (VIMS) have shown that equivalent commercial soft crab yields were obtained under conditions of two water depths, 4 and 8 inches. Over 40 turnovers of water per hour occurred in the shallow depth; over 20 in the deep tank. Thus it should be possible for commercial operations to lower the depth of water in their tanks. This would decrease the flushing time and increase the number of turnovers per hour which should improve the percentage yield in operations which normally experience a high death rate because of marginal pump capacity.

Lowering the water depth conserves water. Some operations could expand the number of tanks providing the turnover rate is maintained. Production then could be increased by maintaining the same density or by decreasing the number of crabs per tank to reduce mortality.

If a greater pump capacity is possible, one could conceivably hold more crabs with a higher turnover rate. If a single pump is to be used to supply water to more than one tank, its capacity must be calcu-

The open flow system is used in shedding operations within reasonable distance of a natural water supply.



The recirculated (closed) system is usually located in areas where it is impractical to pump from a natural water supply.

lated accordingly. In addition, the pump should be selected to insure that the impeller and other internal parts in contact with seawater be of a non-toxic material such as Hypalon[5]. Copper, monel metal, zinc or lead should not be employed.

A wider variety of pumps are available for use in a closed system but this may only make the selection more difficult. The precautions and considerations mentioned for open system pumps also apply here. The volume and flow rate for the system is just as critical, if not more so, in the proper selection of pump and lines.

Submersible pumps that can be placed in the tank are available, but one must be aware of the possibility of corrosion in these types. One may or may not desire to have each tank equipped with its own small capacity pump. Plastic window screening or other comparable material[4] should be used over the pump intake to prevent debris from entering the pump. Intake screens must be cleaned or replaced periodically to prevent excess impedance of flow into the pump.

All piping and related fittings should be corrosion resistant. A wide variety of polyolefin and other chemically inert materials approved for household water supply are being employed today. Plastic, poly-vinyl chloride (PVC) glass fiber and hard rubber are examples of non-toxic materials which are inert in seawater[6].

In open systems, the intake of the system should be placed in as deep a location as close to a channel as possible. A deep channel location is preferable because the water is usually cooler and more saline than in a shallow location. This would alleviate some of the temperature problems mentioned above. The intake should, however, be suspended a few feet above bottom so that mud and sediments are not drawn into the system. A screened intake of large (10-16 square feet) surface area is recommened. The out-flow should be at the surface and as far as possible from the intake. It would be detrimental to the entire system if the deoxygenated, warmer and waste-laden outflow water were to be picked up in the intake and recycled.

Surface fouling organism (sea squirts, barnacles and other encrusting animals) which set on the sides and bottoms of tanks can also set in the pipelines and seriously impede water flow. Periodic shutdown and backflushing with fresh water will kill the organisms and free the lines.

In the Chesapeake area, frequent shutdowns are necessary (bi-weekly in winter, weekly in spring and fall, every three to four days in summer). Since this may not be practical with a single pump and line system, a double system is recommended. The dual system allows one set of pump and lines to be placed in operation while the other set is being cleaned.

It is imperative that pump seals be maintained in good condition and that the plumbing be properly installed to prevent air leakage. If air is drawn into the system and compressed, nitrogen gas reaches supersaturated levels in the seawater. When this pressure is released as the water enters the tank, the nitorgen gas comes out of solution.

This may occur within the blood of the crab, in which case nitrogen bubbles form, blocking the blood vessels in the gills and obstructing the heart. This "gas bubble disease" ultimately leads to death of the animal.

WATER QUALITY

A closed system does not have the problem of intake and outflow positioning as does the open operation, but in either case one must consider the source of seawater and what can be done to keep it "healthy" for some time.

Some operators of a closed system may wish to transport natural seawater to their installation. The feasibility of this will depend on the volume of their operation, the distance from the source and the quality of the natural water. One would have to determine the difference in cost between the transportation of natural water (if it is satisfactory) and the use of artificial seawater.

If the shedding operation is located within a short distance of a brackish or marine water supply, it would appear obvious that such a source should be utilized. However, it is suggested that the operator determine the quality of the water before making any decision.

Since it is particularly beneficial to have the salinity (salt content) of the receiving water in a tank operation (or float, for the matter) nearly the same as that from which the crabs were caught, and in which they are transferred, the dealer should obtain this information. Open ocean seawater is nearly 35 parts per thousand (ppt) salinity which is equal to 3.5 percent salt.

Depending on the location in the estuarine bay system, shedding houses can be served by water ranging from 1 to 30 ppt salinity. Such information may be available from marine laboratories or other state agencies operating in the region.

The natural water source may not be totally satisfactory, even if the salinity is within the desired range. The suspended sediment matter may be at a level that would be detrimental to the operation in the form of shut-down time for such tasks as cleaning tanks and clogged pipes and repairing pumps.

The natural water supply may contain undesirable concentrations of phosphates, nitrates, pesticides, heavy metals and other forms of pollution. The extent of pollution, and the nature of the pollutant should be determined beforehand.

Dissolved organic wastes and suspended organic matter may kill crabs. Even if this is not the case, the presence of organic pollution can seriously lower the amount of dissolved oxygen in the water. Rather than operate with water of low quality, one might consider transporting water from another source, building a filtration system, or making artificial sea water.

Under comparable conditions in closed experimental systems at VIMS, the incidence of dead, partially shed crabs was higher in artificial sea water than in natural sea water. This feature alone may dictate avoidance of artificial water in operations for which natural water is available. If the latter is not available, sea salts may be tried. They have been used successfully in some lobster operations and are available commerically from at least three sources[7]. They are convenient in that one can concoct any salinity desired. Common table salt or commerical rock salt are not satisfactory for use in making artificial water.

Sea salts contain the major chemical elements and most of the minor elements in the same proportions as in natural sea water (Table 2). The salt mixtures are designed to be made up with fresh water. Some brands condone the use of tap water; others specify that deionized or distilled water be used in the recipe. The latter would require distillation[8] or the passage of fresh water through exchange resins[9], also available from sea salt suppliers. Regardless of the brand of artificial salt used, it is necessary to know the quality of the freshwater supply.

Water district offices should be able to supply water quality data for the local water supply. They can also provide the names of agencies to contact if analyses of well water supplies are desired. Excessive hardness, chlorination or concentrations of any one or more mineral elements may be detrimental to the entire operation. Since the product concerned in this operation is one destined for human comsumption, it goes without saying that the water used should be acceptable under the standards set by the U.S. Public Health Service. Coliform bacterial counts should also be made and considered along with the chemical analyses. If any doubts exist, consultation with local health department officials should be sought.

Table 2.

Chemical elements dissolved in sea water.

Major	Minor
Chlorine*	Silicon
Sodium*	Fluorine
Magnesium	Aluminum
Sulfur	Rubidium
Calcium	Lithium
Potassium	Phosphorus
Bromine	Barium
Carbon	Iodine
Strontium	Arsenic
Boron	Manganese
	Copper
	Zinc
	Lead
	Selenium
	Cesium
	(At least 16 others)

*Elements combined as sodium chloride in common table salt.

TEMPERATURE

Water temperatures ranging from 72° to 86°F are common in locations where shedding floats are used. Higher temperatures generally are accompanied by a higher death rate. Reported peeler mortalities are probably due to the combined effect of high temperature and critically low dissolved oxygen concentration of the water. As the temperature of the water increases, the quantity of oxygen that can be dissolved in it decreases (Table 3).

The active blue crab must be exposed to moderate or high concentrations of dissolved oxygen. Oxygen levels near 2.5 parts per million (ppm) are potentially critical to survival since the blue crab is unable to adjust its ventilation (breathing) rate beyond this point. At concentrations less than 1 ppm, crabs will die in 12 to 24 hours.

The number of crabs that can be held in a tank depends on the size of the animal, and on the rate of water flow as well as the ambient water temperature. Temperatures near 72°F are required for active shedding of crabs. It would be beneficial to maintain this temperature to help prevent undue mortality. If one intends only to hold hard crabs, the water temperature could be much lower. This would extend the holding time and reduce the maintenance problem since lower temperatures depress the metabolism of the crabs. It is known, for example, that American lobsters survive best under crowded conditions at 35° to 40°F even though they can withstand higher temperatures.

Excessively high temperatures encountered in float operations have been somewhat avoided simply by placing the tanks in a shed. Even in an open-air arrangement, the roof provides a sun shade and the water pumped into the tanks may be kept a few degrees lower than that measured at the surface of the source water. As walls, insulation, ventilation and air conditioning are added, the temperature of the water in the tanks more closely approaches the optimum.

Some recirculated operations have achieved a measure of success at temperature control by setting their main storage tank in the ground. One such reservoir was made of concrete curbing set in cement and extended 13 feet into the ground.

These measures are, at best, indirect ways of controlling temperature. If one is really serious about solving thermal problems, he should consider installing a direct method of cooling and control.

Stewart and Power (1965) placed a refrigerator evaporator coil of ½ inch copper tubing in the bottom of the display tank. The coil was bonded to the tank with polyester resin containing aluminum particles as a heat transfer agent. The refrigeration unit was secured under the tank.

A 15 x 30 foot concrete tank equipped with mechanical refrigeration equipment has been used in the successful storage of large quantities of lobsters in England. Special treatment of the evaporator coils was also necessary in this case.

Since it is sometimes difficult to maintain the isolation of metal from sea water, even when coated as described above, a two-stage cooling method could be applied. The refrigeration unit[10] could be used to cool a bath of fresh water or ethylene glycol (major component of antifreeze solutions) in an isolated tank. A small pump circulates the coolant through tubing[11] which can be loosely coiled in the tanks containing the crabs. An alternative would be to circulate sea water through a heat-exchange manifold of glass (Parisot, 1967) or other acceptable tubing which is placed in the coolant bath.

The tubing used in heat exchange operations should be thin-walled to promote as efficient a transfer of heat as possible. However, none of the plastic, polyethylene or linear polypropylene tubings available on the market are good thermal conductors. If is estimated, for example, that 100 times more thin-walled linear polypropylene tubing would be required to perform a given heat exchange than copper tubing.

Temperature control, particularly in the form of refrigeration, of even the smallest recirculation unit can be costly. Thus far we have discussed (1) keeping water temperature aound 72°F for purposes of bringing crabs through a molt, (2) performing this task by cooling during the critically hot periods of the year, and (3) doing this in a closed operation.

Tempering water in an open flow system of any size can be done only with heat exchangers[12] and a sizeable cash outlay. An idea of the type of equipment necessary for temperature control in a variety of systems can be obtained from Clark and Clark (1964) and Lasker and Vlymen (1969).

It is recommended that anyone seriously interested in tempering water for an operation seek professional help for an appraisal of the situation before any equipment is purchased.

Table 3.

Dissolved oxygen concentration (in parts per million) in fresh water and in various salinities at different temperatures. Figures in body of the table represent dissolved oxygen concentration.

Temp		Salinity, parts per thousand			
(F)	(C)	0	10	20	30
32	0	14.2	13.3	12.5	11.6
50	10	10.9	10.3	9.7	9.1
68	20	8.8	8.4	7.9	7.4
86	30	7.5	7.1	6.7	6.3

DISSOLVED OXYGEN

Maintaining a high oxygen level for blue crabs is extremely important. Increasing the surface area of the water supply and increasing its contact with a source of oxygen will increase the oxygen content of the water. A variety of aeration methods have been built into both open and closed systems and are reviewed below.

Since the water is introduced to the tanks under pressure, modifications in the plumbing can be made in conjunction with a variety of fittings to implement not only the direction of flow of water in the tanks, but also the introduction of oxygen by aeration. Some systems simply have small holes punched into overhead pipes. The force of the water from these fine streams striking the water in the tank aerates the water.

Other systems employ aspirator valves[13] in the section of pipe supplying each tank. Still other operations simply introduce water to the tank in the form of a spray by reducing the bore size of the pipe immediately supplying each tank.

Most of these methods cause a great deal of splash. If this is not desirable, one could install an air pump or compressor[14] and distribute air to the tanks through perforated pipe or air stones, available at aquarium dealers. Other modifications are possible depending on how elaborate a system is designed. Aeration, as well as temperature control, can be incorporated into a filtration unit (Clark and Clark, 1964; Spotte, 1970). However, if one is able to provide a high turnover rate of well-aerated water to the system, it would be unnecessary to install cumbersome, splashing devices for aeration.

A closed system, regardless of size, must have an aerobic (aerated) filter. If properly designed, this filter will (1) build up a growth of bacteria which will break down waste products (principally ammonia) from crab urine and feces, (2) maintain the pH (degree of acidity and alkalinity) at an acceptable level, (3) remove solid waste matter suspended in the water, and (4) aerate the water. The size and location of the filter will depend largely on the overall design of the operation.

The most important feature of the aerobic filter is the surface area available for bacterial growth. A calcareous gravel such as dolomite[15] (grain size ⅛ to ¼ inch) is perhaps the most acceptable granular filtrant. The grain size allows an efficient flow of water through the filter bed and provides a good surface area for the growth of bacteria. Dolomite is also a good buffer against sudden changes in hydrogen ion concentration (pH) because of the high percentage of magnesium in its composition [$CaMg(CO_3)2$].

The acceptable pH range in marine culturing is 7.5 to 8.3 (based on a 14-unit scale with 7 being neutral; pH less than 7, acid; pH greater than 7, alkaline). The acceptable range in brackish water (estuarine) systems is 7.1 to 8.0. Any drastic changes in pH, particularly those tending toward acid conditions, indicate system failure which should be investigated. Acid water increases the level of free carbon dioxide in solution which may interfere with oxygen uptake by the crabs.

Crushed oyster shells are a source of calcium carbonate and may be used in place of dolomitic gravel. They are considered inferior to dolomite, but better than pure limestone.

Charcoal[16] in granular form may be used as an accessory filtrant but it is not a buffer. Charcoal has a tremendous adsorptive capacity because of its porous nature, and removes suspended solids and dissolved organic compounds. There is some speculation, however, that the usefulness of the charcoal is short-lived. The adsorptive capacity is drastically reduced after only a short time of operation.

Sand and gravel are excellent for mechanical filtration and as a surface for bacterial growth. They may be incorporated into a system, but these materials do not provide buffering or adsorptive capacity to the system.

These filtrants can be combined in an operation, but it must be emphasized that the more filtrant and the finer the grain size used in the filter, the slower will be the rate of water flow through the system.

A reservoir system (Figure 1) has been designed at VIMS to provide filtration and water treatment (ozone, protein skimmers, aeration) in the reservoir unit thus leaving the main tank free of apparatus. This arrangement facilitates the handling of crabs and general servicing of the tank.

Water flows from tank (1) through 1½ inch pipes

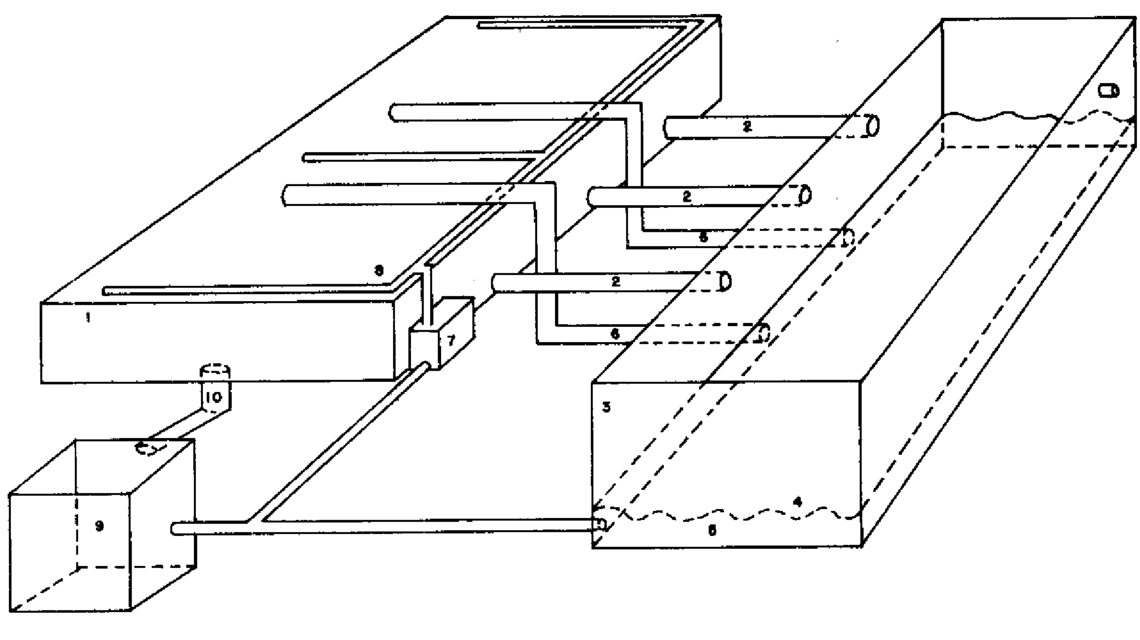


Figure 1. Basic plan of tank and supporting reservoir/filtration/water treatment unit.

(2) into the reservoir (3) where it is aerated, and treated by ozonized air-driven protein skimmers (see Fig. 1). The water flows through polyvinyl chloride modules[18] (see Fig. 1) or dolomitic gravel supported by a false bottom of perforated, corrugated Fiberglas roofing material[17] (4). The water entering the bottom chamber (5) is air lifted (compressed air and airstones) back to tank (1) through 1½-inch pipes (6) or is delivered by a pump (7) through a 1-inch pipe distribution network (8). The airlift and pump may be operated simultaneously. A temperature control unit (9) may be hooked into the system by connection with the main drain (10) of tank (1) and the pump (7). The filter unit itself is heavily aerated.

A second type of recirculated system used at VIMS is a self-contained unit in which the dolomitic filtrant and false bottom are situated in the main tank rather than in a separate unit. Circulation of water in this system is accomplished by an airlift from the main tank drain. A pump may be used separately, or in conjunction with the air lift as in the reservoir system.

Some other combinations and arrangements for various capacity operations can be seen in Clark and Clark (1964), Parisot (1967), Lasker and Vlymen (1969) and Spotte (1970). Most of the recirculated units are incapable of supporting heavy commercial loads of organisms because of the intense accumulation of nitrates and nitrites which occurs as ammonia is broken down by the bacteria in the aerobic filter.

A breakthrough in fresh water culture systems has been made at the University of Rhode Island (Meade, 1973). The URI system has incorporated polyvinyl chloride modules[18] into the aerobic filters to provide a large rigid surface for growth of nitrifying bacteria, thus reducing the requirement for a gravel bed. It is also possible to continuously remove nitrate from the system by establishing denitrifying bacteria in an anaerobic column (St. Amant and McCarty, 1969; Smith et al., 1972).

Although this system contains fresh water, Sieburth and Balderston of URI have initiated work on a seawater system and believe it should be as successful as the freshwater counterpart. The same principles have been employed in a lobster culture system at the University of California at Davis (Shleser and Tchobanoglous, 1973). Further modifications of the VIMS system are being made along the lines of the Rhode Island and California plans.

PROTEIN SKIMMING

Certain chemicals such as proteins, fats and sugars are released in crab feces and urine. They dissolve in water and may build up to critical levels even when a filter is in operation. Since these compounds remove oxygen from the water, they compete with crabs for available oxygen. Nitrogenous compounds such as proteins, if not broken down and used by filtrant bacteria, may result in lethal concentrations of ammonia (NH_3).

Survival of animals in recirculated systems depends on the conversion, by bacteria, or organic matter to sublethal levels of ammonia. These materials may be artifically accumulated for disposal by mechanical devices which concentrate and flocculate these products at the surface of the water.

This may be accomplished by having the water leaving the tank splash into small reservoirs. The splashing creates aeration which brings the waste products into contact with air and causes the formation of foam. The foam can be skimmed off the surface of the water and discarded. Commerical skimmers are available[19] in a variety of sizes. They utilize a counter current flow of compressed air against water which creates the foam and causes it to flow into a chamber which can be emptied at periodic intervals.

OZONE

Ozone is a purifying gas that has been used to reduce bacterial populations in water supplies. It also enhances foam production in protein skimming. The gas is transformed from oxygen in the air by means of a high electric voltage.

The device known as an Ozonizer (Ozonater) was developed for use in a compressed air line system serving marine tanks and aquaria. The apparatus is available from the same source as the protein skimmer, and since it operates on compressed air, it would be a simple matter to install both units. An accessory air pressure regulator[20] may have to be installed in the air line ahead of the ozonizer because these devices operate only at low pressures (less than 5 psi).

ULTRAVIOLET STERILIZATION

The use of ultraviolet irradiation as a means of controlling bacterial growth and disinfecting water in recirculated systems may be considered. In the design of a water treatment system, care must be exercised to protect personnel against electrical shock or excessive radiation. It is suggested that interested parties obtain a copy of the "Policy statement on use of the ultraviolet process for disinfection of water"[21]. Ultraviolet sterilization systems are now available for use in seawater systems[22].

WATER CHEMISTRY

In any type of operation involving holding or culturing of aquatic animals, certain water quality tests must be made on a routine basis. All of the parameters mentioned below can be measured with sophisticated instruments or chemical methods. There are, however, water chemistry kits[23] on the market which allow such analyses to be performed simply and conveniently. In recirculated systems the recommended analyses should include ammonia (NH_3), nitrate (NO_3 +), nitrite (NO_2 −), dissolved oxygen (DO), pH and salinity. Open flow or float operations should be concerned with DO, pH and salinity.

Salinity is the only parameter which cannot be measured with the water chemistry kits mentioned above. It is easily estimated by measuring the specific gravity of the water with an hydrometer, available from most aquarium supply houses[16]. The relation of salinity to specific gravity is indicated in Table 4.

Table 4.

The relations between salinity and specific gravity at 68 and 77°F. Figures in the body of the table represent specific gravity.

Salinity (ppt)	Temperature 68°F	77°F
0	0.998	0.997
5	1.002	1.001
10	1.006	1.005
15	1.009	1.008
20	1.013	1.012
25	1.017	1.016
30	1.021	1.020
35	1.025	1.023

DISEASES OF THE BLUE CRAB

Studies of crabs in their natural habitat have disclosed certain parasites and diseased conditions. Disease may have profound effects on survival, particularly when crabs are confined during holding and shedding operations. Furthermore, healthy crabs may harbor disease organisms in very low numbers, but when the crab is weakened by injury, malnutrition, environmental changes or crowded impoundment, the disease organism can multiply swiftly and contribute to or cause death of the crab.

The parasites and diseases known to occur in blue crabs are briefly described below. At the present time cures are not known. Control of the disease can be effected only by destroying the affected animals and by reducing crowded conditions. Marine laboratories should be notified when disease is suspected. If samples are required for examination, the scientists will provide instructions as to how the crabs should be handled.

"Gray crab" disease derives its name from the grayish or translucent appearance of the bottom side of sick or dead crabs, usually peelers or soft crabs. Sich crabs are sluggish and are likely to die within a few minutes if removed from the water. Sick peelers may molt, but die soon afterwards. In advanced cases, the legs contain very little solid muscle since they are filled with a watery fluid that has a cloudy appearance.

The causative agent of this disease is a one-celled animal, *Paramoeba perniciosa.* The known geographical range of this disease is Chincoteague Bay (where it was discovered in 1965) to Georgia.

Nosema sp. is another parasite which destroys the muscles of the blue crab. The organism occurs throughout the musclature and produces visible signs in cases of massive infection. The muscles are an opaque white, as if they had been cooked, and have a coarse, fibrous texture. They give the animal a creamy color when they show through the shell. Where the cream color is overlaid with blue of the shell, the effect is a pale green color.

This parasite was found at Solomons Island in the Chesapeake Bay in 1963 and has been reported from upper Tangier Sound, lower Patuxent River, York Spit and the Eastern Shore of Virginia.

Lagenophrys callinectes and *Epistylis* sp. are protozoans that attach themselves to the gill surface of the blue crab. Discovered in Cincoteague and Chesapeake Bays, there is no evidence that they gain any nourishment from the crab or that they cause any direct injury to the host. However, heavy infestations could interfere with the normal exchange or oxygen and carbon dioxide across the gill. At each shedding, the ciliates are lost with the old shell and the recently molted crab is free of the parasite. The method of reinfestation or new infestation in not known.

Blanketing of the gills by these animals could reduce oxygen uptake by the crab and contribute to sluggish behavior. It is possible that any of the gill parasites, if present in large numbers, could cause this problem. Some of the other known gill parasites of blue crabs include the bryozoan *Triticella elongata,* and the stalked barnacle, *Octolasmus lowei.*

Larvae of the trematode worm, *Microphallus nicolli*, encyst in the body muscles, heart and hepatopancreas of the blue crab. A protozoan, *Urosporidium crescens,* parasitizes these encysted worms and causes the cysts to become darkly pigmented. Masses of such dark spots have led to the descriptive term "pepper crab".

"Shell disease" in blue crabs is caused by chitin-destroying bacteria. It is characterized by a pitting and sculpturing of the shell. Although it has not been related to death of crabs, it may result in economic loss because it detracts from the normal appearance of the crab and its visual acceptance by the consumer.

Vibrio parahaemolyticus is a bacterium which causes food poisoning in humans. It may also be involved in death of blue crabs and has been isolated from the sluggish and dying blue crabs in Chesapeake Bay. This bacterium is found in the estuarine environment and healthy crabs and oysters harbor the organism in very low but detectable numbers. When the animal is weakened, this bacterium can reach fatal proportions. It is a potential cause of disease in estuarine animals but only secondarily a cause of disease in humans.

FOOTNOTES

1. Travaco Laboratories, Inc., 345 Eastern Ave., Chelsea, Mass. 02150. Available from boating equipment and supply dealers.
2. GPX, Georgia-Pacific Corp. Similar products available from other firms and building material supply dealers.
3. Carolina Fiberglas Products Co., 510 E. Jones St., Wilson, N. C. 27893; Plywood and Plastics, Inc., 1727 Arlington Rd., Richmond, Va. 23230; Fabricators of Fiberglas boats may also design and construct tanks.
4. E. I. DuPont de Nemours Co., River Road, Buffalo, N. Y. 14207.
5. Barnes Mfg. Co., Mansfield, Ohio; Dorr-Oliver Inc., Stamford, Conn. 06902; March Mfg. Co., 1819 Pickwick Ave., Glenview Ill. 60025; Tate Engineering, Inc., 601 W. West St., Baltimore, Md. 21230.
6. Dixon Valve and Coupling Co., Philadelphia, Pa. 19122; Norva Plastics, 114 E. 25th St., Norfolk, Va. 23517; Richmond Plumbing and Heating Supply Co., 3303 Lanvale Ave., Richmond, Va. 23230; United States Plastic Corp., 1550 Elida Rd., Lima, Ohio 45804; C. A. Wright Assoc., P. O. Box 177, Portsmouth, Va. 23705; Sentinel Glass Co., Hatboro, Pa. 19040.
7. Aquarium Systems, Inc., 1450 E. 289th St., Wickliffe, Ohio 44092; Dayno Sales Co., 678 Washington St., Lynn, Mass. 01901; Rila Products, P. O. Box 114, Teaneck, N. J. 07666.
8. Barnstead Co., 225 Rivermoor St., Boston, Mass. 02132.
9. Ion Exchange Products, Inc., 4500 N. Clark St., Chicago, Ill. 60640.
10. Forma Scientific, Inc., Box 649, Marietta, Ohio 45750; Frigid Units, Inc., 3214 Sylvania Ave., Toledo, Ohio 43613; Hotpack Corp., Cottman Ave. at Melrose St., Philadelphia, Pa. 19135; Neslab Instruments, Inc., 871 Islington St., Portsmouth, N. H. 03801.
11. Bel-Art Products, Pequannock, N. J. 07440; Norva Plastics, 114 E. 25th St., Norfolk, Va. 23517; Plywood and Plastics, Inc., 1727 Arlington Rd., Richmond, Va. 23230; Thermoplastic Processes, Inc., Valley Rd., Stirling, N. J. 07980; United States Plastic Corp., 1550 Elida Rd., Lima, Ohio 45805.
12. Corning Glass Works, 80 Houghton Park, Corning, N. Y. 14830; The Carbone Corp., Boonton, N. J. 07005; Sentinel Glass Co., Hatboro, Pa. 19040.
13. Hypro Engineering, Inc., Minneapolis, Minn. Available as 89-27585 (jet agitator) from Montgomery Ward Farm Catalog.
14. Karguard Co., Marinette, Wisc. 54143; Matheson Gas Products, P. O. Box 85, East Rutherford, N. J. 07073; Parker-Hannifin Corp., Des Plaines, Ill. 60016; Pump Division, Conde Milking Machine Co., Inc. Sherrill, N. Y. 13461.
15. Aquarium Systems, Inc., 1450 E. 289th St., Wickliffe, Ohio 44092.
16. Aquarium Stock Co., Inc., 31 Warren St., New York, N. Y. 10007; Aquarium Systems, 1450 E. 289th St., Wickliffe, Ohio 44092; Dayno Sales Co., 678 Washington St., Lynn, Mass. 01901; General Biological Supply House, 8200 S. Hoyne Ave., Chicago, Ill. 60620; Marine Aquarium Products, 12112 Grandview Ave., Wheaton, Md. 20902; Westchester Aquarium Supply Co., Inc., 454 Mamaroneck Ave., White Plains, N. Y. 10605; World-Wide Aquarium Supply Co., Inc., 1899 Nostrand Ave., Brooklyn, N.Y. 11229.
17. Available at building material supply dealers.
18. "Vinyl Core II" B. F. Goodrich General Products Co., 500 South Maine St., Akron, Ohio 44318.
19. Aquarium Stock Co., 31 Warren St., New York, N. Y. 10007.
20. Matheson Gas Products, P. O. Box 85, East Rutherford, N. J. 07073.
21. Department of Health, Education and Welfare; Public Health Service; Division of Environmental Engineering and Food Protection, Washington, D. C. 20201.
22. Aquanomics, Inc., 1145 E. Dominquez St., Suite H, Carson, Calif. 90746.
23. Hach Chemical Co., P. O. Box 174, Cherry Hill, N. J. 08034; La Motte Chemical Products, Co., Chestertown, Md. 21620; Delta Scientific Corp. 120 E. Hoffman Ave., Lindenhurst, N. Y. 11757.

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