The Suitability of the Purple-Hinge Rock Scallop to Marine Aquaculture

by
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Report No. T- CSGP 001
Center for Marine Studies Contribution No. 50

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A California Sea Grant College Program Publication

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March 1, 1981

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Published by the California Sea Grant College Program, Institute of Marine Resources, University of California, La Jolla, California, 1981. A limited number of additional copies is available from Sea Grant Marine Advisory Program Extension Wildlife and Sea Grant, 554 Hutchinson Hall, University of California, Davis, California 95616.

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I. INTRODUCTION

A major goal of aquaculture, especially in the United States, should be to find worthy crop organisms which may be brought to harvest with a minimum investment of capital, labor and energy resources. These considerations favor cultivation of fish and shellfish belonging to the first trophic level. The bivalve mollusks, including oysters, mussels, clams, and some species of scallops, are of recognized value to marine aquaculture. Commercial production of these shellfish owes its success largely to the fact that their food is supplied primarily by natural stocks of phytoplankton.

With few exceptions, aquaculture of bivalve marine mollusks is practiced in bays, lagoons and estuaries. The open ocean has been scarcely tapped as rearing ground for shellfish, yet it offers limitless space and plant plankton resources which could, with development of appropriate technology, support massive production of harvestable protein directly utilizable by man.

This report concerns the purple-hinge rock scallop, Hinnites multirugosus*, and stems from an earlier investigation of field growth and requirements for larvae in culture by Leighton and Chess (Leighton and Phleger 1977). The rock scallop is found from southern Alaska to central Baja California, Mexico (Grau 1959), and is prized for its flavorful meat (the adductor muscle, Figure 1). It is collected exclusively by sport divers in California, where the catch ranks close to that for abalone and lobster (Young 1973). Rock scallops are locally abundant on jetty rock and concrete structures (pier pilings) near entrances to bays in southern California, and are often found on rocky reefs offshore to depths of 30 m. However, distribution of the shellfish is discontinuous and lasting commercial

*Hinnites multirugosus is synonymous with H. giganteus (Roth and Coan, 1978), but common usage has been upheld here.

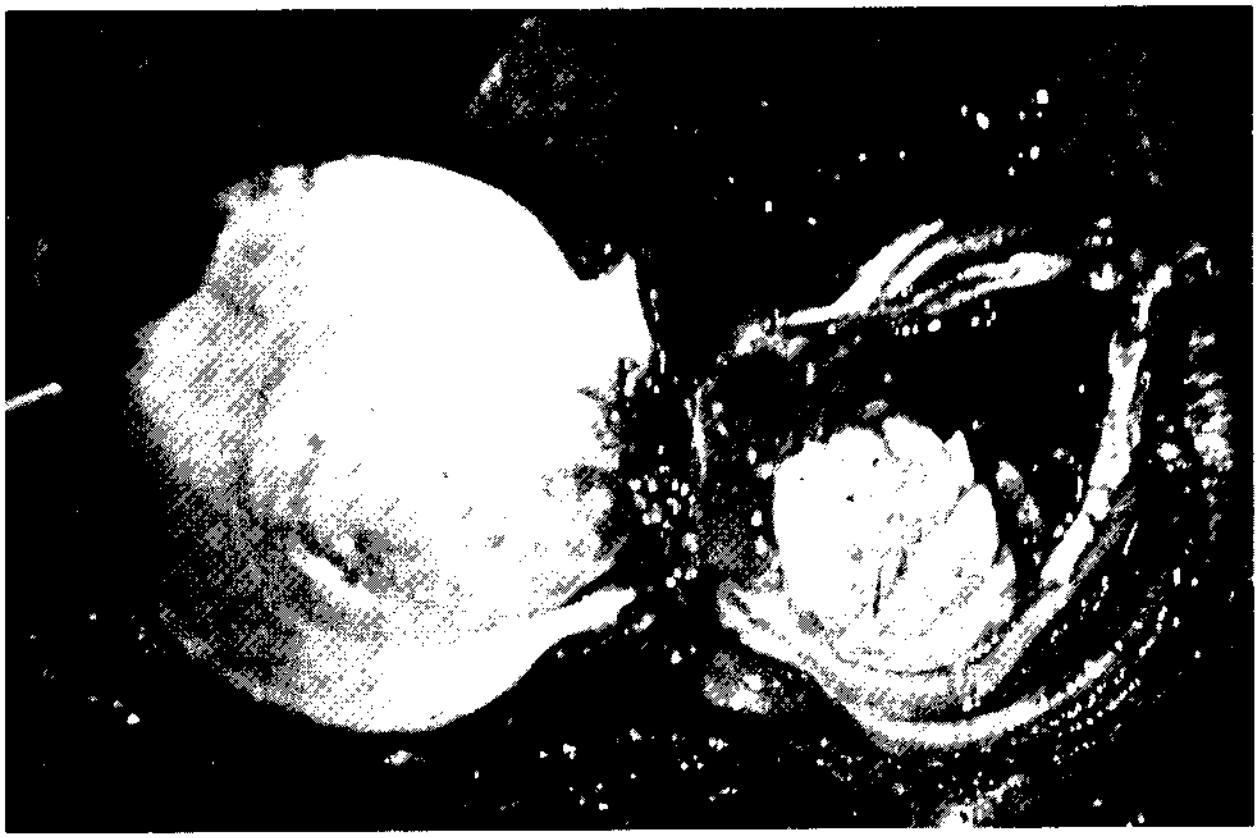

Figure 1. A small adult rock scallop, Hinnites multirugosus, freshly opened to show the large adductor muscle. This individual, a female, is fully gravid.

exploitation could not be sustained. For this reason, H. multirugosus is currently excluded from commercial harvesting in California by state law.

In contrast to most pectinid bivalves, Hinnites multirugosus cements itself to rock or shell substrates after completion of free-living larval and early juvenile stages (Yonge 1951). Cementation begins at an age of about six months when the juvenile is 2-3 cm in diameter. Byssal threads produced by the scallop hold the body securely while deposition of shell material by the right valve is made in conformity with the microrelief of the adopted surface. The process of cementation is continued with growth so long as the right shell valve margin contacts the substrate. H. multirugosus may attain a comparatively large adult size. Specimens exceeding 20 cm in diameter are common on some deeper reefs.

The purple-hinge rock scallop is a prime candidate for marine aquaculture (Leighton and Phleger 1976). Through a descriptive flavor profile analysis (Foremost Foods Research Laboratory), Hinnites was compared with commercially available scallop species and was ranked highly (Phleger et al. 1978). Prospects for marketing appear good. Culture of this scallop from egg to harvest size (10-13 cm) within a period of two and one-half years has now been achieved applying methods similar to those for oyster production. The cementing habit of Hinnites is an attribute of major advantage to its extensive culture. Juveniles secure themselves to concrete, asbestos board, plastic sheet and mesh, and other artificial materials. Methods have been developed which ensure scallop cementation to these substrates at densities optimal for growth.

It is anticipated that the rock scallop will prove amenable to large-scale aquaculture both in well circulated bays and in open ocean environments where temperature and salinity fall within an appropriate range and where

natural phytoplankton is abundant. This shellfish may extend attempts to harvest plankton-converting bivalves beyond limits of location true for oyster and mussel culture. Since the rock scallop cements itself to rearing structures, cages and pens employed in culture of sea and bay scallops (Taguchi 1976, Castagna and Duggan 1971) are not required to contain advanced young and adult stages.

This report summarizes research done by students and the principal investigators at San Diego State University during the period September 1975-August 1978. On revision of the text, some more recently obtained information has been included for completeness. While much remains to be learned concerning the biology and culture of the rock scallop, a sufficiently broad body of knowledge has been gained to appreciate the potential offered by this mollusk to aquaculture. Refinements in culture, including control over ripening of broodstock and the design of improved systems for mass culture of larvae, are in progress at this time. New methods to facilitate rearing scallops in the extensive phase are being developed.

The subjects of this technical account are presented in ten distinct but obviously interrelated sections. The departure from the traditional organization (methods, results, discussion) is considered appropriate for this technical report since the several subject areas require distinct treatment. A limited Materials and Methods section is included below and a general discussion is provided in the last sections. Methods applicable to each study precede results and pertinent discussion in the sections to follow.

II. MATERIALS AND METHODS

Facilities at San Diego State University and at the Southwest Fisheries Center (National Marine Fisheries Service), La Jolla, were used for laboratory

research on reproductive cycles, morphometric relations, chemical constitution and larval culture. A vessel outfitted as a laboratory and moored in Quivira Basin, Mission Bay, San Diego, provided space to study methods for rearing scallops to marketable size (Phleger and Leighton 1976). Field observations on growth and recruitment were carried out in Mission Bay and at several locations offshore. An oceanographic platform (U.S. Navy, Naval Ocean Systems Center) and a station 5 km off the La Jolla coast were locations for studies of rock scallop growth rate. A large portion of this work, including frequent collection of experimental material and periodic measurement of marked scallops required diving (SCUBA) and underwater observation.

A. Growth Rate Observations

Most observations on growth of late juvenile and early adult stages of H. multirugosus required collection of wild stock from local concrete pilings and jetty rock in Mission Bay. Free-living juveniles were often found in abundance (30-50/man-hour searching) beneath smaller rocks comprising jetty "rip-rap" bordering the entrance channel to Mission Bay. During low tide (-0.5 to -1.8 ft) juvenile scallops could be collected from shore. Young adults were most easily obtained from pilings and offshore reefs by diving.

Identifying marks were provided scallops used in growth rate studies by tagging or by securing individuals in labeled positions on experimental rearing structures. Embossing tape labels or laminated type-print tags described elsewhere (Leighton 1978a) were tied to shells by threading monofilament nylon line or plastic coated stainless steel wire (trolling line) through a small hole drilled in the shell auricle anterior to the hinge. Tags were also secured to the rugose surface of the left valve using underwater-setting epoxy cement. Alternatively, juvenile scallops were glued with epoxy

cement to asbestos board, plastic sheet or concrete slabs in numbered positions. A most effective method was developed in which juvenile scallops were admitted to small plastic mesh cagelets affixed to asbestos board until cementing themselves in place. This method is described elsewhere (Leighton 1978b), but is summarized here in Section III.

Growth studies at ocean and bay stations usually employed cages of heavy-duty polyethylene mesh (Conwed Corp., 2.5 cm unoriented netting) to protect and hold substrate panels or boards. Smaller mesh sizes were used for juvenile containment. Holding and experimental cages of a variety of shapes and dimensions were suspended beneath the floating laboratory in Quivira Basin. Oyster rearing trays (Nestier style) holding juveniles 1-3 cm were stacked and held at mid depths (4 m), but fouling was heavy and periodic hauling and cleaning of the trays were necessary. If scallops were held for extended periods in oyster trays, they cemented to the perforated surfaces and were often damaged when removed for measurements. Accordingly, mesh cages were used in observations on growth at different depths, stocking densities and locations.

Our studies of scallop growth to compare field environments and holding conditions have made wide use of asbestos construction board. This material is easily cut to desired dimensions by scoring (no sawing necessary) and is extremely durable and long-lived in seawater. Asbestos board can be salvaged and used repeatedly. Concrete poured to form thin (2 cm) sheets and plastic materials (styrene sheet) vacuum-formed to provide points for scallop attachment (patent pending, Leighton 1978b) have proved useful and inexpensive.

B. Experimental Materials and Structures for Culture of Rock Scallops

Culture of H. multirugosus was necessarily and logically divided into three phases: 1) hatchery culture of larvae to juvenile stages, 2) containment of juveniles in natural waters for growth to a size practical for introduction to final rearing structures ("juvenile fattening"), and 3) extensive culture from advanced juvenile to marketable adult size ("crop production"). Each phase requires a specific set of conditions and appropriate equipment.

Methods and procedures found successful for spawn-induction and larval culture are similar to those described by Uki and Kikuchi (1974) and by Gruffydd and Beaumont (1972). Details are given in Section V.

Juvenile rock scallops were transferred from the hatchery laboratory to natural waters in Mission Bay when 3-5 mm in shell diameter. Several hundred individuals were held in each cage (cylinder of 1 mm mesh fiberglass window screen) suspended at 4 m beneath the floating facility. No special care was needed during the three to six months juveniles were allowed to mature in this approach, but cages were lifted weekly to brush away fouling organisms. New mesh containers of larger size (5 mm mesh) were substituted once juveniles reached 10-15 mm.

Cementing juveniles (20-30 mm) were admitted to the several designs of rearing structures mentioned above and described in detail in Sections III, X and XI.

III. GROWTH RATES IN JUVENILES AND ADULTS

A. Early Growth

Larvae from eggs spawned at the Southwest Fisheries Center (NMFS)

laboratory April 6, 1976 developed to post-larval stages by May and reached juvenile sizes appropriate for introduction to cages in the bay by September (Leighton and Phleger 1977). One group reared under favorable conditions in both the laboratory and later in the bay reached a maximum of 22 mm (14.5 mm average, n=10) and was beginning to cement at seven months. Another group from a more recent spawning (October 26, 1978) transplanted to the bay after 2.6 months, averaged 17.3 mm (range 10.0-23.0 mm) at an age of six months. Largest individuals were beginning to cement at that age.

B. Growth of Advanced Juveniles and Adults

In a preliminary study begun in 1972 (Leighton and Chess), a group of 20 young scallops was held in small plastic mesh cages suspended beneath a dock in Quivira Basin for a period of two years (Leighton and Phleger 1977). Individuals 40-60 mm at the onset increased in average shell diameter (height + width/2) almost 30 mm/yr. Larger scallops, initially 100-120 mm, gained an average of 12 mm/yr. In this set of observations, fouling by tunicates and mussels was heavy and scallops were crowded. Subsequent study has shown growth rates are higher when these restricting conditions are minimized.

Improved growth rates were found when juveniles and young adults were held under less crowded conditions. Information on growth rate through the first year following cementation was gained from a number of separate observations in which juveniles were introduced to different areas within Mission Bay and at different depths and stocking densities beneath the floating laboratory in Quivira Basin and the Navy Oceanographic Platform offshore (discussed in detail in Section XI). In most cases, group mean growth in shell diameter was 50-60 mm/yr.

A group of pre-cementing juveniles placed in stacked oyster rearing trays and suspended at a depth of 4 m beneath the floating laboratory increased an average 7.9 mm/mo during summer 1975 (20-22°C), 4.0 and 5.1 mm/mo during fall and winter (13-21°C), and 3.0 mm/mo during spring 1976 (14-19°C). Increases in shell diameter slowed as valve depth increased with age. The deepening body profile is characteristic of adults of this species (Leighton and Phleger 1977).

Two groups of young scallops occupied oyster rearing trays for a period of three years while suspended at a depth of 4 m in Quivira Basin. One group receiving a relatively free water exchange (mean 33.0 mm, October 1975, n=7) reached 105 mm after three years (Table 1, Figure 2). A second group with a mean shell diameter of 36 mm at the onset reached only 95 mm in the same period. The second group occupied trays in the center of the stack and water exchange was reduced. All scallops confined in oyster trays probably received food supplies which were less than optimal.

The rate of weight gain found for scallops in suspended trays was approximately linear from year 1 to year 3. These scallops, after the first year, increased at a rate of 135 gm/yr. The prospective rock scallop aquaculturist is, of course, most interested in the quantity of adductor muscle harvestable after one, two and three years. Adductor muscle constitutes approximately 10% of the total in-shell weight and 40-50% of the soft body weight in adult scallops of average size (see Section VIII). If juveniles 10-20 mm are reared in Mission Bay, we would expect that at one year adductor muscle weights would be 10-15 gm, and after two years 25-35 gm.

Table I. Sizes and weights for scallops held in suspended tray culture, 4 m depth, Quivira Basin, Mission Bay.

	Tab No.	10/10/75 mm	10/10/75 gm	3/31/76 mm	3/31/76 gm	10/2/76 mm	10/2/76 gm	4/10/77 mm	4/10/77 gm
Group I	83	34	6.5	56	24	69	75	97	161
	84	28	3.7	55	24	71	100	86	186
	88	32	5.2	59	31	70	100	85	170
	93	31	5.0	60	33	70	85	79	147
	98	30	4.6	54	23	70	96	90	188
	105	34	6.4	59	31	81	121	94	192
	106	42	12.0	67	56	81	150	101	225
	Mean	33.0	6.2	58.6	31.7	73.1	103.9	90.3	181.3

	10/2/77 mm	10/2/77 gm	4/9/78 mm	4/9/78 gm	10/11/78 mm	10/11/78 gm
83	105	229	107	241	111	347
84	89	208	93	268	98	363
88	93	259	96	275	98	347
93	84	198	85	215	87	252
98	96	280	104	320	110	455
105	101	256	110	309	110	394
106	110	334	118	398	124	544
Mean	96.9	252.0	101.9	289.4	105.4	386.0

	Tab No.	10/10/75 mm	10/10/75 gm	3/31/76 mm	3/31/76 gm	10/9/76 mm	10/9/76 gm	4/10/77 mm	4/10/77 gm
Group II	75	39	9.4	68	70	85	151	96	220
	82	45	14.2	67	67	77	121	82	155
	92	34	6.4	55	24	69	68	80	128
	95	24	2.6	55	24	68	68	82	130
	102	34	6.6	62	37	84	105	90	159
	103	29	4.3	42	12	57	53	70	98
	108	44	13.0	68	68	84	138	88	207
	Mean	35.6	8.1	59.6	43.1	74.9	100.6	84.0	156.7

	10/2/77 mm	10/2/77 gm	4/9/78 mm	4/9/78 gm	10/11/78 mm	10/11/78 gm
75	98	232	108	298	111	398
82	86	166	89	186	95	250
92	87	161	89	205	90	235
95	83	153	85	182	89	235
102	95	197	95	203	101	301
103	82	153	88	200	95	257
108	91	215	94	232	85	168
Mean	88.9	182.4	92.6	215.1	95.1	263.5

Group II scallops occupied middle stack Nestier trays and received restricted water exchange; growth was consequently less than for Group I (see text).

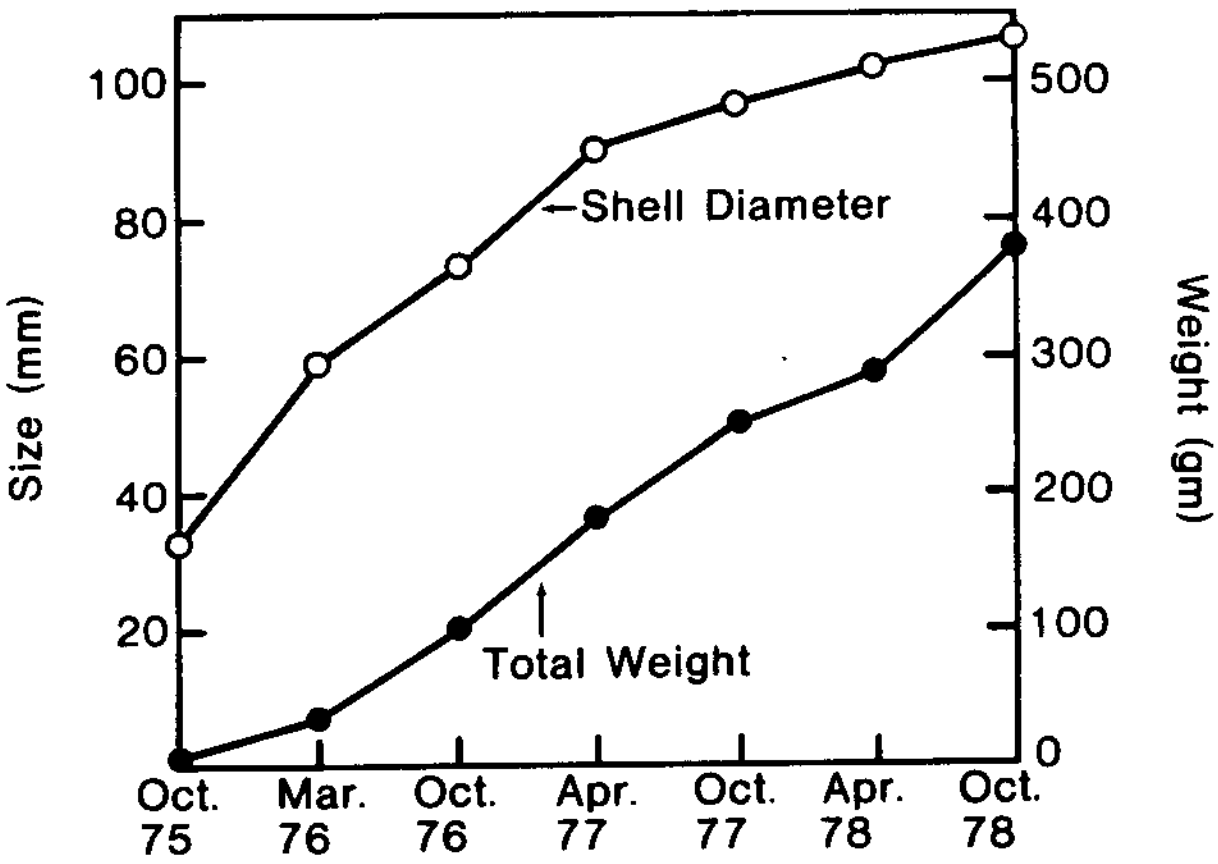

Figure 2: Mean semiannual size and weight for scallops held in suspended tray culture in Quivira Basin, Mission Bay, at 4 m depth.

IV. REPRODUCTIVE PERIODS AND SPAWNING IN SOUTHERN CALIFORNIA ROCK SCALLOPS

An understanding of patterns of reproduction in natural populations and in retained broodstock is highly important to hatchery culture. Larval production is dependent on a supply of gravid adults. While spawnings have occurred during most months of the year (Leighton and Phleger 1977), Hinnites multirugosus has produced most frequently in spring and early summer and again during mid-fall to early winter (Table 2). Changes in relative gonad bulk (the gonad-digestive system index) with season were found in two populations of H. multirugosus in the San Diego area (Jacobsen 1977). During 1975-76, approximately 15 adult rock scallops were collected monthly from Mission Bay (Quivira Basin), depth 3 m, and the reefs off Point Loma (depth 12-15 m). Histological examination of gonadal tissue and measurements of gonadal volume confirmed the semi-annual reproductive cycle suggested for these populations on the basis of spawn-induction trials. Those individuals from Mission Bay exhibited peaks during spring and mid-fall (Figure 3) and those from Point Loma during early summer and late fall (Figure 4). Final stages of gametogenesis and spawning appeared associated with seasonal temperatures and occurred during times of most rapid temperature change (2-3°C/mo) in both environments.

We have used several methods to induce spawning in the laboratory. Initially we employed "thermal shock" (raising water temperature about 5°C above ambient) or desiccation to prompt release of gametes in rock scallops. Often a suspension of sperm from biopsied testis matter was added to water containing adults in these trials. Success was experienced on less than 25% of these attempts, however. Since publication of the "UV method" (Uki and Kikuchi 1974), we have adopted this simple procedure to spawn gravid adult

Table II. Record of laboratory spawnings in Hinnites multirugosus for 1971-1976.

Date	Laboratory	Manner Induced	Remarks
9/10/71	NMFS	Spontaneous	Collected 2 wks earlier, Mission Bay
2/2/72	NMFS	Testis fluid	Collected 2 wks earlier, Mission Bay
4/26/74	CMA	Transferred to cleaned tank with filtered seawater	From Newport Bay, held 3 mo in outdoor tank
5/23/75	HMS	Natural	Group in cage 3 m beneath floating lab, airlift delivery to tanks
6/10/75	HMS	Natural	Same as above
10/2/75	HMS	Testis and ovary "extracts"	Scallops in tank aboard lab
12/29/75	NMFS	UV-irradiated water, 5°C over ambient, testis fluid added	Collected 2 wks earlier, Pt. Loma, 18 m
2/2/76	HMS	UV-irradiated water and testis fluid	Bay population, in tank aboard lab
4/5/76	HMS	UV-irradiated water alone	Same as above
10/22/76	NMFS	5-8°C "heat shock" during transport	Freshly collected from bay

NMFS - National Marine Fisheries Service Laboratory, La Jolla, CA
CMA - California Marine Associates abalone hatchery, Pt. Estero, CA
HMS - HMS Hinnites floating laboratory, Mission Bay, CA

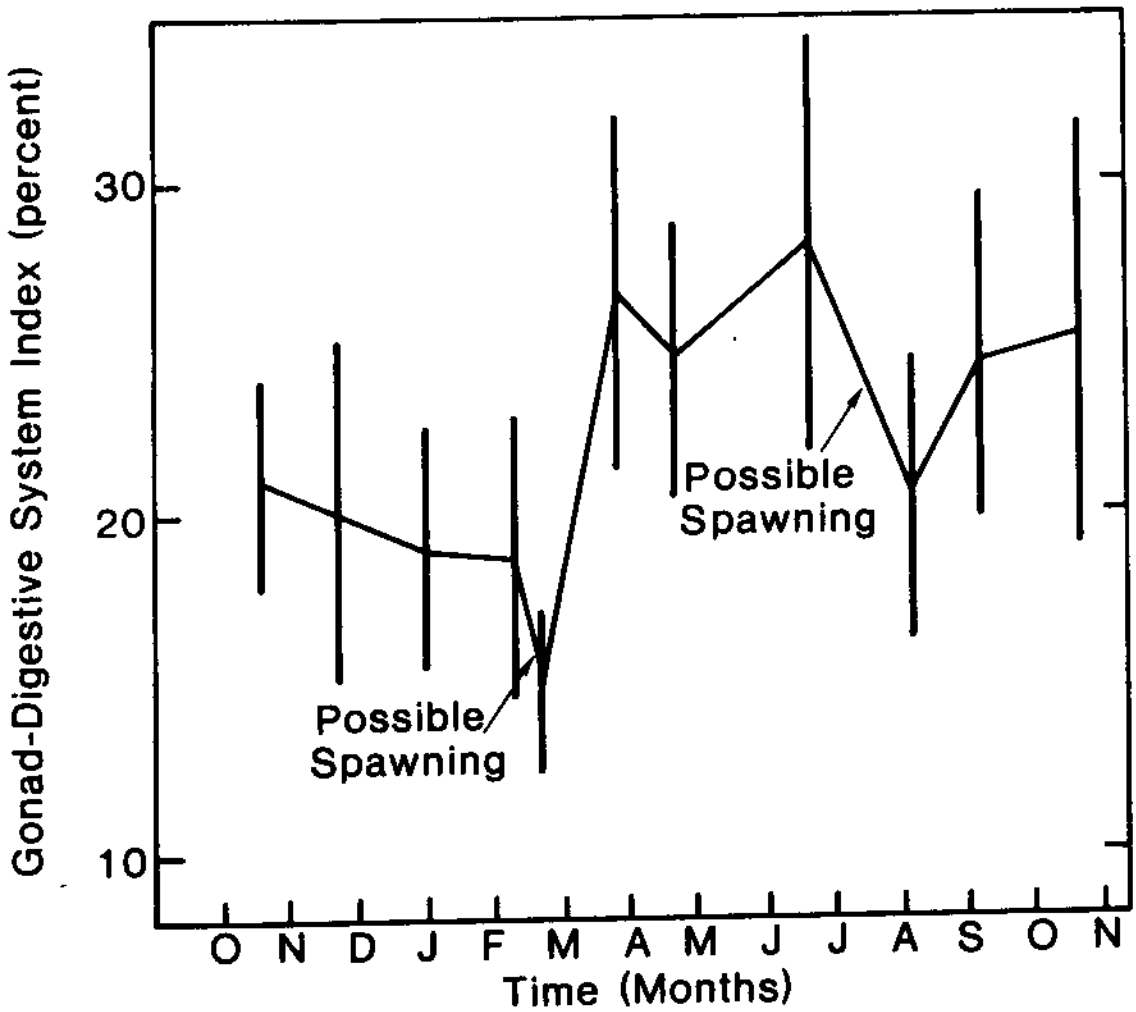

Figure 3: Gonad-digestive system index for the Mission Bay scallop population during 1976. Ranges are represented by vertical lines.

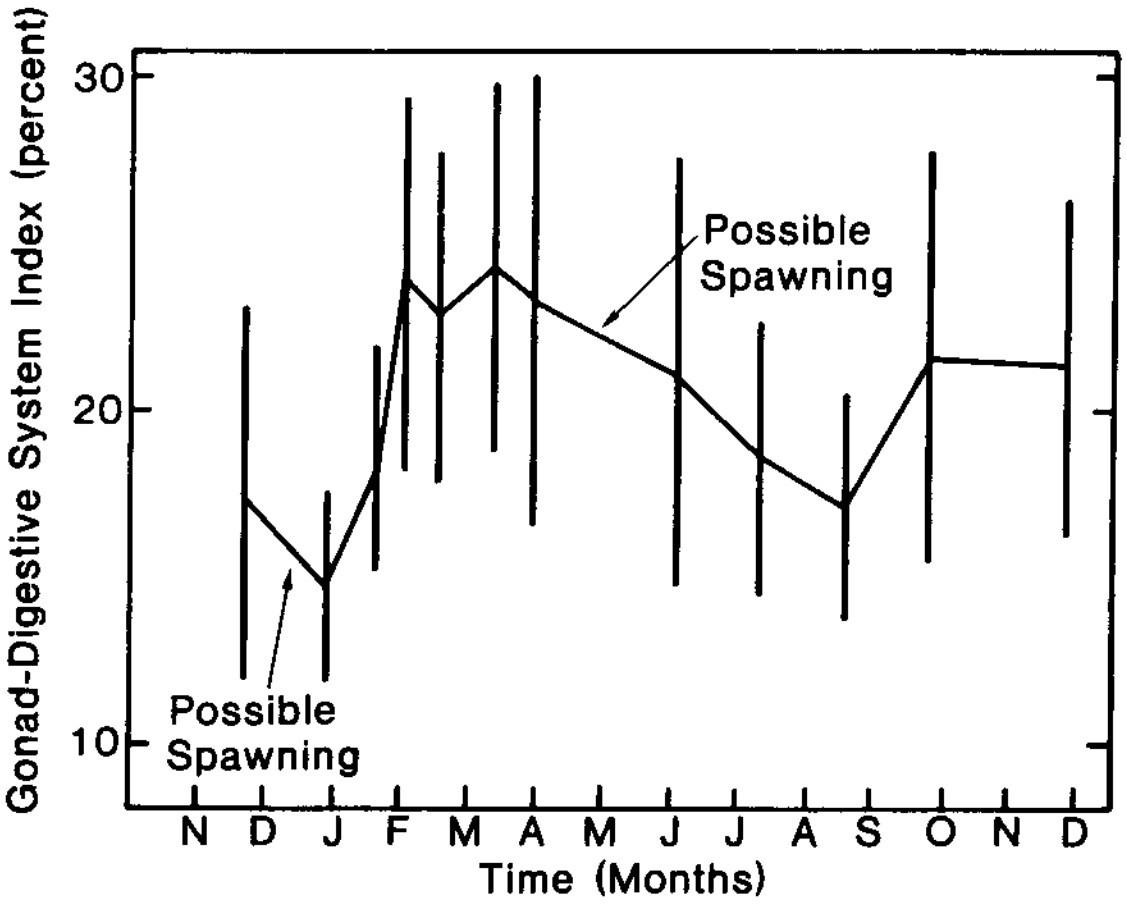

Figure 4: Gonad-digestive system index for the Point Loma scallop population during 1976. Ranges are represented by vertical lines.

rock scallops (Leighton 1977). Ripe scallops generally show response to water subjected to ultraviolet light (germicidal wave lengths 254 mμ) within 45 minutes with a display of "valve clapping." This frequent and vigorous gaping and closure of the shell valves is followed within 15-30 minutes by release of sperm among the males. Females then follow, expelling eggs as dense orange clouds. In the spawning process, gametes may be jetted over 10 cm through the water. Spawning may continue for about an hour.

Use of the UV method, when water is also passed through a filter (se use a cannister type, 5 μm filter), has the additional advantage of providing relatively clean, bacteria-reduced medium to receive the gametes. We routinely use UV-irradiated, filtered seawater for incubation of eggs and larvae (see following section). The UV unit used consists of two 60 cm germicidal fluorescent lamps held within PVC pipe jackets and is similar to that described by Loosanoff and Davis (1963).

V. CULTURE OF LARVAE THROUGH METAMORPHOSIS

Larvae were first successfully reared to advanced stages in 1972 (Leighton and Phleger 1977), but none progress through metamorphosis. High mortality occurred in larvae during the second week of culture in several subsequent attempts to rear scallops in the laboratory. In 1976, however, techniques were improved and several hundred larvae were carried through metamorphosis to juvenile and adult stages. Problems of early larval mortality has now been solved and increasing percentages of larvae are reaching post-metamorphic stages. A recent spawning (November 1978) yielded over 3,000 juvenile rock scallops, representing approximately 25% of the number of advanced larvae in this case (see below). These observations suggest three

conditions must be satisfied to assure survival through the critical period of metamorphosis in Hinnites: 1) maintenance of proper temperature and low light intensity in culture containers, 2) provision of an adequate diet consisting of a mixture of algal species, and 3) a routine of rather intensive care (frequent changes of water and food). These areas are considered in detail below.

A. Procedures for Incubation and Care of Eggs and Larvae

Freshly spawned eggs should be collected by siphon to clean containers as soon as possible. We have found poor survival in eggs allowed to remain in sperm-laden water for extended periods. To avoid problems associated with polyspermy and to minimize bacterial contamination we routinely control fertilization by placing females in the act of spawning in freshly filtered, UV sterilized seawater. Approximately 10 ml of a dilute suspension of sperm is added to 10 liters of seawater with freshly spawned eggs. After 30 minutes, washing is begun in which supernatent water is decanted and fertilized eggs are resuspended in filtered seawater. Since the eggs of Hinnites are small (60-70 μm in diameter), settling of eggs during the washing operation requires about one-half hour. Decantation and resuspension of eggs in renewed volumes of water is done two to four times. Eggs are incubated under antibiotic prophylaxis (penicillin G potassium and streptomycin sulfate, 10-50 ppm) at 14-18°C in polyethylene pails (10 l). Concentration of eggs should be approximately 10/ml. Since only gentle shallow aeration is supplied (an air stone immersed just beneath the surface), eggs remain on the bottom of the containers until hatching (36-48 hr), forming a layer one egg's thickness ($300-500/cm^2$).

Hatching time varied inversely with temperature (Figure 5) within the tolerated range (6-20°C) while larval development proceeded at an optimal rate

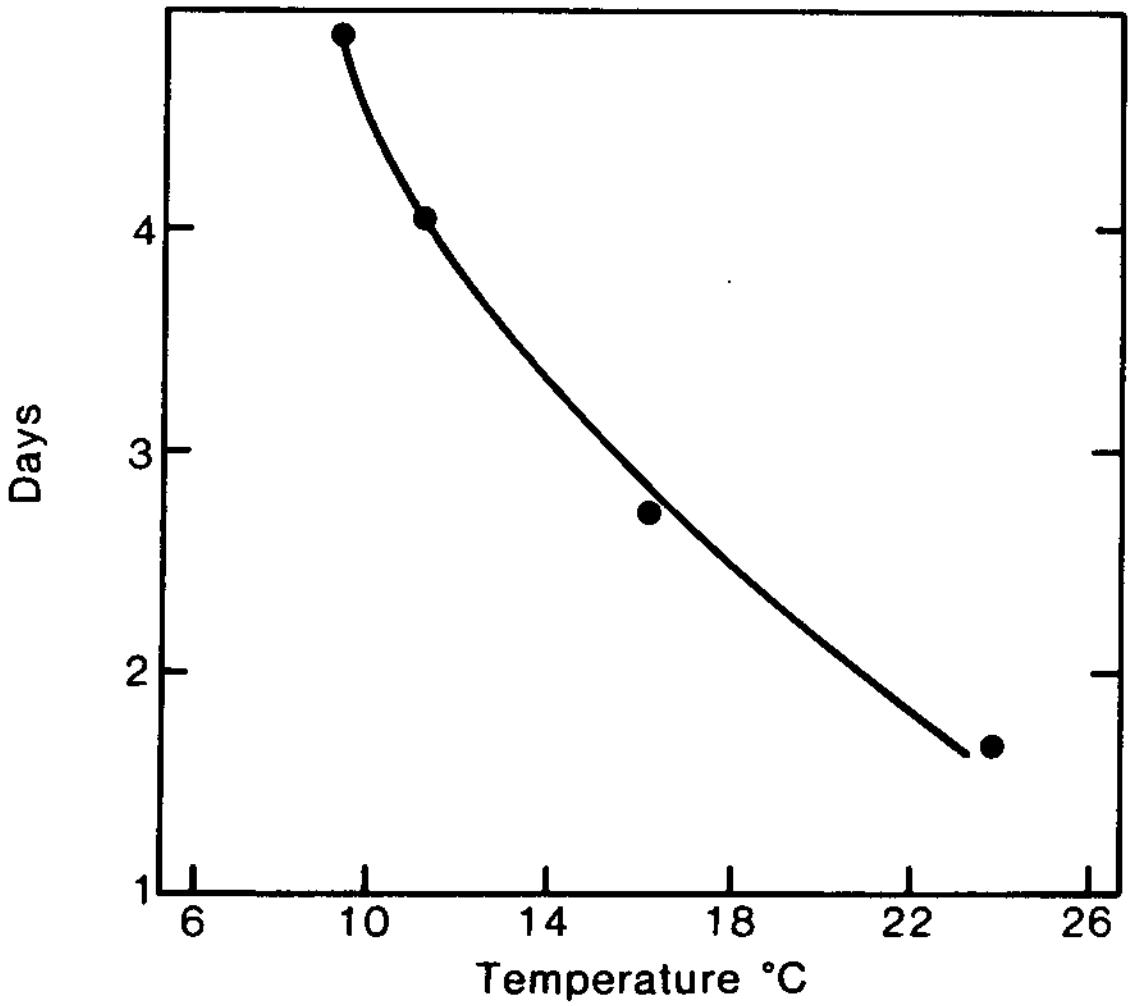

Figure 5: Days to hatching for *Hinnites* eggs incubated at different temperatures.

at 18°C with minimal attrition (Figure 6). At that temperature larvae reached the straight hinge stage ("D" stage) and were 100-110 µm in width by the fourth day. During that initial period of culture, water was changed daily and antibiotics renewed. A nylon mesh (44 µm) mounted on a wooden frame was immersed in filtered seawater to collect hatched and swimming larvae at each water change. Once larvae passed the straight hinge stage, a mesh of larger opening size (86 µm) was used.

B. Food and Feeding

Routinely, algal food organisms were provided scallop larvae after the third day. Species found most effective as food for early larvae include those algae commonly successful in oyster and clam culture: Monochrysis lutheri and Isochrysis galbana. Other algae tested as foods for larvae were Tetraselmis suecica, Phaeodactylum tricornutum, Rhodomonas sp., Nannochloris sp., Dunaliella sp., and Skeletonema costatum. Of these, Rhodomonas proved of greatest value, an especially good food for advanced larvae, metamorphosing post-larvae and post-metamorphic juveniles. Results of a typical experiment to assess relative value of algae and mixtures of these algae as foods for Hinnites larvae are provided in Table III. Tetraselmis, Nannochloris and Dunaliella proved inadequate foods for larvae of this bivalve.

Cultures of these algae were obtained from the collection of William Thomas at the Scripps Institution of Oceanography, La Jolla, California. Small volumes were grown in two-liter Fernbach flasks under constant illumination at 16-18°C using enriched seawater. In addition, larger volumes of Monochrysis and Isochrysis cultures (to 400 liters) were contained in acrylic cauldron tanks. Nutrients consisted of commercial liquid plant fertilizer (Atlas, 1:5:1, 0.1 ml/liter). These cultures were maintained by Eric Lynn of the National Marine Fisheries Service.

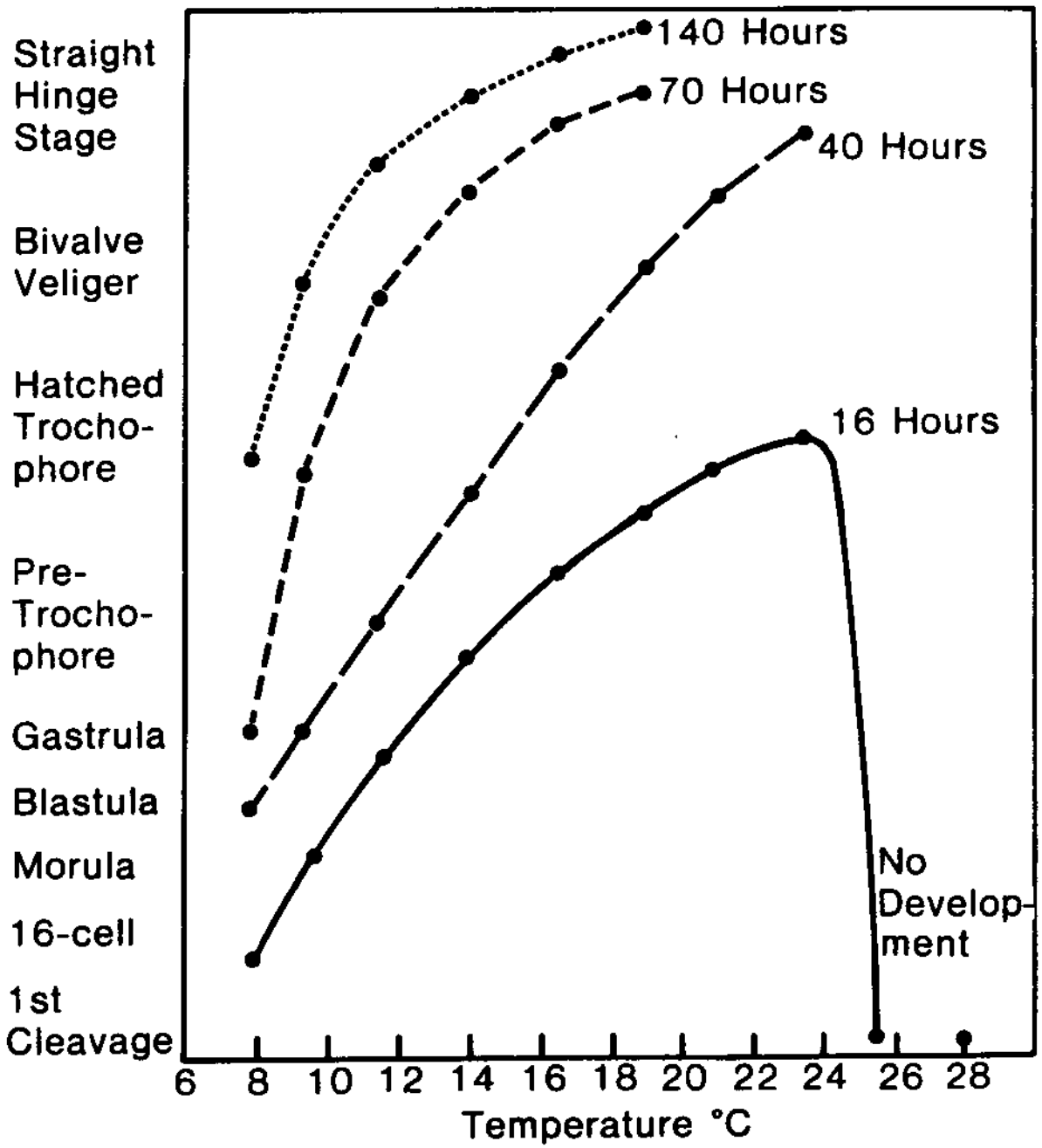

Figure 6: Developmental stages attained by *Hinnites* larvae reared at different temperatures (from Leighton and Phleger, 1977).

Table III. Growth and survival of Hinnites larvae reared on single and combined diets over a three-week period.

Diet		Group Mean Shell Diameter (µm)	Standard Deviation	Range	% Survival	#/Sample
Isochrysis galbana	1	149.3	22.1	128-240	94.7	23
	2	147.1	10.6	129-165	100.0	23
	3	158.7	16.0	128-192	93.3	21
Monochrysis lutheri	1	139.8	9.1	128-166	95.4	21
	2	138.3	12.3	118-157	71.4	21
	3	135.3	9.6	119-152	76.5	21
Rhodomonas sp.	1	124.7	4.1	118-130	48.1	17
	2	132.8	6.0	122-146	85.7	20
	3	126.5	5.0	120-139	94.1	20
Rhodomonas and Monochrysis	1	141.3	18.4	120-206	54.8	19
	2	142.0	9.6	125-160	95.8	14
Isochrysis and Monochrysis	1	123.2	5.4	115-130	89.5	20
	2	127.1	6.5	113-142	96.3	18
Rhodomonas, Isochrysis and Monochrysis	1	141.6	11.0	126-160	100.0	20
	2	145.2	9.3	130-165	94.1	18
Other algal diets:						
Phaeodactylum		144.2	12.9	120-172	80.0	17
Skeletonema		126.7	8.6	118-148	31.6	12
Nannochloris sp.	1	127.3	4.7	118-145	12.5	7
	2	All perished				
	3	All perished				
Dunaliella	1-3	All perished				
Tetraselmis	1-3	All perished				

Larvae at three days were admitted to 500 ml seawater in liter beakers (polypropylene) at 1.5 larvae/ml. Groups were fed indicated algae each four days and water changed weekly. Incubation temperature 16-17°C.

In our earlier studies, no attempt was made to quantitate foods provided to larvae. Cultured algae were added to containers with larvae at each water change (every two to four days) in amounts sufficient to produce a tinge of color in the water. Microscopic examination and hemocytometer counts revealed this method provided a sufficient food supply for the interval.

C. Success of Post-Larvae

Metamorphosis of larvae was most successful when pre-metamorphic individuals were transferred from the polyethylene incubation containers at the age of three to four weeks to a 40-liter mesh bottom black fiberglass tank which was immersed in a larger white-surfaced tank (Figure 7). Relatively high survival and growth rates for late stage larvae and early juveniles were achieved using this culture system. Future improvements will modify this basic design.

In practice, larvae at three weeks (150-200 μm) were admitted to the mesh bottom tank at approximately 1/ml. The algae Isochrysis, Monochrysis and Rhodomonas were added each three to four days to bring the concentration of food organisms to 10,000-20,000 cells/ml. Nutrients (liquid fertilizer described above, or more recently, the Ortho Brand formula (5:10:5) were added to the outer tank at 0.1 ml/liter once weekly. Post-larval scallops reached approximately 1.5 mm at two months and 5-7 mm at four months (16-20°C).

A comparison was made of growth and survival of post-larvae held on cultured algae in the laboratory or confined in Nitex mesh (500 μm) cages submerged in waters of Mission Bay to feed on natural phytoplankton. In our early experiments post-larvae in the laboratory were provided Isochrysis, Monochrysis and Tetraselmis (prior to the discovery of the value of Rhodomonas to young Hinnites). Laboratory-reared juveniles reached 6.1 mm (group mean 4.8 mm) at seven months. The scallops reared in natural waters, however,

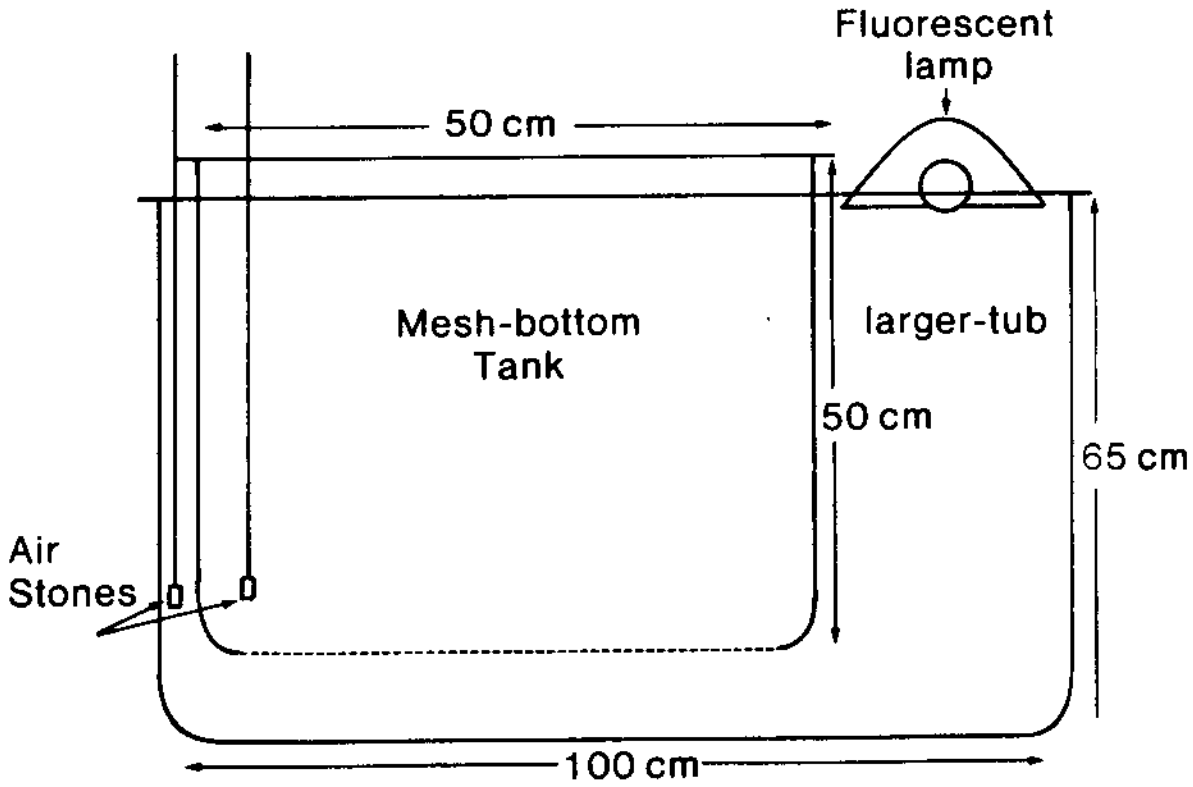

Figure 7: Culture tank successfully used to rear *Hinnites* larvae through metamorphosis and early juvenile stages. A mesh-bottom tank is immersed in a larger tub holding sea-water and algae. Developing scallops occupy the darkened interior of the mesh-bottom tank. Fluorescent lamp illumination is provided to the outer medium. Aeration mixes both chambers.

reached 21.8 mm (group mean 14.5 mm) after that interval. Current research using Rhodomonas in laboratory culture is demonstrating a superiority of that alga. Groups held in natural waters and those in the culture laboratory now show comparable growth rates (Leighton, in prep.).

D. Food of Adult Hinnites

Smaller monads and diatoms were utilized in growth of larvae, post-larvae and early juveniles, as discussed above. Observations on foods of young adults were made by examination of gut content in freshly collected individuals and by experimentally feeding specific or mixed phytoplankton to scallops brought into the laboratory.

Results of microscopic examination of stomach and intestinal contents suggest that smaller algae constitute the bulk of the diet in nature. Often, however, larger phytoplankton (Prorocentrum, Gonyaulax and Ceratium) were abundant in the gut. Notably absent were chain-forming chaetose diatoms (Chaetoceros and Skeletonema). The possibility that Hinnites might select species of phytoplankton for ingestion was explored by providing algae of several types to scallops held in beakers. Feeding was allowed for an interval and the scallops then dissected for examination of gut content.

In a typical experiment, three young adult Hinnites were placed in aerated seawater to which had been added a concentrate of natural plankton including several species of dinoflagellates and diatoms. After two hours, examination of pseudofeces, gut and fecal pellets showed pseudofeces to consist almost purely of chaetose chain-forming diatoms, while intestinal contents indicated ingestion of the complementary flora.

These observations suggest Hinnites is a quasi-selective filter feeder. Certain species of phytoplankton are rejected prior to ingestion, perhaps due

to mechanical sorting and acceptance by size and form. Much ingested material was found to be fine particulate matter, largely cellular in nature. These may be the remains of small monads and microflagellates ranging in size from 2 to 10 μm. Detritus does not appear to be ingested or utilized.

VI. RECRUITMENT IN NATURE

Mussel aquaculture is almost exclusively dependent on collection of natural set post-larvae on ropes, stakes and other materials placed in bays and estuaries during periods of their greatest abundance (MacIntyre et al. 1977). Oyster spat are obtained both through hatchery production and, alternatively, by simply placing culch (parent oyster shell or bay scallop shell) in shallow waters native to the species to attract and collect post-larvae from the plankton (Anderson 1977). We have attempted to find appropriate collectors for juvenile Hinnites (see Section VII). Juvenile stock for our various studies of behavior, substrate selection, physiological tolerances and growth were either produced in the laboratory or, more often, collected as natural set on rocks of the Mission Bay jetties. We wished to observe both intensity and seasonality of recruitment to allow prediction of times and locations which might be most productive of juvenile stock.

The rocky environment of the jetties guarding the entrance to Mission Bay provided an ideal situation for study of natural recruitment. Pre-cementing juveniles could be found clinging by byssal threads to the undersides of rocks forming the bayward portion of the jetties during all months of the year. This particular environment was consistently productive of juvenile Hinnites except during 1978 (see below). In 1975-76, greatest influx of smallest individuals occurred during late spring and early summer. A year-long study was undertaken to suggest months of peak recruitment and to find

evidence recruitment continues throughout the year.

Collections made bimonthly were grouped by size class (Figure 8). Pre-cementing individuals appeared in all samples, but smallest juveniles (3-10 mm) were found in abundance only during late spring and early summer. Usually 30-50 young scallops could be found by one diver or low tide collector turning approximately 50 rocks in the course of an hour and a half. The yield/effort was reduced during winter and early spring.

The jetty environment studied provided many hundreds of juvenile Hinnites for our various requirements. Cemented adults were, however, relatively uncommon and none were found larger than 8 cm. Predation by starfish is probably not a major cause of early mortality of cemented young adults here (Hinnites seem very adept, through quick and forceful closure of sharp-edged valves, at discouraging would-be predators). We suspected periodic environmental change might be responsible for the short-lived success of Hinnites in shallow depths in the Mission Bay entrance channel. This was found to be the case when extreme dilution of channel water occurred in winter 1978. In mid-January, flow from the San Diego River (Flood Control Channel) brought channel salinity close to that of fresh water (Sp. Gr. 1.008). At the same time, low salinity water entered Quivira Basin with the result that all our experimental scallops situated in shallow depths (to 2.0 m beneath the floating laboratory) and natural set on nearby pilings were killed. This evidence suggests that survival to adulthood among jetty rip-rap near the entrance to Mission Bay is probably a rare event, despite the relatively intense settlement of juveniles in the area. The subject is developed further in consideration of Hinnites' tolerance to reduced salinity in Section IX.

Recruitment in populations offshore is likely seldom influenced by salinity changes and may be expected to continue throughout the year. Study

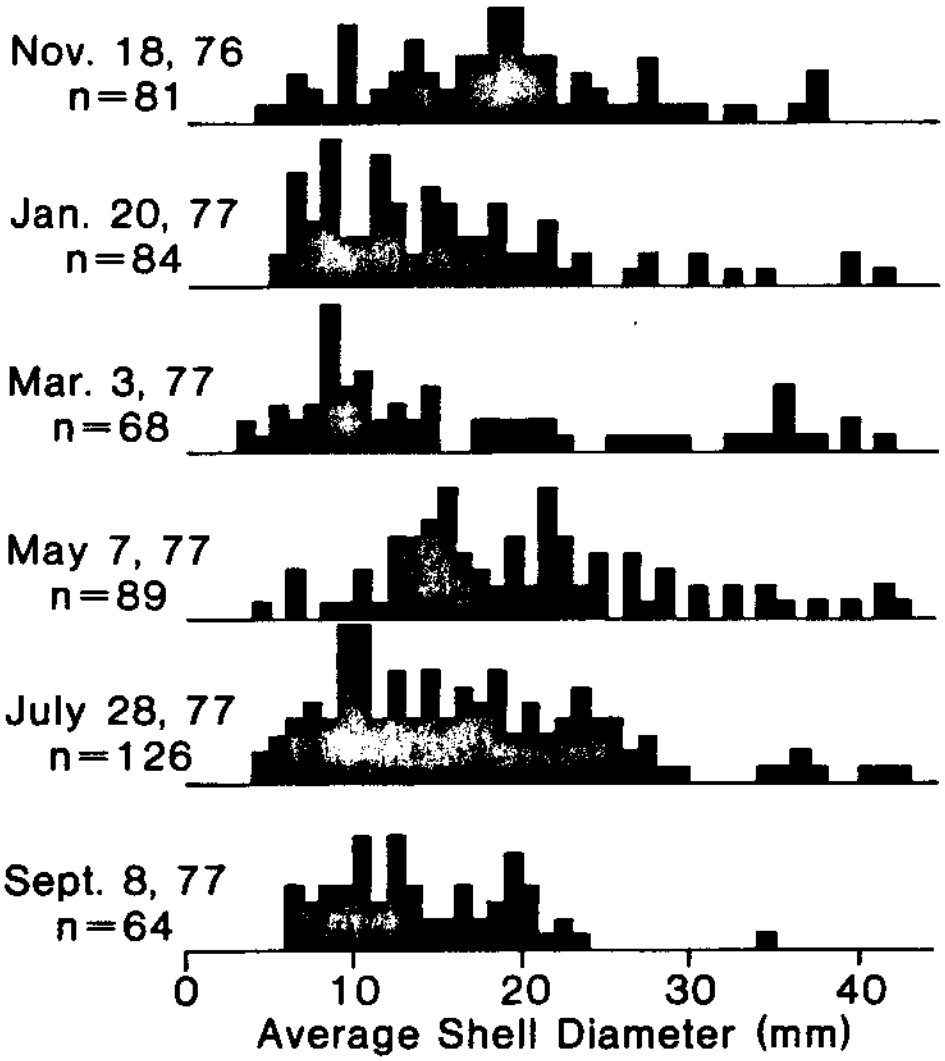

Figure 8: Size frequency histograms for juvenile *Hinnites* collected bimonthly from jetty rock, entrance channel, Mission Bay, 1976-77.

of recruitment in these offshore populations has not been made.

VII. BEHAVIOR AND SUBSTRATE PREFERENCE IN JUVENILES

An understanding of aspects of behavior in juveniles is fundamental to development of effective methods to collect "spat" in natural environments, an alternative to hatchery production of postlarvae and to collection of juveniles by hand. We have conducted observations on swimming and other modes of movement in early stages of development in Hinnites. Substrate selection has been tested in the laboratory and preliminary studies of "spat collectors" have been made in the field. Our findings may guide subsequent design and choice of materials for juvenile attractant structures.

Larvae reared in the laboratory continued to swim in culture vessels until about four weeks of age. As larvae approached metamorphosis, swimming was concentrated near the bottom. Metamorphosing scallops lost the ability to swim and instead crawled on container bottoms and sides using the newly formed extensible foot (Leighton and Phleger 1977). A similar change in mode of movement was found for Pecten maximus (Gruffydd and Beaumont 1972). Hinnites completing metamorphosis gained the ability to form byssal thread anchors. Vertical sides of culture containers were preferred to tank bottoms. Swimming by juveniles is accomplished by valve clapping and jetting of water in the manner typical of free-living scallop species. Post-larvae and very early juveniles never demonstrated swimming behavior, however. These observations suggest Hinnites is dispersed in the plankton only during larval life. Juveniles displayed swimming only in short bursts, a behavior of advantage in escape from predators or in short-range relocation.

Juvenile Hinnites were almost invariably found in nature either clinging to the shaded undersides of jetty rock, or within concavities of mussel and

scallop shells on pilings. Laboratory observations wherein juveniles were provided a choice of illuminated and shaded surfaces revealed a strong tendency away from light. Shading, therefore, appears to be an important factor governing distribution and should be considered in design of collectors.

A portion of our research was directed to search for specific materials which would prove attractive to settling rock scallops. Two studies were conducted independently to examine selection by juvenile Hinnites among several natural and artificial substrates. Shell of rock scallops, abalone, mussels and oyster represented natural substances, and concrete and PVC plastic served as artificial materials. A typical experiment is described here as follows:

This substrate preference test employed a tank 1 x 0.5 x 0.2 m supplied with running seawater. Shell and concrete pieces were grouped in clumps to provide approximately equal surface and shaded underside areas. Each material was represented by two distinct clumps; all were distributed in a random manner about the bottom of the tank. Positions of clumps were changed between runs. Juvenile scallops (40-50 individuals) were released as evenly as possible over the water surface at the start of each 24-hour run. Counts made at the end of each run included scallops securely attached by byssal threads, those on substrates, but not secured, those beneath substrates, and those occupying edges and corners of the tank.

Results were analyzed by a ranking procedure (Kendall 1955). The coefficient of concordance, W, a measure of agreement between sets of ranked data, was in this case 0.54 (Table IV). Reasonably good correspondence was found among runs and results may therefore be described by the choice order: old scallop shells, abalone shells, fresh mussel shells, fresh scallop shells, old mussel shells, and concrete, in order of decreasing preference.

Table IV. Substrate selection experiments with pre-cementing juvenile Hinnites.

Material	Number of scallops in position after 24 hours run: 1	2	3	4	5	6	7	8	Total
Abalone shell	4(1)*	5(1)	3(2)	3(5)	2(4)	1(2)	3(2)	1(1)	40
Scallop shell									
Fresh	1(1)	2(3)	2(0)	1(4)	2(3)	0(1)	2(0)	5(1)	28
Old	4(3)	5(4)	3(5)	2(2)	2(5)	1(2)	2(4)	4(3)	51
Mussel shell									
Fresh	0(3)	2(3)	3(1)	2(1)	1(3)	4(2)	3(1)	2(2)	33
Old	2(1)	0(1)	0(0)	1(2)	1(2)	2(4)	2(1)	1(0)	20
Concrete	0(0)	1(0)	3(2)	1(0)	0(2)	1(0)	1(1)	1(0)	13
Shaded beneath substrates	12	5	4	1	9	10	6	4	51
Free on tank bottom	13	13	17	18	14	20	22	25	142

*Numbers in parentheses are scallops on substrates but not secured by byssal threads

The Coefficient of Concordance (Kendall 1955), W, is given by ranked data by

$$W = \frac{12 \text{ (sum of squared deviations)}}{m^2(n^3 - n)}$$

Here, W = 0.54
Associated p beyond 5%

where

m = number of rankings, 8

n = number of substrates ranked, 6

Range of W, 0 = no agreement; 1.0 = complete agreement of rank orders.

Subsequent study (Klicpera 1978) indicated similar preferences by Hinnites when presented like materials. Selectivity, however, appeared reduced in time. These experiments need further replication, but results at hand suggest juvenile Hinnites may discriminate between adult scallop shell and other materials and that freshly killed scallop may even be repellent (a reaction of possible selective value).

To explore further the subject of substrate selection by juvenile Hinnites and to provide guidelines for development of collectors, a series of polyethylene mesh bags (1 cm mesh) was filled with either mussel (Mytilus edulis), rock oyster (Chama pellucida) or rock scallop shells and placed among rocks of the Mission Bay jetty. In an experiment begun April 11, 1978, four bags of an original eight were collected July 26. Two bags containing rock scallop shell yielded juvenile Hinnites (three individuals 8.8-31.8 mm). Bags with mussel and oyster shell produced no juveniles and after extensive searching in normal habitat among surrounding rocks (over 50 rocks turned), no additional juvenile or young adult Hinnites were found.

Juvenile rock scallops are frequently found attached by byssal threads or cemented to the inner surfaces of empty adult scallop shells in the dock piling habitat of Quivira Basin. A collection of approximately 200 juveniles was made in summer 1976, of which an estimated 85% were found within old scallop shells. The balance were either on the cement piling surface or in empty mussel and rock oyster shell.

We have occasionally found adventitious settlement of juvenile scallops in our experimental cages holding young adult Hinnites. This finding, supported by results of substrate preference and collector experiments, suggests chemoattractant substances may be active in localizing settling. This concept invites further study. Together, these observations should guide

development of effective collectors for juvenile scallops which will compete successfully with the natural substratum. Through this means, an important method to gain juvenile stock to support aquaculture would become available as an alternative to hatchery production of seed.

VIII. MORPHOMETRIC OBSERVATIONS

Morphometry was considered in several aspects of this investigation to allow comparison of populations native to, or reared in, different environments, depths and densities. Seasonal changes in the proportionality of the gonad and other organs to the total body weight, soft body weight and shell dimensions were examined in the course of studies of reproductive cycles (Jacobsen 1977). Perhaps the most direct importance of these observations to aquaculture is their value to assessment of production of adductor muscle in both time and location.

Shell dimensions recorded were height, width and thickness (depth). Height is taken as the distance from the umbo to the ventral margin and width is the distance from anterior to posterior margins of the valves. An average of these two was usually used in computations involving shell size since shell outline was seldom regular. Shell depth was usually neglected when describing size in juvenile and young adult Hinnites. However, since cupping and deepening of the body profile occurs with age beyond the first year, the contribution of shell depth to size should be considered.

The relation of total body weight to average shell diameter was found for Hinnites collected from pilings in Quivira Basin and for the Point Loma reef population. For juveniles and young adults from Quivira Basin, the relation

$$\text{Log Wt} = 2.5(\text{Log } \bar{D}) - 3.00$$

holds for individuals 2-6 cm. Because of shell cupping with age, a second expression of weight as a function of average shell diameter ($\bar{D}$) was found applicable. Larger scallops (6-12 cm) are described by

$$\text{Log Wt} = 3.8(\text{Log } \bar{D}) - 5.10.$$

Point Loma scallops display a conspicuously different growth form. Shells are slightly heavier and more rugose than scallops from Mission Bay. Our data support the relations

$$\text{Log Wt} = 2.54(\text{Log } \bar{D}) - 2.63$$

and

$$\text{Log Wt} = 3.28(\text{Log } \bar{D}) - 4.14$$

for Point Loma scallops 3-10 cm and 10-16 cm, respectively.

Adductor muscle formed approximately 10% (10.12 ± 3.5%) of the total in-shell body weight for scallops native to Quivira Basin. Samples from Point Loma yielded adductor muscle weights which formed a slightly lower proportion of the total body weight (9.47 ± 5.0%). The two ratios are not significantly different, but many scallops from Point Loma exceeded 12 cm and had adductor muscle weights which were significantly lower in proportion to the total weight than did smaller individuals. Among Point Loma scallops larger than 12 cm, adductor muscle comprised only about 6% of the total weight. This difference is due to the greater contribution of shell material in larger adults. Comparable size distributions, however, were not found in Quivira Basin and few scallops over 12 cm entered samples from that location. Scallops from both Point Loma and Quivira Basin in the size range 6-12 cm had closely similar adductor muscle weights in proportion to total body weight.

Morphometric data collected for samples of Hinnites from Point Loma and Mission Bay during 1976-77 (Appendix) suggest variation in relative size of adductor muscle occurs with season and also with sex. A thorough analysis of this data, however, has not yet been made. Studies of growth rate in

natural populations in both the bay and the ocean are in progress and should provide results to support a meaningful interpretation of trends suggested by this information.

A detailed analysis of morphometric relations for Hinnites collected from Mission Bay as juveniles and introduced to cages in bay and ocean environments for a full year's growth has been completed (Monical 1980). Regression comparisons show differences in growth form, and bimonthly measurements of size reflect contrasts in growth rate for scallops held in cages on the Point Loma shelf, the Navy Platform and the Quivira Basin stations (see Section X).

IX. TEMPERATURE AND SALINITY TOLERANCES

The distribution of Hinnites multirugosus over a rather broad range of latitude and depth along the Pacific Coast of North America suggests the species is relatively flexible in its requirements for temperature and salinity. Its absence from innermost reaches of bays and its only temporary population of other areas noted for wide variation of these factors suggest limitations to distribution may be imposed by seasonal fluctuations in salinity and temperature.

We have conducted laboratory tests of temperature and salinity tolerance for larvae, juveniles and adults and made observations on survival and growth of scallops introduced to a range of ocean and bay environments. Following heavy runoff from winter storms this year, we observed widespread mortality of Hinnites in portions of Mission Bay subject to greatest dilution. Growth and survival of rock scallops held in seawater at elevated temperatures was studied in a related project at the Agua Hedionda Lagoon, San Diego Gas & Electric Company effluent basin (Foe 1978).

Development of larvae held at a series of temperatures (8-28°C) in a thermal gradient apparatus (Leighton and Phleger 1977) became abnormal and survival was limited at temperatures greater than 18°C. The optimal thermal range for culture of Hinnites larvae appears to be 12-18°C (Figure 6).

Juvenile scallops held at temperatures above 20°C showed reduced growth. Survival declined above 23°C (Foe 1978). The recommendation is given in that study that culture of Hinnites be done in water temperatures below 20°C. Our observations in Mission Bay, however, have shown juvenile growth rates to be superior during summer months when temperatures lie between 20 and 23°C (Leighton and Phleger 1977). Few controlled experiments to show lower thermal limits to growth and survival have been made, although juveniles held for three months at 120 m (10-12°C) in the ocean off La Jolla increased in diameter far less than those at 8-30 m (see following section). Laboratory specimens held at 5°C for 24 hours were stressed; two of a group of eight recovered after 24 hours in running ambient (19°C) seawater. Further study to establish LD_{50}'s for thermal extremes are planned.

More than moderate dilution of seawater by rain runoff is not tolerated by Hinnites. During January-February 1978 excessive runoff filled the San Diego River (flood control channel) and Quivira Basin received a surface wedge of fresh water via the entrance channel at incoming tides (Sp. Gr. 1 m depth 1.009, 3 m depth 1.020, Equiv. Sal. 12.2 and 29.4 ppt, January 18). All Hinnites held in cages suspended from the dock at a depth of 0-2 m were killed. Those at greater depths survived. Similar mortality was observed in shallow water throughout Quivira Basin and the entrance channel jetties.

Experimental scallops subjected to salinity tolerance tests survived deviations above and below normal (34.3 ppt) of slightly greater than 10 ppt. Preliminary experiments to find LD_{50} levels for adult Hinnites from Mission

Bay indicated a tolerated range of 22.2-46.5 ppt (24 hours). These salinity limits represent a dilution and increased concentration of approximately 35%. Salinity tolerance studies are continuing.

It would appear that aquaculture of the rock scallop must avoid surface waters where dilution is common. Use of small, shallow bays along the western U.S. northern coast might prove precarious. It remains to be established, however, if northern Hinnites can survive lower salinities than observed for Mission Bay scallops. Possibly some preadaptation exists.

X. COMPARISON OF REARING ENVIRONMENTS

Juvenile Hinnites were collected from jetty rock at the entrance to Mission Bay for use in a variety of studies to explore the suitability of bay and ocean environments for extensive rearing of this shellfish. Study sites included two stations in the ocean and five locations in Mission Bay . Juvenile scallops were secured to asbestos board pallets (Phleger and Leighton 1977) and protected within plastic mesh cages (2 cm mesh). They were either tied to pilings and crossmembers of the U.S. Navy Oceanographic Platform 1.1 km off Mission Beach (Figure 9), attached to buoyed lines in deep water (Figure 10), or bound to weighted redwood stakes driven into the sand bottom (Figure 11). In most cases, growth of scallops was followed throughout one year in each situation.

A. Mission Bay Stations

Quivira Basin, a cove flushed by offshore water with each tidal cycle, was the principal site for many of our observations on growth. Four additional stations were established within Mission Bay on September 15, 1977 to study growth and survival of scallops held for one year in fore-, mid- and

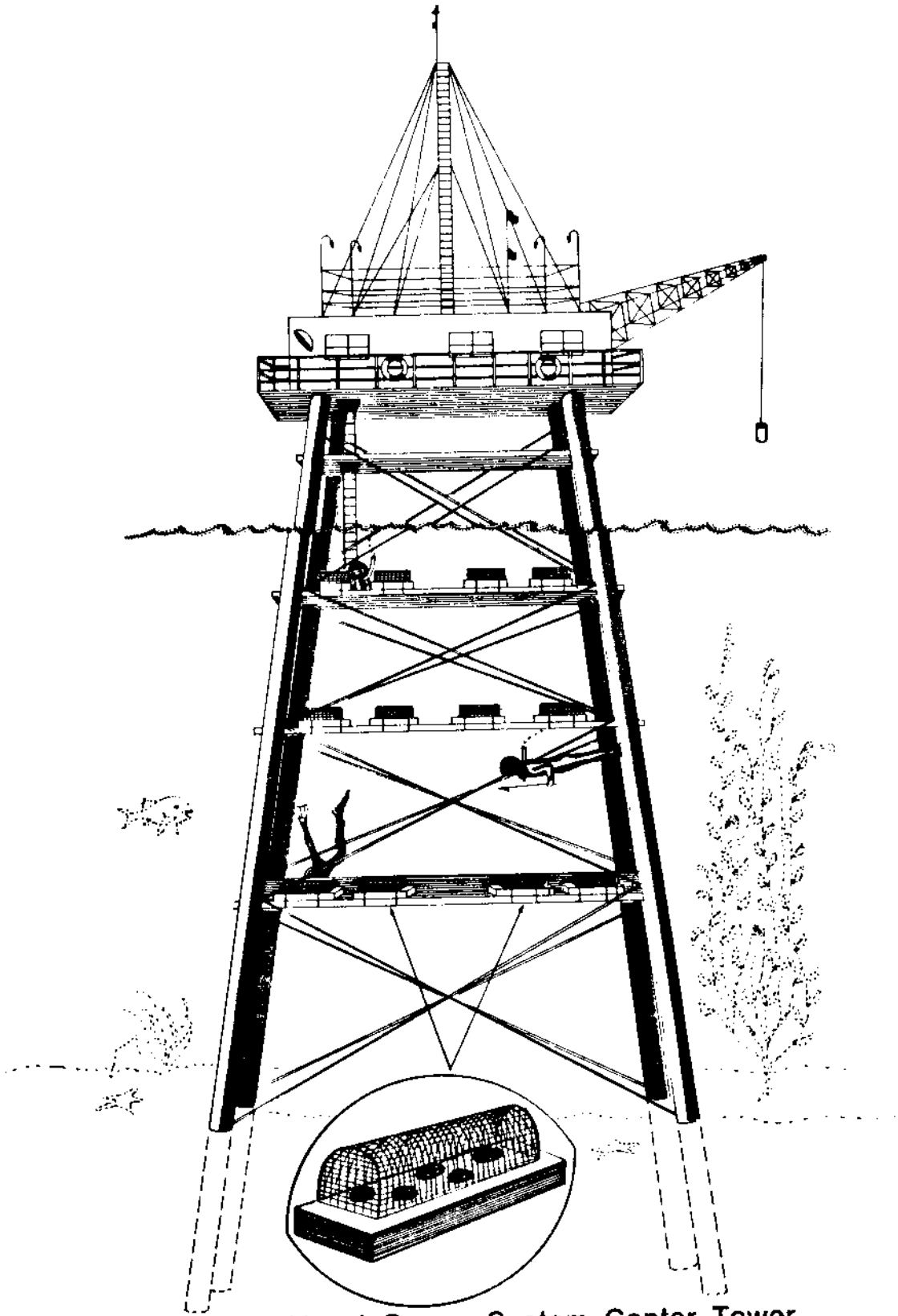

Figure 9: Naval Ocean System Center Tower, located off Mission Beach, San Diego, California, which has been used for open ocean growth studies of the purple-hinge rock scallop.

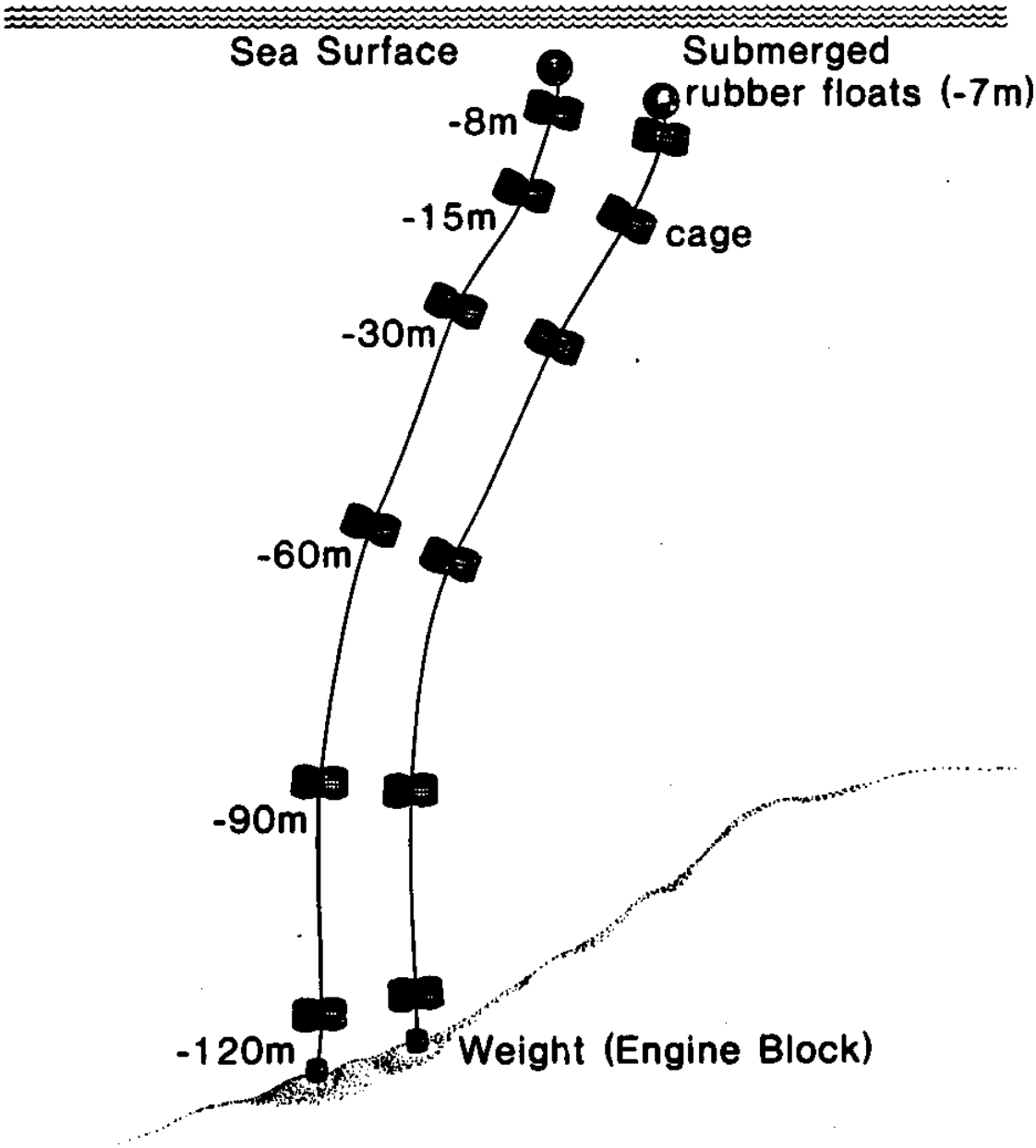

Figure 10: Buoyed lines holding caged scallops at depths to 120m in the ocean off La Jolla, California (Leighton, 1979).

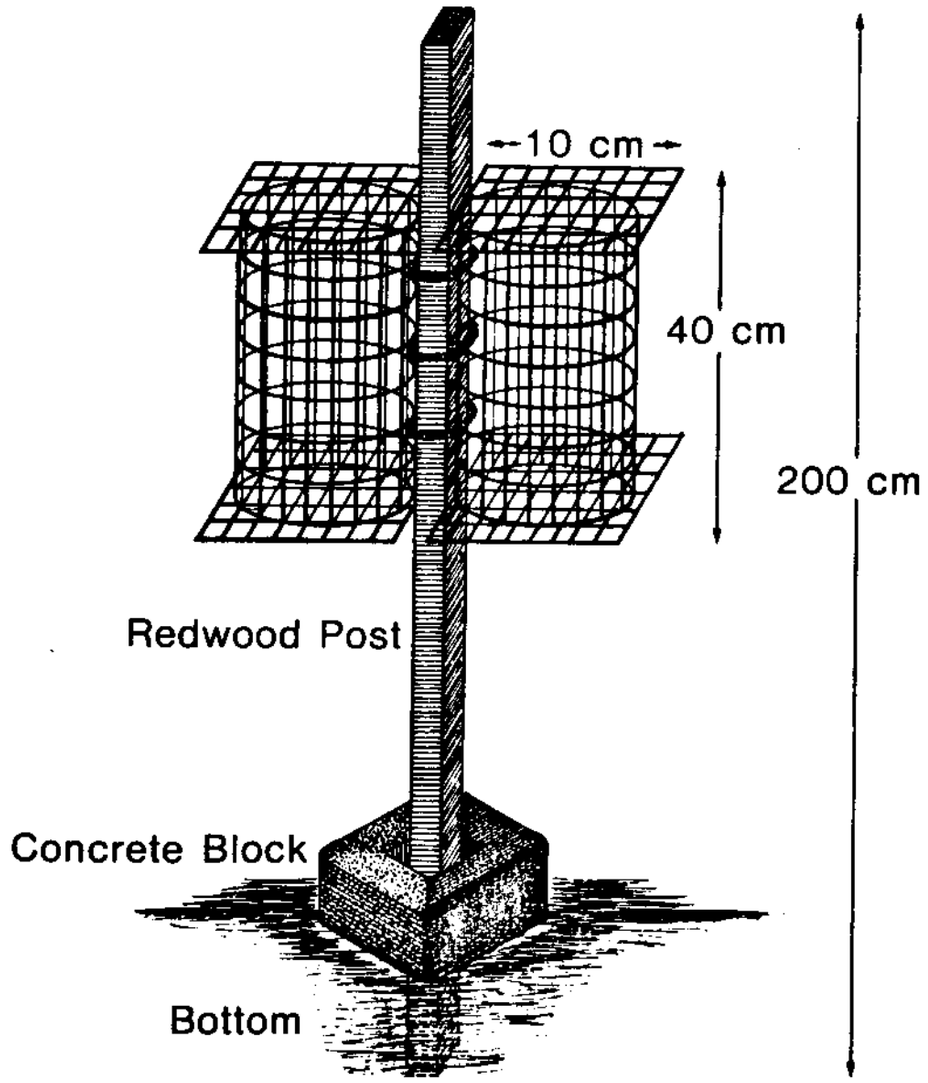

Figure 11: Cages attached to weighted redwood posts used to study growth of *Hinnites* in Mission Bay, San Diego, California. Concrete "cinder block" weights held posts vertically, Cages were one meter off bottom.

back bay environments. The stations are identified by the nearest landmark (Figure 12). Quivira Basin, as indicated above, is situated in the fore bay. The ski dock station is in the main channel between the entrance and the back bay. Bahia and Catamaran stations are in protected mid-bay areas, and the Hilton station is in the extreme back bay.

All cages were secured to weighted redwood stakes and positioned 1 m above the bottom (depth 4-6 m). No surface markers were used, since we wished to maintain cages entirely below water used by boaters and swimmers. Stations were easily relocated for inspection and measurements each three months using landmark bearings and diving equipment.

A total of 12 groups of juvenile scallops of pre-cementing age (10 individuals/group) were introduced to the cages. Mean shell diameters for groups ranged from 11.9 to 18.0 mm at the onset. At visits to each station made quarterly, numbers of scallops surviving and remaining secured to the substrates were noted and their shell height, width and depth recorded. Water samples for salinity determinations and phytoplankton content (chlorophyll and predominant algal species) were taken at each visit and temperatures of surface and bottom waters recorded then and at intervals between visits to measure scallops.

Stations nearest the entrance to Mission Bay yielded best survival and growth (Table V, Figure 13). At Bahia Basin, the mid-channel ski dock and Quivira Basin, scallop group mean shell diameters reached 72-82 mm at the end of a one-year period. Poor results were obtained at the back bay (Hilton) station, where many individuals succumbed or indicated only slight growth by the first recording date (December 15, 1977) and none survived the summer period (1978). High water temperatures were frequently recorded in the back bay, to a maximum of 27°C in early August, and are concluded responsible for

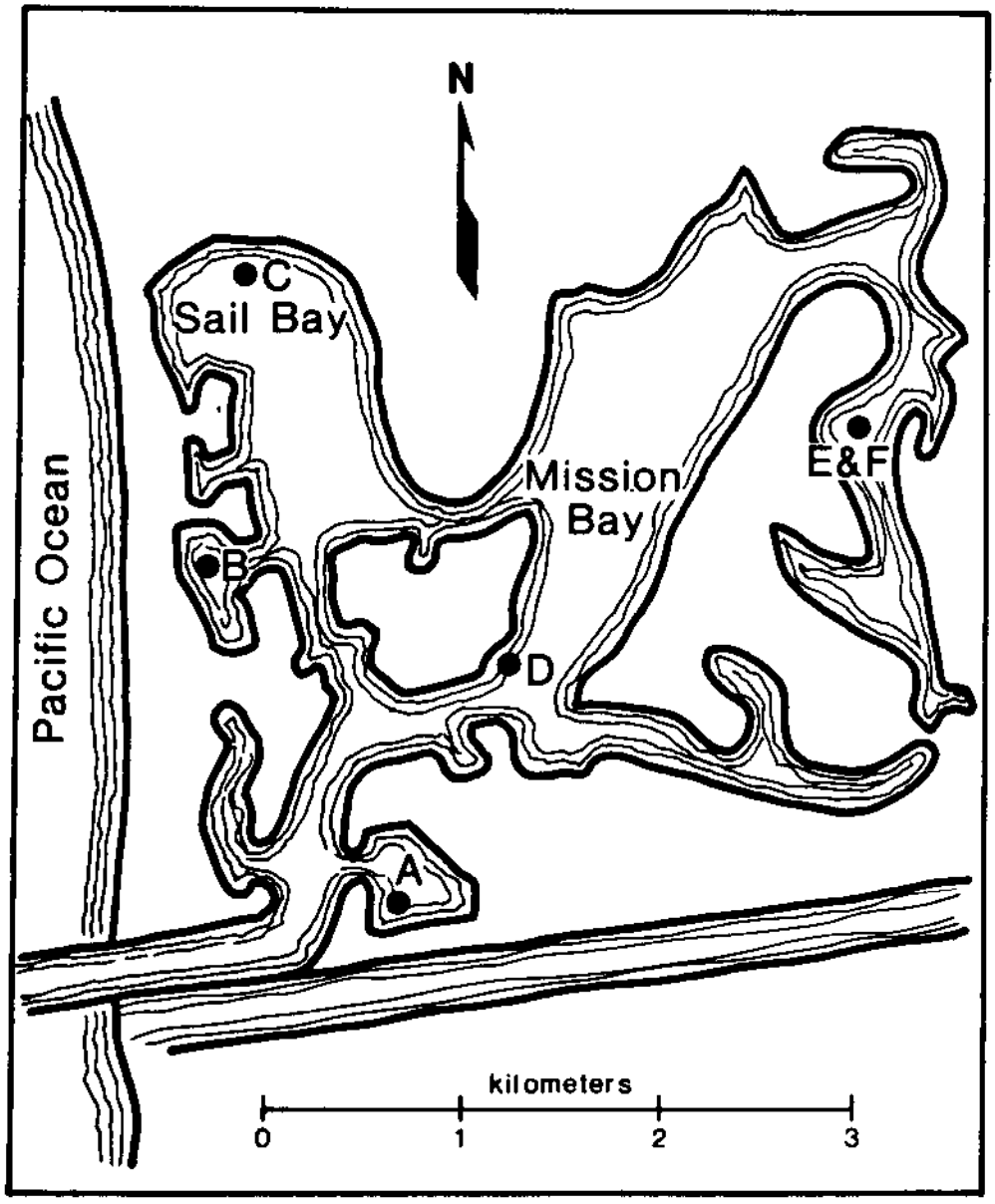

Figure 12: Map of Mission Bay showing location of stations for *Hinnites* growth studies. A. Quivira Basin, B. Bahia Bay, C. Catamaran Bay, D. Ski Dock, E & F. Back Bay, "Hilton" Stations.

Table V. Growth of Hinnites at five locations in Mission Bay over a period of one year, September 1977 - September 1978.

Station		Group Mean Size (mm) 9/15/77	9/20/78	Quarterly Gains in Shell Diameter (mm) I	II	III	IV*	Survival (%)
Quivira Basin	A	15.9	72.1	21.3 (10)	12.5 (10)	10.9 (10)	11.5 (10)	100
	B	14.8	76.6	26.7 (10)	11.4 (8)	11.1 (8)	12.6 (7)	70*
Bahia Basin	A	15.8	82.2	28.9 (7)	19.1 (6)	9.4 (6)	9.0 (6)	60*
	B	15.6	78.9	27.8 (10)	17.3 (8)	11.4 (7)	6.8 (6)	70*
Catamaran	A	15.7	69.0	22.4 (10)	20.0 (5)	6.6 (4)	4.3 (2)	20*
	B	12.1	69.3	22.3 (10)	16.7 (5)	9.4 (5)	8.8 (3)	30
Ski Dock	A	13.8	78.4	23.9 (10)	24.2 (6)	13.0 (6)	3.5 (6)	50*
	B	11.9	78.9	23.7 (10)	21.8 (9)	11.8 (9)	9.7 (9)	90
Hilton Back Bay†	A	18.0	-	2.8 (6)	16.3 (5)	9.3 (5)	- (0)	0
	B	15.1	-	2.6 (7)	15.5 (6)	2.5 (2)	- (0)	0
	C	14.5	-	4.1 (7)	19.7 (5)	4.6 (2)	- (0)	0
	D	14.8	-	1.3 (8)	18.6 (5)	4.2 (3)	- (0)	0

*Reduced survival reflects individuals dislodged from substrates (not found dead).

†Two stations were placed in the back bay in anticipation of low survival.

Numbers in parentheses represent individuals surviving and remaining attached to asbestos board panels at the end of the period.

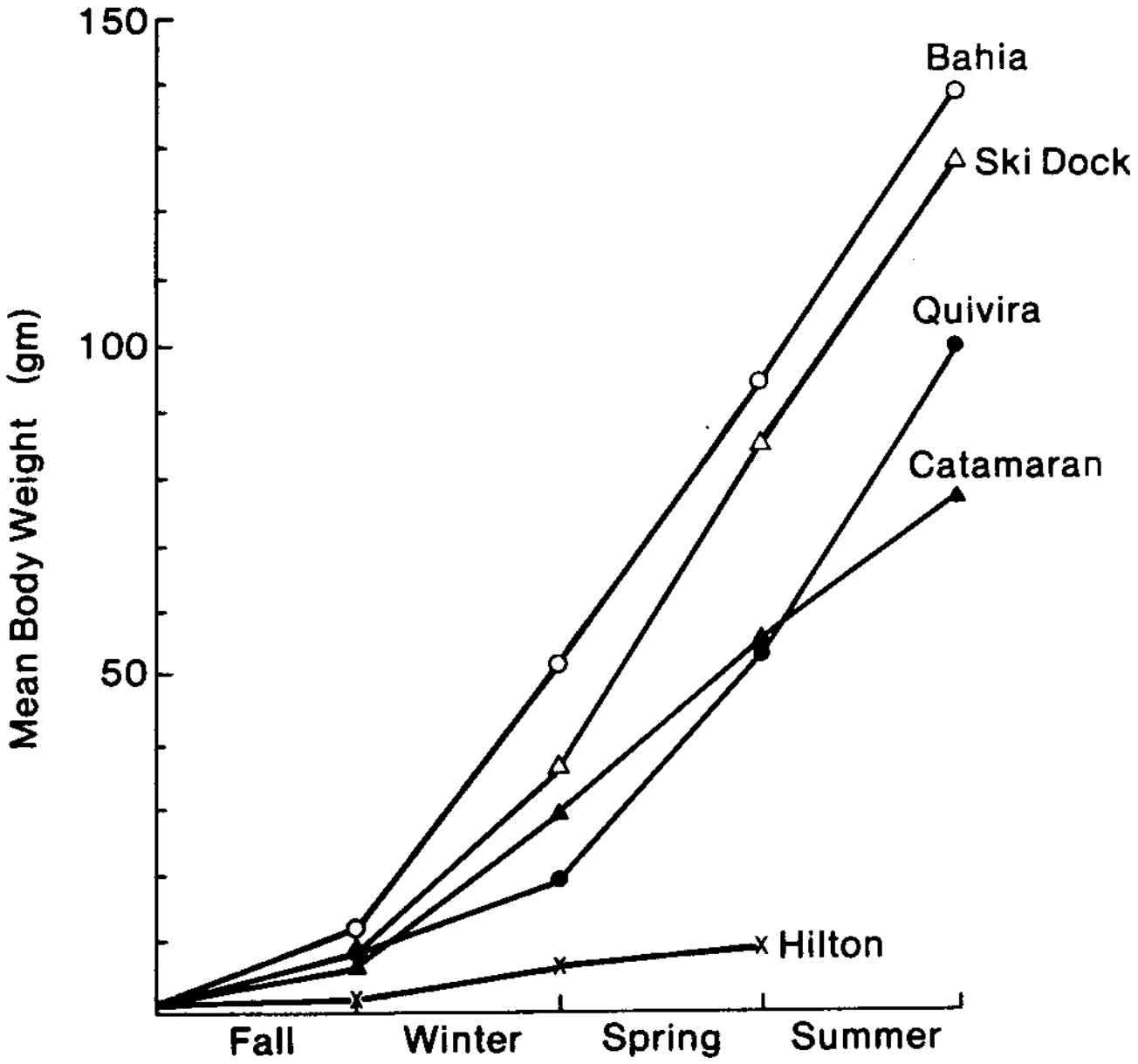

Figure 13: Mean total body weights for scallops held in cages at five stations in Mission Bay (see Table V). Weights were estimated from group mean shell diameters using relations described in Section VIII.

the decline of scallops at this station. Extreme dilution of the bay near the Catamaran in winter 1978, following heavy rains, is thought to be the cause of high mortality there. Food organisms were always abundant at both the Hilton and the Catamaran stations. An analysis of data gained in this study and an interpretation of influences of temperature, salinity, fouling and other factors on scallop growth in bay and offshore environments is in progress.

B. Growth of Scallops Beneath an Offshore Platform

Following preliminary tests of cage and habitat structures for durability when secured to pilings of the U.S. Navy (NOSC) Oceanographic Platform (Figure 14), a simple concrete-based plastic mesh cage was developed which was applied in a year-long study of scallop growth at that ocean station (Phleger and Leighton 1977). A series of 24 cages was divided between three depths (3, 9 and 18 m) and stocked with juvenile Hinnites distributed on strips of asbestos board (Monical 1980). Increases in shell size were recorded bimonthly throughout 1977. Chlorophyll, particulate carbon and temperature were followed during the course of these observations.

At the same time scallops were introduced to cages at the offshore platform station, a comparable group was distributed among cages at three depths (1, 3 and 6 m) in Quivira Basin, Mission Bay. Results of this comparative study are summarized in Table VI. Juveniles held at intermediate depths beneath the Navy platform and in Quivira Basin exhibited best growth. It is of interest to note that size attained after one year was remarkably close for both locations: 82.5 and 87.5 mm group mean shell diameter, respectively. Growth was superior throughout most of the year in scallops held in Quivira Basin (Table VI, Figure 15).

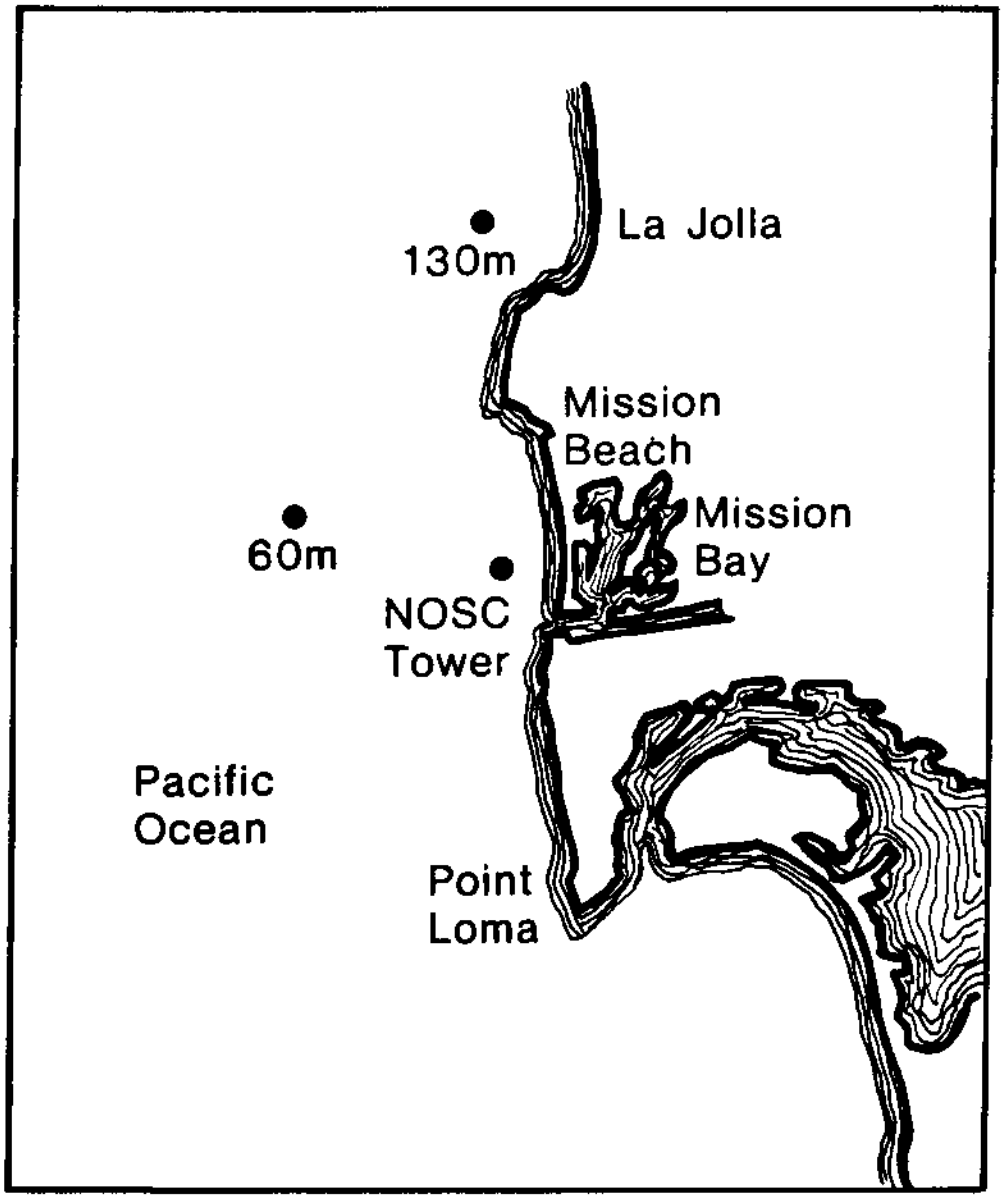

Figure 14: Map of San Diego coast showing offshore stations for *Hinnites* growth studies.

Table VI. Year growth for scallops held in different environments, depths and concentrations*.

Location	Depth	Density	Group Means (±SD) 12/76	12/77	Number	Survival (%)
Mission Bay	3 m	5/0.1 m^2	23.1 (3.7)	87.5 (8.6)	39	97.5
Navy Platform	9 m	"	22.4 (3.5)	82.5 (6.3)	37	92.5
Point Loma	12 m	"	20.9 (3.3)	63.1 (7.3)	21	52.5
Mission Bay	1 m	"	23.8 (3.7)	72.6 (9.6)	22	55.0
"	3 m	"	22.7 (3.9)	85.3 (6.0)	32	80.0
"	6 m	"	23.0 (3.8)	79.1 (7.9)	32	80.0
Navy Platform	3 m	"	21.8 (4.0)	Lost**		
	9 m	"	23.2 (3.9)	81.6 (6.8)	31	77.5
	18 m	"	22.7 (3.7)	76.7 (5.2)	30	75.0
Mission Bay	3 m					
		5/0.1 m^2	23.6 (1.7)	93.3 (6.9)	9	90.0
		10/0.1 m^2	23.3 (3.4)	92.1 (8.2)	10	100.0
		20/0.1 m^2	23.3 (3.6)	75.9 (8.9)	38	95.0
		40/0.1 m^2	23.3 (3.5)	crowding extreme by 4th month***		

*From Monical 1980.

**Those at shallow depths beneath the Navy Platform were largely lost when severe surge tore cages from pilings.

***The influence of competition for food and growing space appeared earliest in scallops stocked at 40/0.1 m^2. In April, groups at 5, 10 and 20/0.1 m^2 had reached average diameters of 55-57 mm; those at 40/0.1 m^2 refused to cement, and all averaged only 42 mm. That experiment was discontinued at that time.

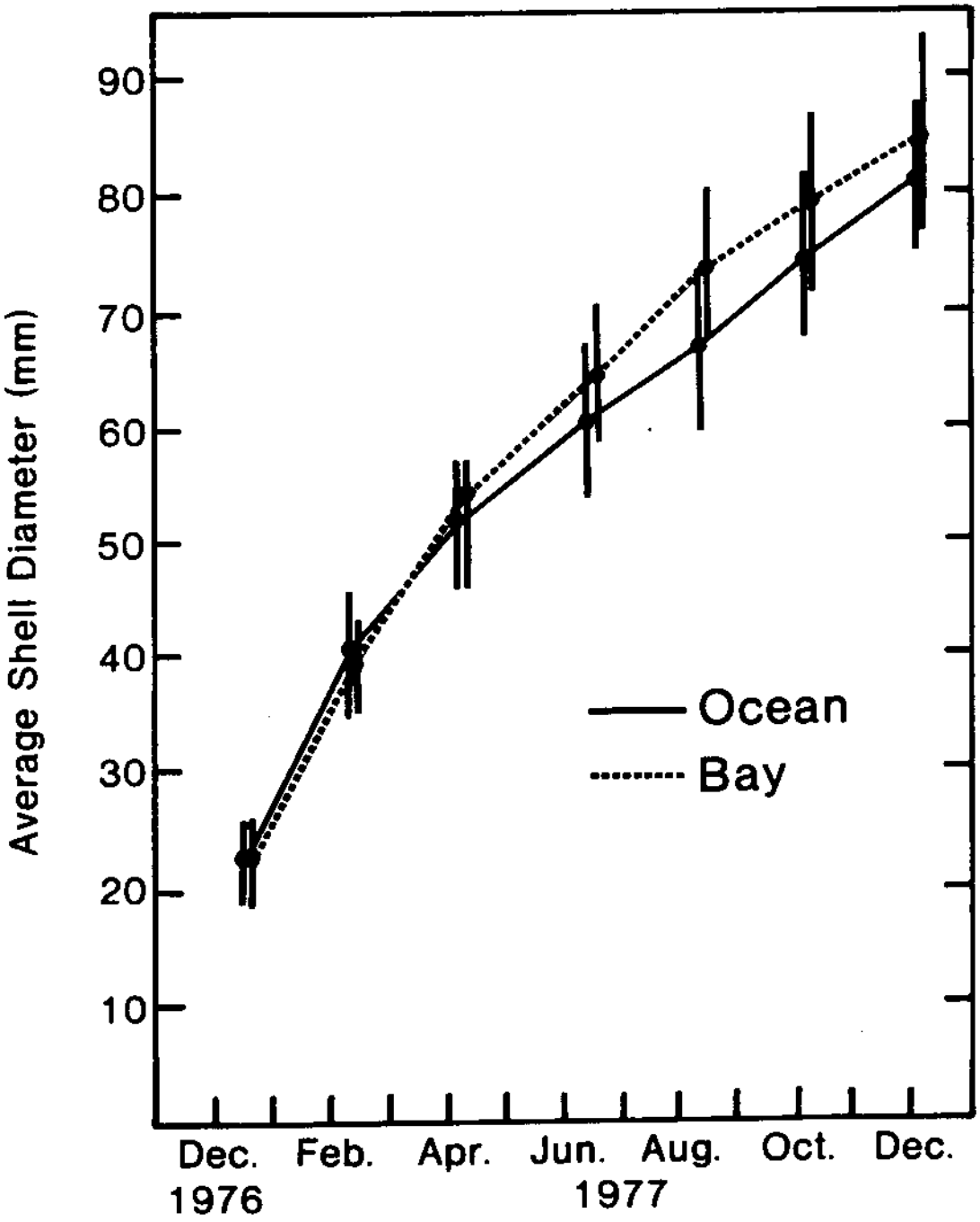

Figure 15: Growth of scallops held in cages beneath the NOSC platform (Ocean) and in Quivira Basin (Bay). (from Monical, 1978)

C. A Vertical Profile for Scallop Growth in the Open Ocean

As a first step to assess the potential of waters over the southern California inner continental shelf to support growth of the rock scallop, a station was established 5 km off La Jolla where water depth was 130 m. Cages holding juvenile Hinnites were secured to two lines at depths of 8, 15, 30, 60, 90 and 120 m. Growth was recorded for scallops from one line after three months (Leighton 1979). Survival was 97% for 60 individuals distributed at 10/depth (Table VII). Growth at 8, 15 and 30 m was 6.1-8.1 mm/mo group average shell diameter increase. At the greater depths, growth declined (2.5-4.8 mm/mo) (Figure 16). Both low temperature and paucity of food no doubt influenced reduced growth below 60 m at the La Jolla submarine canyon station during the fall 1977 observation period (marked decline in temperature: 10-12°C at 50-100 m) and low stocks of phytoplankton are recorded by the Scripps Institution of Oceanography Food Chain Research Group for this location below 50 m (Leighton 1979). We anticipate improved growth of scallops will be found at depths of 30-90 m in studies planned for location on shelfland off the San Diego coast, however, since food and temperature distributions should be more favorable away from the canyon slopes.

D. Discussion of Growth Observations in Bay and Ocean

It was considered most important to conduct observations on growth of scallops at stations selected to represent a range of environments open to future aquaculture. To be most applicable in this respect, observations should encompass at least one year. Most of our studies, including those in progress, comply with that limitation. To date we have year-long observations from several independent studies in Quivira Basin and from two ocean locations, the NOSC platform and the inner Point Loma shelf. The study of

Table VII. Growth of Hinnites multirugosus buoyed at six depths for three months in the ocean off La Jolla, California.

Depth (m)	Mean Shell Diameter (mm) 8/29	12/2	Incr.	SD	Shell Growth %	mm/mo	Mean Weight (gm) 12/2/77	Temperature* (°C) 12/2/77
8	20.0	39.3	19.3	9.0	197	6.1	9.4	17.5
15	19.8	45.3	25.5	2.5	229	8.1	11.3	16.1
30	21.5	43.2	21.7	5.9	201	6.9	9.5	15.6
60	17.4	32.7	15.3	2.5	188	4.8	3.6	14.1
90	17.5	26.0	8.5	3.3	149	2.7	2.3	12.1
120	17.1	24.9	7.8	2.5	146	2.5	1.8	10.8

*Ten individuals comprised each group at the onset. Two of the 60 scallops died during the 95-day period, one from 8 m and another from 120 m.

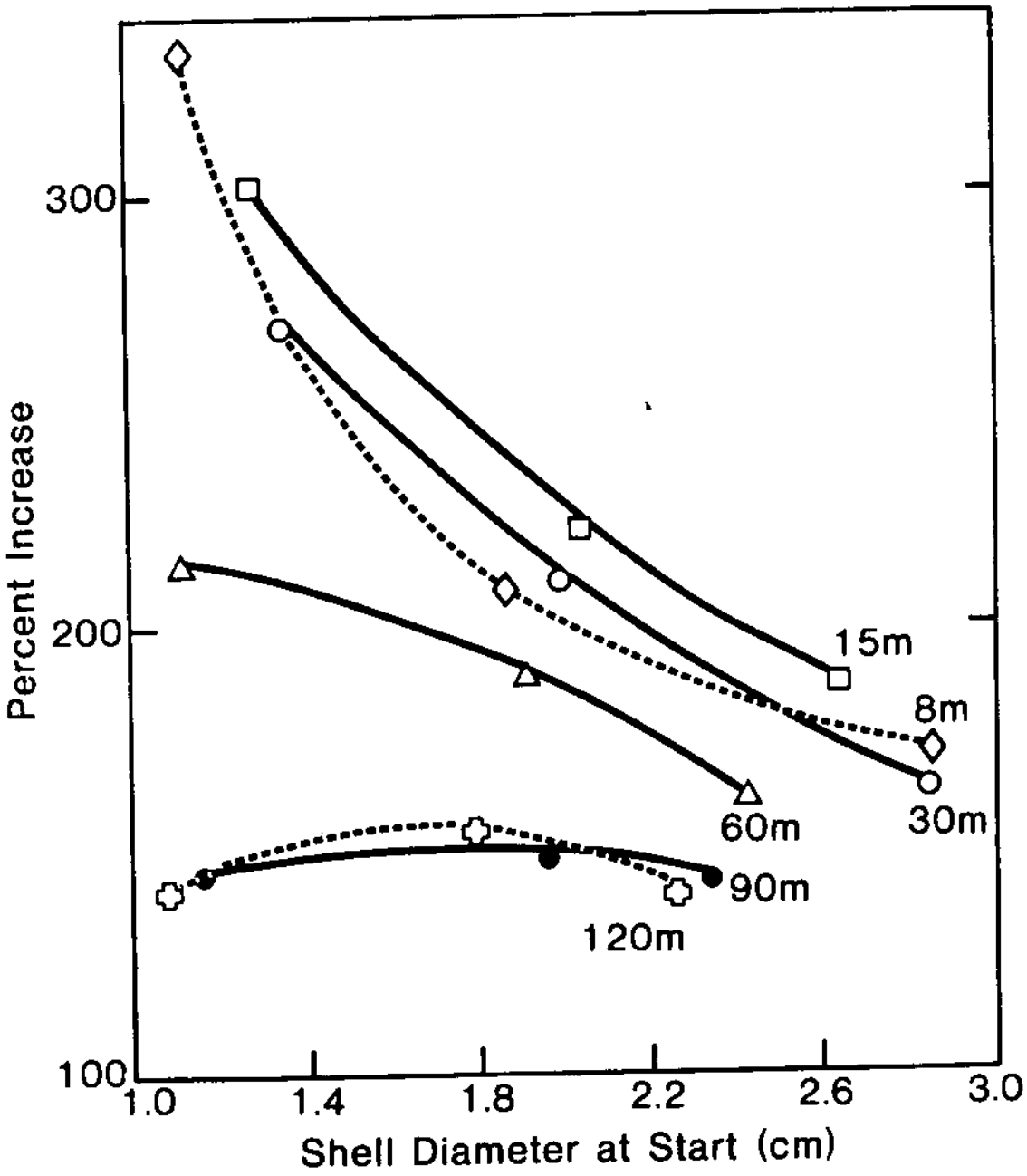

Figure 16: Relative size increases for scallops held for three months at depths from 8 to 120m in the ocean 5 km off La Jolla, California (from Leighton ,1979).

growth among scallops held at different locations within Mission Bay reached one year in September 1978. The deep water vertical transect off La Jolla was relocated in that month as well. Three years' observations on one group of scallops in Quivira Basin was completed in October 1978 (see Section III).

Data now available indicate Hinnites will grow and show excellent survival almost equally well in both bay and near-shore environments in southern California. Low salinity and high temperatures with winter rain runoff and summer insolation may be principal factors limiting growing areas and depths in bays, and offshore, low temperature and paucity of food may restrict growth at depths greater than 50 m.

XI. EXPERIMENTAL MATERIALS AND STRUCTURES FOR ROCK SCALLOP CULTURE

Culture of Hinnites was necessarily and logically divided into three phases: hatchery culture of larvae to juvenile stages, containment of juveniles in natural waters for growth to a size practical for introduction to final rearing structures, and extensive culture from advanced juvenile to marketable adult size. These phases are simply described as larval culture, juvenile fattening, and crop production. Each requires a specific set of conditions and appropriate equipment.

Spawning of adults and rearing larvae through metamorphosis was done both in the laboratory (Southwest Fisheries Center, National Marine Fisheries Service, La Jolla) and aboard a vessel equipped as a laboratory moored in Quivira Basin, Mission Bay (Leighton and Phleger 1977). Equipment used most successfully for larval culture and maintaining postlarvae to early juvenile stages is discussed above (Section V).

Juvenile Hinnites 3-20 mm were held in cages constructed with nylon mesh (1 mm openings), weighted and suspended beneath the floating laboratory. No special care was needed over the period of three to six months juveniles were allowed to mature in this approach, but cages were lifted weekly to brush away fouling organisms. New mesh containers of larger mesh size (5 mm) were substituted once juveniles reached 8-10 mm. We have conceptualized several designs of pens appropriate for containment of juveniles during fattening in protected waters. Large-scale containment could be achieved effectively using stacked mesh flats or a series of horizontally mounted plastic partitions wrapped with replaceable meshing.

Our studies of scallop growth have made wide use of asbestos construction board, a material which is easily cut to desired dimensions by scoring (no sawing necessary) and is extremely durable and long-lived in seawater. Asbestos board may be salvaged and used repeatedly. Concrete poured to form thin (2 cm) sheets and plastic materials vacuum-formed to provide points for scallop attachment (see below) have proved useful and inexpensive.

Juvenile scallops nearing cementing maturity have been attached to concrete, asbestos board and plastic surfaces using underwater-setting epoxy cement. This method, however, was often unsuccessful, as some scallops became detached soon after being immersed in seawater. The most useful and simplest method to introduce juveniles to rearing surfaces employed small cup-shaped cages (10 cm diameter) heat-formed from polyethylene mesh. Cup cagelets were cemented to asbestos board or embedded in setting concrete in the desired spatial distribution. Juvenile scallops were simply admitted singly to cagelets through a small slit cut in the mesh. Cagelets secured with silicon rubber sealant were easily removed after a month or two when scallops had cemented themselves securely in place to the base substrate.

Success of this method led to development of a pre-formed plastic panel providing depressions which were covered with polyethylene mesh (5 mm). This rearing pallet is currently being tested and is described elsewhere (Leighton 1978b). Success or failure of the technique will be reported at a later date.

For our studies of scallop survival and growth at five stations in Mission Bay, cages holding asbestos board sheets (30 x 50 cm) were secured to redwood 2 x 2 in (5 x 5 cm) stakes mounted vertically on the bottom (c.f. Figure 11). While these structures proved adequate for one year's use, supports constructed of PVC or concrete will be used in our planned long-term studies to develop methods for commercial application.

XII. CHEMICAL AND SENSORY ANALYSES OF ADDUCTOR MUSCLE

Following a preliminary estimation of the proximate composition of adductor muscle, scallops were collected from Mission Bay and from Point Loma offshore reefs for detailed compositional analysis of carbohydrate and lipid fractions. At the same time scallops which had been held in the laboratory for several weeks under food-deprived conditions were sacrificed for comparisons. This was done since we had found that starved scallops lost much of the characteristic flavor and possibly the bland taste might be reflected in a quantitative reduction in specific lipid and/or carbohydrates (Phleger et al. 1978).

Flavor evaluations were made by the Foremost Foods Research Center (Dublin, California). Samples of Hinnites adductor muscle from individuals collected in Mission Bay were packed in ice and sent immediately by air freight to the San Francisco laboratory (Phleger et al. 1978). Within 24 hours the samples were thawed and sensory characteristics assessed in comparative evaluation with four brands of bay and sea scallops available commercially.

Methods and results of chemical and flavor analyses are described below.

A. Chemical Analyses

Proximate analyses of adductor muscle were made from a total of six individual Hinnites collected off Point Loma and from Mission Bay. Protein averaged 70% (r = 66-77%), carbohydrate 24% (r = 18-28%), lipid 2% (r = 1-3%) and ash 4% (r = 4-5%), as percent dry weight. Average water content in adductor muscle was 74% (r = 73-75%). In this analysis, protein was determined by a modified Biuret method using bovine serum albumen as a standard. Lipid was extracted with chloroform:methanol (2:1), ash and water were found by standard AOAC procedures, and total carbohydrate was determined by difference.

Fatty acids were saponified with 0.5% KOH in methanol (85°C) and methylated with boron trifluoride in methanol. They were analyzed using a Beckman GC-45 gas chromatograph. Carbohydrates were analyzed as trimethylsilyl ethers using Tri-Sil "2" derivitizing reagent (Pierce) with gas chromatography or, for glycogen, found by the method of Dubois et al. (1956). Cholesterol was quantitated by a Leiberman-Burchard reaction, specific for β-hydroxy sterols (Kabara 1957). Gas chromatography showed cholesterol to be the only sterol present in the Hinnites adductor muscle.

B. Fatty Acids

Fatty acids of the lipid in Hinnites adductor muscle are expressed on a relative basis and results are shown in Figure 17. The principal fatty acids are 16:1 (13-16%), 18:2 (13-16%), 18:3 (10-16%), 20:1 (12-18%) and 20:5 (19-25%). Lesser amounts of 18:1 (5-7%), 22:1 (3-6%) and 22:UNK (3-5%) were present. There were only minor or trace amounts of saturated fatty acids (14:0, 16:0, 17:0 and 20:0). The total percent unsaturation for all samples

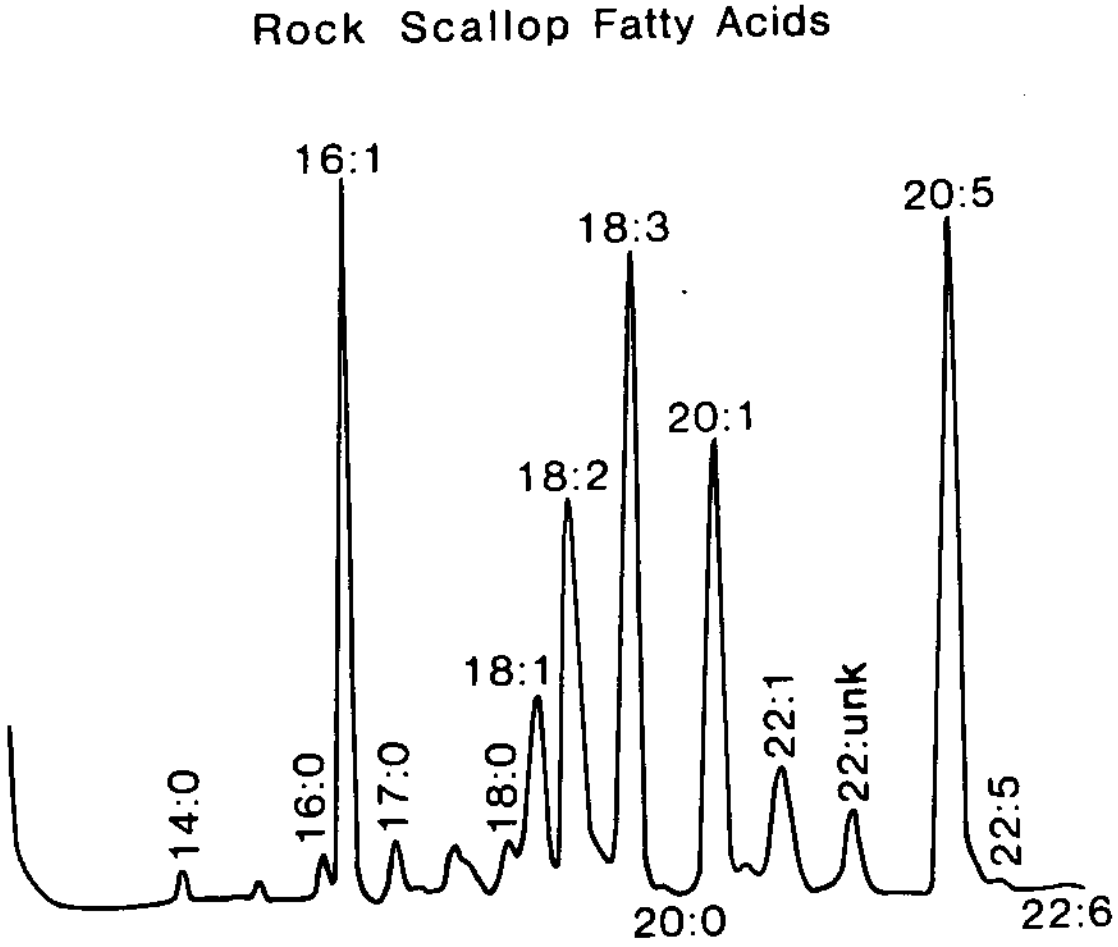

Figure 17: Gas chromatographic spectrum of fatty acids found in adductor muscle lipid of *Hinnites*.

ranged from 93 to 96%. The percent polyunsaturated acids ranged from 52 to 57%. Principal polyunsaturated acids were 18:2, 18:3 and 20:5. Only trace amounts of 22:5 and 22:6 were present.

The proportion of unsaturated fatty acids in Hinnites adductor muscle is greater than reported for the sea scallop, Placopecten magellanicus, the Pacific oyster, Crassostrea gigas, and the littleneck clam, Protothaca sp., in which unsaturated fatty acids were 66-70% (Gruger et al. 1964). One of the principal reasons for this difference is that Hinnites contained more 18:2 and 18:3 acids (23-32% compared to 0.3-1.6% for these three species). Conversely, Hinnites had only trace amounts of 22:6, compared to 14.5-26.2% for the other bivalves.

Eicosopentanoic acid (20:5) is one of the major unsaturated fatty acids in Hinnites adductor muscle. Recent studies have shown that diets high in 20:5 fatty acid suppress thrombosis. Eskimos have such a diet which is rich in 20:5 and low in 20:4 (arachidonic acid) and have a very low incidence of atherosclerosis and heart disease. Eicosopentanoic acid is a substrate for the enzyme that forms prostaglandins, and this leads to prostaglandins having an additional double bond. James W. Aiken, with the Experimental Biology group in the UpJohn Company, is currently doing some preliminary tests to see if Hinnites adductor muscle enzymes convert 20:5 fatty acid to prostaglandins.

Since other studies of lipid composition in marine bivalve mollusks have shown capabilities for filtration of finely particulate lipids from seawater (Morena et al. 1976) and demonstrate seasonal changes in fatty acid composition in body tissue (Ackman et al. 1971), further study of Hinnites in this respect would be valuable. A dietary study might reveal the source of certain unusual fatty acids. Our samples described here, however, indicated no significant differences in fatty acid methyl esters among

well-nourished and under-nourished groups.

C. Carbyhydrates

Adductor muscle glycogen was analyzed in samples from Point Loma and Mission Bay and compared to that for scallops starved in the laboratory and having a distinctly bland flavor (see below). As anticipated, Hinnites freshly collected from Point Loma and from Mission Bay had considerably higher concentrations of glycogen (1.54% std. dev. 0.72% and 1.74%, std. dev. 0.33%, respectively) than did under-nourished scallops (0.24%, std. dev. 0.34%).

Total monosaccharides for Point Loma and Mission Bay scallops were 1.047-1.739 μ moles monosaccharides per mg protein. Laboratory-held scallops had only 0.292-0.511 μ moles monosaccharide per mg protein. The principal monosaccharides found in adductor muscle of freshly collected rock scallops include glucose (0.527-1.339 μ moles per mg protein), glucosamine (0.145-0.256 μ moles per mg protein), galactosamine (0.088-0.198), sialic acid (0.028-0.086), mannose (0.003-0.053) and fucose (0.004-0.126) (values given in μ moles monosaccharide per mg protein and are ranges for five replicates each, Figure 18). Quantitative values obtained for starved scallops were approximately one order less than these (Figure 19).

D. Descriptive Flavor Profile Analysis

Routinely, aspects of food quality are checked by a trained panel of flavor analysts at the Foremost Research Center. We arranged to have samples of freshly collected Hinnites adductor muscle compared to existing commercial brands of scallops by this means. Qualities judged by the panel of six analysts fell into four categories: flavor by mouth, texture, aroma and aftertaste. Each category was, in turn, divided into several characteristics

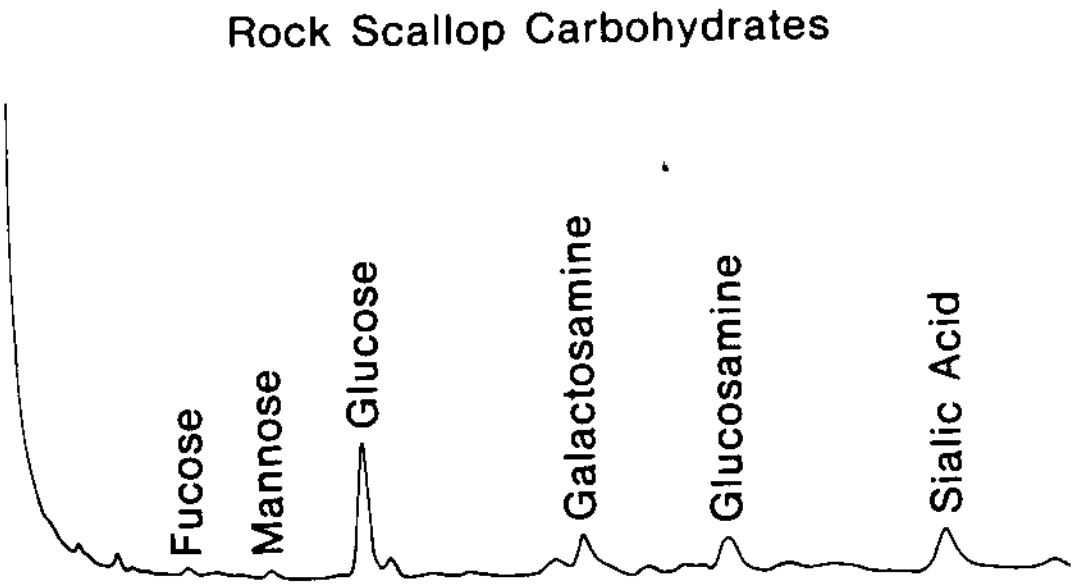

Figure 18: Carbohydrates in adductor muscle of Hinnites.

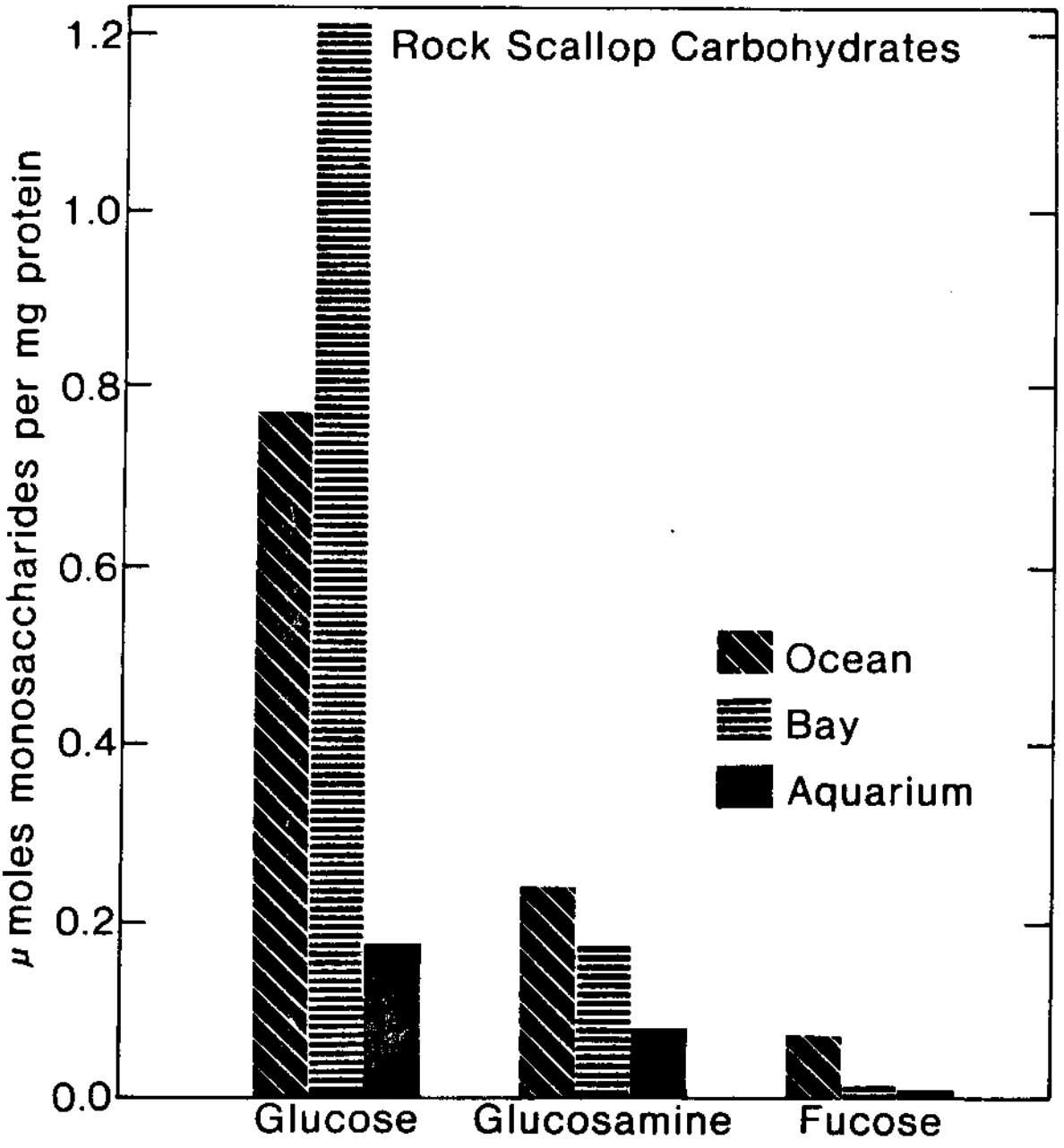

Figure 19: Concentration of the monosaccharides glucose, glucosamine, and fucose in adductor muscle from well-nourished scallops (ocean and bay samples), and from a food-deprived group held for two months in a laboratory aquarium.

which could be described and ranked by degree or intensity.

Results of the flavor analysis indicate Hinnites has sensory qualitites in comparison with other species of scallops which are supportive of its excellent market potential. Rock scallops had a slight to moderate scallop flavor, as did sea and bay scallops (species unknown with certainty) from Nova Scotia, the Atlantic Coast and Thailand, but were rated high and even superior in many of the subtle respects looked for in the survey (Table VIII). In contrast to the other four, rock scallops lacked a fishy aroma. The texture of Hinnites was rated from tender to chewy, depending on size. Larger individuals, while cooked in butter for the same short time as smaller ones, were considered less chewy (we have found, when tested in raw state, smaller and younger rock scallops are more tender than larger and older samples). Grittiness was absent in rock scallops, yet noted among others. Rock scallops had a scallop, sweet and buttery aftertaste, while two of the commercial scallops had a fried aftertaste and one was even rated as sour.

The flavor profile evaluation ranked Hinnites very high among comparable seafood products. This information, supported by our analyses of carbohydrate and lipid composition, indicate the rock scallop is a rich and flavorful seafood relatively low in cholesterol and high in unsaturated fatty acids. We expect the shellfish will command a high market price.

XIII. PROJECTIONS FOR COMMERCIAL AQUACULTURE

A. Hatchery Systems

A dependable supply of juvenile Hinnites is essential for support of rock scallop aquaculture. Collection of natural set scallops by means of improvised culch or similar devices remains a possibility (see Section XIV), but yields from wild production will vary widely by location and time. The basic

Table VIII.

Overall Impression	Nova Scotia H	Thailand MH	Atlantic MH	Coast MH	Rock Scallop H
	Aroma				
Sweet	χ-1	χ-1	χ-1	χ-1	χ-1
Buttery	χ-1	χ-1	χ-1	χ-1	1
Milky	χ-1	-	χ-1	χ	1
Briny	χ	χ-1	χ-1	χ-1	χ-1
Fried	1	1	χ-1	1-2	χ-1
Scallop	1	χ-1	1-2	1	1-2
Fishy	χ	1-2	1	1	-
Earthy	χ-1	χ	χ-1	χ-1	χ-1
Oily	-	χ	-	-	-
	Feeling Factor				
Firm	+	+	-	+	-
Chewy	+	+	-	-	+
Sand grains	-	-	-	-	-
Tender	-	+	-	-	+
Dry	-	+	-	-	-
Gritty	+	+	Sl.	-	-
Fibrous					

Overall Impression	Nova Scotia MH	Thailand M	Atlantic MH	Coast MH	Rock Scallop MH
	Flavor by Mouth				
Sweet	χ-1	χ-1	1	1	χ-1
Buttery	χ-1	1	χ-1	χ-1	χ-1
Scallop	1-2	1	1-2	1	1-2
Salty	χ-1	χ-1	χ-1	χ-1	χ-1
Fishy	χ	1-2	-	χ-1	χ-1
Sour	χ	χ	χ-1	χ	χ-1
Earthy	χ	χ-1	χ	χ-1	χ-1
Milky	-	χ-1	-	-	-
Oily	-	1	-	-	-
Fried	1	1	χ-1	1	χ-1
	Aftertaste				
Scallop	+	-	+	+	+
Sweet	+	+	+	+	+
Sour	Sl.	-	-	-	-
Buttery	+	+	+	+	+
Fried	-	+	-	+	-
Earthy					

Scale: χ = threshold; 1 = slight; 2 = moderate; 3 = strong; underlining indicates emphasis.

(From Phleger et al., 1978)

requirements for laboratory or hatchery production of "seed stock" are now known. Guaranteed performance on a scale necessary to serve the requirements of sea farming industry cannot be made until pilot facilities are established and effective procedures for mass culture of larvae and post-larvae are developed.

Principal requirements for the pilot facility are: 1) a building equipped with an air conditioned algal culture room, 2) a trustworthy supply of coastal seawater proven to be suitable for maintenance of larval and adult rock scallops, 3) an ample system and array of culture tanks and 4) a source of brood stock. Based purely on experience gained in this study, the seawater supply need not be continuous, but delivery of 50-100 gpm when needed should be assured. Future research will be directed to the resolution of the requirements of the hatchery facility.

A functional and economic accessory to the hatchery would be a semi-controlled environment within space in protected waters of a bay or lagoon proven suitable for survival and growth of juvenile scallops. Hatchery-produced early juveniles could be held in pens and cages to feed on natural phytoplankton during the two to six month "fattening period."

B. Extensive Culture in Protected Environments

Methods for rearing Hinnites applied experimentally have employed relatively small sheets of plastic, concrete and asbestos board. We have also dispersed scallops on heavy-duty plastic mesh supported horizontally 0.5 m above the bottom. This method is used in oyster culture in southern France, referred to as rack culture (Anderson 1977). Suspended cage and vertically strung scallop culture was attempted as well. The latter methods invited heavy fouling.

In bay waters where recreational activities, boating and esthetics demand unobstructed and unmarred surface waters, bottom culture is the necessary alternative. Rack culture and adaptations of the rack design to hold batteries of mesh trays would seem the most appropriate for application to rock scallop culture in California bays. Structures holding scallops nearer the bottom would avoid low salinity surface water except in smaller shallow bays near sources of heavy rain runoff. In southern California alone, vast acreages of deeper bay bottom could be devoted, laws permitting, to scallop aquaculture.

Panels of plastic sheet described earlier (see Section X), each holding scallops at a density of 40-50/m^2, could be positioned vertically and arranged in series giving 10 sheets/m^2 of bottom area. Our studies of growth vs density have shown growth of young adult scallops is not reduced at even greater densities. However, since over 400 scallops would occupy each m^3 of water volume, competition for food may occur in quiet water areas. We have not conducted growth observations for scallops held in such high (per unit volume) concentrations in work to date. If individual weight gains become reduced at some point in the extensive culture program, this design for scallop containment has the advantage of permitting thinning (pulling alternate sheets for location elsewhere).

We have shown (Section III) that, reared in either bay or ocean environments, Hinnites juveniles may reach a marketable size of 10-12 cm in a period of two years. Adductor muscles weighing 20-40 gm are yielded from scallops in this size range (Figure 20). Current wholesale prices of fresh/frozen scallops are approximately $3.50/lb (quote from Ocean Fresh Seafoods, La Jolla, June 1977). Harvested rock scallops, once shucked and the meats cleaned, would be worth $0.20-0.30 each. If rock scallops were reared extensively at

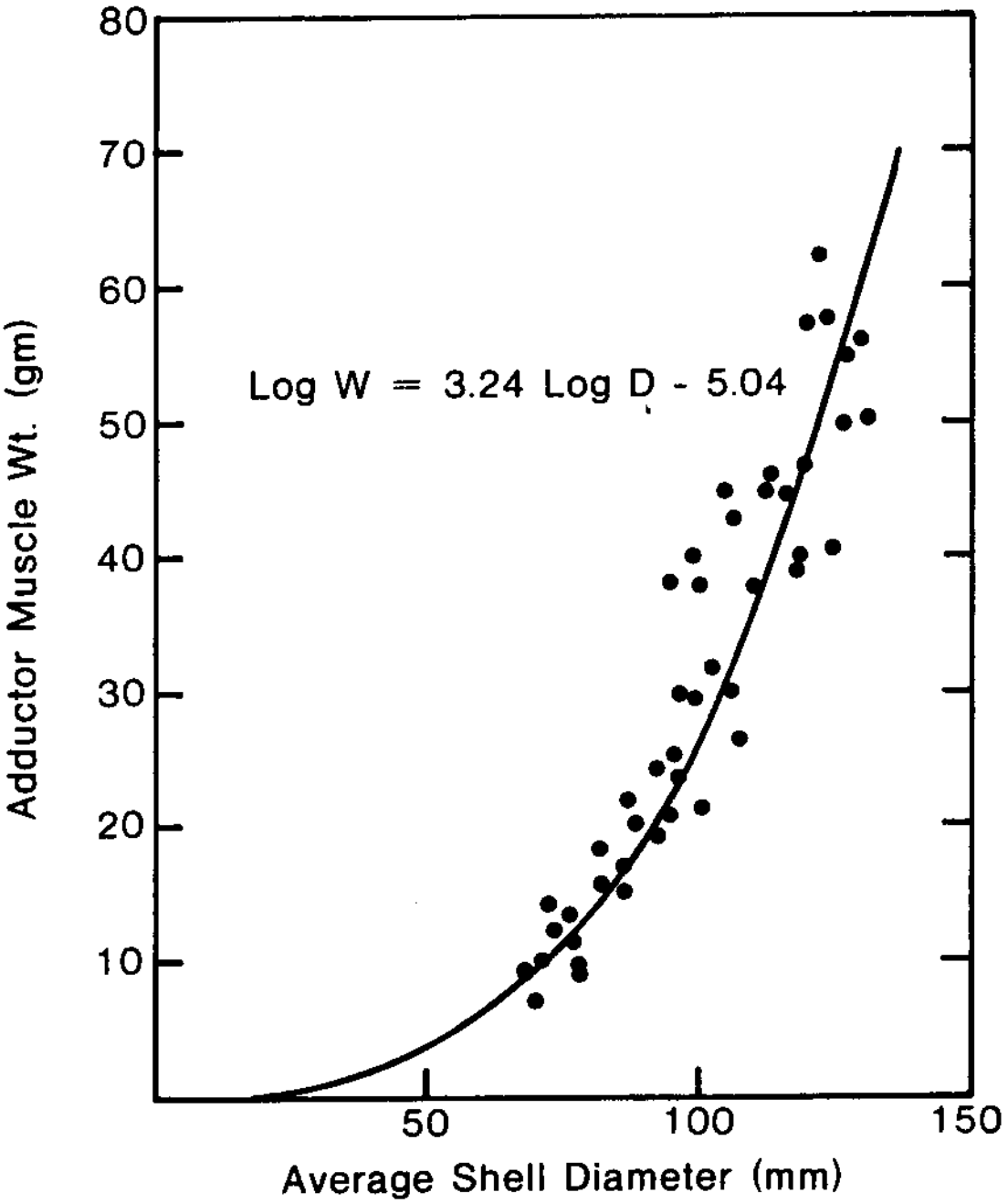

Figure 20: Adductor muscle weight versus average shell diameter for *Hinnites* from Quivira Basin Mission Bay, San Diego

400/m^2, each unit (m^2) should yield approximately $100 gross, each two years. Highly concentrated culture in well circulated, but protected bay waters could conceivably produce 4 x 10^6 scallops in an operation grossing one-half million dollares/hectare/year.

C. Ocean Farming of Rock Scallops

Our still rather preliminary observations on application of potentially commercial methods to rear rock scallops in the exposed ocean have indicated excellent possibilities exist for large-scale scallop farming on and above the sea floor at depths to 30-60 m off the southern California coast. Growth rates of scallops at 10-18 m beneath the U.S. Navy Platform and those suspended in cages at 8-30 m depths near the La Jolla Submarine Canyon were comparable to best growth observed in groups held in Mission Bay (Section III). Problems associated with shallow depths (fouling, entanglement with drift Macrocystis, disruption and loss during high seas and strong currents and interaction with navigation activities) are minimized when structures for holding scallops are situated at depths greater than 10 m. Practical considerations of installation, tending and harvesting with present day technology will necessarily limit efficient scallop aquaculture to depths in the sea between 10 and perhaps 40 m.

Structures adopted for use in the ocean will differ from those applied to culture in protected waters. Whether done over firm and rocky bottom or on sedimentary sea floor, these supports and habitats must be constructed to withstand surge and endure long periods in the sea. Structures designed to be lifted to the surface, or hauled aboard a harvesting vessel, must support added weight of motion during such operations.

We envision a simple design of concrete post with a hollow pipe core to

permit setting by jetting water under pressure into the sand bottom. Concrete posts 10 m long, if roughly 10 x 10 cm, could accommodate 200 scallops distributed 1/dm over 5 m of the post length (posts penetrating 3-4 m into the bottom) on all four sides. If posts were spaced $1/m^2$, adequate room would exist for diver inspection, in situ harvesting and replanting.

A surge-stable configuration of posts and crosslinks to maximize surface within a prescribed area of bottom could take the form of a tetrahedron or pyramid. Many alternatives for scallop farming trellises have been conceived, but none has been tested to date. It would appear that the major costs of establishing the sea farm would not reside in materials (assuming reusable forms for concrete post construction), but in the labor and barge employed for installation. Once in place, post and trellis structures could remain to be tended by divers. After repeated use, the original costs would become negligible compared to production profits.

XIV. CONCLUSIONS AND RECOMMENDATIONS

Basic information gained through observations of this investigation confirms our belief that the rock scallop is easily reared from the laboratory-spawned egg to a marketable size within a period of two and one-half years. Large-scale production of the rock scallop by aquaculture must await solution of two principal problems: hatchery provision of substantial numbers of "seed stock" to prospective scallop farming industry and economic and effective procedures for containment and maintenance of scallops in natural waters until ready for harvest. Current study directed to these aspects of scallop aquaculture suggest that survival and growth of larval Hinnites will improve as specific food requirements for metamorphosis and for the physical environment

in culture are better understood. Methods to rear juvenile scallops to marketable size in bays are being tested with encouraging results and corresponding approaches applicable to ocean environments are planned.

Cost effective methods to hold and rear scallops from juvenile stages to adulthood permitting maintenance and harvesting with a minimum of labor and special equipment are highly desirable. Requirements of extensive culture in protected bay waters are rather different from those for rearing scallops in offshore areas. Fouling is a major problem in bays, especially during late spring and summer months. Tests of materials coated with antifoulant paints, for example, have yet to be applied to cages and supports for juvenile and adult Hinnites. Structures of concrete, plastic or other materials suitable for scallop rearing on sand or rock bottom (or through the overlying water column) in the open ocean have scarcely been conceived or tested.

Meaningful economic studies cannot be undertaken until more information is available on production costs. Hatchery systems need not be expensive; our culture experience using an old boat moored in Quivira Basin have demonstrated this fact. Methods to rear juveniles and adults in bay waters employ inexpensive materials. Unless comparably simple procedures and low-cost equipment are found for use in the ocean, operation of scallop culture there could prove a relatively expensive proposition.

Harvesting, processing and marketing appear to present no great difficulties. Rock scallops are simply pried from rearing surfaces either by divers equipped with "abalone irons" or by tools used aboard a barge once substrates are lifted by wench. Shells are easily opened using a carborendum blade saw to cut the hinge line. Adductor muscles may be separated from the shell with a spatula and cleaned with a minimum of handling. Market potential appears to be sound (see Section XI).

Hinnites enjoys protection from commercial exploitation in California coastal waters at the present time. Rock scallops produced by aquaculture should, however, be freely marketable. Legal constraints imposed by current regulations must be modified to accommodate development of rock scallop aquaculture enterprise in the State of California.

We offer the following recommendations for future research:

1. Procedures to control gametogenesis in brood stock scallops must be developed to free hatchery programs from dependence on natural cycles in local populations. We believe control of photoperiod and temperature will allow controlled maturation in gonads of well nourished scallops.

2. Additional study needs to be directed to foods and nutrition of larvae. We have found Monochrysis lutheri is a good food for early and late larvae and useful to post-larvae and juveniles as well. Mixed diets including M. lutheri supported best growth and survival, but additional algae (e.g. Rhodomonas) may be required during metamorphosis.

3. Methods and equipment (e.g. innovative designs of culture containers) to ensure appropriate conditions (light, water motion and aeration, temperature, metabolite removal, etc.) must be found. In our experience, survival through metamorphosis occurred only when late larvae were transferred to black pigmented fiberglass tanks with fine mesh bottoms. These containers were immersed in larger tanks to which algal cultures were supplied regularly. Aeration and moderate water motion was essential to best growth.

4. Since best growth of juveniles was found when individuals were placed in natural waters to feed on wild plankton, simple means to hold juveniles during the pre-cementing "fattening period" should be devised.

5. Our several methods to confine and support scallops during extensive rearing to market size are appropriate for aquaculture in protected marine

environments. Structures practical for ocean use need yet to be developed. Innovations in design of habitats and rearing structures must consider, whether used in bay or ocean environments, stability, durability, ease of tending for stocking, maintenance and harvesting, and most importantly, economy.

6. The chief "bottleneck" facing scallop aquaculture at this point appears to be the low yields of juveniles produced by present laboratory culture or field collecting methods. Parallel to development of reliable hatchery technology should be studies of methods to attract and collect natural set scallops. Results of our preliminary studies suggest both physical and chemical elements may be important in design of effective juvenile collectors. Chemoattractant substances, possibly emanating from adult shell, should be examined.

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APPENDIX A

Morphometric observations on scallops collected from Mission Bay. All weights are given in grams (g), volumes in milliliters (ml), and diameters in millimeters (mm).

October 18, 1975

Sex	Soft Body Weight	Muscle Weight	Gonad-Digestive System Weight	Muscle Volume	Gonad-Digestive System Volume	Soft Body Volume	Muscle Diameter	Average Shell Diameter
Female	29.53	12.88	7.21	12.00	6.00	25.00	28.20	80.7
Female	16.05	6.06	3.48	5.00	4.00	14.00	20.40	58.6
Male	29.45	12.26	5.64	13.00	4.00	25.00	27.20	74.9
Female	27.85	12.60	5.34	13.00	5.00	25.00	23.70	70.6
Male	23.90	10.60	3.92	9.00	4.00	20.00	29.50	69.5
Female	50.37	21.52	9.66	20.00	9.00	43.00	36.70	98.9
Male	47.92	19.65	11.23	20.00	10.00	42.00	32.80	89.8
Male	39.41	15.93	6.27	15.00	5.00	34.00	30.20	100.3
Female	52.44	14.47	14.46	17.00	13.00	43.00	35.60	102.7
Male	59.34	28.78	10.46	26.00	10.00	54.00	33.50	98.0
Female	40.46	16.34	9.13	15.00	9.00	33.00	28.70	86.5
Female	73.08	29.86	14.40	28.90	12.00	61.00	39.90	108.5
Male	73.22	27.11	18.29	24.00	17.00	59.00	31.60	102.0
Female	76.42	33.84	13.14	32.00	10.00	60.00	39.10	110.1
Male	51.30	20.97	8.86	20.00	8.00	42.00	30.70	106.0
Female	87.12	35.35	20.43	32.00	19.00	71.00	35.40	113.3
Male	112.38	49.72	26.42	46.00	24.00	92.00	42.90	117.7
Female	106.56	45.62	24.58	40.00	24.00	85.00	40.30	117.9
Male	49.00	18.82	9.76	19.00	10.00	41.00	27.60	101.7
Female	76.74	28.33	17.10	26.00	17.00	62.00	33.40	103.9

Appendix A. (continued)

November 25, 1975

Sex	Soft Body Weight	Muscle Weight	Gonad-Digestive System Weight	Muscle Volume	Gonad-Digestive System Volume	Soft Body Volume	Muscle Diameter	Average Shell Diameter
Female	47.90	20.25	7.55	19.00	6.00	40.00	25.20	88.3
Female	61.14	28.50	11.78	26.00	12.00	54.00	35.50	93.4
Female	100.25	46.81	17.90	44.00	16.00	85.00	47.30	113.3
Male	13.90	6.08	2.52	8.00	2.00	15.00	28.00	67.3
Female	99.29	37.43	32.69	33.00	30.00	83.00	37.80	110.8
Male	34.04	14.52	5.79	14.00	5.00	30.00	27.40	78.8
Female	81.81	31.17	17.84	30.00	15.00	68.00	39.90	110.1
Female	109.54	50.17	21.80	49.00	20.00	94.00	42.40	113.1
Female	36.93	15.43	6.98	15.00	8.00	34.00	28.60	82.9
Female	37.88	15.67	6.90	14.00	5.00	29.00	31.90	83.2
Female	64.22	25.71	12.81	23.00	13.00	51.00	36.60	109.7
Female	36.01	18.01	7.24	23.00	8.00	37.00	30.10	71.1
Female	45.41	19.22	10.89	17.00	12.00	40.00	30.30	85.0
Male	50.99	26.47	8.48	25.00	8.00	45.00	36.80	85.9
Female	72.13	30.49	24.69	27.00	25.00	57.00	34.40	96.4
Male	62.25	28.67	12.80	33.00	7.00	50.00	34.20	95.6
Female	38.69	17.77	7.31	14.00	9.00	33.00	30.80	89.7
Male	55.72	27.60	8.63	24.00	8.00	46.00	35.20	94.7
Male	67.15	28.93	11.96	28.00	10.00	55.00	35.80	101.1
Female	40.78	18.73	6.98	19.00	6.00	36.00	32.80	89.1

Appendix A (continued)

December 31, 1975

Sex	Soft Body Weight	Muscle Weight	Gonad-Digestive System Weight	Muscle Volume	Gonad-Digestive System Volume	Soft Body Volume	Muscle Diameter	Average Shell Diameter
Male	62.52	29.88	9.57	28.00	9.00	55.00	31.80	103.5
Female	97.43	46.63	18.72	44.00	16.90	84.00	41.30	131.3
Female	20.05	7.47	3.71	6.50	3.50	17.00	23.30	66.0
Male	31.19	11.53	5.43	10.90	5.00	24.30	25.10	85.5
Male	48.45	19.26	7.97	17.00	7.20	39.00	32.60	93.0
Male	37.73	16.03	8.17	16.00	8.00	35.00	30.00	90.0
Female	60.52	22.92	11.30	21.00	10.60	50.00	31.20	100.9
Male	75.97	32.21	13.13	30.00	11.90	64.00	33.30	156.1
Male	34.88	10.65	9.38	9.40	8.60	26.90	27.10	89.2
Male	29.84	13.95	5.69	12.80	5.70	25.80	29.20	77.1
Female	56.05	21.12	11.60	20.00	10.80	46.00	31.20	89.3
Female	40.20	16.08	7.49	15.00	7.00	34.00	27.80	92.6
Male	33.16	15.51	5.24	14.00	4.70	28.00	34.10	87.0
Female	31.15	13.09	7.62	13.00	7.00	29.00	28.70	84.5
Female	37.17	15.46	5.38	14.00	5.00	30.00	28.70	85.6

February 9, 1976

Male	57.94	23.68	8.54	24.00	7.80	47.00	32.60	99.0
Male	77.96	34.15	13.10	32.00	11.90	66.00	42.20	112.9
Female	95.09	39.88	16.29	36.00	15.00	75.00	41.00	120.4
Male	51.59	18.63	8.06	18.00	7.50	39.00	33.80	99.9
Female	46.24	19.59	7.53	18.00	7.00	39.00	33.80	91.1
Female	31.33	11.22	7.62	11.00	7.20	27.00	28.70	83.3
Male	34.37	14.02	8.84	14.00	8.10	31.00	27.80	80.5
Female	39.01	18.47	4.22	19.00	3.90	32.00	26.10	81.9

Appendix A. (continued)

Sex	Soft Body Weight	Muscle Weight	Gonad-Digestive System Weight	Muscle Volume	Gonad-Digestive System Volume	Soft Body Volume	Muscle Diameter	Average Shell Diameter
Female	26.98	9.69	6.12	9.00	5.50	21.60	26.40	71.7
Female	29.84	12.72	5.43	15.00	5.00	30.00	24.70	82.8
Female	20.91	7.34	4.08	7.00	3.90	16.40	21.40	64.8
Male	21.24	7.54	3.16	7.00	3.10	17.00	23.00	78.4
Female	43.40	15.79	8.46	15.00	7.80	33.00	31.30	94.0
Male	21.96	9.41	4.81	8.50	4.60	20.00	25.80	77.5
Female	37.11	12.21	8.36	11.30	7.80	29.00	29.10	90.9
				February 22, 1976				
Male	32.65	12.00	3.22	10.90	3.00	23.00	30.20	82.8
Female	117.73	53.87	20.81	50.00	19.10	96.00	39.30	136.1
Female	58.21	22.81	10.01	22.00	9.10	48.00	35.20	95.6
Female	82.48	37.55	9.68	34.00	9.20	64.00	41.80	120.7
Female	32.03	13.21	5.24	12.10	4.90	26.00	39.10	95.3
Male	49.42	22.13	6.58	20.00	6.00	42.00	37.10	109.7
Male	51.36	22.08	8.21	20.00	7.90	43.00	33.60	100.1
Female	66.32	26.81	10.96	25.00	10.10	53.00	35.50	107.4
Female	32.24	11.84	4.08	11.00	4.00	26.00	27.50	86.8
Male	44.33	18.79	7.15	17.00	6.40	38.00	30.50	100.4

Appendix A. (continued)

March 23, 1976

Sex	Soft Body Weight	Muscle Weight	Gonad-Digestive System Weight	Muscle Volume	Gonad-Digestive System Volume	Soft Body Volume	Muscle Diameter	Average Shell Diameter
Female	23.14	6.87	7.84	6.10	7.00	19.90	25.90	70.5
Female	112.43	35.49	27.85	34.00	24.80	82.00	44.90	122.5
Female	110.30	47.64	20.63	44.00	21.10	91.00	53.10	130.8
Female	52.35	17.03	18.61	15.00	17.40	44.00	32.70	92.8
Female	112.92	44.66	30.65	40.00	27.50	92.00	46.70	112.8
Female	134.65	54.36	33.47	50.00	30.00	112.00	47.00	135.4
Female	121.64	49.71	26.78	45.00	26.00	100.00	28.40	124.6
Female	52.15	18.04	14.28	16.00	13.40	45.00	34.00	103.6
Female	62.86	25.21	16.18	23.00	15.00	55.00	38.2	107.0
Female	33.20	11.52	9.55	10.30	8.90	27.50	28.50	84.3
Male	51.36	18.92	13.27	18.00	12.10	44.00	35.40	101.2
Female	63.94	26.51	21.53	24.00	19.60	57.00	37.50	105.7
Male	47.09	19.02	9.12	17.00	8.10	39.00	32.80	94.3
Female	54.97	21.44	11.62	20.00	10.80	45.00	33.10	99.5
Female	24.70	7.50	7.77	7.20	7.10	20.00	24.30	73.3

April 19, 1976

Female	75.77	28.94	15.50	27.00	14.90	64.00	38.40	107.2
Male	43.76	17.64	9.11	16.00	8.00	36.00	36.50	98.1
Female	45.22	16.34	12.16	15.00	11.10	38.00	32.50	86.1
Female	55.67	18.69	14.71	17.00	13.20	45.00	31.20	102.0
Female	57.74	27.04	11.24	25.00	10.40	50.00	36.40	86.5
Female	29.28	11.16	4.29	10.00	3.90	23.00	30.30	80.3
Male	32.11	13.45	8.92	12.70	8.00	28.00	30.50	82.2
Male	17.17	5.25	4.91	5.00	4.90	14.00	26.10	73.8

Appendix A. (continued)

Sex	Soft Body Weight	Muscle Weight	Gonad-Digestive System Weight	Muscle Volume	Gonad-Digestive System Volume	Soft Body Volume	Muscle Diameter	Average Shell Diameter
Female	42.42	18.66	10.94	19.00	10.00	39.00	32.80	87.4
Female	27.28	9.57	8.05	8.90	8.00	24.00	24.90	74.3
Female	71.84	24.87	18.52	24.00	17.40	60.00	37.50	109.2
Female	41.83	14.27	10.61	14.00	9.90	35.00	36.90	94.1
Female	45.33	17.73	11.15	15.00	10.00	37.00	34.60	84.4
Female	59.77	23.44	15.80	22.00	14.80	52.00	37.40	98.5
Female	75.33	28.36	19.37	25.00	17.90	60.00	36.60	103.9
				June 20, 1976				
Female	125.70	49.84	37.64	45.00	32.50	105.00	47.00	137.0
Male	70.12	29.22	13.78	26.00	12.70	59.00	40.80	107.1
Female	104.58	39.05	40.07	35.00	36.6	90.00	38.30	106.7
Male	61.72	29.48	15.30	27.00	14.00	55.00	38.30	97.3
Female	60.55	21.85	20.12	21.00	19.50	54.00	33.70	96.0
Female	94.95	32.15	34.73	30.00	31.50	80.00	42.30	116.3
Female	105.94	45.00	27.66	42.00	25.00	90.00	44.90	117.6
Male	50.00	18.75	14.92	16.00	40.00	13.90	34.00	82.2
Female	34.37	12.51	9.14	11.00	8.60	29.00	26.60	81.9
Male	62.87	25.52	14.62	24.00	13.40	55.00	32.10	99.5
Male	53.56	21.84	15.18	20.00	13.90	47.00	36.40	98.2
Male	29.45	9.58	10.38	9.00	9.10	25.00	26.90	73.2
Female	77.96	37.93	17.82	35.00	16.60	67.00	42.10	111.3
Male	37.23	14.80	12.04	14.00	11.00	34.00	29.50	85.4
Female	45.79	22.74	7.67	20.00	7.50	39.00	31.20	95.2

Appendix A (continued)

August 6, 1976

Sex	Soft Body Weight	Muscle Weight	Gonad-Digestive System Weight	Muscle Volume	Gonad-Digestive System Volume	Soft Body Volume	Muscle Diameter	Average Shell Diameter
Female	96.42	40.92	18.30	37.00	16.40	78.00	4.530	128.0
Female	82.14	35.67	17.83	34.00	16.00	69.00	45.60	111.7
Female	65.55	24.51	16.33	22.00	15.00	55.00	37.90	102.8
Hermaph.	48.71	18.16	12.95	17.00	11.90	43.00	32.70	98.1
Female	47.24	18.27	10.64	16.00	9.90	38.00	34.00	88.4
Female	34.69	16.40	4.98	15.00	4.80	29.00	32.30	81.8
Female	30.93	10.54	6.39	10.00	6.00	23.00	29.60	91.2
Male	56.53	22.64	14.00	20.00	12.70	48.00	39.10	99.2
Female	34.33	15.35	5.81	13.00	5.40	27.00	33.30	91.2
Female	50.12	20.21	9.33	19.00	8.90	40.00	3.510	97.1
Male	32.73	14.88	4.51	13.50	4.00	28.00	33.50	82.5
Female	41.04	15.36	10.11	15.00	9.80	35.00	32.20	88.4
Female	36.54	12.43	9.11	11.60	8.00	27.50	30.10	83.5
Male	24.88	10.58	4.41	9.90	4.00	21.00	30.90	76.8
Male	25.12	12.33	3.41	11.10	3.20	21.50	31.10	72.7

September 6, 1976

Male	58.95	22.66	17.99	20.00	16.00	50.00	35.40	94.0
Female	156.74	66.76	39.64	67.00	36.40	130.00	54.50	144.1
Female	94.06	38.78	23.03	35.00	21.00	79.00	44.90	122.2
Female	128.13	46.83	45.25	43.00	42.10	109.00	46.80	122.2
Female	86.43	33.90	24.58	30.00	22.90	72.00	43.80	113.2
Female	86.02	38.81	19.75	35.00	18.00	71.00	42.80	101.4
Male	58.55	29.52	9.05	25.00	8.00	49.00	40.6	94.9
Female	100.09	45.89	25.55	42.00	23.80	85.00	45.30	104.7

Appendix A. (continued)

Sex	Soft Body Weight	Muscle Weight	Gonad-Digestive System Weight	Muscle Volume	Gonad-Digestive System Volume	Soft Body Volume	Muscle Diameter	Average Shell Diameter
Female	64.61	30.30	15.11	27.00	13.00	--	37.00	90.3
Male	40.00	17.39	10.99	15.00	10.20	34.00	34.20	77.9
Female	49.56	22.33	11.08	20.00	10.10	43.00	36.10	88.5
Female	47.40	19.72	10.45	18.00	9.90	38.00	38.70	90.4
Female	51.26	20.84	12.01	15.00	10.90	40.00	34.40	95.1
Male	47.09	22.72	9.19	20.00	8.50	40.00	36.60	85.4
				October 20, 1976				
Male	132.31	58.14	38.67	53.00	34.00	115.00	52.10	125.8
Female	119.30	50.93	17.78	47.00	16.80	98.00	47.60	124.8
Male	69.21	23.04	13.83	20.00	12.90	52.00	39.00	121.4
Female	126.76	48.87	39.00	45.00	36.10	108.00	49.7	124.8
Female	71.81	32.98	15.42	30.00	14.00	63.00	40.20	106.2
Female	39.15	17.59	5.71	16.00	5.30	32.00	34.40	88.1
Male	78.76	29.88	22.95	27.00	21.00	67.00	40.90	108.5
Female	37.54	15.26	11.70	14.00	11.00	33.00	31.40	84.65
Male	63.37	29.90	11.66	27.00	11.00	55.00	38.00	100.6
Male	51.46	19.24	16.43	18.00	15.20	45.00	34.70	89.3
Female	64.28	22.98	17.42	20.00	15.90	51.00	32.50	90.7
Female	70.92	27.51	21.31	25.00	19.90	60.00	42.40	98.2
Female	65.61	21.70	22.09	20.00	20.30	55.00	34.50	101.3
Male	28.78	10.40	8.21	9.60	7.40	24.00	29.10	79.3
Male	34.27	10.55	7.40	14.00	7.00	30.00	34.10	83.3

APPENDIX B

Morphometric observations on scallops collected off Point Loma. All weights are given in grams (g), volumes in milliliters (ml), and diameters in millimeters (mm).

November 20, 1975

Sex	Soft Body Weight	Muscle Weight	Gonad-Digestive System Weight	Muscle Volume	Gonad-Digestive System Volume	Soft Body Volume	Muscle Diameter	Average Shell Diameter
Male	90.23	47.86	10.51	65.00	11.00	80.00	45.40	118.9
Male	103.04	52.75	13.44	50.00	14.00	90.00	50.70	115.5
Female	119.17	53.12	24.67	45.00	25.00	102.00	45.60	136.6
Female	141.24	60.01	24.48	55.00	20.00	110.00	45.80	148.5
Female	59.15	27.44	6.89	25.00	5.00	41.00	34.90	104.2
Male	32.80	14.19	4.61	14.00	5.00	26.00	29.70	80.8
Female	121.81	59.29	24.82	52.00	23.00	105.00	47.90	139.3
Female	86.07	37.00	21.43	30.00	20.00	72.00	37.60	115.7
Female	38.72	18.45	4.65	17.00	5.00	32.00	31.90	86.8
Female	32.58	11.74	11.34	10.00	12.00	30.00	25.50	83.1
Female	102.64	50.47	15.41	46.00	15.00	87.00	46.30	122.4
Male	60.36	26.10	9.22	24.00	7.00	50.00	35.10	102.2
Male	146.90	65.86	25.86	52.00	33.00	118.00	43.10	125.5
Male	88.45	41.46	15.83	39.00	15.00	75.00	42.90	115.1
Male	72.80	32.85	10.74	30.00	10.00	60.00	39.90	108.8
Male	136.13	67.62	17.76	62.00	17.00	109.00	49.60	138.4
Female	67.08	27.75	16.20	25.00	14.00	54.00	36.10	104.1
Female	54.74	23.60	11.34	23.00	11.00	45.00	32.00	89.6
Female	51.67	24.52	8.24	24.00	6.00	45.00	35.70	91.1
Male	52.59	24.60	6.47	25.00	5.00	44.00	34.30	91.5

Appendix B.. (continued)

December 29, 1975

Sex	Soft Body Weight	Muscle Weight	Gonad-Digestive System Weight	Muscle Volume	Gonad-Digestive System Volume	Soft Body Volume	Muscle Diameter	Average Shell Diameter
Female	106.32	48.39	20.86	41.00	19.00	85.00	43.70	123.5
Female	172.01	91.44	20.67	85.00	19.50	140.00	55.70	139.9
Male	119.85	58.16	14.93	53.00	13.00	96.00	48.40	143.8
Female	171.14	73.23	32.03	68.00	29.10	135.00	58.20	160.1
Male	129.55	63.87	12.88	59.00	11.40	97.00	41.40	131.3
Female	221.47	107.46	33.49	99.00	31.50	175.00	60.70	168.4
Female	83.78	38.26	13.93	35.00	13.10	67.00	44.20	119.5
Female	61.63	30.65	8.60	27.00	7.80	50.00	40.00	108.5
Female	63.61	35.04	9.13	33.00	8.50	55.00	43.30	107.8
Female	110.43	48.38	18.16	44.00	16.70	83.00	45.80	127.0
Male	125.52	60.51	20.00	56.00	18.00	100.00	52.40	127.7
Female	104.32	44.55	18.52	40.00	17.00	80.00	42.00	119.0
Male	111.72	50.17	12.45	45.00	11.10	79.00	44.30	118.6
Female	31.57	13.78	4.52	13.00	4.80	25.00	25.70	76.0
Female	24.30	11.88	2.91	10.80	2.80	19.60	28.70	77.1

January 15, 1976

Female	171.00	78.17	27.18	72.00	23.90	130.00	55.70	147.1
Female	84.41	40.58	15.44	38.00	14.00	74.00	44.60	109.5
Male	34.62	14.63	7.90	14.00	7.00	30.00	25.30	81.8
Male	58.68	24.60	10.51	23.00	9.50	0.00	36.10	100.7
Female	91.29	35.78	17.71	30.00	16.50	69.00	38.80	125.6
Female	125.65	48.59	26.61	45.00	23.00	95.00	40.00	135.4
Female	102.62	46.02	18.77	42.00	17.40	82.00	44.90	133.4
Female	107.58	59.48	14.35	55.00	13.60	90.00	46.40	113.5

Appendix B. (continued)

Sex	Soft Body Weight	Muscle Weight	Gonad-Digestive System Weight	Muscle Volume	Gonad-Digestive System Volume	Soft Body Volume	Muscle Diameter	Average Shell Diameter
Male	111.28	48.98	13.97	45.00	12.80	84.00	44.50	113.4
Female	145.14	67.29	32.19	62.00	29.00	117.00	43.40	114.4
Female	50.02	19.48	11.69	18.00	11.00	40.00	32.80	85.0
Male	52.77	25.79	9.23	25.00	8.80	45.00	33.90	85.5
Female	32.54	13.88	7.39	11.00	6.90	26.00	28.80	80.8
Female	77.34	39.04	13.93	35.00	12.90	65.00	36.80	98.4
Female	75.15	41.73	11.33	38.00	10.00	62.00	40.00	90.4
				February 2, 1976				
Female	95.83	37.57	22.55	35.00	21.00	78.00	43.70	122.3
Male	94.98	47.33	15.53	43.00	14.50	80.00	40.80	121.3
Female	123.20	53.42	31.44	48.00	28.70	100.00	41.50	124.8
Female	186.94	84.20	41.67	78.00	39.40	158.00	56.20	149.9
Female	127.56	46.32	33.35	42.00	30.50	98.00	44.40	143.8
Female	50.33	19.10	15.34	18.00	14.00	43.00	29.10	83.8
Male	104.08	71.24	26.81	65.00	24.00	115.00	36.60	140.2
Male	55.00	25.28	8.47	23.00	8.00	42.00	33.50	86.7
Male	60.19	24.21	15.86	23.00	15.00	50.00	33.90	98.0
Female	81.01	31.75	20.58	30.00	19.60	68.00	35.60	106.4
Female	84.27	42.65	16.63	40.00	15.80	75.00	35.50	97.9
Female	106.88	47.76	21.05	44.00	14.00	80.00	42.30	117.7
Female	103.30	36.48	34.94	34.00	32.90	88.00	33.40	100.5
Female	122.32	57.52	26.55	54.00	24.00	105.00	43.60	118.8
Male	52.87	20.15	16.91	18.00	15.80	45.00	30.90	82.4

Appendix B. (continued)

February 19, 1976

Sex	Soft Body Weight	Muscle Weight	Gonad-Digestive System Weight	Muscle Volume	Gonad-Digestive System Volume	Soft Body Volume	Muscle Diameter	Average Shell Diameter
Female	83.58	26.18	17.38	24.00	16.00	62.00	38.90	149.4
Female	130.76	50.19	27.18	47.00	23.50	93.00	40.50	113.5
Female	143.62	67.78	30.61	62.00	27.50	124.00	46.20	130.3
Female	106.50	52.34	23.76	50.99	22.00	90.00	43.50	111.6
Female	238.60	99.73	52.76	96.00	48.00	194.00	56.90	192.3
Male	100.34	51.86	11.23	48.00	10.00	80.00	41.40	118.8
Female	130.17	46.81	25.16	44.00	22.50	97.50	35.20	130.7
Female	152.96	73.48	34.79	68.00	32.00	130.00	48.60	117.1
Female	93.23	41.62	26.35	38.00	24.90	80.00	41.90	107.6
Male	29.89	11.81	8.69	11.00	8.00	25.20	29.20	71.6
Female	74.32	36.15	15.60	33.00	14.90	63.00	38.10	97.6
Female	25.64	9.76	7.52	9.00	7.10	21.50	24.50	67.5
Male	25.07	9.22	7.87	8.20	8.00	21.60	25.00	74.7
Male	21.44	9.06	4.21	8.10	4.10	17.10	22.10	73.9
Female	20.72	8.04	4.41	7.20	4.50	17.00	22.20	61.9

March 12, 1976

Male	124.53	52.13	36.05	49.00	32.00	105.00	46.00	117.9
Male	107.64	55.90	16.10	51.00	14.10	93.00	49.40	115.7
Female	104.24	36.85	25.66	34.00	23.90	82.00	29.70	135.3
Female	120.45	48.43	31.44	45.00	28.50	100.00	40.90	145.2
Male	64.02	25.23	18.83	23.00	14.50	52.00	31.50	108.9
Male	33.86	14.47	7.35	14.00	6.90	29.00	29.70	74.7
Male	38.57	16.01	7.40	15.00	7.00	31.00	30.30	80.4
Male	62.08	22.20	17.69	20.00	15.20	50.00	31.30	96.4
Female	33.53	11.28	11.31	10.50	10.10	28.00	24.00	79.9
Female	93.53	44.12	18.14	40.00	17.50	81.00	41.00	120.2

Appendix B, (continued)

Sex	Soft Body Weight	Muscle Weight	Gonad-Digestive System Weight	Muscle Volume	Gonad-Digestive System Volume	Soft Body Volume	Muscle Diameter	Average Shell Diameter
Male	112.83	48.96	27.72	46.00	24.60	97.00	43.10	117.3
Male	72.42	32.08	13.04	30.00	11.80	60.00	38.30	92.5
Male	31.94	10.15	9.78	9.40	9.60	27.00	29.20	80.9
Male	21.75	9.10	4.10	8.50	4.00	17.60	25.30	62.2
Female	33.68	12.45	9.12	11.50	8.50	27.00	28.60	69.3
				March 30, 1976				
Female	291.52	126.33	71.96	110.00	67.00	226.00	76.60	184.7
Male	137.14	54.18	21.17	50.00	19.10	105.00	47.60	106.9
Female	15.08	53.07	22.96	48.00	20.10	98.00	50.00	131.1
Female	45.23	19.87	11.97	19.00	11.00	40.00	36.70	89.7
Male	30.88	8.69	12.00	8.00	10.90	24.00	25.60	69.7
Male	28.43	10.75	9.33	9.80	8.00	23.90	26.90	72.4
Male	72.35	32.80	14.64	30.00	13.60	60.00	40.10	108.5
Female	101.54	39.66	30.36	35.00	27.00	83.00	43.90	111.0
Male	70.04	33.08	13.91	30.00	13.70	60.00	39.40	91.9
Female	93.12	48.83	17.39	45.00	16.00	84.00	44.10	109.0
Male	37.04	15.15	9.41	15.00	8.80	33.00	38.00	81.0
Female	77.80	32.60	17.21	29.00	15.80	64.00	40.30	99.9
Male	54.59	27.91	11.37	25.00	10.00	49.00	37.10	87.8
Male	35.98	14.30	5.56	14.00	5.00	27.00	30.80	78.2
Female	43.01	19.41	7.32	19.00	6.60	35.00	32.10	79.00

Appendix B. (continued)

June 6, 1976

Sex	Soft Body Weight	Muscle Weight	Gonad-Digestive System Weight	Muscle Volume	Gonad-Digestive System Volume	Soft Body Volume	Muscle Diameter	Average Shell Diameter
Female	150.67	75.77	25.67	70.00	22.80	120.00	55.20	134.6
Female	152.57	55.31	28.66	50.00	25.90	105.00	49.20	144.4
Male	22.65	6.73	6.97	6.10	6.10	17.00	22.90	68.5
Male	34.30	13.33	9.03	13.00	8.50	30.00	29.50	85.8
Female	50.58	26.34	7.29	23.00	6.90	41.00	38.20	96.7
Male	42.83	17.14	8.93	16.00	8.40	35.00	27.30	83.8
Male	33.32	14.94	4.17	13.00	3.90	27.00	32.70	92.1
Female	130.27	62.84	25.67	59.00	23.50	110.00	54.50	142.6
Female	183.31	77.82	52.67	73.00	47.00	154.00	57.70	153.3

July 12, 1976

Female	98.16	47.61	17.92	44.00	16.60	80.00	47.10	115.0
Female	81.67	38.98	13.94	36.00	12.60	69.00	44.80	114.5
Male	107.35	54.40	16.20	50.00	15.00	90.00	45.40	116.9
Female	102.74	48.42	23.25	46.00	21.90	88.00	44.80	113.0
Female	182.64	86.62	39.26	80.00	35.80	145.00	61.30	149.8
Female	189.40	81.23	47.48	75.00	44.50	155.00	51.40	154.6
Female	48.11	22.46	9.10	20.00	8.00	40.00	36.90	106.2
Female	92.34	42.38	15.54	40.00	14.40	75.00	45.60	121.8
Male	111.10	53.42	21.47	48.00	19.90	93.00	49.60	130.8
Female	96.56	44.11	22.81	40.00	20.40	84.00	45.00	117.9
Female	170.42	82.19	25.06	75.00	22.50	132.00	55.40	142.8
Female	63.89	31.65	14.72	24.00	13.90	51.00	38.40	104.0
Male	54.46	27.39	8.51	20.00	8.00	39.00	39.60	105.3
Female	112.95	52.45	14.36	49.00	13.00	90.00	47.70	135.5
Male	187.48	105.60	21.23	98.00	20.00	158.00	61.10	150.1

Appendix B. (continued)

August 19, 1976

Sex	Soft Body Weight	Muscle Weight	Gonad-Digestive System Weight	Muscle Volume	Gonad-Digestive System Volume	Soft Body Volume	Muscle Diameter	Average Shell Diameter
Female	26.01	12.67	5.13	11.90	5.00	22.00	32.20	70.4
Male	70.15	31.68	10.78	29.00	10.10	55.00	38.10	112.7
Male	88.29	48.24	10.43	45.00	9.50	74.00	43.20	109.2
Male	74.83	34.02	11.88	30.00	11.00	60.00	43.00	105.9
Male	83.25	39.12	13.38	35.00	12.60	68.00	42.10	126.9
Male	92.40	45.75	13.82	40.00	13.90	75.00	41.90	122.6
Female	105.22	51.93	19.83	47.00	18.90	92.00	44.60	135.4
Male	102.24	56.22	15.62	50.00	14.10	86.00	44.70	115.0
Female	57.56	29.22	10.19	26.00	9.80	50.00	37.00	105.5
Female	44.47	20.26	6.21	18.00	5.80	35.00	31.50	85.3
Male	58.97	25.81	9.17	24.00	8.10	47.00	35.20	106.2
Male	24.72	10.39	3.27	9.50	3.00	19.00	27.80	82.2
Female	27.96	9.80	7.35	9.00	7.00	22.00	26.90	80.1
Male	24.13	11.30	3.72	10.70	3.10	20.00	27.50	70.8
Male	21.28	8.91	4.62	8.40	4.00	19.00	22.90	72.3

Appendix B. (continued)

September 26, 1976

Sex	Soft Body Weight	Muscle Weight	Gonad-Digestive System Weight	Muscle Volume	Gonad-Digestive System Volume	Soft Body Volume	Muscle Diameter	Average Shell Diameter
Female	102.17	40.32	23.81	37.00	21.90	81.00	44.10	113.4
Female	87.43	35.76	18.53	34.00	17.10	70.00	42.70	110.5
Female	64.35	28.85	15.76	26.00	14.70	55.00	39.80	92.0
Female	57.41	24.90	11.82	23.00	11.20	46.00	34.10	96.2
Female	156.51	77.17	27.94	73.00	25.00	126.00	55.70	144.9
Female	58.93	28.16	10.42	25.00	9.80	48.00	40.10	107.1
Female	67.17	29.62	14.76	27.00	14.00	57.00	40.50	106.4
Male	49.37	20.73	10.73	19.00	10.00	40.00	37.50	87.7
Male	86.70	37.81	15.74	35.00	14.60	73.00	47.30	111.9
Female	72.78	26.27	22.61	45.00	21.00	65.00	38.80	114.6
Female	65.52	22.15	24.07	20.00	22.80	56.00	36.30	96.3
Female	94.52	43.93	15.75	41.00	14.70	54.00	45.20	122.6
Female	35.83	17.13	6.57	15.00	6.10	32.00	36.40	89.8
Female	57.60	26.37	12.99	24.00	12.00	49.00	37.80	86.5
Female	46.44	24.32	5.00	22.00	4.90	40.00	38.50	88.9