FLORIDA SEA GRANT PROGRAM

LUGWORM AQUACULTURE

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REPORT NUMBER 16 SEPTEMBER 1976

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PART I. A PRELIMINARY PLAN FOR A COMMERCIAL BAIT-WORM HATCHERY TO PRODUCE THE LUGWORM, *ARENICOLA CRISTATA* STIMPSON

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Report Number 16
State University System of Florida
Sea Grant College Program
September, 1976

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PART I

A PRELIMINARY PLAN FOR A COMMERCIAL BAIT-WORM HATCHERY TO PRODUCE THE LUGWORM, *ARENICOLA CRISTATA* STIMPSON

by

CHARLES N. D'ASARO

INTRODUCTION

Proposals that marine bait-worm farms are practical, at least biologically, were made by Pope (1961) and Taylor and Saloman (1968). Their suggestions have recently appeared implementable because demand and value of marine bait-worms have increased and can support some types of bait-worm aquaculture.

Users of Marine Bait-Worms

Leisure time activity in the United States is increasing as the work-week decreases and the proportion of retired individuals increases (Weiskopf, 1975). Such activity contributed significantly to Iversen's (1968) estimate that the number of sport fishermen in the country is increasing more than two and a half times as fast as the population. The National Survey of Fishing and Hunting (U. S. Department of Interior, 1970) indicated that 33 million sport fishermen (up from 28 million in 1965) spent close to five billion dollars on their sport. Of these, 9.5 million fishermen spent 1.2 billion dollars on salt-water fishing of which 146 million dollars was spent on all types of bait. These individuals, as well as millions of occasional fishermen who may fish in the marine environment only during their annual vacations (and are not usually considered in surveys) represent the actual and potential users of marine bait-worms.

Demand for Marine Bait-Worms

In various countries marine bait-worms have a long history of use for commercial as well as sport purposes. Lugworms were used as early as the fourteenth century in the British Isles (Belon, 1555 cited by Wells, 1945) and are presently a major bait in that area as well as on the European continent, in Korea and Japan (pers. comm., J. Park, Chung Ung Co., Seoul, Korea) and South Africa (pers. comm., C. M. Gaigher, Department of Nature Conservation, Jonkershoek Fishery Station, Stellenbosch, South Africa). The demand has been sustained in recent years because sport fishermen, especially unskilled, leisure time fishermen, want a natural bait which reliably attracts fish.

European lugworms, *Arenicola marina*, are routinely used to catch cod, dab, haddock, plaice, and whiting (Ashworth, 1904; Blegvad, 1914; Bulycheva, 1948). *Arenicola marina* retails for as much as 4.8 cents apiece in England (Tampa Tribune, 1974). Responses to inquiries made in England indicated that no official records or statistics concerning the lugworm fishery are collected (pers. comm., A. R. Margetts, Information Officer, Ministry of Agriculture, Fisheries and Food, Fisheries Laboratory, Lowestoft, Suffolk, England); however, the demand is sufficient to produce local scarcity in bait and tackle ships that distribute them (London Daily Mirror, 1973). In South Africa where heavy demand occurs, harvest of A. loveni is limited to five worms per day per fisherman to prevent over exploitation (pers. comm., C. M. Gaigher).

In American waters A. cristata, which is quite similar in appearance and quality to A. marina, is the most common lugworm. American lugworms are used only occasionally as bait because they are difficult to harvest and are not recognized by the average sport fisherman. On the Gulf coast, especially near Tampa Bay, lugworms retail for 75 cents per dozen or more when available (Jack's Bait House, St. Petersburg, Florida) and are used primarily for sheepshead and redfish (channel bass). There are no estimates concerning annual harvests of A. cristata in the United States.

The major marine bait-worms harvested in North America are the bloodworm, Glycera dibranchiata, and the sandworm or clamworm, Neanthes virens. These relatives of the lugworm are collected by licensed diggers, mostly in Maine. In 1974, the average retail price for bloodworms was $1.85 per dozen (refer to the following paper by Chen). Over 712,000 pounds of bloodworms and 822,000 pounds of sandworms are harvested annually in Maine (U.S. Department of Commerce, 1975).

Bloodworms and sandworms are used chiefly on the east coast between New York and North Carolina and on the California coast. The fishes caught with these baits include blackfish, bluefish, flounder, fluke, kingfish, porgy, sea bass, striped bass, and weakfish (MacPhail, 1954). Sport fishermen are so eager to obtain bloodworms and sandworms that sometimes supply can not meet demand (New England Marine Resources, 1973). Strong demand has forced prices up to a point at which bait-worms on a per pound basis are among the most valuable regularly harvested marine organisms landed in the United States.

Sources of Marine Bait-Worms

All marine bait-worms presently marketed are harvested from natural stocks. In England lugworms, A. marina, are manually raked from exposed mudflats, sorted on trays in lots of one hundred, covered with newspaper and delivered to retailers within 24 hours (pers. comm., Dr. John Taylor, Taylor Biological, Lyn Haven, Florida).

Bloodworms and sandworms are collected by licensed commercial diggers who work in knee-deep mud and expose the worms by digging a trench with a fork (Klawe and Dickie, 1957). Diggers count and sort worms into trays lined with newspaper and sell them immediately to local wholesalers for approximately 5.5 cents apiece. (Licensed diggers recently began a strike and are attempting to get 7 cents per worm.) The worms are stored and shipped in trays filled with an alga, Ascophyllum mackaii (Ganaros, 1951). They are shipped by parcel post, air freight or truck depending upon the requirements and location of the wholesaler and retailer.

Aquaculture as a Source of Marine Bait-Worms

Aquaculture of certain marine bait-worms was suggested because it can be used to meet effectively increasing demand and to eliminate certain problems currently encountered by bait-worm dealers. Of the species mentioned, the bloodworm is the most difficult to culture; in fact, the animal has not been reared through the complete life cycle in the laboratory (see Simpson, 1962a). In addition, two years or more in Maine are required for a worm to grow to a marketable size of 12 cm (ca. 5 in) (Creaser, 1973) while in warmer waters (Maryland) they may spawn before marketable size is reached (see Simpson, 1962b). Sandworms can be cultured through their life cycle (Bass and Brafield, 1972) but feeding habits present complications and at least a year is required to produce marketable worms in northern waters.

Although there are no reports of egg to egg cultivation of the northern or European lugworm, Arenicola marina, most ontogenetic stages were described from material collected in the field (Newell, 1949; Smidt, 1951). Estimates of growth rates to marketable size (6 cm = 2.4 in, or larger) were at least one year in European waters (Smidt, 1951). Established bloodworm and sandworm dealers report such basic problems as: (1) supply of worms is not predictable; (2) size is variable; (3) average size has decreased in recent years; (4) mortality is high during storage; (5) certain species bite and can produce an allergenic reaction (refer to following paper by H. Chen).

In contrast to other marine baitworms, Arenicola cristata is extremely easy to cultivate. Research completed in conjunciton with preparation of this report demonstrated that it can be cultured, egg to egg, in an ordinary aquarium without special care. The advantages in selecting this species for aquaculture are significant.

(1) All ontogenetic stages can be cultured and selective breeding is possible.
(2) Marketable worms of a relatively uniform size can be produced in 90 days in temperate localities in predictable quantities.
(3) Lugworms tolerate adverse conditions including anoxia and sudden extreme changes in temperature and salinity.
(4) Estimated production costs are low (less than 3¢ per worm).
(5) Lugworms can be marketed both as a bait and as a live food for tropical fish.
(6) There are no legal or environmental constraints on their culture, if recommended methods are used.

There are disadvantages also, especially the large area of the physical plant, special handling required during shipment and the fact that no significant market specifically for lugworms exists in the United States at this time. Yet when biological, physical and economic features are evaluated for the various bait-worms mentioned, A. cristata is by far the most practical to consider for aquaculture.

Since the lugworm appeared to be a promising species to consider for aquaculture, a pilot study was funded by the State University System of Florida Sea Grant Program and The University of West Florida. A hatchery of limited capacity was constructed at the Gulf Breeze Enviromental Research

Laboratory (EPA) on Sabine Island near Pensacola, Florida. The primary objective of the work in the pilot hatchery was to develop a plan for commercial culture of the lugworm, Arenicola cristata, as a source of bait for sport fishermen. The research was directed mainly toward obtaining answers to specific aquacultural questions. These areas were considered in some detail because they appeared to be most promising in terms of obtaining essential information for an aquacultural plan:

(1) facilities and methods to culture larval and juvenile lugworms,
(2) methods to control swimming by juveniles and adults,
(3) food for all stages formulated from available and inexpensive ingredients,
(4) efficient feeding techniques,
(5) selective breeding for rapid growth and amenibility to culture,
(6) packaging and shipping methods,
(7) evaluation of possible detrimental environmental impact by lugworm hatcheries.

By using data collected during the study, practical experience in the pilot hatchery, data from the literature and personal communication with various specialists, it was possible to prepare this plan for a commercial hatchery with a minimum production capacity of at least one million marketable lugworms per year. I believe that the plan as presented herein can be used for commercial production; however, potential users should consider these points. As presently conceived, the process was not tested on a large scale. Grow-out units in the pilot hatchery contained only 25 m^2 (only 2.5% of the area recommended for a single grow-out unit in one option of the plan). At least 1,000 m^2 (approx. one quarter acre) grow-out units should be tested. In addition, large scale harvesting methods require testing. Data and observations presented in this report are based on work completed with a race of lugworms indigenous to the northeastern Gulf of Mexico. As Wells (1962) noted, there are several varieties or subspecies of A. cristata. These varieties would be expected to have somewhat different biological requirements. Before attempting full-scale commercial production, individuals who are using this plan as a guide are cautioned to evaluate carefully the physical features of the proposed location as well as biological characteristics of local races and to complete rearing experiments in the selected locality for one season.

BIOLOGY OF ARENICOLA CRISTATA

Before culture can be discussed, it is necessary to review some general biological characters of the lugworm. This review is based on observations made on "group B" worms (Wells, 1962) from northwest Florida. The emphasis is on characters which allow an individual with some knowledge of biology to identify the worm and recognize those features which affect hatchery location and design. Comparisons with a similar species, *A. marina*, are made when direct data on *A. cristata* are not available. Such comparisons are valuable because as Wells (1964) observed, the way of life and general appearance of the 24 named lugworm varieties are the same.

Anatomy

Arenicola cristata is a large polychaete with a "cigar-shaped body" divided into 17 setigerous segments which comprise the head-trunk region, and a tail of reduced diameter and variable number of autotomizable segments (Fig. 1*). There are normally 11 pairs of gills on segments 7 to 17. Mature animals in their second year are usually 12 cm** total length. (Total length as applied in this plan was determined with fully contracted worms. When relaxed the same animals can be 50% longer). The major distinguishing anatomical feature, which can only be viewed in cross-sections of the body, is that the ventral nerve cord is separated from the circular muscles by longitudinal muscles (Wells, 1961) (Fig. 2).

Coloration varies with age. Very young juveniles are light pink with yellow tails and are transparent. Older juveniles are red with yellow-green tails and are increasingly opaque. After sexual maturity, the worms become red-brown and opaque and finally red-black after 200 days. Mature worms in their second year are black with red gills. The tail may retain a yellow-green tint.

Behavior in the Field

Arenicola cristata inhabits muddy sand (200-700 μ particle diameter) in shallow or intertidal waters, especially in or near areas in which seagrasses (*Thalassia testudinum* and other species) are common. Since it inhabits more dense substrate than *A. marina* (< 200 μ; Longbottom, 1970a) it is comparatively more difficult to harvest. The worm occupies a roughly U-shaped, mucus-lined burrow (21 cm average depth) which is marked at the surface by a funnelform depression at the headshaft and a mound of sand at the tailshaft. The tailshaft may be covered by flattened, slightly yellowish castings and/or contain a small respiratory hole (Fig. 3). Accessory headshafts and tailshafts are often present. The headshaft is filled with sand which gradually collapses into the burrow due to activity of the worm. Sand and organic material in the headshaft are eventually swallowed; available food is digested; and waste is defecated at the tailshaft. As Jacobson (1967) demonstrated for *A. marina*, the lugworm's food is obtained essentially from the surface layers in its habitat.

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* Figures and tables are at the end of each paper
** 1 centimeter = 0.39 inches; 1 inch = 2.54 cm

Arenicola marina was shown to have a regular activity cycle (Wells, 1949a, 1949b) in which water is drawn into the burrow via the tailshaft by rhythmic peristaltic movements of the body. Some particulate material suspended in this water, including plankton, is trapped in loose sand in the headshaft and can be ingested. However, Jacobsen (1967) demonstrated that trapped plankton is not a major source of food for the worms. Lugworms also reverse peristaltic waves and force water out of the burrow through the tailshaft. Currents induced by peristaltic waves are used to carry away excretory wastes, which are released directly into the burrow, and to transport gametes. Peristaltic activity exhibited by A. cristata appears to be similar to that reported for A. marina.

Spawning begins when the water temperature rises above a specific limiting level (16-18°C = ca. 61-64°F for "group B" worms from northwest Florida). The diecious worms release gametes directly into their burrows at regular intervals (up to four per month) as long as the temperature is above the limiting level. Usually males spawn first. As spermatozoa are drawn into a female's burrow by normal pumping activity, mucus from epidermal glands is released and eventually ova are extruded through the nephridia. Fertilization takes place as a mucus egg mass is gradually extruded from the burrow to which it remains attached for three days (Fig. 4). Larvae which escape from the mass settle in the same habitat as the adults. After 25-30 days at 25°C (77°F) larvae complete development of the seventeenth setigerous segment and begin to produce nonsetigerous caudal segments. They are now described as juveniles and have the same morphological characters as adults (Fig. 5). In 60-90 days juveniles mature sexually and begin to spawn.

Physiology

Lugworms are highly tolerant of extremes in temperature. During pilot studies, Arenicola cristata survived exposure after acclimation to temperatures between 1 and 40°C (ca. 34-104°F) without mortality (Rubinstein, 1976). Mature lugworms subjected to sudden thermal changes between 10 and 35°C over a range of 25°C were not adversely affected after 24 hours (Rubinstein, 1976). At environmental temperatures below 10°C lugworms are quiescent. Optimum temperatures for rapid growth lie between 20 and 30°C (Rubinstein, 1976). At temperatures above 35°C the activity cycle is again interrupted and substrate modifying activity decreases.

As Krogh (1939) observed for European A. marina, A. cristata is an osmoconformer capable of tolerating wide ranges in salinity. To maintain normal activity, A. cristata requires salinities above 10‰ and below 35‰ Rubinstein (1976) determined that the optimum salinity for rapid growth lies between 20 and 25‰ and that the worms survive sudden 15‰ changes in salinity. For short periods (several days) A. cristata in burrows will survive suprasubstrate salinities as low as 8‰. When salinities below 10‰ occur lugworms interrupt their normal activity cycle and substrate modifying activity ceases.

Respiratory activities within the burrow, as described by Wells (1949b) for A. marina, are essentially the same as those exhibited by A. cristata and were mentioned earlier. Lugworms employ hemoglobin as a respiratory pigment (Fox, 1945). Contrary to popular belief, the worms store oxygen only for a few minutes (Elaissen, 1955); however, A. cristata can exist at least 72 hours in an oxygen-free environment. In contrast, survival by A. marina is lower in a 100% oxygen environment (Fox and Taylor, 1935). Similar observations concerning survival in a 100% oxygen environment were made for A. cristata during packaging experiments completed in conjunction with preparation of this report.

Geographic Distribution

Arenicola cristata occurs in the Atlantic and Pacific Oceans essentially between the 20°C summer surface-water isotherms (Wells, 1963). Various races are distributed in the Western Atlantic from Woods Hole, Massachusetts to Key West, Florida, and throughout the Gulf of Mexico and the Caribbean Sea (Wells, 1962). In the Eastern Pacific, its reported range is from Humboldt Bay, California to Mission Bay, California. Wells (1961) stated that A. cristata is typically found in estuarine or inland waters. It is also common in calcareous sands and marl in many parts of subtropical and tropical America where hermatypic corals abound and the salinity rarely drops below 30‰. As indicated by its distribution especially in the Atlantic Ocean, A. cristata can be characterized as an inhabitant of temperate and tropical waters with an extremely broad latitudinal range.

PHYSICAL PLANT OF A PROPOSED LUGWORM HATCHERY*

Site Selection

The lugworm's biological requirements, as well as proximity of potential markets and culture methods to be employed, are criteria which determine the location of a hatchery. For "group B" worms from northwest Florida, these are pertinent criteria for several design options in which an open seawater system is to be employed.

(1) The physical plant should be near a relatively unpolluted estuary in which salinities range between 10 and 35‰. Immediate proximity to the estuary is not necessary because seawater can be pumped several hundred feet inland if easements for supply lines and drains are obtainable and appropriate pumps are used. If ground sources of good quality saline water are available, they are preferred.
(2) Mean annual temperature at the latitude selected should be above 15°C (59°F).
(3) Construction should be on land sufficiently elevated (at least 1.0 m above mean high water of spring tides) to permit economical dike and embankment construction with spoil from the prospective grow-out units, allow complete drainage of grow-out units and prevent erosion by storm tides.
(4) The area required to produce at least one million marketable worms per year is 1.6 hectares (4.0 acres), of which 0.6 ha (1.5 a) or more will actually be in production.
(5) Soil in the area should not contain deposits of shell, rock, or debris which could damage a PVC liner used to waterproof rearing units. Substrate of the proper type (calcareous or siliceous sand) and particle size (200-700 μ) should be available on the site or nearby.
(6) A local source of seagrass is preferred.
(7) There should be enough prospective dealers to provide a local market within 300 km (186 mi) of the hatchery.
(8) An airport located within 40 km, with freight facilities insuring direct connections to major east coast markets, is highly desirable.

Lugworm hatcheries can be located adjacent to waters which the State of Florida classifies as Class III (recreation, propagation and management of fish and wildlife) because proper hatchery operation will not degrade environmental quality. The environmental criteria (Florida Administrative Code, Supplement 35, 17-3.09) for the Class III category are:

(1) Industrial wastes shall receive modern effective treatment (removal of 90% or organic material).
(2) Receiving waters shall not be caused to vary more than one unit on the pH scale from normal background level (the range should not be less than 6.0 or greater than 8.5).

*The inclusion of brand names in this plan does not constitute endorsement by the NOAA Office of Sea Grant or The University of West Florida.

(3) Dissolved oxygen levels shall not be artifically depressed below 4.0 mg/l.
(4) Coliform bacteria shall not exceed 1,000/100 ml monthly average.
(5) No substances shall be present which are toxic or harmful to humans, animal or aquatic life.
(6) The water shall be free from materials producing color, odor or other conditions in such degree to create a nuisance.
(7) Turbidity shall not exceed 50 Jackson turbidity units above background.
(8) Temperature shall not be increased so as to cause damage to aquatic life.

A summary of observations made on operational lugworm grow-out units located adjacent to Santa Rosa Sound (Table I) can be compared with the criteria. The apparent indication is that effluent water returned to the Sound was essentially unchanged in most categories. In fact during certain periods in the summer, effluent water had more oxygen and lower nutrient levels than influent water.

Since lugworm hatcheries must be constructed in the coastal zone and the designs suggested require at least an effluent ditch opening into an estuary, specific permits for construction are required from governmental agencies at several levels. In each state, the agencies involved and permitting procedures are somewhat different. For Florida, the specific agencies which issue permits for waterfront construction and the procedures required to obtain the permits are outlined by Collier (1975). (Recent legislation has altered some of the requirements.)

Alternative Designs

Based on experience in the small-scale pilot hatchery, several major design options for a lugworm hatchery can be proposed:

(I) Open systems with seawater pumped from an estuary or a ground source to grow-out units waterproofed with PVC liners.
(II) Open systems with estuarine seawater supplied by tidal activity to sea level grow-out units without PVC liners.
(III) Biologically filtered, semiclosed systems which are flushed and renewed with seawater from an estuary only when required by evaporation, precipitation or accumulated wastes.
(IV) Closed systems with biological filters in which the grow-out units are enclosed or covered and environmental conditions are controlled.

Option I was tested in part on a small scale and can be made immediately operational on a commercial scale. It is the recommended method for early development of lugworm aquaculture to which the other options can be compared on a cost-benefit basis.

Only the first two options are discussed in this plan. All dimensions are given initially in metric units unless standard manufacturers sizes are used; then dimensions in English units only are given.

Option I:

An Open System Lugworm Hatchery with Seawater Supplied by Pumps to PVC Lined Grow-Out Units

An estuary-dependent hatchery supplied with seawater by pumps would inculde these major components:

(1) seawater system (pumps, filters, supply lines and drains),
(2) brood-stock units,
(3) rearing facilities for larvae and young juveniles,
(4) grow-out units for bait-worms,
(5) processing, storage and distribution facilities for food,
(6) harvesting, inventory storage, packaging and shipping facilities.

Figure 6 is a schematic diagram of a proposed hatchery which includes six 1,000 square meter* grow-out units.

Seawater System

Schematic diagrams of a proposed system are shown in Figures 7 & 8. The system is served by paired 3-inch pumps which deliver water together at a maximum rate of 750 gpm (total dynamic head approximately 32 ft) directly to an elevated (10 ft) filter-reservoir. (The assumption was made that the location selected will not require an inlet system that will reduce the combined capacity of the recommended pumps below 750 gpm.) Pumps are self priming centrifugal units (Model 34EL-17D, Marlow) driven by 7.5 HP electric motors (see Pruder et al., 1973 for additional specifications concerning the pump lining; for operational data refer to Marlow Pumps Engineering Manual, EM-611, and preformance curves prepared by the manufacturer). Seawater is drawn from a depth in the adjacent estuary at which optimum salinities have been observed throughout the tidal cycle. To prevent egg masses of wild lugworms from being drawn into the system, inlets should not be located near large spawning populations. Inlet supply lines are perforated 3-inch PVC (polyvinylchloride) pipes (positioned horizontally) with capped ends raised at least 0.5 m from the bottom. Each perforated pipe is attached to the main supply line by a threaded coupling to allow for removal and replacement with a clean unit at intervals. To control fouling, facilities are available to fill supply lines in place with hot freshwater (65-70°C) (149-158°F) at regular intervals and when they are not operational. A 50-gallon natural gas water heater and 120-gallon glass-lined storage unit are recommended for this purpose. An alternate source of seawater would be a well located near the estuary. See Clark and Eisler (1964) for details concerning type and location.

The elevated filter-reservoir (constructed from exterior plywood waterproofed with fiberglass cloth and epoxy resin) maintains pressure in the system. Seawater enters near a constant level standpipe and flows through three nylon or stainless steel screens (2 mm mesh) before it enters the low velocity supply system. All low velocity supply lines are PVC (schedule 40 for potable water). Suggested diameters are indicated in Figure 7.

*One square meter (m^2) = 10.76 sq ft = 1.196 sq yds

From the reservoir, water is distributed to outdoor brood-stock units, composting units, grow-out units and to another reservoir in the service building. Siphons from the service reservoir serve brood-stock units, rearing units and storage facilities in the building. There are no gate valves in the proposed system. Flow rates are adjusted or terminated with caps applied at critical junctions (Fig. 7). Since flow rates to grow-out units are not rapid enough to prevent fouling, the grow-out supply system must be capped and filled with 65-70°C freshwater at frequent intervals. Threaded clean-out ports provide access.

Effluent water leaves grow-out units through concrete monks or sluiceways (Fig. 9) such as those described by Huet (1973). Each unit is equipped with a screen, double leveling boards and a bonding strip for the PVC liner. Sluiceways open into 30 cm diameter culverts under the service roads. Culverts discharge into open drainage ditches which are unsealed except at the mouth of each culvert where a layer of asphalt prevents erosion. Effluent from the service building is channelled through an asphalt-lined ditch to the main drainage ditch or directly to the estuary.

Brood-Stock Units

Three types are employed for brood animals: small plastic pans or trays for selective breeding; heated units for breeding during colder months; and outdoor brood-stock units for holding large seasonally spawning populations. Almost any nontoxic container of six or more liters capacity is suitable for selective breeding. Fifteen liter trays are recommended. Storage (holding) units (Fig. 10) on a closed system with environmental controls can be used to maintain brood-stock in spawning condition during the winter. Outdoor brood-stock units, constructed essentially as miniature grow-out units equipped with standpipes instead of monks are recommended for warmer months (Fig. 11). Five-square-meter units can support 100 large brood animals.

Rearing Facilities for Larvae and Young Juveniles

Egg masses must be hatched in closed systems, most conveniently in aerated 15 l trays. If large-scale production is necessary, storage units (without live cars) as shown in Figure 10 are satisfactory. The units can be used to produce juvenile worms suitable for stocking or for live, tropical fish food. Figure 8 represents a suggested design for a hatchery service building equipped with the multiple purpose units.

When larger juveniles are required for stocking, two options in construction can be considered. Either the previously mentioned storage units can be used for this purpose or separate outdoor facilities can be constructed. The latter would be least expensive and easier to operate. A five-square-meter unit constructed like the outdoor brood-stock unit would provide sufficient juveniles to stock one grow-out unit during a production cycle in Option 1.

Grow-Out Units for Bait-Worms

Two designs, which can be constructed within a 1.6 ha physical plant, are suggested: (a) six grow-out units with 6,000 m^2 production area (Fig. 6) or (b) four grow-out units with 7,200 m^2 production area (Fig. 12). Both require plastic liners (PVC) for water-proofing. Advantages of each are discussed later.

Grow-out units are constructed by removing soil from the central area and forming embankments. Rocky soil, deposits of shell or sharp bladed grasses should be avoided or covered with clay to prevent damage to the PVC liner. (Site preparation should follow recommendations published by the manufacturer of the liner.) Concrete culverts (30 cm diameter) for drains are installed while embankments are being constructed. Culverts are connected to modified monks or sluiceways each of which has bonding strips at the sides and base (Fig. 9). Embankments are compacted and graded to a 3:1 maximum slope (Fig. 11). The rearing area in each unit is graded to allow complete drainage after harvest. Pond construction techniques are outlined in Agriculture Handbook No. 387 (U.S. Department of Agriculture, 1971). PVC liners (15 mil or thicker) are installed and folded into a trench on the crest of the embankments. After the liner is in place, calcareous or siliceous sand is spread uniformly in each unit to a depth of at least 15 cm. This step is facilitated by leaving a gap in each embankment with the PVC liner folded down to allow access by a front loader. The front loader can operate only where the liner is covered by 15 cm or more of sand.

After the substrate in the rearing area is applied, the exposed liner on the embankments is covered with a layer of marl which provides protection from abrasion, sunlight and fouling organisms. A slight ridge at the base of each embankment (Fig. 11) serves to hold the marl in place. Embankments are protected from erosion by bahia or bermuda grass. The grass should cover the point at which the liner is folded into the embankment and part of the marl also. Service roads on all embankments can be surfaced with clay or crushed shell. The latter is least desirable because it can be accidentally carried into the grow-out units. Supply lines are buried only at intersections with service roads where they are covered with reinforced concrete slabs which distribute weight and protect the pipe.

<u>Processing, Storage, and Distribution Facilities for Food</u>

Seagrasses can be collected and processed by hatchery operators or private contractors. If the hatchery staff is involved, the following equipment is necessary:

(1) four-wheel drive vehicle with power take off (Jeep C5-J),
(2) pasture rake (local construction; no specific design),
(3) one-ton capacity utility trailer with removable wire-mesh sides and a matching 1,200 l plywood tank (local construction),
(4) hammer mill (Model 950, International Harvester Grinder-Mixer) with specially modified screens to control particle size,
(5) three-metric-ton capacity (3,800 l/metric ton) elevated dry storage facility (local construction; no specific design),
(6) three inch, single port, open volute pump (Model 1503, Neilson Metal Industries).

After the grass is collected, it must be sun-dried. A grassy area (approximately 80 m^2 per ton) near the storage facility covered by polyethylene sheets can be designated for this purpose. Seagrass dries faster when elevated in containers or on racks which allow air to circulate. After drying the grass is ground immediately and blown into an elevated storage container by the grinder-mixer.

Processed grass is mixed with seawater before distribution to grow-out units. To implement this procedure, the sides of the utility trailer are removed and a 1,200 l plywood tank is installed. The three inch pump, placed on a platform in front of the tank, is used to distribute a slurry of seagrass. It is suggested that this be accomplished by fitting the inlet pipe with a T-junction and an additional, smaller inlet pipe. The smaller pipe permits slurry to be drawn from the tank, mixed with water from a rearing unit, passed through the pump and sprayed over the surface of the same rearing unit.

Harvesting, Inventory Storage, Packaging and Shipping Facilities

The recommended procedure for harvesting is to pump substrate from grow-out units with a floating harvesting device supporting a three inch pump (the same unit recommended in the previous section) which will pass adult lugworms without injury (Fig. 13). A protective frame on the flexible inlet pipe allows substrate containing worms to pass but holds the PVC liner in position. The pump discharges substrate containing worms on a 0.5 cm mesh screen mounted on the floating platform. As the worms roll down the screen they are manually sorted into floating live cars designed to fit directly into storage units in the service building (Figs. 10 & 14). The floating platform can be disassembled to facilitate transport. The pump is portable and can be moved by two men.

Open and closed-system storage facilities are included in the proposed design. In the former, five double-layered units each with a capacity of 24 live cars (1,000 worms/car) are sufficient to store 120,000 lugworms for at least one month without substrate or food (Fig. 10). Closed system storage capacity is limited to 48,000 individuals held in two double-layered units supported by biological filters (Fig. 8). Storage units and the filter body are constructed from exterior plywood waterproofed with fiberglass cloth and epoxy resin. The filters are equipped with water chillers (Model DI-33, Frigid Units) and immersion heaters. The main functions of the closed systems are to cool lugworms prior to shipment, provide capacity to spawn worms during the winter and serve as an emergency support system for inventory.

For long distance transport by air, lugworms are packaged in styrofoam insulated boxes (standard tropical fish shipping containers) containing four plastic bags each holding approximately 250 worms. Several tables in the service building provide space for packaging operations. Overhead garage-type doors facilitate loading operations.

Short distance, surface transport (<300 km) is accomplished by shipping worms packaged in the same containers used for air freight or in bulk in a tank-type live hauling unit mounted in a van or pickup truck (Fig. 15). Water chillers and/or air conditioning in the van are used to maintain appropriate temperatures during shipment.

Option II:

An Open System Lugworm Hatchery with a Tidal Source of Seawater and Unlined Grow-Out Units

Estuary-dependent hatcheries supplied with seawater mainly by tidal activity would include these major components:

(1) seawater system (pumps, filters, supply lines and drains for all facilities except grow-out units).
(2) brood-stock units,
(3) rearing facilities for larvae and young juveniles,
(4) tidally flushed grow-out units for bait-worms,
(5) processing, storage, and distribution facilities for food,
(6) harvesting, inventory storage, packaging and shipping facilities.

Figure 16 is a schematic diagram of a tidal hatchery which includes four 1,800 m^2 grow-out units. This option differs from Option I in the capacity of the plumbed seawater system and that the grow-out units are essentially tidal basins. The major constraint on size, if land is available, is the operator's ability to provide food and to control predation.

Seawater System

This system is essentially the same as that shown in Figure 7 except that plumbing for seawater extends only to the service building and outdoor brood-stock units. A single 150 gpm centrifugal pump driven by an electric motor (Model 34EL-11D, Marlow; see Pruder et al., 1973 for additional specifications concerning the pump lining) is satisfactory to próvide water to the service building and other support facilities.

Tidally Flushed Grow-Out Units

Four grow-out units with 7,200 m^2 total capacity, as shown in Figure 16, can be employed. Size as compared to other options can be doubled because construction costs are significantly lower (see section on estimated construction costs). Site selection is important because 0.5 m or greater tidal amplitudes, proper substrate in the immediate vicinity, and high salinities in surface waters of the estuary are required. To facilitate harvesting, deposits of shell or stones must be avoided. During construction, sand is removed from the units and used to raise embankments. Seepage through the rearing area is not a concern; hence a liner is not necessary. Topsoil and grass are used to stabilize embankments. The surface of the substrate in each unit should be several centimeters above the mean low tide level so complete drainage is possible at some period in the tidal cycle. The units are equipped with two or more concrete monks and culverts.

Tidal flushing is controlled by two, one-way flapper valves, one on each culvert (Fig. 17), which permit seawater to enter on one side as the tide rises and exhaust on the opposite side as the tide ebbs. Flushing occurs between mean tide level and high tide level for a specific day. Water level in a grow-out unit is controlled by leveling boards in each monk. Screens behind the leveling boards provide limited control for large predators only. To prevent erosion, the effluent ditch should be as wide as practical and lined at critical intersections with riprap. Emergent salt-marsh grasses should be planted for the same purpose.

Harvesting Facilities

Lugworms in very large scale, tidal grow-out units can be harvested with some variation of a Long Island hydraulic bar dredge (see Parker, 1971 for basic designs) modified so that behavior of the lugworm is taken into account. Modifications should include mechanisms to hold floating lugworms in the bag, a mesh size which prevents lugworms from becoming entangled when they attempt to burrow, and a mechanism which facilitates rapid and frequent emptying of the bag. Figure 18 is a suggested design for an inexpensive, light-weight hydraulic dredge propelled by a cable attached to a vehicle-mounted winch. Additional facilities required are identical to those suggested in Option I.

OPERATION OF THE PHYSICAL PLANT

Recommended Food for Lugworms

Four seagrasses were included in the diet fed to lugworms in hatchery experiments: turtle grass, *Thalassia testudinum*; manatee grass, *Syringodium filiforme*; shoal grass, *Diplanthèra wrightii*; widgeon grass, *Ruppia maritima*. Of these, turtle grass was the major component comprising 75% of the diet used in growth studies (Table II). These seagrasses or similar species such as eel grass, *Zostera marina*, which are available throughout the North American range of *Arenicola cristata*, are the recommended food for lugworms reared in commercial hatcheries. Although many additives, supplements, or substitutes for seagrasses were tested in closed systems (Table III), none were found to be entirely satisfactory.

Sources of Food

The leaves of seagrasses are constantly being abraded by water currents and biological activity. After storms, tons of seagrass leaves are eventually deposited on nearby beaches. These leaves, which often lie in uniform windrows on the berm, are the raw material which must be collected and processed. Public beaches on sandy barrier islands are the best source. Excessive shell or pollutants (oil, plastic, treated wood) mixed with grass should be avoided. Most unavoidable contaminants, which are processed with seagrass, float when the food is distributed and are flushed eventually from grow-out units.

Collecting, Processing and Distributing Lugworm Food

Seagrasses can be collected by hatchery operators or private contractors. The recommended procedure, which was developed from less complicated methods used in the pilot hatchery, is to accumulate the grass with a pasture rake operated by a four-wheel drive vehicle. When sufficient grass is concentrated in an area, the rake is replaced with a one-ton capacity utility trailer into which the grass is forked manually. If the process is completed after seagrass has dried for one week on the berm, the yield of processed food is estimated at 250 kg/load. Four loads per day can be collected if the source is in the immediate vicinity (one mile or less from the hatchery). The grass is transported to the hatchery, allowed to dry completely in the sun and ground (to less than 700 microns [μ] particle size) in a hammer mill operated by power take-off from the four-wheel drive vehicle.

After processing, seagrass is stored as indicated earlier. To produce one million marketable bait-worms, approximately 20 metric tons* of processed grass are required. Since precipitation occasionally restricts processing of food, at least two metric tons should be in storage at all times. Estimated cost per ton, $64.00, was based mainly on labor and fuel required to collect, dry and grind the grass.

Food is distributed to the grow-out units by mixing it with seawater in a trailerable 1,200 l (ca. 317 gallons) tank and spraying the slurry uniformly on the rearing area with a three-inch pump connected to the previously described double intake system. If the processed seagrass is

* one metric ton = 1000 kilograms; 1 kg = 2.20 lbs.

allowed to soak in seawater for one hour prior to distribution, it will sink immediately upon application. (Refer to the section on rearing juvenile and adult worms for specific details concerning feeding.)

Seagrasses are more suitable as a food for lugworms after composting in seawater in the presence of sufficient light to support photosynthesis. Figure 19 illustrates growth rates of lugworms fed diets of salt marsh peat (which contains seagrass), uncomposted seagrass and composted seagrass (exposed to sunlight). Composting takes place directly in grow-out units. Benthic diatoms, especially Nitzschia closterium in dense populations, appear to be indicators of optimal conditions within the recommended ranges of environmental parameters (Table IV).

Special composting units are required to prepare food for larvae cultured indoors. These are small, sand-free versions of the grow-out unit similar in size to brood-stock units. Ground seagrass and an inoculum of fresh compost are added at the beginning of the composting process. In 7-10 days at the recommended operational conditions for grow-out units after diatoms form a yellow-brown layer on the substrate, the composted grass is ready for use. The somewhat consolidated compost is removed with a long handled sieve and ground again in an industrial blender. A 25 μ particle diameter or smaller is required by larvae. The thick, black slurry produced by blender is poured directly into rearing units. (Refer to the section on hatching and rearing larval stages for specific details concerning feeding.)

Reproduction and Rearing

Methods for Obtaining Brood-Stock

As Wells (1962) observed, many physiological races of widely distributed lugworm species exist. The best brood-stock for a particular location can be developed from a race indigenous to it. Because lugworms have a generation time less than 120 days, it is practical to rapidly breed a domesticated variety and begin to select for superior characters such as rapid growth in culture or resistance to disease.

Location of Wild Adult Lugworms. - Substrate indicators which can be used to identify natural worm beds in shallow areas or exposed flats have been described. Unfortunately, similar surface perturbations may be produced by callianassid shrimp and certain holothurians. Consequently, the massive mucus egg masses which warm water lugworms attach their burrows are the best indicators of natural worm beds. Egg masses of Arenicola cristata from northwest Florida are spherical, ovoid or cylindrical structures 2 to 40 cm long which contain as many as 800,000 light brown embryos (Fig. 4). The simpliest method to collect adult worms when they are in soft sand is to dig by hand to a depth of 20 cm and rely on locating the worm by touching it. With practice, a collector can locate 20-30 undamaged individuals in an hour.

Size and Frequency of Spawning. - Egg masses from wild worms can be used initially for commercial production. Once a spawning population is located, production of egg masses can be expected at 13-day or shorter intervals when the temperature is above 16-18°C and the salinity is above 12‰. Where the population is 14 worms/m^2, wild worms can produce an average of 12 egg masses/m^2/month. During a single mass spawning event, these individuals can produce three million egg per square meter.

Methods for Obtaining Spawn for Commercial Production

Spawning by lugworms was attributed to specific environmental stimuli by various authors (Okada, 1941; Newell, 1948; Howie, 1959; Duncan, 1960). It is not necessary to manipulate environmental parameters to induce spawning by *A. cristata*. Wild or hatchery reared individuals can be maintained in brood units where they will spawn at regular intervals (up to four times per month) without stimulus if sufficient food is available and environmental conditions are optimal. If the methods recommended in following sections are applied, these specific conditions are required to insure spawning:

(1) temperature: 18 to 32°C,
(2) salinity: 12 to 35‰
(3) food: at least 140 g seagrass/m^2 made available in an open system exposed to sunlight; or an equal amount of seagrass compost (prepared available in a closed system;
(4) substrate: 200 to 700 μ particle size; depth should exceed twice the average total length of the worms.

Spawning will occur throughout the year in closed systems.

When open systems are used, captive or hatchery reared lugworms will spawn on the same cycle and with the same intensity as wild worms in the estuary from which seawater is obtained. For example, in a population of 80 unsexed, hatchery-reared individuals 120 days old, 54 egg masses were produced in a single spawning event. Estimated production was 30,000 embryos per mass or a total in excess of 1.6 million embryos. Based on an average spawning event by worms 8-10 cm long, the recommended stocking rate for brood units (5 m^2 surface area) to serve a commercial hatchery with a one million worm production capacity is 10 mature worms/m^2 (1:1 sex ratio).

Selective Breeding. - The reproductive response of *A. cristata* is strong even when worms are confined in small containers (15 l capacity). Consequently it is practical to selectively breed lugworms by isolating paired, mature individuals in trays in closed or open systems as Okada (1941) demonstrated for *A. brasiliensis*. Environmental conditions should be the same as those recommended for large brood-stock units. To prevent uncontrolled spawning, brood-stock held for selective breeding must be sexed and kept in culture units containing individuals of the same sex. Sexing is described in the next section.

Induced Selective Breeding. - A technique like that developed by Howie (1961a, 1961b, 1963) for *A. marina*, which involves injecting macerated prostomial tissue, can be used to obtain gemetes for selective breeding. This method can be used during the winter to obtain spawn if other procedures are not successful; but it is limited to selective breeding because average release of ova per female is only 4,200. Procedures for direct induction of females are outlined below.

(1) Select worms at least 6 cm (but less than 16 cm) total length. Larger worms are often killed when injected.
(2) Determine sex by identifying gametes in coelomic fluid withdrawn

with a 21 gauge hypodermic needle inserted into the coelom through the right side of the seventh segment. Avoid injury to major blood vessels and and nerves. Gametes, which can be examined with a hand lens or microscope, are distinctive. Spermatozoa usually appear clustered together.

(3) For each female to be induced, select two male and two female donors.

(4) Rapidly chill donors (in seawater) in a freezer until they become fully relaxed (as indicated by extruded proboscises and lack of contraction when stimulated).

(5) Remove prostomia and peristomia with scissors (as indicated in Figure 20).

(6) Grind tissue into a paste (Ten Broeck tissue grinder or a mortar and pestle) and add sufficient streptomycin sulfate (50 ppm) and seawater (filtered through a 10 μ Nitex nylon filter but not sterilized) to make 1 ml.

(7) Inject macerated tissue into the coelom at the seventh segment on the left side ventral to and between the gills. Then place the injected worm in aerated seawater.

Shedding of ova, usually with little mucus, occurs within approximately 12 hours. Males are induced in the same manner except that only one donor of each sex is necessary. Since shedding of spermatozoa begins in 30-60 minutes, it is necessary to induce females several hours before males. Fertilization can be obtained by holding injected individuals of both sexes in the same dish or by adding spermatozoa to several dishes containing ova.

Hatching and Rearing Larval Stages

The environmental requirements for rearing larval *A. cristata* are the same as those outlined for adults. Artificial seawater is acceptable as a rearing medium. Culture vessels can be constructed from almost any nonleaching or nontoxic material. Recommended units for commercial production were discussed earlier.

Hatching Egg Masses. - Mucus egg masses must be collected from the field or brood-stock units immediately after production while the mucus is still firm. Selection should include only spawn with evenly distributed light brown embryos and without excessive surface fouling. Population density is estimated by measuring the volume of each egg mass in a graduated cylinder (use a pipette to draw off water trapped under the mass) and counting embryos in samples of known volume taken from a core through the mass. The recommended stocking rate for hatching trays is 400,000 embryos/m^2.

At stocking, the egg mass is divided with scissors into several subunits to insure more even dispersal of larvae. Initially, no substrate is necessary. A closed, aerated, noncirculating system must be used. Seawater in the system must be filtered to remove larvae of predators and treated with streptomycin sulfate (30 ppm) if disease resistant stock is not used. (Larvae are highly suseptible to an unidentified pathogen which destroys all exposed individuals in seven to ten days. After the young worms develop the caudal segments, they are no longer affected and further prophylactic treatment is unnecessary.) Water in each unit must be changed at least weekly usually just prior to feeding.

After three days, most embryos in an egg mass become free swimming trochophores with a positive phototaxis (Fig. 5). Okada (1941) described and illustrated larvae which are essentially identical to those observed during this study. Larvae trapped in the disintegrating egg mass develop normally and enter the substrate directly. Swimming larvae can be concentrated on the surface film by bright light or directed light. Consequently for the first 24-hours, low light levels (<100 lumens/m^2) insure more uniform dispersal and greater survival. After 24 hours, the larvae which have three setigerous segments respond photonegatively, settle on any available surface and immediately begin to construct tubes from organic material attached to the mucus which envelops their bodies. As larvae increase in size they add small particles of sand to their tubes.

Larval lugworms are fed composted seagrass in excess of their normal requirements. Within 12 hours after hatching or before the 3-setiger stage develops, compost processed in a blender (until the average particle size is 25 μ) must be added. Sufficient food (which is also the initial substrate) is introduced to cover the bottom of the culture tray with a layer 1 mm deep. Sand of a large particle diameter (1.5 mm) scattered through the compost provides raised areas on which larvae often construct tubes; consequently it enhances survival. After the larvae settle further feeding is determined by activity. Hungry larvae gather compost into mounds and form copious castings. Whenever these features are observed on the substrate 3-5 mm of compost should be added to cover the mounds. Sand (200-700 μ particle size) can also be added. Depth of the substrate after 24 days should be less than 2 cm.

The larval period is completed between 24 and 28 days after spawning when caudal segments develop (Fig. 5). Growth during the larval period is approximately 0.36 mm/day at 25°C (Fig. 21). Worms can be stocked in grow-out units when they are 0.7-0.8 cm total length. At an estimated production rate of 120,000 juveniles/m^2/month, each tray in a multipurpose storage and rearing unit can produce 336,000 juveniles per month. Total production from the five unit facility (Fig. 8), if it were committed solely to the production of juveniles, would be approximately 40.3 million juveniles per year, of which two million or less would be required for bait culture.

Intermediate Rearing Units for Juveniles

Intermediate rearing units can be used if it is necessary to produce larger juveniles for stocking. Preparation prior to stocking is the same as for grow-out units except that enriched substrate (two parts sand to one part composted seagrass) 3-4 cm deep is required. Juveniles averaging 0.7 cm or less total length are introduced at 25,000/m^2. At three-day intervals, the young worms are fed sufficient additional compost to cover perturbations on the substrate. At this stage if the juveniles are hungry, they are extremely responsive to slight changes in environmental conditions, begin to swim almost immediately and can be lost at the drain (see section on behavior). Flushing must be limited to two or three daily cycles directly observed by the hatchery operator who is prepared to terminate the flow if swimming occurs. It is estimated that intermediate rearing units can be used to increase the average size of stockable juveniles one centimeter in 30 days, thereby condensing the final grow-out period 12-15 days. Figure 22 demonstrates growth by juveniles initially stocked for grow-out when their average length was twice the recommended size.

Rearing Juvenile and Adult Lugworms

Preparation of Grow-Out Units. - Prior to stocking, grow-out units must be purged of predators and residual adult lugworms (which could spawn and cause overpopulation). In open, unfiltered systems, most nonsessile carnivores or omnivores present will attack newly stocked, juvenile lugworms. In northwest Florida, the most significant predators encountered during culture were portunid crabs (*Callinectes sapidus*), and polychaetes (*Neanthes succinea* and *Glycera americana*). These predators were able to attack lugworms within the substrate and had the greatest effect on individuals less than 4 cm total length. Drying grow-out units after a harvest during the summer will eliminate portunids and most residual lugworms, but has little effect, even after two weeks, on the other polychaetes mentioned. If infaunal predators are present in sieved samples of substrate, a pesticide should be used to control them. Tests in the hatchery indicated that a degradeable pesticide such as malathion (62.5-125 ppm at contact) applied in drained grow-out units after harvest can be used successfully to eliminate all predators and competitors in 48 hours (Hails, in manuscript). After seven days over 99% of the pesticide was decomposed. After 14 days, standing water (2 cm deep) in experimental units (closed system) contained less than 2.5 ppb residual malathion (Table V). No malathion was detectable in the substrate. A slight elevation of ambient pH could be used to degrade any residual pesticide (at pH 9, 50% hydrolyses in 12 hours; Environmental Protection Agency, 1975). After grow-out units are initally filled, the pesticide should be present in the initial effluent at concentrations below 0.26 ppb (unofficial level above which EPA suggests that malathion not be released in the marine environment) and below recommended maximum concentrations of malathion in unfiltered freshwater (0.008 ppb; Environmental Protection Agency, 1973). In actual experiments with grow-out units treated with malathion, the pesticide was undetectable after the unit was flushed once (Hails, in manuscript).

Substrate Requirements. - In northwest Florida, *Arenicola cristata* is found in siliceous substrates in which the majority of particles have diameters between 200 and 350 μ (Table VI). Culture in grow-out units was successful when the majority of particles had diameters between 400 and 700 μ. At least 15 cm of substrate in a grow-out unit provides sufficient depth to protect worms as well as to limit burrowing activity and facilitate harvesting (White, in manuscript). (Average depth of burrows produced by wild worms in the field is 21 cm). Prior to stocking, substrate in a grow-out unit is leveled; then the unit is filled to operational depth with seawater and flushed rapidly for two cycles (a cycle is the time required to fill the unit to operational depth). Operational depth exceeds 30 cm and is temperature dependent. (Refer to sections on feeding and maintaining worms in grow-out units). Processed seagrass is mixed with seawater as indicated earlier and applied uniformly at approximately 60 g/m^2. Combined with the grass is an inoculum of substrate from an operational grow-out unit or a composting unit which provides various microorganisms for the composting process. Some diatoms are introduced with the seawater. In seven to ten days the substrate is covered by an epibenthic community heavily populated by diatoms. (*Nitzschia closterium* and various species of *Amphora* and *Pleurosigma* were observed most frequently during culture and appeared to be indicators of optimal conditions.)

Stocking Grow-Out Units.- After the rearing area is improved with a layer of composted seagrass, and while the epibenthic community is developing, stocking is accomplished by spraying juveniles of appropriate size (0.7 cm average length) uniformly over the substrate. Uniformity is required becouse juveniles will not disperse more than a few centimeters unless they are starving. (See section on behavior). The methods used to distribute worms are the same as those used to apply processed seagrass. Juveniles burrow immediately upon encountering the substrate. Individuals that do not burrow or later return to the surface usually have damaged gills.

Stocking density varies with existing conditions. In predator-free systems, stocking density should be at least 60 juveniles/m^2 plus 10% to compensate for escape or mortality from undetermined causes. In systems which do not exclude predators, compensation for their activity can require 50-60% overstocking. No losses in experimental grow-out units stocked with juveniles were attributed to disease.

It is recommended that a producer stock individual grow-out units at weekly intervals. Then harvesting can be completed at similar intervals.

Feeding and Maintaining Worms in Grow-Out Units. - Table VII is a recommended feeding schedule based on an estimated stocking rate of 60 worms/m^2 plus 50% to compensate for predation. Feeding rates should always be excessive and responsive to conditions in the grow-out unit. During the first three weeks, juveniles turn over substrate slowly and compost often accumulates in mats. Photosynthetic activity produces bubbles of oxygen which cause the mats to float; consequently a portion of the compost is lost at the drain. The problem is controlled by decreasing the feeding rate to match the conditions in a particular grow-out unit. Conversely, during the three weeks prior to harvest the worms rapidly turn over the substrate, often the whole surface within three days. At this point, feeding should be increased in frequency and amount to insure that the surface of the substrate always has processed seagrass available as substrate for colonization by diatoms and other microorganisms. Addition of seagrass as recommended in Table VII results in accumulation of organic material, consequently less grass is required for subsequent crops. The exact reduction in amount was not calculated.

Recommended environmental criteria for the grow-out system are noted in Table IV. Dissolved oxygen concentrations and pH are not expected to be limiting factors during commercial culture. Dissolved oxygen concentrations below 0.5 mg/l for 24 hours do not adversely affect lugworms. In experimental culture units pH values below 7.5 were not observed. Temperature should be monitored continuously just above substrate in at least one operational grow-out unit in the system. Depth of water should be maintained between 30 and 50 cm. When the maximum daily temperature reaches 35°C, the standard operational depth of water in all units should be increased to approximately one meter. When the maximum daily temperature drops below 15°C, the operational depth of water should be decreased to 30 cm. Daily records of salinity at high and low tide should be made. After heavy rains in the watershed of the source estuary, circulation in open systems must be terminated when the salinity drops to 12‰. Seawater can be circulated only at high tide when more saline water is obtainable. Lugworms in grow-out units will survive and continue to grow in standing water for 2-3 weeks if the maximum daily temperature remains below 36°C and the salinity remains above 12‰.

Behavior of Lugworms in Grow-Out Units. - Within 24 hours after stocking, juvenile lugworms feed normally and castings appear on the substrate. Feeding appears to continue cyclicly as Wells (1949a) observed for *A. marina*. The pattern of activity on the substrate reflects the position at which the lugworm entered the substrate. If worms are stocked too densely in certain areas, fecal castings soon overlap feeding zones of adjacent individuals. When considerable overlap occurs and the food supply is depleted, juvenile worms leave the substrate and swim slowly tail first toward the surface. They drift with the current and then settle to the bottom. If an individual worm happens to contact an area containing satisfactory food (substrate), it will immediately enter the substrate and build a normal burrow. Swimming should be prevented by uniform stocking at appropriate concentrations and overfeeding; or excessive losses due to epifaunal predation or escape at the drain will occur. As the worms grow older, evidence of individual activity becomes less obvious because of perturbations on the substrate. If activity completely ceases it is usually due to fluctuations in environmental conditions which exceed a limiting value. For example, if salinity drops below 10-12‰ the activity cycle is disrupted; feeding and pumping cease.

During the breeding season, between 50 and 60 days after stocking 0.7 cm juveniles, egg masses begin to appear scattered across the substrate in grow-out units. After 60 days, mass spawning usually occurs and egg masses litter the system. If the grow-out unit will be harvested 90 days after stocking, egg masses do not present a problem. If longer grow-out periods are planned and disease resistant stock is used, overpopulation will eventually result.

Growth in Grow Out-Units. - Within the recommended ranges for environmental conditions, juveniles stocked in the spring at an average size of 0.7 cm grow 0.54 cm/wk and reach an average marketable size of 7.5 cm total length in 90 days (Fig. 23). All worms are marketable at harvest; over 95% are expected to exceed 7 cm in length. Growth rates during the fall are essentially the same (Fig. 24). Growth rates during the winter were reduced considerably when the temperature was below 15°C; however, after the maximum observed temperature in the grow-out units reached 20°C, the rates matched or exceeded rates observed during the previous spring and summer (Fig. 25). Rubinstein (1976) showed that sharply reduced growth rates can be expected when the temperature falls below 15°C.

During commercial culture, growth rates should be monitored at three-week intervals. A plateau in the growth curve when temperature is above 15°C is an indication that food is a limiting factor (Fig. 22). If food remains limiting, the average length of the stock will actually decrease.

Predation in Grow-Out Units. - If predators are observed during operation, the simplest procedure to control epifaunal species during the summer is to drain and dry the unit for 8 hours between sunrise and sunset. If this procedure is completed during a period in which substrate temperatures do not exceed 35°C, most epibenthic predators are eliminated before lugworms are affected. This procedure is not recommended for grow-out units containing worms smaller than 3.5 cm because these individuals cannot easily avoid overheating of the substrate due to insolation because their burrows are too shallow. No effective method to control infaunal predators during the grow-out period is available.

Maintenance

Aside from routine maintenance required by machinery recommended in Option I, certain special maintenance should be mentioned. Maintenance of the PVC liner in brood-stock and grow-out units is required only to insure that the liner remains covered by sand or marl because exposed plastic is gradually degraded by sunlight. If the liner is torn, it can be patched or replaced in situ without difficulty according to the manufacturer's directions.

Epoxy resin and plywood vessels are recommended for use in a hatchery; however, there are some disadvantages. When these containers are exposed to sunlight, the epoxy resin gradually cracks and falls off. Exposed vessels require routine reapplication of resin at 2-3 year intervals. Initial application of resin to the interior of all vessels which will contain flowing seawater should include application of tightly woven glass cloth to all seams and all wood directly immersed in water and not covered by sand. At intervals (usually every two weeks during the summer) fouling organisms must be brushed and scraped from such containers. If scraped improperly or struck hard with a tool at a seam, the resin will crack and wood will be exposed to seawater. The result is either a leak or attack by shipworms. Borer activity or internal leaks can be identified under unpainted resin as dark brown stains. Such areas must be dried and recoated by resin thickened with talc.

It is recommended that all supply lines be exposed except at intersections with the road. Supply lines not under direct pressure from a pump should not be glued at joints. If glue is required, a silicone-based type is satisfactory. This facilitates complete disassembly of a section that might become fouled and require reaming or treatment with acid.

Concrete sluiceways and culverts in both options require scraping to remove fouling organisms after each grow-out period. The defouling process requires that a curved steel blade be drawn through the culvert to remove oysters and barnacles.

Other maintenance is directly related to fouling. If the low velocity supply system is not redundant or paired, it must be filled with hot freshwater overnight at least at weekly intervals. Temperature of the freshwater should not be high enough to cause the PVC pipe to sag or seams to burst. After the water cools, it is flushed directly into grow-out units when normal flow resumes. At biweekly intervals, perforated inlet pipes must be exchanged by a diver. This is necessary because fouling and floating debris gradually close the perforations. Non-operational inlet lines must be filled with freshwater and capped.

Harvesting Lugworms

Harvesting should begin when average total length (contracted) as determined by routine sampling is approximately 7.5 cm. As indicated by growth experiments in small closed systems and some field observations, growth rates of worms stocked at 1.3 cm in length can be as rapid at 0.69 cm/wk; consequently, under certain conditions (especially lower grow-out densities) marketable worms are available 60 days after stocking (Fig. 22). Under average conditions during all seasons except winter, marketable worms are ready to be harvested in 90 days (Figs. 23-25).

Pump Facilitated Methods

The recommended procedure for harvesting is to move substrate from a grow-out unit with a pump which will pass worms without injury. The pump is mounted on a floating platform which also supports the sorting screen (Fig. 13). Two men operate the harvesting unit; one controls the rate at which substrate enters the inlet pipe, while the second sorts and counts worms and controls the position of the platform in the grow-out unit. Lugworms are separated from the substrate on an inclined sorting screen and accumulate in a sorting area at the base. The second operator positions the platform so that sieved substrate falls into previously harvested areas. This operator can control the pump by a cut-off switch. Harvested worms are sorted into floating live cars (1,000/car) (Fig. 14) which remain in the grow-out unit until they can be conveniently removed. The live cars are transported (without water) in a trailer directly to holding units in the service building. Lugworms remain in live cars until they are packaged for shipment to dealers. Harvesting a 1,000 m^2 grow-out unit can be completed in less than one day with a pump which can move 150 gallons of slurry per minute.

Dredge Facilitated Methods

A modified hydraulic dredge can be used to harvest lugworms in unlined grow-out units. It is proposed that the design for a Long Island hydraulic bar clam dredge (Parker, 1971) can be adapted by replacing the net with wire mesh and extending the mesh screens along sides to prevent loss of swimming or neutrally buoyant worms (Fig. 18). At intervals the dredge basket must be raised so that captured worms can be sorted and transferred to live cars.

Harvesting Juvenile Lugworms

Juveniles reared to stock grow-out units can be harvested manually by passing the substrate through nylon screens (1.0 mm mesh). During harvest the screens must be emptied frequently to prevent entanglement of juveniles in the mesh. A partial harvest from juvenile rearing units can be facilitated by manipulating feeding. If crowded juveniles are starved for one week prior to harvest, the majority will respond by swimming when a small amount of food is stirred into the culture. Harvesting is then accomplished with dipnets.

Storage and Handling of Lugworms Harvested as Bait-Worms

As previously indicated *A. cristata* can tolerate considerable stress due to sudden fluctuations in environmental conditions. However, lugworms can not tolerate for more than 24 hours accumulated metabolic wastes or decomposing lugworm tissue in their immediate environment. This observation is the key to storage and shipping procedures.

Any storage facility which includes the features listed below can be used to hold lugworms for at least one month with mortality less than 5% per week:

(1) continuously flowing seawater (five to seven exchanges of water per hour per unit) from natural sources or a biological filter,

(2) trays equipped with airstones which allow free circulation over and below worms arranged in layers three individuals deep (no food or substrate are necessary),

(3) environmental parameters within the recommended ranges (Table IV) (temperatures below 20°C increase survival),

(4) routine removal of dead worms (which can be identified by their yellow or gray color and extended proboscises and setae).

The open system storage units shown in Figure 10 can support up to 24,000 lugworms each. The proposed hatchery has an open system capacity of 120,000. Individuals which have been stored without substrate for four weeks or more are not normally restockable without considerable mortality because their gills are gradually eroded during storage by constant movement in a foreign environment. This damage does not complicate storage or decrease their value as bait. Extended storage does result in a gradual decrease in total length.

Capacity of individual storage units can be increased for short periods by increasing the flushing rate (especially at temperatures below 200°C) to 10-15 or more exchanges of water per hour per unit. Under these conditions capacity can be increased 50 to 100% for periods less than one week. Increased mortality occurs (exact percentage not determined); consequently this method is recommended for application only in situations where established markets are immediately available.

In case of emergency (e.g., failure of both pumps; unusually low salinities in the estuary) the closed system storage units can be used to support harvested worms in all storage units. Since the capacity of the biological filters is limited, this measure would provide only 2-3 days of support before a complete change of water became necessary.

Storage can also be accomplished by maintaining worms in grow-out units but obviously at the cost of reduced production per unit. If worms are harvested and restocked at greatly increased concentrations per square meter, they can be kept for several months but at a significant disadvantage. Depending on degree of competition and food available, the worms gradually decrease in size. This phenomenon which was observed by various investigators (Newell, 1948) is more pronounced during this type of storage than during storage in an open system without substrate.

Packaging and Shipping Methods (for Producers or Wholesalers)

For hatcheries located close to major markets, suggested packaging and shipping procedures required to insure survival are as follows:

(1) Newly harvested worms are held overnight in circulating seawater, (at ambient temperatures) and injured individuals are removed.
(2) For short distance shipment (<300 km) in less than 12 hours, worms in live-car lots (1,000) are placed in polyethylene bags (5-8 liter volume) containing sufficient water to prevent dehydration (2 ml water/individual. The bags are packaged in cartons and shipped in an air conditioned, insulated van. The entire harvest of a 1,000 m^2 grow-out unit (60,000 worms) can be shipped at one time.
(3) Long distance shipment (>300 km) can be made by two methods: surface transport and air freight.
    (a) For surface transport the worms are prechilled (<12°C) in a closed system storage unit and sorted into shallow, strongly

aerated or stirred transport tanks (2 ml water/individual) equipped with cooling units (Fig. 15). Under these conditions delivery can be made by surface transport in 48 hours or less without mortality.

(b) Shipment by air freight is possible only if the <u>total</u> transit time is 24 hours or less (18 hours is optimal). Time is measured from the moment the worms are placed in the shipping container to actual transfer to clean seawater at the destination. Styrofoam insulated cardboard boxes (tropical fish shipping cartons) with four polyethylene bags (1,000 lugworms total capacity) containing 2 ml seawater per worm weigh 21-22 lbs. Shipment is most economical in lots of four boxes that weigh just under 100 lbs (approximately 4,000 lugworms per lot).

Worms shipped in plastic bags will survive sudden thermal shock over a range of 25°C and normally can be placed directly into circulating or aerated holding or storage units in a dealer's shop. If the expected thermal shock at transfer ranges more than 20°C, gradual acclimation (2-3 hours) is recommended (especially if worms are to be stored more than 48 hours). Acclimation to different salinities is required only at the extremes because the worms adjust rapidly to sudden changes between 15 and 30‰. If water quality in receiving tanks is maintained within the recommended ranges (Table IV), the worms can be held for at least one week without significant mortality and up to one month with mortality less than 5% per week (actual mortality in the pilot hatchery was 1.4% per week).

Storage Facilities for Wholesalers

Storage units for wholesalers are essentially identical to those used by the producer (Figs. 8, 10 & 14). Construction costs can be calculated from the data in the costs section. The storage facility can be connected to a biological filter to eliminate dependence on an immediate source of seawater. Operation of suitable biological filters is reviewed by Spotte (1970). Artificial sea salts can be used to prepare seawater for storage units; however, this is an expensive alternative.

Storage Facilities for Retailers

Since the average purchase of marine bait-worms by retailers is approximately 30 dozen per week (refer to the following paper by H. Chen), equivalent or larger storage capacity would be required for lugworms. Facilities to hold up to 6,000 individuals could be obtained in a smaller version of the storage units described for the producer or wholesaler if seawater were immediately available (Fig. 26). Estimated cost for the unit including an electrical pump (5 gpm), plumbing and a plywood and epoxy resin storage unit is less than $100.00 Closed systems, consisting of aquaria with natural or artificial seawater, biologically filtered, are also effective. Figure 27 is a recommended unit in which 1,000 worms could be held for several weeks. Surface area for the filter is approximately 1.7m^2. The estimated cost for the system including the pump is less than $100.00

Handling by Retailers

Upon receipt, the retailer can prepackage lugworms in plastic bags (12 individuals/120 ml seawater) and store them in a refrigerator (9-12°C) for at least 6 days. Freezing must be avoided otherwise the worms lose their turgor, become flaccid and lose some of their effectiveness as bait. The recommended retailing procedure is to dispense live worms directly from seawater aquaria or similar storage facilities. A large storage unit filled with potential bait is promotional in itself. Lugworms can be dispensed on demand in plastic cups or bags or placed directly in a container provided by the fisherman.

As Dales (1963) observed with reference to *Arenicola marina*, *A. cristata* also releases a yellow fluorescent fluid which can stain the handler's skin. Release is often most pronounced just as the worm is placed on a hook. The stain, which becomes black and fades after 24 hours, can be removed from the skin by vigorous scrubbing with household cleanser. Retailers could furnish disposable plastic gloves to individuals who object to the stain. It should be noted that this stain has not diminished the popularity of lugworms as a bait in Europe, South Africa or Japan.

Handling by Fishermen

Like most live baits, lugworms must be protected from extreme overheating or freezing while in bait buckets. When treated with reasonable care while confined in nontoxic buckets, the highly tolerant worms remain alive for at least 12 hours. If water in the container is replaced occasionally, this period can be extended to several days.

Lugworms can be used as bait whole or in pieces. Whole worms are used by placing a hook directly through the mouth and the third segment. A second hook in the posterior body is useful. The worms have a fluid-filled coelom and collapse somewhat when the posterior four-fifths of the body is punctured. Tying or clipping worms to a hook prevents loss of coelomic fluid.

Under most circumstances whole worms are used by slowly bouncing or jigging them along the bottom or simply allowing them to rest on the bottom. They can also be used over seagrass beds if suspended by a float. Depending on size and proposed use, each worm can be separated into two or three pieces. Since the proboscis is tough, the anterior portion can be used repreatedly. Although loss of volume occurs, cut lugworm bait attracts many species of fish as readily as the whole animal.

In estuaries in northwest Florida, 13 species of fish normally encountered by sport fishermen were caught during evaluations of the bait's effectiveness (Table VIII). Of the species preferred by sport fishermen, lugworms were most effective as a bait for redfish, *Sciaenops ocellata*.

DISCUSSION

Location of a Commercial Bait-Worm Hatchery

Criteria which can be used to determine a suitable location for lugworm hatcheries have been outlined. These indicate that most biological requirements for lugworm culture can be met on the Gulf of Mexico and the east coast of the United States south of Chesapeake Bay. Culture may be practical in southernmost California; however, environmental conditions are marginal and will affect production.

Environmental conditions on the northern Gulf coast which affect growth are closely equivalent to conditions on the Atlantic coast south of Cape Fear. For example, oysters, *Crassostrea virginica*, grown in South Carolina and northwest Florida produced similar yields (Butler, 1953). Lugworm hatcheries, located just south of Cape Fear, could supply the Chesapeake Bay market as well as most of the southeastern Atlantic Coast where major markets for marine bait-worms exist. If a hatchery is located north of Cape Hatteras, slower growth resulting in reduced production is expected during late fall, winter, and early spring, unless some method to heat the system such as power-plant effluent (refer to Kildow and Huguenim, 1974), is available. As the accompanying paper by Chen indicates, reduced production would definitely affect economic feasibility of the proposed plan.

It should be emphasized that the east coast of Florida and the Gulf coast are biologically ideal for production; however, these areas do not contain satisfactory actual or potential local markets for bait-worms. Chen demonstrates that lugworms will not be competitive with live shrimp in areas south of the Carolinas. Consequently, if a hatchery is located along the Gulf coast, the product would have to be shipped to markets located mainly between New York and North Carolina.

Design of the Physical Plant

Comparison of Options

Two options for open-system lugworm hatcheries have been described in some detail. In each case, biological requirements and economic construction and operation were primary considerations. Option I, overall, offers more advantages to an operator because more variables are controlled. When Options I and II are compared, the advantages of the former are:

(1) more effective control of predators,
(2) complete control of water level and flow rate,
(3) less labor required to harvest worms or control water,
(4) fewer legal restrictions involving construction exist.

Since the system can be rapidly drained, epifaunal predation is less significant. In addition, pumps permit the operator to respond to thermal problems effectively. Most significantly, pumping allows the operator to compensate for excessive precipitation. The liner restricts burrowing, consequently less effort is involved in moving sand during the harvesting process. Pumps require considerably less maintenance than monks with screens.

In contrast, the advantages of Option II are lower construction costs and more permanent construction. A major construction expenditure for Option I, the liner, is not required. Maintenance and replacement costs for the liner are eliminated. Because construction costs are lowered, the production area can be increased without a compensating increase in storage capacity. Worms can be maintained in the additional grow-out units until needed. A major disadvantage is that worms in a tidal system are difficult to protect from abnormal low salinities which can kill a whole crop.

Option II could be modified by pumping water either from a ground source or an estuary thereby eliminating construction, maintenance, and operation of inlet monks or sluiceways with screens. This would also permit more effective control of predation. Estimated savings in construction costs, if a groundwater source is used, is at least $4,000. For these reasons and others mentioned later, this combination of both options should be successful. The major limitation is that there are fewer potential locations for this type of operation

Option I included two designs for grow-out units: six units with 6,000 m^2 production area or four units with 7,200 m^2 production area. When they are compared, the advantages of the six-unit system are as follows.

(1) Production can be closely adjusted to seasonal demands.
(2) Less storage capacity for harvested worms is necessary.
(3) Lower production losses are expected because storage time is reduced.

The major disadvantage of the six-unit system is that two additional embankments must be built which increase construction costs and decrease production capacity 20%. Greater production capacity is the major advantage in the four-unit design. However, a four-unit system would require the operator to process near capacity inventory (108,000 worms per harvest) which will tax the facility, especially if storage units are used for other purposes (rearing larvae, holding brood-stock). If markets are available which permit rapid turn over of inventory, storage capacity can be expanded by increasing flushing rates. Under these conditions, or if additional storage facilities are included in the original design, four 1,800 m^2 grow-out units are recommended.

Pump Capacity

Sufficient capacity to raise or lower water level in a grow-out unit and to control flow rates in the service building is critical during operation. During the summer, insolation can elevate temperatures in shallow grow-out units close to the upper lethal limit. To moderate elevated temperatures, sufficient pump capacity is required to raise the depth to one meter in approximately 48 hours. Thereafter, the larger volume of water is warmed less rapidly and the maximum daily temperature in the grow-out unit is lower. Lugworms in grow-out units can be subjected to daily 35-37^{o}C (ca. 95-99^{o}F) maximum temperatures for 14 days and still reach marketable size in 90 days. During the winter, lower water levels and reduced flushing can be used to take advantage of insolation to warm water and substrate in the grow-out area.

In the service building, sufficient water is required to flush metabolitic wastes from holding units. The capacity to increase flow rates is necessary after a harvest when storage facilities are operating a maximum capacity. To compensate for increased demand, flow rates of 100 gpm should be available in the service building.

Precipitation during commercial production can be critical in two ways: by immediately lowering salinity in grow-out or brood units below the lethal limit or by causing abnormal flushing in the source estuary which results in depressed salinity levels for long periods. Although the immediate effect on lugworms in grow-out units of salinities below 10‰ is not death but reduced peristaltic activity, sufficient pumping capacity is necessary to flush culture units in 48 hours or the worms will eventually die. At certain locations, cyclic periods of low salinity can be expected and compensated by controlled pumping; however, castastrophic events such as hurricanes can flush an estuary with freshwater and leave the hatchery operator without a source of saline water for days. For example, in Santa Rosa Sound salinity at Sabine Island (location of the pilot hatchery) did not fall below 10‰ for 8 years prior to 1975 (unpublished EPA records). In 1975, a hurricane and a tropical depression caused salinity levels at the pump inlet to drop to less than 8‰ for seven days and to less than 10‰ for 23 days. The result was almost complete mortality of lugworms in natural beds in the Sound and adjacent salt marshes. Yet by pumping only on high tide and then retaining water in the grow-out units at the maximum level, it was possible to hold salinity in experimental grow-out units just above the critical level and prevent mortality. Since lugworms interrupt their activity cycle at salinities below 10‰, some effect on growth was expected; yet after the previously mentioned event, the lugworms reached marketable size in 90 days.

The hurricane was also the cause of mass mortality in experimental storage units because no method was immediately available to flush the units on a closed system. This event emphasizes the requirements that lugworm hatcheries have biological filters available which are capable of recycling some portion of the water in storage units on a closed system. It also emphasizes the necessity to limit inventory during seasons when catastrophic events can be expected.

Alternate Sources of Seawater

If a shallow groundwater source is available, its use is highly recommended because larvae of fouling invertebrates and predators are not present (Clark and Eisler, 1964). If this source is utilized it will allow accurate production estimates based on initial stocking, eliminate labor and construction costs related to controlling fouling, and insure more uniform conditions during culture. Recommended procedures for obtaining saline groundwater are discussed by Clark and Eisler (1964). It is necessary to test groundwater at a particular site before commencing construction to insure adequate supply and determine if potentially toxic minerals are present. Low dissolved oxygen and some hydrogen sulfide in groundwater are not expected to be major problems in lugworm culture.

If a groundwater source is not satisfactory, a system utilizing estuarine water must deal with fouling in supply lines and predation in grow-out units. Fouling organisms, in particular barnacles, oysters, mussels, and ascideans, can completely close supply lines in a few weeks. In addition, they encrust exposed lining material and culverts in grow-out units and provide sites in which predators can become established. In the pilot hatchery, which was constructed including suggestions from the staff at the Gulf Breeze Environmental Research Laboratory, redundant or paired supply lines were installed from the pumps. At regular intervals, use of lines was rotated. No severe fouling occurred in high velocity lines after three years. Construction of redundant lines will add approximately $1,000 to the installation costs listed for Option I.

Operation of a Hatchery

Brood-Stock

Identification of the preferred species for culture can be difficult because there are two similar species on the eastern and Gulf coasts of North America. According to Wells (1961) Arenicola cristata and A. brasiliensis rarely exist in the same habitat and exhibit certain reproductive, behavioral, and morphological differences. For example, A. cristata has a cylindrical egg mass and A. brasiliensis has spherical or ovoid egg masses. Arenicola cristata can best be identified by the position of the ventral nerve cord which lies dorsal to longitudinal muscles that separate the nerve cord from circular muscles of the body wall. Lugworms used in the pilot study had this morphological character and were identified by Dr. G. Wells as A. cristata, group B; yet all produced spherical or ovoid egg masses in culture and in the field (Fig. 4). Tubular egg masses were rarely observed and then only when strong water currents were present. In addition, all juvenile and a few mature A. cristata in culture and in the field produced cylindrical castings which Wells (1961) refers to A. brasiliensis. Because the situation is somewhat confusing, the best recommendation for an aquaculturist attempting to obtain wild brood-stock of the preferred species (A. cristata) is to collect individuals in the same habitat and examine several to be sure that longitudinal muscles are situated between the ventral nerve cord and the circular muscles of the body wall (Fig. 2).

Selective breeding has been recommended; however, there is a behavioral problem which must be controlled before breeding can be implemented effectively. Due to short generation time and frequent reproduction, holding units containing mature worms of both sexes are rapidly overpopulated by their progeny in 90-120 days. After 180 days it may be difficult to distinguish between the original brood-stock and their offspring. Isolation of sexes to prevent unnecessary reproduction is the only efficient solution to this problem.

Selective breeding in the pilot hatchery resulted in the production of stock resistant to a virulent disease which killed larval worms. Use of stock with this character can reduce operating costs because antibiotics are unnecessary when larvae are cultured.

Food and Feeding

Food is a major concern in lugworm aquaculture. The lugworm's feeding habits, which involve ingesting detritus, sand, and associated organisms worked down from the surface layers near the burrow (Wells, 1945; Jacobsen, 1967), present an aquaculturist with a problem. The worm does not seek nourishment at great distances from the burrow unless there is a drastic decline in available food coupled with overpopulation (D'Asaro, in manuscript). Consequently, it is necessary to feed lugworms by uniformly broadcasting food on the substrate in their habitat. In addition, surplus food is necessary to insure rapid growth because lugworms, like other deposit feeders (Levinton, 1972), constantly recycle the substrate and reduce availability as well as concentration. These requirements severely limit the types of food which can be presented to the worms, because food must be in a form which will gradually decompose due to microbial activity and will not contribute to immediate environmental degradation.

Initial experiments in the pilot hatchery were based on the premise that supplementary feeding could be accomplished by adding small amounts of commercial animal foods to various systems. The foods tested are listed in Table III. It was obvious in nearly all cases that even one precent by weight of a particular supplement in the substrate degraded substrate quality or even water quality. Under natural circumstances detritus is available only in small amounts or in a form which degrades slowly (chitin, fragmented algae or seagrasses, fecal pellets). Seagrasses are an ideal food simply because they can be added to rearing units in excess; yet environmental quality is not degraded because cell walls of the grasses decompose slowly and gradually release nutrients.

On the assumption that the compostition of seagrass, if defined, would identify an acceptable diet which could be artifically duplicated, MerEco, Inc., College Station, Texas, analyzed processed seagrass from the pilot hatchery and produced a compounded diet based on the analysis. This mixture was tested in the pilot hatchery, but it was not as effective as uncomposted seagrass; and substrate and water quality were degraded. On the chance that micro-encapsulation of supplements would stimulate natural decomposition rates of seagrasses, diets initially prepared for shrimp were obtained from Capsulated Systems, Inc., Yellow Springs, Ohio, and tested. There was a delay in decomposition but eventually environmental quality in rearing units was degraded. Alginate-bound diets containing seagrasses and supplements prepared by Dr. S. Meyers, Louisiana State University, were used to rear worms with marginal success in systems with considerable flushing. This particular method of supplementary feeding requires additional study because it may provide a mechanism through which lugworm aquaculture can become less dependent on seagrasses.

Seagrass compost may provide little more than a substrate for microorganisms, especially bacteria, ciliates, and certain photosynthetic organisms, which serve as the actual food for lugworms. This situation was reported for an amphipod that feeds on Thalassia detritus (Fenchel, 1970) and was confirmed by Hylleberg (1975) for Abarenicola. For Arenicola cristata the hypothesis is supported by the fact that composted seagrass (in which the total nutritional value is actually lowered) produces more rapid growth than uncomposted seagrass or seagrass composted in the absence of sufficient light to support photosynthesis. It is assumed that A. cristata is unable to use most of the nutrients in fiberous seagrass detritus directly because it lacks a cellulase, as does A. marina (Longbottom, 1970b). Experiments in the pilot hatchery indicated that the upper 1 cm of seagrass compost in a tray exposed to sufficient light to support photosynthesis produces more rapid growth than compost from deeper layers in the same tray. Since the surface layer contains numerous benthic diatoms and other primary producers, these organisms or associated species may contain or release an essential ingredient for rapid growth. If specific organisms which A. cristata actually digests can be identified, it may be possible to mass culture these organisms and use them as a live supplementary food.

Seagrasses are abundant and a nuisance on many public beaches, for example, in south Florida and southern California, and are removed at considerable public expense. Although many suggestions have been made concerning its use, seagrass has no established commercial value. The grass does have value as a component in detrital food chains, consequently public sources represent a supply which could be regulated if lugworm hatcheries create a significant demand. Additional research should be directed to determining the value of substitutes or supplements such as Macrocystis, various types of salt marsh grasses (which can be cultivated), or possibly a specially encapsulated artifical food which decomposes slowly in seawater.

Processing seagrasses or similar foods requires consideration of two potential problems: contamination, and particle size. Due to the source, some contamination of the processed seagrass is unavoidable. Buoyant pollutants float when seagrass is added to rearing units and are flushed from the system; but some types of chemically treated wood may settle on the substrate with the grass. To avoid potential problems, a hatchery's source of seagrass should be in an area with minimal commercial activity and few recreational docks. Another source of contamination can occur if processed seagrass is obtained from a contractor who employed the services of a commercial feed processor to grind the grass. Such processors normally use hammer mills in which residues accumulate. Consequently, seagrasses prepared by these operators can be contaminated with residues, especially feed grains and pesticides, which drastically affect the composting process. During operation of the pilot hatchery, the only problem with contamination actually encountered was caused by corn residues mixed in seagrass ground by a commercial processor.

Particle size of processed seagrass is most critical when larvae are fed. If larvae are offered particles too large to swallow they use the grass only to build tubes. During culture under such conditions, uningestible substrate is gathered into a mass of tubes while all ingestible, fine material is swallowed and compacted into fecal pellets. After all fine material is compacted into unusable pellets, the worms starve to death in the presence of what appears to be excess food. This is preventable if the compost is prepared as suggested.

Growth

During culture in outdoor grow-out units, growth rates are uniform under the conditions outlined. Uniform growth is the most significant parameter which can be used as an indication of potential success during the grow-out period. If there is insufficient seagrass (food) in a culture unit, even for one week, there is a measurable decrease in growth rates which is manifested as a plateau in the growth curve (Figs. 19 & 22). If food remains limiting, the plateau may be apparent for months or a measurable decrease in size can occur. During pilot studies with 25-square-meter grow-out units, increased quantity and frequent feeding with freshly processed seagrass were used successfully to reestablish the normal growth rate after a plateau was recognized.

Predation

Controlling predators in estuarine water is the second major concern of lugworm aquaculturists. In the design for Option I, holes drilled in inlet pipes act as an initial barrier to many adult predators but planktonic larvae, juveniles and certain adult polychaetes are not excluded. Various methods to remove planktonic organisms were considered during operation of the pilot plant. Ozonation was rejected because it is expensive and potentially dangerous to the cultured organism and operator (see Kinne, 1976). Rapid sand filters were evaluated in terms of recognized problems. Cost for a sand filter with a minimum capacity of 884 gpm is $4,000. Additional plumbing plus installation would increase the initial expense to approximately $5,000. In silty estuarine waters such units require frequent backflushing and maintenance at a significant cost in labor nearly equal to that required to remove fouling in an unfiltered system. The only advantage is that sand filters can capture planktonic larvae of many predators. For this reason they can be applied, but no recommendation is made.

Predators and residual lugworms in grow-out units can be controlled most inexpensively by poisoning prior to stocking and periodic draining and drying during grow-out. Of various pesticides tested in the pilot hatchery (nicotine sulfate, malathion, quicklime), malathion was most efficient because it rapidly killed major infaunal predators (Glycera americana, Neanthes succinea) and lugworms (overlooked from previous grow-out periods) and degraded sufficiently in two weeks to meet environmental quality criteria for Class III waters in Florida. Experiments designed to determine long range effects in grow-out units are still in progress. To date, there is no evidence that routine use of malathion will adversely affect lugworms in culture.

If periodic draining and drying during grow-out are standard procedures to control epifaunal predators entering as larvae, only simple screen filters in the main reservoir are required to exclude small adult predators that pass through the pumps. Such screens require regular maintenance, but this is routine and uncomplicated. Most planktonic larvae that pass through the screens are not a problem during the 90-day grow-out period because juvenile lugworms grow so rapidly that their bulk protects them from most younger and smaller predators that consume whole prey. In drainable enclosures, periodic drying during warm weather eliminates surviving epifaunal predators without harming lugworms.

When the system cannot be efficiently drained for an extended period (tidal option) or cold weather decreases the effectiveness of draining, epifaunal predators such as the blue crab, Callinectes sapidus, become significant problems. For example, this species reaches 7.5 cm carapace width in grow-out units and survives for days when a unit is drained during cold weather by burrowing into the substrate. Sufficient substrate (at least 15 cm deep) is the only protection for adult lugworms from the blue crab. Trapping can be used as a control but it is inefficient and labor intensive.

Harvesting

Removing lugworms from grow-out units by pumping the substrate over a sorting screen is the recommended harvesting method for Option I. The apparent advantages are significant.

(1) All lugworms in a unit can be removed.
(2) Sorting and counting can be completed immediately.
(3) Fewer opportunities to damage the PVC liner exist.

Pumps with specially designed impellers, which are used to move vegetables and fruits in processing plants and live fish in hatcheries (Bedell and Flint, 1969), can be used to harvest lugworms. The suggested model, marketed by Neilson Metal Industries, meets criteria established in the pilot hatchery: it can pass large objects in a slurry without clogging or damaging the objects; it can move 150 gpm at a seven foot head; and it is portable. This unit has not been tested under the conditions described in this plan.

Harvesting was accomplished during the pilot experiments by a method essentially identical to hydraulic dredging. A jet of water was used to move substrate over a screen which was gradually advanced through the substrate. The process was satisfactory for the pilot study, but was generally rated as inefficient. The disadvantages are considerable and are expected to apply to Long Island type dredges also unless they are specially modified.

(1) Dredging was unsatisfactory in a PVC lined grow-out unit because it was difficult to protect the liner from abrasion or to prevent worms from being lost between the bottom edge of the dredge and the liner. (After 90 days all lugworms have burrows which extend to the liner.)
(2) Lugworms flushed from the sediment moved with the current, began to swim, and often escaped. (In the pilot study each unit was dredged twice to capture escapees.)
(3) Raising and emptying a dredge was difficult and time consuming. If the dredge was not emptied frequently, the worms become trapped in the mesh because they attempted to burrow through it.

Modifications in design could reduce escape from a dredge but the major objection with respect to Option I, contact with the liner, would remain. The main advantage of a dredge is that it can penetrate 20 cm or deeper into the substrate (the depth marketable worms reach without a PVC liner). It is believed that specially modified and tested dredges can be used in unlined grow-out systems (Option II); therefore they are suggested for that application (Fig. 18).

<u>Shipping</u>

Transporting lugworms to the market is the third major concern in bait-worm aquaculture. Because lugworms cannot tolerate metabolic wastes from other lugworms or putrifying tissue in a shipping container for more than a few hours, the methods by which they can be shipped efficiently and economically are limited. Moist, light weight fillers (algae, vermiculite, styrofoam) can be used; but they do not improve survival over water alone, because lugworms have a positive geotaxis and concentrate below the filler in a shipping carton. However, lugworm hatcheries located close to airports and major markets for bait-worms can market their product without loss if delivery can be guaranteed in 24 hours or less. Such delivery can be obtained via air freight only on direct flights and can be facilitated if the purchaser picks up the shipment on arrival. When transshipment is necessary, air freight is often delayed because it is forwarded on a space available basis.

Delay beyond the recommended 24 hours will result in almost total mortality unless water in the shipping container is replaced. Shipping time can be extended if 20 ml or more of seawater per individual are included. However, it is obvious that shipping large volumes of water with the worms is not economically feasible.

<u>Marketing</u>

Competition in the market place from individuals who are able to collect wild lugworms in not expected to be a significant problem for several reasons. An aquaculturist has the potential to produce lugworms at a lower unit cost than an individual who harvests wild lugworms manually as bloodworms are harvested in Maine. The actual physical labor involved to collect a dozen lugworms by digging is considerable. In the United States, lugworm populations, especially *A. cristata* populations, have a density less than that reported by Longbottom

(1970a) for European populations. Average density is ten 8 cm long individuals per square meter in good lugworm beds (northwest Florida). Most dense populations are associated with seagrass beds in shallow water. To harvest one million wild lugworms by mechanical means would require dredging over 24 acres of productive bay bottom at least 25 cm deep. Because dredging on this scale in soft sediments or grass beds is quite destructive, most states restrict or regulate the activity by statute (Florida Administrative Code, 253.124).

A market perspective for lugworms (as a substitute for other baitworms) directed toward the east coast of the United States was completed by Chen and is the companion paper in this report. He used data from surveys and interviews, and biological data and cost estimates which I supplied late in 1974. The cost estimates in this report, which were slightly modified by more recent findings, still support his conclusion that lugworm aquaculture is economically feasible in certain locations. However, it remains a fact that the American sport fisherman, unlike his African, Asian or European counterpart, does not recognize the potential of the lugworm as a bait for marine sport fish. Appreciation of the bait by sport fishermen and test marketing remain major objectives which must be accomplished before lugworm aquaculture can be economically successful. When there is a recognized market, continued success will be a function of the market volume criterion (as defined by Gates et al., 1974). Because lugworms are easy and inexpensive to culture, it is expected that increasing supplies, if accepted as a substitute for other bait-worms, will depress retail prices and reduce predicted income.

Other Markets for Lugworms

Biologists consider lugworms to be a representative invertebrate type. Diagrams of dissected individuals are included in most invertebrate zoology textbooks and laboratory manuals used in high schools, junior colleges, and universities. Preserved specimens to be used by students retail for $13.00-$18.00 per dozen depending on size. This represents a small but reliable market for lugworms produced in a hatchery.

Lugworms are also being used in laboratories for physiological experiments and as test organisms in bioassays. Most recent users with the latter application are the Environmental Protection Agency, Gulf Breeze, Florida; Bionomics Marine Laboratory, Pensacola, Florida; U.S. Army Corps of Engineers, Vicksburg, Mississippi. This market has only slight economic significance.

There is excellent promise that cultivation of juvenile lugworms (0.7 cm average length) as a food for tropical fish will be economically successful. Live organisms such as brine shrimp, *Artemia salina* (refer to Helfrich, 1973), and certain freshwater oligochaete worms, *Tubifex* sp., are presently used as supplementary foods for tropical fish. To demonstrate that juvenile lugworms are a practical substitute acceptable to tropical fish, especially freshwater varieties, 41 species in 10 families were offered live, active worms in place of their normal diet. Only two species refused to eat them. Of those that accepted them, 29 species were obviously aggressive and swallowed the worms immediately.

In the last three years, the author received hundreds of requests for information concerning lugworm hatcheries on a small scale in limited space. It is obvious that commercial culture of marine bait-worms requires considerable space and investment. However, culturing juveniles to be marketed as a food for tropical fish and other species can be attempted on a very small scale. An entirely closed system can be used. There are no major restrictions on location. No immediate source of natural seawater is required. The operation would require a physical plant essentially identical to the service area in this hatchery plan. As indicated earlier, potential production could exceed 40 million 0.7 cm juveniles per year. Shipping juveniles to the market is less difficult than shipping adults. In addition, the producer could market a product by shipping egg masses directly to users who would rear their own juveniles. In this case, a kit complete with instructions and necessary supplies would be included. With the kit the user would be able to produce a continuous supply of juveniles for 60 days or longer. A plan describing a hatchery for juvenile lugworms, production methods, and marketing techniques is available (D'Asaro, in manuscript).

ESTIMATED CONSTRUCTION AND PRODUCTION COSTS

For each option suggested in this preliminary plan, estimates of construction costs were made with reference to the physical plant with an anticipated production capacity of at least one million marketable lugworms per year. Costs were based on local estimates obtained in Pensacola, Florida between September, 1974 and September, 1975. It was assumed that some construction, especially of certain equipment to be used in the hatchery, would be completed by the hatchery manager or a local contractor under the manager's direction. Total area required for each option is 4.0 acres. Cost of land was not included in the estimate. Chen (in the following paper) used essentially the same data to prepare a detailed cost-benefit analysis of lugworm aquaculture which takes into account imputed value for land and other items not included in this estimate.

Option I: Open System with Seawater Pumped to PVC Lined Grow-Out Units

A. Initial Costs	
1. Seawater system	
a. Pumps, motors, and accessories	
(1) 400 gpm pump and 7.5 hp electric motor (model 34EL-17D; ITT Marlow, Midland Park, New Jersey); two units	$ 1,950
(2) Stainless steel couplings (3 inch)	630
(3) Installation (local contractor)	400
b. Main reservoir (exterior plywood and epoxy resin); screen filter (Nitex nylon) (on site construction)	380
c. Supply lines (schedule 40 PVC)	
(1) 4 inch pipe (520 feet)	460
(2) 3 inch pipe (190 feet)	120
(3) Couplings, etc.	100
(4) Installation (local contractor).	300
2. Brood-Stock units	
a. Outdoor brood-stock units (5-10 m^2 with PVC liner; used for composting also)	100
b. Indoor facility with biological filters (exterior plywood and epoxy resin tanks containing crushed shell and limestone; local construction). . . .	300
3. Intermediate rearing facility for juveniles (5-10 m^2 outdoor units with PVC liner; used for composting also)	100
4. Grow-out units	
a. Clearing land, all excavation and earth moving and application of grass seed to stabilize embankments	4,500
b. 15 mil PVC lines; 117,000 sq ft (Staff Industries, Upper Montclair, New Jersey)	16,750
c. Marl or white clay for protective layer	100
d. Sand for culture	300
e. Installation of liner, sand, and marl	1,000

f. Roads	
(1) Clay surface	350
(2) Concrete pipe covers (local construction)	100
g. Drains	
(1) Concrete monks or sluiceways (on site construction)	1,200
(2) Asphalt for drainage ditches	150
(3) 30 cm diameter concrete culverts (local construction)	300
5. <u>Processing, storage, and distribution facilities for food</u>	
a. Jeep (model C5-J with 4-wheel drive and power take-off)	4,580
b. Pasture rake (local construction)	200
c. 1-ton utility trailer with wire sides(local construction)	400
d. Grinder-mixer (model 950; International Harvester, Atlanta, Georgia)	2,500
e. Elevated storage for processed seagrass (local construction)	250
f. Industrial blender (1 gal capacity)	350
6. <u>Harvesting, inventory storage, packaging and shipping facilities</u>	
a. Harvesting unit	
(1) 3 inch single port, open volute pump (model 1503; Neilson Metal Industries, Salem, Oregon)	1,900
(2) Floating platform and sorting screens (local construction)	300
(3) Live cars (120 units; local construction)	350
b. Service building (rearing, processing, wet and dry storage and office)	
(1) Sears steel and aluminum building (600 sq ft which includes one basic building, model 60731; two ten foot extensions, model 60732; one overhead door, model 60708; two doors, model 60756; three windows, model 60755)	3,900
(2) Concrete slab, plumbing, wiring,and installation	2,100
(3) Rheem water heater (50 gal; natural gas)	120
(4) Dixie 120 gal, glass-lined storage tank (hot water reservoir)	220
(5) Plumbing for culture (reservoir and supply lines)	300
(6) Window-type air conditioner	500
(7) Space heater (natural gas)	350
c. Storage units (exterior plywood, epoxy resin) (local construction)	500
d. Tables for packaging and shipping (local construction)	140
e. Ford van (6 cylinder, air-conditioned)	4,450
f. Insulated live wells (exterior plywood, epoxy resin and styrofoam) (local construction)	90

g. Cooling unit for live wells or storage; (Min-O-Cool, model DI-33; Frigid Units, Toledo, Ohio); 2 units 1,140

TOTAL $54,230

B. Annual fixed costs

1. Amortization of physical plant and equipment (8 year period) . . . . $ 6,780
2. Annual maintenance (3% of construction costs) 1,630

TOTAL $ 8,410

C. Annual production costs

1. Labor
   a. Full time manager (an individual with experience as a farmer and mechanic who appreciates biology) $ 9,000
   b. Full time laborer (minimum wage) 4,780
2. Lugworm food
   a. Harvesting and processing seagrass (20 metric tons at $64 per ton) 1,280
   b. Supplementary food (if demonstrated to be of value) 500
3. Energy
   a. Electricity 2,000
   b. Gasoline and oil 1,600
   c. Natural gas 200
4. Chemicals (antibiotics, pesticides) 150
5. Miscellaneous tools and supplies 500
6. Packaging materials 250
7. Shipping expenses (air freight for one third of crop) 1,500
8. Telephone 350

TOTAL $22,110

Option II: Open System with Tidal, Unlined Grow-Out Units

Unless specified, construction, installation, model number and sizes are as outlined for Option I.

A. Initial costs

1. Seawater system
   a. Pumps, motors, and accessories
      (1) 150 gpm pump and 3 hp electric motor (model 34EL-11D; ITT Marlow) . . . . $ 920
      (2) Stainless steel couplings 320
      (3) Installation 300
   b. Main reservoir 380
   c. Supply lines to service building (schedule 40, PVC)
      (1) 3 inch pipe (450 feet) 280
      (2) Couplings 100
      (3) Installation (local contractor). 200
2. Brood-stock units 400
3. Rearing facility for larvae and young juveniles . . . 100
4. Tidal grow-out units
   a. Clearing land, all exacavation, and earth moving (sand for culture is available at the site) . . . 5,500

b. Marl to protect embankments	300
c. Topsoil and grass seed to protect embankments . .	1,000
d. Roads (clay surface)	350
e. Drains	
(1) Concrete monks (on site construction) . . .	2,400
(2) 36-inch concrete culverts (200 ft total) . .	3,650
(3) Weir or screens to control predators . . .	400
(4) Riprap to protect ditches from erosion (200 yd^3)	800
5. <u>Processing, storage and distribution facilities for food</u>	8,780
6. <u>Harvesting, inventory storage, packaging, and shipping facilities</u>	
a. Modified Long Island dredge	920
b. Live cars	350
c. Remaining items listed in Option 1.6.b through g	13,810
TOTAL	$41,260

B. Annual fixed costs

1. Amortization of physical plant and equipment (8 year period)	5,160
2. Annual maintenance (3% of construction costs)	1,240
TOTAL	6,400

C. Annual production costs (are expected to be essentially identical to Option 1) . . . . TOTAL $22,110

PREDICTED RETURNS

Predicted returns (for bait-worm production only) are given for the options discussed. In each case 5% mortality due to handling and accidents was allowed. Since production per unit area in pilot grow-out units was just above 60 worms/m^2, this figure was used as a conservative estimate in both options. Actual annual production per grow-out unit is expected to range between three and four crops per year.

Option I: Open System with Seawater Pumped to PVC-Lined Grow-Out Units

A. Estimated gross returns to producer

	Producer's wholesale price at three locations: 4¢ each (Florida or North Carolina)	6¢ each (Maryland)
1. 1,026,000 bait-worms (3 crops/yr)	$41,000	$62,000
2. 1,368,000 bait-worms (4 crops/yr)	$55,000	$82,000

B. Estimated net returns to producer before taxes

1. 1,026,000 bait-worms	$10,500	$31,500
2. 1,368,000 bait-worms	$24,500	$51,500

Option II: Open System with Tidal, Unlined Grow-Out Units

A. Estimated gross returns to producer are the same as those listed for Option I.

B. Estimated net return to producer before taxes.

1. 1,026,000 bait-worms	$12,500	$33,500
2. 1,368,000 bait-worms	$26,500	$53,500

CONCLUSIONS

The preliminary plan for a commercial bait-worm hatchery could be used to construct and operate a large scale pilot plant or a full scale commercial plant with the capacity to produce at least one million lugworms per year. This level of production could be expanded three to five times if the production area is increased. No predictions are made concerning problems that may arise due to increased size.

The next logical step in development of lugworm aquaculture would be to obtain sufficient worms for test marketing and possibly to create a demand in areas where marine worms are currently popular baits. These worms could be obtained from an area where they are presently harvested (England) or from a facility of the type suggested in this plan.

As presented, the preliminary plan is not highly sophisticated and is subject to modification due to operational and engineering changes in the proposed designs. Significant advancements in technology will probably involve development of an enriched diet, a satisfactory dietary supplement and/or a substitute for seagrasses. Selective breeding should result in a variety which grows more rapidly. Other advancements could come with development of closed systems which may be economically feasible after sufficient demand for lugworms has been generated and income can be more accurately predicted.

It is significant to note that although certain biological risks to aquacultural enterprises as defined by Webber (1973) are considerations in lugworm aquaculture, simple, easily applicable techniques can be used to reduce or eliminate these risks. The remaining problems involve non-biological techniques or economics. It is assumed that solutions can be found for them.

ACKNOWLEDGMENTS

I wish to acknowledge gratefully assistance from many individuals and organizations: Mr. I. Flye, Maine Bait Company for sharing observations on packaging methods for lugworms; Dr. J. Pearson, MerEco Inc., for allowing me to test several diets prepared especially for lugworms; Mr. F. Owen for providing alfalfa and kelp used in certain feeding experiments; Dr. R. Bayless, Capsulated Systems Inc., for providing several encapsulated diets; Mr. R. Wulff, Ralston Purina Company, for helping to obtain a special diet for shrimp; Dr. T. Hopkins, University of Alabama, for providing facilities and staff to complete water and sediment analyses while he was Chairman of the Faculty of Biology, University of West Florida; Dr. T. Duke, Environmental Protection Agency, for providing laboratory facilities and environmental data.

Special thanks are due to Dr. S. Meyer, Louisiana State University, for preparing several alginate-bound diets designed especially for lugworms; Dr. G. Wells, University College, London, for identifying lugworms used in the hatchery; Mrs. P. Riehm for her work concerning essential amino acids; and to Ms. R. Broughton, Ms. S. Hails, Mr. H. McDonald, Mr. C. Merritt, Mr. R. Parker, Mr. N. Rubinstein and Mr. C. White, University of West Florida, for their efforts in completing various aspects of this study. Mr. Rubinstein deserves additional recognition for his work with temperature and salinity parameters, Ms. Hails for her work with pesticides and Mr. White for preparing the drawings and photographs used in this report and for his work on predator-prey relationships.

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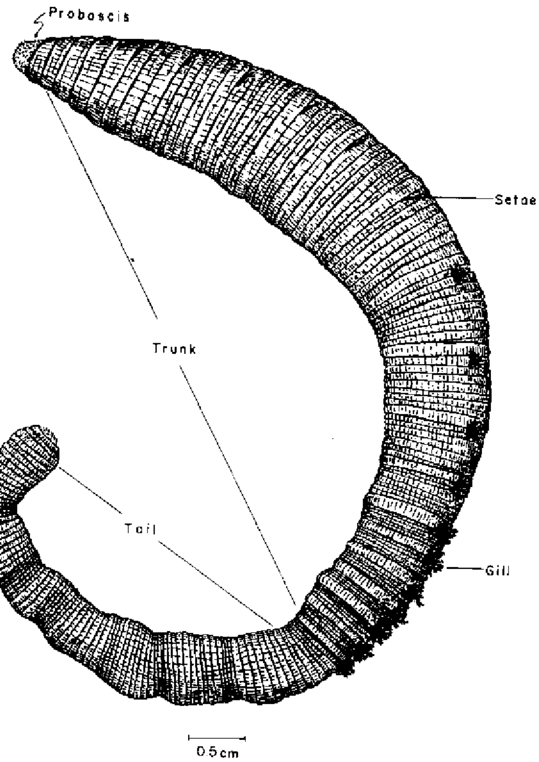

Figure 1. Left side of a partially relaxed adult lugworm, Arenicola cristata Stimpson, showing divisions of the body and other obvious features.

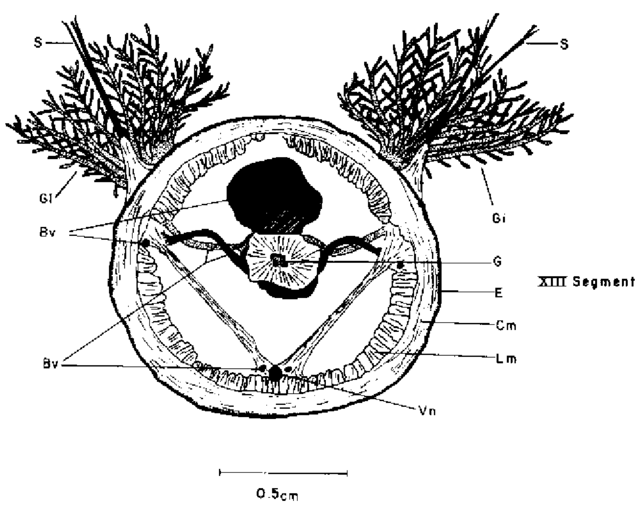

Figure 2. Section through the thirteenth segment of a mature lugworm, Arenicola cristata, demonstrating the position of the ventral nerve cord in relation to the longitudinal and circular muscles in the body wall. (Legend: bv - blood vessel; cm - circular muscle; e - epidermis; g - gut; gi - gill; lm - longitudinal muscle; s - setae; vn - ventral nerve.)

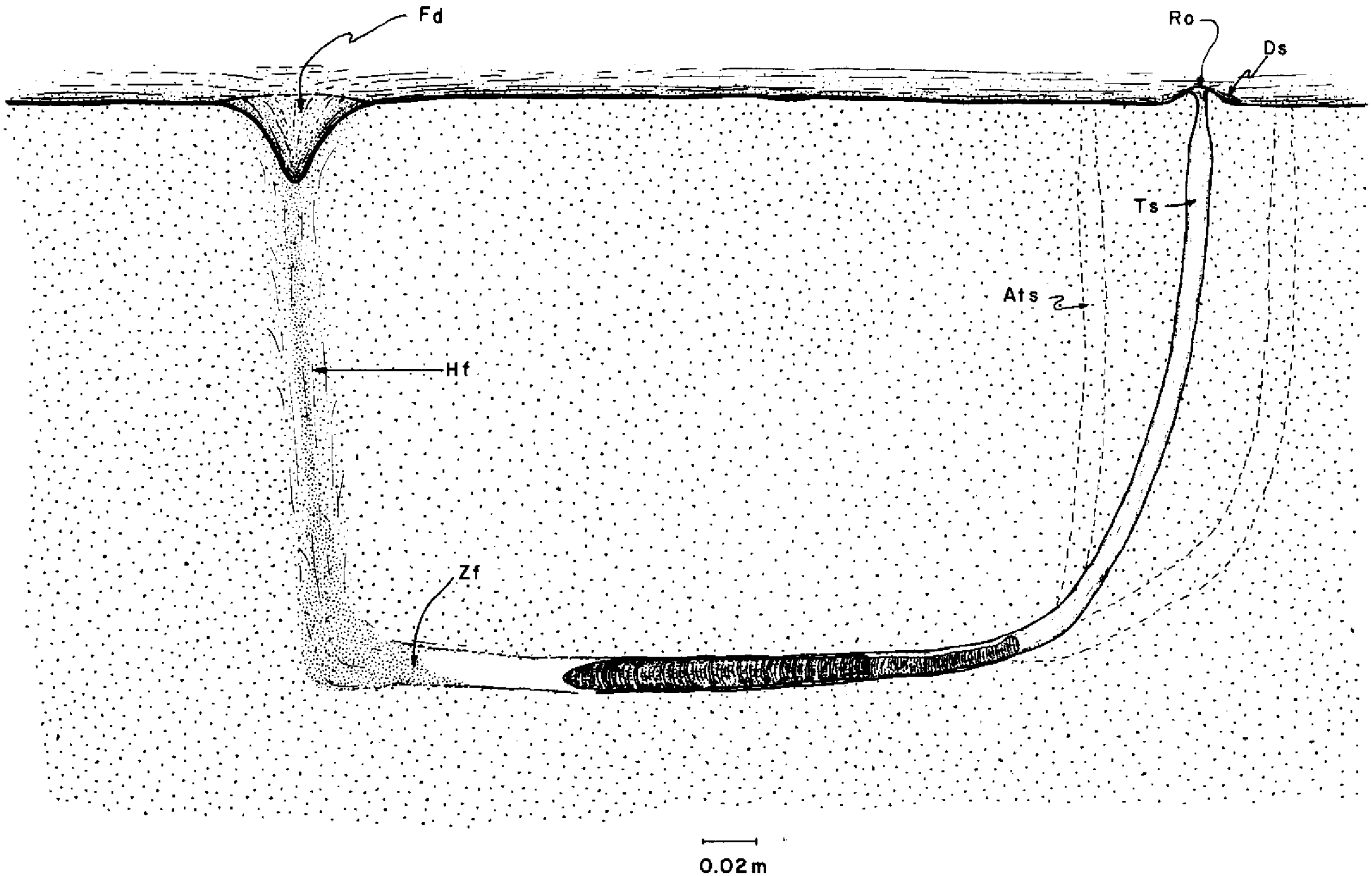

Figure 3. Typical burrow occupied by juvenile or adult lugworms. ats - accessory tailshaft; ds - defecated sand; fd - funnelform depression; hf - headshaft; ro - respiratory opening; ts - tailshaft; zf - zone where feeding occurs.

Figure 4. Typical round or ovoid egg masses produced by hatchery reared lugworms in northwest Florida. Each mass was attached by the short stalk to the burrow.

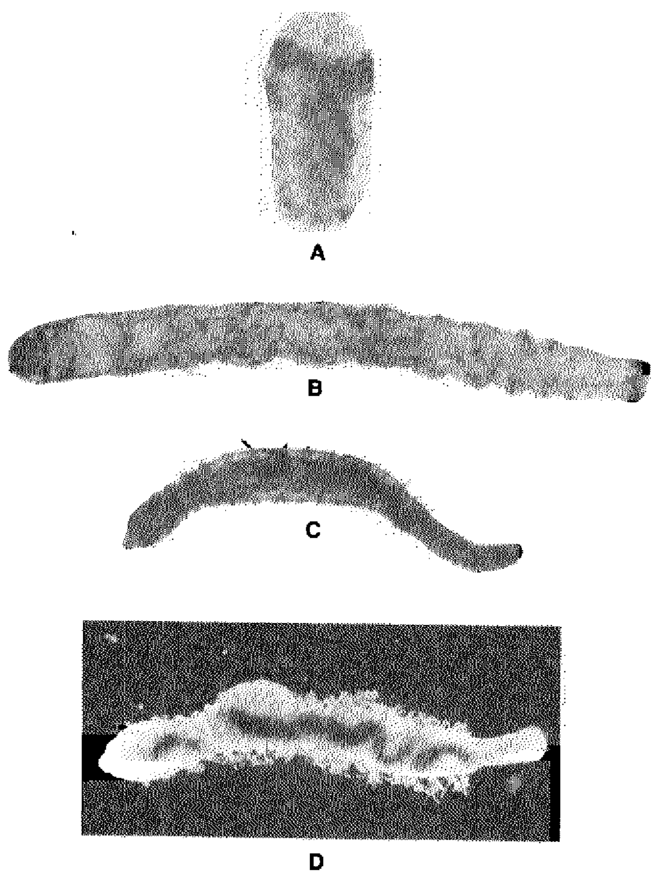

Figure 5. Larval and early juvenile stages of the lugworm, Arenicola cristata: A. two setiger larva at hatching (0.26 mm length); B. nine setiger larva (1.03 mm length measured partically expanded); C. young juvenile (17 setigers plus caudal segments) approximately stocking size (0.7 mm); D. dark field photograph of a young juvenile with its gut filled with composted seagrass.

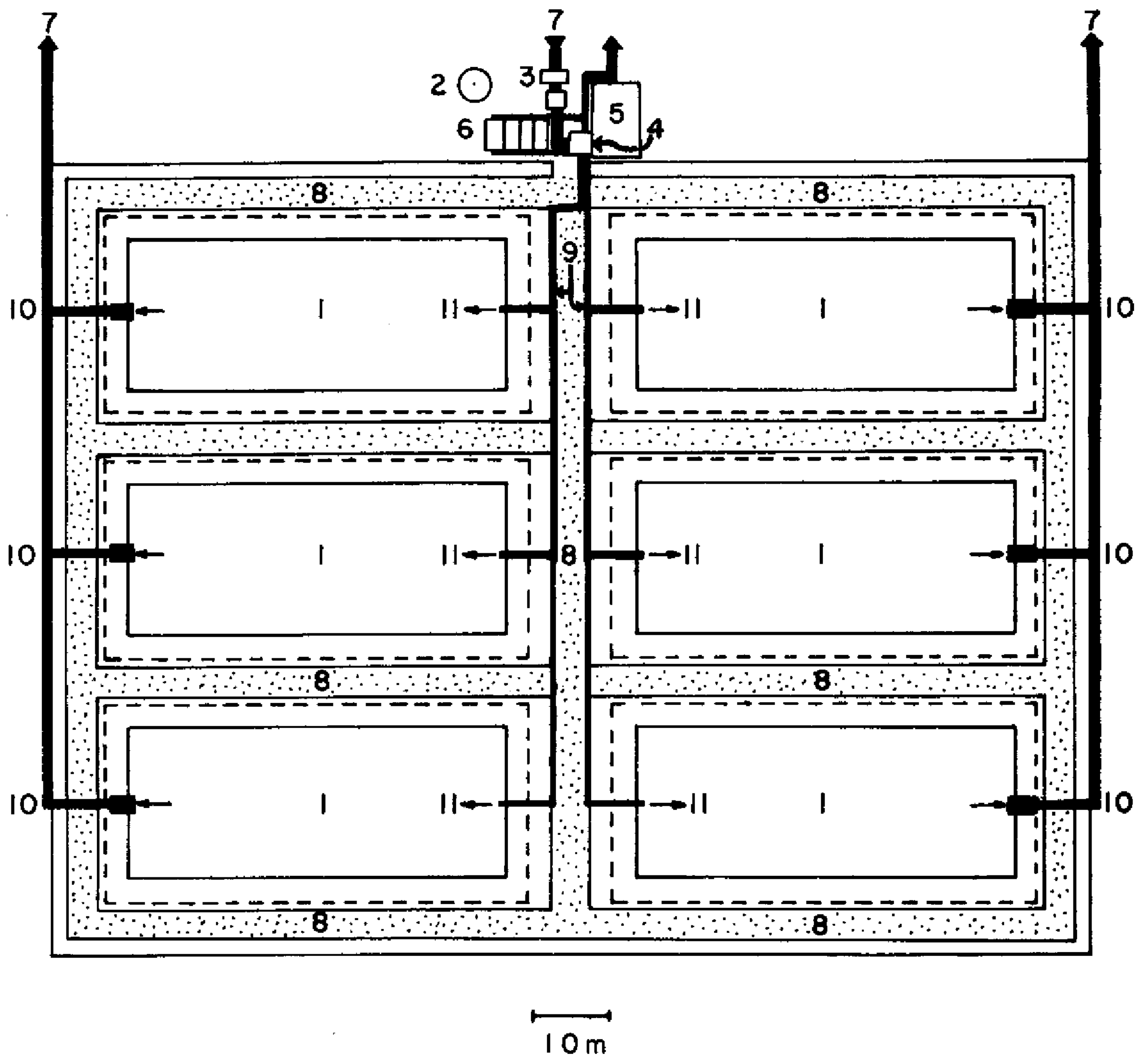

Figure 6. Option 1: proposed open-system lugworm hatchery with six 1,000 m^2 grow-out units. 1 - grow-out unit; 2 - storage for processed seagrass; 3 - pumps; 4 - main reservoir and filter; 5 - service building; 6 - brood-stock and composting units; 7 - estuary; 8 - access road on embankment; 9 - main supply lines; 10 - effluent ditch; 11 - supply inlet.

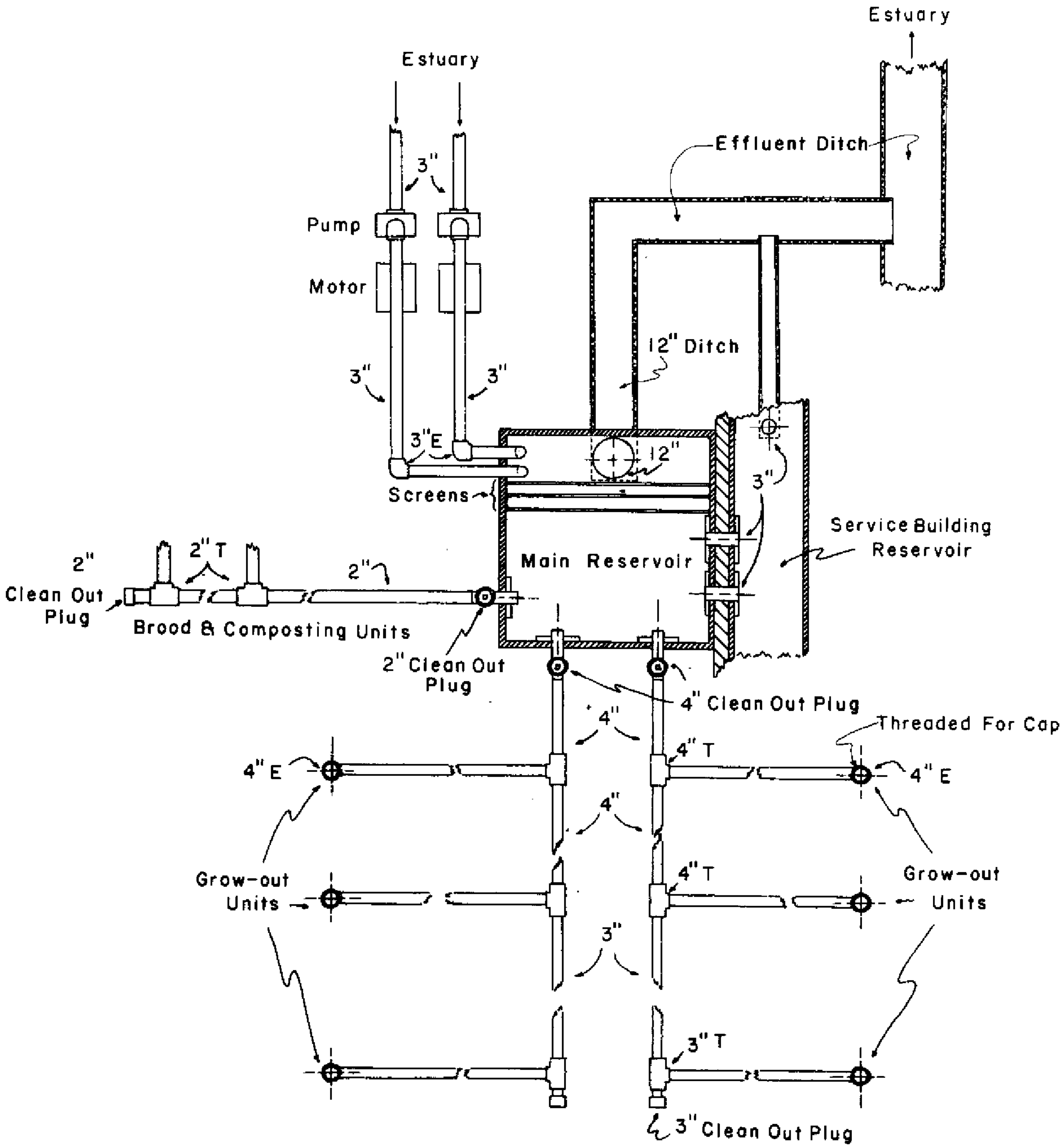

Figure 7. Option 1: proposed seawater system constructed from PVC pipe. All units are supplied from a central reservoir by gravity. There are no valves. Water flow is restricted or terminated with caps (threaded or unthreaded) applied at the reservoir and in rearing units. Hot water to control fouling is added at the reservoir where clean out plugs are indicated.

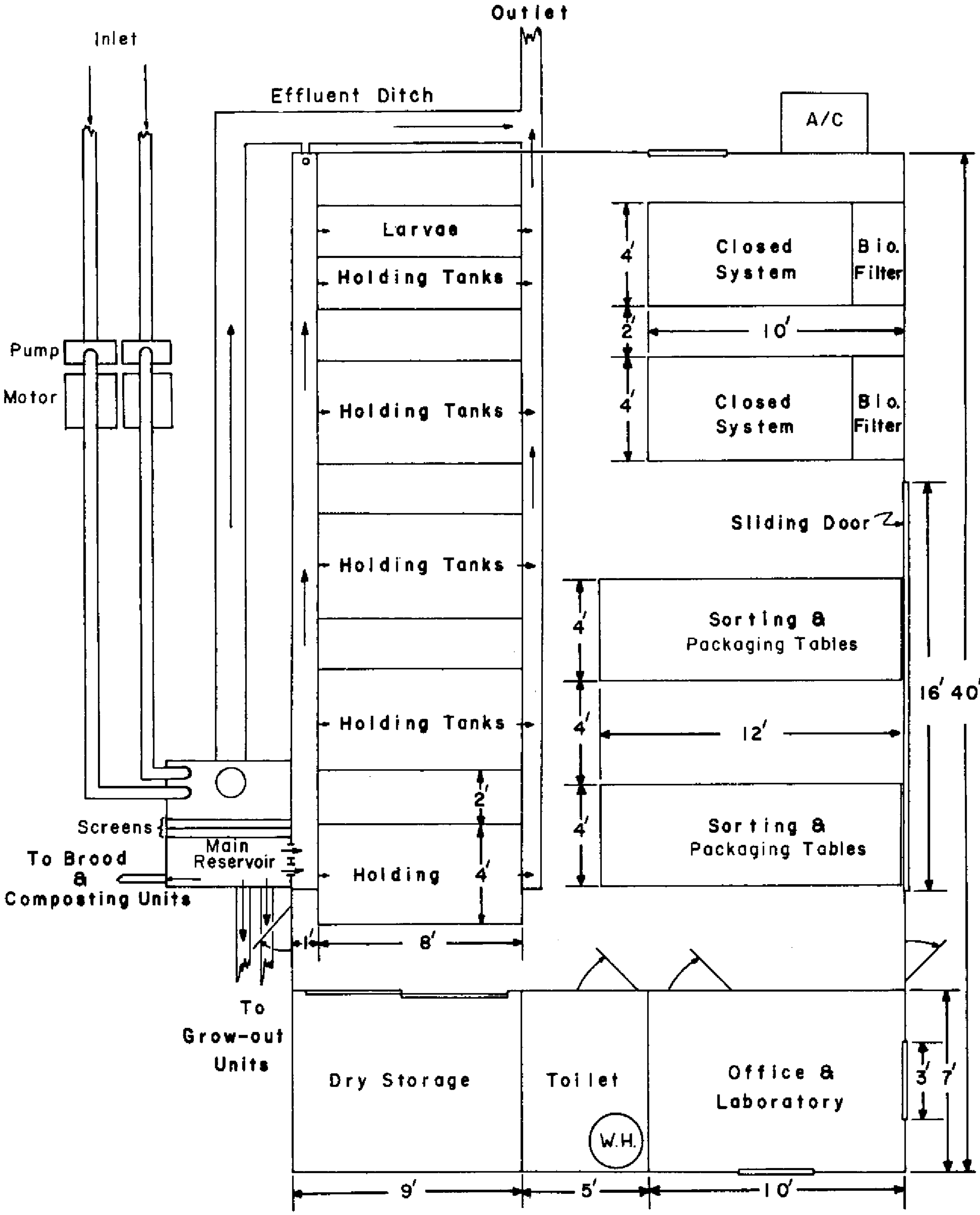

Figure 8. Floor plan of the proposed service building shown with plumbing to match Option I. The same floor plan would be used in Option II but only one 150 gpm pump is required.

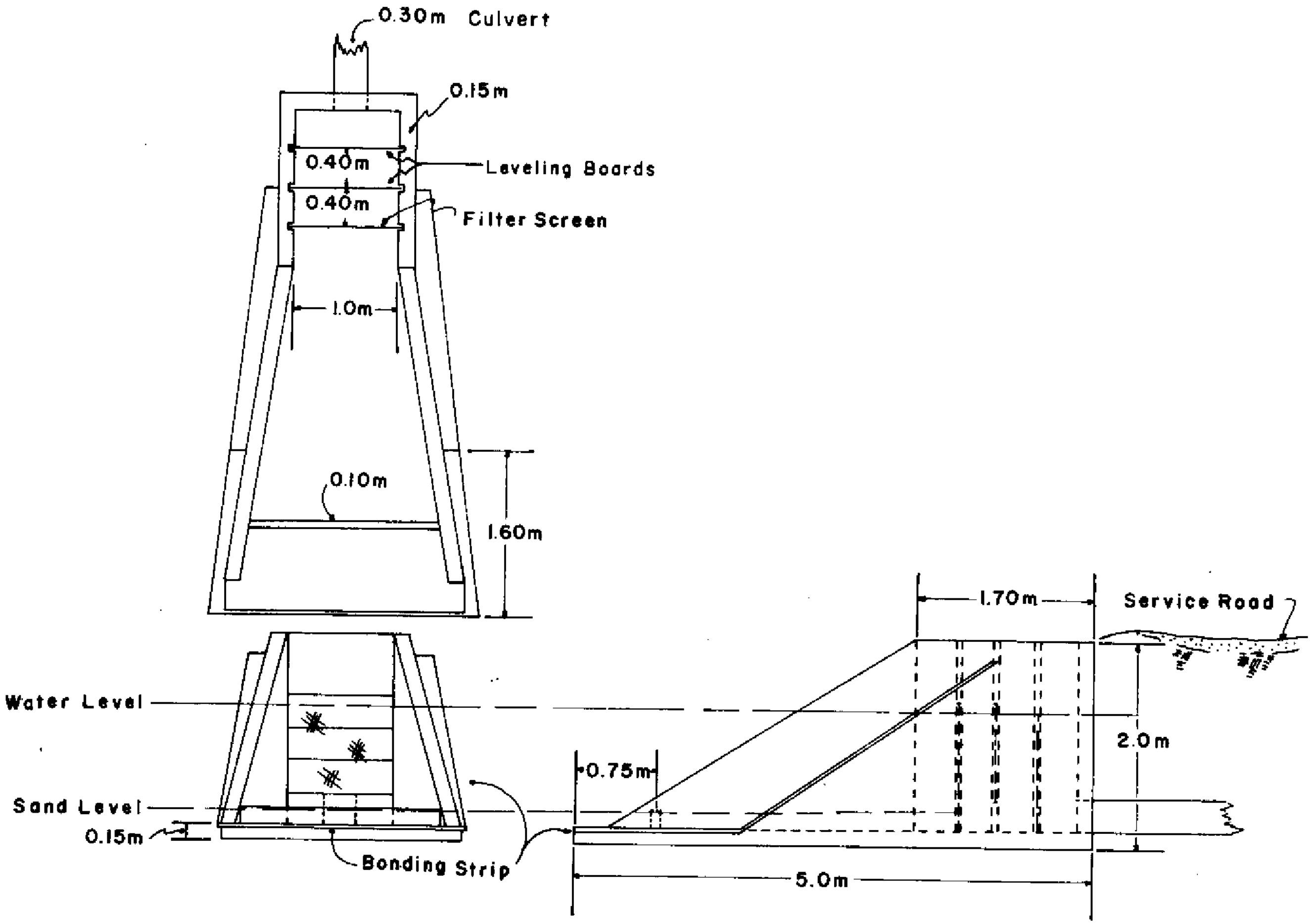

Figure 9. Concrete monk and culvert suggested for a grow-out unit in Option 1. The monk has a filter to catch swimming worms. Water level is adjusted by adding or removing leveling boards.

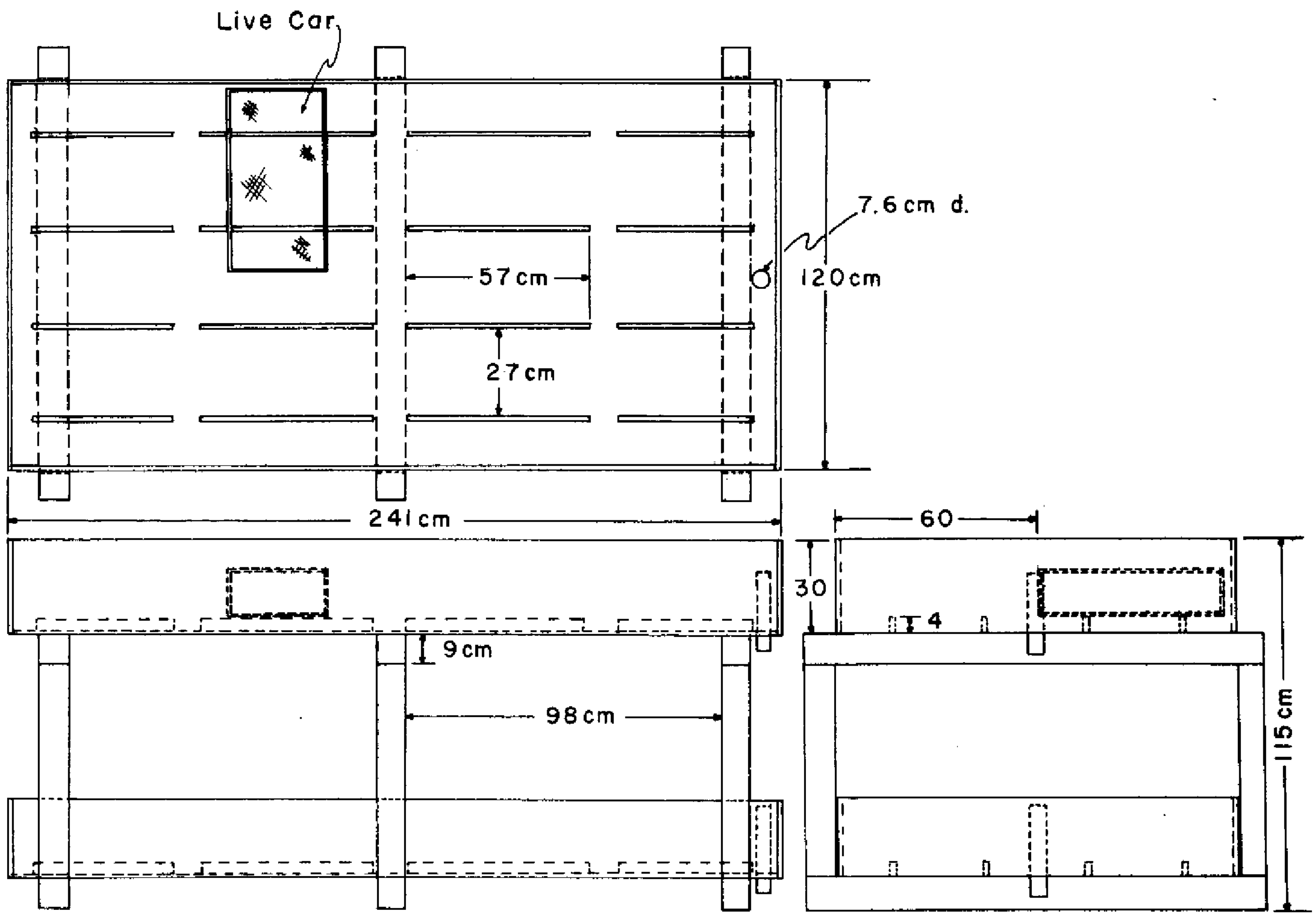

Figure 10. Double layered, multipurpose storage units (constructed from exterior plywood reinforced with fiberglass cloth and epoxy resin and mounted on a wooden frame) can be used to store harvested worms, rear larval worms or breed stock. Each layer normally would hold 12 live cars each containing 1,000 worms. Only one live car is shown in position.

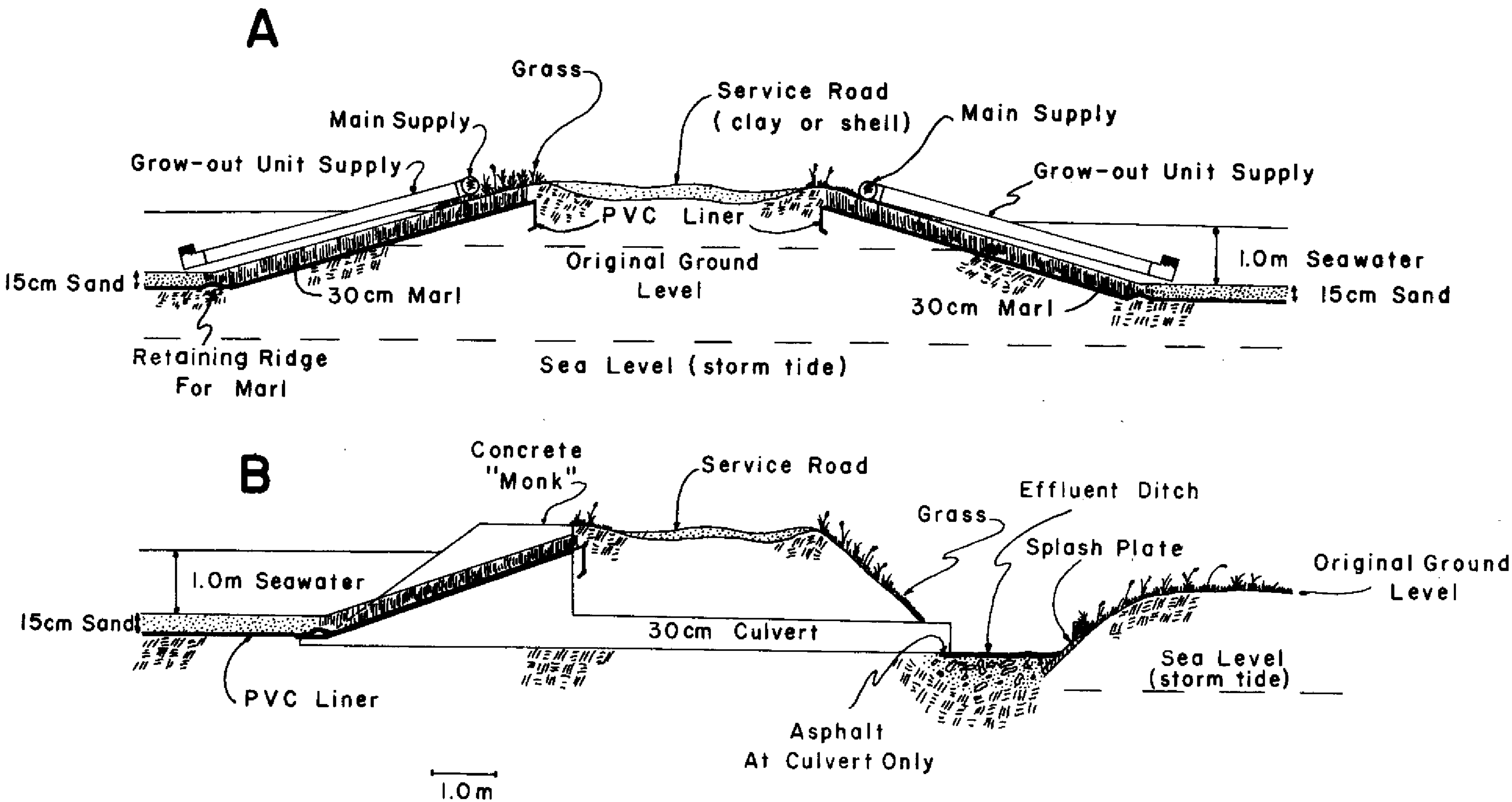

Figure 11. Details of embankments recommended for Option I: A. section through the supply area: B. section through the monk and effluent ditch. The PVC liner is shown as a solid black line much larger than actual scale.

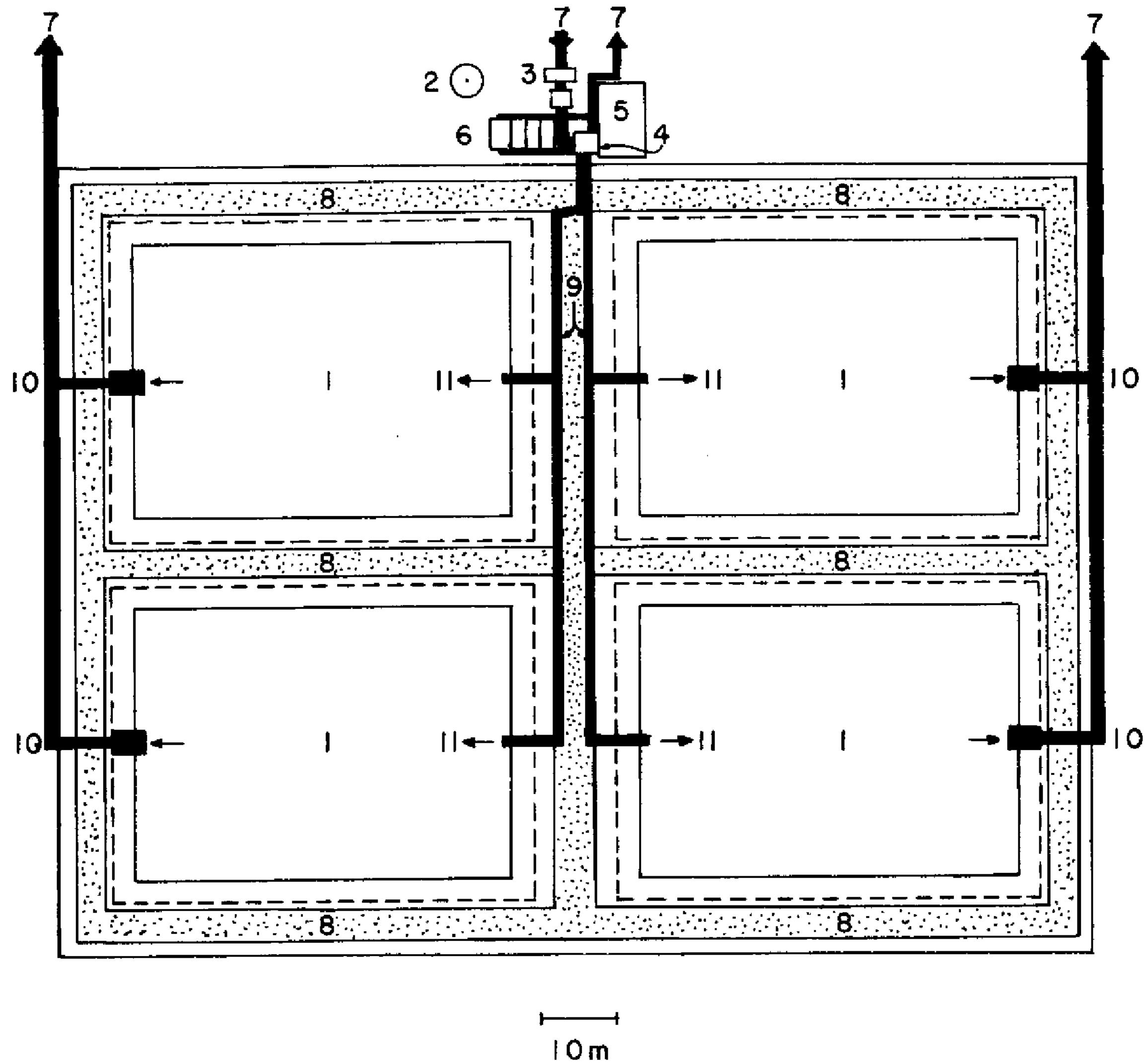

Figure 12. Option 1: proposed open-system lugworm hatchery with four 1,800 m^2 grow-out units: 1 - grow-out unit; 2 - storage for processed seagrass; 3 - pumps; 4 - main reservoir and composting units; 7 - estuary; 8 - access road on embankment; 9 - main supply lines; 10 - effluent ditch; 11 - supply inlet.

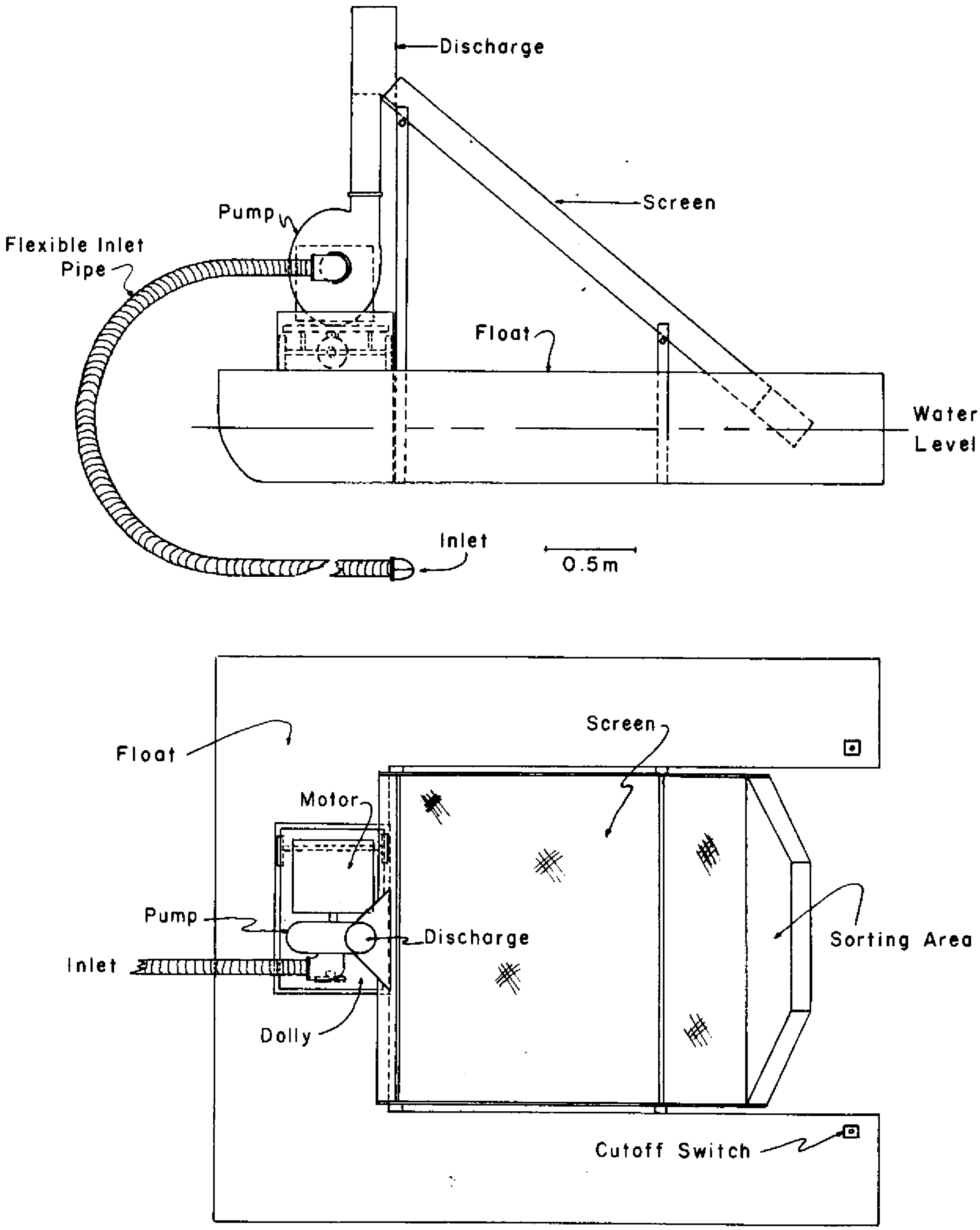

Figure 13. Suggested pump facilitated harvesting device includes a 3-inch single port, open volute pump which moves a slurry of sand and water (150 gpm) to an inclined screen from which the worms are sorted into floating live cars. The device is operated by two men who can harvest a 1,000 m^2 grow-out unit in less than one day.

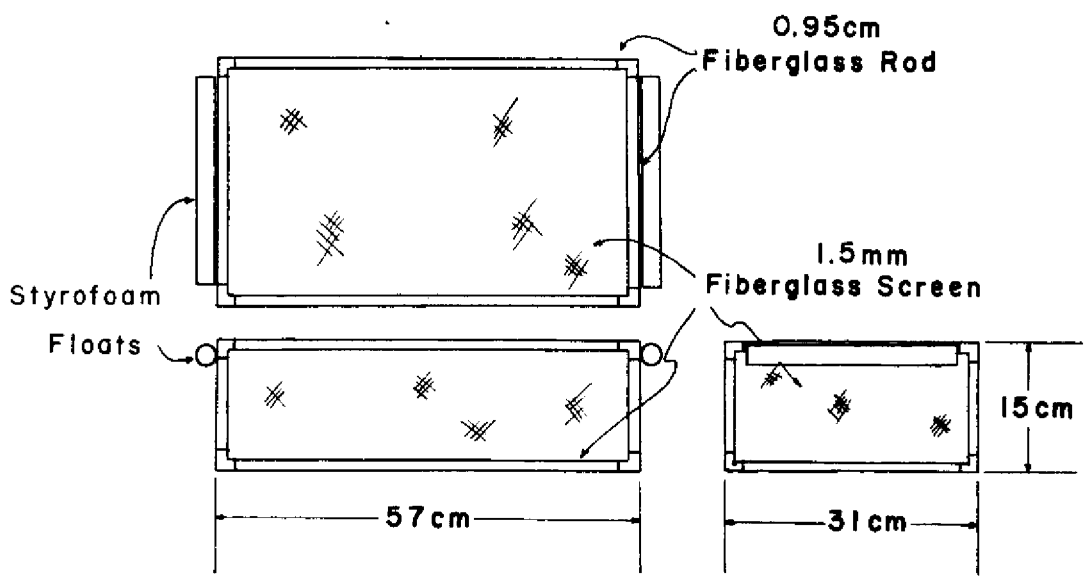

Figure 14. Floating live car used to collect and store lugworms after harvest. Dacron or nylon screen can also be used. PVC pipe can be used in place of rods. Removable styrofoam cylinders provide flotation.

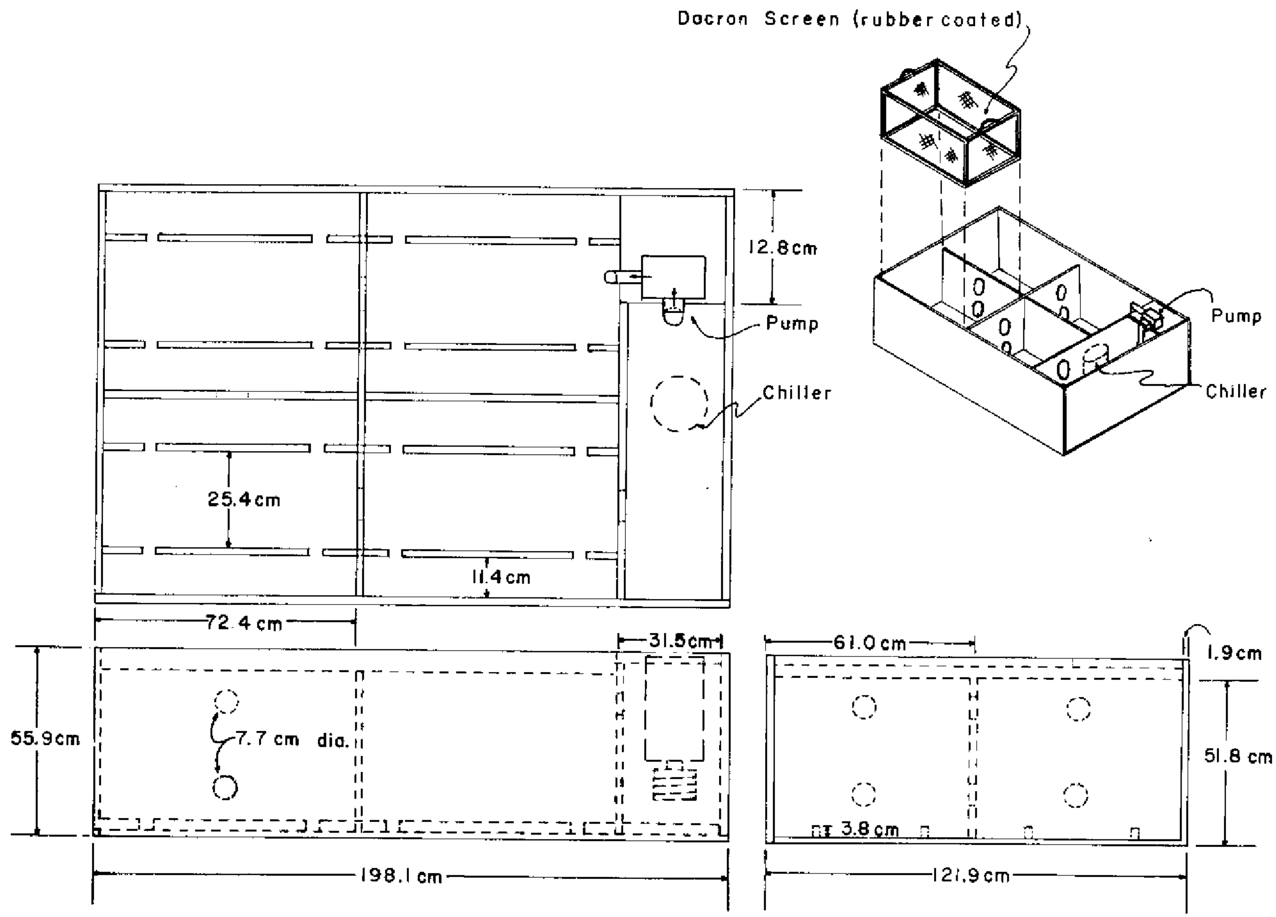

Figure 15. Shipping container for bulk lots of live lugworms. The suggested container includes a portable cooling unit and pump to maintain circulation of water over baskets holding lugworms. The unit is surrounded by styrofoam insulation.

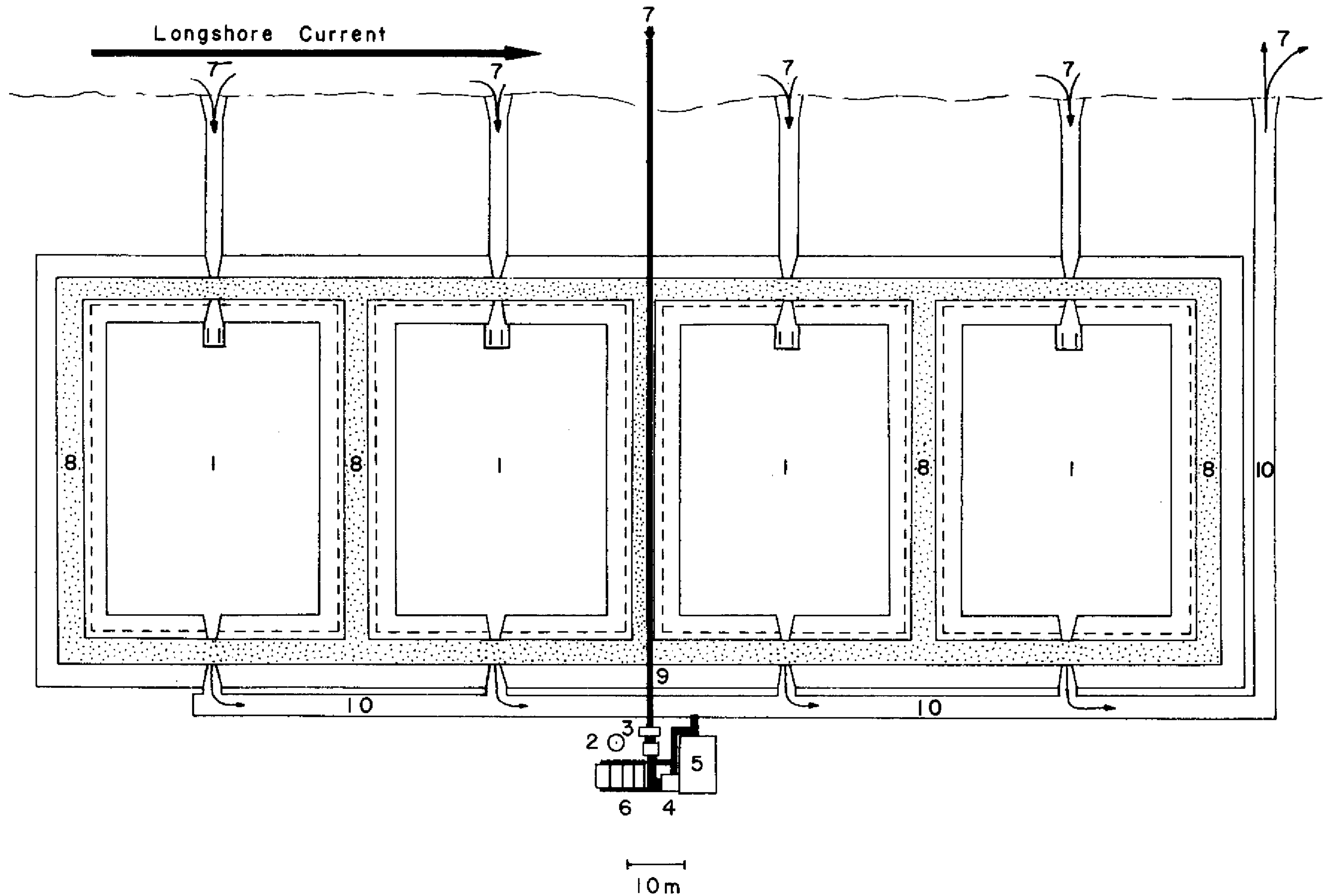

Figure 16. Option II: proposed open system lugworm hatchery with four 1,800 m^2 grow-out units flushed by tidal action. 1 - grow-out unit; 2 - storage for processed seagrass; 3 - pump (150 gpm); 4 - main reservoir and filter; 5 - service building; 6 - broodstock and composting units; 7 - estuary with access to high salinity water; 8 - access road on embankment; 9 - inlet supply to pump; 10 - effluent ditch (on ebb tide only); 11 - inlet with splash pan to control erosion.

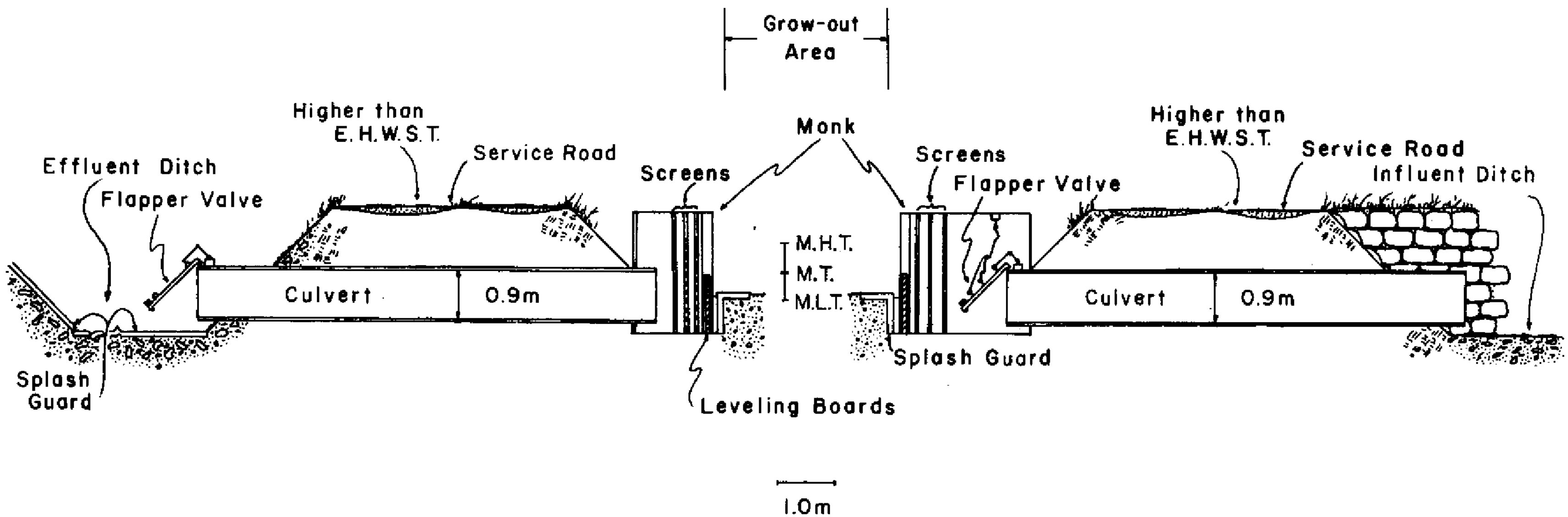

Figure 17. Details of embankments, monks and culverts with one-way flapper valves suggested for use in Option II. Exact design of the valves is now shown. Culverts are cleaned on spring low tides. (M.H.T. - mean high tide; M. T. - mean tide; M.L.T. - mean low tide; E.H.W.S.T. - extreme high water spring tide).

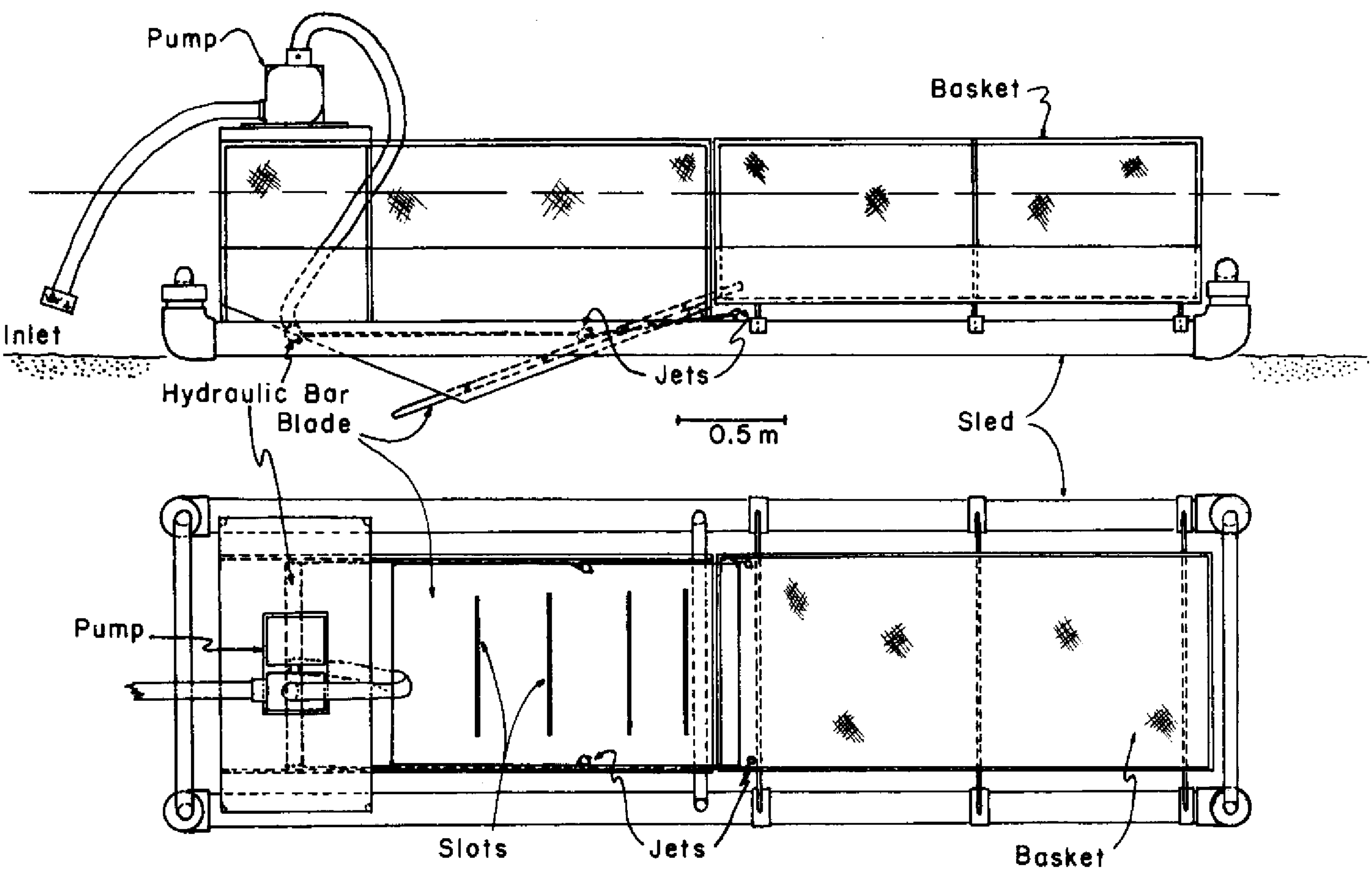

Figure 18. Suggested dredge facilitated harvesting device. Propulsion is provided by a winch mounted on a vehicle. The screen bag or cage can be rapidly raised and emptied into floating live cars. The frame is constructed from plastic or iron pipe.

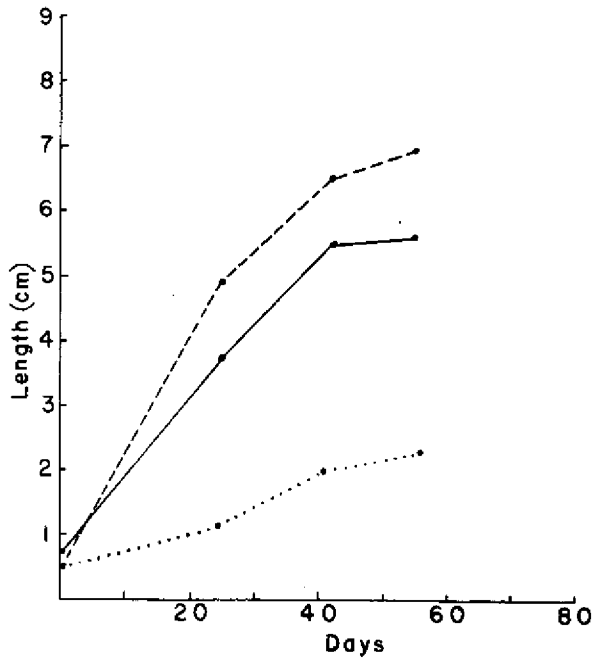

Figure 19. Growth of juvenile lugworms in closed systems (density equivalent to 58 worm/m^2) when fed salt marsh peat (....), uncomposted seagrass (—), and seagrass composted in seawater in the presence of sufficient light to support photosynthesis (----).

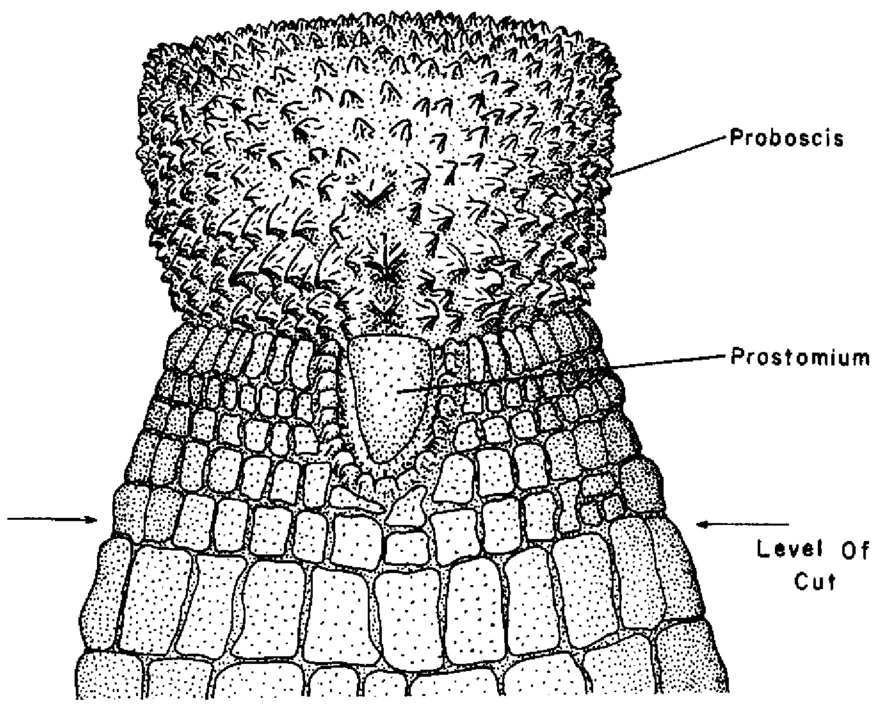

Figure 20. Head of Arenicola cristata demonstrating the point at which the prostomium should be removed to provide tissue for induction of spawning.

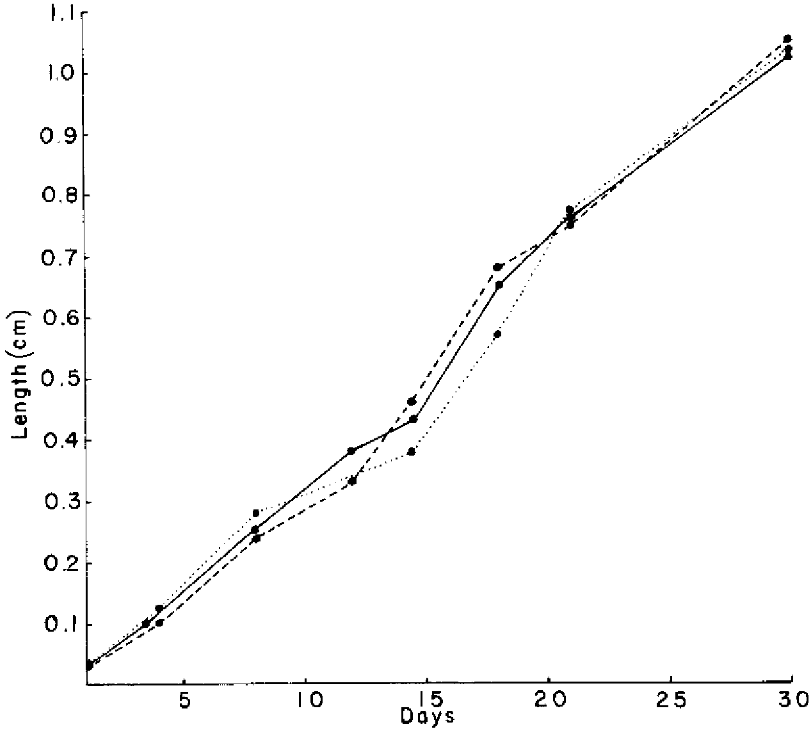

Figure 21. Growth by larval lugworms at different stocking rates, 280,000/m^2 (----), 420,000/m^2 (....), 560,000/m^2 (——), when fed excess composted seagrass (processed in a blender until the average particle size was 25 μ).

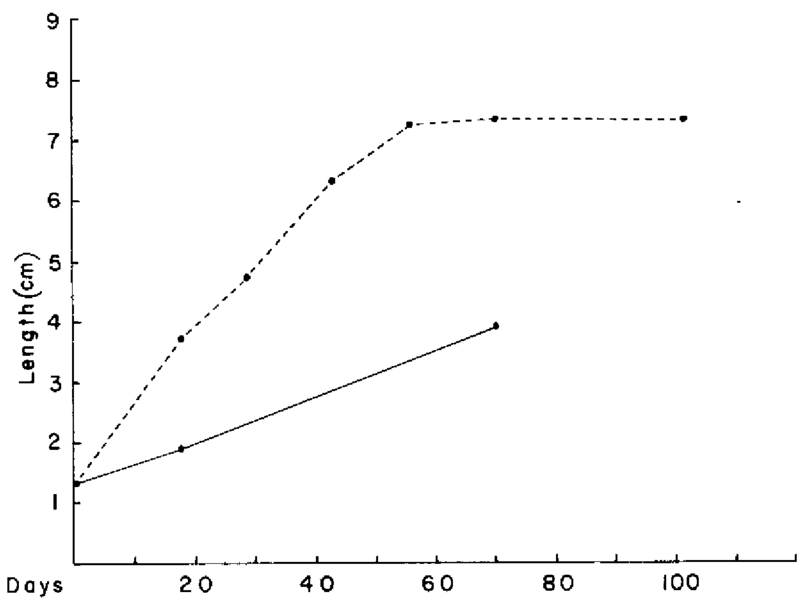

Figure 22. Growth of juvenile lugworms reared in trays (density equivalent to 14/m^2) at an optimum temperature and fed composted seagrass (----) and uncomposted seagrass (——).

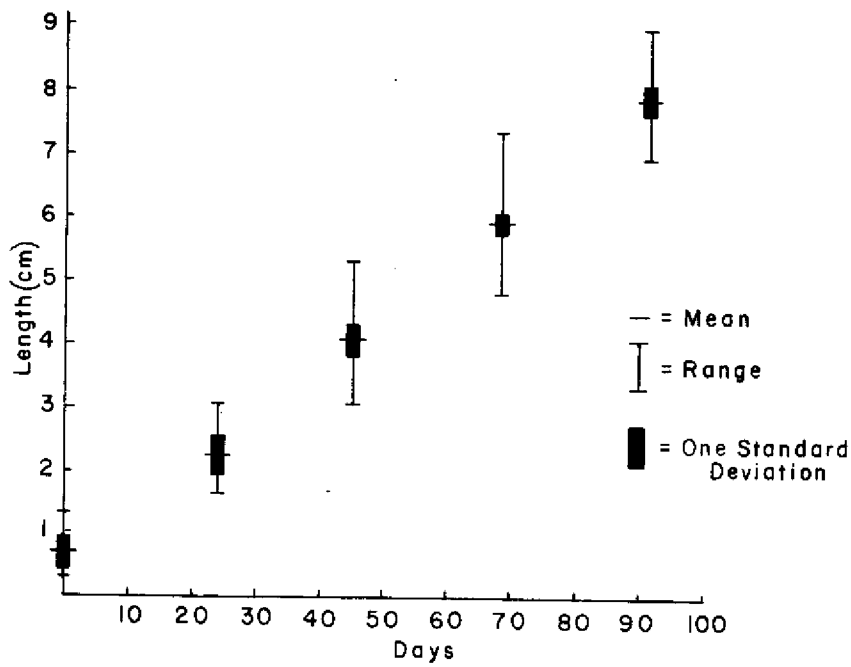

Figure 23. Growth during spring and summer (April-July) of juvenile lugworms in open-system grow-out units stocked at 60 individuals/m^2 with nc allowance for predation. Worms were fed seagrasses as recommended in this report.

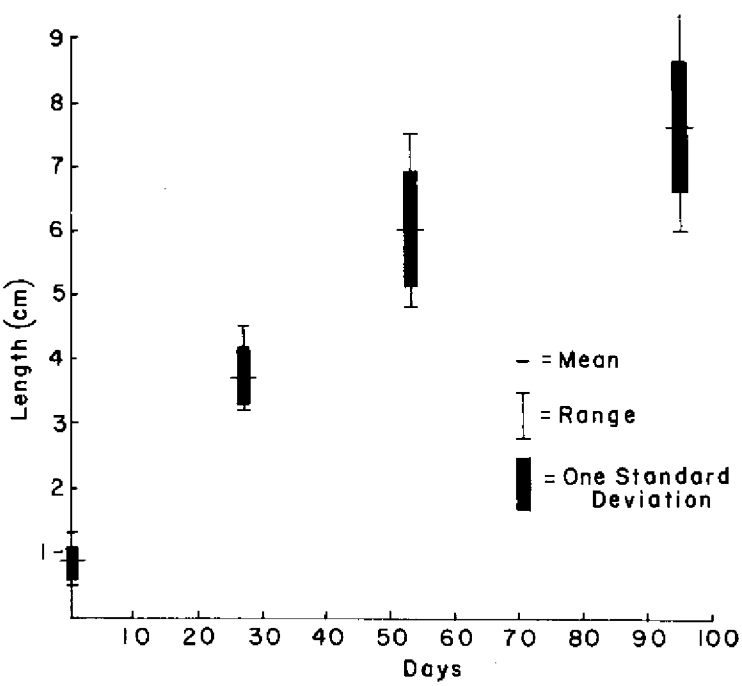

Figure 24. Growth during later summer and fall (August-October) of juvenile lugworms in open-system grow-out units stocked at 60 individuals/m^2 plus 50% overstocking to allow for predation. Worms were fed seagrass as recommended in this report.

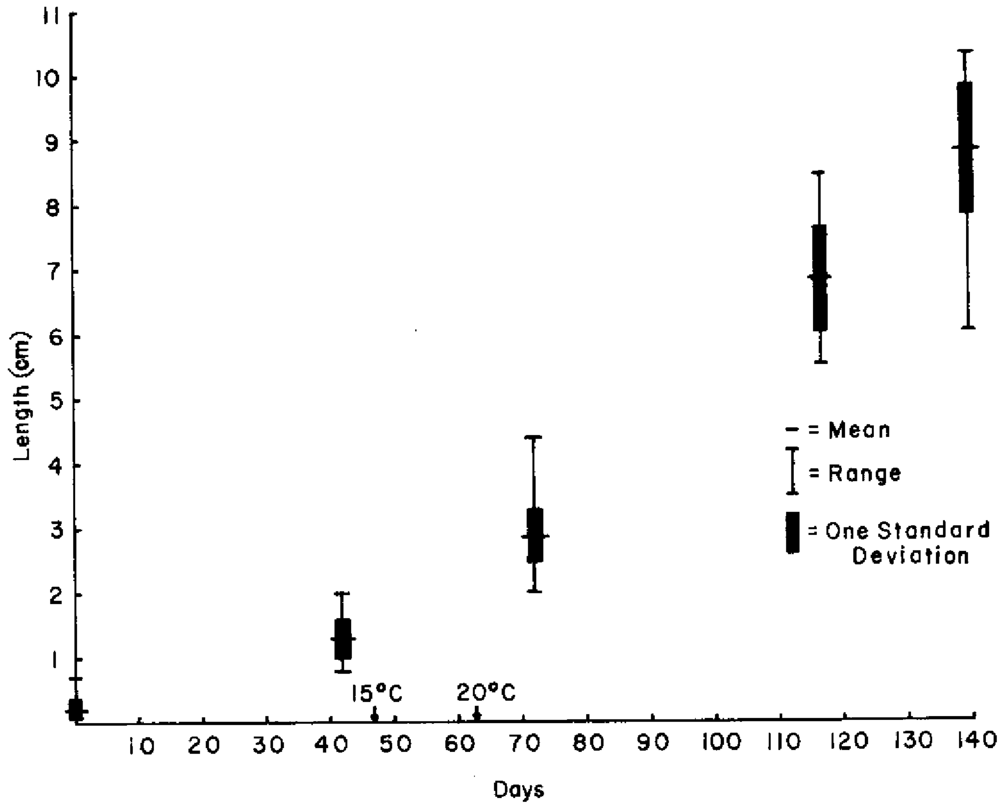

Figure 25. Growth during winter and spring (January-June) in open-system grow-out units stocked at 60 individuals/m^2 plus 50% over-stocking to allow for predation. Worms were fed seagrass as recommended. Arrows indicate the first day on which water temperature in the unit reached 15°C and 20°C.

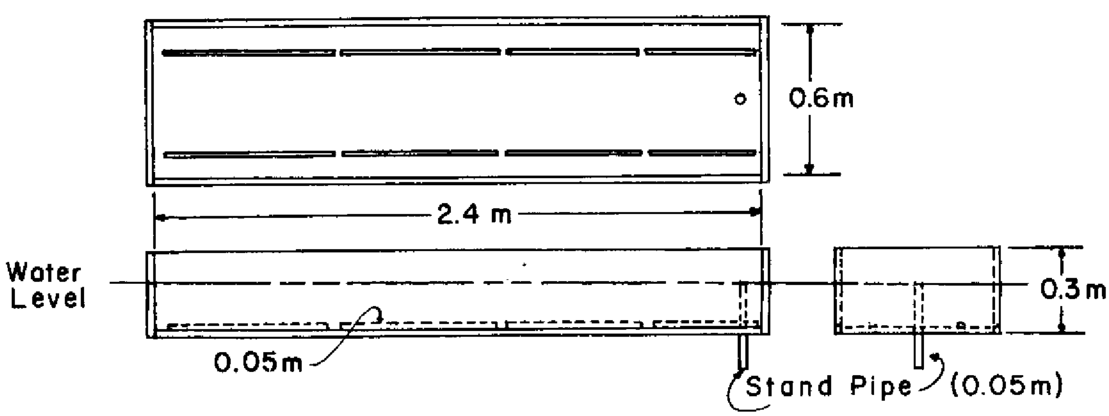

Figure 26. Open system storage-unit (constructed from plywood and epoxy resin) for a retailer which could be used to hold 6,000 bait-worms. Live cars shown in Figure 14 are also required.

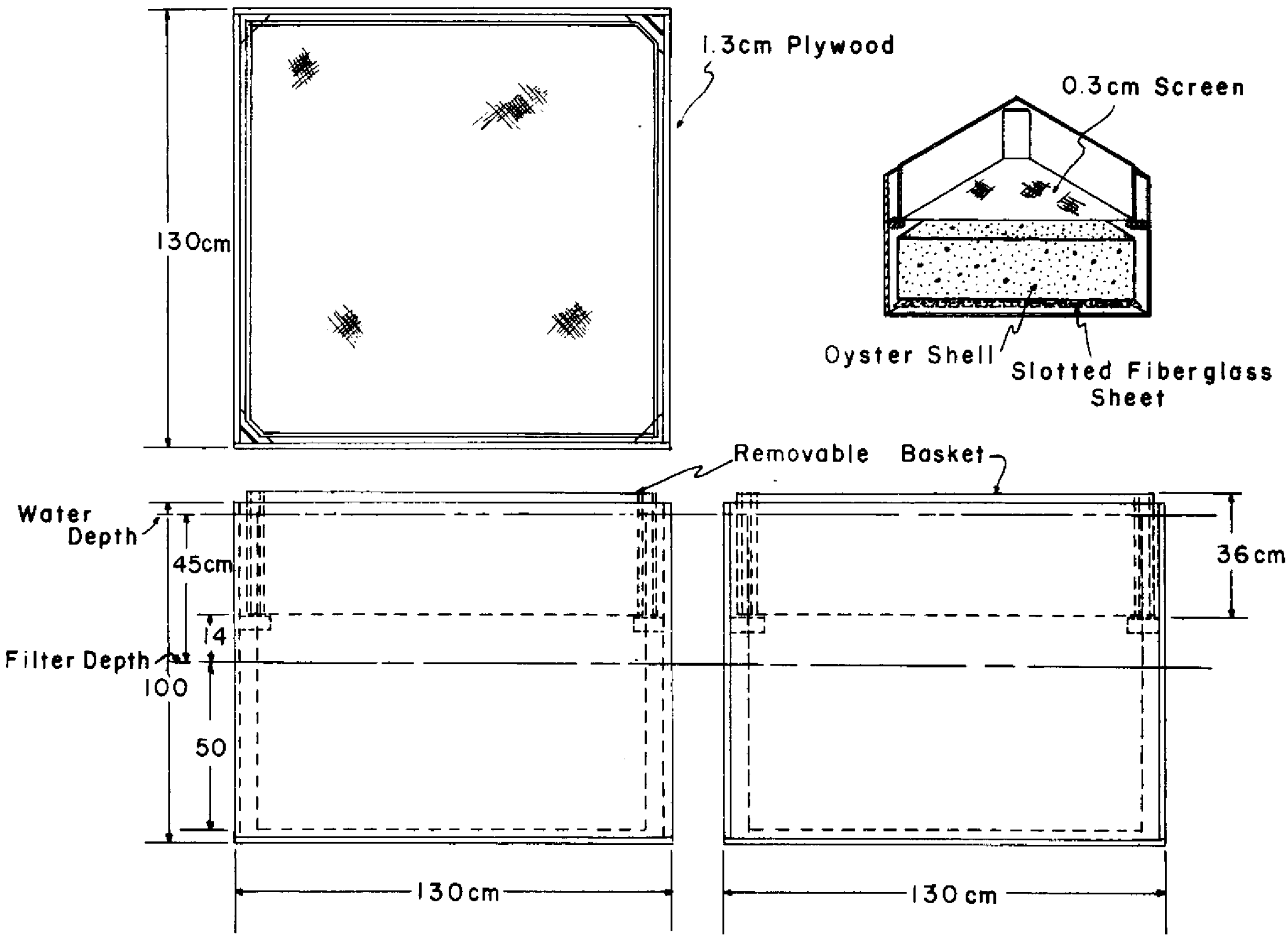

Figure 27. Closed system storage-unit (constructed from plywood and epoxy resin) for a retailer which could be used to hold 1,000 bait-worms. Oyster shell in the bottom of the unit acts as a biological filter. An ordinary aquarium of sufficient size is a satisfactory substitute.

TABLE I

OBSERVED MAXIMUM RANGES IN WATER QUALITY PARAMETERS OVER 90 DAYS IN INFLUENT AND EFFLUENT DURING OPERATION OF A GROW-OUT UNIT (AUGUST - NOVEMBER, 1975)

Parameter	Influent (Santa Rosa Sound)	Effluent
Nutrients[1]		
Total Kjeldahl Nitrogen	0.10-0.93 mg/l	0.07-0.64 mg/l
Total Phosphorus	0.007-0.050 mg/l	0.008-0.048 mg/l
pH	7.7-8.3	7.7-8.3
Dissolved Oxygen[2]	3.0-6.3 mg/l	3.2-6.3 mg/l
Coliform Bacteria	none detected	none detected
Toxic Substances [3]	----	none detected
Turbidity	2.0-2.2 turbidity units	2.0-2.5 turbidity units
Temperature[4]	13-31°C	14-33°C

[1]Data from a small scale grow-out unit representing 14 weekly samples.
[2]Maximum daily change was 2.2 mg/l increase in dissolved oxygen in effluent.
[3]Data based on experiments with open and closed systems completed during 1976.
[4]Maximum daily change was 3°C elevation of temperature in effluent.

TABLE II

PERCENT COMPOSITION OF SEAGRASSES COLLECTED FROM WINDROWS AT STATIONS IN BIG LAGOON AND SANTA ROSA SOUND, FLORIDA

Component	Stations					
	1	2	3	4	5	Average
Thalassia	82	47	77	86	81	75
Diplanthera, *Ruppia* and Other Seagrasses	7	44	17	8	10	17
Misc. Organic Material	5	6	2	4	5	4
Sand and Shell	6	3	4	2	4	4

TABLE III

SUPPLEMENTS OR SPECIAL DIETS TESTED AS FOOD FOR LUGWORMS

Supplement or Diet	Origin or Manufacturer
Alfalfa, field dried	Southern California
Catfish diet, dry pellets	Ralston Purina
Catfood, dry	Ralston Purina
Cottonseed meal (unrefined)	Southern Alabama
Dogfood, dry	Ralston Purina
Encapsulated, standard diet 1 for penaeids	Capsulated Systems
Gulfweed (*Sargassum filipendula*)	Northwest Florida
Kelp (*Macrocystis pyrifera*)	Southern California
Lugworm diet (ingredients based on analysis of processed seagrasses)	MerEco
Lugworm diet prepared with supplements added to processed seagrass and bound with alginates	S. Meyers
Menhaden meal (unrefined)	Gulf of Mexico
Rabbit diet, pellets	Ralston Purina
Shrimp diet, dry pellets	Ralston Purina
Soybean flour	Fearn Soya Foods
Soybean protein	Fearn Soya Foods
Worm and cricket diet	Bama Feed

TABLE IV

RECOMMENDED ENVIRONMENTAL CRITERIA FOR LUGWORM CULTURE IN OPEN-SYSTEM GROW-OUT UNITS

Criterion	Observed Tolerance Range	Lethal point after Acclimation		Observed Optimum	Recommended Range in Culture
		Low	High		
Temperature	1 - 40°C	< 1°C	41°C	25°C	18 - 32°C
Salinity	8 - 35‰	< 8‰	>35‰	22‰	12 - 35‰
Dissolved Oxygen	0 to saturation	—	—	—	>3 mg/l
pH (Seawater)	7.5 to 8.4	—	—	—	7.5 to 8.4
Flow Rate (Seawater)	Permanently Stagnant to Continuous Flushing	—	—	—	more than one exchange of water in 72 hours

TABLE V

NATURAL DECOMPOSITION OF MALATHION IN SIMULATED, DRAINED GROW-OUT UNITS (Source: Hails, in manuscript)

Sample number and concentration	Time 1 hr	1 Day	4 Days	7 Days	11 Days	14 Days
1 (125 ppm)	79.25 ppm	34.31 ppm	13.28 ppm	476 ppb	30.72 ppb	2.48 ppb
% degraded	36.000	72.552	89.376	99.619	99.975	99.998
2 (125 ppm)	82.75 ppm	47.32 ppm	16.23 ppm	518 ppb	42.3 ppb	2.48 ppb
% degraded	33.800	62.144	87.016	99.586	99.966	99.998
3 (62.5 ppm)	40.87 ppm	18.67 ppm	6.34 ppm	312 ppb	19.8 ppb	1.18 ppb
% degraded	34.608	70.128	89.986	99.501	99.968	99.998
4 (62.5 ppm)	42.63 ppm	15.86 ppm	10.21 ppm	421 ppb	21.8 ppb	1.33 ppb
% degraded	31.792	74.624	83.664	99.326	99.965	99.998

TABLE VI

PARTICLE DIAMETERS OF LOW ORGANIC SILICEOUS SAND USED IN GROW-OUT UNITS COMPARED TO PROCESSED SEAGRASS AND SAND FROM A NATURAL LUGWORM BED

Particle Diameter	Processed Seagrass	Santa Rosa Island Sand (used in grow-out units)		Destin Pass Sand (from natural lugworm beds)
		Site A	Site B	
(μ)	(%)	(%)	(%)	(%)
> 841	—	—	—	0.2
841 - 707	0.1	—	0.6	0.7
707 - 420	27.3	56.6	47.1	11.4
420 - 354	11.4	19.0	28.5	10.9
354 - 250	20.1	18.5	20.2	45.1
250 - 177	14.6	4.0	2.3	28.9
177 - 125	10.4	0.4	—	0.7
125 - 88	5.3	—	—	—
88 - 63	2.0	—	—	—
63 - 44	3.0	—	—	—
< 44	4.2	—	—	—
	98.4	98.5	98.7	97.8

TABLE VII

RECOMMENDED FEEDING SCHEDULE

Event	Amount of Seagrass Added (g/m^2)	Week
Preparation for Stocking	60	1
Stocking	—	2
Feeding	60	3
Feeding*	—	4
Feeding	120	5
Feeding*	—	6
Feeding	120	7
Feeding	120	8
Feeding	120	9
Feeding	120	10
Feeding*	120	11
Feeding*	140	12
Feeding*	140	13
Harvesting	—	14

*Actual amount added to the system should be based on activity as indicated by disturbed substrate. Less food is required in grow-out units which have been used for previous crops. This will reduce the average amount added to 87 g/m^2/wk.

TABLE VIII

SPORT FISH CAUGHT ON LUGWORM BAIT NEAR PENSACOLA, FLORIDA

Common Name	Scientific Name
Blue Fin Grouper or Gag	Mycteroperca microlepis
Blue Runner	Caranx crysos
Croaker	Micropogon undulatus
Gray (Mangrove) Snapper	Lutjanus griseus
Marine Catfish	Arius felis
Pigfish	Orthopristis chysopterus
Pinfish	Lagodon rhomboides
Redfish or Channel Bass	Sciaenops ocellata
Rock (Speckled) Hind	Epinephelus drummondhayi
Speckled Trout	Cynoscion nebulosus
Spot	Leiostomus xanthurus
White Grunt	Haemulon plumieri
White (Sand) Trout	Cynoscion arenarius

PART II

MARKET PERSPECTIVE OF LUGWORMS

by

HENRY C. K. CHEN

INTRODUCTION

This report summarizes the analysis and findings of a research survey concerning the market perspective of lugworms, *Arenicola cristata*. It describes the market potential and market behavior of the salt water bait industry in the upper Eastern Coast and the Gulf of Mexico regions and analyzes the economic feasibility of lugworms reared in a commercial bait-worm hatchery.

The analysis presented is a long-run analysis, and the projected rate of return on investment is a conservative estimate of the long term average return on investment. All of the cost data used in this report were collected and estimated locally from Pensacola, Florida. The investigator recognizes that input costs differ from region to region; therefore, it is suggested that a specific feasibility analysis be conducted once the site of a venture plant has been determined. Despite the long run and general nature of this report, the description of market potential and behavior are still valid and the methodology used in the analysis should provide the basic approach for a specific feasibility analysis.

Evaluation Criteria

The evaluation criteria for the economic feasibility analysis of lugworms consist of the study of:

(1) Product analysis
(2) The market analysis
(3) Buyer's acceptance of lugworms as salt water fishing bait
(4) The distributional environment and requirements
(5) Cost/benefit analysis of different marketing plans
(6) Competitive environment
(7) Legal environment
(8) The availability of resources for the production of lugworms

The overall evaluation of the commercialization of lugworms reflects the survey and analytic findings of each variable described above. A minimum acceptance level for cost/benefit, measured by rate of return on investment, has been set at 15% before tax. This criterion has been determined based upon analysis of the bait industry, its associated risk, existing profit level and the market practice within the industry. Acceptance levels of other variables included in this study should also reflect favorable environmental conditions. If the findings of any given criterion do not meet the minimum acceptance level or indicate an unfavorable condition, the whole project will be ruled as economically unfeasible.

DATA AND COLLECTION OF DATA

Lugworms are a new salt water bait in the United States, and as a result, no market information is readily available. Due to the similarity of physical attributes with other types of salt water baits, it is plausible to assume that lugworms may, to some degree, be used as a substitute for other types of salt water baits. This does not imply that lugworms can substitute for all other types of salt water baits. The degree of substitution depends on how closely the physical characteristics of lugworms match a given type of bait and the price of this bait. Analytically, lugworms are very close to bloodworms and sandworms in physical characteristics and price per dozen. Therefore, along with information on other baits, the data on bloodworms and sandworms have been used as proxy data for the analysis of lugworms.

Data related to market, demand, buyer's acceptance, degree of substitution, and price for bloodworms, sandworms, and other salt water baits were gathered from questionnaires through personal interviews, mail, questionnaires and telephone interviews of existing producers of bloodworms, sandworms, and other salt water baits, plus wholesalers, retailers, commercial fishermen and sporting anglers. (Copies of the questionnaires used for this study are in the final project report to Sea Grant.)

Personal interviews, along with telephone interviews, were conducted with producers of bloodworms and sandworms. Although the total number of producers interviewed was only six, their total production accounted for more than 50% of the total production of bloodworms and sandworms in the country. About 100 questionnaires were collected from bait retailers and wholesalers through either personal interviews or mail questionnaires from the upper Eastern Coast and the Gulf of Mexico regions. A number of telephone interviews were also conducted with wholesalers and retailers to verify the data.

Secondary data on the supply of bloodworms and sandworms per year at landing value were collected through government agencies. Cost data were collected on local price basis.

FINDINGS AND ANALYSIS

Product and Market Analysis

Description of Product

Lugworms are a large marine polychaetous annelid which have been popular salt water bait with sporting anglers in Europe, especially in England. The physical characteristics of lugworms and the types of fish frequently caught in field experiments in the Gulf of Mexico area are described in the preceding paper by D'Asaro. A brief description follows:

Color. - Light brown to dark brown.

Weight. - Approximately 65 worms per pound.

Size. - Four to six inches (measured relaxed).

Other. - Easy to handle; can be cut or used whole; can live for three months in fresh salt water without feeding; do not bite, as do other marine worms, but may stain the skin temporarily.

Product Substitution

Since the prices of the popular baits varied according to region, the degree of substitution of lugworms for other types of baits would vary from region to region. Table I describes the average prices of different types of baits at retail value within different market regions.

Other popular baits in the northern areas are ballyhoo and peelers (which can be cut into 12 pieces). The average price for these baits is approximately $1.20 for 12 baits. The prices for popular salt water baits in regions north of North Carolina are on the average higher than prices within the Gulf of Mexico region. This is especially obvious for live shrimp. The retail price of live shrimp in regions north of North Carolina was about $1.75 per dozen, whereas the price in Florida, Louisiana, and Mississippi was approximately $.70 per dozen.* Sales of bloodworms and sandworms were very limited in regions south of South Carolina. The most popular salt water baits in the upper East Coast regions were bloodworms, sandworms, squid and other live baits. The most popular baits in the Gulf of Mexico regions were live shrimp, frozen shrimp, squid, and frozen fish.

Buyer's Perception and Degree of Substitution

Buyer's perception will definitely affect the degree of substitution of lugworms for other types of salt water baits. It is desirable to determine the degree of substitution of lugworms for all other types of salt water baits independent of the price effect and based solely on the similarity of lugworms to other baits with respect to physical characteristics, usage pattern, end use (types of fish that can be caught with

*Data from a survey by the author in 1974.

with lugworms compared to other baits), physical handling, and overall perception. However, it is recognized that the wholesalers, retailers, and sporting anglers interviewed, when responding to questions concerning buyer perception of the product, will inevitably have difficulty separating the price effects from the non-price effects. Nevertheless, the ratings provided by the respondents surveyed should reflect their overall perception regarding the degree of substitution of lugworms for other types of salt water baits. This perception is provided in Table II.

Most buyers considered lugworms an excellent substitute for bloodworms and sandworms as well as a good substitute for shrimp, cut baits and squid.

Therefore, from the aspect of the total product, it can be concluded that lugworms are a good substitute for bloodworms and sandworms, squid, and other types of salt water baits in regions north of North Carolina. However, in the Gulf of Mexico regions, lugworms would be a less competitive substitute for other types of salt water baits due to the low prices of these baits.

Market Size

The current total market size of salt water baits in the Atlantic coastal area and the Gulf of Mexico is not available due to the difficulty in disaggregated sales of shrimp, squid, cut fish and other types of salt water baits by end use of the product (i.e., human consumption or fishing bait). However, the total salt water bait market in these regions was estimated at $131.6 million at retail value in 1970 (U. S. Dept. Interior, 1970:10). The bloodworm and sandworm market, exclusively salt water baits, was approximately seven million dollars at retail in 1974. The landing value and estimated retail value from 1965 to 1974 for these worms are provided in Table III. Although total sales have increased over time, this change is a result of an increase in cost of production from two cents per worm during 1950-1965 to five cents per worm during 1973-1974. The total quantity (in pounds) of bloodworms and sandworms produced remained fairly constant from 1965-1974, and it is expected (according to interviews with producers) that the future supply of bloodworms and sandworms will fluctuate within one to two percent annually.

Market Trend

Demand for all types of salt water bait, especially bloodworms and sandworms, is expected to increase. Ninety percent of the interviewed bait producers, wholesalers, and retailers indicated that the trend in the salt water bait market will increase due to increasing affluence and availability of leisure time of the American consumer. This observation was supported by another survey which revealed that the total number of fishermen in the Atlantic Coastal area and the Gulf of Mexico regions has increased from approximately 8.3 million in 1950 to approximately 13.1 million in 1970 (U. S. Dept. Interior, 1970:91-92). It is plausible to assume that an increase in the number of sporting anglers will definitely increase the demand for salt water baits of all types. Although the total current retail value of salt water baits, other than bloodworms and sandworms, is unknown, it is estimated that the total demand would be at least

15 times the retail value of bloodworms and sandworms (U. S. Dept. Interior, 1970:10).

The demand for bait in different geographical areas (Table IV) varies because of regional differences.

Distribution

The packing, distribution, storage, and shipment of lugworms require special handling due to the unique physical and biological characteristics of the lugworm. Experiments revealed that lugworms are capable of surviving for about 18-24 hours in insulated packages. However, beyond 24 hours, the mortality rate increases significantly, unless the water in the container is renewed. Methods for packing and shipping lugworms are described in the preceding paper.

Due to the packing, shipping and storage requirements, it is apparent that the distribution of lugworms would be an extremely expensive and time consuming task. Therefore, it is suggested that the distribution channel should be as short as possible. The shorter the channel the less the handling and shipping required, and consequently, the lower the distribution cost which would enable lugworms to be more competitive with other types of baits. With this in mind, three alternative distribution channels have been developed (see previous paper):

Alternative I

Producer distributes lugworms to wholesalers by own truck that is equipped with an isolated tank containing a pump that will circulate the fresh salt water.

Alternative II

Producer bypasses wholesalersand distributes lugworms directly to retailers with his own truck. With this alternative, the handling effort and shipping time will be kept at a minimum. The disadvantage of this alternative is that the market will be limited.

Alternative III

Producer ships lugworms to adjacent retailers directly as described in Alternative II. In addition, the producer will ship lugworms to the long distance buyer by air. Air freight and insurance will be charged to the buyer.

The cost and benefit of each alternative are discussed in the next section.

Regardless of the option selected, the common problems in the distribution and storage of lugworms can be categorized as follows:

(1) It is a costly and time consuming effort to ship and handle lugworms.

(2) The trading zone of a producer is limited due to the time factor for the delivery of lugworms.

(3) It may be difficult for a producer to persuade the individual wholesaler or retailer to spend time and effort in handling lugworms.

(4) Because of the storage requirements, it may be difficult for a producer to persuade the individual wholesaler and retailer to install the type of tank required for the storage of lugworms, especially for wholesalers due to the cost of installation of the storage system. The cost of a tank capable of stocking at least 100,000 lugworms is estimated to be approximately $1,000.00

Having recognized these problems, it is suggested that further technical research should be conducted in the packing and shipping of lugworms that will reduce the handling effort and shipping cost, as well as the requirements for storage.

Cost and Benefit Analysis

The cost and benefit analysis discussed below is based upon the three different marketing distribution systems referred to as Alternatives I, II, and III. The cost data used in this analysis are based on local prices (Pensacola, Florida). The analysis represents the long-run average gain for a plant of a given size.

Assumptions

The cost and benefit analysis is based on the following assumptions and conditions:

Plant Capacity. - Six grow-out units, as specified in the preceding technical requirements, are capable of a harvest of 360,000 lugworms at 100% capacity for each crop. Three crops at full capacity are suggested for a year.

Sales. - Assuming that the producer is able to sell all of the crops produced.

Cost Information . - Collected and estimated in the Pensacola region.

Suggested Retail Price of Lugworms. - $1.50 per dozen*

Trade Practice. - Wholesaler markup 40%; Retailer markup 80%.

Cost and Benefits. - Measured in terms of monetary profit.

Profit Analysis. - Conducted from the producer's position as well as wholesaler and retailer's position.

Cost and Benefit Analysis. - Conducted based on three alternative marketing programs:

Alternative I: Distribution: Producer - Wholesaler
Physical Distribution: By producer's own truck
Price: $.65 per dozen C.I.F. (Cost, insur. & fr't pd.)
Trading Zone: 200 mile radius from the producer. Strong coverage within the zone.

Alternative II: Distribution: Producer - Retailer
Physical Distribution: By producer's own specially equipped truck.
Price: $.95 per dozen C.I.F.
Trading Zone: 200 miles radius from producer; (less extensive coverage compared to Alternative 1)

Alternative III: Distribution: Producer - Retailer (Same as Alternative II)
Producer - Retailer/Wholesaler for long distance
Physical Distribution: Short distances - 200 miles, shipped by own truck. Long distances - shipped by air with special packaging.
Price: Short distance - $.95 per dozen C.I.F. Long distance: $.65 per dozen F.O.B., plant.
Trading Zone: Unlimited.

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*Existing trade practice in the bloodworm and sandworm industry revealed that the markup for wholesalers averaged 40% and the markup for retailers averaged 80%. In order to meet the minimum acceptance rate of return on investment of 15%, the producer must sell the lugworms at a price of $.65 per dozen to wholesalers. (See calculations in Appendix I.) By following the existing practice, one can determine that the wholesaler has to sell at a price of at least $.95 per dozen to the retailer. Assuming the retailer's markup is 80%, the retail price will be $.95 + .80 = $1.70 per dozen. However, due to the relatively low mortality rate and homogeneous size of lugworms, it is suggested that the retail price of lugworms per dozen should be set at $1.50. This price is lower than the existing price per dozen of bloodworms and sandworms. The existing producer's selling price averaged $.72 per dozen and the wholesale price was $1.00-$1.20 per dozen.

A detailed analysis and calculation of profit and loss for each alternative for producer, wholesaler and retailer is attached in Appendix I. Results of the analysis for different alternatives are summarized as follows.

Cost of Production

The calculation of cost of production is based on the production capacity of six tanks producing at 100% capacity with three crops a year. The total gross production in a year will be 1,080,000 lugworms. Taking into consideration the mortality rate of lugworms in handling and inventory, the net production available for sales is around 81,600 dozen. The unit cost of production is estimated at $.30 per dozen. The cost of production represents the optimum cost at the suggested capacity. However, if an additional tank should be added to the production line, the cost of production per dozen will be decreased slightly. The cost of production at different scales is not calculated in this study.

Operating Costs for Producer, Wholesaler and Retailer

Operating costs for producer, wholesaler and retailer are estimated at local prices. The operating costs include the administration cost, shipping and packing costs and other overhead not directly involved in production but essential for the venture. Detailed items are presented in Appendix I.

Overall Cost and Benefit Analysis

The overall profit and loss analyses are evaluated based on the three alternative marketing plans mentioned above. Detailed calculations of profit and loss statements, capital requirements and rate of return on investment are presented in Appendix I.

Profit and Loss Analysis of Alternative I

Producer.- Assuming that a producer is able to sell the total production to the wholesaler at $.65 per dozen, the annual profit before tax is estimated at $12,830, and the rate of return on the investment is approximately 19%. The total capital requirement is estimated at $67,615 while the breakeven point is estimated at $28,677, or 44,118 dozen.

Wholesaler. - The operating expense under this alternative is estimated at $12,500. The breakeven quantity is 41,667 dozen.

Retailer. - The costs of operating and handling of lugworms are negligible. If the retailer is able to sell lugworms at $1.50 per dozen, the profit margin of the retailer is about 40%, or approximately a 70% markup which is considered compatible with the existing trade margin of other types of salt water baits.

Alternative I is considered economically feasible for producer, wholesaler, and retailer.

Profit and Loss Analysis of Alternative II

Producer. - The cost of production per dozen remains the same as alternative I: $.30 per dozen. The operating costs will be higher compared with Alternative I. The selling price to retailers will also be higher at $.95 per dozen. The net profit (annual) for producers is estimated around $15,210, and the rate of return on investment is approximately 19% before taxes. The capital requirements are estimated at $78,415 while the breakeven point under this option is 42,731 dozen or approximately $40,595.

Wholesaler. - Since the wholesaler is bypassed under this alternative, no discussion will be made.

Retailer. - The retailer purchases lugworms at $.95 per dozen and sells at the suggested retail price of $1.50 - $1.75 per dozen.

The markup is about 80%, or the trade margin about 40%. This would be considered a profitable investment.

Alternative II is considered economically feasible for both producer and retailer.

Profit and Loss Analysis of Alternative III

Producer. - Under this alternative, the producer sells all the products to retailers or wholesalers. The annual profit before tax is estimated at $15,210-$16,505, and the rate of return on investment before tax is approximately 19-24%. The capital requirement is estimated at $67,615 (same as Alternative I).

Wholesaler. - The breakeven point of a wholesaler, within a 200 mile radius from the producer, is the same as Alternative I. If the wholesaler purchases lugworms by air freight, the cost of shipping and packing would be prohibitively high. Unless the wholesaler is able to sell lugworms to retailers at a minimum of $1.10 per dozen, the wholesaler is not likely to make a profit. Due to price competition of other types of salt water baits, it is improbable that the wholesaler will be able to sell to retailers at a price of $1.10 per dozen. Therefore, based on the cost and benefit criterion alone, it is not economically feasible if the buyer is a wholesaler.

Retailer. - Under this alternative, if the retailer purchases lugworms at $.95 per dozen, freight paid, the profit margin is the same as Alternatives I and II. If the retailer purchases them at $.65 per dozen C.I.F. and ships lugworms by air, the retailer's profit margin will be the same as Alternative I and II provided the minimum size of a retail order is 69 dozen. The retailer's markup will be 80% or a trade margin of 40%. However, if the order size is greater than 69 dozen, the retailer will be better off as compared with Alternative I and II, provided the retailer is able to sell lugworms at a retail price of $1.50 per dozen or more.

Alternative III is economically feasible for the producer but not the wholesaler. The alternative will be considered economically feasible for a retailer if the retailer: (1) purchases the lugworms locally at C.I.F. prices, or (2) purchases from long distance by F.O.B. air freight prepaid at an order size equal to or greater than 69 dozen.

Buyer's Acceptance

Buyer's acceptance of a product is of primary importance to the marketability of a given product. It is generally agreed that buyer's acceptance is the result of the buyer's perception of the product, price, prices of substitutes, the end use of the product, produce appearance, and the handling requirements. Results of the survey and analysis of buyer's acceptance of salt water baits revealed bloodworms and sandworms enjoyed a favorable buyer's acceptance among all wholesalers, retailers, and sporting anglers. The only reservations were their high prices (average price ranged from $1.80 to $2.20 per dozen) and the high mortality rate as a result of their susceptibility to heat and hot weather which resulted in storage problems at the wholesale and retailer level. The sporting angler also complained about the high mortality rate in storage.

Commercial fishermen, producers, wholesalers, retailers, and sporting anglers were interviewed concerning their willingness to try lugworms, and their attitude toward the lugworm as a substitute for other types of salt water baits. Their responses follow.

Commercial Fishermen

All of the hand-line commercial fishermen responded that it was not pratical to use lugworms for commercial fishing because of the high price. They also considered it impractical since the worms would not reamin confined within the trap. Today most commercial fishermen use cut bait. or scraps of fish as bait. The most popular deep sea fishing baits used in the Gulf Coast regions were skipjack, mackerel, and cigar minnow. The prices for these baits were $.19 per pound for skipjack, $.35 for mackerel, and $.40 for cigar minnow. Lugworms must be sole for at least $2.50 per pound (with about 65 lugworms per pound) to generate the minimum level of profit of 15% return on investment before taxes. Therefore, based on the price aspect alone, it is not economically feasible for commercial fishermen to use lugworms as deep sea fishing bait. The fishermen interviewed indicated that unless the price of lugworms were compatible with the price of existing baits and unless the lugworms have been proven successful in catching most types of deep sea fish, they would not be willing to risk trying lugworms as bait.

Wholesalers and Retailers

Due to the favorable response toward bloodworms and sandworms from the sporting anglers, wholesalers and retailers are forced to carry these items. Most of the wholesalers and retailers interviewed stated that they did not make money on bloodworms and sandworms because of the high mortality rate in handling and storage, and because of the practice of giving fourteen or more for a dozen purchase. They considered carrying bloodworms and sandworms a necessary evil and expressed the opinion that if the lugworms have the same end use and the price is compatible to bloodworms and sandworms, but have a low mortality rate, then they would be more than willing to carry and promote this new bait. Of 98 wholesalers and retailers interviewed, 43% indicated that they would definitely carry lugworms, 45% indicated that they would try to promote it, and only 9% indicated that they definitely would not try them.

The general feelings of those who indicated that they would definitely carry lugworms may be summarized by the representative response: "Definitely would carry the lugworm due to the lugworm's durable characteristics, and if the price was competitive, and if the characteristics of the lugworm are proven."

The general feelings of those who indicated that they might carry lugworms are summarized as follows: "Might carry the lugworm if the price was competitive and if a promotion campaign was carried out to educate the market; another consideration was the concern toward shipping time and cost of the lugworm, and if the product would receive notice through various sources. . . advertisement, publicity . . ."

The general feelings of those who indicated that they would definitely not carry lugworms are summarized as follows: "Would not carry due to the competition of other baits and the effort involved with a new product; and due to the difficulty of customer acceptance of a new product."

Sporting Anglers

All of the sporting anglers interviewed indicated that they were indifferent to the type of bait as long as the new bait could catch fish. They are willing to buy it even at a slightly higher price. The color, packing, and handling of the bait was not important to them. In general, sporting anglers indicated that they were willing to try lugworms if the lugworm was available on the market.

Availability of Resources and Legal Environments

The resource requirements for the production of lugworms include land, feeding, labor, sea water, and material for the construction of a lugworm hatchery. Research indicates that these resources are readily available. Salt water can be acquired by using artical sea salt; feed for lugworms are readidly available on many beach shore areas near sea-grass beds. Construction material for the hatchery ponds and annexes are also readily available. Since the rearing of lugworms does not require skilled labor, the manpower is available in abundance. Shortage of the resources mentioned above is not likely in the foreseeable future.

In general, there are no legal constraints on the construction of lugworm hatcheries and the rearing of lugworms. The only legal environmental requirements involve the disposal of the waste water.

Economic Feasibility of the Lugworm Venture

As previously discussed, the use of lugworms by commercial fishermen is not economically feasible due to the high price of lugworms compared to existing baits, and negative product acceptance expressed by the commercial fishermen interviewed.

However for sport fishing, lugworms have the same or superior characteristics compared to existing salt water baits, and a lower mortality rate compared with the most popular baits (i.e., bloodworms and sandworms). Lugworms have proven successful in catching estuarine and marine fish of many types. Eighty-five percent of the respondents surveyed in this project considered lugworms a superior product and felt that from the aspects of characteristics and quality, they would be a good substitute for shrimp, squid, and cut baits; and an excellent substitute for bloodworms and sandworms. However, the prices of the most popular substitute salt water baits in regions south of North Carolina are relatively low (Table V).

Since the suggested retail price of lugworms is $1.50 per dozen (24 cuts of bait), it would be difficult to effectively compete with other types of salt water bait in these regions; and because of the higher retail price of lugworms, sporting anglers might be hesitant to try lugworms. Therefore, from price and competition aspects, marketing lugworms in regions south of North Carolina is not economically feasible at this time. However, due to angler and dealer enthusiasm and willingness to try this product, a mini-market test may be a desirable alternative at this time.

However, in regions north of North Carolina most of the salt water baits are sold at relatively higher prices (Table VI). From the price and substitution aspects, it is apparent that lugworms have a competitive edge over other salt water baits in regions north of North Carolina.

An analysis of the demand for different types of salt water baits indicated a strong demand for bloodworms and sandworms, about seven million dollars a year, followed by squid, frozen bait and live cut bait. Based upon the combined findings related to the physical characteristics, price, market, demand, competition and substitution, as well as the user and distributor's favorable reactions to the product, I conclude that the introduction of lugworms in markets north of North Carolina would be feasible. For producers and retailers, each of the three marketing alternatives is economically feasible. The rate of return on investment before tax for the producer, for each alternative, is estimated at 19% or more (for Alternative III) which is higher than the existing profit margin of the bait producer. The profit margin for the retailer is estimated compatible or higher than the existing industry profit margin. At the wholesaler level, Alternative III would not be considered economically feasible.

The cost and benefit analysis of each marketing alternative is based on the assumption that the producer is able to sell all of the available lugworms produced at the suggested capacity (i.e., six ponds* and three crops a year). The pivotal problem is whether the producer is able to sell all of the crop at the suggested price(s) - that is $122,400 (81,600 dozen X $1.50/dz.). One way to determine whether a producer is able to sell $122,400 is to compare this figure to the total market of bloodworms and sandworms. The $122,400 represents only about 1.75% of the total market of bloodworms and sandworms, approximately seven million dollars a year. However, it is reasonable to assume that lugworms can substitute for a small portion of other salt water baits in regions north of North Carolina. The total current retail value of these baits is unknown; however, it was known that the total salt water bait in the Atlantic Coastal area was approximately $84 million at retail value in 1970, which would represent at least 15 times the retail value of the bloodworm and sandworm market.** Based on this demand estimate, it is apparent that the required market share for lugworms at the suggested price would be less than one percent of the total salt water bait market.

The above market share estimate was calculated based upon the total market size in regions north of North Carolina. However, due to the distributional requirements and shipping method for lugworms, the trading zone of a producer would be limited to a 200 mile radius. Therefore, one has to look into the total market size and demand trend of bloodworms and sandworms, along with other salt water baits within that given trading zone, and compare the profitable amount of sales, $122,400, with the market of salt water baits within the producer's trading zone. The subregional demand of salt water baits is not readily available. However, it is apparent that a radius of 200 miles would cover a 400 mile strip. The distance from Augusta, Maine to Norfolk, Virginia is approximately 750 miles. If one assumed that the demand for salt water baits within this region is homogeneous, then the demand within a 400 mile strip would be estimated at approximately 50% of the total demand in the regions north of North Carolina, and the required market share for the suggested level of profit for a producer would be double that calculated in the previous section, about 1% of the total market of the trading zone. Even if the market demand in regions north of North Carolina is not homogeneous, a producer may select a site that would cover a 200 mile radius with a demand over 50% of the total demand within the regions north of North Carolina. Based on the

*For the cultivation of adult worms - grow out unit

**1970 National Survey of Fishing and Hunting, O. P. Cit., p. 10. The total salt water bait market in the Atlantic Coastal area was estimated at $84 million in retail value in 1970, and the retail value of bloodworms and sandworms sold in the same year was approximately $5.5 million. If the ratio between all other salt water vaits and bloodworms/sandworms would hold over time, which is very likely, then the retail value of all other baits would be estimated at least 15 times the retail value of the bloodworms and sandworms.

superior product characteristics of lugworms, competitive price and the favorable buyer's acceptance of lugworms, the required producer's market share of less than one percent should be obtainable. Of course, the ability of the producer to sell all of the crops produced depends upon the contacts of the individual investors, and his past experience in the bait industry.

Since the cost structure and the market potential vary from region to region, it is suggested that a detailed regional feasibility analysis be conducted once the site of a lugworm hatchery is selected.

Distribution and Storage of Lugworms

It is concluded that the lugworm venture is economically feasible in regions north of North Carolina based on the market potential, degree of substitution, competition, buyer's acceptance and cost and benefit aspects under different marketing distributional systems. However, the distribution of lugworms from producer to wholesaler and from wholesaler to retailer, although workable, prohibits the large scale commercialization of lugworms, because of their perishable nature. As mentioned earlier, lugworms require special packing and timely delivery as well as special storage tanks for lugworm inventory. To overcome this difficulty, it is suggested that the producer and wholesaler deliver lugworms directly to retailers by specially equipped trucks. This delivery method will enable the producer or wholesaler to control the delivery time and consequently minimize the mortality rate.

Concerning storage of inventory, it is suggested that under the best conditions lugworms should be kept in ponds or tanks with circulated fresh salt water. This type of storage tank could be installed not only for the producer but also for the wholesaler and retailer. Small scale storage tanks require a biological filter, a water pump, and natural or artifical sea water. The cost of a system capable of stocking 1,000 lugworms (suggested size for a retailer) is estimated at about $100. The cost of the similar storage system for a wholesaler is estimated at $1,000. The tank is capable of storing 100,000 worms. For the producer, the investment of a storage unit is included in the initial capital requirements. In addition to the storage tank, a wholesaler must purchase a specially equipped delivery truck. The reader should realize the justification of why the distributional and storage requirements of lugworms impose a serious problem for the lugworm venture.

Although marketing of lugworms is economically feasible regardless of the distribution system selected, there are some reservations. In the case of Alternative I, it can be expected that the individual wholesaler may not be willing to invest approximately $1,000 for the installation of the storage system and $6,000 for a specially equipped delivery truck for a new product that has not yet been accepted by the sporting anglers. Therefore, despite its economic feasibility, Alternative I may not be operationally feasible from the practical standpoint. In the case of Alternatives II and III, the only distributional requirement for the producer is to install the storage system and purchase the specially equipped delivery truck.

Since the study projected an attractive profit and rate of return and revealed favorable conditions for all other variables relevant to the lugworm venture, it is concluded that Alternatives II and III are both economically and operationally feasible.

Summary

Tables VII and VIII provide a quick review of the overall analysis and findings of the study. Due to the average lower prices of all types of salt water baits in regions south of North Carolina, it is economically unfeasible to market lugworms in these regions. However, the introduction of lugworms on a small scale test market basis may be the desirable approach at this time.

It is economically feasible to market lugworms in regions north of North Carolina for the following reasons:

(1) Lugworms enjoyed a favorable price advantage over other types of salt water baits in these regions.

(2) It was found that all three marketing alternatives are economically feasible for the producer and retailer; however, from the wholesaler's viewpoint, Alternative III is considered economically unfeasible.

(3) The rate of return on investment for Alternatives I and II for the producer is approximately 19% before tax; and the rate of return on investment for Alternative III for the producer is estimated at 19-24% before tax. The margin for the retailer for all alternatives is approximately 40%.

(4) The market potential in these regions is strong and the trend is expected to increase over time. Buyer acceptance of lugworms was very favorable; and there were no legal constraints that would inhibit the commercial venture of lugworms. The resources for the production of lugworms are in ample supply and no shortages of these resources are predicted in the foreseeable future.

Although it was found that each of the three marketing alternatives is economically feasible, it may be difficult for the producer to persuade the wholesaler or the retailer to install the storage system, especially for the wholesaler, due to the storage and associated handling requirements and the investment committed. Therefore, it is concluded that Alternative I, though economically feasible, may not be operationally feasible. Alternatives II and III, in all probability, are both economically and operationally feasible. Therefore, it is recommended that the interested investor should give major consideration to these two alternatives.

The projected profit and loss for each alternative was analyzed based upon conservative estimates of the mortality rate in handling and inventory; and the suggested selling price of \$.65 per dozen and \$.95 per dozen of lugworms resulted in a rate of return on investment of 19% or more for the producer. However, if the producer is willing to accept a rate of return on investment lower than 19%, the selling price may be below the suggested price which will make lugworms more competitive with other types of salt water baits and increase the economic feasibility of the commercialization of lugworms.

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TABLE I

AVERAGE PRICES OF MAJOR SALT WATER BAITS BY REGIONS

Region	Live Shrimp/ Dz.	Frozen Shrimp/ Lb.	Frozen Bait/ Dz.	Bloodworms/ Dz.	Sandworms/ Dz.	Squid/ ½ Lb.
Maine, N. H., Del., Mass.	$1.00	$1.50	$1.00	$1.80	$1.30	$1.25
N. J., Conn.	-	$1.30	-	$1.70	$1.80	$1.25
N. Y., Penn.	$2.00	$1.75	$1.25	$1.72	$1.68	$1.12
N. Y., Vir., D. C.	$1.50	$2.20	$1.15	$2.00	$1.50	$1.23
N. C., S. C.[1]	-	-	-	-	-	-
Ga., Fla.	$ .68	$1.30	$ .62	-	-	$1.00
Miss., La. Ala.	$ .75	-	$ .35	-	-	$ .65

[1]Too few data collected to include

TABLE II

OVERALL RATING OF LUGWORMS AS SUBSTITUTES FOR OTHER BAITS.
(SCALE: 0-4, WITH HIGHER SCORE REFLECTING HIGHER SUBSTITUTION.)

Types of Bait	Degree of Substitution[1]	N.H., Del., Mass., N.J., Vir., Conn., N.Y., D.C., Penn.	Miss., Ala., Fla., La. Ga.
Live Shrimp	Good	2.0	2.9
Frozen Shrimp	Good	1.5	2.5
Bloodworms	Excellent	3.5	-
Sandworms	Excellent	3.5	-
Frozen Fish (Bait)	Fair	1.7	2.4
Live Cut Bait	Good	2.2	3.0
Squid	Good	2.2	2.5
Other Live Bait	Good		

[1]In verbal description

TABLE III

LANDING VALUE AND ESTIMATED RETAIL VALUE
OF BLOODWORMS AND SANDWORMS
(1965-1974) [1]

Year	Landing Value		Estimated Retail Value		Estimated Total Retail Value
	Bloodworms	Sandworms	Bloodworms	Sandworms	
1965	$ 759,582	$447,341	$2,278,000	$1,342,000	$3,620,000
1966	$ 731,335	$509,018	$2,194,000	$1,527,000	$3,721,000
1967	$ 834,826	$492,384	$2,504,000	$1,477,000	$3,981,000
1968	$1,049,581	$533,358	$3,149,000	$1,572,000	$4,721,000
1969	$ 999,787	$523,826	$2,999,000	$1,600,000	$4,599,000
1970	$1,215,474	$621,471	$3,646,000	$1,864,000	$4,410,000
1971	$1,381,676	$674,296	$4,145,000	$2,023,000	$6,168,000
1972	$1,162,208	$556,504	$3,467,000	$1,670,000	$5,137,000
1973	$1,492,234	$888,009	$4,478,000	$2,664,000	$7,142,000
1974	$1,384,386	$839,357	$4,153,000	$2,518,000	$6,671,000

[1] Landing value source: Department of Marine Resources Statistics, State of Maine, Booth Bay Research Center. Retail value is calculated by multiplying three times the landing value.

TABLE IV. DEMAND OF SALT WATER BAIT BY REGIONS

Regions	Live Shrimp	Frozen Shrimp	Cutbait	Frozen Bait	Bloodworms	Sandworms	Squid
Maine, N. H. Del., Mass.	L	L	MH	MH	H	H	H
N.J., Conn.	L	L	MH	-	H	H	H
Penn., N.Y., Vir., D.C.	L	L	MH	MH	H	H	H
Fla., Ga.	H	MH	L	MH	-	-	M
Miss., La., Ala.	H	MH	L	MH	-	-	M

(Scale: L=Low; M=Medium; MH=Medium High; H=High)

TABLE V. AVERAGE BAIT PRICES IN REGIONS SOUTH OF NORTH CAROLINA[1]

	Lugworms	Live Shrimp	Frozen Shrimp	Frozen Bait	Squid	Others
Price per dozen	$1.50	$.70	$.39	$.50	$.85	$1.00
No. of baits	24 baits	12 cut	12 cut	12 cut	24 baits	12 cut
Unit Price[2]	$.063	$.058	$.033	$.042	$.035	$.083

[1]Bloodworms or sandworms are not used as bait.
[2]To compare the prices of different types of baits measured in various units, such as pound, box, dozen, pieces (as in live fish), the investigator has covered all these measurements into one comparable dimension. The common dimension is the number of cuts per different measurement. For instance, lugworms, bloodworms, and sandworms can be cut into two pieces for each worm, therefore, one dozen worms can be used as 24 fishing baits. One half pound of squid can be cut into 24 cuts; also, other live baits such as ballyhoo can be cut into 12 pieces. Prices of different types of bait are compared on the single bait basis.

TABLE VI. AVERAGE BAIT PRICES IN REGIONS NORTH OF NORTH CAROLINA[1]

	Lugworm	Live Shrimp	Frozen Shrimp	Frozen Bait	Bloodworms	Sandworms	Squid	Other Live Bait[2]
Price per dozen	$1.50	$1.50	$.64	$1.15	$1.60	$1.25	$1.20($\frac{1}{2}$ doz)	$1.00
No. of baits	24 baits	12 cut	12 cut	12 or 36 cut	24 cut	24 cut	24 cut	12 cut
Unit Price[3]	$.063	$.125	$.053	$.096 or $.032	$.067	$.052	$.05	$.083

[1]Includes the states Maine, New Hampshire, Delaware, Massachusetts, New Jersey, New York, Virginia, D. C., North Carolina, Connecticut, and Maryland
[2]Ballyhoo, peeler.
[3]Refer to footnote 2, Table V.

TABLE VII

REVIEW OF OVERALL FINDINGS
IN REGIONS NORTH OF NORTH CAROLINA[1]

		Alternative I	Alternative II	Alternative III
Product Substitution	Physical Attributes	VG	VG	VG
	Degree of Substitution - Price Aspect	G	G	G
	Degree of Substitution - Other Product Aspect	VG	VG	VG
Market	Market Size	VG	VG	VG
	Trend	G	G	G
	Potential	G	G	VG
	Price	G	G	G
Buyer's Acceptance	Commercial Fishermen	NA	NA	NA
	Wholesaler	G	G	G
	Retailer	G	G	G
	Anglers	G	G	G
Dis-tributional Environment	Commercial Fishermen	NA	NA	NA
	Producer	VG	VG	G
	Wholesaler	M	-	NA
	Retailer	G	G	G
Cost/ Benefit	Producer	19% R.O.I.	19% R.O.I.	19%-24%
	Wholesaler	M	-	-
	Retailer	70% Markup	70% Markup	70% Markup or more
	Capital Requirements	$67,615	$78,415	$67,615
	Legal Aspect	G	G	G
Availability of Resources	Present	E	E	E
	Trend	E	E	E

[1]Scale: Excellent (E), Very Good (VG), Good (G), Marginal (M), Not Acceptable (NA).

TABLE VIII

REVIEW OF OVERALL FINDINGS IN REGIONS SOUTH OF NORTH CAROLINA[1]

		Alternative I	Alternative II	Alternative III
Product Substitution	Physical Attributes	VG	VG	VG
	Degree of Substitution - Price Aspect	M	M	M
	Degree of Substitution - Other Product Aspect	VG	VG	VG
Market	Market Size	G	G	G
	Trend	G	G	G
	Potential	G	G	VG
	Price	M	M	M
Buyer's Acceptance	Commercial Fishermen	NA	NA	NA
	Wholesaler	G	G	G
	Retailer	G	G	G
	Anglers	G	G	G
Dis-tributional Environment	Commercial Fishermen	NA	NA	NA
	Producer	G	G	G
	Wholesaler	NA	-	NA
	Retailer	G	G	G
Cost/Benefit	Producer	Not Been Calculated		
	Wholesaler			
	Retailer			
	Capital Requirements	-	-	-
	Legal Aspect	G	G	G
	Availability of Resources — Present	E	E	E
	Availability of Resources — Trend	E	E	E

[1] Scale: Excellent (E), Very Good (VG), Good (G), Marginal (M), Not Acceptable (NA).

APPENDIX I

COST AND BENEFIT ANALYSIS

I. Production Schedule and Capacity

Demand for bloodworms and sandworms is seasonal; the season starts around March and levels off around November. The peak season is during April to October, and demand during the peak season is about 200,000 - 300,000 worms per week.[1] Based on the above information, it is our suggestion that the production schedule of three crops (six tanks) should be set as follows:

A. Production Schedule: Three crops a year

Date	Production Capacity	Total Gross Production (Unit)
12/1-3/1	100%	360,000
3/5-6/5	100%	360,000
6/10-9/10	100%	360,000
		1,080,000
Subtract 5% handling loss		54,000[2]
		1,026,000

[1]Source: Mr. Flye of Maine Bait Company - 10% of total bloodworm and sandworm market.

[2]The 5% loss represents a conservative estimate. Laboratory experiments revealed that the actual handling loss was about 1.4% Source: Dr. C.N. D'Asaro.

B. Inventory Schedule and Loss (Estimated): 2.5% Loss per Week[3]

Week	Estimated Sales	On Stock	Estimated Loss
1st	100,000	260,000	0
2nd	70,000	190,000	6,500
3rd	70,000	120,000	4,750
4th	60,000	60,000	3,000
5th	60,000	0	1,500
			15,750

Three crops: The total inventory loss for a year will be 15,750 X 3 = 47,000.

C. Net Lugworms Available for Sales in a Year (Three crops at full capacity)

1,026,000
47,000

979,000 or approximately equal to 81,600 dozens

II. Cost of Production: Per Year - Three Crops

A. Cost of material - Food $ 1,460

B. Cost of Direct Labor $ 10,000

(Manager: $10,000/year; 2/3 time in production
One Helper and Driver: $9,000/year; 1/3 time in production.)

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[3]The 2.5% loss represents a conservative estimate. Laboratory experiments revealed that the actual inventory loss was about 1.4% per week.

C. Overhead

Electricity	$ 800	
Chemicals	$ 150	
Depreciation	$ 4,825	
Land (imputed)	$ 4,800	
Maintenance	$ 1,500	
Administration and Miscellaneous	$ 1,000	$ 13,075
TOTAL		$ 24,535

D. Cost/Dozen: $24,535/81,600 dozen = $ .30

E. Other Considerations: This estimate is based on three crops at full capacity (six production ponds). However, the cost of production per dozen will be lower if two additional production tanks are added. It is possible to add one more tank without significantly increasing any fixed cost and the variable cost (food). At the present time, the cost of the closest substitute for lugworms, the bloodworm and sandworm, is about $ .60 per dozen.[4]

III. Overall Profit and Loss Analysis

The profit and loss of this project will be used to measure the cost/benefit of the venture. Profit and loss analysis should be based on different marketing programs. Due to extremely high shipping and handling cost of lugworms, the following three alternative marketing programs are suggested in distributing this product.

A. Alternative I - Option I

Lugworms will be distributed to wholesalers by producers trucks: wholesalers will distribute lugworms to retailers by truck or other means of transportation.

Advantages:

1. The producer, by using wholesalers, is able to penetrate his market more extensively within his trading zone.
2. The producer is able to control the delivery time to wholesalers.

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[4]Diggers are paid five cents per worm, and it is expected that the price paid to the digger will be increased by one cent per worm in the future.

3. This option will foster better relationships between producer and wholesaler.

<u>Disadvantages:</u>

1. The final consumer has to bear the shipping cost twice - from producer to wholesaler and from wholesaler to retailer.

2. There is a limited trading zone. It is expected that the driver has to make some preliminary preparation, such as packing worms, route study, and soliciting customers; consequently, the actual driving time available for a day is estimated at about four to five hours or within 200 miles. Therefore, the trading zone under this alternative is estimated within 200 miles radius from the hatchery plant.

3. The individual wholesaler may not be willing to buy trucks and spend most of his time and effort in delivering this product to retailers.

B. <u>Alternative II</u> - <u>Option II</u>

Producer bypasses wholesaler and delivers lugworms directly to retailers or wholesalers.

<u>Advantages:</u>

1. This option eliminates the duplication of shipping charges, from producer to wholesaler and from wholesaler to retailers; consequently, the retail price will be more competitive and lower.

2. This option also reduces the amount of handling and, consequently, reduces the mortality rate.

3. The producer is able to control channel and delivery time, which will improve the seller and buyer's relationship.

<u>Disadvantages:</u>

1. The producer will spend too much time and effort involved in the delivery of lugworms.

2. The market coverage is much smaller when compared to Option I. The coverage is about a 200 mile radius, but will be less intensively covered due to the loss of service from wholesalers.

3. This option involves higher shipping cost; the average order size is about 20-50 dozen per order (average 30 dozen per order).

4. In order to reduce the cost of distribution, the plant has to be constructed near the retailer market. As a result, the land and other costs will be higher.

5. This option may result in a conflict between the interest of the wholesaler and the producer.

C. Alternative III - Option III

1. Producer delivers lugworms to retailers within 200 miles by owned truck and ships long-haul out-of-town to retailers or wholesalers by air freight (lugworms have to be delivered to retailers within 18 hours, water to water).

2. Price charged to retailer - $ .95 per dozen C.I.F. Price charged to wholesaler or retailers (out-of-town) $ .65 per dozen F.O.B. plant.

Advantages: a. This option has the same advantage as Option I.

b. The producer is able to widen the market trading zone - shipping by air to out-of-town wholesalers or retailers.

D. Profit and Loss Analysis of Alternative I

1. Pro Forma Statement (Annual) for Producer

a. Net Sales: 81,600 dozen X Price per Dozen

		$.55/dz.	$.60/dz.	$.65/dz.	$.70/dz.
All Prices are C.I.F.		$44,880	$48,960	$53,040	$57,120
b. Cost of Goods Sold		$24,535	$24,535	$24,535	$24,535
c. Gross Profit on Sales		$20,345	$24,425	$28,505	$32,585
d. Operating Expenses:					
Salary	$9,000[5]				
Packing	500				
Gasoline	2,000				
Postage	500				
Depreciation	675				
Travel	1,000				
Maintenance	1,000				
Miscellaneous	1,000				
Total		$15,675	$15,675	$15,675	$15,675

[5]Salary: Manager - 1/3 time; Helper/Driver - 2/3 time in administration.

e.	Net Profit before Tax:	4,670	8,750	12,830	16,910
f.	Breakeven Quantity:[6]	62,500/ Dozen	51,725/ Dozen	44,118/ Dozen	38,462 Dozen
g.	Rate of Return on Investment:[7]	.069%	13.1%	19.0%	25.0+%

2. <u>Capital Requirement and Rate of Return on Investment</u>

Capital requirement under Alternative I will consist of the initial capital investment, working capital, and the average inventory cost.

a. The Initial Investment Requirement [8] $50,540

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[6]Breakeven quantity is calculated on the formula:

$$\frac{\text{Total Fixed Cost}}{\underset{\text{(In Dozen)}}{\text{Unit Price}} - \underset{\text{(In Dozen)}}{\text{Unit Variable Cost}}}$$

Unit Variable Cost (in Dozen) = Production Cost.

[7]Rate of return on investment is calculated based on the net profit, at different price levels, divided by the total capital requirement for the venture. That is, R.O.I. = Net Profit/Total Capital Requirement.

[8]Data provided by Dr. Charles D'Asaro in 1974; revised to $54,230.00 in 1975.

b. Working Capital Requirements[9]

Working Capital Required for Operating Expenses $6,125
(Five months of operating expenses)

[9]It is assumed that the producer will not receive any cash during the first five months (three months for production, and two months on sales on accounts receivable). Existing trade practice is not/60 days. Therefore, the producer requires a working capital for operating expenses for the first five months. The working capital requirements for operating expenses is calculated below:

Salary	5/12 of $9,000	$3,750
*Gasoline	1/3 Of $2,000	666
*Packing Material	1/3 of $ 500	166
*Postage and Shipping	1/3 of $ 500	166
*Traveling	1/3 of $1,000	333
Maintenance	5/12 of $1,000	417
Miscellaneous	5/12 of Annual Expense or 5/12 of $1,500	625
Total Working Capital of Operating Expenses		$6,125

*During the first five months, the producer will deliver only one crop because the second crop is not ready. Therefore, only one-third of the annual packing, postage, traveling expenses and gasoline will be needed.

Working capital required for production is 1 2/3 crops with the exception of depreciation because the depreciation represents a non-cash flow account. Also, if the rent expenses are imputed, then there will be no cash flow involved. Therefore, the imputed rent value should be excluded from the calculation of cost of production. The working capital required for production is:

($25,210 - $5,500) ÷ 3 = $6,570 for one production cycle. Two months = 2/3 of one production cycle - 2/3 X $6,570 = $4,380. Total working capital requirement for production is $6,570 + $4,380 = $10,950.

Total working capital requirement for Option 1: $6,125 + $10,950 = $17,075.

Working Capital Required for Production	$10,950	
(One and two-thirds production cycle for raw material and other cost of production - depreciation is excluded.)		$17,075
c. Average Inventory: Explicitly included in the working capital requirement.		-
d. Total Capital Requirement for Option 1		-
		$67,615

3. Profit and Loss Analysis - For Wholesaler

In order to distribute the lugworms to retailers within a wholesaler's trading zone, the wholesaler has to purchase a truck and hire a driver to deliver this product. Therefore, the distribution cost of this venture is estimated as follows:

Operating Cost for Distributing Lugworms (Annual Base)

Truck Driver	$ 9,000
Gasoline	2,000
Traveling and Other (Insurance and Maintenance)	1,500
	$12,500

If the wholesale price is set at $.95 per dozen and the producer's price is set at $.65 per dozen, then the breakeven quantity, in dozen, for a wholesaler will be:

Breakeven Quantity (Dz.) = $12,500/ ($.95 - .65) = 41,667 dozen

The feasibility of this venture for a wholesaler will depend upon market size in the wholesaler's trading zone, and the wholesaler's willingness to invest his time and money in such a venture.

4. Profit and Loss Analysis - For Retailer

In general, the retailer will make an attractive rate of return on investment. The purchase price, or the cost of goods sold, is estimated at $.95 per dozen and this suggested that the selling price would be at $1.50 per dozen. The operating expenses are negligible in connection with the distribution of lugworms. Therefore, the gross margin is about 40% which is compatible with the existing trade margin of salt water baits.[10]

[10] The existing trading margin of bloodworms and sandworms for retailers is about 40%

E. Profit and Loss Analysis of Alternative II

1. Pro Forma Statement (Annual) for Producer

a.	Gross sales: 81,600 dozen X $.95	$77,520	
	Less allowance for quantity discount	10,000	
			$67,520
b.	Cost of Goods Sold		24,535
c.	Gross Profit on Sale		$42,985
d.	Operating Expenses		
	(1) Same setup as Option I	$15,675	
	(2) Additional Expenses[11]	12,100	
			$27,775
e.	Net Profit Before Tax		$15,210

[11] Assuming that the producer can sell the full crops, 81,600 dozen, in any given year given that the average order size for retailer is about 20-50 dozen per order (findings from questionnaires and telephone interviews with existing producers and wholesalers as well as retailers), the delivery time during March and November will be 50% delivery time of the peak months. Therefore, the total peak season delivery time equivalence is eight months. The total number of shipments per year will be:

> 81,600 dozen/30 dozen (per order) = 2,720 times average monthly delivery = 2,720/8 peak seasons equivalence months = 340. Average daily delivery = 340/25 working days per month = 14.

It is reasonable to believe that 14 deliveries for a driver is too heavy a work load; therefore, it is suggested that a second driver be hired for the additional truck. The costs associated with the second driver and the truck are estimated as follows:

Additional Expenses Incurred with Option II:

Truck Driver I	$ 9,000
Additional Traveling	500
Additional Gasoline	1,000
Additional Maintenance and Miscellaneous	1,000
Depreciation (Excluded from working capital calculations)	600
	$12,100

f. Rate of Return on Investment = $15,210 ÷ $78,415 = 19.0%

g. Breakeven point: ($27,775/($.95 - .30) = 42,731 dozen)

2. <u>Capital Requirements and Rate of Return</u>

a. Initial Capital Requirement

One additional delivery truck, $6,000, is required in addition to the initial capital required for Option I. Therefore, the total initial capital requirement of this option is $50,540 + $4,800. — $56,540

b. Working Capital Requirements

Because of the additional operating expenses involved in the distribution of lugworms with this alternative, the working capital will be an addition of 5/12 of $11,500 to Option I.[12] That is $17,075 + $4,800. — $21,875

c. Inventory (Implicit in b) — -

d. Total Capital Requirement for Option II: — $78,415

3. <u>Profit and Loss for a Retailer Within 200 Miles Under This Option</u>

The individual retailer purchases lugworms at a wholesale price of $.95/dozen and sell at a market price ranging from $1.50 to $1.75. The gross profit margin is about 40% which is compatible with the existing profit margin of bloodworms and sandworms. However, because of the maintenance expenses and handling expenses of lugworms, it is less than that of bloodworms and sandworms. Therefore, the profit margin of this option should be very attractive to the existing retailer.

F. <u>Profit and Loss Analysis of Alternative III</u>

1. <u>Pro Forma Statement (Annual) for Producer</u>

a. If 100 % of the sales were made to retailers within 200 miles, then the profit/loss would be the same as Option II and the R.O.I. still around 19%.

[12] <u>Ibid.</u>

b. If 100% of the sales were made out-of-town by air, then the profit/loss statement of this option would be as follows:

(1)	Net Sales: 81,600 dozen X $.65		$53,040
(2)	Cost of Goods Sold		24,535
(3)	Gross Profit on Sales		$28,505
(4)	Operating Expenses[13]		
	Salary	$9,000	
	Packing	500	
	Gas	500	
	Postage	500	
	Maintenance and Insurance	500	
	Miscellaneous	1,000	
	Total		12,000
(5)	Net Profit Before Tax		$16,505
(6)	Rate of Return on Investment		24.4%

c. If part of the sales were made to retailers within 200 miles and the remainder are shipped to out-of-town retailer or wholesalers by air, then the profit will depend upon the proportion of sales within 200 miles and sales out-of-town shipment. The profit and loss under this option will be in between that of Alternative I and III-b ($15,210-$16,505). The rate of return on investment should be between 19-24.4%.

2. Capital Requirements: Same as Option I, $67,615.

3. Profit and Loss Analysis for Wholesaler or Retailers Using Air Shipment Arrangements

The air freight within 1,200 miles is approximately $16 per 100 pounds. Lugworms will be packed in a container similar to a tropical fish container. The shipping weight for each container, capable of stocking 1,000 lugworms with the required amount of water, will be around 21-22 pounds. The air freight per dozen depends on the number of lugworms shipped in each order. The following charts show the air freight charge per dozen of lugworms for different size shipments.

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[13]Under this option, one truck will be needed. It would be feasible to assume that the delivery costs would be reduced and the cost of packing, gas, postage, maintenance and insurance would be lower as compared to Option I and II. The figures above represent the adjusted amounts.

[14]Capital requirements are the same as Option I, $67,615.

Order Size	In Dozen	Shipping Weight (lb.)	No. of Container	Air Freight	Packing Cost	Insur.	Total Freight	Freight /Dz.
820	68	13	1	$16.00	$ 2.50	$2.00	$20.50	$.300
1000	83	21	1	$16.00	$ 2.50	$2.00	$20.50	$.246
2000	166	42	2	$16.00	$ 5.00	$4.00	$25.00	$.150
3000	250	63	3	$16.00	$ 7.50	$6.00	$29.50	$.118
4000	333	84	4	$16.00	$10.00	$8.00	$34.00	$.100

The cost of each dozen for the out-of-town retailer or wholesaler freight included follows:

Order Size	Price/Dz. F.O.B.	Freight/Dz.	Total Cost/Dz.
820	$.650	$.300	$.950
1000	$.650	$.246	$.896
2000	$.650	$.150	$.800
3000	$.650	$.118	$.768
4000	$.650	$.100	$.750

If the purchaser is a wholesaler, then this venture will not be considered economically feasible, because the wholesaler must redistribute the lugworms through owned trucks to his retailers and the costs of the redistribution will be relatively higher. In order to make a reasonable profit level, the wholesaler has to sell lugworms to retailers for at least $1.10 per dozen. Provided the retailer charges a normal 80% markup, the market price of lugworms per dozen will be around $1.80 - $2.10. This price will be too high to compete with existing salt water baits such as squid, shrimp, and frozen fish. However, if the out-of-town purchaser is a retailer, and if the order size is equal or greater than 820 lugworms per order, then his cost will be $.90 per dozen or lower, and the market price will be $1.50 - $1.75. This profit margin is very attractive. Therefore, under this option, if the purchaser is a retailer, the project is economically feasible.

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The Florida Sea Grant Program is supported by award of the Office of Sea Grant, National Oceanic and Atmospheric Administration, U. S. Department of Commerce, contract number 04-3-158-43, under provisions of the National Sea Grant College and Programs Act of 1966. The Florida Sea Grant Program was initiated in 1972 with three major components: applied marine research, education, and advisory services.

This public document was promulgated at a cost of $2,594.40 or $1.73 per copy to provide current information to persons interested in the commercial lugworm industry.

State University System of Florida Sea Grant Reports are published by the Marine Advisory Program which functions as a component of the Florida Cooperative Extension Service, Joe N. Busby, dean, in conducting Cooperative Extension work in Agriculture, Home Economics, and Marine Sciences, State of Florida, U. S. Department of Agriculture, U. S. Department of Commerce, and Boards of County Commissioners, cooperating. Printed and distributed in furtherance of the Acts of Congress of May 8 and June 14, 1914.