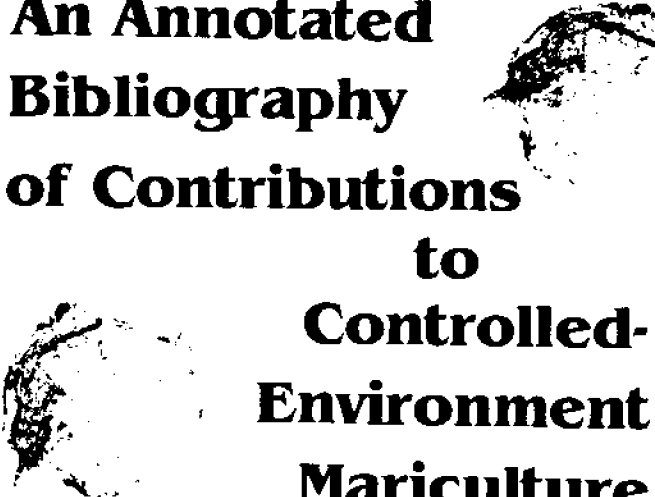


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**An Annotated
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An Annotated Bibliography of Contributions to Controlled-Environment Mariculture

A supplement to *Intensive Marine Bivalve Cultivation
in a Controlled Recirculating Seawater Prototype
System*. DEL-SG-07-82.

Compiled by
Diane M. Counts
Melbourne R. Carriker

DEL-SG-01-85

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University of Delaware
Sea Grant College Program
Newark, Delaware 19716

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A useful tool for those interested in learning more about controlled-environment mariculture, this annotated bibliography provides readers with contributions made to the discipline by the faculty, staff, and students of the University of Delaware.

Our bibliography includes works on bivalve physiology and nutrition, algal culture, water-quality maintenance, and related subjects. And in some areas, to benefit readers in comparative study, we have included works on organisms that typically are not raised in closed culture.

Much of the groundwork for this bibliography was done by Dr. Ellis Bolton, N. Dean Dey, and Marianne Ottolini. Mildred Weer gave constant cheerful assistance with library resources, and Rae Clark provided typing and proofreading skills. These contributions are gratefully acknowledged.

We appeal to the generosity of the reader in the event that any omissions or errors have occurred. It is our hope that the references abstracted here will direct the reader both to areas of interest already investigated and to those yet to be explored.

Diane M. Counts
Melbourne R. Carriker

Alatalo, P. 1980. Yeast utilization in oysters and clams. Master's thesis, University of Delaware, College of Marine Studies, Lewes, DE, 44 pp.

Juvenile oysters (Crassostrea virginica) and juvenile clams (Mercenaria mercenaria) were fed one of three diets consisting of either Isochrysis galbana, the torulan yeast Candida utilis, or a 50% dry-weight mixture of each. Increases in most growth parameters were higher for both oysters and clams fed algae or the mixture than for those fed yeast alone.

Ali, S. 1981. Effects of inorganic particles on growth of the oyster Crassostrea virginica (Gmelin). Master's thesis, University of Delaware, College of Marine Studies, Lewes, DE, 113 pp.

Seven concentrations of oxidized silt over three algal rations were fed to Crassostrea virginica. Algae used were Thalassiosira pseudonana and Isochrysis galbana in a 1:1 mixture. Fastest oyster growth was obtained when silt, up to 25 mg/l, was added to the highest algal ration.

Berg, D. 1981. The effects of variation on chemical composition of the diatom Thalassiosira pseudonana on growth and composition of the larvae of Crassostrea virginica. Master's thesis, University of Delaware, College of Marine Studies, Lewes, DE, 58 pp.

Examines the effects of algal food of differing dietary protein and energy levels on larval oysters, C. virginica. T. pseudonana was cultured under conditions yielding two populations: low-protein algae, averaging 22% protein, 25% lipid, and 47% carbohydrate; and high-protein algae, averaging 65% protein, 15% lipid, and 6% carbohydrate. These populations were fed in various proportions to oysters. Larval growth and metabolism varied with the ratio of dietary non-protein calories to protein calories.

Bockrath, J. and D. Wheeler. 1975. Closed-cycle mariculture in Maryland, Virginia, and Delaware: an examination of the adaptability of existing fishery laws to new technology. William and Mary Law Review 12(1):85-107, DEL-SG-02-76.

Examines current fisheries statutes in Maryland, Virginia, and Delaware in the context of possible development of a closed-cycle mariculture industry. Authors conclude that some statutory modification will be required to accommodate recent advances in mariculture technology.

Bockrath, J. and K. Marcel. 1981. Closed-cycle mariculture and the Food, Drug, and Cosmetic Act. Houston Law Review 18:43-102.

Discusses applicability of the Federal Food, Drug, and Cosmetic Act to closed-cycle mariculture of oysters and concludes that the wide administrative discretion accorded the Food and Drug Administration makes it likely that the FDA would be able to accommodate a properly functioning closed-cycle mariculture facility if it were so inclined.

Bolton, E. T. and N. D. Dey. 1979. Process for marking molluscs. United States Patent #4,133,294.

Describes a new method to mark permanently large numbers of molluscs. Molluscs are placed in a tank containing media, food, and tetracycline at 0.5-200 mg/l. Those bivalves treated daily for one to fourteen days or longer will be permanently marked. The mark is normally only faintly visible but fluoresces a vivid yellow-orange when exposed to ultraviolet light.

Boran, D. 1981. Effects of ambient zinc on the activity of the zinc metalloenzyme carbonic anhydrase in mantle tissue of Crassostrea virginica (Gmelin). Master's thesis, University of Delaware, College of Marine Studies, Lewes, DE, 43 pp.

Examines the role of zinc as a critical nutrient for carbonic anhydrase activity in the mantle of C. virginica. Carbonic anhydrase activity decreased in response to decreasing ambient concentrations of trace metals and zinc.

Bottom, D. L. 1975. A continuous flow-through apparatus for the measurement of primary production in algal macrophytes. Master's thesis, University of Delaware, College of Marine Studies, Lewes, DE, 130 pp.

A flow-through system for in situ measurement of primary production, monitored as changes in dissolved oxygen, was developed. Production of Ulva lactuca was examined under changing light levels over one- to twelve-hour incubations. Comparisons were made between production measurements with the flow-through system and those with a closed bell-jar system.

Bottom, D. L. 1981. A flow-through system for field measurements of production by marine macroalgae. Mar. Biol. 64:251-257.

Describes a continuous flow-through chamber for in situ measurement of primary production in macrophytic algae.

exemplified by Ulva lactuca. Rapid mixing occurred within the chamber, independent of flow rate or amount of algal tissue, thus closely approximating a "complete mix reactor" model. Field experiments with the apparatus revealed a rapid response to short-term variations in production rate as well as a close correlation between production and changing light levels. Compared to the traditional closed bell-jar apparatus, this method gave similar results when incubations were less than several hours. During longer periods, productivity in the closed system was sometimes depressed. The flow-through system permits reliable measurements of macroalgal production for periods of twelve hours or longer.

Carriker, M. R. and R. E. Palmer. 1979. Ultrastructural morphogenesis of prodissoconch and early dissoconch valves of the oyster Crassostrea virginica. Proc. Natl. Shellfish Assoc. 69:103-128.

The ultrastructure of C. virginica valves was examined with a scanning electron microscope. Normal developmental ultramorphology of prodissoconchs raised under favorable hatchery conditions was emphasized. Developmental anatomical features studied previously by light microscopy are reviewed, and structures visible only by scanning-electron microscopy are described for the first time. Terms for larval stages are defined. Results of mineralogical determinations are reported.

Carriker, M. R. and R. E. Palmer. 1979. A new mineralized layer in the hinge of the oyster. Science 206(11/9):691-693.

Reports, for apparently the first time, a discrete, calcareous layer that binds the foliated calcite of the shell of Crassostrea virginica to the organic ligament in the hinge. Named the ligostracum, this layer is ultrastructurally, and generally mineralogically, different from the underlying foliated calcite.

Carriker, M. R., R. E. Palmer and R. S. Prezant. 1980. Functional ultramorphology of the dissoconch valves of the oyster Crassostrea virginica. Proc. Natl. Shellfish Assoc. 70(2):139-183.

Presents an illustrated scanning-electron microscopic overview of the structure, grouping, and layering of microstructures of the dissoconch valves of C. virginica. Development and function of microstructures relative to configuration, growth, and function of valves of oysters grown either in a local estuary or in a controlled laboratory habitat are emphasized. New insights on shell structure are provided and profitable avenues for research on shell formation are suggested.

Carriker, M. R., R. E. Palmer, L. V. Sick and C. C. Johnson. 1980. Interaction of mineral elements in seawater and shell of oysters (*Crassostrea virginica*) cultured in controlled and natural systems. J. Exp. Mar. Biol. Ecol. 46(2/3):279-296.

Reports the interaction of selected elements (Cd, Ca, Cu, Fe, Mg, Mn, Sr, and Zn) with soft tissues, prismatic calcite of the right valve and foliated calcite of right and left valves of genetically similar *C. virginica* grown in a natural habitat and in two environmentally controlled experimental systems (flow-through and recycling). Trace elements added as algal nutrients in ambient seawater were reflected in higher concentrations of trace metals in shells and soft tissues of oysters grown in experimental systems. Some differences in distribution of these trace elements within animals were found among the three experimental groups. As concentrations of Mg, Sr, Mn, Zn, and Cd increased in valves in experimental systems, pigmentation of valves decreased. Besides confirming the capacity of oysters to concentrate several elements in their valves as concentration of these elements increased in ambient seawater, the study disclosed the heterogeneous distribution of these elements in major regions of the valves.

Carriker, M. R., C. P. Swann and J. W. Ewart. 1982. An exploratory study within the proton microprobe of the ontogenetic distribution of 16 elements in the shell of living oysters, *Crassostrea virginica*. Mar. Biol. 69(3):235-246.

Distribution of elements (Na to Sr) in the shell of juvenile oysters was studied in situ with a proton microprobe. The nondestructive proton microprobe beam analyzes the surface layer of the shell. Shells of living oysters were analyzed at monthly intervals for four months. Relative concentrations of 16 elements were measured in the newly deposited prismatic edge of the right valve of three oysters reared under controlled laboratory conditions; Na, Mg, Al, Si, S, Cl, K, Ca, Ti, Cr, Mn, Fe, Cu, Zn, Br, and Sr were detected in concentrations as low as a few parts per million relative to the concentration of standards added to pure CaCO_3 .

Fluctuations in concentration of Na, Mg, S, Cl, Ca, Mn, Fe, Cu, and Zn were generally similar in the two normally growing oysters, but these concentrations differed from those in the oyster that stopped growing. Trends in concentration of Al, Si, and Sr were similar in the three oysters; those of Br were variable. Relative concentrations of Na, Cl, S, Mn, Fe, and Zn increased slightly with age of oysters while concentrations of other elements stayed constant. Concentration of most elements was higher in shell than in seawater. Variable concentrations, especially of Na, Cl, and Si in valve edges, support the hypothesis that

separate mineral phases are present as impurities entrapped within the shell during calcification.

- Conway, W. P. 1979. Copper, cadmium, and manganese concentrations within the soft tissues of the marsh mussel, Geukensia demissa (Dillwyn). Master's thesis, University of Delaware, College of Marine Studies, Lewes, DE, 165 pp.

G. demissa from different tidal heights and substrata at three different marsh sites in lower Delaware were analyzed for body concentration and enrichment of Cu, Cd, and Mn. G. demissa was found to accumulate these metals to concentrations greater than ambient concentrations.

- Costello, F. A. and B. L. Marsh. 1972. Systems engineering of oyster production--Optimization of an oyster production system in the presence of uncertainty. University of Delaware, College of Marine Studies, Lewes, DE, DEL-SG-05-72.

A computer model of a closed-cycle system for rearing algae and oysters has been constructed; emphasis is on optimization in the presence of uncertainty. An automated systems-analysis ALGOL program to solve equations that describe the system is given. The output makes possible the selection of independent variables over which optimization may take place and the identification of significant stochastic variables.

- Cucci, T. L. 1978. Effects of the water-soluble fractions of Kuwait crude and No. 2 fuel oil on the larval and juvenile development of Eurypanopeus depressus (Brachyura: xanthidae). Master's thesis, University of Delaware, College of Marine Studies, Lewes, DE, 63 pp.

Compares the effects of water-soluble fractions (WSF) of a crude oil (Kuwait crude) and a refined oil (No. 2 fuel oil) on larval and juvenile development of the estuarine crab, E. depressus. Increases in both WSFs resulted in marked decreases in larval survival and molting frequency.

- Cucci, T. L. and C. E. Epifanio. 1979. Long-term effects of water-soluble fractions of Kuwait crude oil on the larval and juvenile development of the mud crab Eurypanopeus depressus. Mar. Biol. 55(3):215-220.

Larvae of E. depressus were reared in various concentrations of the water-soluble fraction of Kuwait crude oil. The forty-eight-hour TL_m (median tolerance limit) for Zoea Stage I was approximately 10 ppm total dissolved hydrocarbons while that for Zoea Stage II was approximately 17 ppm. Chronic toxicity of more dilute solutions (4.3 and 8.7 ppm) was independently assessed for each larval stage and for subsequent developmental stages through Crab Stage

5. In animals continuously exposed to oil from hatching, there was differential mortality relative to controls in every larval stage and increased duration of intermolt periods at every stage through Crab Stage 5. Mortality in groups not exposed until Zoea Stages III or IV was not greater than controls. Neither concentration (4.3 nor 8.7 ppm) of crude oil caused increased mortality during juvenile crab stages. Increased occurrence of an extra and morphologically abnormal megalopa stage associated with exposure to the crude oil was reported for the first time.

Cunningham, P. A. and M. R. Tripp. 1973. Accumulation and depuration of mercury in the American oyster Crassostrea virginica. Mar. Biol. 20(1):14-19.

So that the kinetics of Hg uptake could be studied, adult C. virginica were held for sixty days in seawater containing 10 µg Hg/l (ppb) or 100 µg/l (ppb) as mercuric acetate. Mercury concentrations in tissues were determined by analysis of individually homogenized oyster meats, using wet digestion and flameless atomic absorption spectrophotometry. After forty-five days, average Hg tissue concentration was 140,000 µg Hg/kg (ppb) and 28,000 µg Hg/kg tissue (ppb) in the 100 ppb and 10 ppb experimental groups, respectively. After this time, concentrations dropped sharply, probably due to spawning. Clearance of Hg from tissue was studied by exposing treated adults to estuarine water. Total purification was not achieved over a six-month cleansing period.

Cunningham, P. A. 1976. Inhibition of shell growth in the presence of mercury and subsequent recovery of juvenile oysters. Proc. Natl. Shellfish Assoc. 66:1-5.

Juvenile C. virginica were given static exposure to mercuric acetate at 100 ppb mercury or 10 ppb mercury for twelve hours daily over forty-seven days. Inhibition of shell growth served as an indicator of physiological stress. After forty-seven days, compared to controls, shell growth (measured as increase in height) was reduced by 77% for the 100 ppb group and 33% for the 10 ppb group. Oysters held in seawater for a 162-day depuration period demonstrated shell growth rates comparable to controls within thirty-four days (100 ppb) and twenty days (10 ppb).

Davis, S. R. 1978. Chemotactic responses of the seastar Asterias forbesi to effluents from prey bivalves. Master's thesis, University of Delaware, College of Marine Studies, Lewes, DE, 122 pp.

Chemotactic responses of A. forbesi to effluents from intact bivalves, injured bivalves, and seastars feeding on bivalves

were examined in a Y-tank olfactometer. A. forbesi was attracted to seastars feeding on mussels (Mytilis edulis) or oysters Crassostrea virginica, but chose the control arm rather than the arm with effluent from intact mussels. Effluent from injured mussels caused seastars to reverse their normally positive rheotaxis. There was no evidence that ingestive conditioning occurs in A. forbesi.

Dey, N. D. and E. T. Bolton. 1978. Tetracycline as a bivalve shell marker. Proc. Natl. Shellfish Assoc. 68:77 (abstract).

Crassostrea virginica, Mercenaria mercenaria, and Mytilis edulis were exposed to the antibiotic tetracycline in filtered seawater to which algal food was added for periods of one week to several months. Tetracycline was incorporated into newly deposited shell. This inlaid tetracycline fluoresces a vivid yellow-orange under ultraviolet light. Marking was vivid at exposures of 25-200 mg/l tetracycline. No deaths or obvious morphological defects were noted. The mark remained undiminished in vivo for at least seven months.

Dey, N. D. 1979. Growth of sibling hard clams, Mercenaria mercenaria, in a controlled environment. Master's thesis, University of Delaware, College of Marine Studies, Lewes, DE, 66 pp.

A sibling population of M. mercenaria was raised in a controlled environment with excess food. Wide variation was observed in shell length and volume. Large clams continued to grow at a faster rate than smaller clams at 18°C and 25°C. Early-setting clams grew more rapidly than late-setting clams. The size distribution pattern established at setting was maintained in hatchery-reared clams for at least a year.

Di Michele, L. 1977. Toxicity of naphthalene in Fundulus heteroclitus L. Master's thesis, University of Delaware, College of Marine Studies, Lewes, DE, 95 pp.

Examines toxicity of naphthalene in F. heteroclitus at various concentrations and exposure times. Pathology was observed at all concentrations by histological examination. Serum glucose, protein, and cortisol were measured as stress indicators. Naphthalene distribution within the animals was traced with ¹⁴C-naphthalene. Animals accumulated naphthalene at two times the ambient level.

Dobroski, C. 1978. Controlled food-chain transfer of 3,4,benzo(a) pyrene, a known carcinogen. Master's thesis, University of Delaware, College of Marine Studies, Lewes, DE, 66 pp.

The polycyclic aromatic hydrocarbon 3,4,benzo (a) pyrene [B(a)P] was assessed for transfer and accumulation in a

simple food chain. The diatom Thalassiosira pseudonana was exposed to ^{14}C -B(a)P in seawater for twenty-four hours, accumulating B(a)P to a level nearly 400 times the ambient level. Larvae of the clam Mercenaria mercenaria that were fed the contaminated algae accumulated B(a)P to a level 200 times the ambient.

Dobroski, C. and C. E. Epifanio. 1980. Accumulation of benzo(a) pyrene in a larval bivalve via trophic transfer. Can. J. Fish Aquat. Sci. 37(12):2318-2322.

The diatom Thalassiosira pseudonana was cultured in 10 $\mu\text{g}/\text{l}$ ^{14}C -benzo(a) pyrene [B(a)P] and fed to larvae of the hard clam Mercenaria mercenaria. Rate of direct uptake of B(a)P from saltwater by diatoms was much greater than rate of trophic transfer of B(a)P from diatoms to clam larvae. This was attributed to greater efficiency of direct uptake and to larger quantity of B(a)P available in the water. Comparison of direct uptake by bivalves (from the literature) with trophic transfer indicated that the processes may be equally important in accumulation of B(a)P in natural populations of bivalves.

Dwivedy, R. C. 1972. Controlled-environmental system for culturing oysters. In Annual Progress Report of Sea Grant Program, September 1, 1970 to August 31, 1971. University of Delaware, College of Marine Studies, Lewes, DE, DEL-SG-01-72, pp. 17-22.

A brief and qualitative description of a closed system for culturing oysters.

Dwivedy, R. C. 1972. A study of chemo-receptors on labial palps of the American oyster using microelectrodes. Proc. Natl. Shellfish Assoc. 63:20-26.

Tungsten microelectrodes, insulated except for their tips, were used to pick up receptor potentials from chemical receptor cells on labial palps of Crassostrea virginica. The receptor cell responded with decreasing sensitivity to four major taste substances: HCl, quinine sulfate, sucrose, and NaCl. An equation was derived defining the relationship between taste receptor potential and strength of chemical stimulant.

Dwivedy, R. C. 1973. Techniques and instrumentation to control some environmental factors for shellfish nutritional studies. Delaware Agric. Exp. Sta. Bulletin No. 403, 27 pp.; University of Delaware, College of Marine Studies, Lewes, DE, DEL-SG-11-73.

Describes techniques and instrumentation to control environmental factors such as feed density, flow rate, flow volume, and

light for oysters feeding in a recirculating system. Range of feed-density control was $\pm 5\%$ of present value using the algae Nitzschia closterium and $\pm 2.7\%$ using cornstarch. The system is recommended for use in radioactive tracer studies.

Dwivedy, R. C. 1973. Instrumentation and technique of electrophysiological studies of chemoreceptors on labial palps of the American oyster. Trans. Am. Soc. Agric. Eng. 16(2):367-373, DEL-SG-16-73.

Electrical responses to chemical stimuli of labial palps of adult C. virginica were monitored using tungsten microelectrodes. Electrical response, latent period, shell movement, and rate of pumping by the oyster were simultaneously measured. Individual oyster taste cells responded, in order of decreasing sensitivity, to HCl, quinine, sucrose, and NaCl.

Dwivedy, R. C. 1974. A proposed method of waste management in closed-cycle mariculture systems through foam-fractionation and chlorination. Proc. Natl. Shellfish Assoc. 64:111-117, DEL-SG-08-75.

Presents a scheme for waste management independent of bacterial filters in closed-cycle oyster culture systems. Foam-fractionation for organic removal and for prevention of NH_3 build-up is recommended. Breakpoint chlorination is recommended for removal of remaining low levels of NH_3 . Dechlorination was achieved through carbon filtration. An algal production system could be added to the system if molluscs are to be cultured. Non-bacterial filters remove contaminants rapidly and completely and are not limited by such disadvantages associated with bacterial filters as excessive space requirements and build-up of high concentrations of NO_3 .

Epifanio, C. E. 1971. Effects of dieldrin in seawater on the development of two species of crab larvae, Leptodius floridanus and Panopeus herbstii. Mar. Biol. 11(4):356-362.

Documents the effects of dieldrin on the development of L. floridanus and P. herbstii. Larvae of neither species were able to complete development at 10 ppb dieldrin or higher in seawater. L. floridanus larvae reared in 1 ppb dieldrin had a 15% to 27% higher mortality during development to the postlarval stage than did controls. Highest mortality occurred during the first zoeal stage. Time of development to the megalopa stage was longer among larvae reared in 1 ppb than among controls. Survival of P. herbstii larvae to the first crab stage was not affected by 1 ppb dieldrin in seawater.

- Epifanio, C. E. 1972. Effects of dieldrin-contaminated food on the development of Leptodius floridanus larvae. Mar. Biol. 13(4):292-297.

Larvae of L. floridanus were fed dieldrin-contaminated Artemia nauplii through development to megalopa. Sublethal effects were noted at dieldrin concentrations as low as 5.49 ppm, and no larvae completed development when fed Artemia containing 33 ppm dieldrin. Organochloride pesticide residues measured in zooplankton collected from Onslow Bay, North Carolina, were much lower than those affecting Leptodius larvae in the laboratory.

- Epifanio, C. E. 1973. Dieldrin uptake by larvae of the crab Leptodius floridanus. Mar. Biol. 19(4):320-322.

The rate of uptake of ^{14}C -dieldrin from 0.5 ppb in seawater and from 213 ppb dry weight by L. floridanus larvae was measured. If equal concentrations of dieldrin were available to larvae in food and seawater, they accumulated the pesticide about 8000 times as fast from the water as from the food.

- Epifanio, C. E., G. D. Pruder, M. Hartman and R. F. Srna. 1973. An interdisciplinary study on the feasibility of recirculating systems in mariculture. In Proceedings of the Fourth Annual Workshop World Mariculture Society, ed. by James A. Avault, Jr. Louisiana State University, Baton Rouge, LA, pp. 37-52, DEL-SG-13-74.

Describes a circulating seawater system designed for culture of filter-feeding molluscs on a pilot-plant scale. The system includes a biological filter, a carbon filter, a UV treatment station, and a new apparatus to separate algae from their culture media for subsequent feeding to molluscs. Levels of ammonia, nitrate, nitrite, reactive phosphorous and other chemical parameters were monitored over a two-month period. Trends in the system are reported.

- Epifanio, C. E. 1974. Concepts in aquaculture: intensive vs. extensive systems. In Proceedings of the Sixth National Sea Grant Conference. University of Delaware, College of Marine Studies, Newark, DE, DEL-SG-16-74, pp. 62-72.

A brief discussion of advantages and disadvantages of intensive versus extensive mariculture systems.

- Epifanio, C. E. and R. F. Srna. 1975. Toxicity of ammonia, nitrate ion, and orthophosphate to Mercenaria mercenaria and Crassostrea virginica. Mar. Biol. 33(3):241-246, DEL-SG-05-76.

The ninety-six-hour lethal tolerance limits of M. mercenaria and C. virginica to ammonia, nitrite ion, nitrate ion, and orthophosphate were defined, and sublethal effects of the chemicals on rates at which shellfish removed algal (Isochrysis galbana) cells from suspension were studied. In comparison with other aquatic species that have been studied, hard clams and oysters are extremely tolerant.

Epifanio, C. E., R. F. Srna and G. Pruder. 1975. Mariculture of shellfish in controlled environments: a prognosis. Aquaculture 5:227-241, DEL-SG-16-75.

The literature is reviewed in an attempt to define biological specifications for the design of highly controlled culture systems for oysters and hard clams. Requirements of these bivalves for food and oxygen; their production of CO₂, nitrogenous excreta, and solid wastes; and their tolerance to changes in water quality are discussed. Information necessary for design is either unavailable or available only by inference. Notably absent are equations describing relationships between size of animals and their various physiological processes. Equations that estimate some of these relationships are presented, and safe levels of several water-quality variables are defined.

Epifanio, C. E. and C. A. Mootz. 1976. Growth of oysters in a recirculating maricultural system. Proc. Natl. Shellfish Assoc. 65:32-37, DEL-SG-02-77.

Eight groups of Crassostrea virginica were cultured for nearly one year after setting in a recirculating maricultural system. Each group of approximately 200 animals was fed a different diet, but all diets consisted exclusively of algae from monospecific, not axenic, cultures. This is the first report of oysters grown for an extended period of time on defined diets. Extrapolated growth rates indicate that fastest-growing oysters will reach marketable size approximately two years after setting, which is sooner than the three-to-four years reported for wild oysters in Delaware Bay.

Epifanio, C. E. 1976. Culture of bivalve molluscs in recirculatory systems: nutritional requirements. In Proceedings of the First International Conference of Aquaculture Nutrition, October, 1975, ed. by K. S. Price, W. N. Shaw and K. S. Danberg. University of Delaware, College of Marine Studies, Newark, DE, pp. 173-194.

Reviews nutritional requirements of several species of bivalves, with emphasis on Crassostrea virginica and Mercenaria mercenaria.

Epifanio, C. E. 1976. Shell deformity among scallops, Argopecten irradians Lamark, cultured in a recirculating-seawater system. Aquaculture 9(1):81-85, DEL-SG-27-76.

A. irradians were held in a recirculating seawater system for twenty-five weeks and fed a diet of four species of cultured algae: Thalassiosira pseudonana, Carteria chuii, Isochrysis galbana, and Chroomonas salina. The rate of growth of shellfish was less than reported for scallops from natural areas, and a gross shell deformity was noted among most of the scallops after eighteen weeks of culture. The deformity may have been related to an inadequate diet.

Epifanio, C. E., C. M. Logan and C. Turk. 1976. Culture of six species of bivalves in a recirculating seawater system. In Proceedings of the Tenth European Symposium on Marine Biology, Ostend, Belgium, ed. by G. Persoone, DEL-SG-01-76, pp. 97-108.

Six species of bivalve molluscs were reared for periods ranging from ten weeks to over two years in a recirculating seawater system. Bivalves were exclusively fed defined algal diets. The diatom Phaeodactylum tricornutum was a poor food for all species tested, while Thalassiosira pseudonana proved to be a good food. T. pseudonana yielded growth comparable to that of a four-part diet of Carteria chuii, Chroomonas salina, Isochrysis galbana, and T. pseudonana when fed to Crassostrea virginica, Crassostrea gigas, and Tapes semidecussata; while the four-part diet was superior with Ostrea edulis and Mytilus edulis. Mercenaria mercenaria fed the four-part diet grew to marketable size in one year as compared to three-to-five years for the species in nature.

Epifanio, C. E. and J. Ewart. 1977. Maximum ration of four algal diets for the oyster Crassostrea virginica (Gmelin). Aquaculture 11(1):13-30, DEL-SG-02-77.

Documents the rate of removal of four species of algae (Carteria chuii, Chroomonas salina, Isochrysis galbana, and Thalassiosira pseudonana) from suspension by C. virginica. The number of cells removed per hour depended on size of algal cells, but total dry weight of algal material removed over twenty-four hours was independent of size. Filtration rate was dependent on density of algal suspension, and large quantities of pseudofeces were produced by oysters filtering algae from suspensions denser than 10 µg/ml. Oysters showed periods of high filtering activity and periods of relative quiescence during experimental trials of twenty-four hours. Based on the periodic filtering activity of the oysters, a discontinuous feeding regime is proposed and an equation predicting maximum daily ration of oysters of various sizes is provided.

Epifanio, C. E. 1979. A marine analogue to the husbandry of poultry on land. Trans. Del. Acad. Sci. 4:133-144.

Contains a description of the University of Delaware's shellfish culturing process. Extrapolated growth rates of Mercenaria mercenaria and Crassostrea virginica cultured in a recirculating seawater system indicate that both species can reach marketable size in the system much faster than in nature. A model system is presented, incorporating algal culture, use of treated domestic sewage, and culture of shellfish from eggs to market size.

Epifanio, C. E. 1979. Comparison of yeast and algal diets for bivalve molluscs. Aquaculture 16(3):187-192, DEL-SG-04-79.

Four species of bivalve molluscs were fed diets of varying proportions of the yeast Candida utilis and the diatom Thalassiosira pseudonana. Juvenile Argopecten irradians, Mercenaria mercenaria, and Mytilus edulis grew as fast or faster than controls when fed diets containing as much as 50% yeast. Growth of soft tissue in Crassostrea virginica decreased with the amount of yeast in the diet. Relative food values of different diets were not closely correlated with gross chemical or amino acid composition.

Epifanio, C. E. 1979. Growth in bivalve mollusks: nutritional effects of 2 or more species of algae in diets fed to the American oyster, Crassostrea virginica, and the hard clam, Mercenaria mercenaria. Aquaculture 18(1):1-12, DEL-SG-06-79.

Groups of oysters and hard clams were fed one of fifteen diets composed of various mixtures of four species of algae (Carteria chuii, Isochrysis galbana, Platymonas suecica, Thalassiosira pseudonana) for six weeks. Growth of hard and soft tissues was not correlated with gross chemical (protein, lipid, or ash) or amino acid composition of the diets, but instead was related to the presence or absence of particular algal species. Growth was generally least in diets containing large amounts of I. galbana or T. pseudonana. Diets containing both invariably supported greater growth than diets consisting solely of either species, indicating synergism in the relative food values of the species. P. suecica alone was a relatively poor food, but its food value increased markedly when given with I. galbana or T. pseudonana singly or together. Two contrasting hypotheses explaining this interaction are presented.

Epifanio, C. E., C. C. Valenti and C. L. Turk. 1981. Comparison of Phaeodactylum tricornutum and Thalassiosira pseudonana as foods for the oyster Crassostrea virginica. Aquaculture 23(1-4):347-354, DEL-SG-10-81.

Juvenile *C. virginica* were fed diets of varying proportions of the diatom *P. tricornutum* and *T. pseudonana*. Growth of the oysters over five weeks was inversely proportional to the amount of *P. tricornutum* in their diet. Analysis of diatoms showed similar amounts of protein and lipid in the two species; *P. tricornutum* was higher in carbohydrate and *T. pseudonana* higher in ash. *P. tricornutum* lacked the essential amino acid tryptophan, but this deficiency has been reported for other diatom species that are good foods for bivalves.

Epifanio, C. E. 1982. Phytoplankton and yeast as foods for juvenile bivalves: a review of research at the University of Delaware. In Proceedings of the Second International Conference on Aquaculture Nutrition: Biochemical and Physiological Approaches to Shellfish Nutrition, ed. by G. D. Pruder, C. J. Langdon, and D. E. Conklin. Louisiana State University, Baton Rouge, LA, pp. 292-304.

Discusses quantitative and qualitative aspects of an adequate ration for bivalves. Experiments indicate efficiency of utilization of a given ration is a function of temperature; large rations can be utilized only at high temperature. Qualitative differences in diets are best explained by differential digestibility of food particles. There is little correlation between chemical composition (gross proximate, amino acid, fatty acid) of a diet and its value as a food for bivalves. Synergistic nutritional effects of some dietary components may be due to improved balance of micronutrients or fatty acids.

Ewart, J. W. and C. E. Epifanio. 1981. A tropical flagellate food for larval and juvenile oysters, *Crassostrea virginica*. Aquaculture 22(3):297-300.

Relative values of *Isochrysis galbana* and a high-temperature-tolerant tropical flagellate clone, *Isochrysis aff. galbana* (T-ISO), as foods for larval and juvenile oysters were compared. Two diets were utilized combining equal portions of either *I. galbana* or T-ISO and the centric diatom *Thalassiosira pseudonana*. No significant differences in growth of larval and juvenile oysters fed either diet were observed.

Ewart, J. W. and G. D. Pruder. 1981. Comparative growth of *Isochrysis galbana*, Parke and *Isochrysis aff. galbana* (clone T-ISO) at four temperatures and three light intensities. J. World Mariculture Soc. 12(1):333-339.

Growth of a temperate and a tropical strain of *Isochrysis* was studied at four temperatures and three light intensities. All algae were grown in an enriched artificial seawater medium under constant illumination and were bubbled with

air enriched with 0.1% CO₂. Culture density (cells/ml) was measured periodically during exponential growth. Average growth rates for each combination of temperature and light intensity are presented as doublings/day. Growth under various culture conditions indicates that T-ISO (tropical strain) grows rapidly over a much broader range of temperatures than does I. galbana. Variations in growth at different light intensities suggest that the optimum light level increases as a function of temperature for T-ISO and that the growth of I. galbana is inhibited by high levels of light (1500 $\mu\text{W}/\text{cm}^2$). Relative value of both strains as food for larval and juvenile oysters, and advantages and limitations of large-scale culture are discussed.

- Finney, C. M. 1978. Isotopic labelling of taurine: implications for its synthesis in selected tissues of Homarus americanus. Master's thesis, University of Delaware, College of Marine Studies, Lewes, DE, 70 pp.

Abdominal muscle and ventral-nerve-chord tissue of lobster were incubated with radioactive precursor molecules. Carbohydrates and free amino acids were extracted and monitored for radioactivity in an attempt to trace the metabolic pathways leading to taurine synthesis.

- Flaak, A. R. 1976. The effect of light of different wavelengths on the growth and protein content of the marine diatom Thalassiosira pseudonana, and its nutritional value to the American oyster Crassostrea virginica (Gmelin). Master's thesis, University of Delaware, College of Marine Studies, Lewes, DE, 77 pp.

The effect of light of different wavelengths on the growth, protein content, and carbon-to-nitrogen ratio of Thalassiosira pseudonana was examined. Growth was highest under cool white light and lowest under Agro-lite. Blue light enhanced protein production while cool white light increased the carbon-to-nitrogen ratio, indicating an increase in carbohydrate production. Algae in exponential and stationary phases grown under each light regimen were fed to juvenile oysters for ten weeks. Oysters fed algae in the stationary phase grown under cool white light showed greatest increase in dry weight, shell height, and glycogen content.

- Flaak, A. R. and C. E. Epifanio. 1978. Dietary protein levels and growth of the oyster Crassostrea virginica. Mar. Biol. 45(2):157-164, DEL-SG-02-78.

The diatom Thalassiosira pseudonana in exponential or stationary phase and grown under one of three light regimes was fed to six groups of juvenile oysters for a ten-week period. Oysters fed diets from the stationary phase grew more rapidly

and had a higher glycogen content than those fed diets from the exponential phase. The stationary phase, cool white-light algal diet produced the greatest increase in dry weight, shell height, and glycogen content of the six diets examined. Oysters grew more rapidly when fed diets richer in carbohydrates than proteins.

- Frake, A. 1980. The effect of light on Coscinodiscus sp. Master's thesis, University of Delaware, College of Marine Studies, Lewes, DE, 50 pp.

Compares growth of a centric diatom under various intensities of white, red and blue light. Blue light produced more protein per cell, more ¹⁴C incorporated into protein, and higher productivity, growth rate, and concentrations of photosynthetic pigments than other light regimes. Light intensity affected growth, photosynthetic rate, and chlorophyll concentration.

- Gaither, W. S. 1982. Progress and problems with controlled environment aquaculture. In Proceedings, Seminars in Biotechnology and Genetic Engineering, MIT, March 18-20, 1982, and Progress Report: 1970-1982: Research in Recirculating Aquaculture systems for Growing Commercially Valuable Bivalves. University of Delaware, Newark, DE, 1982, DEL-SG-06-82.

A brief history of aquaculture research at the University of Delaware. Author presents summaries of research on economic feasibility of large-scale industrial culture, bivalve nutrition, and design of algal and bivalve culture systems. Specific areas for future research are outlined.

- Gibbons, M. 1978. Factors stimulating settlement in larvae of the surf clam, Spissula solidissima (Dillwyn). Master's thesis, University of Delaware, College of Marine Studies, Lewes, DE, 80 pp.

An attempt was made to detect an organic compound exuded by adult surf clams that affects settling of surf clam larvae. Larvae were found to settle preferentially on sediment treated with an extract of adult clams over control sediment. However, no preference was demonstrated for natural clam bed sediment, or for seawater in which such sediment had been soaked, over controls that were incinerated to destroy organic compounds. Larvae preferred seawater pumped from adult clams to clean seawater in a Y-maze, but showed no such preference for clam extract over seawater.

Gordon, J. 1978. Ultrastructure and histochemistry of the shell of Mercenaria mercenaria Linne and their relationship to the chemistry of the extrapallial fluid. Doctoral dissertation, University of Delaware, College of Marine Studies, Lewes, DE, 106 pp.

Sections of shells of M. mercenaria were examined with a scanning-electron microscope, revealing a composite prismatic hierarchy in the outer shell region. Growth lines parallel to the growing shell margin consisted of layers of organic matrix between mineralized layers. The organic shell matrix close to the growing margin was analyzed histochemically; levels of tyrosine and lysine found here were higher than elsewhere in the shell. A phenoloxidase exclusive to this area of the matrix was found. It was concluded that growth lines are caused by a slow polymerization of matrix conchiolin. Electrode potential in the extrapallial cavity of the clam was rhythmic, rising as the shell opened for feeding and falling as the shell closed. Shell movements demonstrated rhythms with well-defined periods, different in all individuals and not correlated with exogenous influences.

Gordon, J. and M. R. Carriker. 1978. Growth lines in a bivalve mollusk: Subdaily patterns and dissolution of the shell. Science 202(4367): 519-521.

Scanning-electron micrographs of sections of the prismatic shell of Mercenaria mercenaria revealed narrow subdaily growth striations. The width of these narrow lines, formed by concentrations of organic material, corresponded to the quantity of shell material expected to dissolve during periods of anaerobic metabolism. The pH of the extrapallial fluid of the bivalve decreased when valves were closed, and the amount of dissolution of shell was related to the duration of valve closure.

Gordon, J. and M. R. Carriker. 1980. Sclerotized protein in the shell matrix of a bivalve mollusk. Mar. Biol. 57(4):251-260.

Epsilon-amino groups of lysine and phenolic groups of tyrosine are most heavily concentrated in the newly deposited organic matrix of the shell of Mercenaria mercenaria. A phenoloxidase that oxidizes L-dihydroxyphenylalanine is present only in this new area of the shell matrix. Scanning-electron micrographs of calcified secretions of the shell showed that accretion lines, thought to be layers of organic matrix separating diurnal accretions of calcium carbonate, are not developed until up to four days after deposition of shell material. The shell matrix probably is hardened by some kind of polymerization, and lysine and tyrosine residues in the matrix may be involved in the process.

Accretion lines in polished and etched sections became visible only after complete hardening of the polymer occurred.

- Gordon, J., C. Tomaszewski and M. R. Carriker. 1980. Role of the organic matrix in calcification of the molluscan shell. Proc. Natl. Shellfish Assoc. 70(1):126.

Calcium binding and initiation of calcium carbonate growth by soluble and insoluble organic matrix were investigated using shells of several molluscan species. Insoluble matrix was unable to catalyze crystal growth from a solution saturated with either calcite or aragonite at pH close to that in vivo. There was no evidence of calcium uptake by insoluble matrix. Isolated and purified soluble shell matrix that was observed binding calcium was treated by modifying or blocking specific amino acid residues to test if individual chemical groups were attractive sites for calcium in shell formation. An early conclusion was that dicarboxylic acids are not responsible for the calcium binding properties of the shell matrix.

- Gorham, W. 1978. Effect of algal exometabolites on the filtration rates of Crassostrea virginica (Gmelin). Master's thesis, University of Delaware, College of Marine Studies, Lewes, DE, 48 pp.

Documents the effect of external metabolites of three species of algae on the filtration rate of the oyster. Isochrysis galbana, Phaeodactylum tricornutum, and Thalassiosira pseudonana were grown at 20°C or 25°C and harvested whether in logarithmic or stationary phase. Levels of bacteria and dissolved organic carbon in the cultures were monitored. Filtrates from the cultures, along with yeast suspensions, were presented at two concentrations to oysters. Filtrates from T. pseudonana (20°C-stationary phase, low concentration) enhanced oyster filtration rate; other filtrates reduced it.

- Harasewych, M. G. 1978. Biochemical studies of the hatching process in Busycon. 1978. Master's thesis, University of Delaware, College of Marine Studies, Lewes, DE, 52 pp.

Examines the biochemistry of the egg-capsule hatching enzymes of the gastropods Busycon carica and Busycon canaliculatum. Amino acid analysis showed higher levels of tyrosine, cystine, proline, and histidine in the exit plug (substrate) than in the capsule wall (inert to enzyme). Protein and carbohydrate levels in the intracapsular fluid remained high and protease levels low, until most young reached the post-velar stage, when protein and carbohydrate levels dropped and protease levels increased. Protease demonstrated chymotrypsin activity but no trypsin activity. The hatching enzyme was species specific.

Hartman, M., C. E. Epifanio, G. D. Pruder and R. F. Srna. 1973. Farming the artificial sea: growth of clams in a recirculating seawater system. In Proceedings of the Gulf and Caribbean Fisheries Institute 26th Annual Session, October 1973, DEL-SG-02-75, pp. 59-74.

Eight groups of hatchery-reared Mercenaria mercenaria were cultured in a recirculating-seawater system for twenty-two weeks from setting. Each group was fed a different diet of algae: Phaeodactylum tricornutum, Platymonas sp., Rhodomonas sp., and Isochrysis galbana. Diets of P. tricornutum, Platymonas, and Rhodomonas in a 1:1:1 cell-count ratio and P. tricornutum, Platymonas, and I. galbana in a 1:1:1 ratio yielded the fastest growth rate, faster than that of animals grown under natural conditions.

Hicks, D. T. 1981. Sensory evaluation and selected chemical attributes of cultured and wild oysters, Crassostrea virginica (Gmelin). Master's thesis, University of Delaware, College of Human Resources, Newark, DE, 167 pp.

In April 1979 and July 1980, cultured oysters harvested from the controlled-environment system of the Delaware Mariculture Project were chemically and organoleptically compared to their wild counterpart. Chemical analyses revealed significant differences in nutrient composition among all the oysters. Organoleptic evaluations indicated greenhouse oysters were as good as, or better than, the Broadkill oysters in overall acceptance, aroma, and taste. But texture of the cultivated animals was less desirable than that of the wild animals.

Higgins, P. J., III. 1980. Effects of food availability on the valve movements and feeding behavior of Crassostrea virginica (Gmelin). Master's thesis, University of Delaware, College of Marine Studies, Lewes, DE, 89 pp.

Investigates the effects of availability of algal food, Isochrysis galbana, on valve activity of the oyster. Valve opening varied with food availability. Time-series analysis of valve movements showed that oysters on twenty-four-hour feeding schedules (fed twelve hours, unfed twelve hours, or fed once daily) exhibited a twenty-four-hour periodicity of activity. Continuously fed or unfed oysters showed no rhythmicity. Rate of algal clearance was similar under all schemes.

Jacob, W. F. 1980. A time course study of seawater acclimation in Fundulus heteroclitus L. Master's thesis, University of Delaware, College of Marine Studies, Lewes, DE, 72 pp.

Examines the rate and pattern of acclimation of F. heteroclitus in time-course studies. Serum Na^+ , cortisol, and osmolality, as well as gill $\text{Na}^+ - \text{K}^+ - \text{ATPase}$ activity were measured after transferring freshwater-acclimated fish to seawater. All tested parameters returned to normal levels within four days.

- Keck, R., D. Maurer, J. C. Kauer, and W. A. Sheppard. 1971. Chemical stimulants affecting larval settlement in the American oyster. Proc. Natl. Shellfish Assoc. 61:24-28, DEL-SG-04-71.

Laboratory experiments confirmed that the presence of spat on shells stimulated spatfall of Crassostrea virginica, thus prompting a search for the mechanism of stimulation. Shell liquor, feces, and pseudofeces of the oyster were assayed for presence of natural set stimulants. Highest activity was found in shell liquor that was subjected to separation techniques, including lyophilization and ether extraction, to concentrate the set stimulant. The lyophilized residue and an ether extract of oyster liquor, as well as a commercial sample of "shellfish-glycogen," had high set-stimulant activity.

- Keck, R., D. Maurer and R. Malouf. 1973. Factors influencing the setting behavior of larval hard clams, Mercenaria mercenaria. Proc. Natl. Shellfish Assoc. 64:59-67.

Laboratory experiments with larvae of the hard clam showed that chemical factors (pheromones) and physical factors influenced setting. Clams preferred to set in sand rather than mud and in sediment treated with clam liquor rather than untreated substrate. Chemical factors masked physical selection of sediment by larvae. Clam liquor was a strong setting stimulus, indicating a gregarious setting behavior similar to that of oyster larvae.

- Langdon, C. J. 1982. New techniques and their application to studies of bivalve nutrition. In Proceedings of the Second International Conference on Aquaculture Nutrition: Biochemical and Physiological Approaches to Shellfish Nutrition, ed. by G. D. Pruder, C. J. Langdon and D. E. Conklin. Louisiana State University, Baton Rouge, LA, pp. 305-320.

Describes a new technique to obtain axenic larvae of Crassostrea for nutrition studies without the use of antibiotics and discusses results of preliminary feeding experiments with axenic larvae. Also presents a microencapsulation technique that can affect the encapsulation of proteins, carbohydrates, lipids, and water-soluble vitamins and discusses results of experiments with oysters fed on encapsulated and non-encapsulated nutrients.

Langefoss, C. M. 1973. Energy budget of the American oyster Crassostrea virginica (Gmelin). Master's thesis, University of Delaware, College of Marine Studies, Lewes, DE, 67 pp.

Presents a method to determine an energy budget for C. virginica fed the algae Phaeodactylum tricornutum. An energy budget was calculated using measurements of the amount of algae cleared by the oysters, the caloric and ash content of algae cleared, and feces and pseudofeces produced. Quantity of calories assimilated appeared independent of food concentration. Oysters assimilated, on the average, approximately 30 cal/g dry weight tissue/h. Caloric content, settling rate, and growth characteristics of the algae Nityschia closterium were also studied. The caloric content and percentage ash were found to vary with age of culture.

Langefoss, C. M. and D. Maurer. 1975. Energy partitioning in the American oyster, Crassostrea virginica (Gmelin). Proc. Natl. Shellfish Assoc. 65:20-25.

Research was conducted to develop an energy budget for C. virginica in culture. Caloric values of pseudofeces, feces, food ingested, food cleared, and food assimilated were determined at three levels of algal (Phaeodactylum tricornutum) concentration, 1.0×10^5 cells/ml, 5.0×10^4 cells/ml, and 2.5×10^4 cells/ml at 20°C and 25°C. Approximately 74-148 cal/12 hours were used by oysters. Oysters at the lowest food concentration showed the greatest amount of filtration while oysters at the medium food concentration cleared the most food. The greatest amounts of feces and pseudofeces were produced at the medium food concentration. The amount of energy assimilated at high and medium concentrations differed little.

Levitan, W. M. 1978. The influence of salinity on the physiological and toxicological action of naphthalene in Fundulus heteroclitus. Master's thesis, University of Delaware, College of Marine Studies, Lewes, DE, 74 pp.

Naphthalene toxicity in mummichogs was salinity dependent. Physiological bases for mortality were studied using measurements of naphthalene uptake, osmotic components, and metabolic stress.

Lind, H. F. 1975. The effect of temperature on gametogenic development in two marine bivalve species, Mya arenaria and Modiolus demissus. Master's thesis, University of Delaware, College of Marine Studies, Lewes, DE, 85 pp.

Populations of bivalves from three different areas were examined histologically and their gametogenetic cycles described. M. arenaria from Rehoboth Bay, DE, underwent

two gametogenic cycles in a year; those from the cooler waters of a Massachusetts salt marsh underwent one cycle per year. Irregular development occurred in clams living in the intermediate temperature regime of Salt Pond, MA. M. demissus from both Rehoboth Bay and Salt Pond underwent a single gametogenic cycle per year. Minor differences in development were observed among mussels grown at different temperatures.

Logan, D. T. 1976. A laboratory energy balance for the larvae and juveniles of the American lobster, Homarus americanus. Doctoral dissertation, University of Delaware, College of Marine Studies, Lewes, DE, 122 pp.

Energy budgets were constructed for H. americanus-fed brine shrimp, Artemia salina. Measured energy flows included ingestion, egestion, excretion of ammonia, routine and fed metabolism, growth, and production of exuvia. Minimum ration (g/g) of protein necessary to sustain larval lobsters was estimated. No change associated with metamorphosis was observed in rate of excretion, fed metabolism, or production of exuvia; routine metabolism was higher for larvae than for juveniles. Growth rate changed from exponential in larvae to a less rapid increase in post-larvae.

Logan, D. T. and C. E. Epifanio. 1978. A laboratory energy balance for the larvae and juveniles of the American lobster Homarus americanus. Mar. Biol. 47(4):381-390.

An energy budget was constructed for larval and juvenile lobsters fed brine shrimp Artemia salina. Measured energy flows included ingestion, egestion, NH_3 excretion, routine and fed metabolism, growth, and exuvia production. Digestion and assimilation were calculated and minimum ration of protein necessary to sustain larval lobsters was estimated. No change associated with metamorphosis was observed in rates of excretion, fed metabolism, or exuvia production. Routine metabolism was not significantly higher for larvae than for juveniles. Growth changed from exponential in larvae to a slower rate of increase in post-larvae. Consumption reflected changes in other variables. Changes in energy partitioning and energetic efficiencies associated with metamorphosis were largely due to change in rate of growth.

Malouf, R., R. Keck, D. Maurer and C. Epifanio. 1972. Occurrence of gas-bubble disease in three species of bivalve molluscs. J. Fish. Res. Board Can. 29(5):588-589.

Gas-bubble disease was observed in adult oysters (Crassostrea virginica, C. gigas) and hard clams (Mercenaria mercenaria) held in heated running seawater during the winter. Heating cold seawater in closed heat exchangers caused it to become

supersaturated with atmospheric gases. Exposure of animals to this water caused formation of gas-filled conchiolin blisters on oysters' valves. Bubbles of gas were observed in gill filaments of oysters and clams and in the mantle tissue of oysters. Methods such as use of baffles or an aerated head tank to reduce dissolved gas concentration in water are suggested to prevent the disease.

Marinucci, A. C. 1975. Interrelationships among growth, growth physiology, and external algal metabolites in the larvae of the quahog clam Mercenaria mercenaria L. Master's thesis, University of Delaware, College of Marine Studies, Lewes, DE, 92 pp.

Examines the effect of external metabolites of six species of algae (Phaeodactylum tricornutum, Nannochloris oculata, Isochrysis galbana, Monochrysis lutheri, a Cryptomonas species and Dunaliella tertiolecta) on larvae of M. mercenaria using respiration and food intake as indices of larval growth. External algal metabolites influence the food value of these algae by affecting larval respiration and rate of particle clearance. Metabolites of I. galbana, D. tertiolecta, and Cryptomonas sp. stimulated larval respiration; those of I. galbana and M. lutheri stimulated clearing of inert particles by larvae. Fastest larval growth occurred on a diet of M. lutheri.

Marsh, B. L. 1973. Techniques for design of large-scale systems. Doctoral dissertation, University of Delaware, Newark, DE.

Via computer model, design variables and system costs are applied to an oyster production system. The sensitivity of cost to design variables and to stochastic parameters is automatically determined. Applied to an oyster production, a cost reduction from \$48.89 to \$22.10 per bushel is achieved. Further work on the water-flow requirements of oysters in an artificial environment is indicated.

Marsh, B. L., A. W. Morrison and F. A. Costello. 1973. Systems engineering of oyster production. Proc. Natl. Shellfish Assoc. 64:5.

The authors define important cost factors in closed-system oyster culture. A water recycle system with at least 85% recycle is necessary to bring costs within range of naturally produced oysters. Analysis of research costs and probability of success recommend research, in order of decreasing importance, on heat recovery, growth rate acceleration, algae/oyster culturing in the same tank, cross-breeding for faster growth, less costly tank designs, and definition of water requirements for growing oysters.

Marshall, T. 1981. Copper cycling in the brine shrimp, Artemia salina. Master's thesis, University of Delaware, College of Marine Studies, Lewes, DE, 87 pp.

Cycling of copper in A. salina was quantified by measuring copper input, accumulation, and loss, using atomic absorption spectrophotometry. Assimilation by A. salina of ingested copper from seawater and from two algal species, Thalassiosira pseudonana and Isochrysis galbana, was measured. Copper from food or water could significantly increase copper concentration in shrimp.

Maurer, D. and K. S. Price, Jr. 1968. Holding and spawning Delaware Bay oysters (Crassostrea virginica) out of season: I. Laboratory facilities for retarding spawning. Proc. Natl. Shellfish Assoc. 58:71-77.

Describes laboratory facilities and techniques for retarding the natural spawning of C. virginica from Delaware Bay. Oysters were held in the laboratory from May 1967 to September and October 1967 and January 1968 at which times spawning was successfully stimulated. This demonstrates that oysters do not resorb gametes even when held in the laboratory for eight months if proper temperatures and quantities of water are provided with brood stocks. Proper conditioning is stressed.

Maurer, D. 1970. Selective oyster breeding. In Systems Engineering and Development of Commercially Valuable Marine Resources in the Delaware Region. University of Delaware, Sea Grant Final Report, DEL-SG-01-70, pp. 28-34.

Attempts to hybridize Crassostrea virginica with the Japanese oyster C. gigas and the Portugese oyster C. angulatta are briefly described. Spawning could not be induced in C. angulatta due to poor condition of specimens. Spawning of C. virginica and C. gigas was induced and fertilization occurred, but neither hybrid nor control larvae set. Fertilization of eggs stripped from C. gigas with C. virginica sperm resulted in larvae that suffered high mortality and demonstrated morphological aberration of the hinge line. However, small numbers (eighteen and fifty-two) of these hybrid larvae set. In comparisons of early growth, hybrid oysters grew faster than local oysters.

Maurer, D. 1973. The development of closed system oyster culture. Bull. Am. Malacol. Un. February 1973:18-20, DEL-SG-04-73.

A brief outline of the University of Delaware's oyster production scheme.

Mootz, C. A. and C. E. Epifanio. 1974. An energy budget for Menippe mercenaria larvae fed Artemia nauplii. Biol. Bull. 146:44-55.

An energy budget was constructed for M. Mercenaria larvae from hatching to first juvenile crab. Consumption, growth, caloric content, and respiration were measured. Rejects were obtained by subtraction. Larvae grew exponentially through zoeal stages. Growth rate and feeding decreased prior to molting to the first crab stage. Caloric content increased from 2.503 cal/mg at hatching to 3.746 cal/mg at first juvenile crab; molts contained 1.296 cal/mg. Zoeal respiration was related to body weight by the equation $R=0.0017 W^{0.67}$. During larval development, 7.329 cal were consumed, 2.207 cal were used for growth, 0.502 cal were lost to production of exuvia, 1.933 cal were expended for maintenance, and 2.687 cal were lost as rejecta. Also included in the study were energy budget data and energetic efficiencies of each stage.

Morrison, A. W. 1973. Optimum allocation of funds for research pertaining to a mariculture production system. Master's thesis, University of Delaware, Newark, DE.

Presents a computer model that evaluates proposed interacting research programs and provides an optimum funding scheme for each of several equally spaced funding ranges. Expected return is calculated for all possible combinations of projects. A Taylor series is developed to represent functionally the return for any combination of projects. The allocation model was applied to research projects at an oyster production facility. Through proper allocation of funds, cost per bushel of oysters could be reduced from \$22.30/bushel to \$12.55/bushel.

Muller, G. T. 1978. Effects of ration and temperature on growth rates and growth efficiency in the cultured oyster, Crassostrea virginica. Master's thesis, University of Delaware, College of Marine Studies, Lewes, DE, 96 pp.

Examines growth rates and efficiencies of juvenile oysters maintained at 18°C, 23°C, or 28°C and fed three rations of Thalassiosira pseudonana. Assimilation efficiency proved independent of temperature. Growth rates of oysters fed low or medium rations were also temperature independent. Maximum growth rate was obtained at 28°C and high ration; these oysters sextupled their wet weight in twenty-eight days.

Palmer, R. E. and M. R. Carriker. 1979. Effects of cultural conditions on morphology of the shell of the oyster Crassostrea virginica. Proc. Natl. Shellfish Assoc. 69:58-72.

Morphological and mineralogical characteristics of the shell were studied in oysters cultured in three well-monitored environments: a natural area with excellent growth, a cultural system in which water was changed every other day, and a cultural system utilizing largely recycled water. Shells from recirculating systems were, in all regards except size, normal in comparison to shells of naturally grown oysters; there were no obvious anomalies associated with culturing. Cultural system did not affect valve shape, strength, or mineralogy, but it did affect valve size and coloration, density, prism size, and growth banding.

Palmer, R. E. 1980. Behavioral and rhythmic aspects of feeding and digestion in the bay scallop Argopecten irradians and the oyster Crassostrea virginica. Doctoral dissertation, University of Delaware, College of Marine Studies, Lewes, DE, 118 pp.

Filtration rate, efficiency, and morphology of digestive tubules of A. irradians and C. virginica in culture were studied at various food concentrations. Filtration rate and cell clearance were measured hourly for twenty-four to thirty-three hours for bivalves fed unialgal suspensions at constant concentrations (Dunaliella tertiolecta, Isochrysis galbana, or Thalassiosira pseudonana). Neither local tidal sequence nor day/night cycles exerted a significant influence on filtration behavior. In A. irradians, filtration activity was relatively constant throughout the experimental period. Filtration rate varied inversely with algal concentration (0.94-9.66 mg/l). Mean filtration rate for oysters was 1.5 l/h/g dry weight; for scallops, 4.7 l/h/g dry weight. Filtration efficiency also was studied over a range of concentrations (0.88-10.89 mg/l) of mixed algae (D. tertiolecta, I. galbana, Platymonas suecica, and T. pseudonana). As algal concentration increased, A. irradians retained more small (2-4 μ m) particles and C. virginica periodically retained fewer small particles. Histological studies of digestive glands of C. virginica showed 68% type II (absorptive) and 20% type I (resting); variation of tubule type was not correlated with laboratory feeding history, indicating that C. virginica did not show endogenous rhythms of intracellular digestion under constant environmental conditions.

Palmer, R. E. 1980. Observations on shell deformities, ultrastructure and increment formation in the bay scallop Argopecten irradians. Mar. Biol. 58(1):15-24.

Shell morphology and ultrastructure were examined in A. irradians cultured in recirculating seawater systems under various conditions of feeding, lighting, and handling. On a unialgal diet of Thalassiosira pseudonana, scallop

growth ranged from 120-183 $\mu\text{m}/\text{day}$ at 20°C, about two-thirds of the growth rate in the field. Differences are reported between shell deposited in the laboratory and that deposited in the field. Excessive handling of scallops in the laboratory resulted in thickening of valve margins; this was completely arrested by a change from daily to weekly handling. Scallops cultured in the same tank with oysters developed shell-thickening on the interior of the valves. Shell abnormalities in bivalves may be elicited by a variety of natural and experimental irritants. Under natural lighting regimes and optimal conditions for growth, scallops deposited exactly one shell increment/day. But under continuous lighting, deposition of growth increments often became aphasial. There was evidence that shell ridge formation occurred intermittently, rather than daily, when shell growth rates fell below approximately 150 $\mu\text{m}/\text{day}$.

Palmer, R. E. 1980. Behavioral and rhythmic aspects of filtration in the bay scallop Argopecten irradians concentricus and the oyster, Crassostrea virginica. J. Exp. Mar. Biol. Ecol. 45(2/3):273-295.

In the laboratory for periods of twenty-four to thirty-three hours, hourly measurements were made of filtration rate and cell clearance rate of thirty-nine individual A. i. concentricus and C. virginica fed suspensions of algae (Dunaliella tertiolecta, Isochrysis galbana, or Thalassiosira pseudonana). Neither local tidal sequence nor laboratory day/night cycles exerted a significant influence on the bivalves' filtration behavior. In A. irradians, filtration activity either remained relatively constant throughout the experimental period or stabilized at a constant level after an initial period of steady decline. There was an inverse relationship between suspended algal concentration and filtration rate of A. irradians so that the average amount of algae cleared hourly was similar throughout the range of concentration (0.94-9.66 mg/l). Filtration behavior of C. virginica was generally characterized by alternating periods of high and low activity. Peaks of oyster filtration activity occurred two-to-three times a day, and the period between peaks did not vary with algal concentration. Oysters filtered actively for 80% of all hourly periods in suspensions of T. pseudonana and 91% in suspensions of I. galbana. Mean filtration rate for C. virginica was 1.5 /hour/g dry weight for all measurements and 1.9 /hour/g dry weight during hourly periods of active filtration.

Palmer, R. E. and L. G. Williams. 1980. Effect of particle concentration on filtration efficiency of the bay scallop Argopecten irradians, and the oyster, Crassostrea virginica. Ophelia 19(2):163-174.

Examines filtration efficiency of A. irradians and C. virginica in the laboratory using dilute algal suspensions over a range of concentrations from 0.88-10.89 mg wet algal wt/l. Efficiency of retention was measured in flowing seawater for each of eight size classes of particles (1.73-9.97 μm diameter) by comparing number of particles in inhalent and exhalent water. Algal suspensions were composed of isogravimetric amounts of Dunaliella tertiolecta, Isochrysis galbana, Platymonas suecica and Thalassiosira pseudonana. In low algal concentrations, A. irradians and C. virginica showed no change in filtration efficiency for particles larger than 7 μm and 3 μm in diameter, respectively. In retaining small particles (2-4 μm) as concentration increased, A. irradians became more efficient due to increased mucus production, and C. virginica periodically became less efficient, probably due to changes in effective ostial size. Conditioning to feeding on large or small algae did not affect the filtration efficiency in A. irradians.

Pennock, J. R. 1981. The role of Spartina alterniflora detritus in the nutrition of the American oyster, Crassostrea virginica. Master's thesis, University of Delaware, College of Marine Studies, Lewes, DE, 88 pp.

In a laboratory feeding study, particulate organic detritus from S. alterniflora was tested for its ability to support growth in C. virginica. Juvenile oysters were fed unicomponent and multicomponent diets at three levels of nitrogen ration of Isochrysis galbana, leached S. alterniflora, and S. alterniflora detritus. Oysters did not grow on either leached S. alterniflora or S. alterniflora detritus alone. Oysters fed algae mixed with detritus grew more than those fed algae mixed with leached S. alterniflora, but the difference was not statistically significant.

Price, K. S., Jr. and D. Maurer. 1971. Holding and spawning Delaware Bay oysters (Crassostrea virginica) out of season: II. Temperature requirements for maturation of gonads. Proc. Natl. Shellfish Assoc. 61:29-34, DEL-SG-05-71.

Reports spawning responses for seven lots of Delaware Bay oysters (nearly 400 individuals) held in the laboratory at temperatures ranging from 11.6°C to 29.4°C for periods ranging from 28- to 248 days. Histological studies of gonadal ripening were conducted on two lots of laboratory-held oysters and on one lot held at field temperatures (as a control). Based on the histological examination of oyster gonads and spawning responses as related to the thermal history of the laboratory-held oysters, a temperature-time schedule is proposed that should allow one to hold, condition, and spawn Delaware Bay oysters in the laboratory or hatchery on a year-round basis. These oysters required from six

to seven times as long to ripen as Long Island oysters at temperatures between 12.0°C and 22.0°C. Within this temperature range, 450 degree days (sum of the daily exposure temperatures above 12.0°C) were required to elicit spawning in at least half of the oysters tested.

Price, K. S., Jr. and D. L. Maurer (eds). 1971. Proceedings of the Conference on Artificial Propagation of Commercially Valuable Shellfish: Oysters. University of Delaware, College of Marine Studies, Lewes, DE, DEL-SG-01-71, 212 pp.

Ten papers with attendant discussions dealing with oyster culture: oyster culture techniques, nutrition, disease, breeding, climate and ecology, hatchery feasibility, environmental control for culturing larvae, shucking techniques, systems engineering approach to culture, and culture-related extension services.

Price, K. S., Jr., N. W. Shaw and K. S. Danberg (eds). 1976. Proceedings of the First International Conference on Aquaculture Nutrition, October 1975, University of Delaware, College of Marine Studies, Lewes, DE, DEL-SG-17-76, 300 pp.

A collection of fifteen papers dealing with the nutrition of fish, molluscs, and crustaceans.

Price, K. S., Jr. 1978. Molluscan shellfish research in the United States with emphasis on controlled system aquaculture at the University of Delaware. In Drugs and Food from the Sea: Myth or Reality, ed. by P. N. Kaul and C. J. Sindermann. University of Oklahoma, Norman, OK, pp. 273-283.

Gives an overview of institutions and researchers involved in oyster, clam, mussel, and scallop mariculture research in the United States, and a review of specific advances in maricultural techniques developed at the University of Delaware.

Price, K. S., M. R. Carriker, C. E. Epifanio, R. F. Srna, G. D. Pruder, E. T. Bolton and K. P. Smith. 1979. Mariculture in controlled environment seawater systems--a review of research at the University of Delaware (1968-1975). In Advances in Aquaculture, ed. by T. V. R. Pillay, and W. A. Dill. Fishing News Books, Ltd., Farnham, Surrey, England, pp. 525-527.

Reviews research at the University of Delaware on the development of closed or recirculating-seawater systems for the culture of commercially valuable bivalves and describes rearing of Mercenaria mercenaria and Crassostrea virginica to market size within one year on cultured, defined algal diets.

Pruder, G. D., C. E. Epifanio and R. Malouf. 1973. The design and completion of the University of Delaware mariculture laboratory. University of Delaware, College of Marine Studies, Newark, DE, DEL-SG-07-73, 96 pp.

A detailed description of facilities and equipment at the University of Delaware mariculture laboratory. Included are cost summaries and specifications for facilities to maintain brood stock, rear larvae, set and grow oysters, and establish an algae culture system and a seawater delivery system. Provides descriptive survey of marine laboratories at eleven major marine research institutions.

Pruder, G. D., E. T. Bolton, E. E. Greenhaugh and R. E. Baggaley. 1976. Engineering aspects of bivalve molluscan mariculture: progress at Delaware 1975. In Proceedings of the Seventh Annual Meeting World Mariculture Society, ed. by James W. Avault, Jr. Louisiana State University, Baton Rouge, LA, DEL-SG-11-76, pp. 607-622.

Reports on system optimization and cost reduction methods in a commercial recirculating mariculture system. Progress is reported in oyster growth-rate acceleration, nutrient-cost reduction and water-quality maintenance by foam fractionation.

Pruder, G. D., E. T. Bolton and C. E. Epifanio. 1977. Hatchery techniques for a controlled environment molluscan maricultural system. In Third Annual Meeting of the I.C.E.S. Working Group of Mariculture, Brest, France, Actes de Colloques du C.N.E.X.O., 4:347-351, DEL-SG-15-77.

Describes the hatchery operation of the University of Delaware's controlled-environment mariculture system for oysters. The broodstock, larvae, spat and juveniles all receive the same diet--equal cell counts of Thalassiosira pseudonana and Isochrysis galbana. All animals are held at 27°C-29°C except the broodstock, which is held at 18°C until spawning is induced.

Pruder, G. D., E. T. Bolton and S. R. Faunce. 1978. System configuration and performance: bivalve molluscan mariculture. In Proceedings of the Ninth Annual Meeting, World Mariculture Society, ed. by James W. Avault, Jr. Louisiana State University, Baton Rouge, LA, pp. 747-759.

Revises a previous estimate of the number of algal cells (Thalassiosira pseudonana and Isochrysis galbana) required to support vigorous growth of oysters. The revised equation, $Y = 8.2 (x)^{-0.21}$ Y=algal cells cleared $\times 10^8$ /g oysters weight including shell/day, takes into account the thinner shells of laboratory-reared oysters in comparison to wild oysters. Reports improvement in mass outdoor cultivation of algae

by controlling pH and dissolved oxygen with a N₂-CO₂ gas mixture and describes an indoor recycling system and a prototypic greenhouse system.

Pruder, G. D. and E. E. Greenhaugh. 1978. Bivalve rearing process. United States Patent #4,080,930.

Presents a method for rearing commercially desirable bivalve molluscs under artificial conditions to marketable size in substantially reduced time periods. Oyster spat are placed in tanks and fed at regular times with specified algae in usually large quantities and maintained at unusually high temperatures (25°C-32°C). Tanks and oysters are meticulously cleaned, and seawater or other source of salts and minerals is added at regular intervals.

Pruder, G. D. 1979. Effect of pH, carbon dioxide, oxygen and light on growth of Thalassiosira pseudonana (Hustedt) Hasle and Heimdal clone 3H, an important food for bivalve molluscan mariculture. Doctoral dissertation, University of Delaware, College of Marine Studies, Lewes, DE, DEL-SG-03-79, 100 pp.

Growth of T. pseudonana cultured in enriched artificial seawater was studied under different conditions of pH, CO₂, oxygen and light. Population density, particulate carbon (PC) and particulate nitrogen (PN) concentrations were measured throughout exponential growth. Growth rates are reported as k in the expression $Y=ae^{kt}$ where Y=cell concentration at time t; a=cell concentration, PC, or PN at t=0; and t=time in hours. Rates were computed by regression analysis for forty-three treatment combinations. A model was developed relating rates of CO₂ generation from HCO₃⁻ to pH, temperature and minimum CO₂ concentrations. The effect of pH and light intensity on the ratio of carbon to chlorophyll was examined. Operating limits for CO₂, pH, oxygen, and light intensity in algae culture systems are suggested.

Pruder, G. D. and E. T. Bolton. 1979. The role of carbon dioxide enrichment of aerating gas in the growth of an estuarine diatom (Thalassiosira pseudonana). Aquaculture 17(1):1-16.

The effect of CO₂ concentration on growth of T. pseudonana was studied at three light intensities and two O₂ concentrations. Algal cultures were grown in enriched artificial seawater under constant illumination in 500 ml bottles. Population density, particulate carbon, and particulate nitrogen were measured periodically during exponential growth. Growth rate did not increase as CO₂ concentration was elevated above 16.0 μmol/l. Freshly inoculated algal cultures did not grow in an organic carbon-free medium

bubbled with CO₂-free air. Kinetics of inorganic carbon mobilization including concentrations, reaction rates, and CO₂ transport, generation, and uptake are analyzed. Use of T. pseudonana as food in mollusc culture is discussed.

- Pruder, G. D. and E. T. Bolton. 1980. Differences between cell division and carbon fixation rates associated with light intensity and oxygen concentration: Implications in the cultivation of an estuarine diatom Thalassiosira pseudonana. Mar. Biol. 59(1):1-6.

Differences between rates of cell division and net carbon fixation in T. pseudonana were found to be dependent on light intensity and oxygen concentration. Under conditions favoring large differences between cell division and net carbon fixation, cultures of T. pseudonana depart from exponential and enter stationary phase at low cell concentrations. The authors conclude that single-cell algae may not be able to balance maintenance, growth, and cell division outside a narrow range of environmental conditions.

- Redmond, M. S. 1981. The effects of Bunker C oil on the survival, reproduction, and growth of the mysid shrimp Mysidopsis bahia (Crustacea: mysidacea). Master's thesis, University of Delaware, College of Marine Studies, Lewes, DE, 38 pp.

Acute and sublethal effects of the water-soluble fraction of Bunker C residual oil on M. bahia were studied in a continuously flowing laboratory system. The ninety-six-hour LC₅₀ for juveniles was 0.70 ppm nominal hydrocarbons. At lower concentrations, there was no effect on number of young, days to first brood-pouch formation, or days to first release of brood.

- Romberger, H. P. 1980. Comparative effects of diets consisting of one or two algal species upon assimilation efficiencies and growths of juvenile oysters Crassostrea virginica (Gmelin). Master's thesis, University of Delaware, College of Marine Studies, Lewes, DE, 37 pp.

Growth and assimilation efficiencies of juvenile oysters were determined during a five-week experiment in which oysters were fed the algae Thalassiosira pseudonana, Platymonas suecica and Isochrysis galbana singly or in two-part diets. Growth of groups fed mixed diets was greater than would be predicted from the growth of groups fed single species. Growth was greatest in oysters fed a mix of T. pseudonana and I. galbana.

Romberger, H. P. and C. E. Epifanio. 1981. Comparative effects of diets consisting of one or two algal species on assimilation efficiencies and growth of juvenile oysters Crassostrea virginica. Aquaculture 25(1):77-88.

Juvenile oysters were fed one of six diets consisting of three species of algae fed singly or in two-species combinations. Dietary components were Isochrysis galbana (Diet I), Platymonas suecica (Diet P), and Thalassiosira pseudonana (Diet T). High (Diet TI), intermediate (Diets T, I, PT, PI), and low (Diet P) growth responses were observed. Intermediate and low growth responses were explained in terms of differing levels of ingestion and assimilation. The high growth response with Diet TI was not explained by measured values of ingestion and assimilation.

Sick, L. V., C. C. Johnson and C. A. Siegfried. 1979. Fluxes of dissolved and particulate calcium in selected tissues of Crassostrea virginica. Mar. Biol. 54(4):293-299.

Rates of calcium incorporation by selected tissues of C. virginica increased in a step-wise fashion from lowest rates among oysters exposed to calcium concentrations of 45 mg/l, to intermediate rates at exposures to 135 mg/l, 225 mg/l, 45 mg/l and 315 mg/l, and to highest rates at 360 mg/l. Excised visceral mass tissue had highest rates of calcium incorporation relative to mantle, muscle, and shell; mantle tissue showed the most dynamic response to changes in ambient calcium concentration. Rates of dissolved calcium incorporated from ambient water were two to three orders of magnitude higher than from ingested algal food. Behavioral response to concentrations of selected ionic species in the environment may be responsible for observed differences.

Sick, L. V. and C. A. Siegfried. 1982. Effects of the ambient environment on metabolic regulation of shell biosynthesis in marine bivalve molluscs. In Proceedings of the Second Annual Conference on Aquaculture Nutrition, ed. by G. D. Pruder, C. J. Langdon, and D. E. Conklin. Louisiana State University, Baton Rouge, LA, pp. 377-399.

Discusses literature relating effects of the ambient environment to mantle tissue metabolism and shell biosynthesis in marine bivalves. Previously published models for shell synthesis and their relation to mantle tissue metabolism are presented. No experimental evidence directly relates nutritional factors to shell formation but aspects of nutrition that may have an indirect influence on rate and quality of shell synthesis are discussed. Presented is data relating calcium concentration and salinity in ambient culture media to amino acid fluxes in mantle and extrapallial fluid. Increases in both ambient

salinity and calcium concentrations resulted in increases in concentrations of several free amino acids in mantle tissue and in excretion of glycine from mantle into culture medium. These results and components of previous models are combined in a new model. Specific mechanisms are invoked to explain how the chemistry of the ambient environment and the nitrogen metabolism of mantle tissue, including effects of nutritional factors, may regulate molluscan shell biosynthesis.

- Srna, R. F., C. E. Epifanio, M. Hartman, G. Pruder and A. Stubbs. 1973. The use of ion-specific electrodes for chemical monitoring of marine systems. Part I: The ammonia electrode as a sensitive water quality indicator probe for recirculating mariculture systems, University of Delaware, College of Marine Studies, Newark, DE, 20 pp., DEL-SG-14-73.

The Orion 95-10 ammonia-ion-specific electrode was tested and characterized for use in monitoring water quality and biological activity in a closed-cycle seawater (32 ppt) system. Because of its precision, rapid response to system perturbations, and predictable recovery pattern, it is recommended for the routine monitoring of a recirculating mariculture system that uses a biological filter. The theory of electrode operation and technical considerations for its use are discussed.

- Srna, R. F. 1974. The use of ion specific electrodes for chemical monitoring of marine systems. Part II: A rapid method of detecting changes in the relative concentration of chloride and divalent ions in seawater. University of Delaware, College of Marine Studies, Lewes, DE, DEL-SG-11-74, 31 pp.

The response of electrodes specific for calcium, divalent cations, or chloride in volumetric dilutions of CaCl_2 solution, artificial seawater, estuarine water from Delaware Bay, and water from a recirculating mariculture system was tested. A method and apparatus were designed to eliminate problems due to electrode drift, electrode shift, temperature variation, mechanical shock, and bubbles adhering to the electrode membrane. Electrode response in millivolts varied linearly with log-ion concentration over a range of at least 50% dilution.

- Srna, R. F. 1975. A modular nitrification filter design based on a study of the kinetics of nitrification of marine bacteria. In Proceedings of the Sixth Annual Meeting, World Mariculture Society, ed. by James W. Avault, Jr. Louisiana State University, Baton Rouge, LA, DEL-SG-07-76, pp. 463-470.

Discusses maintenance of water quality in recirculating mariculture systems. A quantitative study of kinetics of important nutrient cycles is proposed to establish minimum system volumes, design optimization, and requisite environmental controls. Significant results in a study of inorganic nutrient cycling and toxicity in recirculating systems are reported. A modular filter design suggested by a study of the kinetics of nitrification demonstrates how a knowledge of kinetics and chemical factors can lead to improved water treatment hardware.

- Srna, R. F. and A. Baggaley. 1975. Kinetic response of perturbed marine nitrification systems. J. Water Pollut. Control Fed. 47(3 Part 1):472-486, 633; DEL-SG-13-75.

Equations are derived describing the rate at which various concentrations of ammonium ion are oxidized to nitrite and then to nitrate ion by nitrifying bacteria (Nitrosomonas, Nitrobacter) on subgravel biological filters. Temperature, pH, and sulfide ion concentration affect the rate of reaction, but small salinity changes and nitrate ion accumulation do not.

- Srna, R. F., A. S. Baggaley and J. Ewart. 1975. The feasibility of utilization of solid waste material from the cultivation of shellfish as a marketable product. University of Delaware, College of Marine Studies, Lewes, DE, DEL-SG-12-75, 32 pp.

Technical aspects of producing and utilizing shellfish biodeposition as a marketable product are discussed. Feces and pseudofeces of Crassostrea virginica fed Phaeodactylum tricornutum, Isochrysis galbana, and Carteria chuii were found to be as effective a fertilizer as cow manure in the cultivation of bush beans. Chemical analysis showed that oyster manure contained 30,200 mg/kg Kjeldahl nitrogen and 23.7 mg/kg total phosphorus compared to 16.6 mg/kg nitrogen and 21.4 mg/kg phosphorus for cow manure. No relationship was found between algal concentration in the test water and amount of biodeposition.

- Srna, R. F. 1976. Physical-chemical methods for control of algal species and composition in algal culturing facilities. In Proceedings of the Seventh Annual Meeting, World Mariculture Society, ed. by James W. Avault, Jr. Louisiana State University, Baton Rouge, LA, DEL-SG-08-76, pp. 137-155.

Describes three methods for regulating the ratio of one algal species to another in mixed cultures. First, cultures of Thalassiosira pseudonana contaminated with 34% and 60% Phaeodactylum tricornutum were treated with ultrasonic waves, yielding growing cultures of T. pseudonana free of P.

tricornutum. In the second method, extra nutrients were added periodically to mixed cultures of T. pseudonana and P. tricornutum during growth phase. These cultures reached high cell density with only a small percentage of P. tricornutum cells. In the third method, a 50:50 ratio of T. pseudonana and Carteria chuii was maintained, in spite of the slower growth rate of the latter, by continuous seeding with pure C. chuii cells. A design for a recirculated-seawater mariculture system integrating these three methods is given.

Srna, R. F. and A. Baggaley. 1976. Rate of excretion of ammonia by the hard clam Mercenaria mercenaria and the American oyster Crassostrea virginica. Mar. Biol. 36(3):251-258.

M. mercenaria and C. virginica were maintained in an identical laboratory environment and fed the same diet for one month prior to measuring the quantity of NH_3 which they excreted per gram dry weight. Data derived from juveniles and adults of these species were fitted to a log-log equation. M. mercenaria excreted more NH_3 per gram body weight than C. virginica, and considerably more scatter is evident in the fit of data from M. mercenaria to the log-log relationship. Neither temperature fluctuation during experiments nor decomposition of organic N in the test water accounts for the scatter of points. Behavioral differences between species may explain these differences.

Srna, R. F. 1978. Selective destruction of certain algae. United States Patent #4,065,875.

Describes a process for the selective destruction of Phaeodactylum cells in the presence of Thalassiosira cells by subjecting the culture to ultrasonic waves.

Sulkins, S. D. and C. E. Epifanio. 1975. Comparison of rotifers and other diets for rearing early larvae of the blue crab Callinectes sapidus Rathbun. Estuarine Coastal Mar. Sci. 3(1):109-114, DEL-SG-07-75.

Blue crabs in the first two zoeal stages were subjected to one of four diet treatments: unfed control, freshly hatched nauplii of the brine shrimp Artemia salina, gastrulae of the sea urchin Lytechinus variegatus, or the rotifer Brachionus plicatilis. Survival and molt frequency were measured through the second molt. Unfed crab larvae died by day seven without molting to the second stage. Mortality was delayed slightly in larvae fed A. salina, but molting to the second stage was not achieved. Development to the third stage was achieved using both sea urchin larvae and rotifers as diets. Survival was higher on the rotifer diet than on either the sea urchin diet used in this study or in other published diets. Molting to the second zoea was

significantly faster on the rotifer diet than on the sea urchin diet and was more synchronous. The rotifer provides a good diet for rearing the first two zoeal stages of C. sapidus in the laboratory, after which they may be reared on A. salina nauplii with good results.

Thielker, J. F. 1981. Design and test operation of an intensive controlled environment oyster production system. J. World Mariculture Society 122(1):79-93; University of Delaware Sea Grant Technical Report, Lewes, DE, DEL-SG-07-81, 28 pp.

Describes a prototypic controlled-environment oyster production system and gives information on the structure, operation, and management of systems to support oysters, produce algae (Thalassiosira pseudonana and Isochrysis galbana), and handle water and waste.

Thoroughgood, C. A. 1979. Evaluation of palatability and selected nutrients of bivalve molluscs grown in controlled environment mariculture and natural systems. In Proceedings of the Tenth Annual Meeting, World Mariculture Society, ed. by James W. Avault, Jr. Louisiana State University, Baton Rouge, LA, pp. 110-115.

Mercenaria mercenaria from the controlled environment system of the Delaware Mariculture Project and from a natural habitat in Delaware were compared for palatability and proximate composition. Sensory evaluations for appearance, texture, flavor, and overall acceptance were performed on steamed clams from each group by eight trained taste panelists. No significant differences for these characteristics were found. There was some slight preference for the flavor of clams produced in the natural environment. No significant differences were found in protein, moisture, fat, or ash content of raw clams from the two groups.

Tomaszewski, C. 1981. Cementation in the early dissoconch stage of Crassostrea virginica. Master's thesis, University of Delaware, College of Marine Studies, Lewes, DE, 94 pp.

The shell, cement, and mantle of C. virginica spat were examined with transmission-electron microscopy, and histochemically after decalcification. The structure of prodissoconch I and II shell is described. Histochemical and microscopic analysis indicated that the larval cement and dissoconch periostracum are tanned proteins and that the periostracum functions as the dissoconch adhesive. A gland cell rich in phenoloxidase was detected in the inner mantle fold; this cell may assist in hardening the periostracum.

Tripp, M. R. 1973. Hermaphroditism in Bucephalus-infected oysters - J. Invertebr. Pathol. 21(3):321-322.

In three oysters, Crassostrea virginica, dredged from the Mispillion River, Delaware, and infected with Bucephalus sp., clusters of eggs or single eggs were seen in the midst of well-developed testes. This phenomenon was not observed in uninfected oysters nor was sperm ever seen in ovaries of Bucephalus-infected females. This finding suggests that the disturbance of gonad development is physiological rather than mechanical.

Tripp, M. R. 1974. Effects of organophosphate pesticides on adult oysters, Crassostrea virginica. In Pollution and Physiology of Marine Organisms, ed. by F. J. Vernberg, and W. Vernberg. Academic Press, NY, pp. 225-236.

Two organophosphate insecticides, 0,0,0',0'-tetramethyl 0,0'-thiodi-phenylene phosphorothioate (Abate, American Cyanamid) and 1,2-dibromo-2,2-dichloro-ethyl dimethyl phosphate (Dibrom, California Chemical Company) were tested for effects on adult oysters. Four groups of 100 oysters were subjected, respectively, to the following regimes: untreated field control, untreated laboratory control, treated with 0.6 ppm Abate, or treated with 0.5 ppm Dibrom. No significant evidence of acute toxicity of either chemical for adult oysters was found at concentrations up to 10 ppm. Histological examination revealed no tissue damage in treated oysters. However, control oysters that had been held in the lab under low feed conditions spawned when returned to the field; treated oysters subjected to the same conditions did not. Authors conclude that under ordinary conditions these pesticides have little effect on oyster reproduction, but under stressful conditions, an effect is possible.

Tynan, C. T. 1981. The response of the larvae of Rhithropanopeus harrisi (Gould) to hydrostatic pressure and current velocity. Master's thesis, University of Delaware, College of Marine Studies, Lewes, DE, 108 pp.

Responses of larvae of R. harrisi to four regimes of hydrostatic pressure were compared in static and dynamic systems. Behavior in stages II, IV, and Megalopa during changing pressure differed significantly in the two systems. Author stresses importance of studying larval behavior in dynamic systems and suggests that extrapolation of significance of data from static laboratory systems to dynamic estuarine systems may lead to inaccurate conclusions.

Urban, E. R. 1982. Non-algal supplements in the diets of Crassostrea virginica (Gmelin) and Mercenaria mercenaria (Linne).

Master's thesis, University of Delaware, College of Marine Studies, Lewes, DE, 79 pp.

Juvenile C. virginica and M. mercenaria were fed various combinations of algal and non-algal particles for a period of three-to-four weeks, and their growth rates were compared. Yeast and algae supported bivalve growth, but not as well as equivalent levels of algae alone. Addition of cheese whey, Purina^R EMR #25, blood meal, Murray fish starter diet, or Fermino^R to the best algae-yeast mixture did not improve growth. A mix of rice starch, algae, yeast, and kaolin produced significantly more growth than did twice as much algae alone.

Valenti, C. C. 1978. Nitrogen balance of the American oyster Crassostrea virginica (Gmelin). Master's thesis, University of Delaware, College of Marine Studies, Lewes, DE, 51 pp.

Nitrogen assimilation efficiencies for C. virginica fed the algae Isochrysis galbana, Phaeodactylum tricornutum, or the yeast Torula utilis were compared. Oysters fed I. galbana averaged 73% nitrogen assimilation; oyster growth was variable. Those fed P. tricornutum produced more fecal nitrogen than was ingested from the algae; this is attributed to loss from oyster tissue. These oysters decreased in body mass and excreted little ammonia. Oysters fed T. utilis demonstrated 45% nitrogen assimilation and high levels of excreted ammonia, indicating digestion of yeast. Yeast did not support oyster growth. Equations relating cellular nitrogen content and culture density were derived empirically. Cellular nitrogen was found to decline as algal cultures progressed to stationary phase.

Valenti, C. C. and C. E. Epifanio. 1981. The use of a biodeposition collector for estimation of efficiency in oysters. Aquaculture 25(1):89-94.

Describes a device to automatically separate and collect feces and pseudofeces of oysters. This quantitative method allows accurate estimation of assimilation efficiency. C. virginica were fed the diatom Thalassiosira pseudonana at concentrations of $1 \times 10^6 \mu\text{m}^3/\text{ml}$ or $4 \times 10^6 \mu\text{m}^3/\text{ml}$ of algae. Ingestion, fecal and pseudofecal production were greater at the higher concentration but assimilation efficiencies were not significantly different ($\alpha = 0.05$).

Velez, A. and C. E. Epifanio. 1981. Effect of temperature and ration on gametogenesis and growth in the tropical mussel Perna perna. Aquaculture 22(1/2):21-26.

Juvenile mussels were cultured at four combinations of temperature and ration for six weeks. Greatest growth and

gonadal development occurred among mussels fed a high ration at 21°C. There was rapid somatic growth among mussels fed a high ration at 28°C, but gonadal development was inhibited. Overall growth was slow in mussels fed a low ration regardless of temperature, but there was considerable gonadal development at 21°C. Gametogenesis in P. perna is generally inhibited by high temperature. These results cannot be generalized for all tropical bivalves.

Williams, L. G. 1978. Influence of algal cell volume and algal culture filtrates on suspension feeding behavior of the gastropod Crepidula fornicata (Prosobranchia: Calyptraeidae). Doctoral dissertation, University of Delaware, College of Marine Studies, Lewes, DE, 179 pp.

Examines effect of chemical stimuli from five species of algae on suspension feeding behavior of C. fornicata. Feeding behavior was quantified with respect to previous dietary experience, cell size, and cell concentration. Uniform latex spheres were suspended in one of four media: filtrates of algal cultures, filtrates of lysed algal cultures, filtered culture medium, or filtered seawater. There was no significant difference ($p > 0.05$) in rates of clearance of latex spheres between suspensions containing filtrates of algal cultures and control suspensions. Clearance rates using suspensions of latex spheres were less than predicted from experiments using suspensions of algae. Author concludes that algal cells rather than free metabolites are a likely source of allelochemic compounds that could modify suspension-feeding behavior in Crepidula.

Williams, L. G. 1982. Mathematical analysis of the effects of particle retention efficiency on determination of filtration rate. Mar. Biol. 66:171-177.

An exponential model applied to determination of filtration rate originally conceived for filter-feeders clearing suspensions of large, efficiently retained cells was examined for its applicability to filtration of small, inefficiently retained particles. Derivation of this exponential model is reviewed and shown to be inappropriate when filtration efficiency is less than 100%. Box models are constructed for filter feeders that act either as sieves or aerosol filters in suspensions of small, inefficiently filtered cells. The models predict a complex or double exponential decline in cell concentration that cannot easily be translated into filtering or pumping rates. The models further predict that apparent filtration rate will decline over time because of physical limitations rather than behavioral changes. Compartmental analysis of filtration of inefficiently retained particles in a turbidostat system predicts a similar artifact in determination of filtration rate.

Winget, R. R., D. Maurer and L. Anderson. 1973. The feasibility of closed system mariculture: Preliminary experiments with crab molting. Proc. Natl. Shellfish Assoc. 63:88-92.

Describes a recirculating system for inducing shedding in Callinectes sapidus, and preliminary experiments on crab molting. Most important was inducement of out-of-season molting (January-March) in the Delaware Bay area. Temperature was a key factor in promoting this phenomenon.

Winget, R. R., C. E. Epifanio, R. Runnels and P. Austin. 1976. Effects of diet and temperature on growth and mortality of the blue crab Callinectes sapidus, maintained in a recirculating culture system. Proc. Natl. Shellfish Assoc. 66:29-33.

Blue-crab growth parameters were measured over a sixty-day period in a recirculating culture system, with each crab in physical isolation. Dependent variables were molt interval, increase in carapace width per molt, percent molt, and mortality. No consistent growth differences were detected in animals fed diets ranging from 26%-75% protein content. A temperature of 30°C generally increased molt frequency and percent of animals molting compared to a temperature of 20°C. Increased temperature appears to depress cuticle expansion and to decrease mortality.