W34
no. D-78-53
cop. 3
REFERENCE
US-CE-C Property of the United States Government

DREDGED MATERIAL RESEARCH PROGRAM

TECHNICAL REPORT D-78-53

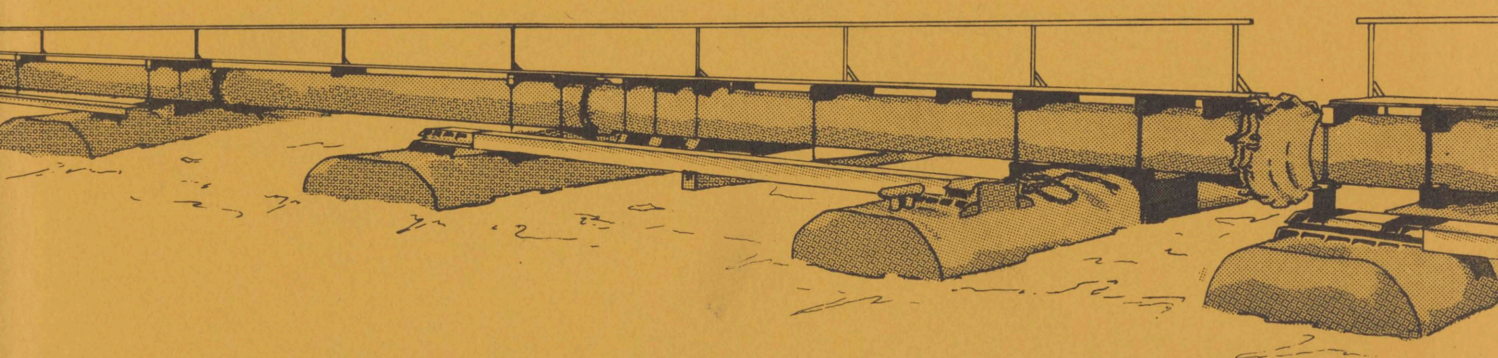
FIELD DEMONSTRATION OF SHRIMP MARICULTURE FEASIBILITY IN DREDGED MATERIAL CONTAINMENT AREAS

by

J. A. Quick, Jr., D. J. Milligan, S. E. Hill
R. J. Hover, W. F. McIlhenny
Dow Chemical U. S. A., Texas Division
Freeport, Texas 77541

August 1978
Final Report

Approved For Public Release; Distribution Unlimited



Prepared for Office, Chief of Engineers, U. S. Army
Washington, D. C. 20314

Under Contract No. DACW39-76-C-0108
(DMRP Work Unit No. 4D03)

Monitored by Environmental Laboratory
U. S. Army Engineer Waterways Experiment Station
P. O. Box 631, Vicksburg, Miss. 39180

LIBRARY BRANCH
TECHNICAL INFORMATION CENTER
US ARMY ENGINEER WATERWAYS EXPERIMENT STATION
VICKSBURG, MISSISSIPPI

Destroy this report when no longer needed. Do not return it to the originator.

USACEWES
TA7 W34 no.D-78-53 c.3
Field demonstration of shrimp maricultur
3 5925 00049 2311

DEPARTMENT OF THE ARMY
WATERWAYS EXPERIMENT STATION, CORPS OF ENGINEERS
P. O. BOX 631
VICKSBURG, MISSISSIPPI 39180

IN REPLY REFER TO: WESEV

13 October 1978

SUBJECT: Transmittal of Technical Report D-78-53

TO: All Report Recipients

1. The report transmitted herewith represents the results of one of several research efforts completed as part of Task 4D (Products Development) of the Corps of Engineers' Dredged Material Research Program (DMRP). Task 4D was included as part of the Productive Uses Project of the DMRP, which, among other considerations, included developing concepts for productively using disposal areas or dredged material removed from these areas.

2. There has been a dramatic increase in the last several years in the amount of land disposal of dredged material, necessitated largely as a result of the need for confining dredged material classified as polluted. Land is continuing to become more and more scarce for disposal activities, and the problem becomes more acute with the need for selecting each new disposal area. Many of these areas are acquired for long periods of time, yet are used intermittently when dredging is being accomplished. The remainder of the time, they are nonproductive, unused land and may be both environmentally and aesthetically displeasing. Attention, therefore, can be profitably and justifiably directed towards concepts that can demonstrate that long-term diked disposal sites can serve as a resource to be used for producing income on a continuing basis.

3. DMRP work units under other tasks have developed improved disposal facility operation and management procedures as well as techniques for the reclamation of potentially valuable materials, both of which could increase area life expectancy as well as enhance the aesthetic and environmental characteristics of disposal areas. However, the total picture would be incomplete without considering concepts for developing marketable products from the dredged material itself or from the disposal areas. To this end, the investigation reported herein was directed at demonstrating the feasibility of shrimp mariculture in dredged material disposal sites.

4. The study was a field investigation verifying results of a previous small-scale study that showed possible feasibility of using containment areas for shrimp mariculture. Seven hundred thousand juvenile shrimp were stocked in a 20-acre section of an existing 158-acre dredged material containment area. Two months later the shrimp were harvested and tested for suitability for human consumption and for bait purposes.

5. The study concludes that shrimp mariculture in dredged material containment areas is technically feasible, although economic feasibility is still somewhat dependent on, among other things, a cheaper system of obtaining the stocking shrimp. The report presents not only a technical analysis but also a complete economic analysis of the project including projections on the probable acreage needed to make future ventures profitable.

6. An additional intent of this study and this report is to promote more widespread interest in and concern over the subsequent use of disposal sites for productive purposes. To this end, it is expected that the basic conceptual design and methodology employed in this study may be of great long-term significance not only to mariculturists but also to persons concerned with land-use planning and management.

JOHN L. CANNON
Colonel, Corps of Engineers
Commander and Director

Unclassified
SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER Technical Report D-78-53	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) FIELD DEMONSTRATION OF SHRIMP MARICULTURE FEASIBILITY IN DREDGED MATERIAL CONTAINMENT AREAS		5. TYPE OF REPORT & PERIOD COVERED Final report 6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) J. A. Quick, Jr. R. J. Hover D. J. Milligan W. F. McIlhenny S. E. Hill		8. CONTRACT OR GRANT NUMBER(s) Contract No. DACW39-76-C-0108
9. PERFORMING ORGANIZATION NAME AND ADDRESS Dow Chemical U. S. A., Texas Division Freeport, Texas 77541		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS DMRP Work Unit No. 4D03
11. CONTROLLING OFFICE NAME AND ADDRESS Office, Chief of Engineers, U. S. Army Washington, D. C. 20314		12. REPORT DATE August 1978 13. NUMBER OF PAGES 139
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office) U. S. Army Engineer Waterways Experiment Station Environmental Laboratory P. O. Box 631, Vicksburg, Miss. 39180		15. SECURITY CLASS. (of this report) Unclassified 15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Containment areas
Dredged material
Dredged material disposal
Shrimps
Waste disposal sites

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Dredging of the nation's waterways results in the production of large volumes of material that must be removed and disposed of. Much of this dredged material is disposed of in diked land disposal sites called dredged material containment areas (dmca). Since dewatering of the disposed sediments takes months or years, these dmca's remain nonproductive over long periods of time. This study was undertaken to determine the potential of shrimp mariculture

(Continued)

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

Unclassified
SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

20. ABSTRACT (Continued).

in dmca's as a productive use of those sites.

A 158-acre dmca located on the Gulf Intracoastal Waterway near Freeport, Texas was chosen as the demonstration site. A manageable 20-acre pond area was isolated from the main containment area by an internal levee and used as the culture pond. The pond was filled with 50-micron-screened seawater pumped from the Intracoastal Waterway. To kill any predators present in the water, the pond was treated with 3 applications of an icthyotoxin. Commercial agriculture fertilizer was added to the pond to stimulate a phytoplankton bloom which served directly and indirectly as the sole food supply for the shrimp. No prepared food was provided to the shrimp during the experimental grow-out. The pond was stocked with 30-day-old "hardened" postlarval penaeid shrimp (*Penaeus setiferus*). Seven weeks later, average survival was estimated to be in the range of 86 to 93 percent and the average size of the shrimp sampled was 5.2 gm. (87 count, heads on). The harvest rate was estimated to average 185 to 200 pounds per acre. Several different harvesting techniques were tested, but unusually early cold weather prevented a complete harvest.

Harvested shrimp were awarded a Certificate of Wholesomeness for human consumption by the U. S. Department of Commerce. No off flavors or other negative qualities were found in organoleptic testing of the shrimp.

It was the conclusion of this study that it is both biologically and economically feasible to culture penaeid shrimp on a commercial scale in dredged material containment areas.

THE CONTENTS OF THIS REPORT ARE NOT TO BE USED FOR ADVERTISING, PUBLICATION, OR PROMOTIONAL PURPOSES. CITATION OF TRADE NAMES DOES NOT CONSTITUTE AN OFFICIAL ENDORSEMENT OR APPROVAL OF THE USE OF SUCH COMMERCIAL PRODUCTS.

SUMMARY

Introduction

Previous studies using simulated dredged material containment areas have demonstrated the potential of utilizing mariculture to turn these disposal sites into valuable natural resources. All the components seem to be poised to make such an endeavor a reality: (1) The mariculture industry is in the early stages of commercial-scale shrimp culture in Central and South America, (2) land acquisition agencies are in serious need of an incentive for landowners to lease or sell their land for construction of dredged material retention areas, (3) the U.S. Army Corps of Engineers needs some means of defraying containment area maintenance costs or of generating revenues, (4) the American people are in need of ways to reduce import deficits with domestic production. These and other potential benefits would come with widespread commercialization of containment area mariculture and especially shrimp mariculture. This study was undertaken to see if shrimp could be cultured to marketable size in an actual flooded active dredged material containment area.

Containment Area Selection and Pond Construction

An 158-acre dredged material containment area on the Gulf Intracoastal Waterway was chosen for this shrimp mariculture demonstration. The retention levee had been built one year earlier and the last of 1.5 million cu. yd. of maintenance dredged sediment was deposited within the disposal area only three months before the project work began.

A 1,000-ft. internal levee was constructed to create a 20-acre pond within the retention area. A pump and pipeline system was constructed to move water from the Intracoastal Waterway into the shrimp pond. A large self-cleaning 50-μm absolute porosity filter was constructed to sieve all incoming seawater to exclude eggs, larvae, and other stages of potential shrimp competitors and predators. Two drainage culverts of 24-in. diameter with control valves were installed through the levee.

Preparation for Stocking

Initially the remnant waters in the containment area contained an animal biomass of about 308 lb. per acre consisting almost exclusively of the grass shrimp (Palaemonetes pugio), the tidewater silverside fish (Menidia beryllina), and the sheepshead minnow (Cyprinodon variegatus). Three applications of the ichthyotoxin rotenone were made prior to stocking to remove these and other potential piscine shrimp competitors or predators.

The pond was fertilized on two occasions prior to stocking with commercial agricultural fertilizer mixed to give a nitrogen to phosphorus ratio of 1:5 and applied at 5 lb. per acre active ingredients. This stimulated a dense phytoplankton bloom dominated by dinoflagellates, especially Gynmodinium sp. and Gyrodinium sp. This natural production served directly and indirectly as the sole food supply for the shrimp; no prepared food was provided.

Hatching and Rearing Shrimp for Pond Stocking

A source of mature gravid female white shrimp (Penaeus setiferus) was located in about 30 ft. of water off Port Aransas, Texas. Brood stock were collected and spawned in the shrimp hatchery in Galveston, Texas. Over 2 million larvae were produced and raised to the early postlarval stage. About 1 million of these were transported to Freeport, Texas, and placed in a 26-ft-diameter by 4-ft-deep hardening pool. A floating brine shrimp hatchery of novel design was used to supply Artemia nauplii as food for the young penaeid shrimp. Both species of shrimp were fed on algae produced by natural growth in the pool and by a single application of 15 lb. of cottonseed meal. The shrimp were held in the hardening pool for 20 days at which time the increased biomass and resultant increased waste exceeded the pool capacity. The most obvious effect of this excess was an increase in pH due to carbon dioxide depletion and carbonate buffer reduction resulting from increased algal photosynthesis as the wastes were utilized for nutrients. The young shrimp (now 5/8 to 1 in. long) were removed from the hardening tank and 390,000 were taken to the containment area shrimp pond. Once there, they were slowly adjusted to pond water conditions and released on 1 September 1976.

Shrimp Grow-Out and Harvest

The shrimp showed a rapid growth rate of up to 400% per week averaging 0.18 gm. per day per shrimp until 4 October 1976. On that day, the first of a continual series of record-breaking cold fronts struck the area, causing pond temperatures to drop from 87°F at a rate of up to 7°F per day. As predicted by laboratory data, shrimp growth virtually ceased after temperatures plunged below 70°F.

Consequently, the harvest planned for November was started on 19 October and continued into November when water temperatures of 54-56°F, high winds and rain, plus the lethargy and burrowing of the shrimp made further efforts useless. A 500-ft. beach seine especially modified to ride over the soft sediment bottom was used initially. A 20-ft. boat-drawn otter trawl proved to provide a better harvest as the temperature continued to fall.

Harvest data were converted to catch per unit area and used to estimate the total pond shrimp biomass. A total of 3,700-4,000 lb. was estimated, representing an 86-93% survival. Shrimp averaged 5.2 gm. each or 87 per pound (= 87 count) heads on and 143 count heads off. This is an ideal size for the fresh and frozen food markets as well as the bait shrimp market. Market value ranged from $10,693 to $14,500 total depending on the end product use. Harvested shrimp were awarded a Certificate of Wholesomeness for human consumption after comprehensive testing by the U.S. Department of Commerce. Test marketing as bait shrimp showed the cultured animals to be preferred over wild-caught shrimp by both purchasers and retailers, especially in the live shrimp trade. No off flavors or other negative qualities were found in organoleptic testing. The shrimp had somewhat thinner-than-normal shells, but this simplified peeling.

Prior to rotenone treatment, the containment area pond was supporting an estimated animal biomass of 308 lb. per acre. At shrimp harvest, it contained about 195 lb. per acre *P. setiferus* plus 165 lb. per acre of other species for a total of 360 lb. per acre. These data suggest that the pond ecosystem was operating near capacity both before and after shrimp stocking. This further suggests that, without the other competing species, shrimp production in excess of 300 lb. per acre could have been achieved.

Conclusions

This study conclusively demonstrated that shrimp could be cultured on a major scale in active dredged material containment areas. In addition, the art and science of this technology were greatly refined and advanced. Noteworthy among these achievements were:

a. The first zero-maintenance, high-volume, low-cost, passive screening system for sieving seawater to the micron-size range.

b. New design and operating techniques for a large-scale floating brine shrimp hatchery.

c. Improvements in management and operation techniques of extensive shrimp culture ponds.

d. Initiation and management of the first controlled phytoplankton culture in a containment area pond.

e. Achievement of an exceptional shrimp growth rate sufficient to rear up to six sequential crops per year.

f. Proof of wholesomeness of containment area-reared shrimp for human consumption.

PREFACE

The purpose of this study was to determine whether shrimp could be cultured to marketable size in an actual flooded active dredged material containment area. The work was performed under Contract No. DACW39-76-C-0108, dated 14 February 1975, between the U.S. Army Engineer Waterways Experiment Station (WES) and the Dow Chemical Company. The study was conducted under Dredged Material Research Program (DMRP) Task 4D, "Products Development," Work Unit No. 4D03, "Field Demonstration of Shrimp Mariculture Feasibility in Dredged Material Containment Area." The DMRP is sponsored by the Office, Chief of Engineers, U.S. Army, and monitored by WES.

The principal investigators and authors of this report were J. A. Quick, Jr., D. J. Milligan, S. E. Hill, R. J. Hover, and W. F. McIlhenny, Dow Chemical Company, Texas Division.

The authors are grateful for considerable assistance from many sources. Especially notable were Mr. A. C. Learned, land owner; Mr. Pete Schraff and the members of the Brazos River Harbor Navigation District; Mr. George Rochen, COL S. McCoy, and other personnel of the Corps of Engineers' Galveston District; Mr. E. Stearns, pond construction engineer and Mr. R. B. Porter, engineer, Dow Research Engineering Department; Mr. J. L. Sorrell, Jr., S & M Construction Co.; and Mr. E. F. Sablatura, S. V. Carlton, and G. R. Bullard, and Mrs. M. M. Wolber and M. Weeks, Dow Chemical Company Resources Research Department. Thanks also to Mr. O. Osborn and R. D. Daniels, past and present Department Directors.

Special thanks are due Mr. Hoyt Holcomb and Mr. David Ramsey and other members of the Texas A & M University Sea Grant Program as well as personnel of the National Marine Fisheries Service Galveston Laboratory who participated in the shrimp sourcing and hatchery operations for this project.

Contract Managers for the study were CPT R. M. Meccia, former Project Manager, and Mr. T. R. Patin, present Project Manager, Productive Uses Project, Environmental Laboratory (EL), WES. The study was conducted under the general supervision of Dr. John Harrison, Chief, EL.

Directors of WES during the conduct of this study and the preparation and publication of this report were COL G. H. Hilt, CE, and COL J. L. Cannon, CE. Technical Director was Mr. F. R. Brown.

TABLE OF CONTENTS

Page

SUMMARY.. ii

PREFACE.. vi

LIST OF FIGURES...viii

LIST OF TABLES... xi

CONVERSION FACTORS, U. S. CUSTOMARY TO METRIC (SI) UNITS OF MEASUREMENT.. xii

I. BACKGROUND... 1

Status of Dredged Material Disposal...................... 1
Status of the Mariculture Industry....................... 11

II. METHODS AND MATERIALS................................ 17

Culture Pond Design and Engineering...................... 31
Pond Fertilization....................................... 49
Competitor and Predator Removal.......................... 51
Shrimp Hatchery Operation................................ 55

III. RESULTS... 79

Pre-Existing Fauna and Flora............................. 79
Competitor and Predator Removal.......................... 83
Shrimp Hardening and Stocking............................ 87
Shrimp Grow-Out.. 89
Pond Harvest... 98

IV. DISCUSSION AND CONCLUSIONS...........................101

General...101
Shrimp Pond Production..................................101
Increasing Productivity.................................104
Economics...105

LITERATURE CITED..110

APPENDIX A: RECOMMENDED DEVELOPMENTAL PROGRAM...........118

LIST OF FIGURES

No.		Page
1	A typical new dredged material containment area	5
2	The edge of containment area	6
3	A typical sediment surface in a dredged material containment area that has not been used for several years	7
4	Shrimp culture pond site	20
5	Map of shrimp pond	21
6	Aerial view of shrimp pond site	22
7	Hydraulic cutterhead dredge	23
8	Hydraulic cutterhead dredge discharge	25
9	Containment area construction technique	26
10	Containment area borrow ditch	27
11	Containment area isobaths	28
12	Shrimp culture pond	29
13	Design of sieve box	34
14	Barges showing spuds and connectors	35
15	Barge positioning during internal levee construction	37
16	Internal levee construction	38
17	Internal levee completion	39
18	Sieve box installation	41
19	Influent structure design	42
20	Discharge pipe placement	43
21	Discharge structure design	44
22	Intake structure	45
23	Seawater intake pump	47
24	Pipeline to shrimp pond	48

List of Figures (continued)

No.		Page
25	Discharge screen	50
26	Rotenone packaging operation with bag holder and funnel	53
27	Application of rotenone powder	54
28	Rotenone suspension application	56
29	Collecting gravid female shrimp in the Gulf	59
30	Dorsal view of gravid female penaeid shrimp showing ovary	60
31	Post larval shrimp hardening tank	64
32	Floating brine shrimp (*Artemia salina*) hatchery	66
33	Harvesting postlarval shrimp from the hardening pool	68
34	Device for secondary concentration of the PL shrimp from the hardening pool	69
35	Hardened PL shrimp being readied for shipment to the pond for stocking	71
36	Adjusting hardened shrimp to the shrimp pond chemical environment prior to stocking	72
37	Berm on retention levee	73
38	Harvesting seine being deployed	76
39	Shrimp pond harvesting technique	77
40	Fishes killed by rotenone applications	85
41	Estimated ranges of lethality of rotenone to shrimp pond ichthyofauna	86
42	Shrimp growth	90
43	Shrimp pond salinity during grow-out	91
44	Shrimp pond temperature during grow-out	92
45	Shrimp pond pH during grow-out	93
46	Rainfall during shrimp grow-out	94
47	Ambient temperature during grow-out	95

List of Figures (continued)

No.		Page
48	Comparative shrimp growth in simulated versus actual containment areas	96
49	A projection of gross costs and incomes	106
50	A projection of net cash balance	107
A1	Artist's rendering of planned *in situ* hatchery installation at the shrimp culture pond site Dredged Material Containment Area (DMCA) No. 85	127
A2	Proposed design for a plastic film barrier for use in separating containment areas into manageable size shrimp culture ponds	128

LIST OF TABLES

No.		Page
1	Stage Duration of *Penaeus aztecus*	62
2	Species and Biomass Present in Containment Area No. 85 Prior to Stocking with Shrimp	81
3	Parametric Data from the Post Larval Shrimp Hardening Pool	88
4	Economic Projections for an Individual 100-Acre Shrimp Culture Pond for One Crop in an 800-Acre Containment Area Shrimp Farm Using Various Grow-Out Times and Stocking Rates to Best Utilize Productivity of the Fertilized Pond (No Supplementary Feeding)	103

CONVERSION FACTORS, U. S. CUSTOMARY TO METRIC (SI) UNITS OF MEASUREMENT

U. S. customary units of measurement used in this report can be converted to metric (SI) units as follows:

Multiply	By	To Obtain
inches	2.54	centimeters
feet	0.3048	metres
miles (U.S. statute)	1.609344	kilometres
square feet	0.09290304	square metres
acres	0.40468	hectares
cubic feet	0.02831685	cubic metres
cubic yards	0.7645549	cubic metres
acre-feet	1233.482	cubic metres
gallons (U.S. liquid)	0.003785	cubic metres
gallons (U.S. liquid) per minute	0.003785	cubic metres per minute
ounces (mass)	28.34952	grams
pounds (mass)	0.4535924	kilograms
pounds (mass) per acre	1.12087	kilograms per hectare
pounds (force)	4.448222	newtons
pounds (force) per square inch	6.894757	kilopascals
feet per second	0.3048	metres per second
miles (U.S. statute) per hour	1.609344	kilometres per hour
knots (international)	0.5144444	metres per second
horsepower (550 foot-pounds per second)	745.699	watts
cubic yards per mile	0.47507	cubic metres per kilometre
bushels (U.S.)	0.03523907	cubic metres
degrees (angle)	0.01745329	radians
Fahrenheit degrees	5/9	Celsius degrees or Kelvins*

* To obtain Celsius (C) temperature readings from Fahrenheit (F) readings, use the following formula: C = 5/9)(F - 32). To obtain Kelvin (K) readings, use: K = (5/9)(F - 32) + 273.15.

FIELD DEMONSTRATION OF SHRIMP MARICULTURE FEASIBILITY IN DREDGED MATERIAL CONTAINMENT AREAS

PART I: BACKGROUND

Status of Dredged Material Disposal

Disposal problems

1. The navigable waterways of the United States are of paramount importance to its economic development, since waterborne transportation is the cheapest, most efficient way to move heavy, bulky cargos. Thousands of miles of the Nation's waterways are not naturally deep enough nor wide enough for the movement of commercial waterborne traffic. This has necessitated the dredging of thousands of miles of canals and channels, an activity which results in the production of large volumes of material which must be removed and disposed of (U.S. Army Engineer Waterways Experiment Station [WES] 1975, 1976a). In addition to new dredging, navigable waterways are constantly subject to reduction in depth from silting and other processes and must be dredged periodically to remove these materials (Herbich 1976).

2. The proper disposal of dredged material from both new and maintenance projects has constituted a continuing major problem for the U.S. Army Corps of Engineers and other agencies, companies, and organizations involved in the construction and maintenance of navigable waterways (Murphy and Zeigler 1974). The situation in Texas is typical of these difficulties. Of the 25,000 miles* of U.S. waterways that the Corps of Engineers is responsible for (WES 1976a), about 1,100 miles are located in Texas (Espey, Huston and Associates, Inc. 1976a,b). Of the 107 harbor areas the Corps maintains nationwide, eight are located in Texas. The average shoaling rate for the 1,000-mile Texas Gulf Intracoastal Waterway is 22,000 cu. yd. per mile, and the statewide total is over 31 million cu. yd. per year. In addition to this maintenance dredging requirement, the Corps is authorized to dredge about 57 million cu. yd. of soil annually for new construction to give a total annual dredging volume of 89 million cu. yd.

---

*A table of factors for converting U.S. Customary units of measurement to metric (SI) units is found on page xii.

for this one agency. Additional non-Federal dredging is estimated to account for another 5-14 million cu. yd. annually for a grand total of 94-103 million cu. yd. or up to 64,000 acre-ft. of dredged material that must be disposed of annually.

3. The disposal problems for such prodigious volumes of dredged material have become acute in the past decade. Disposal has been further complicated by the awareness and resultant public fear of the potential damage that dredged materials can cause if improperly handled (Thompson 1973).

4. Extensive studies have been done, or are underway, to determine the least harmful and best methods of disposing of dredged materials (Mallory and Meccia 1975; Hammer and Blackburn 1977). The majority of this work has been accomplished under funding by the Corps of Engineers by provision of the River and Harbor and Flood Control Act of 1970, which initiated a comprehensive Nationwide study to provide more definitive information on the environmental impact of dredging and dredged material disposal operations (Meccia 1975; WES 1975, 1976a,b; Vaughan and Kimber 1977; Sweeney 1973; Shuba et al. 1977; Pope 1976; Lee and Plumb 1974). Projects funded under the Act also seek to develop new and improved dredged material handling practices (Brannon et al. 1976; Environmental Engineering Consultants, Inc. 1976; Krizek et al. 1976; Green and Rula 1977; Haliburton et al. 1977). A major part of this work is being accomplished through the auspices and support of WES.

Potential solution to dredged material disposal problems

5. Studies of terrigenous disposal have, to date, produced evidence that dredged materials can be used as a manageable resource. Numerous cases of beneficial environmental effects resulting from dredged material disposal have been documented. These include marsh and island development for wildlife habitat and beach erosion control, beach nourishment, and the establishment of new, beneficial, submerged marine habitats (Arthur D. Little, Inc. 1975; Barko et al. 1977; Bartos 1977; Coastal Zone Resources Corporation 1977; Falco and Cali 1977; Garbisch 1977; WES 1977.

6. Research is also underway to investigate the environmental effects of open-water disposal practices (Leathem et al. 1973; O'Connor 1975; Bokuniewicz et al. 1977; Caplan 1977; Nuzzi 1977; Valenti and Peters 1977).

Meanwhile, pressures to end such dispersive disposal of dredged material have already developed, and there is evidence of undesirable environmental consequences in some cases. As a result, there has been an increasing amount of land disposal of dredged materials in the past few years, an increase that promises to continue into the future.

7. Most of the material to be disposed of on land will come from navigable waterways in moderately to highly developed areas where land sites are difficult to obtain (Espey, Huston and Associates, Inc. 1976a,b). The extensive acreages needed for sediment disposal in these areas are increasingly more difficult and expensive to acquire, and obtainable areas tend to be increasingly more remote from the dredging sites. Exercise of land disposal is thus often requiring the employment of expensive material transport in barges, longer pipelines, or hopper dredges in order to move the dredged materials over the increasingly great distances to available land disposal sites (Herbich 1975).

8. Difficulties in obtaining adequate land disposal sites are not limited to areas of heavy development or dense population. Suitable land sites are generally difficult and/or expensive to acquire for new work or for maintenance of large or small projects throughout the country. Future widespread use of coastal marshes for dredged material disposal will undoubtedly be impossible unless benefits from this use can be realized.

9. Land acquisition problems are severe in the southeastern United States, particularly along the Gulf and Atlantic Intercoastal Waterway (Espey, Huston and Associates, Inc. 1976a,b). It is this same southeastern area which is also seeing the greatest increase in dredging activity and marine construction and already accounts for a substantial portion of the dredged materials which must be disposed of in the continental United States (Murden 1976). In many cases, especially near harbors and cities, landowners cannot be found who will provide or sell easements to sufficiently large continuous tracts for use as disposal areas. In these cases, the port authority, navigation district, conservation department, or other agency or organization must purchase the land outright for construction of the disposal area. Exercise of rights of condemnation may even be necessary to accomplish this in heavily populated or industrialized areas.

10. The willingness of the landowner to permit dredged material disposal on his land is influenced strongly by the condition of the land and the nature or composition of the sediments to be disposed. In general, owners of marshy, swampy, or poorly drained lands are more willing to grant an easement for disposal. Private owners of such land are now, however, being urged and in some cases legally prevented from destroying the natural environmental characteristics (Lee and Plumb 1974).

11. From the landowner's practical viewpoint, disposal on the land will frequently remove it from productive usage for periods of years or even decades depending on the character of sediment and frequency and duration of disposal operations. He certainly does not want to commit highly productive land to such an extensive fallow period.

12. On the other hand, if a profit could be realized from new or active dredged material containment areas, the picture would be changed completely. There would no longer be an unproductive fallow period. The characteristics of disposal areas, however, are not compatible with successful employment of most traditional land uses. No permanent structures can be built in active containment areas because of the periodic inundation by added dredged material (Hammer and Blackburn 1977). Agricultural usage such as for pasturage, horticulture, silviculture, or food crop farming are made difficult or impossible by the conditions found in most containment areas (Figures 1, 2, 3). Dredged material, particularly that from maintenance projects (which make up the majority), is usually very fine grained and tends to be nearly impervious to water, thus causing severe soil drainage problems and salt retention (Krizek et al. 1975). In addition, these sediments tend to hold large volumes of water for long periods of time. Such included water commonly exceeds 40% of the total material volume, causing the sediments to remain very soft until sufficient dewatering occurs months or years later (Hammer and Blackburn 1977). Such substrates cannot bear the weight of modern agricultural equipment (Willoughby 1977; Giger and Krizek 1975; Green and Rula 1977). This very soft consistency also severely limits usage of dredged materials for fill or for incorporation into structural or roadway building materials.

Figure 1. A typical new dredged material containment area. This area (Galveston District #85) was built just prior to being photographed. Pumping of maintenance dredged material from the Intracoastal Waterway was underway.

Figure 2. The edge of a containment area (Galveston District #84) filled with sediments after several years of drainage. Grass growing on top of containment levee has failed to encroach into the sediment area.

Figure 3. A typical sediment surface in a dredged material containment area (Galveston District #86) that has not been used for several years. The surface is spongy and the cracks extend downward over 2 ft., often to the level of ground water.

13. Even the concept of continuously reusable disposal areas involves provision for long dewatering periods for each newly used segment of the containment area. As a result, large parts lie unproductive for long periods even though the entire tract, as a whole, is being renewed and reused. Disposal areas must be very large to allow these long residence times for dewatering (Murphy and Zeigler 1974). Research is underway to reduce dewatering periods, but progress has been slow and the solutions promise either to be quite expensive and/or only to shorten the period, not eliminate it (Environmental Engineering Consultants 1976; Krizek et al. 1976; Haliburton et al. 1977).

Mariculture as a solution to dredged material disposal problems

14. There is one potential productive use that appears to be highly suited to some dredged material containment areas--mariculture. Flooding seawater onto the surface of the sediment in most containment areas would provide an environment similar to a coastal estuary. Coastal estuaries form the most biologically productive class of major marine environments. Over 70% of the commercial marine organisms of the Gulf of Mexico spend part or all of their lives in estuaries (calculated from Taylor et al. 1973). Figures indicative of similar importance and productivity would be expected for estuaries in most other areas. Some estuarine environments are more productive than terrestrial wheat or alfalfa fields--even those in which modern hybrid species are grown and heavy fertilization and disease control are exercised (Jones 1968; Odum 1963; Bassham 1976). Selected animals and plants from these highly productive estuarine environments should therefore have the potential for returning similarly high production from dredged material containment areas.

15. Some of the very same characteristics that make disposal areas unusable for traditional agriculture and other conventional uses make them especially appropriate for growth of certain estuarine organisms. Many estuarine species, notably species of commercial shrimp, clams, and worms, prefer the fine-grained, soft sediments that are typical of many containment areas. Some shrimp and worms feed partially or wholly upon organic detritus and bacteria which are normal constituents of many dredged

sediments. Other commercial species feed upon phytoplankton which would be stimulated by the nitrogen and phosphorous compounds and other nutrients typical of sediments (Brannon et al. 1976; Barko et al. 1977; Shuba et al. 1977). It would be expected that, with careful selection of culture species and proper care of them, mariculture should provide a highly profitable and attractive use for new and active containment areas.

16. Under Corps of Engineers funding, the brown shrimp, Penaeus aztecus, was utilized to successfully complete an experimental mariculture program in simulated dredged material containment areas (Quick and Morris 1977; Quick et al. in press). One objective of that study was to determine if shrimp could survive in ponds created by flooding dredged material containment areas. The experiment was carried out in 1/4-acre experimental ponds in which dredged material was placed. Not only did the shrimp survive, but they grew 30% larger in the same time period and produced a 17% larger harvest than the shrimp in similarly sized control ponds.

17. Other parts of these studies showed P. aztecus to be highly tolerant of a variety of contaminated and uncontaminated sediments. An economic analysis indicated reducible hatchery costs to be the only major barrier to commercial scale shrimp culture.

18. The results of that work showed a high potential for penaeid shrimp culture to be a productive use of dredged material containment areas. It was those results that prompted the production-scale trial described here.

Benefits of mariculture in confined disposal areas

19. The routine capability to utilize mariculture (or aquaculture) as a means of deriving an attractive profit from containment areas would serve as a considerable incentive for private landowners to provide sites for disposal purposes. This incentive would not be limited to those individuals who would perform or support the mariculture themselves. For example, the owner or leaseholder of a dredged material containment site could be left free, through legal documents, to lease or sublet the lease to other individuals or business groups who might wish to use it for mariculture. The original landowner or leaseholder would benefit through rental or leasing fees or other compensation.

20. The use of a dredged material containment area for mariculture would eliminate or alleviate other negative features. A typical diked disposal area constructed for maintenance dredging is actually used for only a small proportion of any given year or decade, even though the Corps may hold perpetual easement (Hammer and Blackburn 1977). Filling operations normally last a few weeks to a few months and may be separated by periods of inactivity lasting from several months to two or three years. During these interim periods, legal and financial constraints limit the Corps of Engineers' role to essential maintenance such as that necessary to preserve dike integrity and weir operation. In some case, these functions are the responsibility of local interests.

21. The amount of maintenance and general attention devoted to the containment areas during periods of inactivity is often insufficient to prevent undesirable conditions from developing (Harrison and Chisholm 1974). Containment areas have become mosquito breeding grounds and havens for undesirable forms of wildlife. Excessive algal or other vegetative growth often causes odors or unsightliness. High bacteria counts and excessive suspended solids levels have also been observed in containment area effluent. Following periods of heavy precipitation during warm seasons, containment areas sometime produce obnoxious odors generated by anaerobic decay of organic matter trapped in the dredged material.

22. The use of these areas for mariculture would provide a source of constant maintenance. Weir operation or other water discharge apparatus would be maintained by the mariculturist using the facility. Grass plantings or other levee protection would be utilized to control erosion and preserve levee integrity. Mosquitos would be controlled by the cultured animals. Undesirable water conditions such as high bacteria counts and excessive vegetative growth, turbidity, and anaerobiosis, which have caused problems in the past (Harrison and Chisholm 1974), would have to be kept under control in the interests of the cultured animals.

23. Some of the disadvantageous features of containment areas would be replaced by desirable ones. Water quality must be maintained at a high level and an ecological balance established in a mariculture facility. Effluent water would contain plankton and possibly other life that would

serve as feed for organisms in the receiving waters. The character of discharged bacteria would be altered away from the undesirable anaerobic or pathogenic species toward a more normal marine flora. Use of containment areas for mariculture would thus relieve the Corps or other responsible entity of most or all maintenance costs.

Status of the Mariculture Industry

History

24. Although mariculture has been practiced for more than 2,200 years, the culture (growth under controlled conditions in seawater) of marine organisms is relatively new to the United States (Bardach et al. 1972). Oysters were cultivated by the Romans, and some species of shrimp have been cultivated in Southeast Asia for over five centuries, using trapping and confinement methods (Milne 1972).

25. Greatly improved culture methods have been developed in Japan beginning in 1934 and in the United States in the last decade (Bardach et al. 1972). Both fresh water and saltwater shrimp mariculture technology is now approaching commercial feasibility, particularly if low population densities (extensive culture) are maintained. Shrimp of various species are in commercial production in many countries of the world (Bardach et al. 1972). In general, production (with the special exception of Japan) is limited to tropical and subtropical regions.

26. Much information is available from Southeast Asia on the growth of shrimp in ponds that are dimensionally very similar to flooded dredged material containment areas. Seven species of penaeid shrimp are grown and eaten there, and most of these animals share the habit with Gulf of Mexico shrimp of entering shallow coastal areas when young and returning to the ocean when considerably older and larger. Most areas of Southeast Asia have traditions of primitive brackish water pond mariculture. In the Philippines, the sugpo prawn, _Penaeus monodon_ (the largest of the penaeid shrimps), is pond cultured using more sophisticated and reliable techniques. Often the prawns are grown together with milkfish in a polyculture endeavor, the two species being noncompetitive. Production in Southeast Asia runs up to 1500 kg/ha, but about 900 is more common without auxiliary feeding.

Potential

27. The largest shrimp fishery in the world is that in the Gulf of Mexico exploited primarily by Cuban, Mexican, and American fishermen. Most of the catch (one of three penaeid shrimp--brown shrimp, *P. aztecus*; white shrimp, *P. setiferus*; and pink shrimp, *P. duorarum*) have lived for much of their existence in the bays and estuaries bordering the Gulf. In fact, the only significant exception to this is the rock shrimp, *Sicyonia brevirostris*. Several characteristics of the shrimp industry have led to much interest in shrimp mariculture. Markets are very large and growing (Jones et al. 1974). The decline in estuarine environments promises to continue and thus put increasing restrictions on the nursery grounds that are necessary to support commercial offshore population. The domestic shrimp fishery appears to have reached or may have even exceeded its maximum sustained yield as indicated by a sharply decreasing catch per unit effort. Due to the growing market plus the stabilized supply that has resulted, prices have increased at rates substantially greater than the inflation rate (Gillespic and Houston 1975). The tendency of foreign nations, such as Mexico, to extend their economic zone out to 200 miles, thus restricting United States fishing boats, promises to further reduce the wild stocks of shrimp available to the U.S. Rapidly increasing labor and fuel costs in combination with general inflation have resulted in a situation which may prevent the shrimp industry from ever again being able to capitalize fishing equipment that can compete with that of foreign nations (Griffin and Nichols 1976; Griffin et al. 1976).

Research

28. The people and organizations. The prospects for profit from shrimp mariculture look very good, and both industry and government have responded with considerable research. Notable programs are those shrimp mariculture projects being carried out by Texas A&M University, the University of Miami, Louisiana State University, Jacksonville State University, South Carolina Wildlife and Marine Resource Department, Florida Department of Natural Resources, the Texas Parks and Wildlife Department, Auburn University, the University of Arizona, the University

of Southern California, California State University, Oregon State University, the National Marine Fisheries Service, Trenton State College, U. S. Environmental Protection Agency, the Oceanic Foundation, Woods Hole Oceanographic Institution, Harbor Branch Marine Laboratories, Marifarms, Sea Farms, Sunoco, Ralston Purina, Caribe King Shrimp Company, Maricultura, Groton Associates, and the Dow Chemical Company.

29. Culture of shrimp in ponds very similar to flooded dredged material containment areas has been undertaken by Texas A&M in Brazoria County and near Corpus Christi in Texas; by The Dow Chemical Company near Freeport, Texas; by Ralston Purina at Crystal River, by the University of Miami at Homestead, and by Marifarms in Panama City, all in Florida; and in Louisiana by the Inmont Corporation (Rose et al. 1975). Similar pond culture programs have been conducted in South and Central America, particularly in Panama and Costa Rica.

30. The body of knowledge and experience. The literature on pond mariculture is becoming extensive although specific information on many ongoing projects is not readily available since most of the larger ones are run by private companies preparing for competitive commercial production. However, certain generalities are beginning to emerge from these preproduction mariculture operations. Ponds of 40 to 100 acres seem to be the easiest to manage. A variety of shrimp have been raised by various companies, of which *P. vannami* and *P. stylirostrus* seem to be the most common in South and Central America. However, each species seems to have its own peculiar specific requirements of salinity, temperature, water quality, food, substrate, population density, etc. Information gathered in Texas, for example, has indicated that *P. setiferus* and *P. aztecus* may be the best shrimp for this area, with *P. setiferus* preferring lower and *P. aztecus* higher salinity areas (Lindner and Cook 1970; Venkataramiah et al. 1974; Keiser and Aldrich 1976). The work in South and Central America has indicated that, in any given operation, a pond size of from 500 to 1000 acres is necessary to obtain a profit under the present economic and technological conditions. However, this profit has been projected based upon artificial feeding, and this artificial feeding has accounted for 35-65% of production

costs. Studies have shown that commercial-sized shrimp can be raised in simulated dredged material containment areas without this expensive supplementary feeding (Quick and Morris 1977, Quick et al. in press). Economic analyses in those studies indicated that profitability may eventually be obtained in a farm of 200 to 400 acres, the size of many dredged material containment areas.

31. The crucial breakthroughs. In 1974, the French government announced a major breakthrough that promises to favorably change the cost balance sheets for all extensive penaeid shrimp mariculture. Working in Tahiti, they successfully matured and spawned several species of penaeid shrimp in captivity for the first time. At least one U. S. company, Ralston Purina, is said to have been able to successfully adapt the Tahitian maturation spawning technique to the American *P. setiferus* in ponds in Florida. Successes, albeit sporadic, have also been registered by the team of the University of Arizona and Universidad de Mexico working at Puerto Peñasco, Sonora, Mexico, with *P. stylorostris*.* Maturation has also occurred in ponds operated by Texas A&M University in Corpus Christi, Texas.**

32. These are considerable breakthroughs because routine employment of such techniques will greatly reduce hatchery costs. These cost reductions could be as much as 30-70%, as has been the case in the fresh water shrimp culture industry. One reason for this large cost reduction is that a big part of present hatchery cost is the expense of taking shrimp trawlers and other heavy gear onto the shrimp spawning grounds, which are frequently far offshore. Gravid animals must then be located, captured, and transported alive and healthy back to the laboratory. This is complicated not only by the whims of the weather but also by such conditions as the limited and often changeable area of the spawning grounds, a situation which commonly results in many fruitless trips. The restricted spawning period of many species also increases costs and decreases multiple annual crop capability. If shrimp could be spawned

---

* Personal communication from D. Lightner 1977.

** Personal communication from F. Conte 1977.

upon demand, culture could be timed to make most efficient usage of ponds and equipment, and seasons and harvests could be preplanned to reach the market during highest price periods. The use of wild breeders also results in great variation in egg quality and quantity. Diseases and competitors are commonly introduced resulting in diminished or destroyed crops of larvae. Laboratory maintenance and controlled command spawning would all but eliminate these expensive difficulties.

33. The state of readiness for containment area culture. The production technology as well as the distribution and marketing systems seem to be poised in readiness for the advent of commercial large-scale shrimp mariculture. But it has not happened in the United States. The one company which tried domestic shrimp culture on a large scale, Marifarms of Panama City, Florida, has now fallen into financial receivership.* The reasons for this have been both biological and economic.

34. In Central America and adjacent portions of South America, on the other hand, shrimp mariculture companies have found:

a. Cheap labor to help offset high hatchery and pond operation labor costs,

b. Cheap land for the extensive grow-out ponds that are necessary, and

c. Low construction costs for pond preparation.

Other notable advantages are cooperative governments, lax waste discharge laws, and access to year-round spawning stocks of *P. stylirostris* and *P. vannami* in the adjacent Pacific ocean.

35. It would be necessary to economically offset these foreign advantages to attract shrimp culture back to the United States. (A total economic compensation would not be necessary since there are also disadvantages to foreign operations such as equipment and supply availability, remoteness of markets, and labor forces of inferior training.)

---

* Personal communication from E. A. Joyce, Jr. 1977.

36. Culture of shrimp in dredged material containment areas should provide several offsetting economic plusses:

a. Large tracts of land available for lease at low cost and

b. Free pond construction since the containment area levees would double as pond levees.

37. Previous pond simulations indicated a high chance of success for culture of shrimp in actual containment areas (Quick and Morris 1977, Quick et al. in press). Other parts of these studies indicated that such a venture should be successful in containment areas enclosing a very wide variety of sediments. They further indicated that if shrimp did not work in a given location, there were 403 other species of potential commercial value that showed potential for culture in contanîment areas. And considering the shrimp market size of over $400 million per year, the potential benefits are compelling.

38. With the foregoing background beckoning, this study was developed to demonstrate penaeid shrimp culture on a semicommercial scale in a confinement area containing freshly deposited dredged sediments.

PART II: METHODS AND MATERIALS

Objectives

39. The purpose of this program was to demonstrate that penaeid shrimp could be profitably and reliably cultured in dredged material containment areas. Three broad objectives were approached. The first was to continue development and refinement of techniques and systems for the most efficacious mariculture of shrimp in dredged material containment areas. The second was to provide a demonstration that would be observed directly by as many potential mariculturists as possible and reported through news media and publications to as many other persons as feasible. The third objective was to produce data and information that could be applied by individuals and business groups to establish profitable shrimp culture in dredged material containment areas. Further, attention was given as to the methods by which those techniques might be adapted to the culture of other species, particularly fresh water species, in dredged material containment areas.

40. Penaeid shrimp were used as a typifying species because of the experience gained on animals of this genus in previous simulated dredged material containment area mariculture grow-out efforts (Quick and Morris 1977, Quick et al. in press). In addition, they are a principal marine and estuarine animal of commerce, and a considerable body of information is presently available and is being gathered by other individuals and groups on these animals as described in the previous section. The mariculture demonstration in the dredged material containment area was accomplished in seven sequential tasks as follows:

Task	Description
1	Site Selection
2	Site Preparation
3	Demonstration Start-up
4	Demonstration Grow-out
5	Harvest
6	Marketing
7	Report Preparation

41. Each of these tasks was necessary for the rapid, but careful, demonstration of the feasibility of profitable shrimp mariculture in dredged material containment areas. The actual grow-out site was 20 acres. This made it one of the largest shrimp pond grow-out yet attempted in the continental United States. As a result there were many scale-up factors, technique changes, and operational modifications necessary to adapt technology based on 1/2-acre ponds to a scale-up of 40x. In addition to those factors, this was only the second grow-out attempted over dredged sediments. As a result, the proposed technical program was designed to proceed very carefully and deliberately to develop the answers to uncertainties by the time that they were needed for application in the grow-out operation.

42. Site Selection. The U.S. Army Engineer District, Galveston, was contacted to get a listing of the locations, sizes, and characteristics of all presently active or new dredged material disposal sites along the Gulf coast of the State of Texas. Those that were compatible with the requirements of this particular program were then chosen from the list. These requirements were: 1) proximity to the Dow shrimp hatchery and analytical facilities in Freeport, 2) ready accessibility to facilitate the observation of demonstration ponds by as many people as possible, 3) recent or active disposal on the site (a site was preferred that had been active just prior to or on the proposed projected stocking date), 4) levees capable of containing the additional water that was to be flooded onto the sediments, and 5) proximity to an acceptable seawater source so that water pumped in over the dredged materials could be of sufficient salinity and quality to allow shrimp mariculture.

43. The landowners of the individual sites selected were then contacted to determine if they were agreeable to use of their disposal areas for this demonstration project. Those sites that were made available were inspected and a few preferred ones selected. The determination was then made as to what modifications, if any, to the sites would be necessary to allow shrimp mariculture in them and what equipment and supplies would be required.

44. Meanwhile, samples of dredged materials which comprised the containment pond bottom at each of the selected sites were taken and bioassayed with shrimp to ensure compatibility (in one case these sediments were in an adjacent canal since dredging had not yet begun). Techniques were identical with those used previously to evaluate dredged material (Quick et al. in press). Sites which failed this bioassay test were to have been eliminated from consideration. None failed, however. All the data-engineering costs, biological compatibility, site accessibility, owner cooperation, geographic location, water quality, sediment quality, and other considerations--were then weighed; and a site was selected for the pond demonstration of dredged material containment area shrimp culture.

45. Numerous dredged material containment areas were considered, and plans and work schedules for them were examined. Six were then actually visited and sampled. Sediment samples were collected in the source areas of four containment areas, and bioassays with _P. aztecus_ were performed. Chemical and physical data on the sediments at three of these sites were also obtained. One site was then revisited for detailed examination, sampling, and surveying throughout its enclosed sediments, the dikes, discharge weir, and sediment source areas. Land and easement owners were contacted. Relevant discharge permits were examined.

Containment area selection

46. As a result of this detailed effort, Galveston District Containment Area Number 85 was selected for use as the demonstration shrimp culture pond (Figures 4, 5, 6). The levees for this containment area had been constructed in the summer of 1975 with heavy clays and sand. The crest of the levees was at an elevation of +18 ft., while the surrounding land surfaces were at elevations of +3 to +5 ft. The enclosed area was 158 acres (Corps of Engineers Galveston District 1975).

47. During November 1975 through February 1976, approximately 1,500,000 cu. yd. of maintenance sediment were dredged from the adjacent Gulf Intracoastal Waterway and pumped into Containment Area Number 85. A 30-in. hydraulic cutterhead dredge was used (Figure 7). The discharge entered first one and then the other of the two corners nearest the

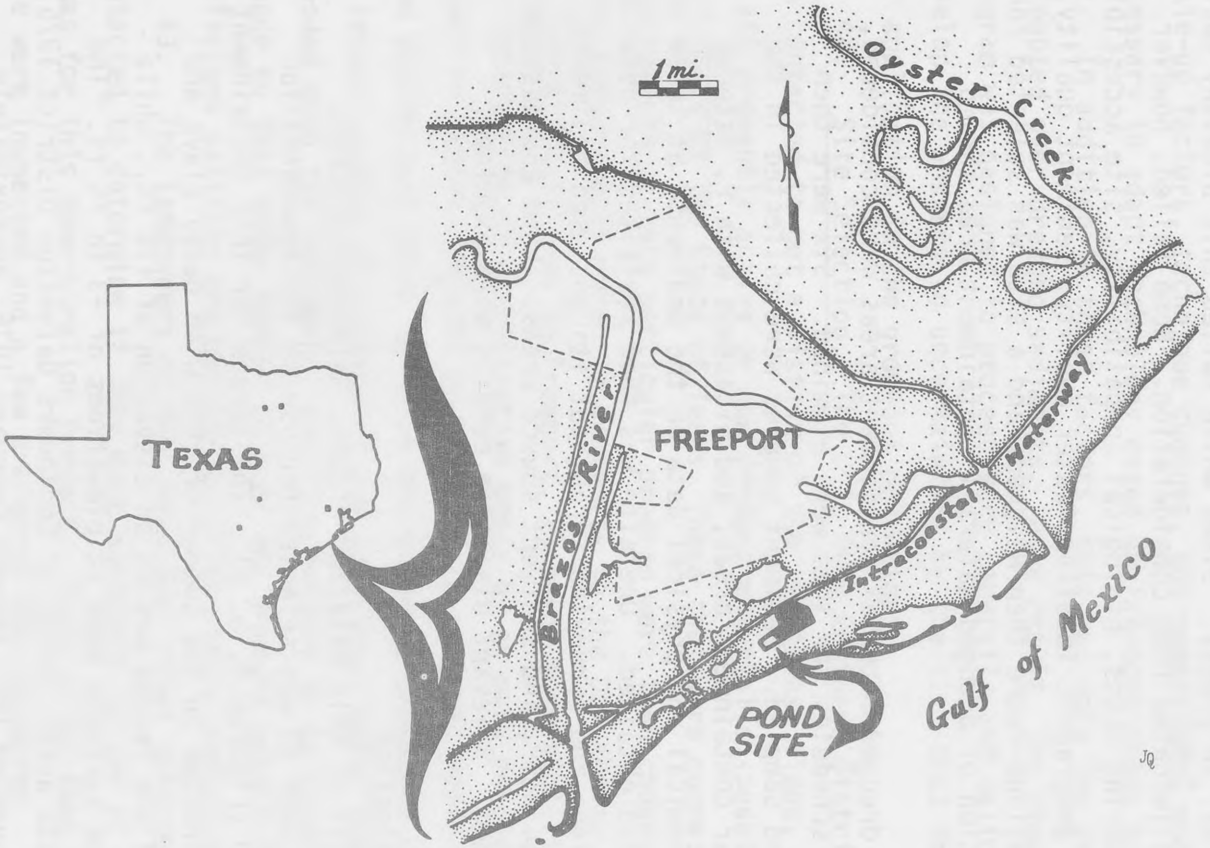


Figure 4. Shrimp culture pond site. Location of the shrimp pond site in dredged material Containment Area No. 85 near Freeport, Texas.

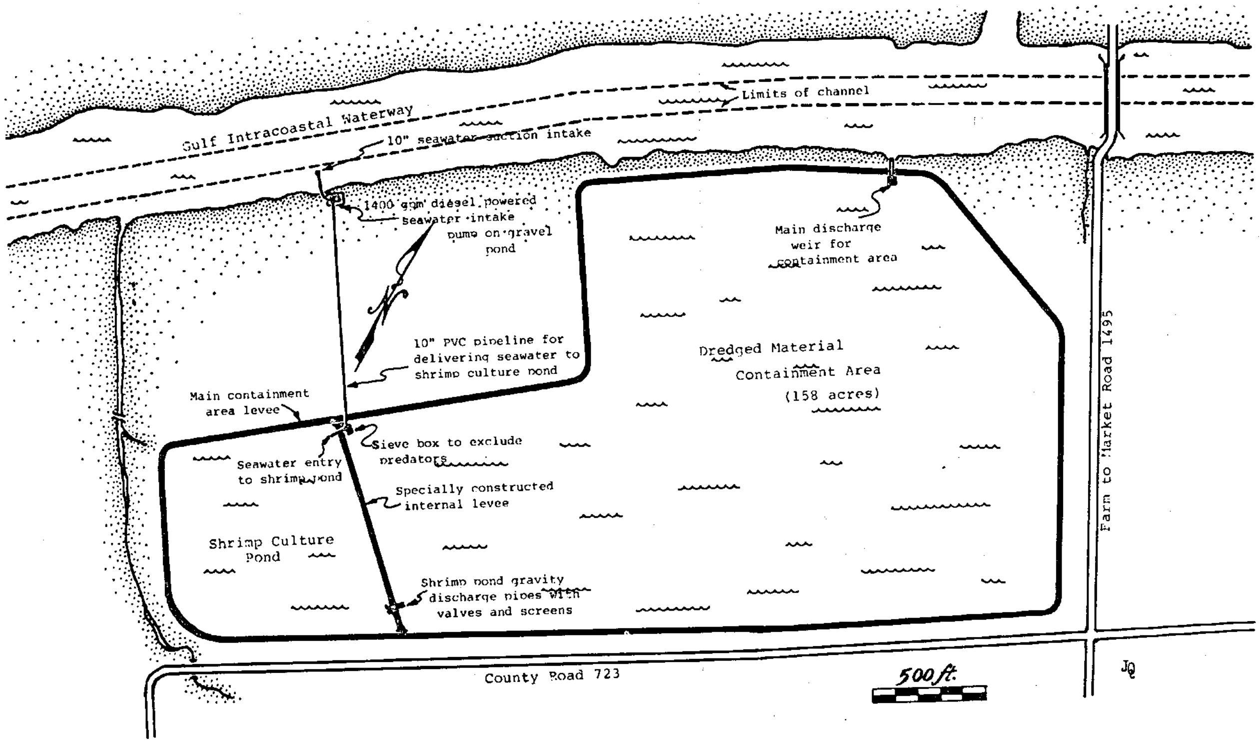


Figure 5. Galveston District dredged material Containment Area No. 85, showing shrimp pond, internal levee, and associated structures.

Figure 6. Aerial view of shrimp pond site. Containment Area No. 85 (center leveed area) one month after completion of dredged material disposal and before shrimp pond construction. All or part of six nearby contained disposal areas as well as the Gulf Intracoastal Waterway and Gulf of Mexico can be seen.

Figure 7. Hydraulic cutterhead dredge. A dredge similar to this one was used to remove sediments from the Gulf Intracoastal Waterway channel and pump the resulting slurry into Containment Area No. 85. (Maintenance dredging of Gulf Intracoastal Waterway off Galveston Bay, Texas.)

Waterway (Figures 6, 8). The very fine-grained clayey silt filled the entire containment area to a depth of at least 2 ft. Due to the locations of the discharge pipes, the sediment elevation along the north side adjacent to the Waterway was about 3 ft. higher than in the southern portion. Since this area of greater sedimentation surrounded the discharge weir, about 3 ft. of water remained over the sediments in the remote southern end even after water had been drained down to the sediment surface at the weir.

48. The entire 158 acres of Containment Area Number 85 was too great for use as a shrimp culture demonstration. However, its shape presented a possibility for constructing a relatively short internal levee to cut off an acceptably smaller acreage in the southern end.

49. Before levee construction was initiated, a detailed bottom survey was made of the proposed area to ascertain the detailed pattern of water depth, sediment thickness, and subsoil conditions. Poleing and coring from a boat and inspections by skin divers were the techniques utilized.

50. These surveys showed that the material for the primary levee was taken from a borrow area just to the inside of the levee as is common practice (Figures 9, 10). The result was a deep (to -10 ft. elevation) and wide (to >100 ft.) borrow ditch. This ditch was the key obstacle in construction of an internal levee because the strength of the dredged sediment in the ditch was insufficient to support the planned levee. In addition, compaction and dewatering of the dredged sediment after deposition had caused the formerly flat sediment surface to slump into the borrow ditches and other areas (Figure 11). It was also anticipated that the great sediment overburden plus the greater depth would make it difficult if not impossible for construction equipment to obtain virgin soils for levee construction from borrow ditch areas.

51. The detailed survey, however, located two gaps in the borrow ditch (Figure 11). Construction of an internal levee crossing these would cut off almost exactly 20 acres of water for use as a shrimp pond (Figure 12). Subsoil composition, sediment thicknesses, and other data indicated that construction of such a levee should be possible. Borrow material for the internal levee would have to be obtained from below the dredged sediments.

Figure 8. Hydraulic cutterhead dredge discharge. A dredge slurry such as this was discharged into Containment Area No. 85 to provide 1,500,000 cu.yd. of sediment, part of which underlaid the shrimp pond. The round objects shown here are clay balls resulting from virgin soil being removed in this particular operation. (Discharge to dredged material Containment Area No. 86 from Brazos Harbor bend easing project.)

Figure 9. Containment area construction technique. This is an example of the construction technique used to build Containment Area No. 85. Levee material is being taken by draglining from a borrow ditch inside the levee. Soil is being rehandled from one dragline to the other because the great height (+30 ft.) of the levee causes its width to exceed the reach of a single dragline. The discharge weir is seen to the right. (Seaways Containment Area, Quintana, Texas.)

Figure 10. Containment area borrow ditch. A new unused containment area showing the borrow ditch inside the levee and intervening berm area. A bridge crossing the ditch can be seen in the background. Bridges such as this allowed economical spanning of the borrow ditch in Containment Area No. 85 during construction of the internal levee. (Seaways containment area, Quintana, Texas.)

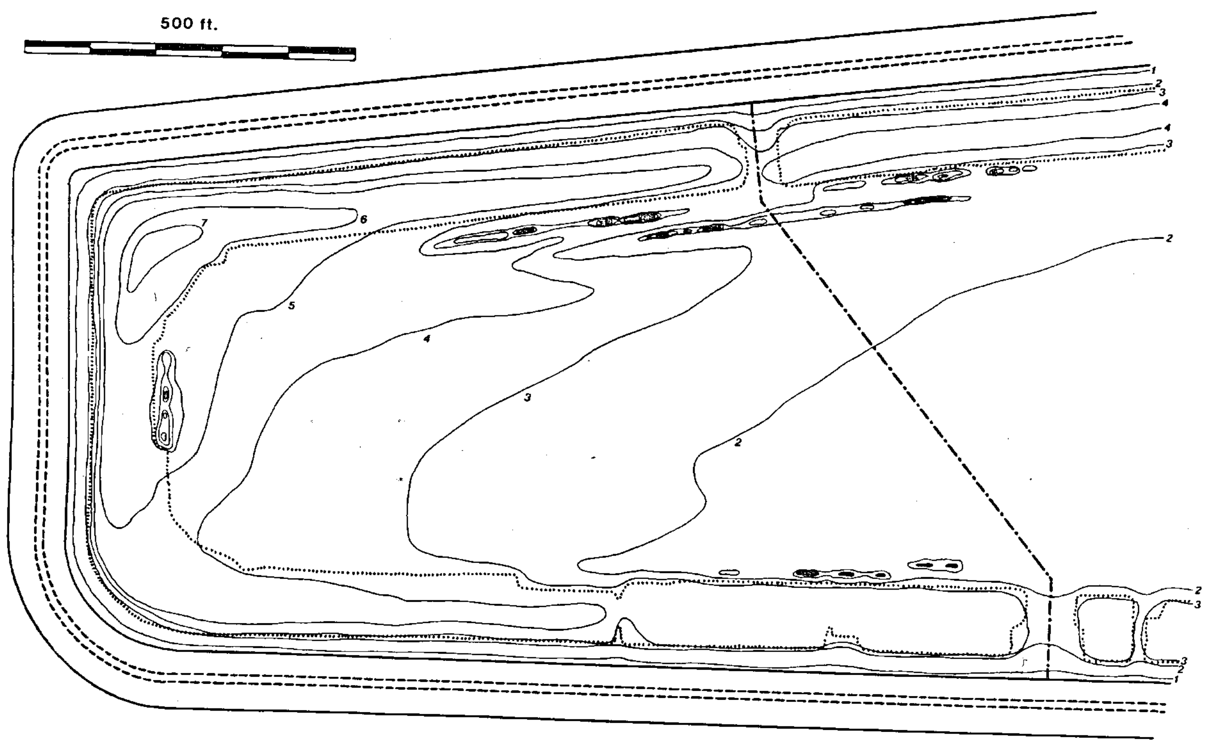


Figure 11. Containment area isobaths. Isobaths of the sediment surface in Containment Area No. 85 prior to shrimp pond construction. The slumping of sediment into borrow ditches shows the positions of gaps or bridges across the ditches. The route of the internal levee across these bridges is shown by the dashed line.

Figure 12. Shrimp culture pond in Containment Area No. 85 showing berm and beach caused by wave action. Such berms protect the levee from further erosion.

Permission and permit acquisition

52. It was necessary to obtain permissions or permits from the following sources before operations could begin:

Source	Purpose
Brazosport River Harbor Authority	Containment Area Landowner
Adjacent Landowners	For access, pump installation, and pipeline crossings
Houston Natural Gas Pipeline Co.	Pipeline crossing of pipeline easement
Southwestern Bell Telephone	Pipeline crossing of cable easement
Houston Lighting and Power Co.	Equipment operation across utilities easement
Brazoria County Road Dept.	Overweight equipment haulage on county roads
Texas Dept. of Public Safety	Overweight equipment haulage on county roads
Corps of Engineers, Real Estate	Use of Corps-operated containment area
Corps of Engineers, Wetlands	Pipeline construction in wetlands area
Corps of Engineers, Permits	Potential pond effluent discharge into navigable waters
Environmental Protection Agency	Potential pond effluent discharge
Texas Water Quality Board	Potential pond effluent discharge
U.S. Fish and Wildlife Service	Potential pond effluent discharge; use of wetlands
National Marine Fisheries Service	Potential pond effluent discharge to marine waters
Texas Parks & Wildlife Dept., Education	Permit to collect predacious fish from pond and gravid shrimp offshore
Texas Parks & Wildlife Dept., Office of the Director	Special permit to use rotenone for biological collection
Texas Parks & Wildlife Dept., Shellfish	Permit to culture shrimp
Texas Parks & Wildlife Dept., Commercial Fisheries	Permit to possess undersized shrimp (bait license)

53. Because of the small size and research nature of this project, most of these permissions and permits were obtained with relative informality and ease. The bottom two Corps of Engineers permits proved to be the most difficult and time-consuming to acquire (permits came from Galveston District Office; funding came through the separate research arm at WES).

Culture Pond Design and Engineering

54. Once all necessary permits were in hand, final design and engineering proceeded. Data were assembled on the environmental tolerances of penaeid shrimp. Both *P. aztecus* and *P. setiferus* were being considered as subjects of culture at this time. Of special importance were the optima and tolerances of each ontogenic stage of each species with respect to salinity, temperature, ammonia, nitrate, phosphate, oxygen, and pH.

55. Climatological data were also gathered, including particularly detailed information on rainfall, temperature, humidity, insolation, and winds. Data from the nearest National Weather Service office in Galveston were not adequate, so local sources were found. Information going back as far as 30 years was obtained from several groups. Corps of Engineers data had been taken at the Brazos River Floodgates about 4 miles from the pond site. Brazosport River Harbor Authority data had been gathered about 3 miles from the site. The most detailed information was gathered by The Dow Chemical Company about 5 miles from the site. In addition, Dow was operating two groups of shallow culture ponds about 4 and 6 miles from the shrimp pond site. The latter of these two projects involved gathering of very detailed information not only on weather but on pond conditions such as pond temperature, penetrating radiant energy, evaporation rate, algal growth, pond mixing, etc. Dow also provided rather detailed salinity and flow data that allowed plotting of the salt wedge in the portion of the Gulf Intracoastal Waterway adjacent to the pond site for the previous 25 years. Similar data for the adjacent Gulf of Mexico were also provided.

56. All these data were utilized to construct probable-case and worst-case weather scenarios for pond operation. The purpose was to

determine what interventions might be necessary to maintain pond conditions within the tolerances and, preferably, at the optima for each stage in the life cycle of the shrimp species being cultured.

57. The white shrimp, P. setiferus, was chosen for culture despite the authors' lack of culture experience with this species. Its lower salinity preference, more accessible brood stock sourcing areas, and late summer spawning season were the major reasons for selection.

58. It was determined that some means of supplying and discharging water to and from the pond would be necessary to control nutrient buildup (principally toxic ammonia, a shrimp waste product), salinity buildup due to evaporation (projected to be up to 87 in. per year at the pond site), and other untoward conditions. The need for low salinity dictated that the water source be the Gulf Intracoastal Waterway rather than the Gulf of Mexico. Well water could have been chosen although drilling and pumping expense as well as elemental imbalances in the water, (low pH, high hydrogen sulfide, and lack of dissolved oxygen) would have mandated a treatment procedure.

59. It was decided to operate the pond at an average depth of 3 ft. (This is the average depth excluding the borrow pit areas near the edges as shown in Figure 11.) A minimal depth of only 1-1/2 ft. is necessary to prevent excessive predation by wading birds. The greater depth, however, would provide a salinity buffer against excessive dilution by heavy rains, which had been known to reach as much as 21 in. in 48 hours in the area. A depth greater then 3 ft. was not used because calculations showed that winds common to the area would have generated waves of such sizes as to cause unacceptable erosion to the surrounding levees.

60. A decision was made to attempt to operate the pond at the upper end of the shrimp salinity tolerange range (35-38$^0/_{00}$ salinity) just before and during the August-November rainy season and conversely, maintain the pond near the lower end of the shrimp salinity range (1.5$^0/_{00}$ salinity) just before and during the midsummer dry season. This would maintain the greatest contrast between pond salinity and Intracoastal Waterway salinity. Ability to correct expected salinity changes would therefore be maximized.

61. The next stage was to design and size the equipment. A water input capacity rate of 1,600 gal. per min. was calculated to be necessary. This capacity figure was set not by the possibility of rain dilution causing an emergency but by the interaction between potential evaporation rates and expected salinities within the salt wedge in the Intracoastal Waterway. If the latter salinities increased as expected, considerable pumping would be necessary to counteract high evaporation rates (up to 1/2 in. dia.). This maximum requirement would be satisfied by a 10-in. diesel-powered 1700 gpm pump placed at the canal to pump water through a 12-in.-diameter pipe over the 1,000 ft. to the shrimp pond.

62. To exclude eggs and larvae of competitive and predacious animals the inflow water was screened through a 50 μm screen. A screen box was designed with a screen area of 30 sq. ft. composed of 50 μm 316 stainless steel mesh over fiberglass reinforcement grating (Figure 13). Water entering the box would strike the screen at an angle of 20-40° off vertical at the upper end. The water would spread and flow down the screen. Baffles across and above the screen would direct splash back onto the screen. Force vectors for particles at the surface of the screen showed that a dip of 4-10° below horizontal would be necessary to provide adequate water velocities to make the screen self-cleaning. Higher angles would cause excessive by-passing of water across the screen surface. Materials caught on the screen would be swept off the end by water rejected by the screen. Design called for a rejection of <5% for reasons of pumping economy. Water passing through the screen would flow into a 4- by 8- by 1-1/2-ft. deep collection box and subsequently into a 4- by 4- by 4-ft. head box. A 16-in. pipe would be necessary to carry this flow of water to the pond (a 24-in. pipe was finally chosen for reasons of availability).

63. It was determined that provision had to be made for a discharge rate of up to 4,300 gal. per min. from the pond to accommodate heavy rains common to the area (2-5 in. per hour rainfall rates occur ∿20 days per year). Due to the potential for very low heads, two 21-in. by 100-ft. pipes would be necessary with full flow valves (2 pipes of 24-in. diameter were used due to availability). It was also determined that a netting of 4- by 40-ft. with 1/8-in. mesh (40% void area) would allow adequate water flow without unacceptable drag and still prevent escape of the shrimp.

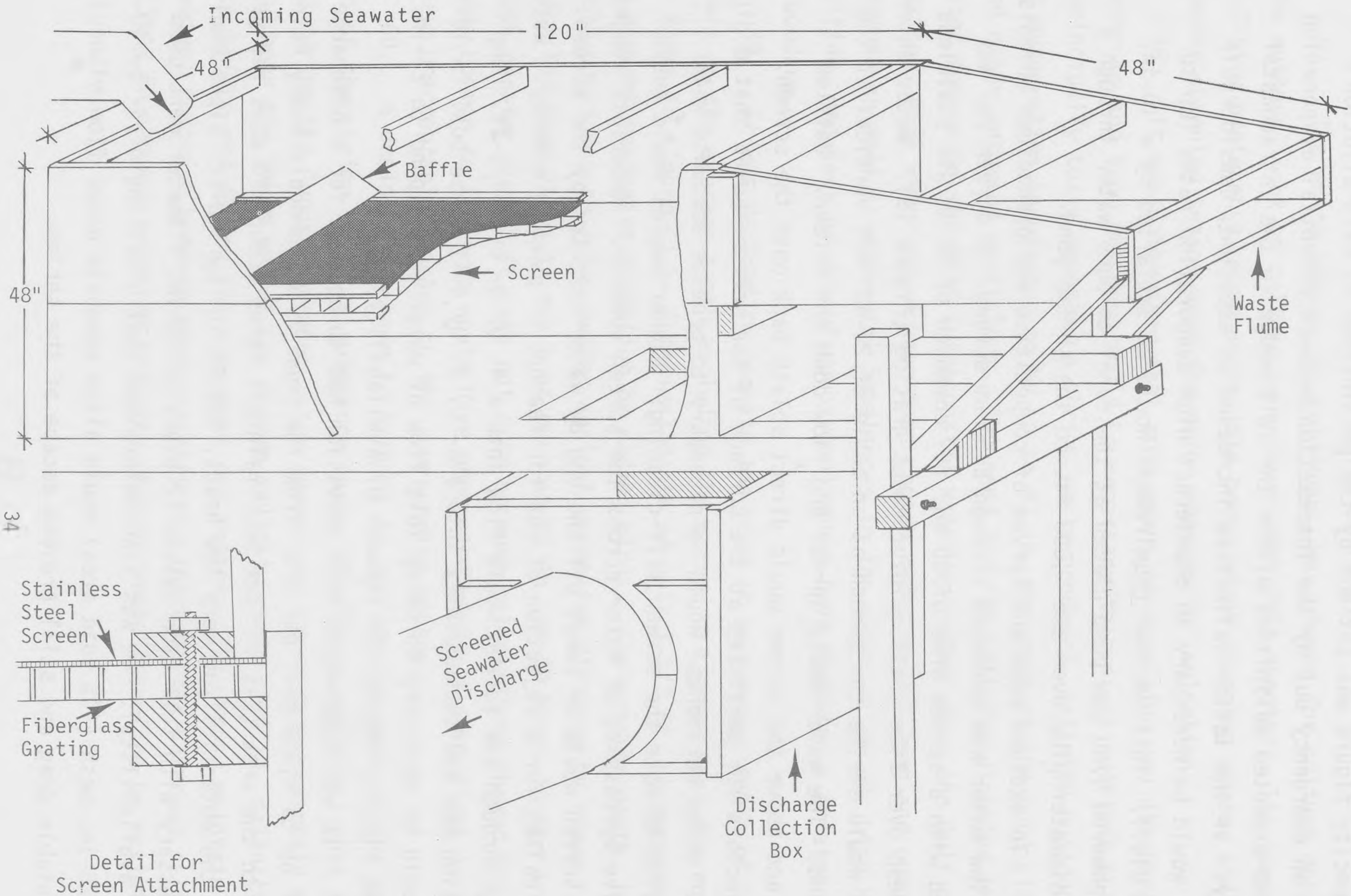


Figure 13. Design of sieve box. This self-cleaning sieve box served to screen all incoming water to 200μm at a continuous flow of 1700 gpm.

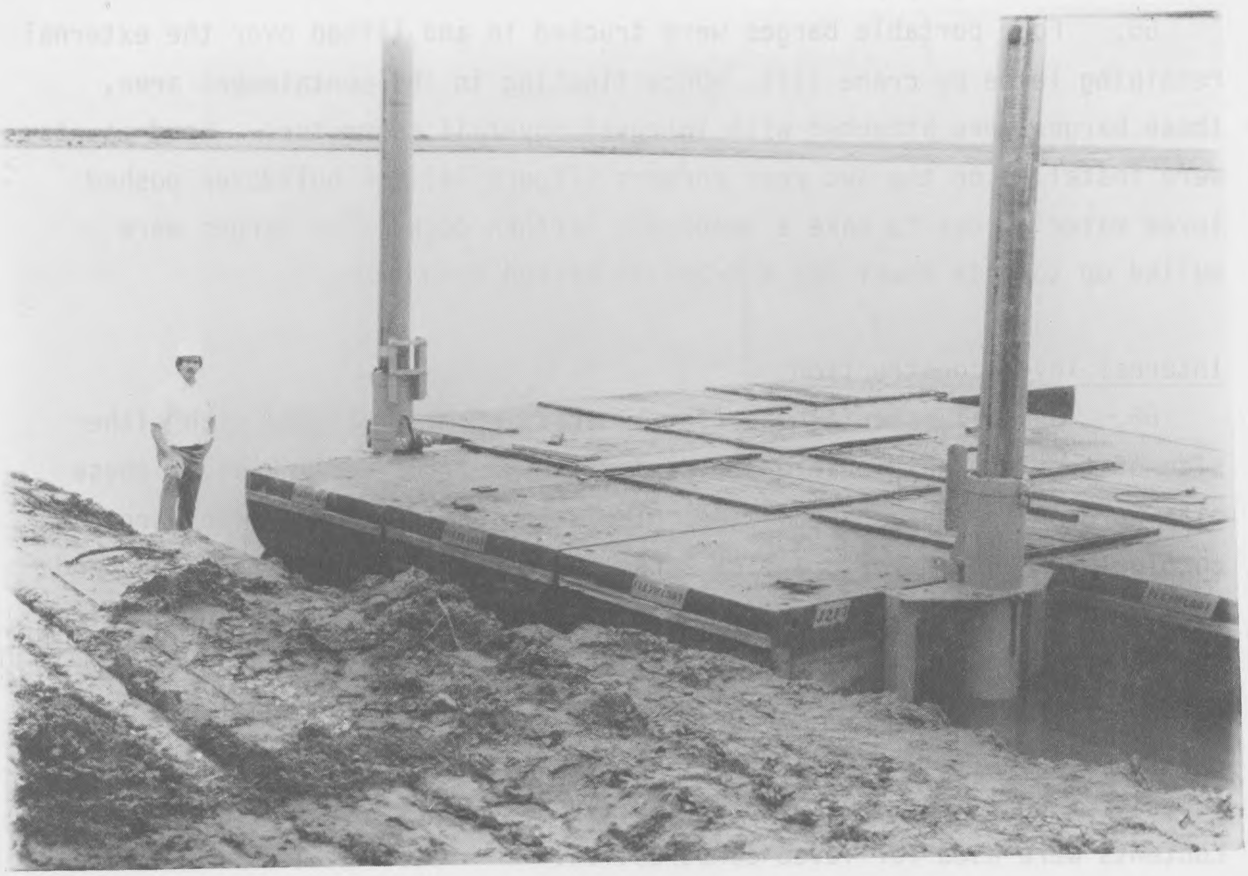


Figure 14. Barges showing spuds and connectors.

64. Data from pond surveys, soils characteristics, projected wind wave generation and erosion, and pond depth were used to design the internal levee. A preferred centerline course for the levee was chosen and surveyed. Divers checked the course for unanticipated conditions and planted marker stakes along its center line. Levee construction was done by contract along with purchase and construction of the pipeline components, sieve box, and pond discharge pipes.

65. Four portable barges were trucked in and lifted over the external retaining levee by crane lift. Once floating in the containment area, these barges were attached with integral dovetail connectors. Spud mounts were installed on the two rear corners (Figure 14). A bulldozer pushed levee material out to make a temporary earthen dock. The barges were pulled up to this wharf and a dragline walked onto them.

Internal levee construction

66. Subsoil material dug from a series of pits aligned with either side of the internal levee was used for its construction. Most of these pits were on the shrimp-pond side. The technique for moving the barge complex was to cast the dragline bucket out ahead, lift the spuds up, and then move forward by retreiving the bucket (Figure 15). Once in a desired position, spuds were lowered. Several bucket casts in one area were adequate to remove the soft dredged material. These soft sediments were utilized to backfill the submerged borrow pits created by removal of levee material. When the more solid virgin material was obtained, the bucket contents were used for levee construction.

67. The internal levee crossed the northwest borrow ditch bridge without problems and proceeded across the pond (Figure 16). At the southeast end, the contractor tried to cross the borrow ditch bridge diagonally rather than at right angles as was done at the opposite end. As a result, much virgin fill sloughed off into the borrow ditch and became mixed with the soft dredged sediment. The resulting fluid mixture would not stand, and as a result, bulldozers had to be utilized to collect a large amount of soil from outside the containment area. This soil was fed to the dragline (Figure 17) to complete internal levee construction.

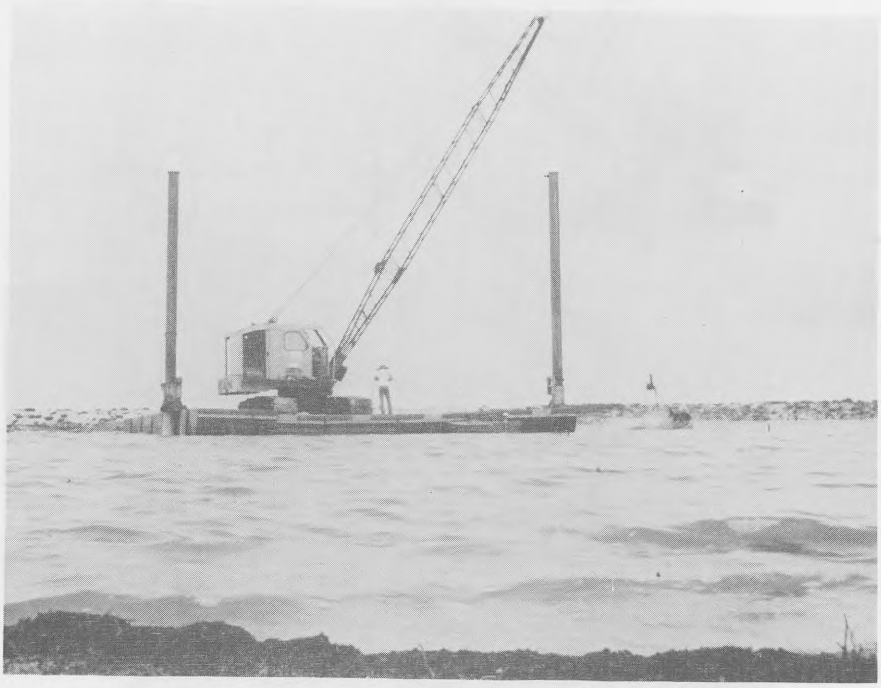


Figure 15. Barge positioning during internal levee construction. With spuds in raised position, bucket casts and retrievals were used to draw the attached barges into new positions as needed.

Figure 16. Internal levee construction. The portion of internal levee in the foreground passes straight out from the shoreline across the borrow ditch bridge before turning slightly to the left to run diagonally to the borrow ditch bridge on the opposite side of the shrimp pond.

Figure 17. Internal levee completion. The last gap in the internal levee had to be filled with soil from outside the containment area. The bulldozer is shown pushing this material along a ramp to within reach of the dragline.

68. The large wooden sieve box was transported close to the pond site by truck and carried through the surrounding salt marsh by bulldozer. The crane was then used to place it on its stand on the inside of the levee. The box was positioned with a screen slope of 4° off the horizontal (Figure 18). It was placed so that rejected water and debris would flow by gravity to the portion of the containment area outside of the internal levee. Filtered water was gravity piped to the shrimp pond (Figure 19).

69. A ramp was constructed over the main confining levee near the southeast end of the internal levee. This ramp passed over the 18-ft. levee crest and down onto a leveled staging area at the junction of the confining levee and the internal levee. This staging area was provided as a boat launching ramp, equipment preparation area, and assembly location.

70. A temporary channel was dug through the internal leveel in one of the deeper-water areas near the southeast end. Two 24-in. dia. corrugated 100-ft.-long pipes were placed therein at a 1:200 slope away from the shrimp pond. These pipes were then covered with soil to provide water passage through the levee (Figures 20, 21). A gate valve was installed on the pond end of each pipe.

Pipeline construction

71. A pump location was chosen where the bank of the Gulf Intracoastal Waterway rises rather abruptly to an elevation of about +3 ft. behind a narrow beach berm. A 10- by 16- by 1-ft.-thick pad of compacted limestone gravel was constructed about 10 ft. inland from the drop-off. A leased, 10-in.-discharge, self-priming, skid-mounted construction pump with direct-drive diesel engine was placed on the pad and tied down to 6-ft.-long screw anchors (Figure 22). A 450-gal. fuel oil tank on a 4-ft. stand was placed on the landward side of the pump.

72. An intake was assembled consisting of 60 ft. of suction-type, noncollapsible, spiral-reinforced, flexible nylon-sheathed 10-in. hose. A 5-ft. section of 12-in.-diameter PVC pipe was perforated with about 200 holes 2 in. in diameter and flanged to the pipe intake to exclude debris. This configuration was chosen to give a flow rate of slightly less than 1 ft. per sec. through the openings at the projected 1,700 gal. per min. capacity; entrapment of debris by suction would thus be minimized.

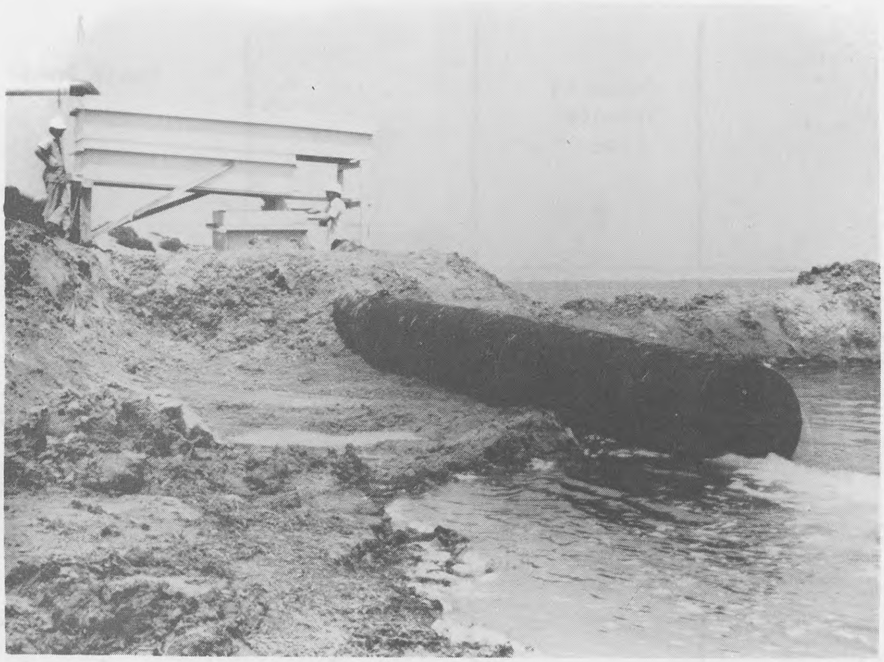


Figure 18. Sieve box installation. Box used to sieve incoming water showing discharge into the shrimp pond in the foreground.

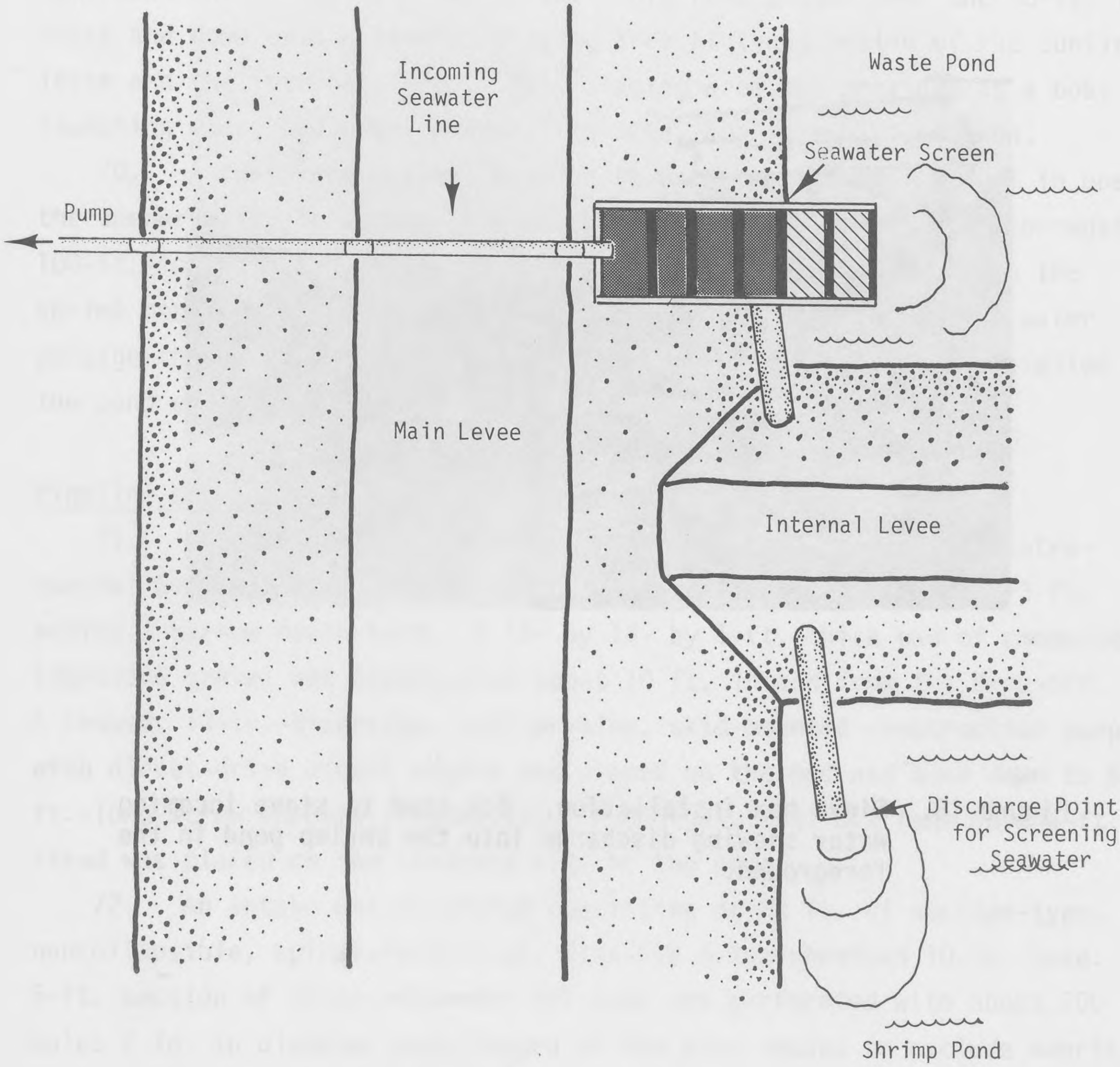


Figure 19. Influent structure design. Plan view of sieve box and associated influent structure layout.

Figure 20. Discharge pipe placement. One of the two 100 ft long discharge pipes with valve attached being placed through the internal levee.

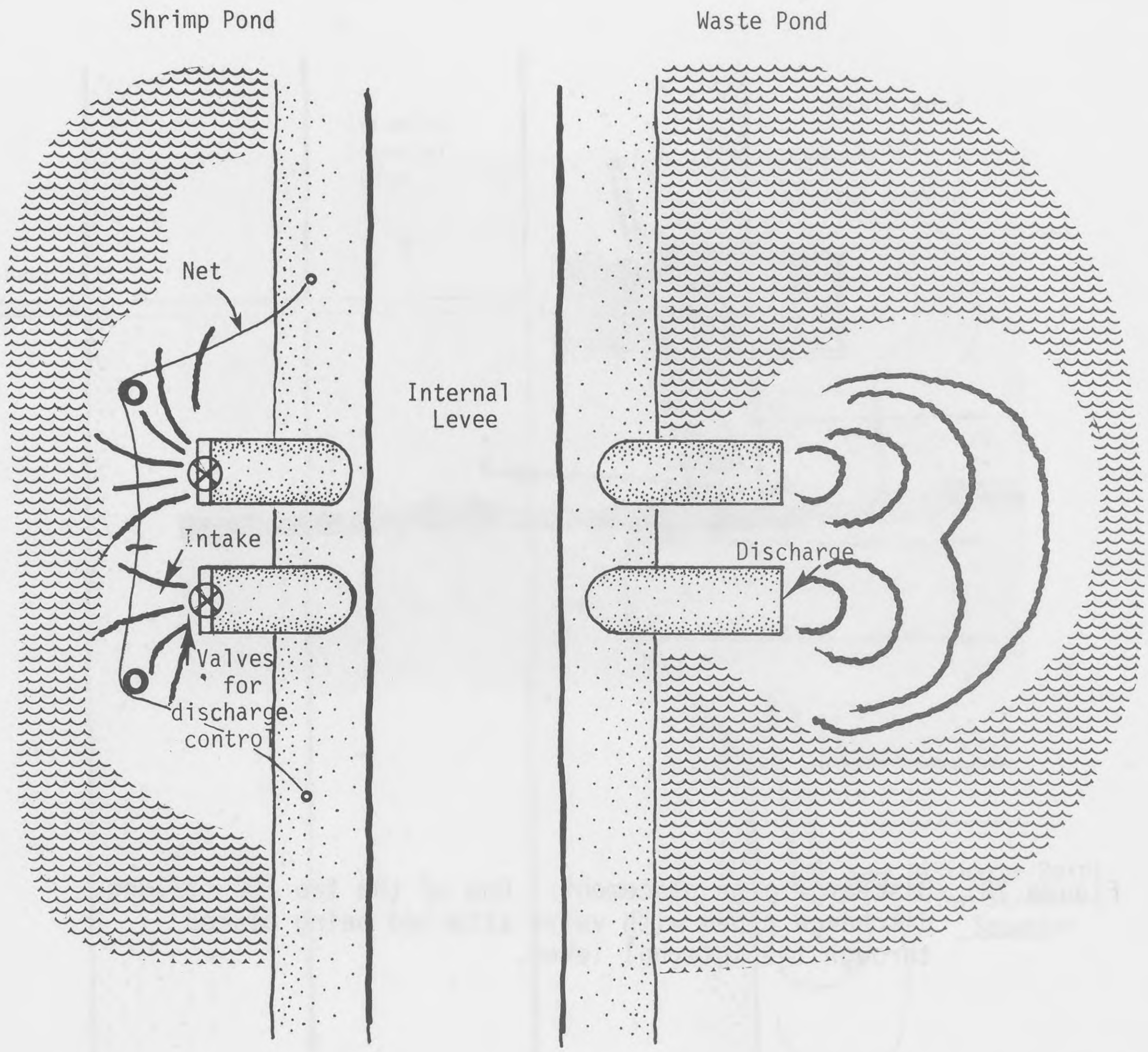


Figure 21. Discharge structure design. Plan view of the discharge pipes and associated structures placed through the internal levee.

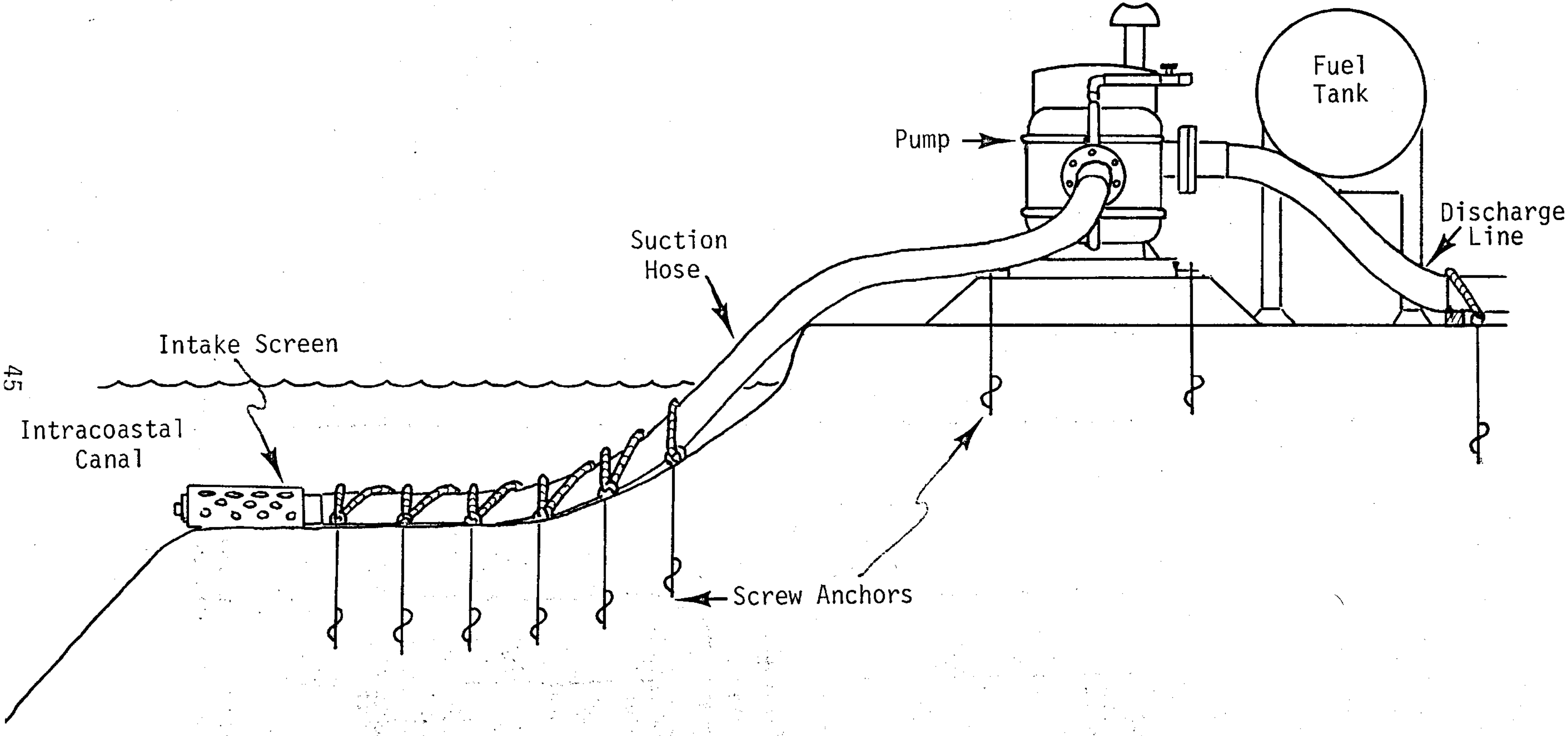


Figure 22. Intake structure. Elevation view of seawater intake on the Gulf Intracoastal Canal.

73. The intake screen was placed on a 4- by 4-ft. plywood sheet and secured to the bottom in 4 ft. of water using polypropylene ropes and 4-ft. ground anchors. The intake hose between the screen and pump was tied down firmly with a lacework of rope and about 20 additional 4-ft. ground anchors. Plans were made to extend the intake to a depth of 9 ft. if it became necessary to pump from the salt wedge to achieve salinity control.

74. A pressure gauge and bleed valve were installed on the pump discharge chamber. The bleed valve was left slightly open (approximately 2 gal. per min. water flow) to provide an air relief to prevent development of water hammer in case of any flow perturbations in the system (Figure 23).

75. A 10-ft. section of flexible rubber, 10-in.-diameter hose was flanged to the pump discharge. It was then connected to the lower end of the 1000-ft.-long, 12-in.-diameter PVC line to the shrimp pond. This flexible section absorbed pump vibration and allowed easing of thermal stresses in the PVC pipeline.

76. Schedule 40 bell and socket irrigation pipe was used for the 1000-ft. pipeline. Rubber gaskets were used at each of the pressure-fit connections. Two 6-ft. ground anchors were installed on either side of the flanged connection between the rubber and PVC lines. Stainless steel 1/4-in. cables were then run through eyebolts on the flange and tightened to put about 2,000 lb. of compression against the PVC line. This compression was necessary to prevent both thermal creep and pressure blowout of the connections

77. The PVC line passed in a straight line to the shrimp pond and up the 18-ft. levee (Figure 24). Soil was piled around the line at several places to prevent lateral displacement due to thermal and hydraulic forces.

78. At the top of the levee, the line passed over to the sieve box where a 45° elbow was installed to direct water onto the screen at the proper angle (Figure 13). Ropes and large ground anchors were used to secure both this pipe and the sieve box against slippage.

Discharge screen placement

79. A custom-made net 60-ft. long by 6-ft. deep with a 1/8-in. heavy-duty mesh was ordered (Nylon Net Company) to use in front of the shrimp pond discharge lines to prevent escape of shrimp. An extra-heavy leadline

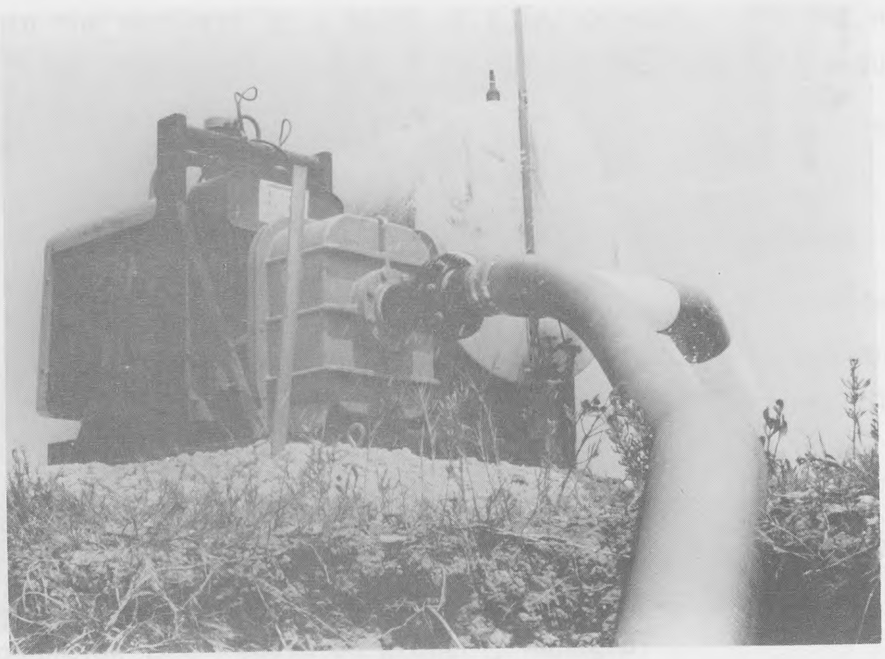


Figure 23. Seawater intake pump. Water from the Gulf Intracoastal Waterway was pulled in through the flexible hose in the foreground and discharged through the PVC pipeline to the rear. This portion of the discharge line was later replaced with a flexible hose. The fuel oil tank can be seen behind the pump engine.

Figure 24. Pipeline to shrimp pond. The 12-in. PVC pipeline passes from the pump in the foreground over the levee in the distance and into the shrimp pond. The vent valve on the pump served to prevent air lock and thence water hammer in the system.

was specified, and the netting was to be rolled over the corkline such that it would stand out of the water when installed (Figure 25).

80. Heavy-duty ground anchors were installed 20 ft. to either side of the discharge pipes at about +1-1/2-ft. elevation on the shrimp pond side of the internal levee. Posts of 3-in. PVC pipe were driven into the bottom about 10 ft. offshore 10 ft. to either side of the discharge pipes. The discharge screen net was then anchored at either end on the levee and passed on the pond side of the posts. Divers (Figure 25) then forced the leadline into the sediment to a depth of 6 in. or more. The net was periodically given visual and tactile inspection by divers to ensure that no gaps had occurred.

Pond Fertilization

81. As soon as the internal levee was completed (before rotenone application), the shrimp pond was fertilized to create a phytoplankton bloom and thus stimulate organic production. Plans called for this production to supply, via the natural food chain, all sustenance for the shrimp as had been done previously by Quick and Morris (1977) and Quick et al. (in press) in simulated containment areas. Economic projections had indicated substantial cost advantages to a culture system relying upon natural production if it could be properly managed.

82. Agricultural fertilizers were purchased at a local agricultural retailer. Pelletized urea assaying at 46-0-0 served as the nitrogen source while pelletized superphosphate assaying at 0-21-0 served as the phosphate source. These fertilizers were mixed to give a 5:1 ratio of nitrogen to phosphorus. This mixture was applied to the shrimp pond by broadcasting across the surface from an outboard motor-driven boat. Application rate was 5 lb. of urea nitrogen per acre on 8 August 1976 and again on 21 August.

83. Previous experience had indicated that later applications of urea would be necessary to maintain a phytoplankton of adequate density to feed the shrimp. However, the density and duration of the bloom resulting from these first applications was so great that no additional fertilizations were necessary.

Figure 25. Discharge screen. This net was installed to screen discharged water to prevent loss of shrimp. More importantly, this screen prevented massive influx of predatory and competitive fish from the hypersaline containment area beyond the internal levee. Note the rolled net top to prevent passage of animals or water over the screen. The diver is inspecting for holes or gaps.

Competitor and Predator Removal

84. The shrimp pond area had been continuously inundated ever since dredged material disposal had been completed. This was due to the higher sediment elevation around the discharge weir (see paragraph 47). As a result, some animals that survived being pumped into the containment area with the dredged material had prospered and even reproduced. A substantial fauna of potential competitors and predators had developed.

85. Removal of many of these organisms was necessary to prevent unacceptable losses to the shrimp crop. It was decided to remove only the fishes because of a) the danger of introducing am arthropod toxin that might later affect the shrimp, b) the lack of a rapidly inactivating invertebrate control agent, and c) the probable small threat by the invertebrates present. An ichthyotoxin, rotenone, was therefore chosen. This poison is relatively nontoxic to invertebrates, readily available, easy to apply, only moderately expensive, relatively safe to handle, rapidly degrading, and backed up by a vast amount of application experience.

86. Application rates espoused in the literature vary greatly as do data on rotenone deactivation rate, which changes markedly with temperature (Meyer 1976). Deactivation rate is not only accelerated at high temperatures but also by high salinities. This latter relationship is not well quantified, however.

87. Based on consultation with field biologists of the Texas Parks and Wildlife Department who had been applying rotenone in adjacent Galveston Bay for fish population studies, it was decided to apply sufficient rotenone to the shrimp pond to give an active dosage of 0.035 ppm. It was felt that this level would be about double that necessary to eradicate the ichthyofauna and thus provide adequate assurance of total competitor/predator removal.

88. To reduce the volume of rotenone required, the pond was drawn down by 30%. The depth surveys (Figure 11) were then used to estimate the pond volume at 17 million gal. An application of 98 lb. of the 5% active powdered rotenone was therefore required to provide the needed toxicant dosage.

89. Rate of deactivation was calculated to determine how rapidly the rotenone should be applied and how long it could be expected to remain effective. The following formula (Meyer 1965) was used:

$$E = 38 - (0.43\ T)$$

where: D = duration of toxic concentration in days
T = mean water temperature in °F

Temperature of the shrimp pond at the time of application was 86°F giving D a value of 1.02 days.

90. Due to evaporation, the salinity in the shrimp pond had climbed from 35 ppt in June to 54 ppt at the time of rotenone application in August. The quantitative effect this might have on toxin activity and decomposition was not known.

91. Since rotenone is photodeactivated (Meyer 1965), it was felt that evening application would maximize toxicity duration.

92. On the afternoon of 11 August 1976, 100 lb. of the rotenone powder was loaded into 1/2-bushel burlap bags. The operation was conducted outdoors using full-face gas masks to minimize exposure to the toxin. A custom-made PVC funnel greatly facilitated handling of the very light fine powder (Figure 26).

93. The bags were carried to the shrimp pond and loaded onto a 14-ft. skiff powered by a 7.5-hp outboard motor. Beginning about 1 hour before sundown, each bag was successively towed at about 6 knots behind the boat in a crisscross pattern to distribute the toxin evenly. Additional rotenone was broadcast into the shoreline shallows. The operation was completed about 1 hour after sundown (Figure 27).

94. Sampling was conducted three days later after the rotenone had theoretically detoxified below an effective level. Beach seines 30 ft. long were used to see if any fish remained. Results showed that a significant percentage of the sheepshead minnow, _Cyprinodon variegatus_, had escaped despite appearance of some dead fish along down-wind.

95. On 18 August 1976, rotenone was applied again at a calculated dosage rate of 0.1 ppm or 300% the previous rate. The same technique was utilized to apply the 300 lb. of rotenone powder.

Figure 26. The difficult job of handling fine, light rotenone dust was greatly facilitated by using a custom-made PVC funnel to fill 1/2 bushel burlap bags.

Figure 27. Application of rotenone powder. A preparation of 5% active rotenone powder was placed in 1/2-bushel burlap bags and towed in a criss cross pattern to disperse the toxin throughout the shrimp pond. Here, a new bag is being placed in the water for towing. Application was made in late evening to minimize photodeactivation.

Sampling was again conducted to see if any threatening ichthyofauna remained. The results were as before; C. variegatus remained.

96. On 25 August 1976, rotenone was again used to treat the shrimp pond. This time, the dosage was doubled again to achieve a calculated toxin concentration of 0.21 ppm using 600 lb. of 5% active powdered rotenone. This time a direct factory shipment was utilized to prevent any possibility of loss of activity due to age or storage conditions.

97. The method of application was also changed in hopes of increasing the effectiveness. It had been observed that much of the powder released from the burlap bags sank rather rapidly toward the bottom in a turbidity current-like phenomenon. To prevent this, a premixed rotenone suspension was sprayed across the surface of the pond or injected directly into the outboard motor propeller discharge zone. This was achieved by mounting a rectangular 100-gal. polyethylene tank on the rotenone application boat. Water from the shrimp pond was pumped into the tank with a 12-volt DC battery-powered pump. Up to 30 lb. of rotenone dust was then added and mixed in using large paddles. After vigorous mixing, the pump was reversed to spray the suspension from the moving boat into the pond (Figure 28). Application was once again made during the evening and night.

98. Some dead fish appeared, predominantly the sheepshead minnow. Sampling for fish three days later showed a substantial reduction in numbers, although a significant number still remained. By this time, the shrimp which were being simultaneously reared for stocking had become too old and large to readily maintain in tanks any longer. As a result, the remaining fish had to be left in the pond and no further attempts at removal were made.

Shrimp Hatchery Operation

Background and planning

99. As noted previously, French government scientists have succeeded in spawning a number of shrimp species in Tahiti under controlled conditions on demand (Hanson and Goodwil 1977). The techniques, however, are difficult and have not yet been perfected. Texas A&M University, the National Marine

Figure 28. Rotenone suspension application. Powdered rotenone was suspended by vigorous mixing in 100 gal of water in this boat-mounted mixing tank. A pump was then used to spray the suspension onto the shrimp pond.

Fisheries Service, The Dow Chemical Company, Ralston Purina, the Coca Cola Company, and others are presently engaged in a program to learn how to apply these techniques to P. aztecus and other species for mariculture of marine shrimp. In the meantime, wild-sourced gravid shrimp must be used as spawning stock for hatchery operations.

100. Penaeid hatchery techniques with excellent reliability have been developed for the production of large numbers of post-larval shrimp of all three Gulf species. Hatcheries are located at Galveston and Freeport, Texas; and in Miami, Crystal River, and Panama City, Florida. Production is, however, restricted; and unless prior commitment is obtained, the availability of suitable shrimp for stocking is limited.

101. The stocking rate of 30,000 hardened post-larval shrimp per acre was decided upon based on previous experience Quick and Morris 1977; Quick et al. (in press). That study stocked at 50,000 shrimp per acre, anticipating only 50% survival. Instead, survival was 76-87% or 38,500-43,500 shrimp harvested per acre. Consequently, there was evidence of food shortage and resultant premature cessation of growth. The lower stocking rate was chosen to prevent a repeat of the stunting in order to raise a larger, more valuable animal. With an expected survival of 70-80%, a harvest of 21,000-24,000 shrimp per acre would be obtained from this 30,000 per acre stocking rate.

102. Good stocking and culling practices plus various sources of mortality typically result in mortalities of 20-30% from egg to stocking of post larvae. This would make it ncessary to hatch 2,000,000-3,000,000 shrimp to provide the 600,000 post larvae needed for stocking. This number was in excess of the design capability of the Dow shrimp hatchery. Plans were, therefore, made to enter into a simultaneous hatchery run with Texas A&M University Sea Grant personnel who were operating the National Marine Fisheries Service hatchery in Galveston, Texas, under contract.

Sourcing of gravid females

103. The search for good locations to capture gravid females of P. setiferus began in June 1977, even before levee construction had started.

The first successful captures were in 30 ft. of water just offshore of Apalachicola, Florida. Severe difficulties were encountered both in moving captured females to the hatchery for spawning or in spawning them in Florida and transporting the eggs. Subsequent sourcing efforts in Mississippi, Louisiana, and the upper Texas coast met with only limited success at best.

104. However, on the night of 30 July 1976, numerous good-quality fertilized female white shrimp were located in 30 ft. of water off Port Aransas, Texas (Figure 29). Over 50 females were successfully transported back to Galveston, and a hatch of 2.13 million good-quality eggs resulted.

105. When sourcing gravid shrimp offshore, it is necessary to obtain only females since, by the time of capture, the males will have already attached sperm packets called spermatophores to the ventral surface of the females. When the females spawn, they release spermatozoa from these spermatophores to fertilize the eggs.

106. Females with "ripe" (fully mature) ovaries can easily be recognized. The ovary is readily observed through the dorsal surface of the shrimp (Figure 30). The nearly mature ovaries are gray, a color which darkens to graygreen as they mature. Fully ripe ovaries are olive green and easily recognized. Females with the darkest and widest ovarian band are selected for spawning.

107. When the shrimp were brought aboard the vessel, they were placed in holding tanks and cooled to 20°C. The shrimp survived best when transported at the lower temperature. Chilled seawater was circulated through the holding tanks as necessary. Acquisition of gravid shrimp usually required 18 to 20 hours aboard a shrimp trawler. When the trawler returned to dock, the shrimp were transferred to tanks equipped with portable aerators for transport to the hatchery tanks.

Operating the hatchery

108. As soon as shrimp arrived at the hatchery area, the best females were selected and placed in containers of fresh seawater. These females were slowly acclimated to hatchery conditions (salinity, temperature, etc.).

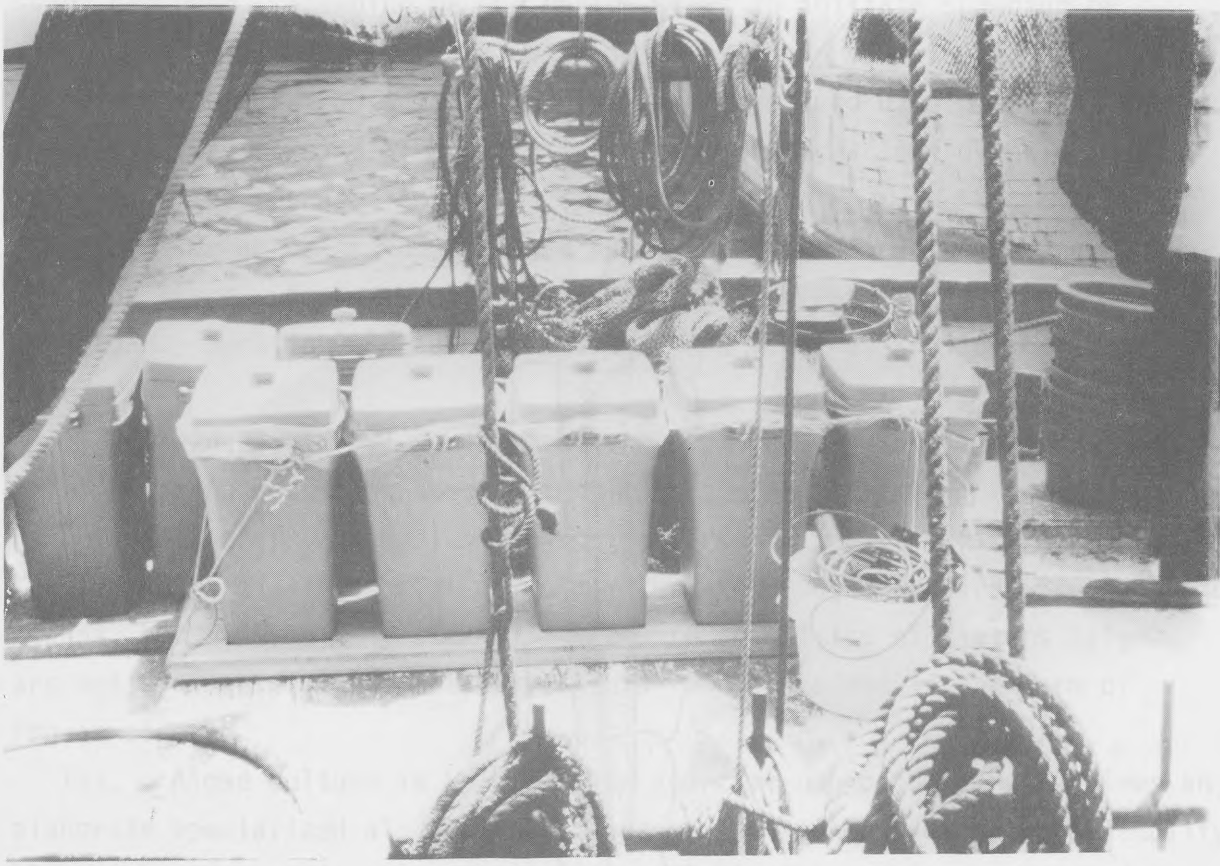


Figure 29. Collecting gravid female shrimp in the Gulf.

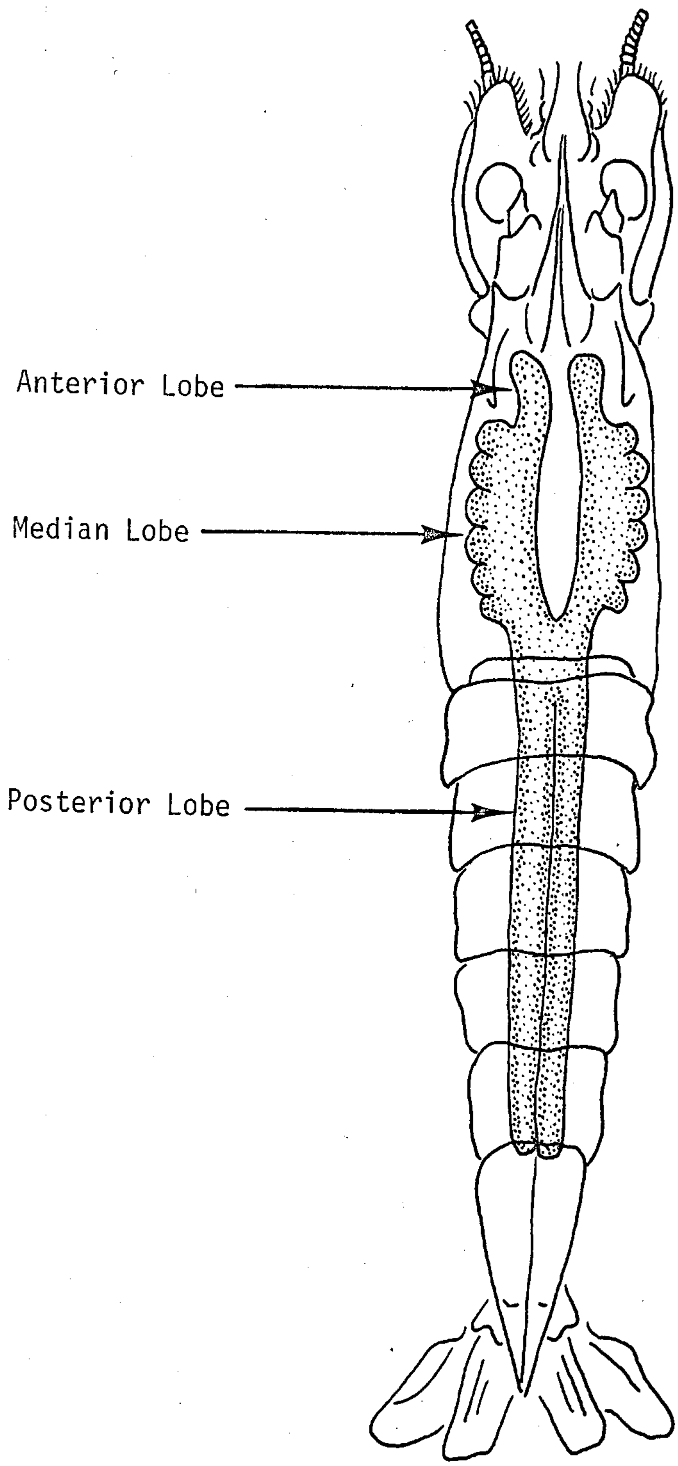


Figure 30. Dorsal view of gravid female penaeid shrimp showing ovary.

109. Between 10 and 30 females were placed in a 1700-ℓ. conical hatching-rearing tank. Once the tank was stocked, it was completely darkened since light appears to inhibit the onset of spawning. This was done by covering the tank with a layer of black plastic film. Care was taken to avoid placing the plastic film in direct contact with the water since most of the necessary oxygen exchange takes place at the surface and would be prevented.

110. Females displaying a ripe ovary usually spawn the night after being captured. Spawning by one shrimp seems to initiate spawning by others, and all the shrimp that will spawn often do so within an hour or two after the first spawning. The shrimp are removed by dip net the next morning after spawning along with any clumps of mucus left over in the water from the spawning activity.

111. Low aeration volumes were used during the first night when spawning took place. Approximately 15 hours after the eggs were spawned, hatching began. Aeration had to be increased to a vigorous rolling boil at this time.

112. Penaeid larval development proceeds rapidly in the early stages after hatching but slows down in the later stages (Table 1). The eggs hatch into the first nauplius stage, the first of eleven larval stages. The larvae partially subsist on yolk material through the first five nauplius stages, but will quickly starve if adequate quantities of diatoms (algae) are not available supplementarily. This food was added in the form of frozen algae.

113. Algae culture is both complex and time-consuming, and requires an elaborate specialized algae-culture system. To reduce the cost and simplify the hatchery operations, commercially available frozen algae were used. Frozen algae has been used for feeding penaeid shrimp larvae for several years and has been found equal or superior to live algae. Enough frozen algae (*Skeletonema costatus* and *Tetraselmis sp.*) was added to each hatchery tank to maintain a density of 40,000-60,000 cells/millilitre in the tank.

114. At least 72 hours prior to the expected time for penaeid larvae to metamorphose from nauplius V into the first protozoea stage, brine shrimp

Table 1
Stage Duration of Penaeus Aztecus

Stage	Av. hrs. elapsed fm. the appearance of one stage until the appearance of the next stage
Egg	14
Nauplius I	4
Nauplius II	7
Nauplius III	7
Nauplius IV	7
Nauplius IV	7
Nauplius V	16
Protozea I	24
Protozea II	48
Protozea III	48
Mysis I	30
Mysis II	48
Mysis III	28
Total	281

Note: Based on experiment utilizing 5 tanks.
Temperatures 28° to 29°C and salinity 30 to 32 ppt.

(Artemia salina) hatching was started in a separate brine shrimp hatchery. An average of eight to ten brine shrimp nauplii per millilitre of tank culture water was maintained by periodic additions as food for the larval shrimp. Algae continued to be added at a reduced rate (10,000-20,000 cells/millilitre) until the penaeid larvae metamorphosed into postlarvae. These algae served as food for the brine shrimp nauplii and made them more nutritious for penaeid shrimp larvae.

115. At a water temperature of 28° to 29°C, penaeid shrimp metamorphose from the egg through all the larval stages in about 280 hours (Table 1). Lower water temperatures result in a somewhat longer time. Four days after metamorphosis into the postlarval stage, the shrimp were removed from the hatchery and released into large hardening tanks.

116. The Galveston hatchery, using these techniques, had an excellent run and produced a total of over 1,500,000 postlarval shrimp. This unexpectedly large production made it unnecessary to operate the Dow hatchery.

Hardening the postlarval shrimp

117. On 13 August 1976, 1,300,000 of postlarval P. setiferus were packed in plastic bags containing about 2 gal. of water inflated with 1/2 cu. ft. of oxygen. Bags were sealed and placed in styrofoam ice chests to retard any temperature changes. Density was about 80,000 per gallon of seawater. The postlarval shrimp were transported to Freeport, Texas, a transport time of about 1-1/2 hours. There, they were slowly acclimated to and released into a 26-ft.-diameter, 13,000-gal. hardening tank (Figure 31).

118. On 15 August 1976, 935,000 additional four-day postlarval white shrimp were shipped from the Galveston hatchery to the Dow hardening facility. Transport was accomplished in large insulated chests at a density of about 20,000 postlarvae per gallon. Aeration was provided by pressure-regulated air from compressed air cylinders flowing through air stones placed with the shrimp.

119. Upon arrival, the shrimp were brought slowly to the temperature of the hardening tank and released into it (Figure 31). No salinity or pH adjustment was necessary since this had been done over a period of days prior to shipment.

Figure 31. Post-larval shrimp hardening tank.

120. Four days prior to the arrival of the shrimp, the hardening pool had been filled with seawater filtered through a matrix filter of 50-μm nominal porosity. The pool was fertilized with 10 lb. of cottonseed meal. A phytoplankton bloom resulted which had become quite dense at the time of stocking, thus providing a food source for the shrimp.

121. A rectangular floating brine shrimp hatchery was placed in the hardening pool. This 4-ft.-square tank (Figure 32) was stocked daily with desiccated brine shrimp cysts. The volume was changed slowly from 4 oz. of cysts per day to 30 oz. as the shrimp grew. The hatching chamber was designed with a mesh bottom of a pore size (1 mm) that would allow the brine shrimp to escape but not allow the penaeid shrimp to enter. The top was covered with black polyethylene plastic film to exclude light. The dominant illumination was, therefore, through the bottom mesh such that the positively phototrophic brine shrimp nauplii were attracted to swim through the mesh into the shrimp culture area. Air stones operated in the hatchery provided the turbulence necessary to achieve a good brine shrimp hatch. The algae being cultured in the pool provided food for the brine shrimp.

122. The original plan had been to stock the shrimp pond on or about 22 August. Both the postlarval shrimp being hardened in Freeport and an additional 300,000 being hardened in Galveston were to have been used. However, the failure of the first rotenone treatment to remove the threatening ichthyofauna resulted in a decision to hold the shrimp in the hardening facilities longer and try a second rotenone application to the pond.

123. By 24 August, the phytoplankton bloom in the hardening tank had begun to respond to the nutrifying wastes released by the shrimp. The stagnating algae population bloomed once again. Carbon dioxide became limiting, and carbonate was alternatively used as a carbon source. The resultant plunge in carbonate level left the buffering system deficient. As a result, pH began to climb after sunrise and approached 9, an alarming level, by midafternoon. Hydrochloric acid additions were made to control these excursions. As much as 8 lb. of concentrated acid was required per day.

124. Meanwhile, the additional 300,000 postlarval shrimp were being held in similar hardening facilities in Galveston. By 23 August, growth caused these shrimp to exceed the capacity of the system. Similarly, there

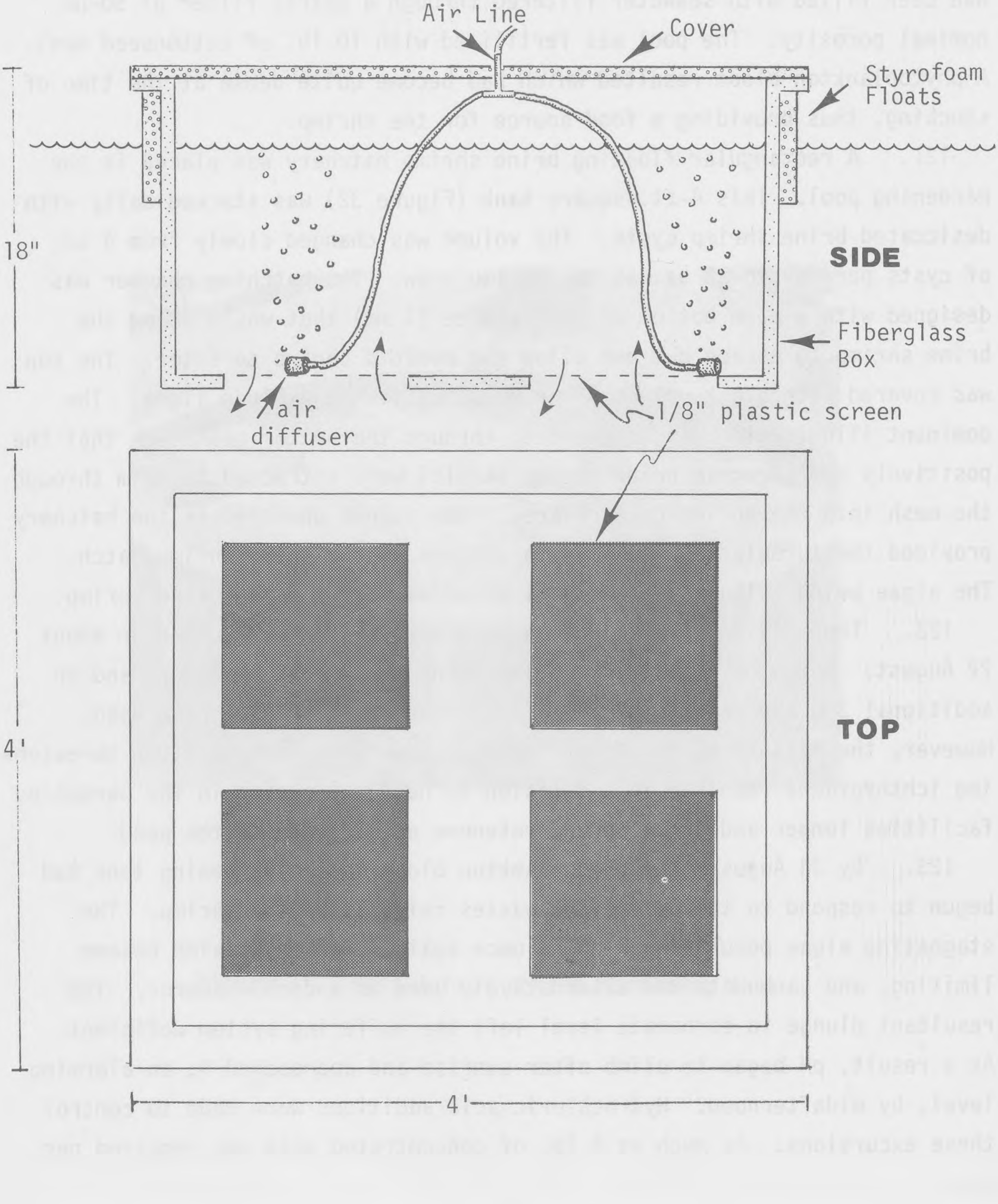


Figure 32. Floating brine shrimp (Artemia salina) hatchery.

was no spare capacity available in the Dow hardening facility to accommodate them. They, therefore, had to be delivered to Freeport and stocked directly into the shrimp pond as an emergency measure. At this time, considerable ichthyofauna remained in the pond; there were two subsequent rotenone applications. Pond salinity was at 42 ppt.

125. By 25 August, the postlarval shrimp in Freeport had exceeded the hardening pool capacity there, and some mortality had begun despite the extraordinary measures being taken to preserve water quality and provide food. Two days were allowed for the detoxification of the last rotenone application, and these shrimp were stocked into the pond.

126. The transfer operation proceeded as follows. The drain line on the hardening pool was opened. A large sieve over the inside of the drain prevented the escape of any shrimp. A 30-ft. seine of 1/8-in. mesh was initially used to corral the shrimp (Figure 33). Shrimp were then dipped out in 5-gal. plastic buckets. The contents of each bucket were poured into a 10-gal. plastic tub placed in a 100-gal. rectangular polyethylene tank (Figure 34). The tub was supported from below such that its rim stood several inches above the water. When concentrated shrimp suspension was poured into the tub, the water escaped through fine mesh panels in the side. The shrimp were thus further concentrated and then transferred into 40-gal. capacity transfer containers for transit to the pond. Each container received about 20 gal. of shrimp. Heavy-gage virgin polyethylene drum liners were used in each container.

127. Once each 40-gal. transfer container was filled, it was hand mixed vigorously and a 1-ℓ. sample was immediately taken. This sample was poured into a shallow transport plastic tray against a black background. The total number of shrimp was counted. A metre stick had been previously calibrated to read the water depth in the 40-gal. containers in units of volume. Use of this volume and shrimp density data for each container allowed calculation of the number of shrimp removed from the hardening pool.

128. As the level of water in the hardening pool decreased due to the progressing drain operation, it became difficult to use the seine. Long-handled fine-meshed dip nets were used to remove the remainder of the shrimp.

Figure 33. Harvesting postlarval shrimp from the hardening pool.

Figure 34. Device for secondary concentration of the post-larval shrimp removed from the hardening pool. Note screened panels in side of 10-gal. tub.

129. After each transfer container received its allotment of shrimp and the shrimp were counted, it was loaded aboard a pickup truck. An air stone was placed in each container and the drum liner was pulled together and tied leaving an air space above the enclosed water (Figure 35). Air was supplied through regulators on a bank of compressed air cylinders.

130. As soon as all hardening pool shrimp had been secured aboard the truck, they were transported the 10 miles to the shrimp pond. There each transfer container was in turn disconnected from the air supply, carried over the retaining levee, placed in about 1 ft. of water at the pond edge, and reconnected to a compressed air supply. Over the next 2 hours, water from the shrimp pond was slowly added to each transfer container to allow the shrimp to adjust to the slightly different chemical environment of the pond, especially the higher salinity (from 29 ppt in the pool to 35 ppt in the pond) and lower pH (from 8.8 to 8.4) (Figure 36). Pool and pond temperatures were the same (88°F), so no adjustment was necessary. The hardened shrimp were then released into the shrimp pond. Similar procedures had been used previously for the 13 August stocking except that the shrimp containers at that time were plastic bags in large ice chests.

Shrimp pond water management

131. When initial surveys of Containment Area Number 85 were made, almost the entire retention area was flooded with water. In the southeast end where the shrimp pond was later constructed, a water depth of about 4 ft. had resulted in considerable wind-wave generation. These waves produced substantial erosion of the retention levee base.

132. In subsequent weeks, as construction began and proceeded, rainfall was first negligible, then frequent, and again absent. During this period, over 1-1/2 ft. of water evaporated from the containment area. As a result, a beach like area was exposed around the inside of the levee (Figure 37). This berm protected the levee from further wave erosion, even in sustained winds of up to 40 knots. Pumping and discharge in and out of the shrimp pond were therefore coordinated to maintain a low water level and thus maintain the protective beach area.

Figure 35. Hardened post larval shrimp being readied for shipment to the pond for stocking.

Figure 36. Adjusting hardened shrimp to the shrimp pond chemical environment prior to stocking.

Figure 37. Berm on retention levee. This beach resulted from a decrease in water level and protected the levee from further wave erosion.

133. The evaporation mentioned above caused a salinity increase from 31 ppt to 56 ppt. Considerable pumping from the Intracoastal Waterway was necessary to bring the salinity down to a safe level of 35 ppt by the time of shrimp stocking on 27 August. The salinity had been 42 ppt on the previous 13 August stocking day.

134. Increases in salinity due to evaporation continued throughout the shrimp grow-out. Water was pumped periodically to keep the salinity below 36 ppt.

135. Toward the end of the grow-out period, phytoplankton blooms became excessively heavy due to the high NH_3 and NO_3 levels caused by the biological activity in the pond. The algae began to reduce the carbonate levels with resultant pH instability. Nighttime dissolved oxygen levels also become dangerously low ($\leq$2.5 ppm). Pumped seawater was therefore exchanged through the pond for two periods of about a week as necessary to flush out the nitrogen compounds, dilute the algae, and replenish the carbonate.

Grow-out sampling

136. The shrimp pond was visited daily and visually checked for water level, algal bloom condition, water conditions, pump operation, intake sieve operation, discharge valve settings, and discharge net condition. Numbers and species of predatory birds were noted. The shore was walked in the latter stages for evidence of poaching or shrimp mortality. The salinity of the pond and the incoming water was checked every second day.

137. Once per week, samples were collected for the following analyses: salinity to ±0.5 ppt, pH to ±0.01, ammonia to ±5%, nitrite to ±3%, oxygen to ±0.2 ppm, turbidity to ±4%, and algae counts to ±5%. Analyses for carbonate, trace elements, contaminants, and other parameters were made as needed.

138. Also once per week, a 50-ft. beach seine was hauled in at least three locations to obtain a semiquantitative shrimp sample. The area covered and duration of each haul were recorded. All captured shrimp were counted and an average weight determined. Shrimp were examined for health, type of food and amount being consumed, antennal length, shell hardness and condition, sexual development, and evidence of epiphytes, parasites, or disease. Antennal length is important because it is a good barometer of

the level of crowding--normal antennae signify no crowding stress, short cropped antennae indicate intense crowding. Shell condition is important as a rough indicator of molting frequency and mineral metabolism.

139. No attempts were made to further control the ichthyofauna. Limited removal of blue crabs (Callinectes sapidus) was achieved using dip nets. Birds were not molested.

140. No organic or prepared food of any kind was added to the pond.

Shrimp pond harvest

141. Original plans called for the harvest of the shrimp pond during the third and forth weeks of November. Record cold beginning on 4 October forced early harvesting.

142. Harvest began on 19 October 1976. A specially altered 500-ft. by 8-ft. seine was used. The leadline had been replaced with a thick bundle of soft cotton cords with weights interspersed at regular intervals. This was done to keep the leadline from digging into the soft mud bottom. Floats on the corkline were spaced at half the usual distance to minimize dipping of the line and consequential loss of shrimp. The mesh was 1/2-in. stretch measurement and tarred.

143. In use, the net was deployed from the stern of the sampling boat along one end of the pond (Figure 38). Long haul lines were then deployed to the opposing shores as shown in Figure 39. The net was then hauled the length of the pond. One end was kept against the shoreline to keep the shrimp from flanking it. When the net reached the far end, it was progressively pulled ashore. Considerable effort was given to keeping leadlines in constant contact with the bottom and keeping corklines on the surface. This required the use of divers, especially in areas of uneven or deep bottom. The record-breaking cold soon made such work uncomfortable, even in wet suits, as water temperatures plunged to 54°F and below and were commonly accompanied by 40°F air temperatures, 30-knot winds, plus rain.

144. As a result, most harvesting done after 20 October was done with a small modified otter trawl. This 30-ft. net had 1/2-in. stretched mesh, no tickler chain, and lightened doors to prevent its digging into the soft mud. Since the extraordinary cold had caused the shrimp to remain buried

Figure 38. Harvesting seine being deployed.

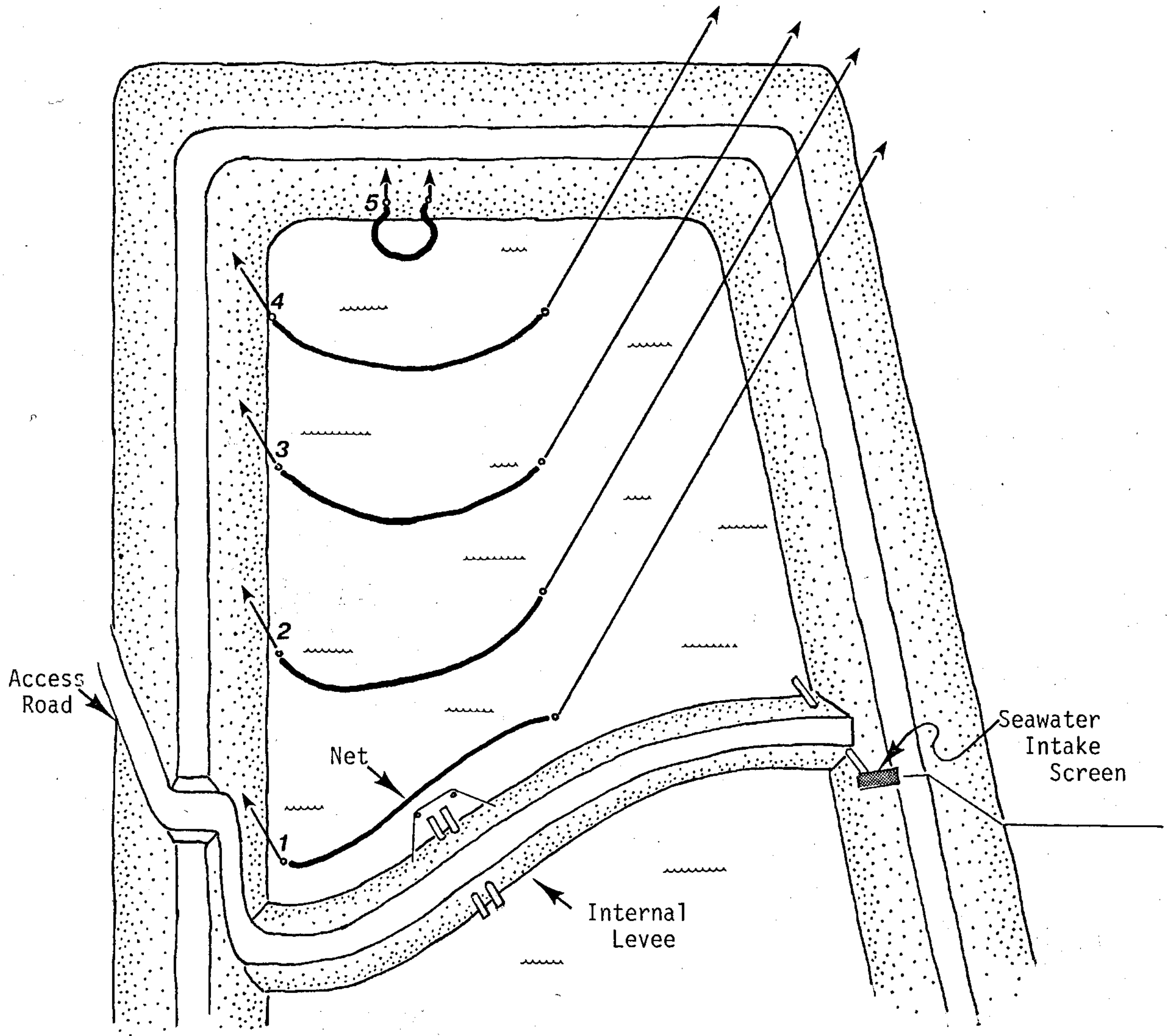


Figure 39. Shrimp pond harvesting technique. The seine is deployed along the near shoreline (1) by boat, and then hauled via long haulage lines progressively up the pond (2)-(4). At the far end, the net is bagged (5) and hauled ashore with the catch.

and relatively insensitive, the standard heavylead line was kept on the net. This caused it to dig into the sediments slightly to capture the lethargic shrimp.

145. Samples of harvested shrimp were sent to the National Marine Fisheries Service National Seafood Quality and Inspection Laboratory in Pascagoula, Mississippi, to be analyzed for total plate count of bacteria (TPC); total coliform bacteria Eschericia coli, Salmonella sp. and Staphylococcus sp.; petrochemicals; methylene chloride; polychlorinated biphenyls (PCB); mercury; chlorinated hydrocarbons; and organoleptic texture and taste quality. This was done to see if the product met U.S. Department of Commerce criteria for raw shrimp and could thus be sold into food markets.

146. Data on the bottom area covered by each sampling haul and the amount of shrimp captured in each haul were used to periodically extrapolate the total population level of the pond. Consistently low estimates derived from a particular harvest technique were indicative of poor capture efficiency.

Test marketing of cultured shrimp

147. Plans were made to test market cultured shrimp through Booth Fisheries Company in Brownsville, Texas. Harvest difficulties caused by the severe weather and sampling gear inefficiencies caused abandonment of this plan. Smaller amounts of shrimp were sold into the bait market, however, through local dealers. In addition, over 1000 lb. of shrimp was distributed for human consumption with subsequent feedback on acceptability and quality.

Economic projections and recommendations

148. The results of this and previous studies were used to evaluate full-scale economics for commercial containment area shrimp culture. Several different operational scenarios were developed and evaluated.

149. The economics suggested that a rather radical departure from present shrimp culture technique should be made. Numerous contacts in government and industry were made to evaluate the technical feasibility of constructing and operating a floating hatchery utilizing an adaptation of the Japanese green-water hatchery technique (Hudinaga 1935, 1942; Hudinaga and Kittaka 1967; Fujinaga 1963, 1969).

PART III: RESULTS

Preexisting Fauna and Flora

150. The containment area chosen for this study was newly constructed. No permanent bodies of water existed in the site prior to construction. The one small (∿3-acre) ephemeral marsh present was fresh water. The minimum elevation was +3 ft. above mean high water, more than enough to prevent tidal inundation.

151. Nevertheless, in the preliminary work just 2 months after the completion of dredged material discharge, a teeming population of sheepshead minnow, C. variegatus, was already present. Population characteristics indicated that the maximum sustainable biomass had already been reached. Gravid females were uncommon and showed low fecundity. Males did not show well-developed courting or display coloration. No juveniles were present, but large numbers of sexually immature or subadults were present, suggesting stunting.

152. Later samplings disclosed large populations of the tidewater silverside minnow, Menidia beryllina, and the grass shrimp, Palaemonetes pugio. No juveniles or gravid females were ever seen among captured M. beryllina. P. pugio, on the other hand, showed an active growing population with numerous gravid females, high fecundity, and all sizes of juveniles. No other Palaemonetes species were found. The cosmopolitan barnacles and oysters were also absent.

153. A number of other species were present in the containment area. Some of these were captured in preconstruction sampling. Most were subsequently identified from the rotenone kill. Rate of catch data from seine sampling allowed rough estimates of biomass for some species. This was done by enclosing specific areas (typically 5,000 ft. sq.) with nets at various sampling locations. Animal density for each species was then calculated for each of 4 basic habitats: shoreline, shallows, borrow ditch, and open pond. This density data was then extrapolated to the total area of each habitat in the pond and totaled. Pond biomass data for other species was calculated from counts and weights of fishes killed by the rotenone

treatments (Figure 40). Nonfloating individuals were sampled to determine unit-area frequenty and added to the totals. Table 2 lists the species present prior to shrimp stocking along with estimated biomass. The biomass data is based on wet weight and should be considered accurate to about a half order of magnitude.

154. There was almost no benthic vegetative growth in the containment area, presumably due to the high turbidity, variable water level, and ever-changing salinity. Attached vegetation in the shallow photic zone would have been alternately exposed to atmospheric drying and submerged into the aphotic zone. Temperatures reaching 106°F in the very shallow (<6 in.) flats could have also been limiting.

155. A moderately dense phytoplankton bloom was present and dominated by small diatoms such as _S. costatum_ at salinities up to about 40 ppt. At higher salinities, various photosynthetic flagellates such as _Dunaliella sp._ became dominant.

156. The phytoplankton was therefore the only significant primary producer group. The small amounts of benthic algae, composed almost totally of cyanophytes such as _Oscillatoria sp._ on soft substrates and _Lyngbya_ on sticks and other debris, were inconsequential. The inner slopes of the confining levees were only sparsely vegetated, primarily with low shrubs and composite flowering plants that furnished little organic input to the containment area biota.

157. Three animal species almost completely and equally dominated the containment area biota: the sheepshead minnow (_C. variegatus_), the tidewater silverside fish (_M. beryllina_), and the grass shrimp (_P. pugio_). Observation and gut analyses indicated that _C. variegatus_ was functioning as an omnivore. Polychaete worms, plant detritus, and mud dominated its stomach contents. The others were primarily herbivorous with planktonic algae dominating the stomach contents.

158. All three species were placed in a 100-gal. aquarium with sand bottom to observe interspecific interactions. Problems arose in providing adequate long-term nutrition to _M. beryllina_. Nevertheless, in a year of observations, no evidence of predation of adults or juveniles was observed. Failure of _P._ pugio larvae to appear following spawning could have been due

Table 2
Species and Biomass Present in Containment Area No. 85
Prior to Stocking with Shrimp

Species	Approximate Biomass, lb	Biomass, lb/acre
Marine Invertebrates		
Palacmonetes pugio, Grass shrimp	1,700	85
Callinectes sapidus, Blue crabs	200	10
Polychaete worms, several species	600	30
Subtotal		125
Marine Vertebrates		
Cyprinodon variegatus, Sheepshead minnow	1,600	80
Leiostomus xanthurus, Spot	250	12.5
Fundulus sp., Spotted top minnow	20	1
Mugil cephalus, Striped mullet	10	0.5
Menidia beryllina, Tidewater silverside	1,800	90
Subtotal		183
Total		309
Terrestrial		
Uca longisignalis, Fiddler crab	60	3
Cicindella sp., Tiger beetle	10	0.5
Subtotal		3.5
Grand Total		312.5

predation or to lack of appropriate larval foods. Intraspecific competition for food, however, seemed to be the primary population-limiting mechanism. Over the first 9 months, the M. beryllina slowly died out. After a year, numbers of P. pugio were reduced by about half and numbers of C. variegatus were virtually unchanged.

159. The dredged material containment area, including that portion of it used later for a shrimp pond, was an almost totally enclosed, independent, functioning ecosystem. It was a system of very low species diversity, probably due to its limited biological input, short period of existence, and stressful specialized environment. Nevertheless, it was biologically active, having production sufficient to support an estimated +300 lb. per acre of mixed herbivores and carnivores.

160. Evaporation caused high salinities to develop in the shrimp pond prior to seawater pumping and later in the portion of the containment area outside the shrimp pond. This slow increase provided a natural laboratory to determine the maximum salinity tolerance of several species. C. sapidus mortalities were first seen at 42 ppt, and no individuals could be found after 56 ppt was exceeded. L. xanthurus began to die at about 50 ppt and were gone by the time 65 ppt was reached. M. beryllina was still present at the salinity maximum of 66 ppt, but numbers were greatly reduced. No evidence of mortality or population decrease was observed for C. variegatus even at 66 ppt.

161. Even though C. variegatus tolerated very high salinities, it obviously preferred values at or below 35 ppt as evidenced by behavior. As that portion of the containment area outside the shrimp pond was approaching 66 ppt salinity, the shrimp pond was being maintained at 31-36 ppt by pumping. A substantial problem was encountered when the discharge valves were opened to discharge water from the shrimp pond. Fish were attracted to the lower salinity water, swam through the pipes, and gathered in a seething mass inside the net installed to prevent escape of shrimp. Even a single small hole would have resulted in the entry of tens of thousands of fish into the shrimp pond.

162. When this phenomenon was discovered, the valves were closed. The mass of fish quickly depleted the dissolved oxygen locally and expired. The valves were cracked open to expel the resulting mass of fish carcasses. Additional fish quickly collected and swam into the pipes until they formed an almost solid mass. The velocity of flow through the small opening due to about 8 in. of head proved too swift to negotiate although the fish continued to gather downstream of the discharge pipes until a large dark mass could be seen.

163. Sections of plastic mesh were subsequently secured over the discharge ends of each of the two pipes to prevent the fish from entering. The fish persisted in jumping against the outflow. This was soon discovered by wading birds, which would stand atop each pipe and catch fish as they jumped toward the pipe. These birds soon pecked large holes in the upper portion of both plastic meshes. The velocity of water through these openings was sufficient to prevent further encroachments by the fish. Later, when the salinity of the water outside the shrimp pond dropped below about 44 ppt, the phenomenon ceased.

Competitor and Predator Removal

164. The first application of rotenone at 0.035-ppm active ingredient almost totally eradicated the M. beryllina population. The fish went into distress within minutes of application. Most were removed from the water even before death by a flock of over 1,000 seabirds that gathered during rotenoning. The flock was estimated to consist of about 800 herring gulls, 100 black skimmers, 100 common egrets, 100 terns, 30 great blue herons, 30 lesser egrets, and lesser numbers of several other species. Consequently, very few M. beryllina ever washed ashore.

165. This application also removed the spot, L. xanthurus. These animals were not picked up by the birds but were dragged from the water and eaten after they reached the shore. The L. xanthurus were all subadult 8-1/2 to 9-1/2 in. standard length. This suggested a single age class that probably entered the ponds with the dredged materials in the form of eggs, larvae, or small juveniles.

166. Almost no C. variegatus or other species were killed by this first application although mullet, Mugil cephalus, were seen to be in distress. The birds showed no ill effects from eating the intoxicated fish. No evidence of distress or mortality was seen among the invertebrates. No further distress was seen among the fish in the pond after 12 hours (night hours). Although numerous carcasses littered the shore after the kill (Figure 40), all were consumed by birds and raccoons and only scattered bones were seen two days later.

167. C. variegatus began to die after the second rotenone treatment of 0.10-ppm active ingredient. Only 15% of the population is estimated to have been eradicated, however. A few M. beryllina and L. xanthurus also were killed. Fundulus sp. and M. cephalus were also eliminated by this application. Birds were again attracted to but refused to eat the C. variegatus. Invertebrates showed no effects. No more distressed fish appeared after 10 hours.

168. The last rotenone treatment of 0.21-ppm active ingredient killed only C. variegatus, presumably because all other ichthyofauna had been eradicated by previous applications. This was supported by the failure to recover any other species during any of the subsequent sampling or harvesting activities. No birds were attracted by this kill. The invertebrates were, once again, not affected. No more distressed fish were seen after 10 hours.

169. The C. variegatus kill was estimated at 40-70% of the original population. The wide range of this estimate is due to the fact that almost all these fish sank immediately postmortem. Later about 30% of them surfaced and floated to shore 1-24 hours postmortem. Subsequent sampling confirmed that the population had been reduced by the estimated amounts, but once again quantification was difficult because of the tendency of the fish to congregate in certain areas, a phenomenon not strongly evident prior to the population reduction.

170. The results of the several rotenone applications underlined the variable tolerances of different piscine species to this respiratory toxin. Responses were used to estimate the range of rotenone concentrations producing lethality. These data are presented in Figure 41. These levels are significantly higher than those found effective by other workers (Meyer 1965). This suggests that some factor, possibly the high salinity, at this application either increased the resistance of the target organisms or detoxified the

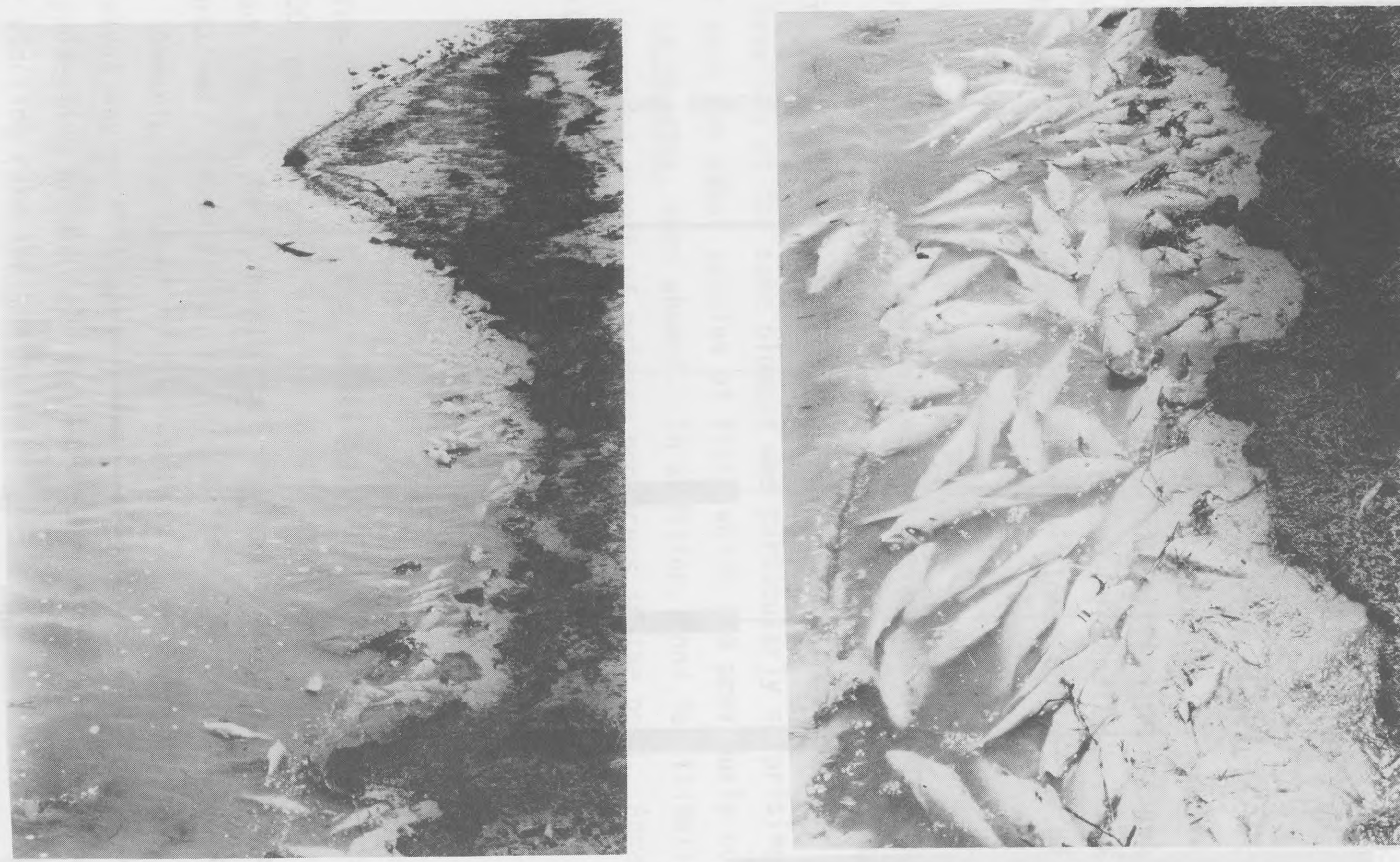


Figure 40. Fish killed by rotenone applications.

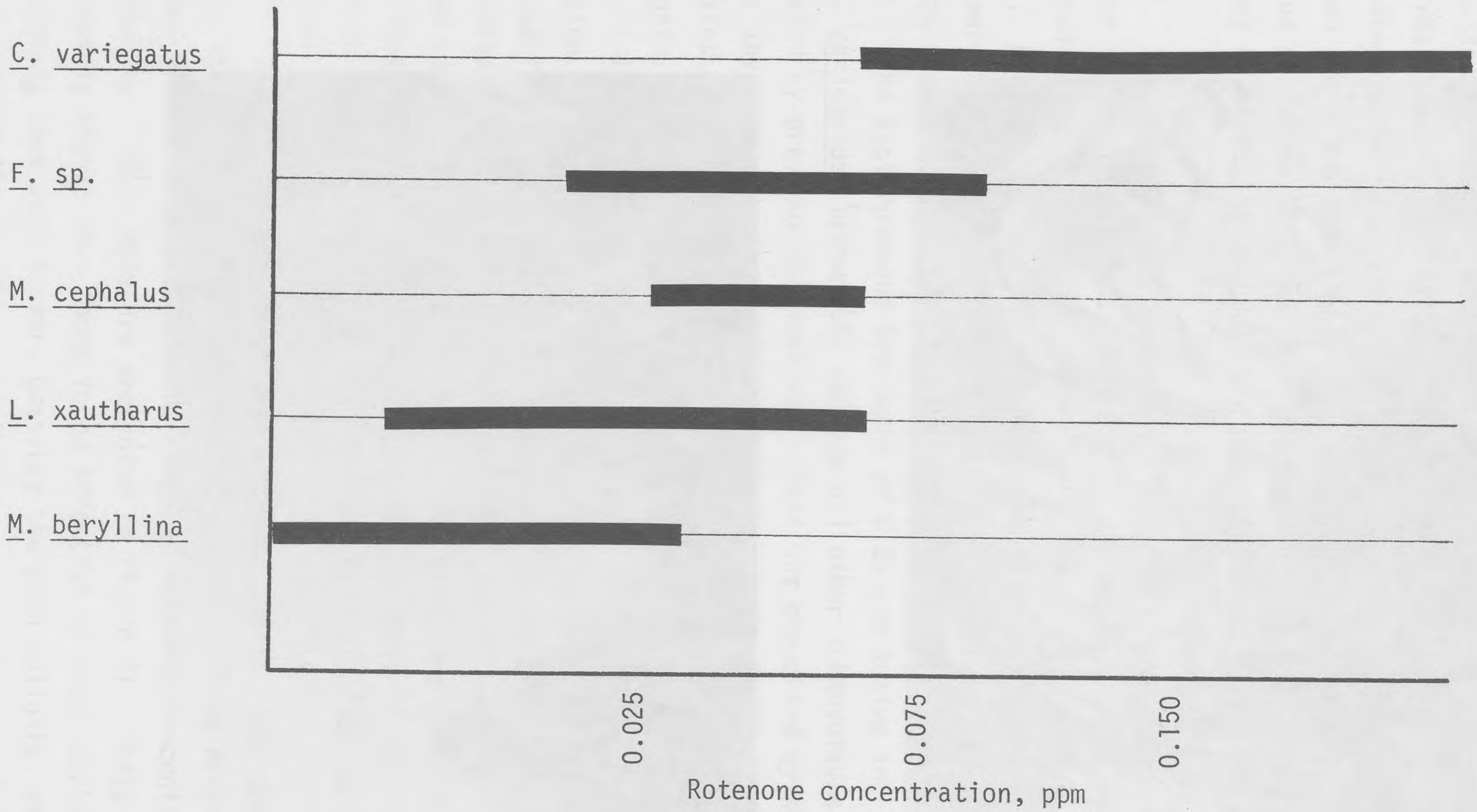


Figure 41. Estimated ranges of lethality of rotenone to shrimp pond ichthyofauna.

rotenone. There is also the possibility of locally high or low concentrations of rotenone in the first two applications. This is unlikely in the last application.

171. The surviving C. variegatus showed an extremely rapid response to the population reduction. Within 1 week, virtually 100% of the females were gravid and significant numbers of very small juveniles were present. At 2 weeks, not only were the females gravid but the fecundity had returned to normal or above normal. Juveniles now made up almost 30% of the biomass and over 70% of the numbers.

172. Within approximately 6 weeks, the population had increased to about 1,700 lb. or 85 lb. per acre, almost exactly the amount present prior to rotenoning. In addition, recruitment had almost ceased with fecundity down, frequency of gravid females reduced, and juveniles almost absent. This population leveling at the same biomass was particularly surprising in view of the fact that the other species of fish, which had previously competed with the C. variegatus, were absent. In addition, pond fertilization had presumably increased growth of primary producers in the pond. Apparently the one new feature of the ecosystem, the stocked shrimp, had replaced the species lost.

Shrimp Hardening and Stocking

173. The first part of the hardening period for the shrimp postlarvae in the 13,000-gal. pool went exactly as planned. Algae growth occurred in the allotted time at the planned rate. Optimal algal concentrations were easily maintained. Temperature, pH, and salinity remained at optimal values (Table 3). Ammonia and other nitrogenous wastes remained at safe levels. Shrimp survival was excellent and growth was very rapid. A confidential system of projecting growth rate and survival several days ahead to determine the proper stocking rate for the brine shrimp hatchery also worked very well. These projections also allowed determination of how fast the shrimp biomass was closing on the pool support capacity.

Table 3

Parametric Data from the Post Larval Shrimp Hardening Pool

	Time Initial	Time Final	Average	Total
Shrimp #	935,000	387,267		
Shrimp size, gm.		.096		
Temperature, °F	85	88		
Salinity, °/₀₀	30.5	34.0		
pH	7.95	8.3		
Ammonia, ppm N	.104	.14		
Fertilization, lb.				15
Artemia, gm. cysts			500 gm/day	
Air temperature, °F			max.=93, min.=72	
Humidity, % RH			max.=90, min.=55	
HCl added				2
D.O., ppm O_2	9.17			

174. Problems arose when the shrimp had to be kept in the pool for five extra days to allow for the third and strongest rotenone application to the pond. The shrimp biomass exceeded the safe capacity of the pond. As a result, concentrations of shrimp metabolites, particularly ammonia, climbed toward dangerous levels. The phytoplankton, utilizing these nutrients, grew profusely, causing depletion of CO_2 from the pool as well as utilization of $CO_3^=$ as an alternate carbon source. As a result, pH began to increase due to the break down of the carbonate buffering system. Despite corrective additions of HCl, the pH reached a debililating level (near pH 10) the day prior to removal of shrimp from the pool, resulting in a partial mortality ($\sim$30%). This occurred again the following day before all the shrimp could be removed from the pool.

175. Shrimp losses during concentration, transport to the pond, acclimation, and release appear to have been negligible.

Shrimp Grow-Out

176. Figures 42, 43, 44, and 45 show shrimp growth and environmental and management conditions during the shrimp grow-out. Figures 46 and 47 show meteorological conditions and other data that are relevant to the shrimp pond but that were actually measured at the nearby Dow Chemical Company brine shrimp culture ponds.

177. The shrimp set rapidly after stocking in the ponds and even exceeded the growth rate of *P. aztecus* in the simulated containment area grow-out of the previous year (Quick and Morris 1977, Quick et al. in press) (Figure 48). This rapid growth unbroken until the unseasonal cooling of the pond in October due to a series of record-breaking cold fronts beginning on 4 October 1976. Virtually no growth occurred after this time. This growth stasis began at a temperature of 73°F. The temperature continued to drop after harvesting was begun, and by November, catch results indicated that most or all of the normally active shrimp were inactive and partially or wholly buried. The temperature had dropped to 58°F when this was first observed. This temperature drop continued after the partial harvest reaching 43°F in late December 1976. Netting in the pond once the water had warmed in April

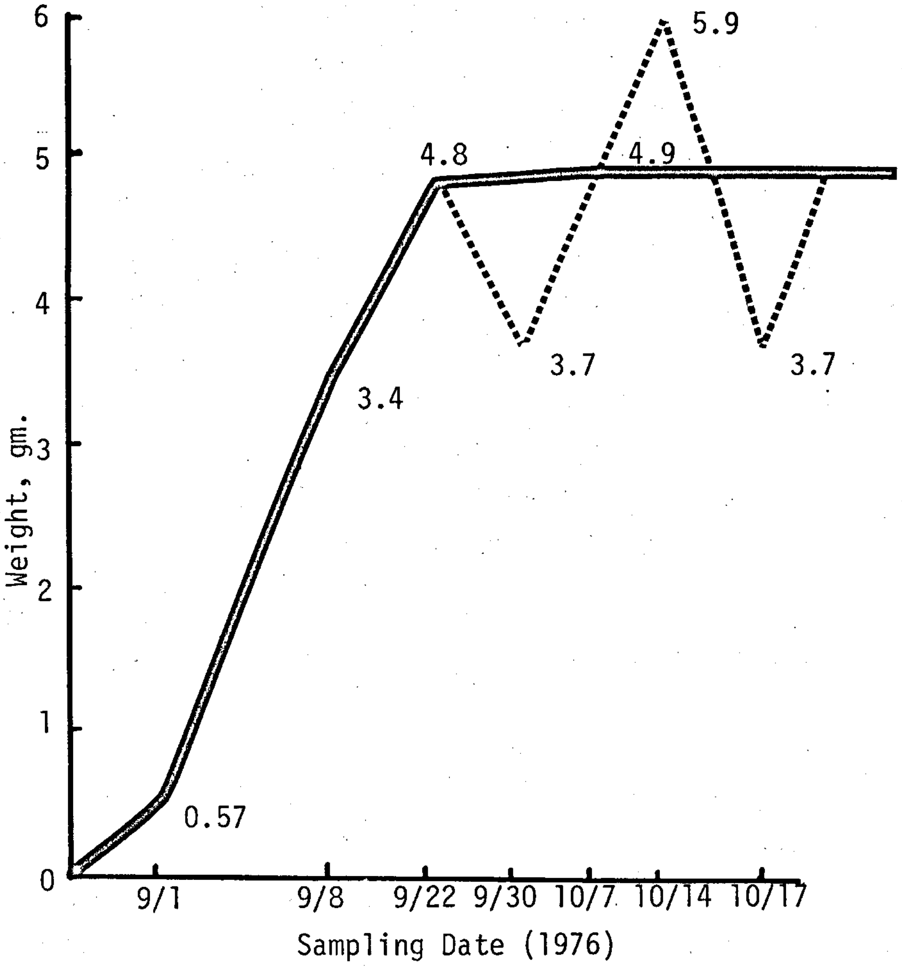


Figure 42. Shrimp growth.

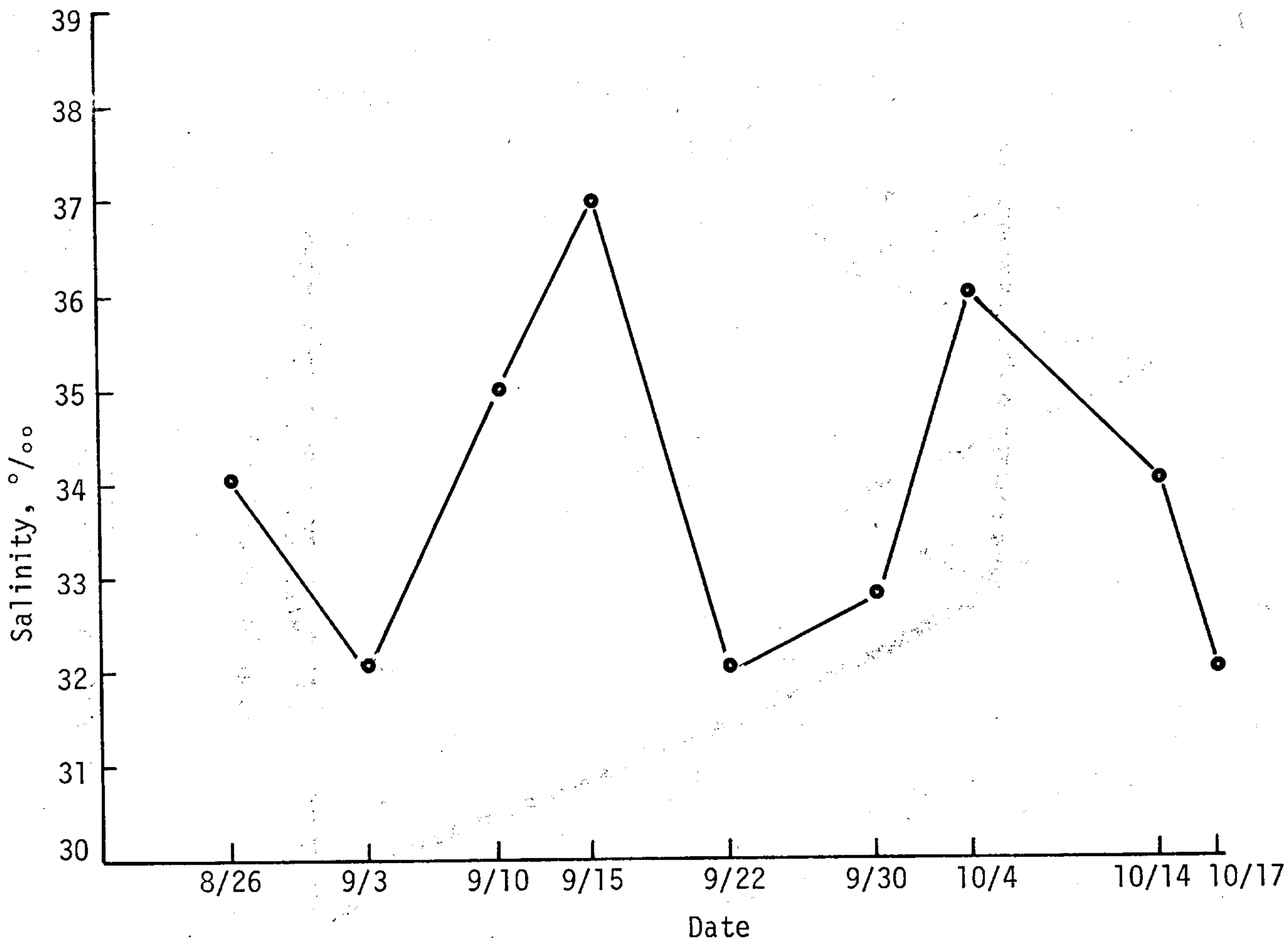


Figure 43. Shrimp pond salinity during grow-out.

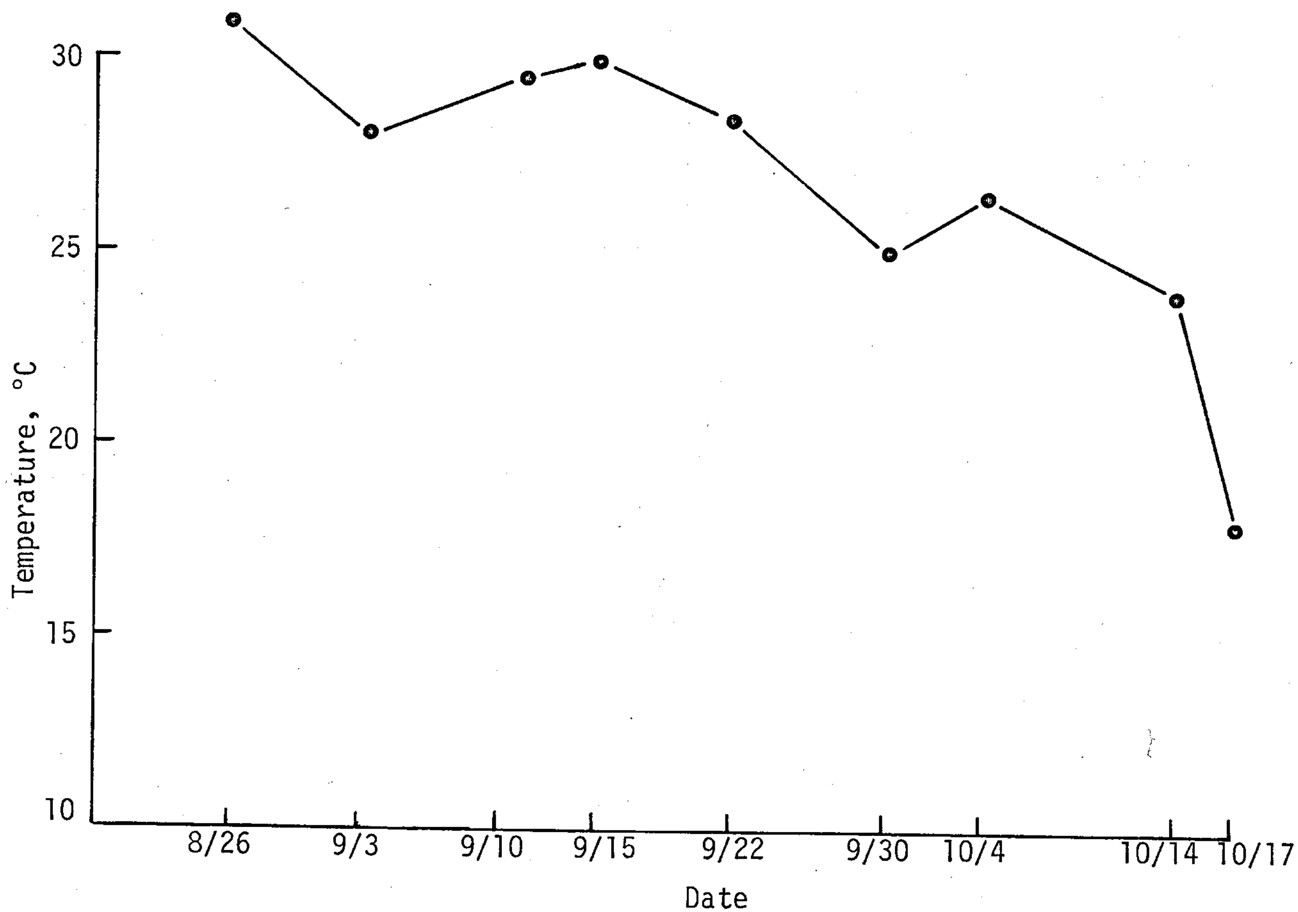


Figure 44. Shrimp pond temperature during grow-out.

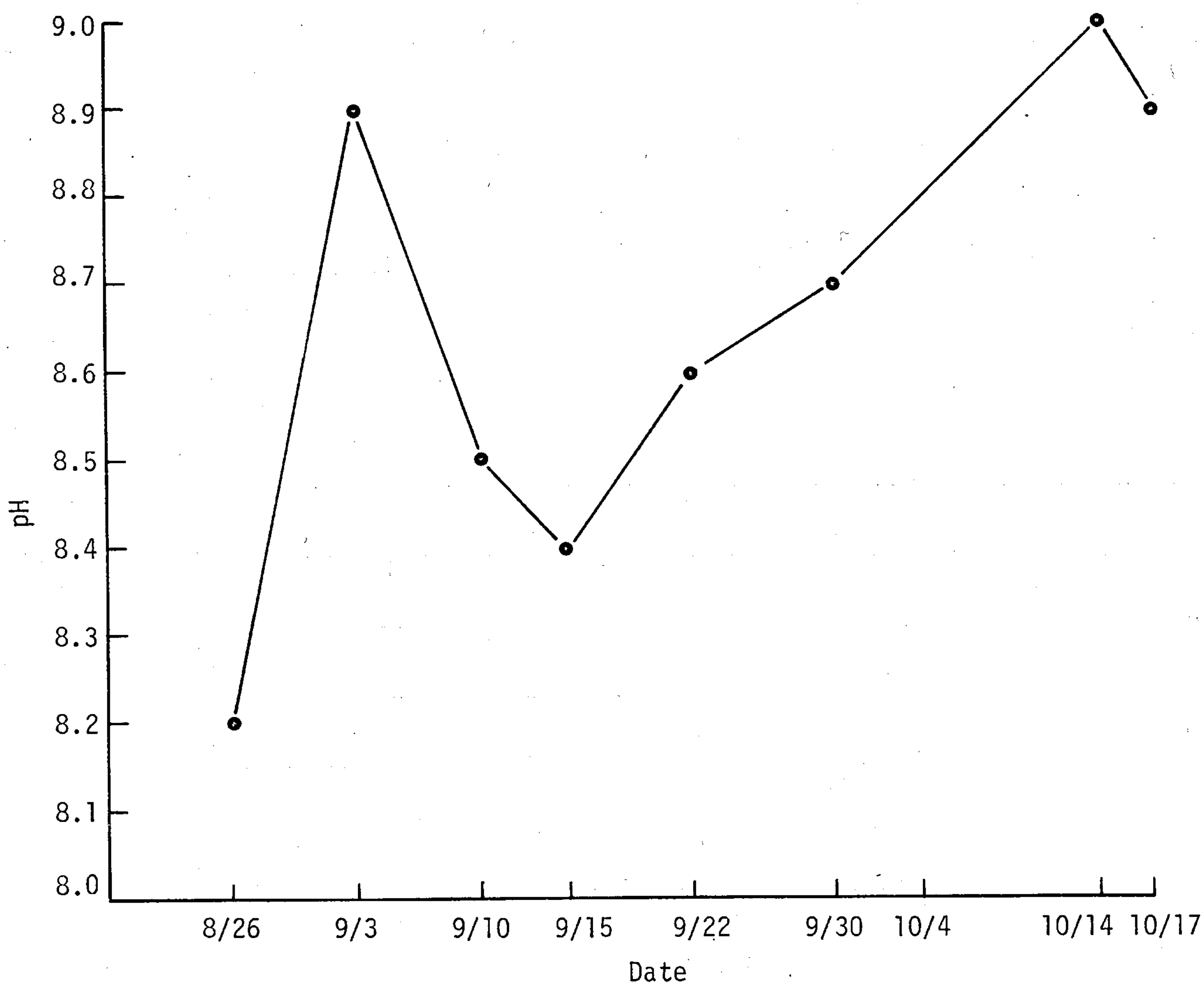


Figure 45. Shrimp pond pH during grow-out.

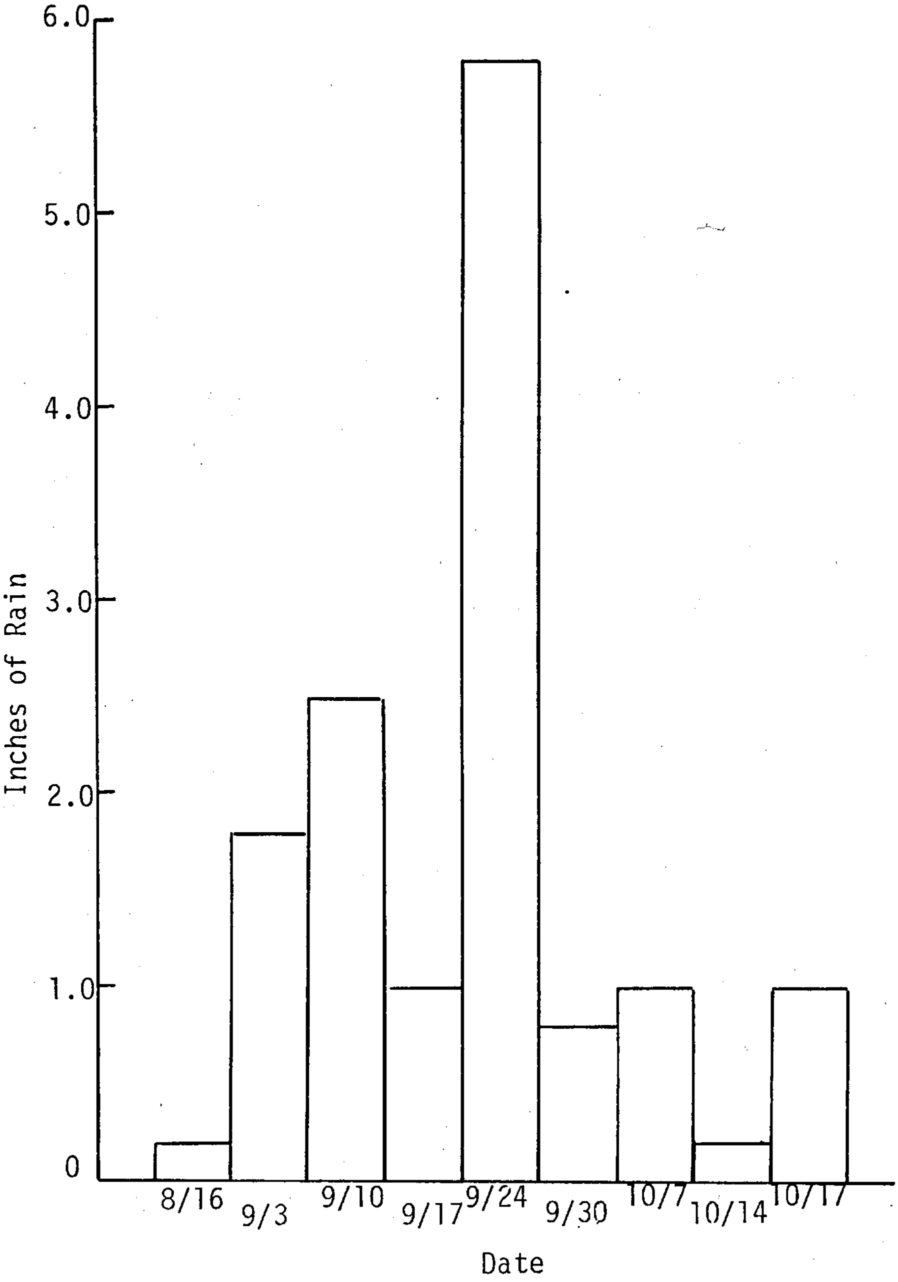


Figure 46. Rainfall during shrimp grow-out.

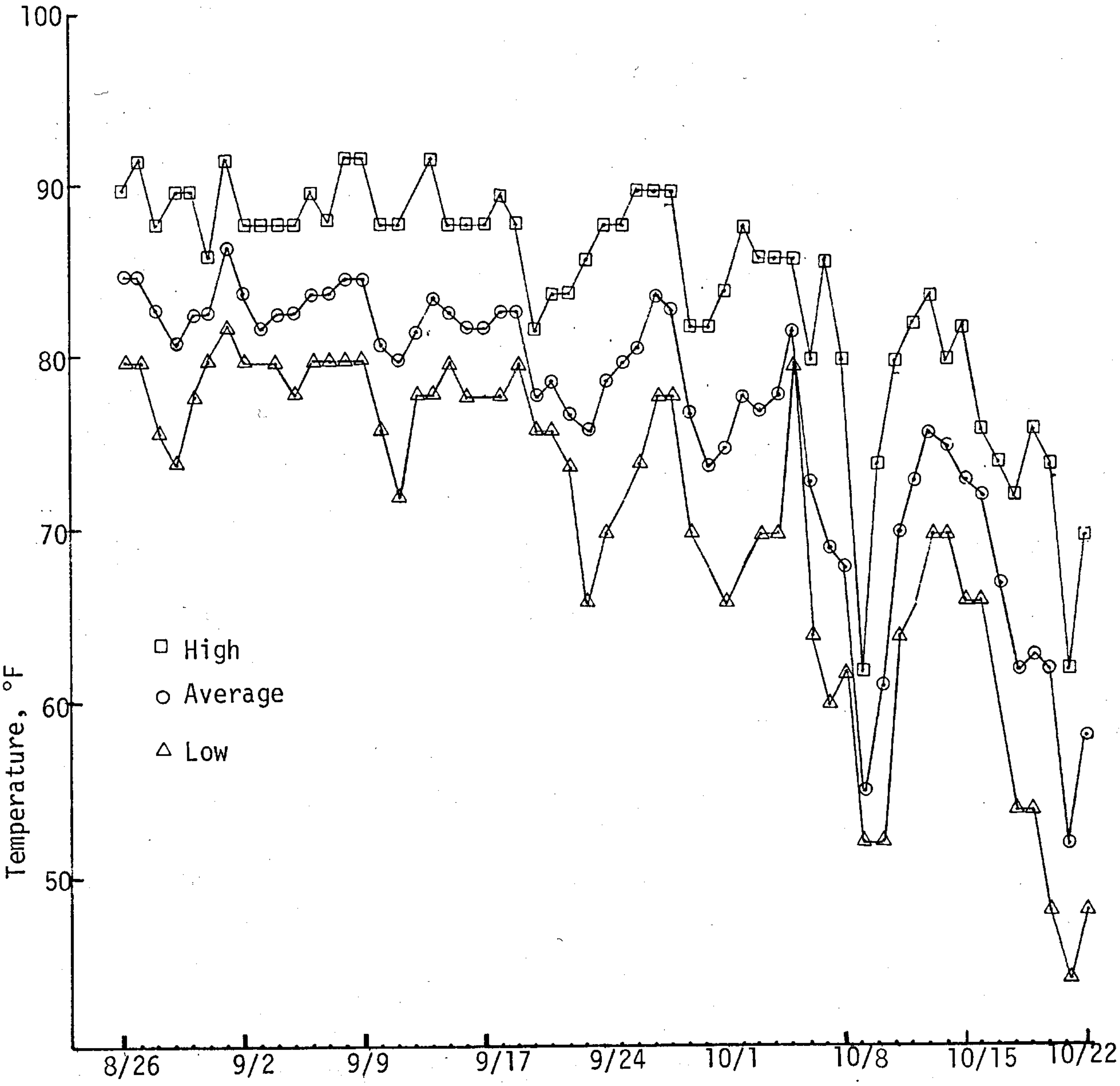


Figure 47. Ambient temperature during grow-out.

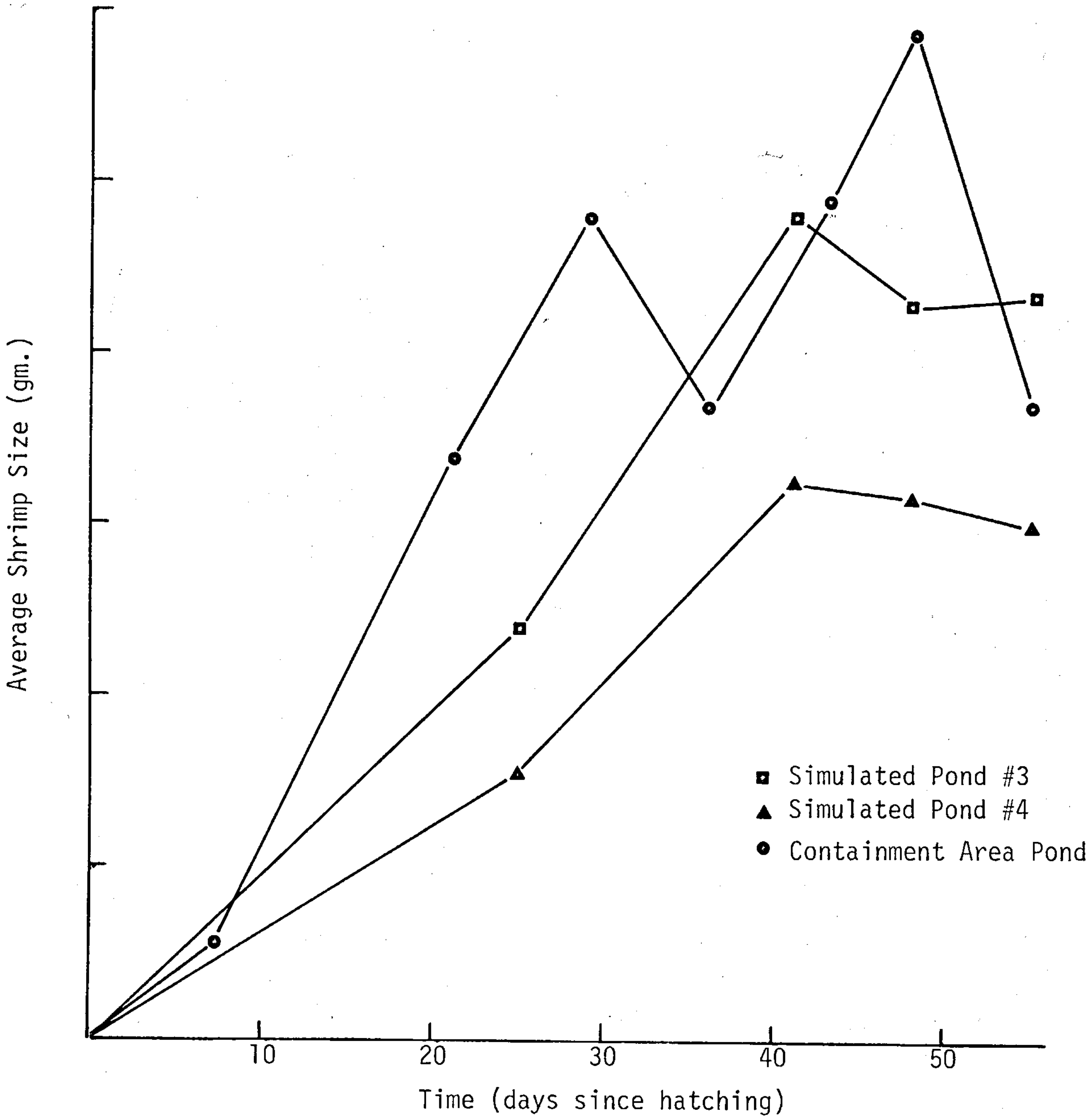


Figure 48. Comparative shrimp growth in simulated versus actual containment areas.

through July 1977 failed to recover any _P. setiferus_. In all probability, the remaining shrimp were killed by the low temperature.

178. No mortality or disease was observed among the shrimp during the grow-out to harvest. Full-length antennae indicated that population stress was low or absent. Color was good. Exoskeletons were initially hard but became softer with time, suggesting mineral depletion from the water. Numerous algae were present in the gut through a size of about 1-1/2 in. After that time, action of the gastric mill prevented identification of chyme components. Presumably, these larger shrimp were feeding primarily on animal prey.

179. Salinity control became increasingly difficult in the pond as the grow-out progressed. The salinity had been kept high to counteract expected rain since August and September are usually wet months in the pond area. Instead, these months were very dry. The salinity in the Intracoastal Waterway climbed steadily, making it necessary to pump greater and greater volumes to dilute the effects of evaporation. Nevertheless, the pond salinity was kept at or below 37 ppt. Approximately 700 gal. of diesel fuel were burned by the pump engine to accomplish this. The expected rains arrived in October and alleviated the need to pump.

180. No perceptable change in the phytoplankton of the shrimp pond occurred during the 2 weeks following the 8 August 1976 fertilization. Consequently, a second application was made under the assumption that there was a nutrient sink in the system. An immediate profuse bloom occurred. This bloom began too rapidly to have been caused entirely by the second application, which was likely not needed.

181. This heavy bloom proceeded and became slowly denser as shrimp metabolites nourished it. By late September, oxygen levels began to get low at night and carbon dioxide became depleted by day due to the algae. This CO_2 depletion began to cause dangerously high pH excursions. To counteract these effects, pumping was used to dilute the nutrients and algae out of the pond while replacing depleted carbonates.

182. The seawater intake and delivery system caused several problems that delayed various parts of the initial phases of stocking and grow-out. The first problem occurred when surges caused by tows passing the Intracoastal Waterway repeatedly ripped the intake line from its substantial

moorings. The rope netting anchored by numerous ground screws as described in paragraph 70 (Figure 22) was necessary to counter this destructive action.

183. Next, a series of pump engine malfunctions occurred. Initial problems involved continuous maintenance of adequate oil pressure and fuel oil bypassing from the injectors to the lubricating oil. This first engine was replaced by an air-cooled one. The new engine progressively vibrated itself apart. Welds broke, bolts vibrated loose, clamps slipped off, and cowlings fell off.

184. The last problem was water hammer of an unusual type. During normal operation, a 1000-ft.-long by 12-in.-diameter cylinder of seawater (49,000 lb.) continually moved through the delivery pipeline at 7 ft. per sec. The water hammer problems began with a fluctuation in pumping rate due to barge passage, trash against the intake screen, or an engine miss. When this happened, a slight vacuum was pulled on the opposite side of the pump due to the momentum of the water in the pipeline. This caused the pump to cavitate and overspeed, further reducing water intake. The vacuum then became so pronounced, that the water in the pipeline decelerated and reversed its direction gathering momentum as it approached the pump. The kinetic energy released upon impact with the pump caused a pressure increase of over 60 psi. The speeding pump then sent the water back down the pipeline at even greater speed. The cycle repeated itself until the increased pressure caused a failure somewhere in the system. On one occasion, a 12-in. PVC 45° elbow was explosively destroyed. Spigot fittings were commonly forced out of the bells. The solution was installation of the small bleed valve as described in paragraph 71 (Figures 23, 24).

185. The intake-water self-cleaning screening system worked flawlessly throughout the study.

Pond Harvest

186. Harvesting planned for November was moved up to begin 19 October 1976 as a result of the unseasonable cold and the cessation of shrimp growth. Difficulties were encountered in using the 500-ft. seine. The leadline floated up in places, allowing the shrimp to escape. Also, much of the corkline continually dipped below the surface, also allowing mass escape of shrimp. Otherwise, the net performed and handled well.

187. As the shrimp became more lethargic and buried themselves in the mud, a trynet proved to be the better sampling device. The thinner, heavier leadline was, upon diver inspection, penetrating the top half inch of sediment and scaring the shrimp up into the net.

188. The lower catch efficiency (Quick et al. in press) and smaller size of otter trawls would make it necessary to make more passes through a pond to achieve acceptable harvest. Nevertheless, the greater ease of handling this type of net might make it preferable.

189. The difficulties encountered in net harvesting the shrimp pond indicate that more attention should be given to the potential use of wall-maze type traps as suggested by Quick et al. (in press).

190. Estimates of the number of shrimp in the pond through the October samplings ranged from 3,700-4,000 lb. These estimates were made using the same basic technique described in paragraph 153 for determining biomass before stocking. The principal difference was the large number (67) and size (1,158 lb. total) of shrimp samples. The shrimp averaged 87 to the pound, heads on and 143 heads off, considerably larger than those harvested from the simulation experiment of the previous year (Quick et al. in press). This biomass represented an estimated shrimp population of 322,000 to 348,000. Based on both groups of shrimp stocked (includes stocking prior to rotenoning), this represents a survival of 48-52%. If only hardened shrimp are considered, the survival is 86-93%. The actual figure is probably somewhere between these two, either of which represents good survival.

191. In mid-November, with the water temperature at 54-56°F, significant numbers of dead shrimp (8-14%) were recovered during harvesting. Biomass estimates dropped to 2,200-2,700 lb. Most of this decrease in estimated population is probably due to failure to capture the expected percentage of these buried lethargic shrimp and not due to mortality.

192. No dead shrimp were ever seen in the pond other than those captured during harvest. Nevertheless, a total mortality apparently occurred during the following winter, probably due to low water temperatures which dropped at least to 43°F and possibly lower. Several samplings in the spring of 1977 failed to capture even a single *P. setiferus*. The pond has since been inundated by 2 million cu. yd. of maintenance dredged material.

193. Shrimp sent for analysis earned a Certificate of Wholesomeness from the U.S. Department of Commerce. The results shown in Table 3 indicate that the condition of these shrimp grown over dredged material was equal to or even better than that of wild-caught shrimp.

194. Boxes (∿200 lb.) of fresh and frozen cultured shrimp were provided to several local bait houses for test marketing. The animals survived live transport and handling better than wild-caught shrimp. Subsequent interviews with retailers and customers indicated that the cultured shrimp were preferred over the wild product.

195. Several hundred pounds were distributed for human consumption. Taste was excellent and shelling was particularly easy (thin shells). Most people overcooked them because the cultured shrimp seemed to cook faster. No off flavors were reported. Deveining was not necessary due to the absence of sand in the gut, certainly a result of the soft sediments of the culture environment.

PART IV: DISCUSSION AND CONCLUSIONS

General

196. This study conclusively proved that shrimp could be cultured successfully in flooded active dredged material containment areas. Numerous new developments or refinements of the technology were achieved. Among these were:

- a. The first zero-maintenance, high-volume, low-cost screening system for sieving to the micron-size range.
- b. New design and operating techniques for a large-scale floating brine shrimp hatchery.
- c. Improvements in management and operation of green-water-technique hardening tanks.
- d. Production and management of the first artificially produced phytoplankton bloom in a containment area pond.
- e. Achievement of a rapid shrimp growth rate.
- f. Proof of wholesomeness of containment area-reared shrimp for human consumption.

Shrimp Pond Production

197. Figure 48 shows growth curves for shrimp cultured without addition of prepared foods in simulated and actual containment area ponds. One of the most striking similarities of both these curves is the rather sudden cessation of growth followed by an extended period of stasis. In the case of the simulation, this growth cessation probably resulted from the shrimp biomass reaching the biological carrying capacity of the ponds. The final weight was equivalent to 243 lb. per acre average. Mean growth rate in the first 5 weeks of culture was 0.9 gm. per week.

198. In the case of the containment area demonstration project, cessation of growth was attributed to an abnormally early winter. Nevertheless, the total shrimp production of 214 lb. per acre was surprisingly close to production in the earlier test. Mean growth rate for the first 5 weeks of culture was 1.1 gm. per week.

199. The shrimp biomass in both studies was produced over the entire period between hatching and harvest. Biomass was almost negligible, however, prior to stocking. Shrimp in both the containment area simulation study and this present study experienced a cessation of growth after 40 and 30 days, respectively. The actual shrimp production per acre during active growth from postlarvae to harvestable size was 42.5 and 49.9 lb. per week, respectively. This figure is higher than the productivity measured in unfertilized estuaries (3-20 lb. per acre per week) (Smith 1974, McConnaughey 1974). Fertilization of enclosed natural waters has been shown to produce substantial increases in productivity to near the level demonstrated in this study.

200. In summary, these data strongly suggest that shrimp production was at or very near the maximum productivity of the ponds in both tests. The production figure for shrimp alone in the demonstration project is probably lower than otherwise possible because of additional production of _C. variegatus_ and other weed species.

201. A classic sequence of events for a nonrecruiting, environment-limited population therefore seems to have occurred in the shrimp ponds. As the shrimp in the population grew, the food requirement increased beyond the pond productivity. Food was increasingly used to satisfy energy and body maintenance requirements with less and less remaining to divert to growth. Therefore, growth rate slowed. As this metabolic energy requirement approached and equalled the total pond productivity, growth stopped and a static state continued. The maximum carrying capacity of the pond had been reached. This process likely caused growth cessation in the simulation project and would probably have done so shortly in the demonstration project had cold weather not intervened.

202. It therefore appears that the productivity of a fertilized containment area pond is slightly above 40 lb. per acre per week and that the

Table 4 – Economic projections for an individual 100-acre shrimp culture pond for one crop in an 800-acre containment area shrimp farm using various grow-out times and stocking rates to best utilize productivity of the fertilized pond (no supplementary feeding).

1.	Length of grow-out after stocking		4 weeks	8 weeks	12 weeks	16 weeks
2.	Stocking rate per acre*		68,750	27,500	16,500	12,400
3.	Number of shrimp in hatchery run*		12.5×10^6	5.1×10^6	3.0×10^6	2.3×10^6
4.	Cost of hatchery run A $5/thousand		$62,500	$25,000	$15,000	$11,250
5.	Total of all other costs**		$ 3,072	$ 6,144	$ 9,216	$12,288
6.	Grand total, all costs (line 4 + line 5)		$65,572	$31,144	$24,216	$23,538
7.	Size of shrimp at harvest, heads on		3.4 gm.	7.8 gm.	12.2 gm.	16.6 gm.
8.	Size of shrimp at harvest, heads off		2.0 gm.	4.7 gm.	7.3 gm.	10.0 gm.
9.	Size of shrimp at harvest, count/lb.		250	100	60	45
10.	Price paid/lb., dockside value***		$0.97	$1.15	$1.40	$1.85
11.	Price paid/lb., wholesale value***		$1.20	$1.35	$1.75	$2.30
12.	Total shrimp harvested		25,000 lb.	25,000 lb.	25,000 lb.	25,000 lb.
13.	Total shrimp value, dockside		$23,750	$28,750	$35,000	$46,000
14.	Total shrimp value, wholesale		$30,000	$33,750	$43,750	$57,500
15.	Net cash balance (line 6-line 13)	Losses	$41,822	---	---	---
		Profits	---	$ 2,394	$10,784	$22,712
16.	Number of crops possible/yr.		6-7	3-4	2	1-2
17.	Cash balance for 1 pond for 1 year at maximum number of crops		-$292,754	$9,576	$21,568	$45,424

* These hatchery run and pond stocking rate numbers assume 50% mortality during hardening and 10-15% mortality during grow out.

** Figures derived from data used to construct Table 3.

*** Values derived from Figure 6.

food requirement to satisfy the metabolic requirement of shrimp is about 0.13 lb. per week per lb. of shrimp (40 lb. per week to satisfy the metabolism of 300 lb. of shrimp). This figure corresponds well with respiratory requirements stated in the literature for a 3-trophic-level tropical ecosystem (Smith 1974). Direct measurements of pond productivity are needed to check this hypothesis.

203. What this means in practical terms is that an unsupplemented but fertilized pond will probably not produce much more than the equivalent of 40 lb. per acre per week of biomass, up to a maximum of 300 lb. per acre at the trophic level of shrimp (first-degree carnivore). This productivity may be utilized in two ways: (a) stock heavily, harvest small shrimp, and produce many crops per year, or (b) stock sparsely, harvest large shrimp, and produce few crops per year. In the first case, the shrimp might grow to a 5.5-gm. average size and produce 5,000 lb. per 20-acre crop. The potential annual harvest (80% harvest efficiency) from four crops per year would therefore be 16,000 lb. with a value of $18,560 (at $1.16 per lb.), minus high stocking costs.

204. In the second case, shrimp should grow to about 11 gm. average size and also produce 5,000 lb. crop. The harvest at 80% recovery from the possible two crops per year would therefore be 8,000 lb. with a value of $15,200 (at $1.90 per lb.; larger shrimp brine a higher price), minus lower stocking costs. Table 4 presents a comparison of costs and profiles for a single crop for various grow-out times at a productivity limit of 300 lb. per acre.

205. The maximum gross income for each 100 acres of shrimp grown with fertilization appears to be less than $20,000, which is relatively low for an agricultural crop.

Increasing Productivity

206. One promising means to raise the projected maximum gross income of shrimp culture acreage would be to use supplemental feeding after the fertilized pond carrying capacity has been reached. Initially, all the added food would go for growth; the pond would be supplying adequate food to satisfy energy needs of the shrimp. There would be no further stocking costs. And

not only would the product increase in weight, but its value per unit weight would also increase as the shrimp got larger. Calculations show that up to $4.30 in increased income can be realized from every $1.00 used for labor, care, and food in a combined pond fertilization/supplementary feeding. these calculations were based on a supplementary feeding rate of 3% of the average shrimp body weight (wet weight) per day with a conversion ratio of 1 lb. (wet weight) of shrimp gained for every pound of food fed (dry weight) and an average shrimp body weight (wet weight) of 5.5 gm. at the initiation of the supplemental feeding. Overhead cost was estimated to be $1,000 per week and feed cost was calculated at $0.25 per lb. Calculations were based on stocking 100 acres with 40,000 shrimp per acre and a 50% survival at the time of harvest with an 80% harvest efficiency. These calculations are shown graphically in Figures 49 and 50.

207. Advantages from such a combined fertilization/feeding program should appear in several forms. The pond productivity stimulated by fertilization greatly reduces the supplementary food necessary. The larger the shrimp get, the smaller the hatchery cost is per pound -- an important factor, considering the high hatchery costs. The longer grow-outs will mean fewer expensive pond preparations, stockings, and harvests per year. The critical sensitive larval and juvenile stages will be encountered less frequently, thus decreasing chances of loss. The larger animals will be easier to harvest, pack, and peel, thus reducing harvesting and preparation costs.

208. In conclusion, supplementary feeding in the final stage of grow-out represents great potential for considerably increasing the profitability potential and reducing the risk of containment area shrimp culture.

Economics

209. Economic analyses of data from this study were made. The results were essentially the same as those obtained previously (Quick and Morris 1977) The major costs of shrimp mariculture are those of land, pond construction, hatchery construction, feeding, and shrimp hatchery operation. However, with the use of a dredged material containment area as the pond site, the land, pond construction, and feeding costs are greatly reduced or eliminated. This

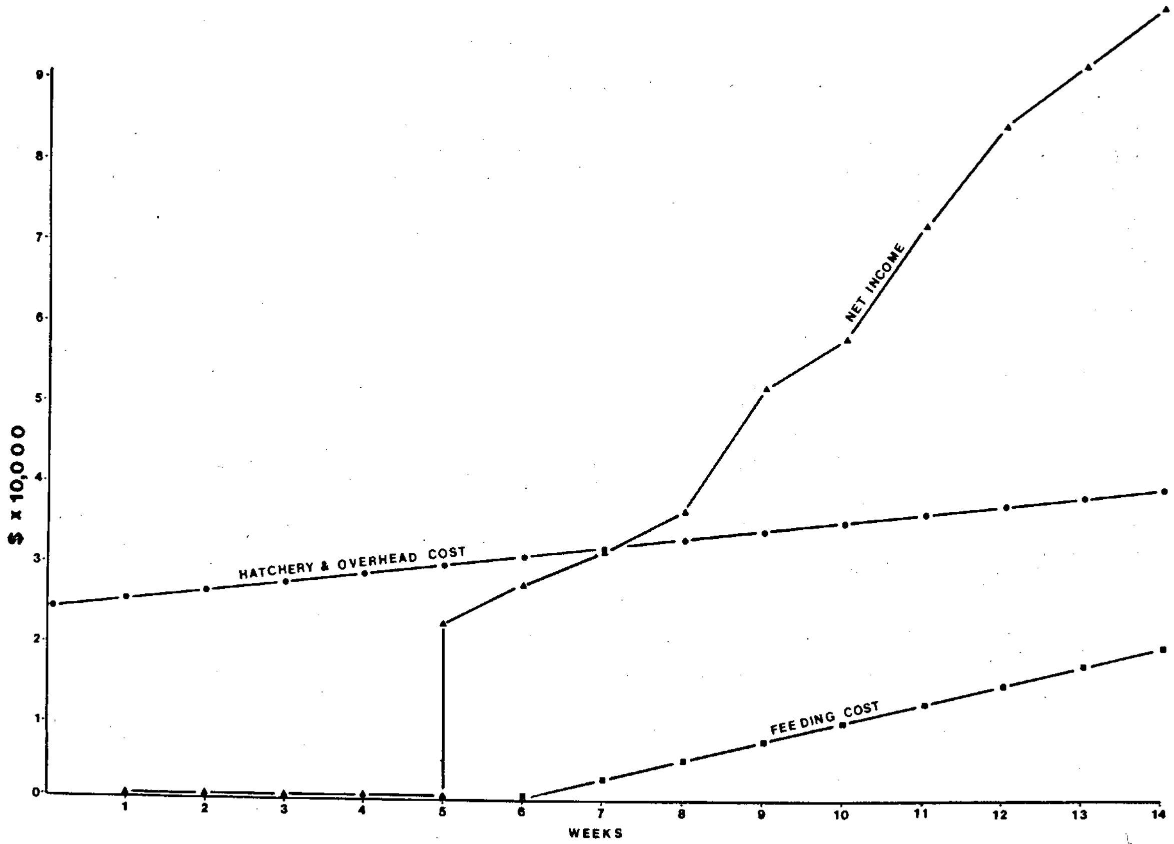


Figure 49. A projection of gross costs and incomes from a single crop in a 100-acre shrimp culture pond of an 800-acre shrimp farm. Fiscal data is compared for various grow-out periods. A combination of pond fertilization and late grow-out supplementary feeding was utilized.

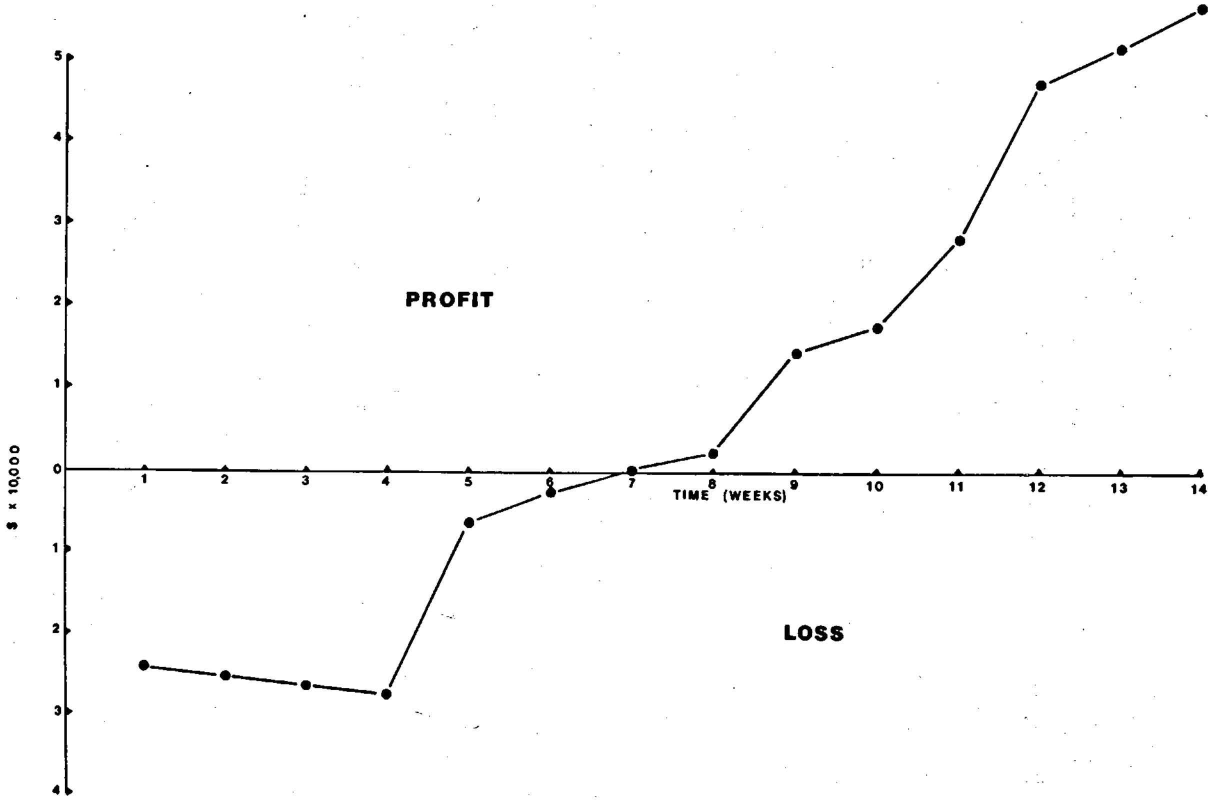


Figure 50. A projection of net cash balance resulting from various grow-out periods for one crop in a single 100-acre pond of an 800-acre shrimp farm. A combination of pond fertilization and supplementary feeding was utilized. The 1975 study of simulated containment area culture produced 4 gm shrimp and the 1976 containment area shrimp culture demonstration produced 6 gm shrimp.

leaves only the cost of building and operating the shrimp hatchery to produce the stockable young shrimp as the major economic obstacle to domestic shrimp mariculture. This hatchery stocking cost can constitute as much as 50% to 90% of the production cost! This cost prohibits economical containment area shrimp mariculture except on a very large scale. Small-scale hatcheries are especially costly to operate.

210. Presently, there are no large or small commercial shrimp hatcheries in the United States from which postlarval shrimp can be obtained. Because of this, containment area shrimp mariculturists will find it necessary to build and operate their own hatcheries. Small-scale hatcheries like the one operated by Dow have a production cost of over $10 per thousand postlarval shrimp. At that price, it would cost more to stock a pond than the crop would be worth if harvested at any size less than a 100-count shrimp (4.5-gm. size) even if there were no other costs. A large production-scale hatchery could reduce the stocking cost to an economical level, but would require a substantial investment. This large capital investment in the construction and operation of a hatchery, especially when considered along with the very high level of technology required for intensive hatchery operation, would severely limit if not eliminate implementation of commercial dredged material containment area shrimp culture by the private sector.

211. If the containment area-mariculture concept is to be successful, it must appeal to a wide assortment of land owners, agronomists, small investors, entrepreneurs, and the typically underfunded mariculturists. To reduce the cost and the technological level of a shrimp mariculture operation to within reach of these groups, a way needs to be found to eliminate the need for complex, costly, remote hatcheries. A method of doing this would be to develop a technique to spawn and hatch shrimp directly inside floating tanks placed in the containment area. The development of this technique could reduce the hatchery construction cost by as much as 90% in addition to reducing the technological level and the need for highly trained, highly paid, experienced hatchery operators needed for spawning and hatching shrimp.

212. Using this technique, a complete shrimp mariculture operation would be carried out entirely within the confines of a dredged material containment area. The shrimp would be spawned, hatched, hardened, and released directly

into the dredged material containment area-culture pond. The shrimp would then feed on the natural food chain that would have been established in the pond by fertilization with commercial fertilizers. A recommended developmental program for this technology is described in Appendix A.

LITERATURE CITED

Arthur D. Little, Inc. 1975. A feasibility study of lawn sod production and/or related activities on dredged material disposal sites, Contract Report D-75-1. Performed by Arthur D. Little, Inc., Acorn Park, Cambridge, Mass., under Contract No. DACW 39-74-3-0101 to U.S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss. 91 pp.

Bardach, J. E., J. H. Ryther, and W. O. McLarney. 1972. Aquaculture: The farming and husbandry of freshwater and marine organisms. Wiley-Interscience Publishers, New York. 868 pp.

Barko, J. W., R. M. Smart, C. R. Lee, M. C. Landin, T. C. Sturgis, and R. N. Gordon. 1977. Establishment and growth of selected freshwater and coastal marsh plants in relation to characteristics of dredged sediments, Technical Report D-77-2. U.S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss. 41 pp.

Bartos, M. J., Jr. 1977. Use of dredged material in solid waste management, Technical Report D-77-11. U.S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss. 85 pp.

Bassham, J. A. 1976. Mechanism and efficiency of photosynthesis in green plants. Pages 205, 228 in Symposium Papers: Clean Fuels from Biomass, Sewage, Urban Refuse, Agricultural Wastes. Inst. of Gas Technology, Chicago, Ill.

Bokuniewicz, H., M. Dowling, J. Gerbert, R. Gordon, P. Kaminsky, C. Philbeam, and C. Tuttle. 1977. Aquatic disposal field investigations, Eatons Neck Disposal Site, Long Island Sound; Appendix A: Investigation of the hydraulic regime and the physical characteristics of bottom sedimentation, Technical Report D-77-6. Performed by Department of Geology and Geophysics, Yale University, New Haven, Conn., under Contract No. DACW 51-75-C-0008 to U.S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss. 195 pp.

Brannon, J. M., R. M. Engler, J. R. Rose, P. G. Hunt, and I. Smith. 1976. Selective analytical partitioning of sediments to evaluate potential mobility of chemical constituents during dredging and disposal operations, Technical Report No. D-76-7. U.S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss. 170 pp.

Caplan, R. I. 1977. Aquatic disposal field investigations, Eatons Neck Disposal Site, Long Island Sound; Appendix E: Predisposal baseline conditions of zooplankton assemblages, Technical Report D-77-6. Performed by New York Ocean Science Laboratory, Montauk, New York, under Contract No. DACW 51-75-C-0015 to U.S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss. 104 pp.

Coastal Zone Resources Corporation. 1977. A comprehensive study of successional patterns of plants and animals at upland disposal areas, Contract Report D-77-2. Performed by Coastal Zone Resources Corporation, Wilmington, N.C. under Contract No. DACW 39-74-C-0092 (Neg.) to U.S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss. 509 pp.

Commission on Marine Science, Engineering and Resources. 1969. Our nation and the sea: A plan for national action. Commission Report to the President, J. A. Stratton, Chairman. 305 pp.

U.S. Army Corps of Engineers. 1968. Permits for work in navigable waters. Department of the Army. 21 pp.

U.S. Army Engineer District, Galveston. 1974. Army engineers publish new permit regulations. Public Affairs Office, U.S. Army Engineer District, Galveston, Texas. 4 pp.

U.S. Army Corps of Engineers, Galveston District. 1975. Engineering and construction specifications, Containment Area No. 85, GIWW. Galveston, Texas.

U.S. Army Engineer Waterways Experiment Station. 1975. Dredged material research program: Second annual report. U.S. Army Engineers Waterways Experiment Station, CE, Vicksburg, Miss. 52 pp.

U.S. Army Engineer Waterways Experiment Station. 1976a. Dredged material research program: Third annual report. U.S. Army Engineers Waterways Experiment Station, CE, Vicksburg, Miss. 78 pp.

Office, Chief of Engineers, U.S. Army. 1974. Applications for Department of the Army permits for activities in waterways, Pamphlet No. 1145-2-1, EP 1145-2-1, DAEN-CWO-N. 26 pp.

Environmental Engineering Consultants, Inc. 1976. Laboratory study of aeration as a feasible technique for dewatering fine-grained dredged material, Contract Report D-76-10. Performed by Environmental Engineering Consultants, Inc., Stillwater, Okla., under Contract No. DACW 39-75-C-0123 to U.S. Army Engineer Waterways Experiment Station, Vicksburg, Miss. 71 pp.

Espey, Huston and Associates, Inc. 1976a. A study of the placement of materials dredged from Texas ports and waterways, Volume I: Texas Coastal Management Program Publications. Austin, Tex. 415 pp.

Espey, Huston and Associates, Inc. 1976b. A study of the placement of materials dredged from Texas ports and waterways, Volume II: Literature search. Texas Coastal Management Program Publications. Austin, Tex. 145 pp.

Falco, P. K. and F. J. Cali. 1977. Pregermination requirements and establishment techniques for salt marsh plants, Miscellaneous Paper No. D-77-1. U.S. Army Engineers Waterways Experiment Station, CE, Vicksburg, Miss. 43 pp.

Fujinaga, M. 1963. Culture of Kuruma shrimp (Penaeus japonicus), Curr. Aft. Bulletin Indo-Pacific Fisheries Council, Volume 36. pp. 10-11.

Fujinaga, M. (Hudinaga). 1969. Kuruma shrimp (Penaeus japonicus) cultivation in Japan, FAO Fisheries Report No. 3, Volume 57. Food and Agricultural Organization of the United Nations. Rome, Italy. pp. 811-832.

Garbisch, E. W., Jr. 1977. Recent and planned marsh establishment work throughout the contiguous United States: A survey and basic guidelines, Contract Report D-77-3. Performed by Environmental Concern, Inc., St. Michaels, Md., under Contract No. DACW 39-75-M-4215 to U.S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss. 48 pp.

Giger, M. W. and R. J. Krizek. 1975. Compressibility and strength of compacted dredging. Pages 140-153 in Proc. Seventh Annual Dredging Seminar, Report. No. CDS-181, J. B. Herbich, ed. Texas A&M University, Sea Grant College, College Station, Tex.

Gillespie, S. M. and M. J. Houston. 1975. An analysis of seafood consumption patterns and product perceptions in Texas, Report. No. TAMU-SG-75-216. Texas A&M University, Sea Grant College, College Station, Tex. 53 pp.

Glade, John B., ed. 1977. NOAA aquaculture plan. U. S. Dept. Commerce, Nat. Marine Fisheries Service and Office of Sea Grant. 41 pp.

Green, C. E. and A. A. Rula. 1977. Low-ground-pressure construction equipment for use in dredged material containment area operation and maintenance - Equipment inventory, Technical Report No. D-77-1. U.S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss. 116 pp.

Griffin, Wade L. and J. P. Nichols. 1976. An analysis of increasing costs to Gulf of Mexico shrimp vessel owners: 1971-1975, Marine Fisheries Report No. 38, Volume 3. pp. 8-12.

Griffin, W. L., N. J. Wardlaw, and J. P. Nichols. 1976. Economic and financial analysis of increasing costs in the Gulf shrimp fleet, Fishery Bulletin No. 74, Volume 2. pp. 301-309.

Haliburton, T. A., G. N. Durham, D. W. Brown, R. E. Peters, and T.B. Delaney, Jr. 1977. Effects of mechanical agitation on drying rate of fine-grained dredged material, Technical Report. No. D-77-10, U.S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss. 78 pp.

Hammer, D. P. and E. D. Blackburn. 1977. Design and construction of retaining dikes for containment of dredged material, Technical Report No. D-77-9, U.S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss. 200 pp.

Hanson, J. A. and H. L. Goodwin. 1977. Shrimp and prawn farming in the western hemisphere. Dowden, Hutchinson and Ross, Inc., Stroudsburg, Pa. 439 pp.

Harrison, J. E. and L. C. Chisolm. 1974. Identification of objectionable environmental conditions and issues associated with confined disposal areas, Contract Report D-74-4. Performed by Arthur D. Little, Inc., Acorn Park, Cambridge, Mass., under Contract No. DACW 39-73-C-0130 to U.S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Herbich, J. B. 1975. Coastal and deep ocean dredging. Gulf Publishing Co. Houston, Tex. 622 pp.

Herbich, J. B. 1976. Engineering aspects of maintenance of the Gulf Intracoastal Waterway in Texas. Proc. 7th World Dredging Conference, July 9-13, 1978, WODCON VII, San Francisco, Calif. 37 pp.

Hudinaga, M. 1935. Studies on the development of Penaeus japonicus, Bate. Rep. Hayatomo Fish. Inst. No. 1, Volume 1. pp. 1-51.

Hudinaga, M. 1942. Reproduction, development and rearing of Penaeus japonicus, Bate. Japanese J. Zool. No. 10, Volume 2. pp. 305-493.

Hudinaga, M. and J. Kittaka. 1967. The large scale production of the young Kuruma prawn Penaeus japonicus, Bate. Info. Bull. on Planktonology in Japan. Commemorative number of Dr. Y. Matsue. pp. 34-46.

Jones, J. A. 1968. Primary productivity by the tropical marine turtle grass, Thalassia testudinum Konig, and its epiphytes. Doctoral Dissertation, Inst. Marine Sci., Univ. of Miami, Fla. 196 pp.

Jones, L. L., J. W. Adams, W. L. Griffin, and J. Allen. 1974. Impact of commercial shrimp landings on the economy of Texas and coastal regions, Report No. TAMU-SG-75-204. Texas A&M University, Sea Grant College, College Station, Tex. 18 pp.

Katz, B. F. 1975. Legal and regulatory considerations concerning the use of wastes in mariculture. Coastal Research News, No. 4, Volume 6. Talahassee, Fla. 6 pp.

Keiser, R. K., Jr. and D. V. Aldrich. 1976. Salinity preference of postlarval brown and white shrimp (Penaeus aztecus and P. setiferus) in gradient tanks, Report No. TAMU-GS-75-208. Texas A&M University, Sea Grant College, College Station, Tex. 260 pp.

Knieper, L. H. and D. D. Culley, Jr. 1975. The effects of crude oil on the palatability of marine crustaceans. Progressive Fish-Culturist, No. 37, Volume 1. pp. 9-14.

Krizek, R. J., J. A. FitzPatrick, and D. K. Atmatzidis. 1976. Dredged material confinement facilities as solid-liquid separation systems. Pages 609-632 in Proc. of the Specialty Conf. on Dredging and its Environmental Effects, Jan. 26-28, 1976, Mobile, Ala. American Society of Civil Engineers.

Krizek, R. J., J. S. Jin, A. M. Salem. 1975. Permeability and drainage characteristics of dredgings. Pages 154-179 in Proc. Seventh Annual Dredging Seminar, Report No. CDS-181, J. B. Herbich ed. Texas A&M University, Sea Grant College, College Station, Tex.

Landis, R. C., ed. 1971. A technology assessment methodology: Mariculture (sea farming), Volume 5, NTIS Order No. PB-202 778-05. The MITRE Corporation, Washington, D.C. 180 pp.

Leathem, W., P. Kinner, D. Maurer, R. Biggs, and W. Treasure. 1973. Effects of spoil disposal on benthic invertebrates. Marine Pollution Bull. No. 4, Volume 8. pp 122-125.

Lee, G. F. and R. H. Plumb. 1974. Literature review on research study for the development of dredged material disposal criteria, Contract Report D-74-1. Performed by Institute for Environmental Studies, Univ. of Texas, Dallas, Under Contract No. DACW 39-74-C-0024 to U.S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss. 145 pp.

Lindner, M. J. and H. L. Cook. 1970. Synopsis of biological data on the white shrimp Penaeus setiferus (Linnaeus) 1767. Food and Agricultural Organization of the United Nations, Rome, Italy. Fish. Rep. No. 4, Volume 57. pp. 1438-1469.

Mallory, C. W. and R. M. Meccia. 1975. Concepts for the reclamation of dredged material. Pages 180-214 in Proc. Seventh Annual Dredging Seminar, Report No. CDS-181, J. B. Herbich, ed. Texas A&M University, Sea Grant College, College Station, Tex.

McConnaughey, B. H. 1974. Introduction to Marine Biology, 2nd ed. C. V. Mosby Company, St. Louis, Mo. 544 pp.

Meccia, R. M. 1975. Overview of dredged material research program (DMRP). Pages 29-42 in Proc. Seventh Annual Dredging Seminar, Report No. CDS-181. J. B. Herbich, ed. Texas A&M University, Sea Grant College, College Station, Tex.

Meyer, F. A. 1965. Chemical control of undesirable fishes. Inland Fisheries Management. Alex Calhoan, ed. State of California Department of Fish and Game, Sacramento, Calif. pp. 498-510.

Milne, P. H. 1972. Fish and shellfish farming in coastal waters. Fishing News (Books) Ltd., London, England. 208 pp.

Motte, G. A. and Y. Iitaka. 1975. Evaluation of trawl performance by statistical inference of the catch, Marine Tech. Rept. No. 36. University of Rhode Island, Fisheries and Marine Technology, Kingston. 21 pp.

Murden, W. R. 1976. National dredging study. Proc. Eighth Annual Dredging Seminar, J. B. Herbich ed. Houston, Texas, November 7, 1975.

Murphy, W. L. and T. W. Zeigler. 1974. Practices and problems in the confinement of dredged material in Corps of Engineers projects, Technical Report D-74-2. U.S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss. 136 pp.

National Marine Fisheries Laboratory. 1977. Hatchery techniques utilized by Texas A&M Mariculture staff in cooperation with National Marine Fisheries Service. National Marine Fisheries Service Galveston Laboratory. Mimeo.: 2 pp.

Nuzzi, R. 1977. Aquatic disposal field investigations, Eastons Neck Disposal Site, Long Island Sound; Appendix F: Predisposal baseline conditions of phytoplankton assemblages, Technical report D-77-6. Performed by New York Ocean Science Laboratory, Montauk, N.Y., under Contract No. DACW 51-75-C-0016 to U.S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss. 44 pp.

O'Connor, J. M. 1975. The effect of suspended and deposited sediments on estuary organisms. Pages 215-234 in Proc. Seventh Annual Dredging Seminar, Report No. DCS-181, TAMU-SG-76-105, J. B. Herbich, ed. Texas A&M University, Sea Grant College, College Station, Tex. pp. 215-234.

Odum, H. T. 1963. Productivity measurements in Texas turtle grass and the effects of dredging an intracoastal canal. Texas Inst. of Marine Science No. 9. pp. 48-58.

Pope, R. M. 1976. Dredged material disposal: Social costs and other externalities. Pages 398-417 in Proc. of the Specialty Conference on Dredging and its Environmental Effects, January 26-28, 1976, Mobile, Ala. P. A. Krenkel, J. Harrison, and J. C. Burdick III, eds. Amer. Soc. Civil Eng., New York.

Quick, J. A., Jr. 1977. Marine Disease Primer: Book One. Marine Hobbyist News Publications, Bloomington, Ill. 48 pp.

Quick, J. A. Jr. and J. A. Morris. 1977. Experimental extensive culture of penaeid shrimp in a simulated dredged material disposal area. Pages 305-325 in Proc. of the Seventh Annual Workshop, World Mariculture Society, January 26-29, 1977, San Diego, Calif. J. W. Avault, Jr., ed. Louisiana State University, Division of Continuing Education, Baton Rouge, La.

Quick, J. A. Jr., J. A. Morris. In Press. Investigation of mariculture as an alternative use of dredged material containment areas. Performed by Dow Chemical U.S.A., Texas Division, Freeport, Tex., under Contract No. DACW 39-75-C-0083 to U.S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

River and Harbor Floow Control act of 1970. Public Law 91-611 (84 Stat. 1818). Second Session, 91st Congress, 31 December 1970.

Rose, C. D., A. H. Harris, and B. Wilson. 1975. Extensive culture of penaeid shrimp in Louisiana salt-marsh impoundments. Trans. Amer. Fisheries Soc. No. 104, Volume 2. pp. 296-307.

Shuba, P. J., J. H. Carroll, and K. L. Wong. 1977. Biological assessment of the soluble fraction of the standard elutriate test, Technical Report No. D-77-3. U.S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss. 107 pp.

Smith, R. L. 1974. Ecology and Field Biology, 2nd ed. Harper and Row, New York, N.Y. 850 pp.

Sweeney, R. A. 1973. Present and potential ecological status of the diked disposal sites in Buffalo Harbor, Buffalo, New York, Report No. NYSSGP-RS-75-004. State University of New York and Cornell University. New York Sea Grant Institute. 27 pp.

Taylor, J. L., D. L. Feigenbaum, and M. L. Stursa. 1973. A Summary of Knowledge of the Eastern Gulf of Mexico: Utilization of marine and coastal resources. Florida State University System Institute of Oceanography, St. Petersburg. IV-1 - IV-63.

Texas A&M University. 1976. Sea Grant mariculturists find source of shrimp seed stock off Texas coast. The University and the Sea, Number 9, Volume 5. Sea Grant College Program, Center for Marine Resources, College Station, Tex. pp. 4-5.

Thompson, R. G., R. W. Cullen, and L. C. Wolken. 1970. Optimal investment and financial decisions for a model shrimp fishing firm, Report No. TAMU-SG-70-205. Texas A&M University, Sea Grant Program, College Station, Tex. 49 pp.

Thompson, J. R. 1973. Ecological effects of offshore dredging and beach nourishment: A review prepared for the U.S. Army Corps of Engineers Coastal Engineering Research Center, MP-1-73. 39 pp.

Valenti, R. J. and S. Peters. 1977. Aquatic disposal field investigations, Eatons Neck Disposal Site, Long Island Sound; Appendix D: Predisposal baseline conditions of demersal fish assemblages, Technical Report D-77-6. Performed by New York Ocean Science Laboratory, Montauk, N.Y., under Contract No. DACW 51-75-C-0016 to U.S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss. 100 pp.

Vaughan, R. and C. Kimber. 1977. Maintenance dredging effects on vegetation adjacent to the Gulf Intracoastal Waterway - Cedar Lakes Section. Report No. TAMU-SG-77-207. Texas A&M University, Sea Grant College, College Station, Tex. 64 pp.

Venkataramiah, A., G. J. Lakshmi, and G. Gunter. 1974. Studies on the effect of salinity and temperature on the commercial shrimp, Penaeus aztecus Ives, with special regard to survival limits, growth, oxygen consumption, and ionic regulation, Contract Report H-74-2. Performed by Gulf Coast Research Laboratory, Ocean Springs, Miss., under Contract No. DACW 39-71-C-008 to U.S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss. 136 pp.

U.S. Army Engineer Waterways Experiment Station. CE. 1976b. DMRP status summary, Vicksburg, Miss. 8 pp.

U.S. Army Engineer Waterways Experiment Station, CE. 1977. Landscape primer for confined dredged material disposal. Vicksburg, Miss. 2 pp.

Willoughby, W. E. 1977. Low-ground-pressure construction equipment for use in dredged material containment area operation and maintenance: Performance predictions, Technical Report No. D-77-7. U. S. Army Engineer Waterways Experiment Station, CE. Vicksburg, Miss. 52 pp.

APPENDIX A: RECOMMENDED DEVELOPMENTAL PROGRAM

1. The following describes a recommended developmental program to attack and solve the final prohibitive costs to commercialization of shrimp mariculture in dredged material containment areas. The proposal is divided into two phases of five and four tasks, respectively. The containment area pond site used for this study is described as the model, but this type of research and development could be carried out in any of numerous containment areas in the United States or abroad.

Phase I

2. The overall objective of this phase would be to develop the necessary techniques and to demonstrate that penaeid shrimp can be economically and reliably spawned and cultured in dredged material containment areas. There would be six specific objectives as follows:

- a. To develop, engineer, and construct a simple inexpensive shrimp hatchery based on the use of floating plastic film tanks.
- b. To develop the techniques for spawning shrimp and hatching the resulting larvae in such a floating tank hatchery placed in a containment area pond.
- c. To use the floating hatchery technique for stocking a containment area and perform a further demonstration of containment area mariculture.
- d. To further refine harvest techniques, demonstrate their use in containment area shrimp culture ponds, and test market the shrimp produced.

e. To provide a demonstration to be observed directly by as many potential mariculturists (investors, entrepreneurs, land owners, etc.) as possible and to provide as much publicity of results as possible through news media and other publications.

f. To produce and make available technical and economic data and information that can be applied by individuals and business groups to establish economical shrimp cultures in dredged material containment areas.

3. The objectives of this proposal are to be accomplished in the following sequential tasks:

Task	Title
1	Site Preparation
2	*In Situ* Hatchery Technique Development
3	Grow-Out
4	Harvest
5	Marketing
6	Final Report Preparation

Task 1: Site Preparation

4. The following is based on use of Galveston District Containment Area Number 85 as the site for this work. This containment area, owned by the Brazos River Harbor Navigation District, is the same containment area used to demonstrate shrimp mariculture in an active containment area.

5. A 1.000-ft. dike was installed to separate a manageable 20-acre section off from the total 158 acres of the containment area. Drainage culverts with valves, pump pad, seawater suction hoses, seawater transport lines, and a filter screen for the incoming water could also be utilized. The only new site preparations necessary would be the installation of equipment necessary for the *in situ* hatchery operation (Figure A1).

6. From previous experience, it was determined that it would not be necessary to protect the inner walls of the levee against wave erosion. Wave action and surface runoff in the pond would form a small beach along the inside of the levee and protect it from further erosion.

7. An intake structure installed on the Intracoastal Waterway would provide seawater to control the salinity in the pond. A 1,400-gal. per min. diesel-powered pump could draw either high-salinity seawater from the bottom of the Intracoastal Waterway or low-salinity water from the surface of the Waterway as needed. The water would be transported to the pond through a 1,000-ft. long, 10-in.-diameter pipeline and would be filtered through a self-cleaning 4- x 10-ft. 500-μm pore size screen to remove any shrimp predators and competitors or their larvae from the incoming seawater.

8. Predation in the pond from land animals would be controlled by maintaining pond depth at 3 to 4 ft. This effectively prevents predation by wading birds and terrestrial animals except at the relatively narrow pond margin. Turbid water, from suspended sediment and planktonic algae, would assist in controlling predation at the edge as well as diving bird predation elsewhere. Prior to stocking, predation from aquatic organisms would be controlled by treating the water with a toxin that would kill predators without leaving any residue that will be harmful to the shrimp. No structural modification of the containment area would be necessary for predator control.

9. A small shed would be installed to house an air supply system for the hatchery operation. Two 500-gal. tanks may be necessary to supply fresh water. The hatching-rearing area would consist of two flexible floating tanks. The smallest tank would be approximately 4 ft. deep and 12 ft. in diameter with a volume of approximately 3,300 gal. This tank would be floated inside a larger tank which also will be 4 ft. deep, but would be 25 ft. in diameter and have a volume of 13,500 gal. Both of these tanks would be supported in the containment area pond by use of flotation collars. A floating ring made out of polyethylene pipe would be placed around both tanks for protection from wave action. A short dock would be constructed to allow access to the tanks from the shore. Figure A1 shows how the complete hatchery system would look.

10. Water would be pumped into the two floating tanks through a 25-μm matrix filter. The salinity will be adjusted within a range of 28 to 32 ppt. If dilution is necessary, fresh water from the storage tanks would be used. In the event higher salinity is needed, artificial sea salts could be added.

Task 2: In Situ Hatchery Technique

11. At least 1 week before the hatchery operation begins, the floating tanks would be placed in the pond and filled with filtered seawater taken directly from the pond. The salinity and possibly the carbonate or other mineral contents would be adjusted as necessary. The tanks would be filled to a depth slightly greater than the water they are floating in. This would result in a greater water pressure inside the tanks and cause them to maintain their shape. The small tank would be floated inside the larger. Weighted air stones would be placed in the tanks to provide properly distributed aeration. Except for the initial filtration, no attempt would be made to minimize contamination.

Task 3: Grow-Out

12. Approximately 1 week prior to stocking, fertilizer would be added to the containment area pond to stimulate a plankton bloom. This plankton would be the base for the development of a natural food chain in the pond. From prior work, it has been demonstrated that this is the only food required by the shrimp until they reach approximately 5 to 8 gm. in weight. Data taken on rate of growth and survival would be used to determine when the limits of natural productivity in the pond were being approached (∿250 lb. per acre). At that time, supplemental feeding would begin and would increase as necessary to maintain good growth and water quality.

13. Depending on weather conditions and water temperature, the grow-out would require 40 to 90 days before the shrimp reach a marketable size. During the grow-out period, water quality and plankton growth would be monitored carefully. Fertilizer will be added as needed to maintain a good plankton bloom in the pond. If needed, fresh seawater could be pumped into the pond to maintain water quality (pH, salinity, NH_3, etc.)

14. Meterological conditions would be recorded in order to assess the impact of different weather conditions on the shrimp mariculture operation. Shrimp would be periodically sampled to assess growth rate, health, and stomach contents. Shrimp from some of these periodic samplings would be frozen for later chemical analysis if needed. If any mortalities or disease were detected, every effort would be made to identify the cause and minimize its effect.

Task 4: Harvest

15. As the shrimp reach marketable size, maze-type wall traps would be set up and used to continuously harvest the larger individuals. Harvest would be controlled such that the amount of food necessary to provide for continued growth of those shrimp remaining in the pond would not result in unacceptable degradation of water quality. Harvest of the remaining shrimp would be done with nets when the pounds production of shrimp per unit time in the pond showed a decline due to reduced numbers, reduced growth rate due to season or approach to adult size, water quality degradation or other reasons. A modified 20-ft. otter trawl towed by a small boat would then be used for harvesting the remaining shrimp. This method of harvest has been found to require a minimum of manpower, capital expense, and time over other methods such as seining and trapping.

16. Prior to harvest, a survey would be made of the local shrimp processing plants and bait dealers. Arrangements could then be made with some of these businesses for test marketing of the shrimp. Mariculturists and other interested visitors would be invited to observe the harvest. As the shrimp were harvested, they would be packed in ice or placed in live wells as required by the market for which they were intended. Income from harvest sales would be used to defray project costs including test marketing efforts.

17. The harvested shrimp would be weighed for total weight, and counts would be made to determine the average weight per shrimp. Groups of shrimp would be individually weighed and measured to get data on length-weight ratios and population distrubution. Percent survival and stocking efficiency could be calculated from harvest data.

Task 5: Marketing

18. Shrimp harvested from the pond would be distributed to several shrimp processors and bait dealers for evaluation. After a sufficient time interval, the participants would be contacted to determine the results.

19. From these data, the market potential of cultured shrimp would be evaluated. Comparisons such as taste, quality, and price would be made between wild-caught shrimp and cultured shrimp. Also, comparisons would be made between marketing the shrimp as bait or for human consumption.

20. After the comparisons are made, a projection of the economic feasibility of containment area shrimp mariculture would be composed. This projection would be based on real data derived from this demonstration. Also, evaluation of factors such as biological know-how needed by the culturist and effects of natural disasters would be made.

21. Every effort would be made to produce a report that a prospective mariculturist could use as an honest and accurate yardstick to measure the potential for success in a containment area shrimp culture venture.

Phase II

22. The work proposed under this optional phase would seek to determine by direct comparison how much value can be added to the harvest of a containment area shrimp pond by supplementary feeding during the latter stages of grow-out. The technique would duplicate the present study and the proposed Phase I in the same divided pond. The method would be to bisect the 20-acre containment area shrimp pond with a net or plastic film barrier and then feed one side while using the other as a control.

Task 1: Pond Bisection

23. This task would begin during Task 3 (Grow-Out) of the main proposal. During that grow-out, both the size of the pond shrimp and their total quality would be monitored by seining various sections of the pond to determine size-density distribution of the shrimp. When it appeared that the shrimp were approaching the carrying capacity of the pond, a 1,000-ft. divider would be placed in the pond, bisecting it. Approach of maximum pond carrying capacity

would be indicated by a biomass nearing 250 lb. per acre in the shrimp trophic level, a shrimp size of 4 to 5 gm., or a slowing of shrimp growth rate. It is anticipated that all three phenomena would occur simultaneously.

24. The separator would be installed to separate the shrimp populations to either side. Divers would bury the leadline, and a cork line would be used to keep the full top edge above the surface. This divider might be a net of sufficiently fine mesh to prevent shrimp from passing through. Although some supplementary food might pass through to the other side, this quantity should be insignificant. Every effort would be made to ensure against shrimp migration across the barrier.

25. A net would probably be preferable from an experimental viewpoint since it would ensure that water quality remained the same in both sides of the pond. It would probably be of value to test a plastic film divider, however (Figure A2). When the shrimp culture pond in Containment Area Number 85 was constructed, a 1,000-ft. internal levee was constructed at a cost of about $40,000 (Figures 15-17). This is too much for a private mariculturist to spend to divide a containment area into ponds. But since most containment areas are too large to stock all at one time practically, some method of splitting them into sections of 100 acres or so must be found. In addition, it would be impossible to obtain fill material as was done in this study from below the dredged sediment in most containment areas that have seen substantial use. Fill would have to be imported in those cases, thus drastically increasing levee construction costs.

26. It is felt that the use of fabricated plastic film dividers would be an economical method of separating containment areas into ponds of manageable size. Such dividers would be much less expensive than levees, about $5.00 per linear foot versus over $40.00 per foot for a levee. They would be easy to deploy and simple to move. Figure A2 shows a probable design. The levee consists of a floating pair of polyethylene pipes inside a large sleeve of cross-laminated linear polyethylene film. Soil or heavy pipe would be used to weight the lower edge. Small sections of mesh would allow water to equalize on either side of the barrier. An additional advantage of such a floating barrier would be that it could be moved aside during dredging operations to facilitate dredged material disposal. Afterward, it would be floated back into position.

27. It is felt that such floating dividers would be an important part of commercial containment area mariculture. Phase II would be an excellent time to develop and test such dividers while also testing supplementary feeding.

Task 2: Supplementary Feeding

28. This task would begin during Task 3 of the main proposal at the time when sampling first indicated that the biological carrying capacity of the fertilized shrimp culture pond was being approached. It is expected that this first indication would be a decrease in growth rate. It is important that supplementary feeding be begun before stunting has occurred. Any substantial hiatus in growth can cause stunting. Therefore, supplementary feeding may be started even without a slowing of growth when sampling indicates that total second trophic level biomass (shrimp plus any competitors) is near 250-300 lb. per acre or when shrimp are nearing the 4- to 5-gm. size.

29. Supplementary feed would be primarily a commercially available ration such as Ralston Purina M25 Shrimp Chow. Feeding would be provided only on the experimental half of the divided pond. Food would be broadcast from shore and/or boat.

30. Feeding rate would vary with time and would be based on sampling data. The biological production of the pond would be calculated from data on growth rates and biomasses at the various trophic levels prior to the onset of feeding. The total amount of food required by the pond shrimp plus competitor populations would be calculated by projection of measured growth rates, biomasses, and conversion ratios. The pond production would be subtracted from this total food requirement, and the remainder of the requirement would be supplied artificially.

31. Data would be taken on stomach contents of the shrimp, ammonia and other nutrients, phytoplankton growth, bottom anaerobiosis, and other pond characteristics to verify the correctness of the feeding rates based on calculations. Feeding rate would be fine tuned as needed. An example of such fine tuning would be a reduction in feeding rate should plankton blooms

and thus pond productivity become excessive, thus endangering pond dissolved oxygen and carbonate buffer levels.

32. As the shrimp grew and the biomass increased, feeding rates would be appropriately increased. Pond data would be monitored to ascertain when the biomass begins to approach the total biological capacity of the pond in terms of maintaining adequate oxidation of ammonia, buffering capacity, oxygen levels, and the like. Pumping of fresh seawater would be used as necessary to maintain biologically adequate conditions during cloudy days and other adverse conditions when this critical period was reached.

Task 3: Harvest

33. When the pond biomass began to get near the total pond holding capacity, harvesting would be started. An immediate attempt would be made to sample in such a way as to determine the total harvestable shrimp population. This would allow the option of a complete harvest at this point or only half a harvest followed by additional grow-out until pond capacity was once again approached. Season, pond condition, shrimp size, and other factors would also enter into this decision.

34. Shrimp would be harvested, either all at once or in two or more harvests, as described in Task 4 of Phase I. The unfed and fed halves of the shrimp culture pond would be harvested in identical fashion. Separate data on shrimp size, numbers, and condition would be taken on each half for later comparison.

35. Shrimp would be marketed as described in Task 5 of Phase I. The press and potential mariculturists would be invited to observe and participate in harvesting and marketing.

Task 4: Data Reduction and Reporting

36. A special effort would be made to realistically project the economics of late grow-out supplemental feeding to a commercial containment-area shrimp-culture operation.

37. If the economics were as good as expected, a direct effort would be made to contact potential mariculturists and cultivate their interest in beginning containment area shrimp farms. This project would reach its full success potential only if a technology transfer to the private sector in the form of one or more active containment-area culture businesses could be made.

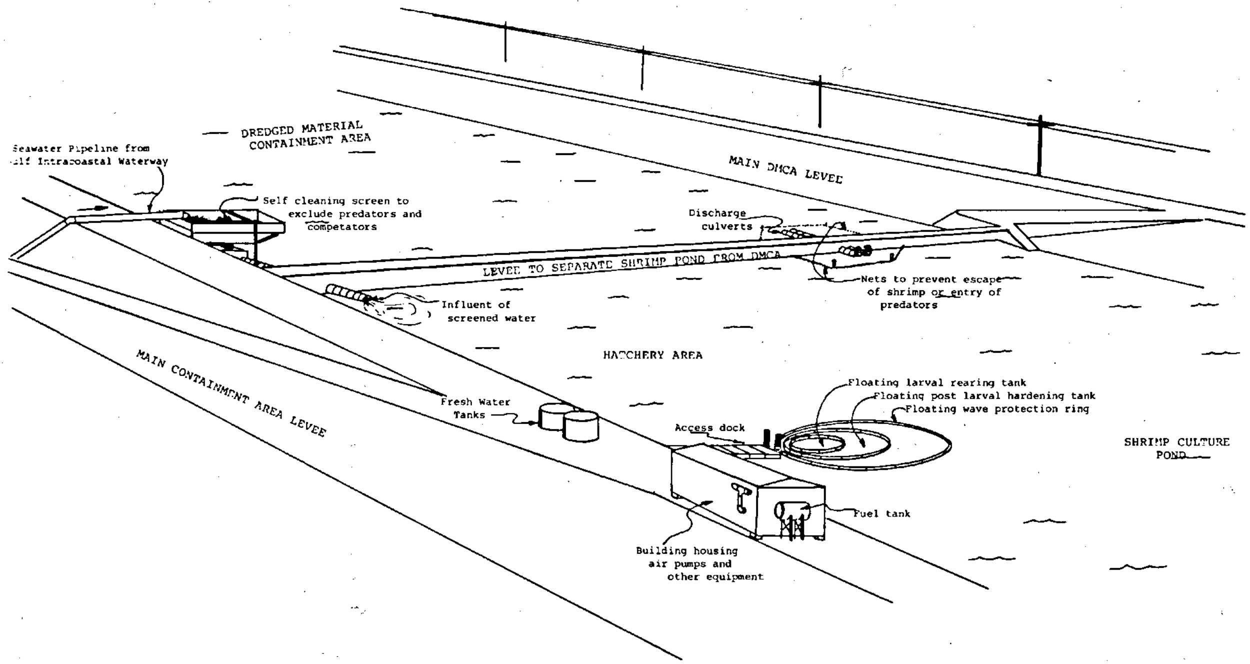


Figure A1. Artist's rendering of planned _in situ_ hatchery installation at the shrimp culture pond site Dredged Material Containment Area (DMCA) No. 85.

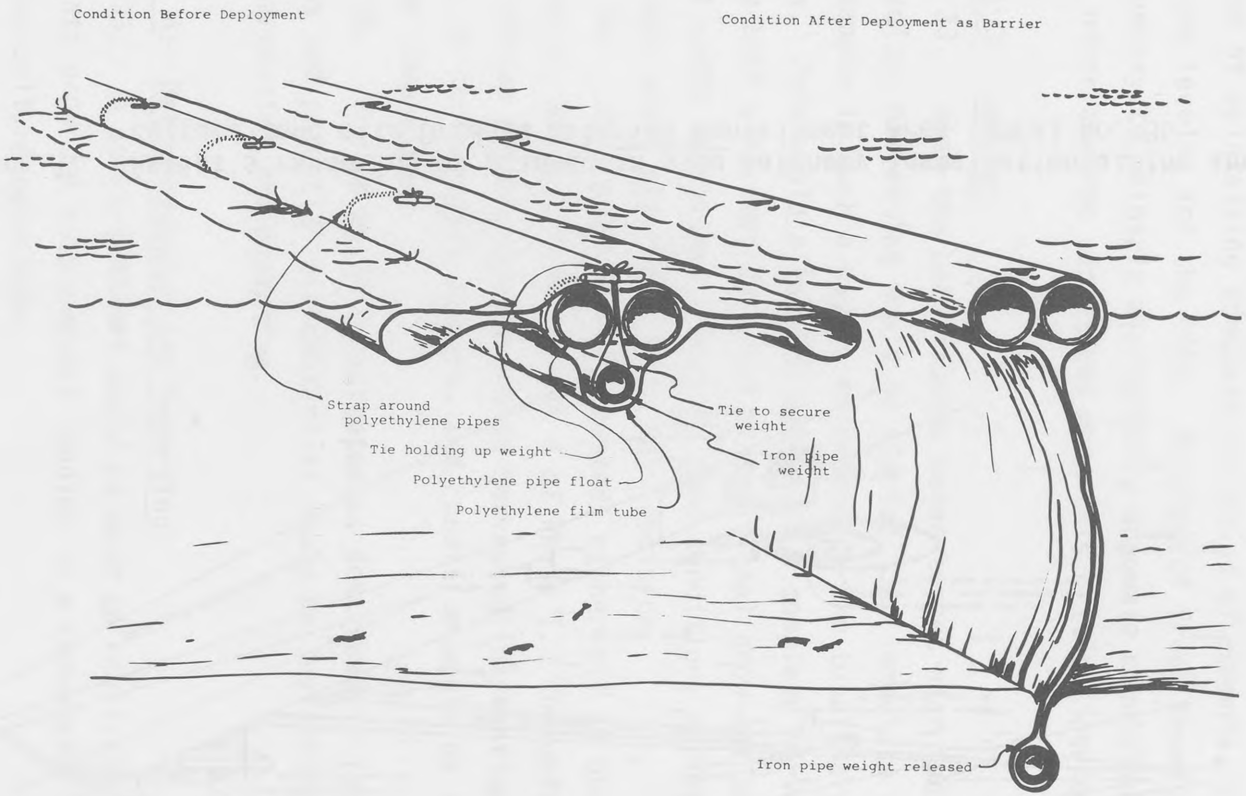


Figure A2. Proposed design for a plastic film barrier for use in separating containment areas into manageable size shrimp culture ponds. The structure is deployed in the configuration shown on the left and floated into position. The ties supporting the anchor pipe are then released, and the pipe drops into the soft mud bottom carrying the plastic film tube with it, thus forming a barrier.

US GOVERNMENT PRINTING OFFICE: 1978-740-235/11

In accordance with letter from DAEN-RDC, DAEN-ASI dated 22 July 1977, Subject: Facsimile Catalog Cards for Laboratory Technical Publications, a facsimile catalog card in Library of Congress MARC format is reproduced below.

Quick, J A

Field demonstration of shrimp mariculture feasibility in dredged material containment areas / by J. A. Quick, Jr. ... [et al.], Dow Chemical U. S. A., Texas Division, Freeport, Texas. Vicksburg, Miss. : U. S. Waterways Experiment Station ; Springfield, Va. : available from National Technical Information Service, 1978.

xii, 128 p. : ill. ; 27 cm. (Technical report - U. S. Army Engineer Waterways Experiment Station ; D-78-53)

Prepared for Office, Chief of Engineers, U. S. Army, Washington, D. C., under Contract No. DACW39-76-C-0108 (DMRP Work Unit No. 4D03)

Literature cited: p. 110-117.

1. Containment areas. 2. Dredged material. 3. Dredged material disposal. 4. Shrimps. 5. Waste disposal sites. I. Dow Chemical Company. Texas Division. II. United States. Army. Corps of Engineers. III. Series: United States. Waterways Experiment Station, Vicksburg, Miss. Technical report ; D-78-53.

TA7.W34 no.D-78-53