MECHANIZED IMPLEMENTS FOR THE CULTIVATION OF MARINE BIVALVE MOLLUSCS

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In recent decades, aquaculture has experienced rapid expansion in the developed western nations, and today cultivated aquatic products make a significant contribution to domestic and global fisheries resources. Although research in the biological sciences has furthered the development of aquaculture, the engineering technology for mechanization of aquatic cultivation has not kept pace with terrestrial agriculture. The need for mechanization in aquaculture is most acute for infaunal mollusc cultivation. Environmental impact, as well as harvesting efficiency, must be considered when designing aquaculture implements. The mechanizaton of farming in the marine environment presents a unique challenge to innovative marine technologists in the decade to come.

INTRODUCTION

Aquaculture, the husbandry of plants and animals in the aquatic environment, has been practiced in Europe and the Far East for centuries (Bardach et al., 1972). Although it remains an artisanal pursuit in many developing nations, in recent decades aquaculture has experienced rapid expansion in the western developed nations, and today aquaculture products make a significant contribution to domestic and global fisheries resources. The world harvest of cultured products has increased by more than two million metric tons of cultured algae, finfish, crustaceans and molluscs since 1986. Some 142 countries have reported substantial increases in their aquaculture production as a contribution to fisheries resources (FAO, 1988). This is particularly true of marine molluscs, where some 2.7 million metric tons were cultivated in 1987 comprising 56% of the world catch of these organisms. Oysters made the greatest contribution to aquacultured mollusc landings, followed by mussels, clams, cockles, scallops, arcshells and several other genera of marine molluscs.

In large part, the recent success of aquaculture can be attributed to increased knowledge of the biology of cultured species and the application of western technology to culture systems, animal nutrition and genetics. However, the design and engineering technology for mechanization in terrestrial agriculture has not been applied to its aquatic counterpart. Consequently, the slow development of mechanized implements for aquaculture has become a major impediment to the industry's expansion. Nowhere is the need for mechanization to increase planting and harvesting efficiency more acute than in the cultivation of marine molluscs grown on or in the substrate. With the rapid expansion of mollusc aquaculture, there will be an increasing need for today's innovative marine technologists to let their collect experience come to bear on the problems associated with mechanized marine farming equipment.

Bivalve molluscs derive nutriment by filtering unicellular algae (phytoplankton) from the water column, and wild populations are most abundant in nutrient-rich estuarine and near-shore waters with high phytoplankton standing crops. These inshore waters also provide critical nursery habitat for many important recreational and commercial fisheries resources. Therefore, both the captive fisheries and submerged-land leases for mollusc cultivation are found in environmentally sensitive areas. State and federal regulatory agencies are charged with the responsibility of reaching an appropriate compromise between uncontrolled application of new fishing technology and unnecessarily cautious protection of these natural ecosystems. In the absence of information regarding the ecological consequences of the application of aquaculture and new fishing technology, most environmental managers have maintained a conservative posture, placing stringent requirements on activities impacting these habitats. The concern of these agencies over the biological integrity and well-being of environmentally critical areas will be the first consideration for the issuance of permits for aquaculture, and it is likely to superceed any economic benefits from an expanding aquacultural industry. The aquatic farmer must recognize from the outset that no agricultural pursuit will be permitted that has a negative impact on water quality or the biota of adjacent waters. It is the objective of this presentation to review the devices currently used for harvesting both wild caught and aquacultured bivalve molluscs, to evaluate their relative merit, both in harvesting efficiency and environmental impact, and to suggest new types of mechanized implements which may serve the needs of the aquaculture community while addressing important environmental concerns.

HAND OPERATED IMPLEMENTS

By far, the most common methods for harvesting bivalve molluscs employ simple devices, such as rakes and tongs. Clam rakes are fixed tine implements similar to the common steel garden rake. Although the width of the rake may vary, the distance between the tines is usually mandated by law (1" apart in most states), which collects only legally harvestable clams in a mesh basket attached to the tines. The clam rake is a laborious and inefficient tool, harvesting only a few square feet of bottom before it must be hauled to the surface and the bag emptied. Peterson et al. (1987),found that mechanical harvesting, such as hydraulic dredging, was 20 to 50 times more efficient, in terms of clams taken per unit time, than manual raking. In contrast, manual raking resulted in only localized siltation and marginal impact on seagrass beds, while mechanical harvesting created extensive plumes of suspended sediment and destruction of seagrass beds observable four years after the activity. In most states, the manual clam rake is the only device permitted for harvesting wild clam populations.

The oyster tong consists of two rakes fixed to the ends of long wooden poles and hinged together with rakelike teeth facing each other. A basket is attached to each rake to collect the oysters. The fisherman stands on the deck of the aboat, lowers the tongs to the bottom and, by opening and closing the handles, scoops up a quantity of oysters between the heads. The tongs are lifted to the deck of the boat where they are culled (Collette, 1989). Although slow and laborious, manual tonging is the only method permitted for harvesting oysters in many states.

SCRAPER-TYPE DREDGES

Several types of scraper dredges are used to harvest both oysters and infaunal bivalves, such as the surf clam, Spisula solidissima, and the ocean quahog, Arctica islandica (Westman, 1946). A blade or scoop of some sort is dragged through the bottom by a boat, depositing the entire contents of the excavated bottom into a holding bag. These types of dredges are usually used in deep water, offshore where the precise direction of the dredge, and its impact on the subsrate and turbidity has been little concern. In near-shore cultured clam beds, the dredge must be easily maneuverable so that the entire bottom of the plot can be harvested. Also, scraper dredges exert substantial drag as the blades are pulled through the substrate, and large, diesel-powered vessels are usually used for these dredging activities. These vessels would be ineffective in shallow waters, and the backwash from the drive units would increase turbidity around the dredging activity.

HYDRAULIC ESCALATOR DREDGE

The hydraulic escalator dredge is widely used to harvest softshell clams, Mya arenaria, in the midatlantic states, and it has been evaluated for several other species of infaunal bivalves. It consists of a boom, usually 12 to 15 meters in length, attached to a dredge head and a wire mesh conveyor belt. The dredge head is approximately 1 X 1 meters at the mouth and tapers slightly to a conveyor belt a few feet beyond the cutting blade. The dredging vessel may be twin-hulled, with the dredge suspended between the pontoons, or a single hulled vessel with the dredge attached either port or starboard. A centrifugal pump, operated by an outdrive unit at 1500 rpm delivers 30 psi to each of several small (1 cm) dredge head nozzles for a total flow rate of about 450 gallons/minute. A hydraulic motor drives the boom winch and rotates the conveyor belt. These high pressure water jets effectively excavate the substrate to some 18 inches, dislodging clams and other benthic fauna, and carry them to the conveyor belt for transport to the pilot house for culling. The dredge head is not forced through the substrate, but rather the water jets erode a trough while the outdrive unit provides steering and forward motion. Virtually every organism in the path of the dredge is harvested; organisms smaller than the mesh of the conveyor return to the bottom, and the harvestable clams are conveyed to the pilot house free of sediment.

Hydraulic escalator dredges are highly efficient and inflict few mortalities on harvested clams. However, excavation of the substrate and the deposition of suspended sediments can cause significant mortalities of benthic organisms with 25 feet of the dredging activity. Suffocation of oyster spat has been observed at a distance of 75 feet from an operating dredge. In addition, seagrasses are completely uprooted during dredging activity and may not recolonize after one year. The negative impact on seagrass beds, important nursery areas for sport and commercial fish species, has led many state agencies to prohibit their use for harvesting both wild and cultured shellfish stocks (Godcharles, 1971).

A similar mechanical harvestor for oysters has been developed and tested in South Carolina. The harvester head consists of two rotating conveyors, 1.2 meter wide, with steel tines 0.8 cm in diameter, 7.5 cm long and spaced 7.5 cm apart located on the cross bars. The conveyor rotates so that the peripheral speed is 0.5 m/sec and in the direction of travel so as to dislodge the oysters from the bottom. The second conveyor is identical in size and shape to the first but rotates in an opposite direction, picking up the oysters and transferring them to a steel pan where they are washed and transported by an escalator belt to the surface. An automatic hydraulic control system maintains a constant force on the bottom to prevent damaging the oysters during harvest (Collier and McLaughlin, 1983).

Harvesting tests conducted by Clemson University and South Carolina Marine Resources Research Institute showed harvest rates of 20 m^3/hour with damage to the oysters and beds equal to or less than hand harvesting.

VENTURI-TYPE SUCTION DREDGE

The venturi-type suction dredge is operated by a gas powered motor and centrifugal pump which draws water through the intake and into the pump, expelling it under pressure into a long hose leading to a suction control valve. The water then passes to a suction head with a reduction nozzle where the flow of water is accelerated, and the pressure below the nozzle falls creating a suction in the harvesting hose (Figure 1). Clams are airlifted throught the hose and deposited on a mesh screen mounted on a surface vessel.

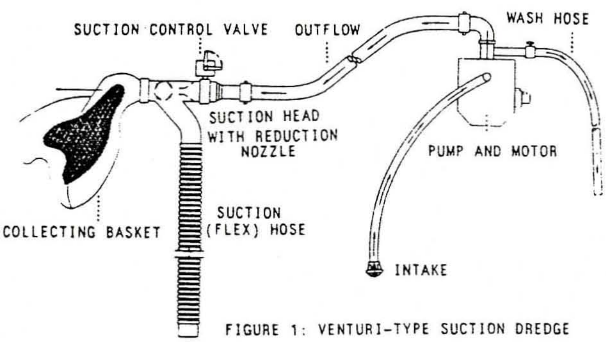

FIGURE 1: VENTURI-TYPE SUCTION DREDGE

This method relies upon complete excavation of the bottom sediment and its subsequent transport and redistribution. All seagrasses, as well as benthic and infaunal invertebrates, are carried by the suction hose to the surface. In addition to complete disruption of the benthic community at the harvested site, the operation of these devices impacts a much larger area by the spreading of suspended silt and sediment in the water column. Attempts to cordone off large settling areas may aid in containing some of the suspended dredge spoil. However, the negative consequence of the containment approach lies in the fact that should it prove to be 100% effective in containing suspended dredge spoil, an unlikely prospect, the net result is to effectively disrupt the benthic community over twice the surface area, the dredged area plus the settlement area.

ALTERNATIVE DESIGNS FOR HARVESTING CULTIVATED CLAMS AND OYSTERS

The extremely high density of clams planted in aquaculture beds (50-70 clams/ft^2) makes harvesting with rakes or similar mechanical fixed-tyne dredges impractical. Hand rakes would require lifting the catch bag to the surface continuously, and fixed-tyne dredges tend to clog with sediment. As a result, researchers at Harbor Branch Oceanographic Institution, Inc. have been developing clam harvesters which allow for continuous harvest, effectively separate the clams from the bottom sediment and do not require excavation of substrate.

ROTARY-TYPE MECHANICAL CLAM RAKE

The rotary-type clam harvester consists of a rotating steel cylinder, approximately 10 cm in diameter and 60 cm long with two rows of tines each 2.5 cm apart and offset 15^o from adjacent tines (Figure 2). Unlike rakes with tines in a single plane, the staggered tines of the rotary rake aid in breaking the cohesive or "sticky" quality of the sediment and provide an even force to rotate the cylinder through 360^o. The tines are set in a herringbone pattern to maintain an even number in the sediment, transport clams to the center of the cylinder, and minimize the force to rotate the cylinder. The cylinder is mounted on a sled which is pulled along the bottom towards a fixed anchor. As the cylinder rotates, a portion of the tines cut through the sediment and raise the clam to the surface, moving it laterally towards the center of the cylinder. As the the cylinder continues to rotate, the clams are transported to a wire mesh collecting basket.

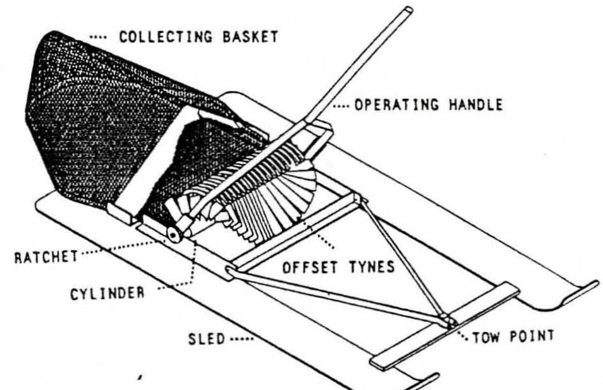

FIGURE 2: THE ROTARY-TYPE CLAM HARVESTER

VIBRATORY CLAM HARVESTER

Our research has indicated that fixed tine rakes, whether the tines are parallel or staggered, pulled with sufficient force to cause obstructions, such as clams, to move up the angle tine, cause quantities of sediment to be raised also, due to cohesive forces. The range of sediments in which clams are found changes the amount of the substrate excavated, but the fact remains that the animals do not live in sediments which lack some cohesive or "sticky" quality. Even rocking the tines back and forth (changing the acute angle) does not solve the problem. This, in effect, is the action used with the manual clam rake; the accumulated sediment is washed from the rake and clams in the water column before the harvest is brought to the surface.

Currently under development at Harbor Branch Oceanographic Institution, Inc. is a rake type clam harvester in which a vibratory motion is applied to the tines causing a fluidization of the sediment. As the pathway immediately ahead of an individual tine is fluidized, the sediment grains are pushed aside and replaced with interstitial water reclaiming the void. The tine is free to move forward slightly, coming in contact with the next sediment grain, and so on. A clam larger than the space between the tines will be forced upward, as the micromotion of the vibrating tine is transmitted to the shell, helping to fluidize the path to the surface. The vibrating rake is mounted on a framework equipped with sled-like runners to maintain its design configuration with respect to the bottom. The sled is pulled by a harvesting vessel.

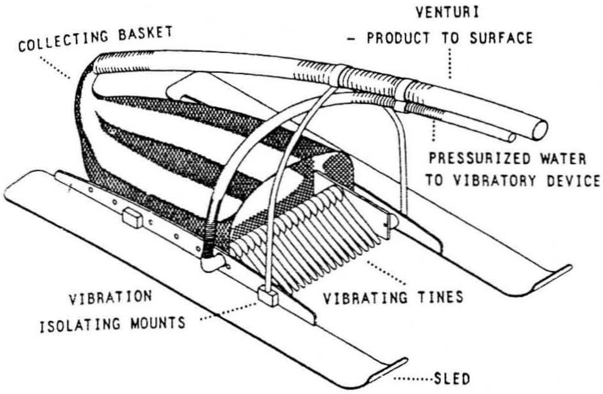

FIGURE 3: THE VIBRATORY CLAM HARVESTER

The vibratory action is produced by seawater pumped from the tending vessel through a flexible hose to the active equipment where it turns a low-pressure turbine wheel mechanically coupled through an eccentric to the main framework of the sled. The exhaust from the rotary device is diverted to an enclosed collecting device resembling a flattened funnel. Its purpose is to wash the harvested product back to the apex where a large diameter suction hose delivers it to the surface vessel.

The rotary-type and vibratory harvesters provide several advantages over existing clam harvesting techniques. They are more efficient than parallel, fixed-tine manual rakes because they allow for continuous harvesting irrespective of clam density. Both types of harvester are amenable to modification with escalator belts to the surface. Without excavating the substrate, excessive dislocation of other infaunal marine organism or seagrasses, and no more suspension of sediments than occurs with manual raking, the rotary and vibratory rake harvesters represent examples of mechanized implements which improve harvesting efficiency and at the same time are environmentally benign.

FLEXIBLE BELT OYSTER GROWING SYSTEM

Historically, intensive cultivation of oysters has been practiced intertidally in bays or sounds where large tidal fluctuations create expansive intertidal flats at ebb tide. Tidal exposure of the crop affords several advantages to the oyster farming: 1) Predation and biofouling are reduced; 2) oyster growing containers are accessible for harvesting and handling. In contrast, estuaries and coastal lagoons in the southeastern United States have small tidal fluctuations, and subtidal cultivation must be practiced. In many state, Florida as an example, require that oyster growing containers or equipment must be limited to within six inches of the bottom. On-bottom cultivation of oysters presents operational problems not encountered with intertidal farming. These include: 1) persistent biofouling; 2) excessive predation requiring containment of oysters throughout their grow-out cycle; 3)limited accessability to submerged growing containers. Current methods for harvesting oysters previously described in this presentation are designed for harvesting natural oyster populations rather than handling containers which house the oysters and protect them from predators.

An innovative "on-bottom" oyster growing system, developed at Harbor Branch Oceanographic Institution, Inc. (U.S. Patent # 4,896,626), utilizes a flexible belt apparatus, oyster growing containers and a specialized tender vessel which lifts the oyster containers to the surface for handling or harvest. Operational advantages of a flexible belt include: (1) a modular design for easy transport; (2) rapid deployment, handling, and harvest of oyster containers without specialized hoists; (3) an efficient method for cleaning oysters and containers; and (4) minimal labor and exposure of workers to adverse working conditions.

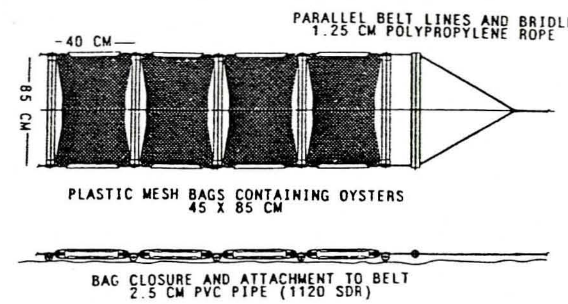

FIGURE 4: TOP AND SIDE VIEWS OF THE FLEXIBLE BELT OYSTER GROWOUT SYSTEM SHOWING PARALLEL LINES, BRIDLE AND COMPARTMENTS

The design features of the flexible belt system include two parallel flexible lines (1/2" polypropylene rope) with a spreader and bridle at each end attached to anchors. A series of individual, removable, plastic mesh bags containing oysters are attached to the two parallel lines (Figure 4).

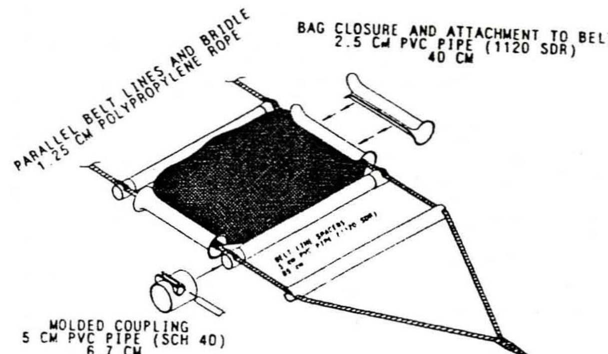

FIGURE 5: CONSTRUCTION DETAIL OF A SINGLE CONTAINER UNIT ATTACHED TO PARALLEL FLEXIBLE LINES

The plastic mesh bags (double open-ended cylinders) are attached to the lines by folding each end over the rope and sealing with a 1" PVC closure with flanged ends to facilitate attachment. Bags are separated by individual crossbars which are detachable from the parallel lines and slide along the lines for desired positioning (Figure 5). Belt components are constructed entirely of PVC pipe to prevent corrosion, and do not require specialized manufacturing equipment.

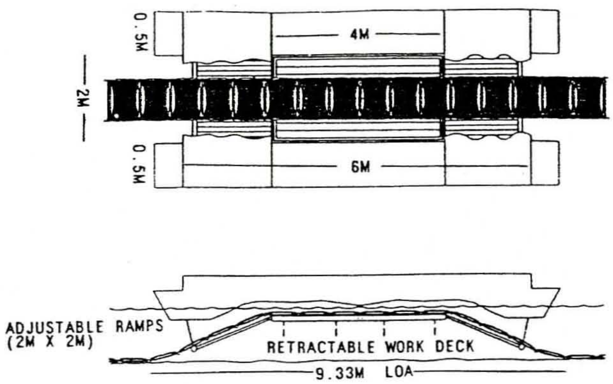

FIGURE 6: PROTOTYPE TENDER VESSEL FOR FLEXIBLE BELT OYSTER GROWOUT SYSTEM (TOP AND SIDE VIEWS).

The belt's modular construction facilitates handling the oyster containers as individual bags can be added or removed quickly and easily. Essentially, the oyster belt is constructed in the field as it is being deployed. Unused space on the belt is merely a pair of lines.

Oyster containers in the flexible belt are lifted to the surface by a twin-hulled tender vessel with a submerged lower deck (Figure 6). The tender vessel consists of two hulls, 2' x 2' in cross section and 16' long, with a 45° vertical taper on one end as a rudimentary bow, for a total length of 18'. During construction, 6" lengths of metal tubing are securely attached to both the top and bottom inside edges of each hull. The hulls are assembled using five 6" lengths of tubing sized to telescope over the tubes affixed to the hulls. When pinned in place, the two hulls become a somewhat flexible vessel. A grating deck is attached to the tubing spacers on the bottom to form a submerged work deck, while 4' x 6' plywood deck sections are fitted to the top spacers to form a removable deck. Transoms may be constructed on the aft ends of the hulls for fitting small outboard engines. Forward and aft ramps (4' x 6' grates of PVC pipe) adjust for depth, and guide the belt to the submerged deck.

Once on board the tender vessel, the containers can be cleaned, removed for thinning, redistribution of oysters or harvested. The belt itself is not moved longitudinally; rather the tender vessel moves along the belt, raising it vertically, and lowering it to its original bottom position. Belt lines are deployed every six feet with a guide line every fourth set of lines. Guide lines are permanently affixed to the substrate to which the tender vessel is attached using "snatch blocks." Lines can be adjusted to position the tender vessel over each belt and to maintain alignment of the vessel. The fore and aft ramps allow the tender vessel to move in either direction along the belt, taking advantage of prevailing winds and current. A single acre plot (400' x 108') will hold 18 belt lines (six foot centers) with 144 bags per belt, or 2592 bags/acre.

The flexible belt oyster growout system provides an effective means for the oyster farmer to carryout efficient tending and harvesting of his crop. Since the oysters are contained in mesh bags on the bottom, they present no navigational hazard nor require specialized frameworks. The system affords rapid deployment and retrieval of the containers, and it does not require any dredging, excavation of the substrate or increased turbidity.

SUMMARY

In summary, only rudimentary mechanization, adapted from the capture fisheries, has been applied to the field of marine mollusc cultivation. In most cases, these devices are inefficient, cumbersome, and exert some negative impact on the marine environment. The equipment described in this presentation have been designed to meet the needs for enhanced efficiency and environmental compatability. The expertise of marine technologists can play an important role in the development of mechanized aquaculture equipment that suit the needs of the marine mollusc farmer and satisfy the concerns of the marine environmentalist.

REFERENCES CITED

Bardach, Ryther and Mclarney 1972.
Aquaculture: The farmaing and husbandry of freshwater and marine organisms. John Wiley and Sons, New YOrk, 868 pp.

Collette, R. L. 1989.
Harvesting techniques. In: The Seafood Industry , R. E. Martin and G. J. Flick (eds.). Van Nostrand Reinhold, New York. 17 - 32 pp.

Collier, J. A. and D. M. McLaughlin 1983.
A mechanical oyster harvester for south carolina estuaries. J. World. Maricul. Soc. 14:297-301.

Creswell, R.L., J. Holt and D. Vaughan 1988
Subtidal cultivation of the American oyster, Crassostrea virginica, utilizing a flexible belt system. Proc. Gulf and Carib. Inst., 42 Ann. (in press).

Godcharles, M. F. 1971.
A study of the effects of a commercial hydraulic clam dredge on benthic communities in estuarine areas. Florida Dept. Nat. Res., Tech. Ser. No. 64. 51 pp.

Peterson, C. H., H. C. Summerson, and S. F. Fegley 1987.
Ecological consequences of mechanical harvesting of clams. Fishery Bulletin 85(2):281-297.

Westman, J. R. 1946.
On the origin, development and the status of the surf clam industry - 1943-1945. New York Conservation Dept. unpubl. mansc., 10 pp.