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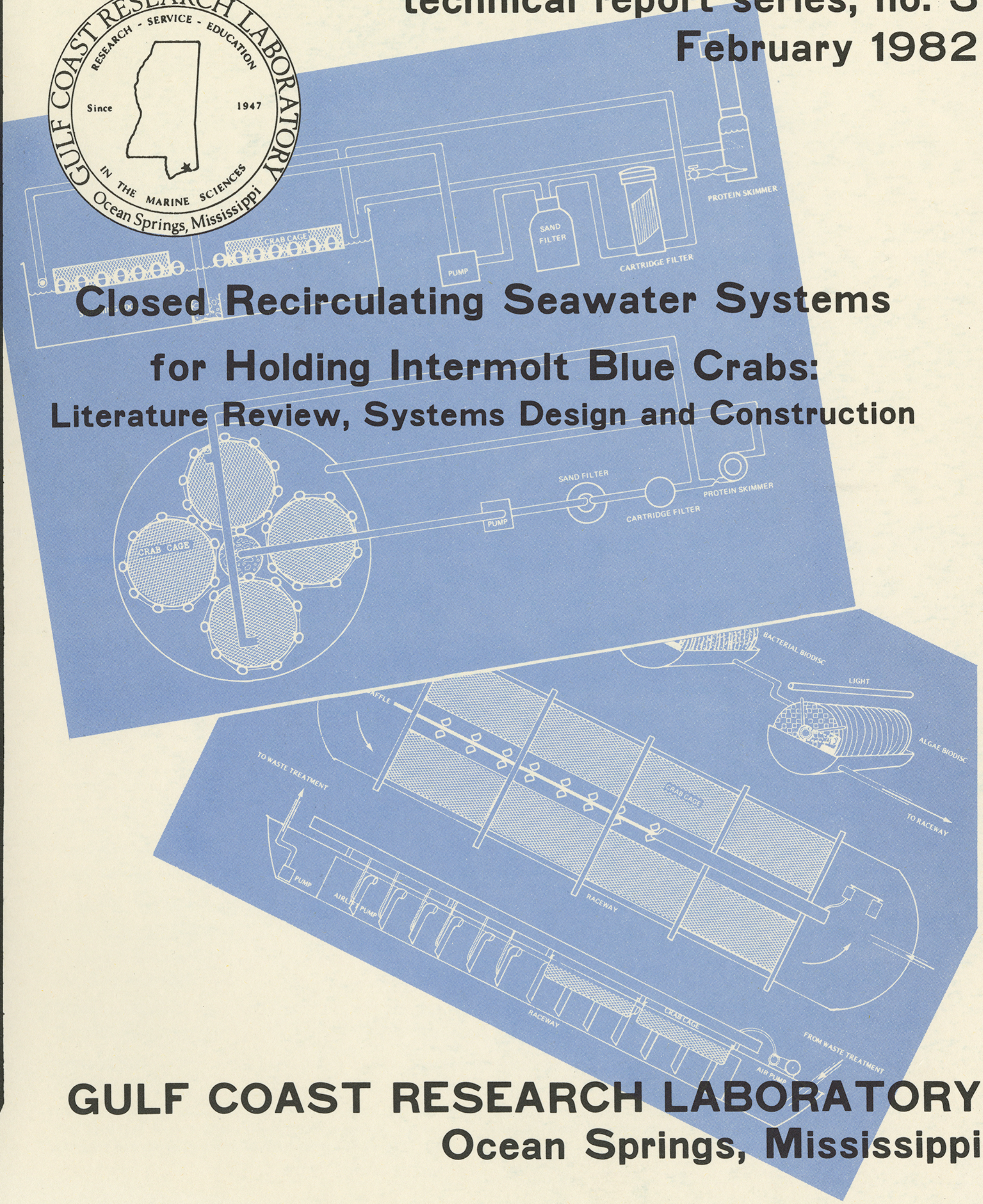

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by

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ABSTRACT

Three closed recirculating seawater systems designed for holding intermolt stage blue crabs are described and illustrated. Pertinent literature dealing with design criteria for closed systems is discussed. The biology of the blue crab is reviewed in relation to data required for design purposes. Cost and capacity of the systems are presented including provision for solar heating. Areas where future work is needed are identified.

INTRODUCTION

Major problems affecting the growth and viability of the soft crab fishery include the continuing decline in the quality of estuarine and coastal waters and the limited supply of peeler (shedding) crabs. The recent development of a commercial-scale closed, recirculating seawater system to hold and shed peeler crabs has allowed for the expansion of the industry independent of coastal water quality. Thus, the supply of peeler crabs now becomes the major limiting factor in growth of the fishery (Perry et al. 1982). Continued expansion of the industry will depend on improved fishing techniques for peelers and/or the development of a closed recirculating seawater system to hold intermolt stage blue crabs until they show visible signs of molting.

DESIGN

The design of closed, recirculating seawater systems has been approached differently by a variety of researchers. The easiest approach is to use guidelines established by large public aquaria where animals are held for long periods of time under pristine water conditions. Saeki (1958) suggests the weight of the filter be 30 times the weight of the animals being cultured, and that the culture enclosure volume be 10 times the volume of the animals. If dolomite is used as a filter medium, it should be used at the rate of 20 lbs/sq ft (personal communication, Chad Donnes, Silent World Aquariums, New Orleans, Louisiana). Flow rate of the system should be 1 gal/min/sq ft of filter (Spotte 1979). Using these data, calculations show that for 100 lbs of crabs (approx. 300), the filter would have to be 150 sq ft, or a box 12.25 ft sq, containing 3,000 lbs of dolomite. Crabs would require 125 gal of water which would pass through the filter once every 52.08 sec. these figures are probably excessive to the requirements of a crab holding system.

Using a different approach in evaluating recirculating systems for the culture of channel catfish, Parker and Simco (1974) developed an equation to reflect the maximum water quality that could be designed into any one system. Incorporated in the equation are filter retention time, water exchange, filter turnover, and the tank-to-filter ratio. With this equation, they were able to assign a numerical value to the relationship of factors that influence water quality through system design. Parker, Simco and Strawn (1975) modified that equation to predict the carrying capacity of a recirculating system at a given loading factor (F). Thus, while this design equation for water quality is useful in comparing a variety of systems, the calculation of carrying capacity is of little value in designing systems where the loading factor is unknown.

The use of an equation by Hirayama (1974) for sizing loads for small marine aquaria is of more value. The equation sets oxygen consumption of the filter as equal to the rate of production of metabolites in the system, based upon the number of fish and the feeding rate. Spotte (1979) simplified Hirayama's calculations by providing a table for "pollution load," but cautioned that the method was developed using a single species of fish at one temperature and, therefore, the table should be used only as a guideline.

Experimentally generated data relating metabolic activity to environmental factors have been used to design facilities for holding trout (Speece 1973, Liao and Mayo 1974). For a given rate and ration of feeding, the oxygen required, ammonia, BOD (biological oxygen demand), and suspended solids production can be expressed as a function of fish length. In addition, the temperature dependence of feeding rate and nitrification capacity were incorporated to predict the filter capacity required for recycling. That was accomplished by Liao and Mayo (1974) by using equations relating the various parameters, while Speece (1973) generated a number of graphs and nomograms for that purpose. Though this method was developed to design recirculating systems for cold freshwater fish and is not directly applicable to the culture of a warm saltwater crustacean, a similar approach could be used to develop a design method for holding intermolt stage blue crabs. Use of this method would, however,

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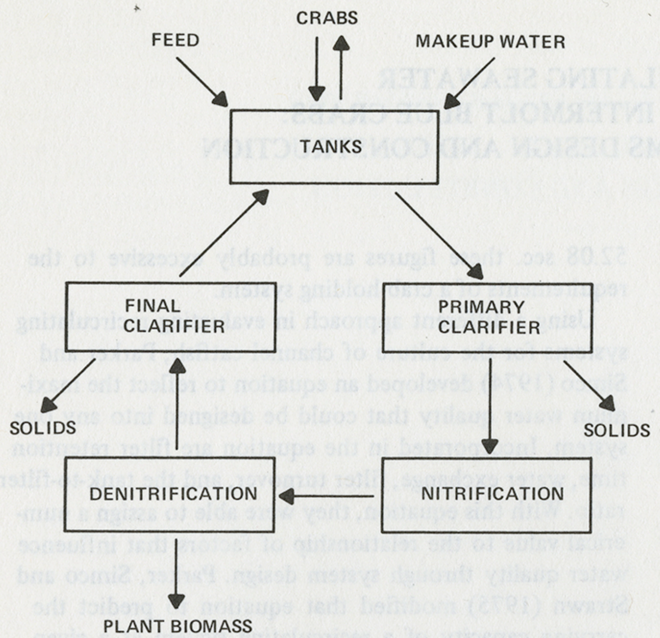

Figure 1. Generalized closed recirculating seawater system.

require a knowledge of basic physiological data relating metabolic activity to environmental factors.

Drawing on the aforementioned design methods to develop criteria for holding intermolt blue crabs, the following factors must be considered:

1. Determination of an adequate diet.
2. Assimilation of diet and wastage produced in terms of biodeposition and ammonia excretion per unit of weight.
3. Evaluation and quantification of the efficiency of the waste treatment system in order to size it to waste load.
4. Determination of the quality of water necessary to facilitate initiation of proecdysis.

A generalized system which takes into account suspended solids and particulate removal, nitrification, and denitrification is illustrated in Figure 1.

A survey of available literature was made to locate information of value for design purposes. While much of the data necessary to develop a system for blue crabs is lacking, some useful information for design purposes is available.

Diet. Blue crabs are known to be opportunistic and omnivorous feeders, but data on feeding preference, rate, and frequency are lacking. Dietary requirements have not been defined sufficiently to allow an artificial diet to be produced. Systematic studies of larval development and work on larval culture of blue crabs have provided some dietary information. Costlow and Bookhout (1959) noted that unicellular algae fed as the sole food source did not provide enough nutrition for successful molting; Whitney (1970) suggested that animal sterols were required for rapid molting and tissue growth. Optimal food size for the first and second zoeal stages was found to be 110 μm or less (Sulkin and Epifanio 1975), with rotifers or sea urchin eggs fed in combination with *Artemia* nauplii being necessary for successful molting of those early zoeae (Sulkin 1975). In later zoeal stages, the high lipid content of *Artemia* appears to be required for molting (Sulkin 1975). Sulkin also postulated that the type of embryological development an organism undergoes determines its value as a zoeal food source. Megalopae successfully metamorphosed into first crabs when fed a diet of brine shrimp supplemented with bits of fish (Sulkin 1975).

Although juvenile blue crabs have been reared on artificial and natural diets, specific nutritional requirements are still undefined. Hatchery-reared young blue crabs of identical age and parentage, fed adult *Artemia* or an artificial pelleted diet containing either 23%, 37%, or 49% crude protein, exhibited a greater growth rate (measured as a function of mean weight and mean carapace width) on the brine shrimp diet (Millikin et al. 1980). Additionally, crabs fed pelleted diets of 37% and 49% crude protein were larger than those fed the 23% diet of crude protein. Winget et al. (1976) compared growth of young blue crabs fed the silverside *Menidia menidia* with crabs fed artificial diets containing protein values of 26%, 46%, and 62%. While Winget et al. (1976) noted a lack of dietary effect (dietary protein content did not consistently affect measured growth parameters), in their study growth did not compare favorably with growth of similar size blue crabs held in the natural environment (Tagatz 1968, Gray and Newcombe 1938). There was an increase in the molt interval in laboratory-reared crabs.

High dietary fiber levels appear to exert a negative impact on growth and food conversion efficiencies in juvenile blue crabs (Biddle et al. 1978). Small blue crabs were fed isonitrogenous diets of 3%, 9%, and 27% fiber; heavy mortality and a consistently more aggressive feeding response were noted in crabs fed the 27% fiber diet. Additionally, Biddle et al. (1978) found the high-fiber diet was more difficult to pellet and was the least water stable. Because of these factors, the authors caution against the indiscriminate use of high levels of non-nutritive fiber as a dietary filler.

Holland et al. (1971) fed juvenile blue crabs an artificial food composed of equal parts of fish flour and MNC (milk nutrients concentrated). These authors observed no drawback in the pelleted diet other than a rapid disintegration time. Holland et al. (1971) noted that the major importance of the feed used in the study was that small blue crabs ate it and grew for a period of 45 days. They recorded optimal food conversion occurring between 29.0°C and 30.0°C, with a food conversion ratio of 4:1.

Rebach (1981) compared growth and molting of rock crabs fed one of three diets. Beef scraps (21% protein), a commercial feed used in shrimp mariculture (30% protein) and a pelletized diet consisting of equal parts plant and animal protein (31% protein) were tested. The crabs were fed 1.5% and 2.0% of their body weight daily. Significant weight increases were observed only with the pelletized diet. Additionally, crabs fed the pellets molted successfully with natural frequency, whereas those fed either beef or commercial flakes exhibited a much lower molting frequency or did not molt at all.

Excretion. No quantitative data are available on the production of metabolic by-products of blue crabs fed in a closed system. According to Mangum et al. (1976), blue crabs in reduced salinities excrete primarily ammonia, and the rate of excretion and net acid output is a logarithmic function of body weight. Silverthorn and Krall (from Mangum and Towle 1977) noted that the increase in ammonia excretion at low salinities occurred in males and not in females. The biodeposition of blue crabs fed specified diets (though unknown), coupled with wastage from shredding and disintegration of the food, will impose a heavy particulate load on a system in addition to the normal nitrogenous compounds excreted into the water as metabolic by-products.

Respiration. While some information exists on factors affecting the respiration rates of excised gill tissue from *Callinectes sapidus* (Engel et al. 1975, Engel and Eggert 1974), quantitative data are limited on oxygen consumption using whole animals. Engel and Eggert (1974) noted that effects of salinity on the respiration rate of excised gill tissue can be correlated to behavioral and physiological responses of the whole animal. They found that the overall pattern of salinity response, demonstrated by the excised gill tissue, mirrored the adult crab's response to salinity.

It has been demonstrated that both weight specific and total oxygen consumption are greatest during the premolt stage; that consumption decreases during the molt, then rises again following exuviation (Lewis and Haefner 1976). Leffler (1972) also noted a 65% increase in oxygen consumption for a juvenile blue crab taken from intermolt to molt. That crab, acclimated to 20.0°C and molting at that same temperature, consumed 0.1127 ml $O_2/g \cdot h$ as compared with a value of 0.0741 ml $O_2/g \cdot h$ for a crab in the intermolt stage.

Leffler (1972) recorded the oxygen consumption of small blue crabs acclimated to various test temperatures and found an increase in standard metabolic rate with an increase in temperature. The metabolic rate (ml $O_2/g \cdot h$) ranged from 0.0128 to 0.1299 for crabs acclimated and tested at temperatures from 13.0°C to 34.0°C, respectively. Crabs placed in temperatures other than those to which they had been acclimated showed an increase in metabolic rate when the test temperature was above acclimation temperature and a decrease when it was below acclimation temperature.

Growth–Temperature. Growth of blue crabs is strongly affected by temperature. One of the more obvious effects of temperature on growth rate is the length of time required for crabs to reach maturity. Up to 18 months is necessary for maturation in Chesapeake Bay (Van Engel 1958), while blue crabs in the Gulf of Mexico may reach maturity within a year (Tatum 1982, Perry 1975).

In the laboratory, Leffler (1972) demonstrated that though the molting rate increased with rising temperatures from 13.0°C to 34.0°C, the average size increases/molt were greater at 20.0°C and 15.0°C than at 27.0°C or 34.0°C. He also pointed out that the mortality rate of blue crabs was temperature dependent, and that death at ecdysis was pronounced at 27.0°C and 34.0°C. Blue crabs held at 13.0°C showed little, if any, growth. An optimal temperature range for growth of small blue crabs (5.0 mm to 40.0 mm carapace width) was found by Holland et al. (1971) to be between 29.0°C and 30.0°C. Parker, Holt and Strawn (1975) compared growth of blue crabs held at 30.0°C with those held at ambient temperatures ranging from 20.9°C to 29.2°C. They found that though crabs held at ambient temperatures had a slightly greater increase in weight and carapace width and a higher survival rate than those held at 30.0°C, these differences were not significant.

Growth–Salinity. Salinity also has been demonstrated to affect growth. Holland et al. (1971) found that growth of small blue crabs was similar at salinities of 2.0‰, 4.0‰ and 6.0‰, but was decreased markedly in crabs held at 1.0‰.

Density–Behavior. Little work has been done on the effect of tank design for holding intermolt stage blue crabs. Existing open- and closed-system commercial facilities for shedding crabs use rectangular tanks of either wood or fiberglass. Most of these tanks have dimensions that are easy to fabricate (4 x 8 ft, 3 x 6 ft). Because shedding crabs are nonfeeding and less agressive than those in the intermolt condition, commercial operators have been able to hold them in densities ranging from 300 to 400 crabs/tank (8.6 to 6.4 sq in./crab).

The effect of density on the communal holding of more aggressive, intermolt-stage blue crabs is not known. Molt inhibition, either as a result of the presence of waterborne pheromones or the physical presence of other crabs, must be investigated. The work of Jachowski (1974) on the agonistic behavior of blue crabs in the field and in the laboratory has provided some interesting information. He found agonistic encounters may arise as a result of the mutual attraction of crabs to a food stimulus or a receptive female, and that these encounters may lead to physical combat, but only when threatening postures have failed. Struggles over food many times resulted in the autotomy of an appendage but rarely led to the death of a crab. The occurrence, content, and outcome of agonistic acts were found to be affected by several factors, including size of the individuals, sex, and presence or absence of the chelae. Encounters between crabs that differed greatly in size were more frequent in laboratory-held animals than in the field, where small crabs were able to avoid the larger ones. Distances between individuals exhibiting various manifestations of agonistic behavior differed greatly, however; the frequency of agonistic encounters was highest when crab densities were highest. No pheromone serving agonistic communication is known for crabs, although the possibility has been suggested for other crustaceans. Jachowski (1974) notes that behavioral responses of blue crabs indicate that odor is not essential to agonistic behavior.

The dominance hierarchy formed in communally held lobsters (Cobb and Tamm 1975) is not well developed in blue crabs. Jachowski (1974) suggests that because blue crabs range widely in nature, it is unlikely they form stable dominance systems.

It is generally agreed by those individuals involved in the shedding of premolt blue crabs in closed systems, that the individual holding of intermolt stage crabs is not economically feasible. Banding of the chelae of large numbers of crabs to curb aggressive behavior also has met with unfavorable response from commercial crab shedders. The practice of nicking (breaking one of the fingers of the chela), though used in some shedding operations, is not recommended. Bleeding and possible swelling of the injured tissue may contribute to shedding mortality. Swelling of the injured tissue may prolong the molting process, resulting in the death of the crab.

Substrate–Tank Design. Factors such as substrate presence and type are known to reduce agonistic behavior in laboratory held crabs (Holland et al. 1971), but their value in a pilot commercial system is untried. Such is also the case with different tank designs. The use of circular and artificial habitats has been found effective in reducing mortality in the shrimp *Macrobrachium* (Smith and Sandifer 1979).

Filtration–Mechanical. Characterization and quantification of the particulate load from crab holding tanks will be dependent upon diet composition, and feeding rate and frequency. Once this information is available, it should be possible to engineer a system for the removal of particulate matter at a predetermined level of efficiency.

The use of directed water currents and venturi drains, fake or sloped bottoms, and flushing trays being developed for lobster-holding facilities, may be applicable. Static screens may be fabricated to any size for removal of given sized particles. Problems associated with self-cleaning static screens can be bypassed by using vibrating or rotating screens or by using tangential screens. If settling is required, a number of settling basin designs are available, the simplest being a gravity settling basin. The large square footage required for a gravity settling basin may necessitate investigation of settling cones, swirl concentrators, inclined plate separators, rapid tube clarifiers, or hydroclones as an alternative. Sand beds or rapid sand filters are other possible ways to remove particulate matter.

Filtration–Biodeposition. An alternate approach to the above-mentioned methods of mechanical removal of suspended solids would be the use of biofiltration. The use of oysters as biofilters for shrimp, crab, and fish wastes has been tried unsuccessfully by several investigators (C. Mock, personal communication; Holland et al. 1971; Ogle 1980, respectively). The use of detritus feeders such as shrimp and bullminnows may meet with more success in the removal of suspended solids and in consolidation of the waste. The particle size of crab waste is probably too large for filter-feeding bivalves.

Filtration–Nitrification. The process of nitrification has been well documented and a wide variety of filter designs is available. Filters currently in use in recirculating crab shedding systems are submerged trickling filters, single or multi-media, packed with whole oyster or clam shell, crushed shell, or dolomite, and activated marine carbon (Perry et al. 1982). Although most are downdraft filters, updraft filters are recommended because of their capacity for handling higher hydraulic loads. Activated sludge treatment systems, due to their size and complexity, have been seldom used for treating aquaculture waste (Otte and Rosenthal 1979). Rotating biological contactors are being used in a wide variety of systems (Lewis and Buynak 1976; Mock et al. 1977; Lewis et al. 1978; Kennedy 1980; Van Gorden and Fritch 1980). These biodiscs may have potential in the development of a crab holding system because they operate independent of particulate load and respond well to impact loading. Trickling filters also show promise because they can handle some particulate loading, have greater water flows, and are highly aerobic. Basic filter types have not been compared for application to a marine recirculating system. Removal efficiencies are not known nor is there sufficient information to allow the sizing of such filters to a given load.

Filtration–Denitrification. Nitrification has nitrate as its end product. Though nitrate is less toxic than ammonia, if nitrate accumulates to high levels it may result in death of an organism. Removal of nitrate may be accomplished in one of three ways. The simplest means of removing nitrate and other metabolic by-products is to exchange the water in the system. This is the generally accepted procedure for small- to medium-sized aquaria, with 10%–25% of the volume of the system being exchanged weekly. The use of a denitrification filter is a second alternative. Conversion of nitrate to molecular nitrogen is accomplished by means of selected bacteria on a filter medium under anaerobic conditions. The nitrate concentration in the system is regulated by the addition of an electron donor such as glucose or methanol. This method requires exact monitoring of the nitrate level in the system and, additionally, requires that the treated water be passed through activated carbon to remove traces of the additive. The use of marine plants, a third alternative, appears to be the most viable alternative for denitrification in a crab system though no data are available for design purposes.

Species of *Enteromorpha* were found to thrive in aquatic systems rich in inorganic nitrogen (Harlin 1978). Macroalgae are currently being cultured in commercial facilities for shedding crabs. The species cultured are selected on availability, and are initially taken from natural waters in salinities approximating those of the crab-shedding systems. Under investigation is the use of marine plants for which a commercial value exists either as a food source, energy source, or for the production of compounds such as iota-carrageenan. While the use of vascular plants has met with success in freshwater systems, research has just begun on the use of salt-tolerant species in recirculating marine systems.

From the above discussion it is apparent that sufficient data are not available to allow for the rational design of a facility to hold intermolt blue crabs. It is, however, possible to build a system using a trial-and-error approach, making improvements based upon performance of the animals in the system. In fact, such a procedure is common in setting up aquaculture systems. For the present study, three separate systems are proposed, each designed to meet the requirements of one segment of the industry (backyard culture operation, established live-bait dealers interested in holding crabs, commercial facility for holding and shedding crabs). Available commercial materials are used unless considered cost prohibitive or oversized for the system design. In such cases, equivalent equipment has been constructed.

CONSTRUCTION

Pool System

A plastic lined swimming pool (12 feet in diameter) with crabs held in circular cages is recommended for a system to be used by individuals interested in a "backyard" culture operation (Figure 2). Four cages are fabricated from vinyl-coated hardware cloth available in rolls with a width of 4 ft. This allows a 4-ft diameter circle to be cut. An additional length (12.5 x 1 ft) is cut to serve as the side. The latter section is then wired to the disc, and the top 4 in. are folded to the inside to prevent the crabs from crawling out the top of the cage. The cage is floated by means of styrofoam floats laced to the outside. At a density of 15 sq in./crab, each of the four cages can be stocked with 120 crabs for a total of 480 crabs for the system.

Water is withdrawn from the center of the tank by a 1-hp Teel® centrifugal pump. The intake for the pump is protected from debris by placing it in a perforated basket filled with whole oyster shells. This coarse filter will require cleaning periodically. Output from the pump is plumbed to an 18-in. Hayard® plastic swimming pool filter available from local pool distributors. The filter is filled with 150 lbs of aquarium grade quartz sand. Dolomite used in conjunction with a rapid sand filter is recommended to aid in buffering the system. Output from the sand filter is plumbed to a commercial swimming pool pleated cartridge filter with 150 sq ft of surface area. Pressure gauges on the sand filter and the cartridge indicate when filters are clogged and require washing or backflushing. Output of the cartridge filter is divided and part is diverted back to the pool reservoir. Return water is directed to both sides of the pool to impart a rotation to the water. In addition, the flow is directed through spray nozzles to supply oxygen. The remainder of the water is diverted to a protein skimmer. A protein skimmer operates by producing a foam which adsorbs dissolved organic material at the bubble surface. Removal of the foam formed by the bubbles above the liquid surface eliminates the concentrated solutes. Removal of dissolved organic material reduces the generation of ammonia by removing the protein before biological degradation occurs (Wheaton 1977). The protein skimmer reportedly lowers BOD, chemical oxygen demand (COD), and nitrate, and controls pH. It is possible to increase the efficiency by using ozone-enriched air to produce the foam. Ozone will oxidize many pollutants by breaking down long chain organics into fine particles which are readily adsorbed by foam fractionation. Many inorganic substances are also oxidized into insoluble forms; however, long term effects of ozonation on a closed system are not known. The protein skimmer used in this system is a modification of one designed by Hagan (1970) in which more readily available materials were substituted for the machined parts required by the original design. The body is composed of a plastic tube, 12 in. in diameter and 18 in. long, glued to a plate of plexiglass. The dome is the top to a plastic terrarium having a diameter slightly larger than 13 in. A collar of 4-in. PVC was cut in half and glued to the top of the dome to receive a 4-ft piece of 4-in. PVC for the tower. The venturi aspirator is a faucet aspirator obtained from a scientific supply house (Preiser Scientific Aspirator Pump #13-828b). It is threaded into 1-in. PVC pipe which is affixed to the body by means of Marinetex® adhesive. This system is the simplest of the three designs constructed, requiring limited fabrication. We recommend that bullminnows or shrimp be stocked in the reservoir to graze down waste crab food. Total volume of the system has been estimated to be 2,537 gal, and construction cost was estimated to be $593 when calculated in 1979 (Table 1).

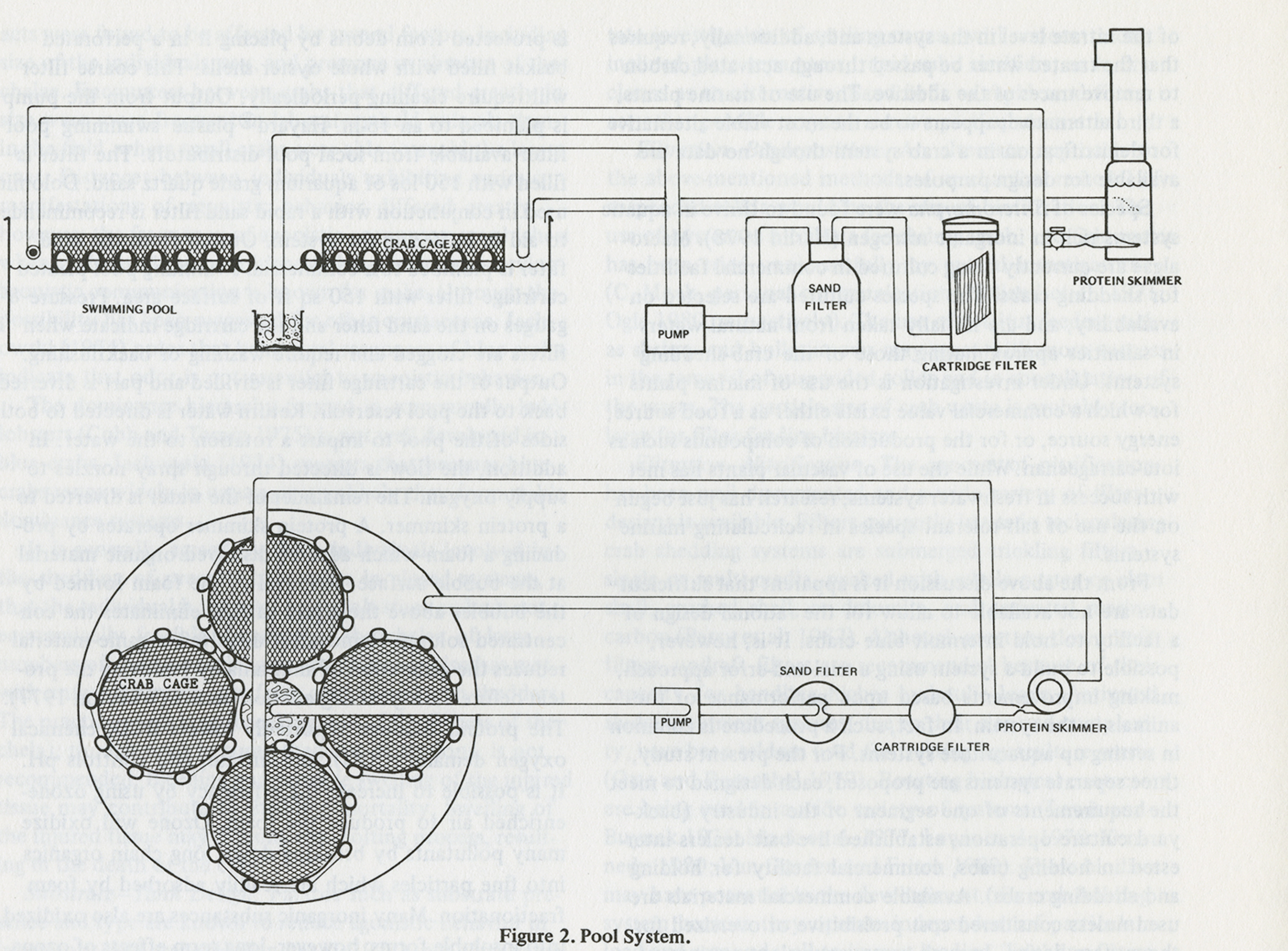

Figure 2. Pool System.

TABLE 1.

A comparison of the systems in terms of capacity, physical plant and cost

	Pool	Raceway	Tank
Vol. (gal)	2537	2264	1340
No. Crabs	480	616	1140
Lb/Ft^3	2.1	1.5	2.1
Cost (1979)	$593	$760† $1940‡	$2868
Cost/Crab*	.10	.10† .03‡	.08

*Assume 6 crops per year. Amortize plastic system for 2 yrs, fiberglass for 5 yrs.
†Plastic lined tank
‡Fiberglass tank

Raceway System

The system developed for adaptation to the bait industry is built around a rectangular raceway (Figure 3). Existing cement or block tanks used by bait dealers can be used, plastic lined raceways constructed, or fiberglass tanks purchased. A fiberglass raceway developed for rearing bait shrimp (Mock et al. 1977) is available from a commercial source (Red Ewald, Inc. P.O. Box 519, Karnes City, TX). Plastic sheeting, either 6-mm greenhouse covering or a more durable 30-mm CPVC commercial pond liner material, can be used to line the inside of a rectangular wooden box. The frame is constructed of 2 x 6-in. or 2 x 12-in. lumber nailed to 4 x 4-in. posts embedded in the ground to form an enclosure 5 x 24 x 2 ft. The corners are blocked to produce a circular flow. We recommend that the grass be removed from underneath the tank to prevent new shoots from growing up through the liners, and that a layer of sawdust or sand be bedded in the bottom to give a smooth surface. We also recommend styrofoam sheets be secured to the sides and, optionally, to the bottom, to give a smooth surface and help prevent tearing of the liners. A center aeration baffle panel, 18 ft long, is secured vertically in the middle of the raceway. The panel is constructed of plastic corrugated roofing panels (12 x 8 ft), joined end to end with a 2-ft overlap and bolted together with plastic screws. Twelve pairs of airlift pumps

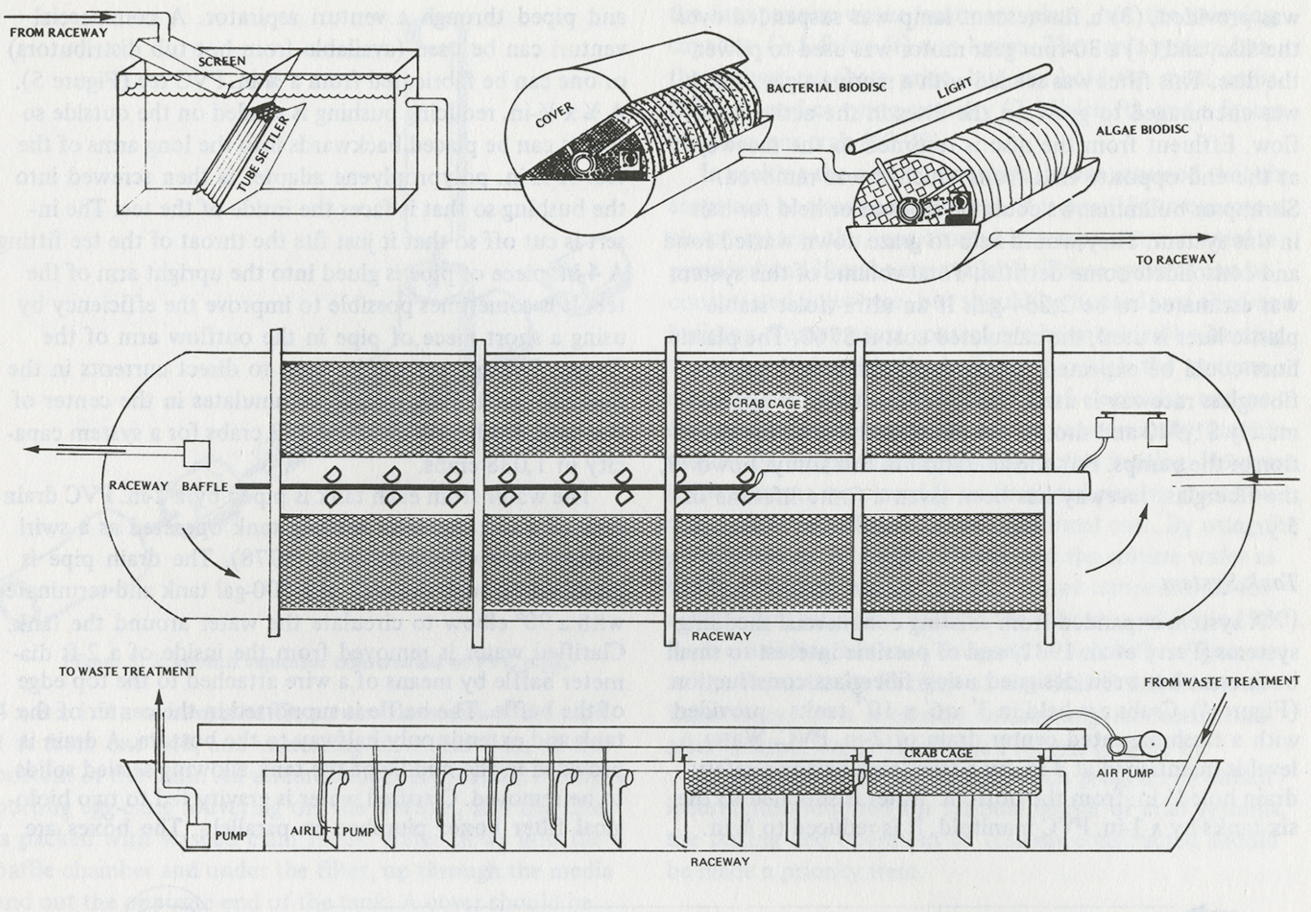

Figure 3. Raceway System.

are secured to the baffle plate, one on each side, every 18 in. along the plate. Air lifts are constructed of an 18-in. piece of 1½-in. PVC pipe. The bottom end is cut at a 45° angle and has a small hole about 3 in. from the end. An air stone is placed inside the tube, and the air supply line runs out the hole and up to the surface where it is connected to a 2-in. PVC manifold pipe through an air line insert. The top of the airlift pump is covered with a 90° elbow directed obliquely to the panel. Four cross members of wood serve to support the baffle approximately ½ in. off the bottom of the tank and in the middle of the raceway. In the plastic lined raceway, an additional strip of plastic should be placed under the airlifts to prevent them from tearing the liner. An automobile smog pump, powered by a 1/3-hp electric motor, supplies air to the manifold to run the pumps. Crabs are held in 2 x 4-ft rectangular cages, 1 ft deep, constructed of vinyl-coated wire. Lids with overlapping lips should be provided to insure that crabs do not escape into the raceway. At a possible density of 77 crabs/cage, the capacity of the eight cages in the system would be 616 crabs. Water is pumped from the raceway with a submersible pump, and passed over a 212-μ sieve before entering a settling chamber.

The settling box is 2 x 4 x 1 ft and contains an inclined plate separator. The separator is fabricated of 12 strips of corrugated plastic material measuring 12 x 20 inches. The corrugations on the strips are alternated to form chambers, and each strip is lapped by ½ in. so the entire structure leans at an angle between 45° and 60°. A baffle forces the water to enter the plate separator from the bottom. Clean water is removed from the top and plumbed to a nitrification biodisc filter. The biodisc was placed into half of a plastic 55-gal drum, cut lengthways. The disc was fabricated of floor-polishing pads, 18 in. in diameter. The pads were placed on a 3-in. PVC shaft and tied to spokes of ½-in. PVC glued into the shaft. The plastic shaft was held onto a threaded metal shaft by nuts at both ends. The metal shaft, held in place by pillow blocks, is powered through a sprocket and chain to a high-torque gear motor turning at 6 rpm. Water enters from above at one end, and is removed at the bottom at the opposite end. An opaque cover was fabricated to keep the filter in the dark. Water is passed from the nitrification biodisc to a denitrification biodisc. This disc was constructed similar to that described above with the following exceptions: (1) egg-crate louvering was used for the discs, (2) no cover was provided, (3) a fluorescent lamp was suspended over the disc, and (4) a 30-rpm gear motor was used to power the disc. This filter was seeded with a marine algae, which was encouraged to grow on the discs in the active water flow. Effluent from the disc is returned to the raceway at the end opposite that from which it was removed. Shrimp or bullminnows could be stocked or held for bait in this system. They would help to graze down wasted food and consolidate some detritus. Total volume of this system was estimated to be 2,264 gal. If an ultra-violet stable plastic liner is used, the calculated cost is $760. The plastic liner could be expected to last approximately 2 yr. If a fiberglass raceway is used, the system would cost approximately $1,940 and should last indefinitely, with the exception of the pumps. For consideration in this study, however, the fiberglass raceway has been given a finite lifetime of 5 yr.

Tank System

A system expanded from existing commercial shedding systems (Perry et al. 1981) and of possible interest to small businesses has been designed using fiberglass construction (Figure 4). Crabs are held in 3′ x 6′ x 10″ tanks provided with a flush-mounted center drain of 2-in. PVC. Water level is maintained at 3 in. by a standpipe having a safety drain hole ½ in. from the bottom. Water is supplied to the six tanks by a 1-in. PVC manifold. It is reduced to ¾ in. and piped through a venturi aspirator. A commercial venturi can be used (available from hot tub distributors) or one can be fabricated from a ¾-in. PVC tee (Figure 5). A ¾ x ½-in. reducing bushing is sanded on the outside so that it can be placed backwards into the long arms of the tee. A ½-in. polypropylene adapter is then screwed into the bushing so that it faces the inside of the tee. The insert is cut off so that it just fits the throat of the tee fitting. A 4-in. piece of pipe is glued into the upright arm of the tee. It is sometimes possible to improve the efficiency by using a short piece of pipe in the outflow arm of the fitting. The venturi can be used to direct currents in the tanks so particulate matter accumulates in the center of the tank. Each tank can hold 173 crabs for a system capacity of 1,038 crabs.

The water from each tank is piped by a 2-in. PVC drain pipe to a 6-ft diameter settling tank operated as a swirl concentrator (Zielinski et al. 1978). The drain pipe is plumbed through the wall of a 500-gal tank and terminated with a 90° elbow to circulate the water around the tank. Clarified water is removed from the inside of a 2-ft diameter baffle by means of a wire attached to the top edge of the baffle. The baffle is supported in the center of the tank and extends only halfway to the bottom. A drain is provided in the middle of the tank allowing settled solids to be removed. Clarified water is gravity fed to two biological filter boxes plumbed in parallel. The boxes are

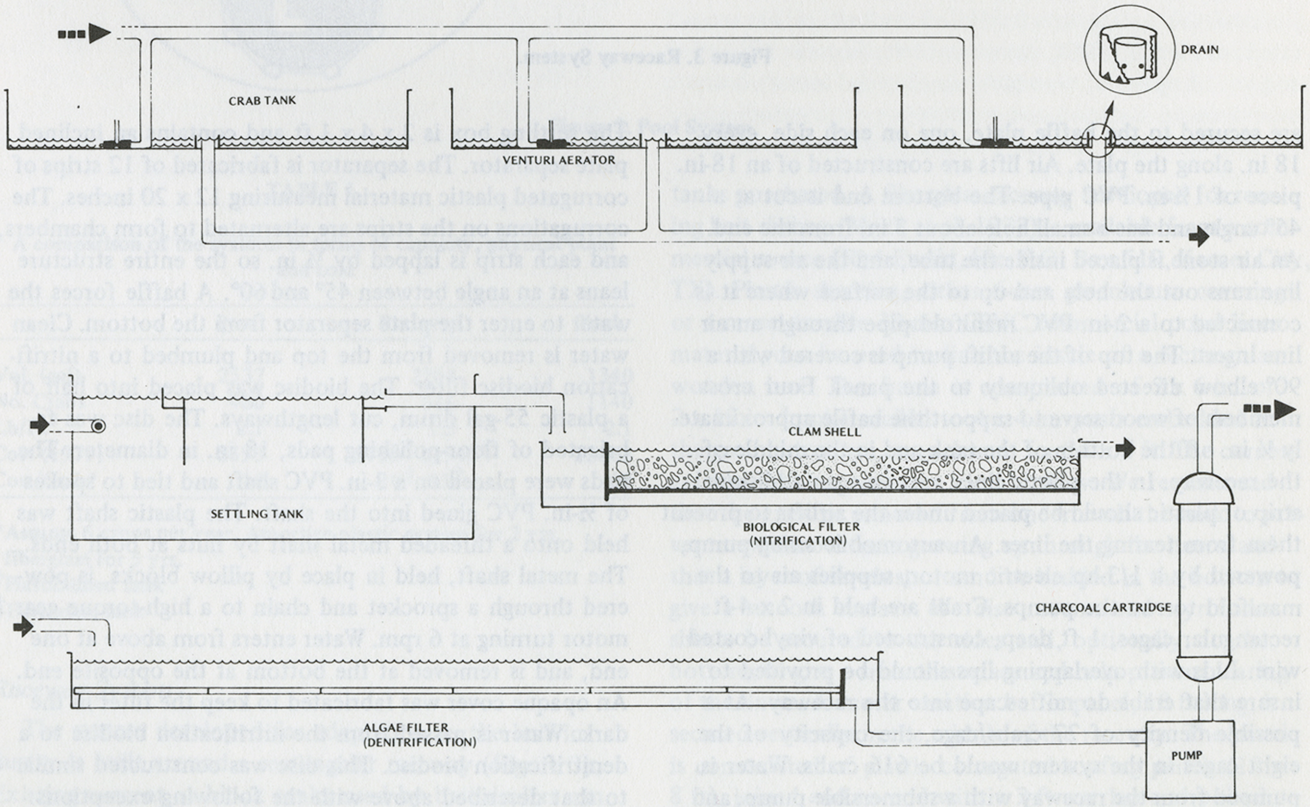

Figure 4. Tank System.

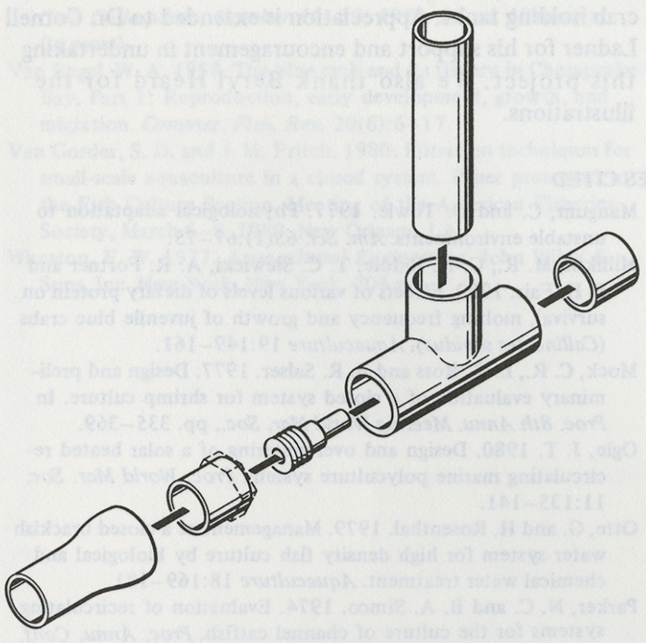

Figure 5. A venturi aspirator constructed of PVC pipe.

4 x 8 x 1 ft and have a baffle across the width of the tank 1 ft from one end, and extending to within 2 in. of the bottom of the tank. An underdrainage is provided by supporting egg-crate louvering off the bottom, and the filter is packed with washed clam shells. Water flows into the baffle chamber and under the filter, up through the media and out the opposite end of the tank. A cover should be provided to keep the filter in the dark. Water then flows into a flume 2 ft wide by 14 ft long. Perforated plastic trays are placed off the bottom in the flume to provide substrate for attachment of a marine alga which is encouraged to grow in this tank. Water is removed from the bottom of this tank and plumbed to a 1-hp centrifugal pump, where it is passed through a 2-ft long cartridge containing activated carbon and then directed back to the crab tanks. The cartridge is constructed of a 4-in. PVC pipe with caps threaded for the 1-in. PVC water lines. The cost of this system is estimated to be $2,868 and the system will hold approximately 1,340 gal of water.

A comparison of the three systems in terms of cost to hold individual crabs ranged from $0.03 to $0.10 per crab (see Table 1). The cost was calculated based upon the capacity of the system and the purchase price of the system. The lifetime of the system was amortized, and it was assumed that six crops could be produced each year. The pool system has the lowest purchase price, but is not expected to last long. It has the lowest capacity in terms of numbers. The carrying capacity, 2.1 lb/ cu ft, is quite good, although for recirculating systems a production of 5 lb/cu ft is a reasonable goal (Parker, Simco and Strawn 1975). The fiberglass raceway had the lowest price per crab ($0.03) due to the life expectancy of the system and the inexpensive water treatment plant, but the carrying capacity (1.5 lb/cu ft) was lower. The tank system has the highest purchase price, but can hold the most crabs. It has a good carrying capacity (2.1 lb/cu ft), and a favorable price per crab ($0.08).

In making the cost comparison, it was assumed that six crops can be produced per year. It is possible to operate a closed system the year around if temperature control is provided and if crabs are available. These systems can be constructed anywhere, but should be housed in a shed or a building. Temperature control can be provided by heating the water or heating the building in which the systems are located. Due to the rising cost of electricity and petroleum, it would probably not be economically feasible to provide temperature control by active heating. However, if the systems are placed in an insulated passive greenhouse, they can be solar heated at no additional cost. By using the greenhouse as the solar collector and the culture water as the heat storage media, suitable water temperatures for aquaculture can be maintained the year around (Ogle 1980). Such a building has been designed to house these systems at the Point Cadet Facility of the Gulf Coast Research Laboratory; it is presently undergoing reconstruction after destruction by Hurricane Frederic (Figure 6).

In addition to setting up a research program to obtain information required for rational design of crab systems, the testing and operation of systems constructed should be made a priority item.

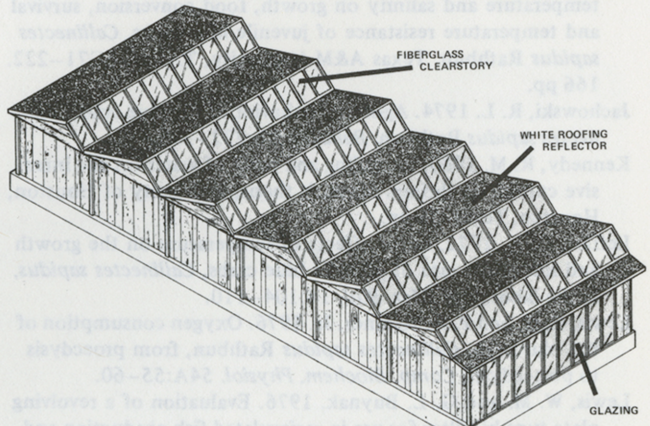

Figure 6. A passively heated solar building to house recirculating seawater systems. Light enters through six clearstories glazed with fiberglass. The roof decking behind each clearstory is covered with white roll roofing that acts as a reflector into the following clearstory. The entire south wall is glazed to allow light to enter for a total of 640 sq ft of glazing. Insulated interior shutters will be used to close off the glazed areas during the summer and at night and on overcast days during the winter.

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