PERFORMANCE EVALUATION OF A SUSPENSION TRAY SYSTEM FOR THE CULTURE OF HALF-SHELL PACIFIC OYSTERS, *Crassostrea gigas* IN TREVENEN BAY, BRITISH COLUMBIA

by

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ABSTRACT

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The objective was to design and evaluate a Suspension oyster tray unit to optimize conditions necessary for successful commercial culture of oysters in British Columbia for the half-shell market. The suspension system was tested against MacNicol and Nestier trays presently used by the industry. Units were located in two sites in Trevenen Bay. One location was sheltered and calm; the other a natural tidal raceway with intense current flow. The purpose was to test the ability of the design to provide more uniform growth, retard fouling, be easily handled and be commercially feasible to construct. Assessing tray performance was based on monitoring shell growth, condition index, fouling occurrence, materials handling and the capital costs of the systems. Field experimentation began in June and terminated in October, 1979. The Nestier unit had the best shell

growth in the calm environment but displayed variation in growth among trays in the stack, suffered retarded growth in the tidal raceway and had significant barnacle accumulation. The MacNicol performed on par with the Suspension system except for variations in growth due to vertical position, the accumulation of mussels and lowered performance at the tidal raceway site. Suspension tray units performed similarly at both sites, exhibited less variation in growth among trays in a stack, retarded fouling and proved the most economically feasible system for commercial use.

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I wish to thank the Spirit Cove Oyster Co-op, the Marine Resources Branch and Celco Plastics of Coquitlam for providing materials and facilities to carry out the research. Thanks are also extended to Dr. J.W. Zahradnik and members of the thesis committee for their participation and advice on this research project.

INTRODUCTION

The North American oyster industry began as an intense fishery on the east coast. The industry initially boomed but declines in natural production became evident. In 1910 shellfish production in New England was 26,000,000 pounds versus 400,000 pounds in 1975 (Turner and Zahradnik, 1975). Such a decline may be attributed to an inadequate understanding of oyster biology and mismanagement of the natural environment. More specifically, factors such as; the inconsistency of natural set, hatchery costs, high mortality in field planted oysters, the long growing time associated with bottom culture, predator control costs, materials handling, pollution and social pressures have contributed to declines in production.

In British Columbia *Ostrea lurida* was the original native oyster marketed as early as 1880 and was the only species available until 1903 when the eastern oyster *Crassostrea virginica* was introduced. The production of both these species ceased by 1936 and action taken to revive oystering led to the introduction of the Pacific oyster, *Crassostrea gigas* in 1912-1913. This hardy species became widely distributed throughout many of the inlets and bays to the point of eventually eliminating the need for further importation of Japanese seed.

The Pacific oyster caused a resurgence in the productivity of the industry in British Columbia(Quayle, 1969). The business changed from a fishery to a group of culturalists. Unfortunately oyster culture in this province is faced with the same problems discussed previously, but rooted primarily in the areas of materials handling and biofouling control.

The growers resorted to trying a variety of culture techniques that have been proven successful elsewhere in an attempt to solve the problem areas. This transplantation of technology philosophy and a failure to consider criteria for a facility development in this province(Table 1) has resulted in many "socio-economic" headaches for the growers. Problems facing oyster culture in British Columbia require scientific investigation rather than a trial and error approach to determine the causes and facilitate the generation of alternatives to be tested.

The purpose of this research is to develop and evaluate an oyster grow out facility adapted to the biophysico-aquatic environment of British Columbia to allow optimal economic and efficient commercial culture of oysters. The objectives behind the research into the facility design are to:

-reduce the problem areas of fouling, waste accumulation and materials handling

-reduce energy requirements

-minimize labour costs

-maintain appreciative returns on investment by constructing an inexpensive durable facility

-using environmental parameters to advantage

-provide an even distribution of feed

-reduce growing time to market size.

The facility was developed initially using system analysis as a design procedure and evaluating its performance using oyster growth over time as the primary indicator.

Table 1. Criteria for the development of an oyster culture facility.

1. SITE SELECTION
   - A) available area and accessibility
   - B) freshwater supply
   - C) environmental change incurred by culture construction
   - D) hydrographic and hydrologic parameters
   - E) climatic conditions
   - F) public health considerations
   - G) species biology
2. MATERIALS
   - A) availability(choice)
   - B) durability
   - C) fouling resistance
   - D) costs
3. LABOUR
   - A) availability
   - B) cost
   - C) skills
4. GENERAL COSTS
   - A) initial investment
   - B) operating costs
   - C) returns
   - D) marketing
5. LEGAL IMPLICATIONS AND SOCIAL CONSTRAINTS
6. PRODUCTIVITY
   - A) yield
   - B) growth period

BACKGROUND

BIOLOGY

Oysters are gregarious, but sessile in the adult stage and are highly fecund. They have a short reproductive cycle, a relatively fast growth rate if cultured properly and an available protein content(Table 2). Their position in the food chain as obligatory herbivorous filter feeders along with increasing market demands has elevated them to probably the most widely cultured aquatic organism. The increasing demand combined with and an oyster shortage has raised the unit price of both shucked oysters and oysters served on the half-shell.

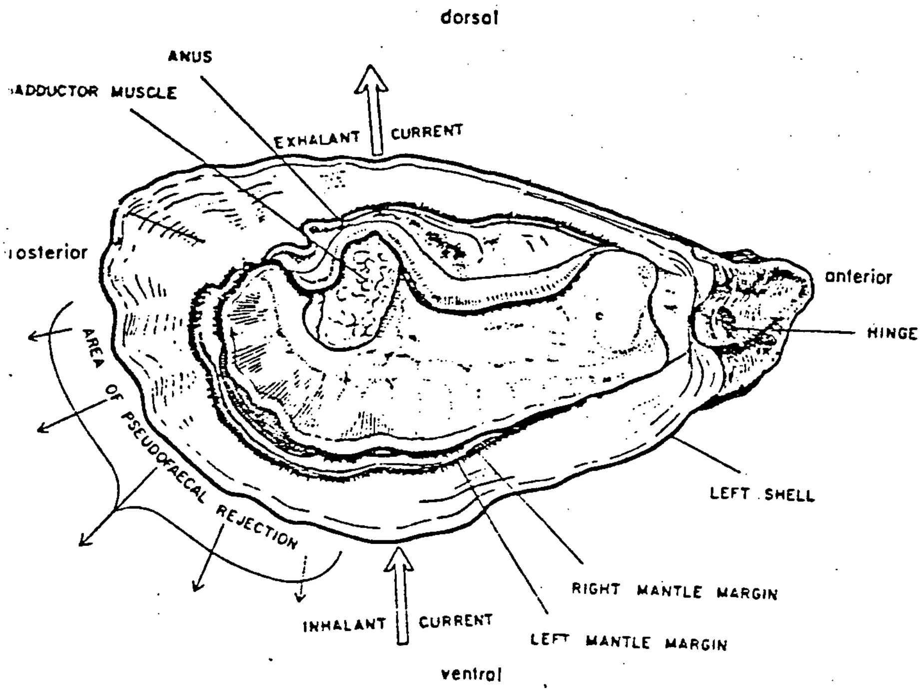
The Pacific oyster is characterized by a fleshy body enclosed within two shells or valves. The shells are hinged at the anterior or umbonal end. The hinge acts to spring the shells apart and this is opposed by the single adductor muscle.

The fleshy body is enveloped by the mantle formed of two right and left lobes that fuse in the anterior region near the mouth. The mantle extracts calcareous material from seawater used in shell deposition.

Oysters feed and respire simultaneously by enlarged gills possessing an efficient ciliated lattice-work of great elaboration and efficiency that creates a powerful water current from which gases are exchanged and particles sieved and passed to the mouth. These basic anatomical characteristics are illustrated in figure 1.

	Average weight (g)	Moisture (%)	Solids calculated on moisture-free flesh Protein (%)	Glycogen (%)	Fat (%)	Ash (%)	Balance
Feb. 9	18.90	78.20	47.80	20.50	10.66	8.66	12.36
Apr.12	18.30	79.84	46.65	24.95	12.94	7.62	7.84
May 30	16.72	77.50	47.70	23.80	13.31	6.87	10.32
Aug. 3	11.07	81.47	54.60	11.85	15.75	7.80	10.00
Oct. 3	17.40	80.00	52.20	14.25	11.72	5.78	16.05
Dec. 7	20.10	83.37	49.90	20.05	13.08	8.42	9.45
Feb. 6	20.00	79.89	49.60	19.00	15.27	6.81	9.32

Table 2. Chemical composition of Pacific oysters in B.C.(Balance represents material not accounted for, and is probably the result of destruction of some of the carbohydrate by chemical action in the analytical procedure)(Quayle, 1969).



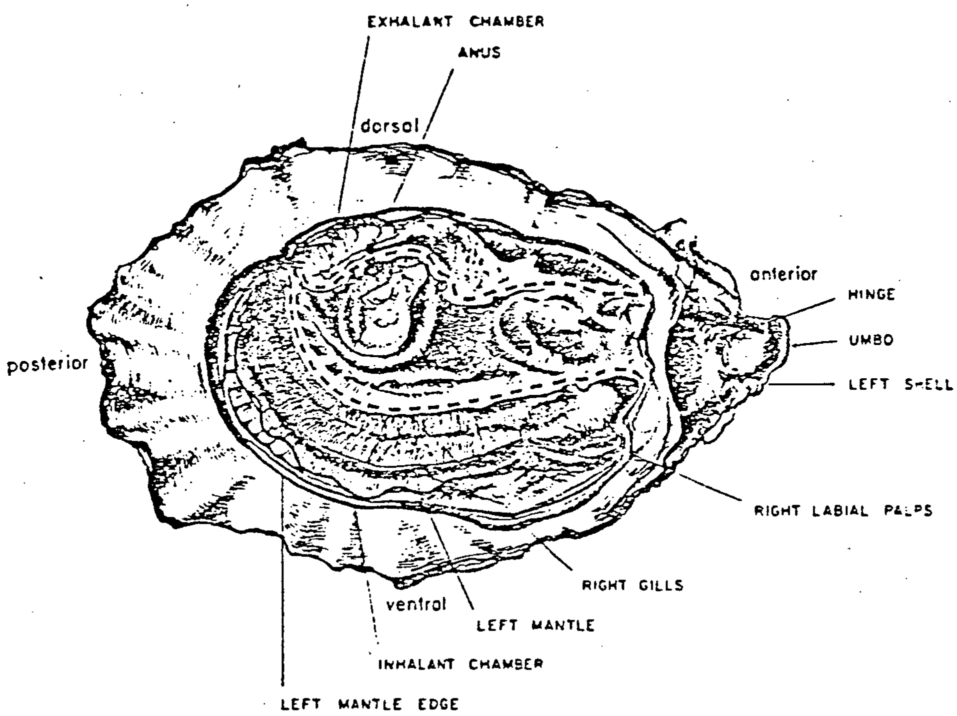


Fig. 1. Basic anatomical characteristics of the Pacific oyster, *Crassostrea gigas* with the right valve removed(Quayle, 1969).

ENVIRONMENTAL REQUIREMENTS AND CONSTRAINTS

The Pacific oyster is able to withstand wide variations in environmental conditions. The oyster is able to detect these changes using sensors located on the labial palps(Dwivedy, 1973). However, the grower should be aware of the optimal environmental requirements of the oyster for growth and development to better meet optimum conditions at the site and in rearing facilities.

Growth, survival and quality depend on tidal exposure, seasonality of location, substrate, pH, temperature, salinity, water velocity, disease, predation, fouling, density and food availability. Collectively these factors interact to determine the fate of a cultured oyster.

Tidal Exposure

Growth rates are usually lower in higher intertidal levels(Quayle, 1969). Quayle(1969) found that oysters exposed for longer than 5 hours per day showed a marked drop in growth rate and the maximum growth rate occurred closest to the zero tide level. Maintaining the oyster in a subtidal zone or continually submerged allows continuous feeding and improved growth rate.

Seasonality

Growth is influenced by seasonal and temperature changes. An elevated water temperature in the summer results in increased food supply and availability of calcium for deposition. Therfore the growth of the Pacific oyster in British Columbia is essentially a summer phenomenon(Quayle, 1969).

Temperature

Growth rate is proportional to temperature. Quayle(1951) found the Pacific oyster had a high growth rate at water temperatures between 15-19 degrees Celsius. Quayle also found that more food and water is taken in at these optimum temperatures. Medcof(1961) also determined that if water temperature becomes too warm growth becomes so rapid that poorly cupped thin shells result. Growth is "essentially zero" at temperatures below 10 degrees Celsius(Bardach et al., 1972).

Figure 2 contains temperature data for Ladysmith Harbour. It can be used as a fingerprint for similar temperature patterns in the inlets along the coast. The optimum temperatures for growth occur during the months of June to September.

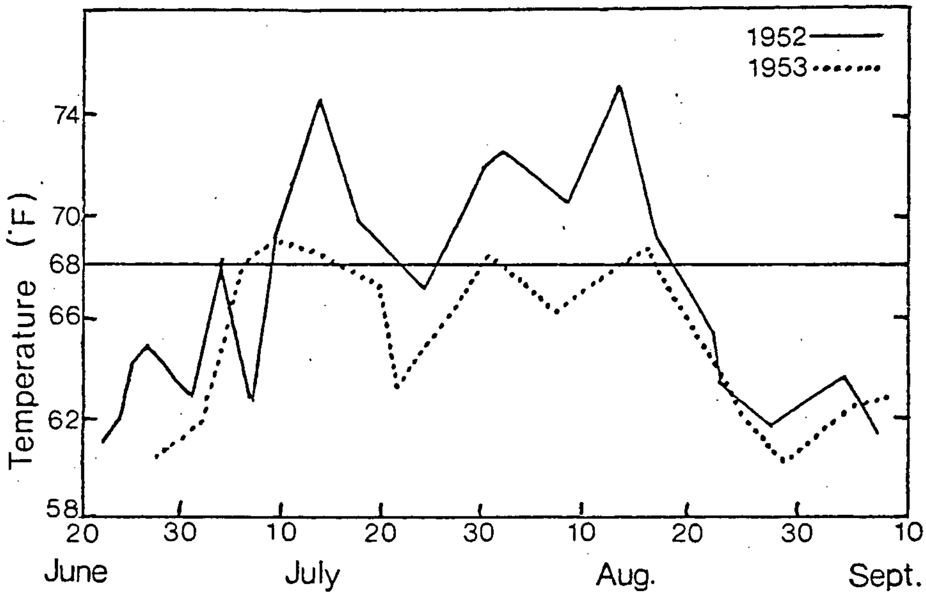


Fig. 2. Seawater temperatures at a depth of 3 feet in Ladysmith Harbour, June to September, 1952 and 1953(Quayle, 1969).

Water Velocity and Food Availability

Feeding rates are influenced by water velocity and food availability as well as temperature(Walne, 1974). A high concentration of suspended material in the form of silt or an overabundance of micro-organisms can cause oysters to reduce or cease filtration. It is believed that dense concentrations of suspended matter can interfere with the pumping process of the gills. Rich algal growth, particularly at sites with low flushing rates, can result in a build-up of bacteria and affect the oyster's gills(Lipopsky and Chew, 1972).

The condition of the oysters is also linked with the food availability at the site. Sites with high primary productivity values provide an excellent food source for oysters. Growth and food removal rates increase with increased food concentration(Walker and Zahradnik, 1976). Figure 3 shows the improvement in the condition factor with increasing primary production of diatoms. The condition factor is the relationship between total volume of whole oysters and the volume of shell cavity. The condition factor is obtained by the fraction: the dry meat weight divided by the unshucked weight minus the shell weight and multiplying the entire expression by 1000.

The average feeding rate increases as water flow increases over the oyster, stimulating them to feed more rapidly(Walne, 1974). Water currents also carry away waste, supply oxygen and distribute greater amounts of food per unit time. Figure 4 illustrates the relationship of growth and flow rate. Therefore a grow-out facility located at a site that takes advantage of tidal flow and designed to allow optimum exchange of water

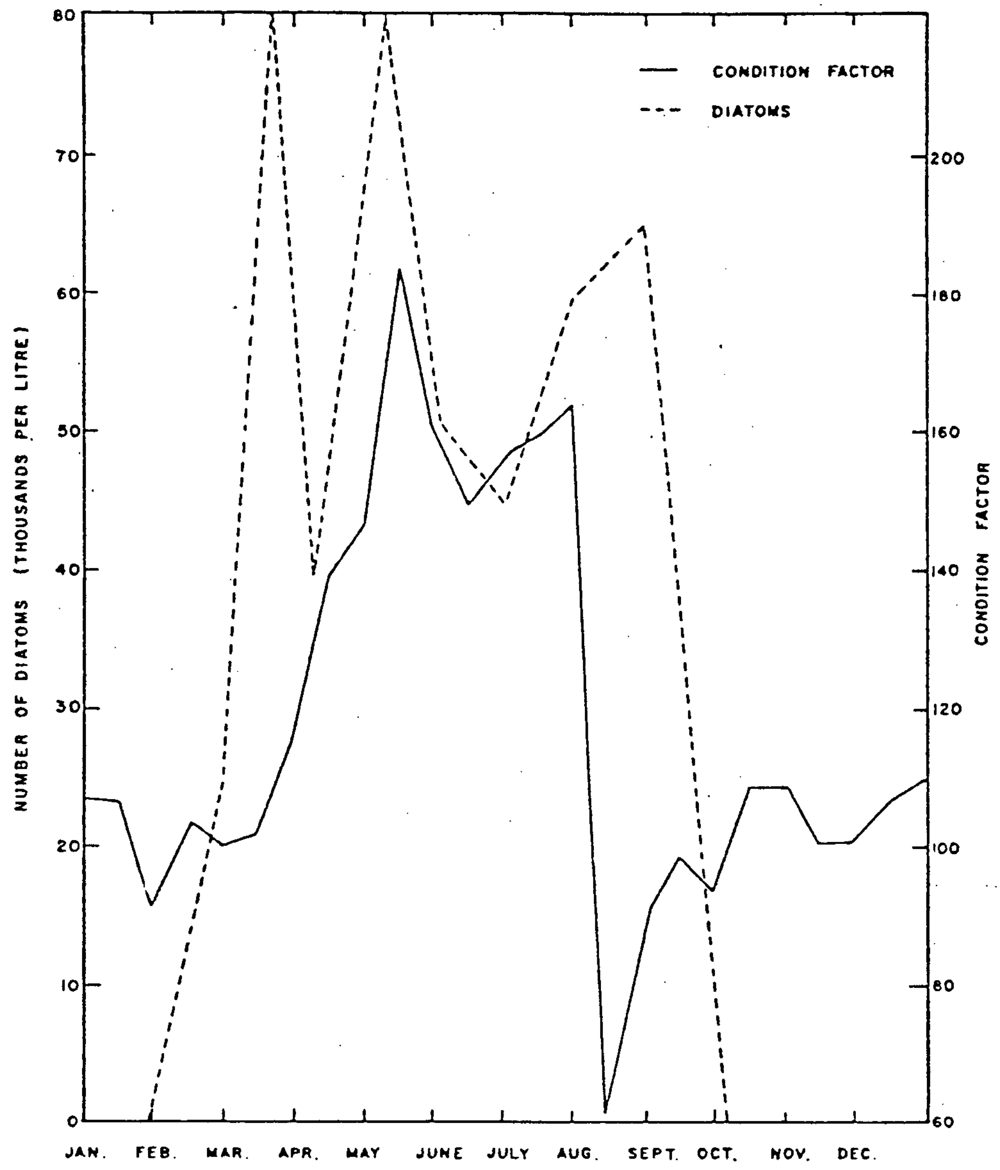


Fig. 3. Relationship between the standing crop(abundance) of diatoms and condition factor of Pacific oysters in Ladysmith Harbour(Quayle, 1969).

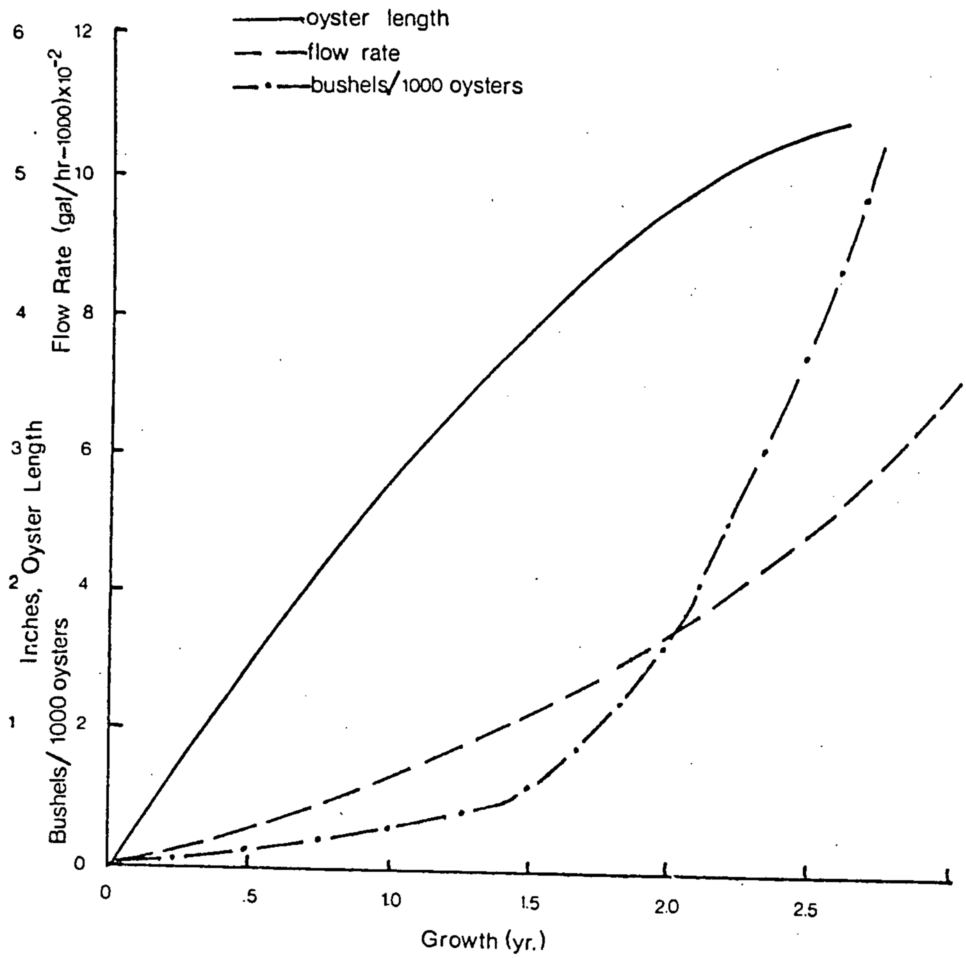


Fig. 4. Relationship between length, volume and flow in the growth of oysters (*Crassostrea virginica*) (Turner and Zahradnik, 1975).

between oyster oyster and environment should provide better growth.

Salinity

Salinity influences the growth and shell quality of Crassostrea gigas. Their overall condition if held at salinities less than 10ppt for more than two weeks will drop(Quayle, 1969). Periodic flooding by major rivers draining into estuaries can kill an oyster population if low salinity is prolonged(Butler, 1952; Andrews, Haven and Quayle, 1959). But, the Pacific oyster is able to withstand salinities as high as 33ppt and survive freshwater exposure up to 8 hours per day(Quayle, 1969).

Shell quality is adversely affected by extreme high and low salinity. Conditions of low salinity produce a smooth soft shell and high salinity produces a hard, brittle shell(Quayle and Smith, 1978). Gametogenesis and spawning is inhibited by prolonged salinity less than 6ppt(Butler, 1949). Quayle(1969) reported the level for feeding, growth and breeding is between 20-30ppt. Salinity requirements are easily met in the coastal waters of the province. Problems can be encountered when dealing with estuarine environments.

PH

Proper pH is generally not a problem in the marine environment since the pH of the open ocean ranges between 7.5-8.5 and may decrease to 7.0 or lower in tidepools, bays and estuaries due to dilution and/or the production of hydrogen sulphide(Sverdrup, Johnson and Fleming, 1942). The pH range for normal growth of Crassostrea virginica is 6.75-8.75 with growth rate dropping at a pH below 6.75(Calabrese and Davis, 1966). Low pH also inhibits spawning(Prytherch, 1928). Adult American oysters(Crassostrea virginica) kept at a pH of 4.25 remained open an average of 76% of the time but pumped only 10% as much water as controls; oysters at pH 6.75-7.00 intially pumped more vigorously than controls but the rate later decreased(Loosanoff and Tomers, 1947).

Substrate and Overcrowding

Shell shape is influenced by the type of substrate and degree of crowding. A hard surface produces a fluted, round and deep shell(Quayle and Smith, 1978). Oysters grown densely lead to poor growth and mortality due to a inhibition of the flow of phytoplankton over the oyster, waste removal and renewal of oxygen. An overpopulation of oysters in a sheltered bay or inlet is thought to affect primary production by reducing the amount of food available to each oyster. Uyeno et al.(1970) found that dense aggregations of filter feeders and their metabolic wastes can lead to local reductions in oxygen and phytoplankton concentrations. Large dense culture operations in areas having limited water circulation release such large amounts of excretory products that they may have to be moved periodically to avoid self-inhibition of growth. Faeces and pseudo-faeces require oxygen for biodegradation causing low oxygen and high ammonia and the possibility of the development of poisonous hydrogen sulphide where shallow water and poor flushing is present(Korringa, 1976). This may account for the observed slower growth in mid sections of trays or strings of shells(Korringa, 1976).

The number of oyster are an important variable in terms of performance and size for handling. Estimation of the size of an oyster population that an area can support should be made before any large scale venture is launched.

Fouling, Disease and Predation

Under natural conditions oysters are killed or crowded out by other marine animals reducing quality, percent survival or growth rate. In the culture situation fouling competitors can inhibit the distribution of food through the unit and interfere with the removal of wastes. Fouling, disease and predation decrease the productivity, compete for food and space and increase the resistance to free flow of water through the facility.

A)Predators

Oyster drills are univalve snails that actively prey on shellfish. They possess an extendable toothed rasping apparatus capable of drilling a hole through the shell and tearing at the meat. There are only two species in British Columbia and both were introduced from Japan(<u>Ocenebra japonica</u>) and the Atlantic coast(<u>Urosalpinx cinera</u>). <u>Ocenebra japonica</u> is found in Boundary Bay, Ladysmith Harbour, Crofton, Thetis Island and Comox(Quayle, 1969). <u>Urosalpinx cinera</u> is found in Boundary Bay only(Quayle, 1969). Drills do not pose a serious threat to the industry at present.

The boring sea worm(*Polydora cilitata*) is a polychaete having a freeswimming larva that setttles on the surface of oysters. They make shallow burrows near the shell edge and sometimes may perforate the shell. The oyster re-directs growth to repair the damage.

The parasitic copepod(*Myticola orientalis*) was introduced from Japan with the importation of seed oysters. It is a minute organism occurring in the small intestine of various molluscan species usually near the anus where it holds its position by special hooks. The highest recorded infecton rate of Pacific oysters is 20%, but so far there is no evidence that it causes mortality or has a serious effect on oyster condition(Quayle, 1969).

Starfish pose a serious threat to bottom culture operations. The active starfish population on the coast is made up of the ochre star(*Pisaster ochroceus*), the pink star(*Pisaster brevispinus*), the mottled star(*Evasterias troschelli*) and the sun star(*Pycnopodia helianthoides*). The starfish problem is eliminated with off-bottom culture.

There are three species of crabs that open and feed on oysters and oyster seed by cracking the shell edges with their claws. They have not posed a serious threat but occasionally have been destructive to young seed. Again, the problem is eliminated in off-bottom culture.

B)Fouling

Other organisms such as: sea squirts, shipworms, barnacles, mussels, tubeworms, hydroids, algae and gastropods compete for food and space with the oyster. Their abundance can crowd out the oyster, adversely affect shell shape and meat quality of those destined for the half-shell market. At present the control of fouling requires intense labour and materials handling. An efficient means of fouling control is the key to minimize labour and materials handling intenseness of half-shell operations.

GROWING SYSTEMS

The Pacific oyster may be grown in-situ or in land based containments with seawater pumped in. The author is of the opinion that land base operations might incur high capital costs and operating expenses proving to be uneconomical in British Columbia. In-situ cultivation eliminates a certain degree of reliance upon advanced technology and the back up requirements that must accompany it. Costs can be minimized by using the natural environment to its fullest whenever possible. Fortunately use of foreshore by oyster culturalists in the province has not reached a social confrontation stage as on the east coast of North America and in Washington and Oregon states. In the future such pressures may force the use of land based systems.

Traditionally oysters have been grown on the bottom and shucked for their meat. The bottom culture of oysters has a long history in France, Portugal and Britain. Eventually the European techniques were transferred to the east coast of North America with an added degree of mechanization. In New England considerable investment has gone into dredges, vessels and divers for benthic oyster culture. The recent more lucrative half-shell trade caters to the gourmet cuisine of restaurants and meat counters. Oysters served on the half-shell bring a higher price than shucked meat, but the grower must adopt techniques that will produce a quality shell.

For the half-shell market, the placing of seed oysters on the bottom in North America has not been successful due to starfish predation, siltation, intense cultivation requirements and exposure to waves and ice(Galtsoff, 1956; Shaw, 1962 and Engle, 1966). Intense bottom culture entails declustering, thinnings, transplanting and resulted in a complicated costly operation. The materials handling, labour demands, the need for "unusual" technology and the long growing period raise questions as to the viability of bottom culture. Substrate variability, siltation, benthic predators, wave action and fouling reduce the possibilities of producing a quality oyster.

The bottom culture of half-shell oysters is not practical in British Columbia. The majority of prime tidal flats are located in estuarine environments in the southwestern portion of the province. Unfortunately these areas are succumbing to the pressures of encroaching industry and urbanization. This has forced closure of many productive oyster grounds due to pollution by domestic and industrial influences. By 1970 approximately 40% of the provinces viable oyster grounds were closed as a result of such pollution(Matthiessen, 1970). Charman and Smith (1976) indicated that there is little suitable intertidal ground remaining and more extensive and efficient use is possible only by off bottom culture techniques. Clean oyster ground must also be brought into production further up the coast of Vancouver Island and the mainland to escape the impact of domestic and industrial pollution.

There has been an increasing interest in off bottom culture in North America over the last decade due to the loss of oyster bottoms, an oyster shortage, increased market values and the commercial interest in oyster seed production(Shaw, 1969). It represents a method of controlling predation, siltation, permitting the farming of a greater number of animals per unit area. The off bottom techniques provide for a three dimensional use of the entire water column with yields as much as ten times that of bottom culture(Quayle, 1971). Studies at Cape Cod, Massachusetts confirmed growth rates were double that of bottom culture (Crassostrea virginica), meat quality was improved, mortality reduced, increased production per unit area and that such techniques were economically feasible(Shaw, 1962; 1963; 1965; Shaw and McCann, 1963). Quayle(1969) found that Crassostrea gigas cultured off the bottom reduced the growing time to marketable size from three years to one to two years. Additional studies reconfirmed faster growth rates, improved meat condition, higher percent survival and formation of a well shaped, deeply cupped shell with the off bottom culture of Crassostrea gigas (Quayle, 1971).

Techniques of off bottom culture may entail using various types of racks or trays. Rack culture is practiced in Australia where it reduced the problems of bottom consistency, tidal height limitations and the predator problems. This technique is not practical in British Columbia due to the lack of extensive tidal flats and the presence of an active starfish population.

Tray culture is a recent development in North America on both coasts using MacNicol, Nestier or individual grower tray designs. Tray culture offers protection of the oyster crop and a faster growth rate if the trays are held off the seabed. Parsons(1974) suggested that the water flow above and below the oysters grown off bottom contributes to the faster growth.

The "accepted" practice is to stack trays in layers of five or six suspended in the water column by raft or longline floatation. The raft technique is self explanatory but it is worth mentioning that it requires sheltered areas and a fair capital investment in materials and assembly. The longline technique is a means of exploiting marginal areas. It is cheaper to construct, to maintain and withstands weathering. The capital cost savings and greater life expectancy compensate for the disadvantage of the units perhaps being harder to handle when it comes to lifting for cleaning, sorting and harvesting.

The existing tray designs have not been without problems. Different growth rates have been known to occur through the vertical series of trays. Further problems have also been encountered with biofouling that restricts water circulation and subsequently food distribution. There existed a definite need for a tray design to meet the demands of fouling control, adequate water circulation and be economically feasible to construct.

THEORY

PROPOSITONS

1. The growth and survival of shellfish is strongly dependent on the following factors: population density, water flow rates, containment type, substrate type, food availability, fouling accumulation, disease, pollution, toxins, temperature, pH and salinity(Loosanoff and Tomers, 1947; Quayle, 1951; 1969; Calabrese and Davis, 1966; Shaw, 1966; Lipovsky and Chew, 1972; Walne, 1974; Walker and Zahradnik, 1976 and Quayle and Smith, 1978).

2. The control of fouling accounts for much of the expense in oyster culture(Quayle, 1969).

3. The off-bottom culture of oysters provides a better quality shell, reduced time from seed to market, facilitates stock management, reduced mortality and increased production per unit area(Shaw, 1962; 1966; 1969; Shaw and McCann, 1963; Quayle, 1969; 1971; and Turner and Zahradnik, 1975).

4. The accumulation of fouling is dependent on the velocity of water passing over the exposed surface(Fink and Boyd, 1970 and LaQue, 1975).

ASSUMPTIONS

1. A culture facility that provides a relatively free exchange of water throughout(eg average velocity higher than that at which fouling organisms will "set") will reduce fouling, improve food distribution providing for better growth characteristics in the rearing facility.

2. The major construction materials for the units consist of: polypropylene net, styrofoam and rigid PVC which are non-toxic to oysters.

INFERENCES

1. Growing oysters in submerged plastic units using longline suspension, population density can be controlled and stock inventory maintained.

2. The flexible nature and "openess" of the design will allow a relatively free exchange of water and by locating in an area having distinct current action will tend to reduce fouling and improve growth characteristics when compared to calmer/sheltered environments and traditional methods of tray culture.

FUNCTIONAL SPECIFICATIONS

1. The design is to permit rapid uniform growth, a commercially acceptable survival rate and produce a marketable product competitive on the half shell market.

2. Allow utilization of the marine environment in three dimensions and the phytoplankton present in the upper layers of the water column. This permits a greater yield of oysters from the volume of water occupied by the system than would have existed in the natural state.

3. Augment water circulation to stabilize flow patterns in and around growing units such that "dead" areas are minimized. This is to provide a better distribution of feed, waste removal and maintains steady environmental conditions.

4. The design and the materials of construction are to reduce fouling and predation below levels which have plagued the state of the art to date.

5. For the purpose of management the design allows access to individual or groups of oysters for cleaning, thinning and observation.

OPERATIONAL FEATURES

1. The trays are to be located below the surface at a depth that affords protection from waves, the attachment of floating debris and maintains an atmosphere of inconspicuousness about the operation.

2. The tray design is to allow an optimum exchange of water between oysters and the environment for waste removal, oxygen renewal and providing even food distribution.

3. The rearing facility composed of trays suspended in layers are to be strong but flexible reducing resistance against fluid forces. The flexibility allows the system to bend and twist enhancing water flow.

4. Spacing between trays is to be adequate enough to permit easier access to oysters.

5. The oysters are to be grown in the facility from seed (30-40mm) to marketable size. Stocking density is to be at a point to reduce thinning and declustering.

6. Trays are to be suspended such that the frame of each layer only has to support its own weight.

STRATEGY BEHIND THE DEVELOPMENT OF THE REARING FACILITY

The purpose of the research was to develop a concept that would increase efficiency and reduce the costs of producing quality half-shell oysters. Initially a conceptual model was generated based on certain objectives, criteria and measures of effectiveness(Table 3). The concept generated areas of uncertainty(Table 4) that became the important questions to be answered by the field tests.

The decision was made to base the tray on a circular design. Frames based on other shapes involved numerous joints and therefore "inherit" a complexity in their construction and response to stress. In the circular frame stress is more evenly distributed instead of being concentrated at corner joints. Given the proper flexible material the circular frame is easier and cheaper to construct.

The size of the tray was based on the weight of oysters per tray and the material handling characteristics. The dimensional specifications were to create optimum conditions for assembly, handling by an individual worker and to maintain water circulation. Analysis of water circulation was beyond the scope of the research, therefore dimensions were based on the repetitive lifting and handling capability of the average human. Size was decided to be .91 meters in diameter, 5.1 cm in height with a 0.5 cm net mesh attached the frame. A single tray had a holding capacity of .668 square meters. The weight and dimensional specifications are within the materials handling

Table 3. Measures of effectiveness.

1. performance
2. reliability
3. maintenance
4. time
5. labour and materials handling
6. cost

Table 4. Areas of uncertainty.

1. materials of construction
2. spacing between trays
3. oyster density per tray
4. interactions between oysters environment and culture system

requirements set down in the beginning of the research. The circular shape requires only a single joint and the diameter is a maximum size that can be handled by a single worker without becoming too cumbersome. The 5.1 cm height was necessary to prevent spillage of seed oysters and the net mesh to allow exchange of water and contain the seed.

The individual tray represented the integral component in the design of the rearing facility. To make efficient use of the water column a system suspending a number of these trays vertically was proposed. The spacing between trays was set to allow access to each tray for inspection, cleaning or harvesting and offer minimal resistance to water flow.

The target goal for the tray assemblage was to be zero maintenance because outage times are costly and maximum profit goes hand in hand with maximum reliability. Along with this goal and the design criteria the initial cost, efficiency in the intended design, the predicted lifetime of the possible materials as influenced by corrosion along with the functional interactions of stress were considered.

STRUCTURAL CONSIDERATIONS

The strength of the material to be used in the structure was the critical concern because the design must be resilient to the forces and loads placed upon it. Stress(load per unit cross-sectional area) can cause deformation in the form of tension, compression or shear. Stress arises because of the dynamic or static loads upon the structure.

Static load is the weight of the structure plus added loads due to maintenance and operations. Dynamic loads vary with time and are a common consideration in off-shore structural design. They result from these dynamic forces and an estimate of this requires knowledge of the drag coefficient of the structural shape; unfortunately many structures are of the form that makes the determination too complex. Wave force determination requires data from longterm measurement of wave data for designing for wave height, wave spectrum or intermediate sea stages. These have direct application to an estimate of fatigue life of a structure. It was evident that a dynamic structural analysis was too complex to be dealt with in the research. The material selection procedure for the structure was based upon expected performance in the marine environment and response to the dynamic and static stresses the structure was to be exposed too.

MATERIAL CONSIDERATIONS

Metals

Selecting a metal for marine application requires knowledge of its corrosion behavior. Factors governing the corrosion of metal are complex and each environmental zone such as atmospheric, splash, tidal, immersed, deep ocean or mud have their own characteristics(Table 5). Design of the equipment to be used in the assembly must be tailored to meet a specific marine situation.

Sea water contains an abundance of halogen compounds such as chloride, bromide and iodide ions whose major effect on corrosion is principally through their power to cause localized breakdown of oxide films responsible for passivity and corrosion resistance of metals such as stainless steel. A second effect is the ability of these ions to form soluble acidic corrosion products such as ferrous chloride which interferes with the restoration of passivity(LaQue, 1975).

For service in the marine environment structural metals are usually provided with a protective coating combined with cathodic protection to achieve optimum corrosion control. Other metals have natural protective oxide films. These films can profoundly affect the corrosion behavior of metals and were it not for such films many common metals would corrode rapidly in the atmosphere and water. Oxidizing agents can sometimes retard corrosion by forming these protective films. Maximum corrosion retardance occurs if the oxide film has a structure which is coherent with that of the underlying metal if oxidation stops at

Table 5. Classification of typical marine environments (Fink and Boyd, 1970).

Marine Zone	Description of Environment	Characteristic Corrosion Behavior of Steel
Atmosphere (above splash)	Minute particles of sea salt are carried by wind. Corrosivity varies with height above water, wind velocity and direction, dew cycle, rainfall, temperature, solar radiation, dust, season, and pollution. Even bird droppings are a factor.	Sheltered surfaces may deteriorate more rapidly than those boldly exposed. Top surfaces may be washed free of salt by rain. Coral dust combined with salt seems to be particularly corrosive to steel equipment. Corrosion usually decreases rapidly as one goes inland.
Splash	Wet, well-aerated surface, no fouling.	Most aggressive zone for many metals, e.g., steel. Protective coatings are more difficult to maintain than in other zones.
Tidal	Marine fouling is apt to be present to high-water mark. Oil coating from polluted harbor water may be present. Usually, ample oxygen is available.	Steel at tidal zone may act cathodically (well) aerated) and receive some protection from the corrosion just below tidal zone, in case of a continuous steel pile. Isolated steel panels show relatively high attack in tidal zone. Oil coating on surface may reduce attack.
Shallow water (near surface and near shore)	Seawater usually is saturated with oxygen. Pollution, sediment, fouling, velocity, etc., all may play an active role.	Corrosion may be more rapid than in marine atmosphere. A calcareous scale forms at cathodic areas. Protective coatings and/or cathodic protection may be used for corrosion control. In most waters a layer of hard shell and other biofouling restricts the available oxygen at the surface and thus reduces corrosion. (Increased stress on structure from weight of fouling must be provided for).
Continental-shelf depth.	No plant fouling, very much less animal (shell) fouling with distance from shore. Some decrease in oxygen, especially in the Pacific, and lower temperature.	
Deep ocean	Oxygen varies, tending to be much lower than at surface in Pacific but not too different in Atlantic. Temperature near 0 C. Velocity low; pH lower than at surface.	Steel corrosion often less. Anode consumption is greater to polarize same area of steel as at surface. Less tendency for protective mineral scale.
Mud	Bacteria are often present, e.g., sulfate reducing type. Bottom sediments vary in origin, characteristics, and behavior.	Mud is usually corrosive, occasionally inert. Mud-to-bottom water corrosion cells seem possible. Partly embedded panels tend to be rapidly attacked in mud. Sulfides are a factor. Less current than in-seawater is consumed to obtain cathodic polarization for buried part of structure.

the proper thickness(eg. oxides of aluminum and chromium form coherent films on the base metal preventing the formation of cracks and therefore these metals are resistant to corrosion(Mellan, 1976).

A lower availability of oxygen will also reduce the protective effect of oxide films. With stainless steel oxygen availability retards corrosion by development and repair of oxide films responsible for passivity(LaQue, 1975). A surface within a crevice(beneath a lap joint rivet or washer) having limited access to dissolved oxygen becomes anodic to the surface outside the crevice accelerating corrosion within the crevice. With plain carbon steel the opposite effect is felt where oxygen accelerates corrosion by serving as a cathodic depolarizer(LaQue, 1975).

A. Galvanic Attack

Sea water is an excellent electrolyte with severe corrosion occurring when two different metals are coupled together(Table 6). It is the high electrical conductivity of sea water that permits large areas to take part in corrosion. One metal in the couple will become anodic to the other and greater the difference in potential the greater will be the acceleration of attack on the anodic member. A single metal may also develop local anodes and cathodes when first immersed because of the compositional or other variations on a metals surface(Fink and Boyd, 1970). Galvanic attack can be controlled by covering the cathode with an insulating barrier breaking the electrical circuit.

Table 6. Corrosion factors for carbon steel immersed in seawater (Fink and Boyd, 1970).

Factor in Seawater	Effect on Iron and Steel
Chloride ion	Highly corrosive to ferrous metals. Carbon steel and common ferrous metals cannot be passivated. (Sea salt is about 55 percent chloride.)
Electrical conductivity	High conductivity makes it possible for anodes and cathodes to operate over long distances, thus corrosion possibilities are increased and the total attack may be much greater than that for the same structure in fresh water.
Oxygen	Steel corrosion is cathodically controlled for the most part. Oxygen, by depolarizing the cathode, facilitates the attack; thus a high oxygen content increases corrosivity.
Velocity	Corrosion rate is increased, especially in turbulent flow. Moving seawater may (1) destroy rust barrier and (2) provide more oxygen. Impingement attack tends to promote rapid penetration. Cavitation damage exposes fresh steel surface to further corrosion.
Temperature	Increasing ambient temperature tends to accelerate attack. Heated seawater may deposit protective scale, or lose its oxygen; either or both actions tend to reduce attack.
Biofouling	Hard-shell animal fouling tends to reduce attack by restricting access of oxygen. Bacteria can take part in corrosion reaction in some cases.
Stress	Cyclic stress sometimes accelerates failure of a corroding steel member. Tensile stresses near yield also promote failure in special situations.
Pollution	Sulfides, which normally are present in polluted seawater greatly accelerate attack on steel. However, the low oxygen content of polluted waters could favor reduced corrosion.
Silt and suspended sediment	Erosion of the steel surface by suspended matter in the flowing seawater greatly increases the tendency to corrode.
Film formation	A coating of rust, or rust and mineral scale (calcium and magnesium salts) will interfere with the diffusion of oxygen to the cathode surface, thus slowing the attack.

B. Crevice Attack

Metals that require plenty of oxygen such as stainless steel and aluminum, to continuously repair breaks in the oxide film and maintain passivity tend to be susceptible to crevice attack.

Crevices develop because of design features such as gaskets, lap joints, under the head of fastenings, gaskets and under fouling organisms. The crevice can be formed between metal and non-metal, between two pieces of the same metal or dissimilar metals where the effect can be increased. If the oxygen in the stagnant water of the crevice is consumed breaks in the passive film occur at a higher rate than fresh water can diffuse in and rapid corrosion results. Occasionally the crevice can become anodic and because of its small area with respect to the outside exposed sea water surface(the cathode) increases the rate of local attack.

C. Pitting, Impingement and Cavitation

Pitting is a localized surface corrosion favored by relatively stagnant conditions and the presence of heavy metal ions such as copper or local deposition of foreign matter.

Impingement attack occurs in metals sensitive to sea water current velocity. When rapidly flowing sea water in association with bubbles impinges against a metal surface protective oxide films may be destroyed and the metal locally attacked.

Cavitation is similar to impingement attack except higher water velocities are involved. Under conditions of water flow bubbles collapse on the metal surface and if the metals are unable to withstand the combined mechanical and electrochemical forces associated with the hammering effect of the collapsing bubbles severe corrosion results. Collapse of these bubbles passing at a high speed over a surface will develop low pressures in sections of a metals' surface causing flaking of the surface.

D. Fouling and Scale Forming Compounds

Fouling is a major factor to be taken into consideration when designing marine facilities. It can overload a structure with extra weight or promote corrosion by creating crevices within which susceptible materials such as stainless steels will suffer accelerated attack.

Maintaining a metal surface free of fouling is necessary when dealing with stainless steel. Passivity of the oxide film is maintained by keeping the surface clean and free of biofouling and deposits. A sea water velocity of 1.5 m/s or higher will prevent fouling and promote passivity of austenitic grades of stainless steel(Fink and Boyd, 1970). Flow above this critical rate generally must be continuous or organisms become attached during periods of no or low velocity flow(LaQue, 1975).

In the case of plain carbon steel hard shell varieties of mussels can reduce the corrosion on steel by reducing the velocity of oxygen carrying water, acting as a diffusion barrier to oxygen at cathodic sites. The cathodic sites may also develop a calcium carbonate mineral scale providing additional protection. Calcium, magnesium and strontium in sea water along with carbonates can be beneficial in retarding corrosion by offsetting the acceleration effects of chlorides through the formation of adherent protective calcareous deposits(LaQue, 1975). These deposits have high electrical resistance and reduce current flow in local action and galvanic cells by reducing the effective cathode area(LaQue, 1975).

Metal Types

A. Stainless Steel

Stainless steel comes in three grades: martensitic, ferretic and austenitic. A sea water velocity of 5 fps or higher will prevent fouling and promote passivity of austenitic grades of stainless steel. Martensitic and ferretic grades are not recommended for submerged marine application(Fink and Boyd, 1970).

Stainless steels find only limited application in the marine environment. They do well where passivity of the oxide film can be maintained by bold exposure of the surface. These steels depend on their passive film for resistance to corrosion. Exposed surfaces or surfaces within a crevice can lose their passivity in the absence of sufficient oxygen to preserve it. The potential difference between the active and passive surfaces can exceed 500mV, therefore crevice corrosion of stainless steel is much more severe than with ordinary steel(LaQue, 1975). High velocity water is favorable because it brings in oxygen promoting the repair of breaks in the film. Quiet sea water can promote pitting(figure 5).

B. Nickel Alloys

Nickel by itself does not have a good resistance to sea water especially under low velocity conditions. When molybdenum is added it tends to virtually eliminate local attack and the addition of chromium further increases the corrosion resistance of the metal. Thirty to forty percent nickel and 20-30% chromium alloy still depends on a passive film for protection in sea water. This alloy tends to pit in sea water(Fink and Boyd, 1970). Nickel base alloys with 15% more chromium and 10% more molybdenum present(called Hastelloy C) are completely resistant to all environments(Fink and Boyd, 1970)(figure 5).

C. Copper Base Alloys

The copper base alloys are among the most resistant to corrosion in the marine environment. The cupronickels are among the most resistant and show less tendency to pit(Fink and Boyd, 1970). The protective film of cuprous oxide forming on the surface of these alloys protects against corrosion and fouling. A corrosion situation can develop with copper alloys where corrosion products containing a high concentration of copper ions become trapped within a crevice while these ions are continually being swept away from surfaces outside the crevice causing accelerated corrosion just outside the crevice (LaQue, 1975). This develops because a copper alloy surface in contact with a solution containing a low concentration of copper ions becomes the anode in a cell where the cathode is a surface of the same alloy in contact with a solution of higher copper ion concentration(LaQue, 1975).

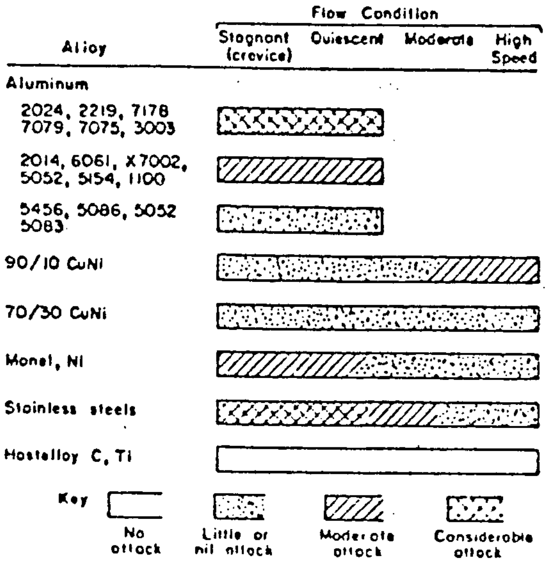


Fig. 5. Comparative localized attack(crevice corrosion and pitting) of some important marine alloys as a function of seawater flow conditions(Fink and Boyd, 1970).

D. Aluminum Alloys

Those alloys containing silicon, manganese and magnesium are the most resistant to corrosion in sea water(Mellan, 1976). Alloys containing copper or zinc have the lowest corrosion resistance(Alcan Report, 1970).

The alloys Al-Mg 5052, 5083, 5347 5474(wrought alloys) and Alcan A320, 332, AAF514.0(foundry alloys) have the highest corrosion resistance(Alcan Report, 1970). When dealing with alloys it must be kept in mind that as their strength increases aluminum alloys show a tendency toward increased brittlement, lower notch toughness and questionable fatigue life(Evan and Adamchak, 1972).

E. Carbon and Low Alloy Steels

A low alloy steel offers no particular corrosion advantage over carbon steel in submerged marine applications. In most situations a rust coating, calcareous scale or a layer of fouling will develop in a few months on the surface and provide an interfering protective barrier. Various factors such as chloride ions, oxygen, temperature, fouling and stress can affect the performance of carbon steel in the sea(table 6).

Plastics

Introduction

The term plastic applies to a large and varied group of synthetic materials that are processed by molding or forming to a final shape. Chemically, plastics are composed of chain-like molecules of high molecular weight called polymers. The polymers have usually been built up from simpler chemicals called monomers. Different monomers or combinations of monomers are used to manufacture a specific type of plastic. By changing the molecular weight and chain geometry of a polymer different properties can be achieved. The properties can be further modified by adding fillers and plasticizers; responses that result from these mixtures necessitates a rather broad approach to exposure to pin down the environmental application of the plastic. It becomes a matter of finding the material with all the essential properties wanted for the product at the lowest final unit cost.

Plastics offer many amenable advantages for use in structural design. Structural plastics have a higher strength to weight ratio than most other engineering materials. They are attractive in appearance and can easily be made translucent or pigmented to give desired tints or colours to the structure. The resistance as a class of materials to environmental corrosion is far superior to all but the most highly corrosion resistant structural metals(Riddell, 1973). They offer low weight, simpler handling, lower transport costs and off-site prefabrication.

The structural designer must be aware of the various differences associated with a particular plastic(Table 7). Plastics unique properties are quite separate from metals. Metals and other hookean materials used in structures are designed with stress strain modulus, yield strength and proportional or elastic limit because these properties are relatively independent of time and temperature(Riddell, 1973). Plastics, rubbers and elastomers do not have linearly related properties to applied loads(Galanti and Mantell, 1965). Materials which do not conform to a simple linear relationship between load and elongation are termed viscoelastic or non-Newtonian(Ganlanti and Mantell, 1965). Viscoelastic behavior is partly elastic and partly that of a viscous fluid. Initial deformation occurs instantaneously(elastic response) upon application of load, then increases at some decreasing rate of time. This is followed by a small but continuous deformation(creep) with time. Removal of the load leads to instantaneous recovery, a time dependent recovery and some permanent deformation. The viscoelastic behavior of plastics makes stress strain data of little use in the design of plastic structures(Riddell, 1973). One must have data which adequately describes the materials response to load with respect to both time and temperature. Relatively hard, brittle and rigid plastics have fairly consistent stress-strain curves, but many show variability and a strong dependence of stress-strain data on temperature and loading rate(Riddell, 1973).

Creep rupture tests are the only valid criteria for the strength of plastics since stress-strain properties such as tensile and flexural strength do not predict longterm rupture

Table 7. Differences to be considered when defining the needs of a plastics oriented structure.

A) Stiffness or flexibility

B) Temperature range in the use environment

C) Tensile range

D) Flexural range

E) Impact range

F) Intensity, frequency and duration of load

G) Stress crack resistance

H) Weather and sunlight resistance over time

I) Design limitations due to materials

J) Methods and economics

K) Material cost/gm/cu cm

L) Material cost per unit strength

performance or necessarily rank materials in order with respect to performance(Riddell, 1973).

Most plastics will also absorb moisture and as a result suffer degrees of deterioration in their physical properties(Smith, 1968). The sensitivity of fibers to moisture effects is dependent on the composition as well as the geometric arrangement of molecular structure of the fiber. This is a serious consideration for a structure designed for marine application. The responses of plastic in many real stress situations are too complex to be stress analyzed and therefore require an empirical approach to part development.

A. Mechanical Behavior of Plastics(Benjamin, 1969)

1. The stress/strain curves are not usually linear up to yield. In some cases there may be no yield at all. This of course depends on the type of plastic. For example, thermoplastics show brittle fracture with absence of yield at low temperatures and higher straining rates.

2. The modulus of elasticity in tension is not necessarily the same as that in compression which is true for most plastics.

3. The modulus of elasticity is very low. Deflections can be so large as to seriously limit the carrying capacity of the structure. This disadvantage can be offset by using structural forms which give added stiffness by virtue of their shape.

4. The mechanical behavior of plastics is affected by the rate of straining of the material. At very high straining rates, the thermoplastics tend to show brittle fracture with absence of yield. It is of interest to note that except for very high rates of strain (such as impact), the mechanical properties may be assumed to be unaffected by this factor. The exact mechanical behavior of plastics, even if fully known over a large range of straining rates would not be very useful.

5. The mechanical behavior of plastics is affected by temperature. The general affects of temperature are to reduce the elastic moduli and ultimate strength of the material. At very low temperatures the thermoplastics show brittle fracture and care should be exercised in their use.

6. Plastics creep considerably under load with time. This is dependent upon the stress level and the ambient temperature. Some fiber reinforcement decreases creep with respect to time.

7. Plastics show a reduction in ultimate strength with time even under static loading conditions.

8. The sum total of all the properties of all plastics are subject to alteration depending upon the environment in which they are in use.

B. Fatigue Analysis

Under repeated cyclic stress, any material will fail in time at stresses considerably below its static breaking strength. The fatigue behavior of plastics is more complex than that of metals because of their viscoelasticity. The deformation of plastics under stress is time dependent due to the presence of internal flow mechanisms that are negligible in structural metals. Single speed type of tests that are commonly used to characterize metals are inadequate for plastics. A more complicated testing program over much longer periods of time is required to generate the necessary design data. In this study the author does not intend to become involved in such testing. The selection of materials and the assembly is based on available data of previous industrial research.

Types of Plastics Under Consideration

Selecting a plastic for use in a submerged marine application narrows the realm of plastics from which to choose. The material must be resistant to the absorption of moisture, the various chemical corrosive activities of sea water, abrasive actions and maintain sufficient strength and dimensional stability over a range of water temperatures from 2-25 degrees Celsius. Economically, the material should lend itself to prefabrication and be relatively low in cost when compared to a lifespan of 5-8 years.

A) Nylon

Nylon is a tough plastic having excellent resistance to wear and chemical corrosion. It has a low coefficient of friction and a tensile strength in the area of 100,000psi(Galanti and Mantell, 1965). Unfortunately nylon is hygroscopic and will absorb moisture producing dimensional changes making it unsuitable for use in a rigid submerged structure(Smith, 1968). The moisture it absorbs acts as a plasticizer lowering stiffness, strength and hardness. However, it represents a useful material for any small scale components in a system.

B) ABS(acrylonitrile-butadiene styrene)

This is a tough plastic having high rigidity and impact strength, fair chemical resistance and low moisture absorption(Guide to Plastics, 1970). The impact strength and low moisture absorption leads to a structure with good dimensional stability and abrasion resistance. However, the absorption of moisture in ABS can lead to a reduction in strength.

C) Vinyl Chloride Polymers(Rigid)

These are considered to be the most versatile of plastic materials. The versatility and wide applicability of PVC is due to a combination of moderate cost with a number of technical factors such as: good general properties as a plastic including chemical resistance, flame resistance, non-toxicity(E.P.A. Report, 1974), strength, moisture resistance and excellent outdoor stability(Table 8).

Rigid PVC is essentially chemically inert. Salt water does not degrade it and it has been shown not to be a threat to aquatic life(EPA Report, 1974). PVC has excellent aging properties, resistance to physical stresses and impact; has a high tensile and flexural strength(B.F. Goodrich Chemical Company Report, 1978).

It is essential that rigid unplasticized PVC be used in a marine application. Osmon et al.(1971) found that plasticized PVC is subject to deterioration by the breakdown mechanisms associated with the build-up of microbial growth(figures 6 and 7).

D) Polypropylene

Polypropylene is suitable for high moisture applications(Guide to Plastics, 1970). Water does not permeate the polypropylene fibers(Galanti and Mantell, 1965). It appears free of environmental stress cracking, has a low density, high

	ASTM Test Method	7082	8700A	8750	82662
Specific gravity, ±.02	D 792	1.47	1.35	1.38	1.36
Hardness, Rockwell R	D 785	107	107	113	—
Durometer D ±3	D 785	78	78	80	78
Compression strength, psi	D 695	10,100	8,600	9,600	10,100
Flexural strength, psi	D 790	16,200	11,500	14,500	16,200
Modulus of elasticity in tension, psi	D 638	410,000	340,000	420,000	410,000
Heat distortion temperature, °F, 264 psi	D 648	161	158	162	161
Izod impact strength, ft lb/in notch at −40°F	D 256	—	0.49	0.35	—
−20		0.81	—	—	0.81
+32		0.99	1.47	0.47	0.99
78		1.75	15.0	0.81	1.75
140		—	18.40	1.26	—
180		—	16.30	18.30	—
Tensile strength, psi	D 638				
at −40°F		—	.2,000	12,000	—
+32		—	7,600	9,000	—
78		7,100	6,200	7,300	7,100
140		—	3,400	3,600	—
180		—	2,200	2,500	—
Coefficient of thermal conductivity	D 177				
Cal/sec/sq cm/°C/cmx10^{-4}		4.5	4.5	4.2	4.5
Coefficient of linear expansion, in/in/°F x 10^{-5}	D 696	3.5	5.5	2.9	3.5
Flammability	D 635	All compounds self-extinguishing			

Table 8. The properties of rigid PVC(B.F. Goodrich report, 1978).

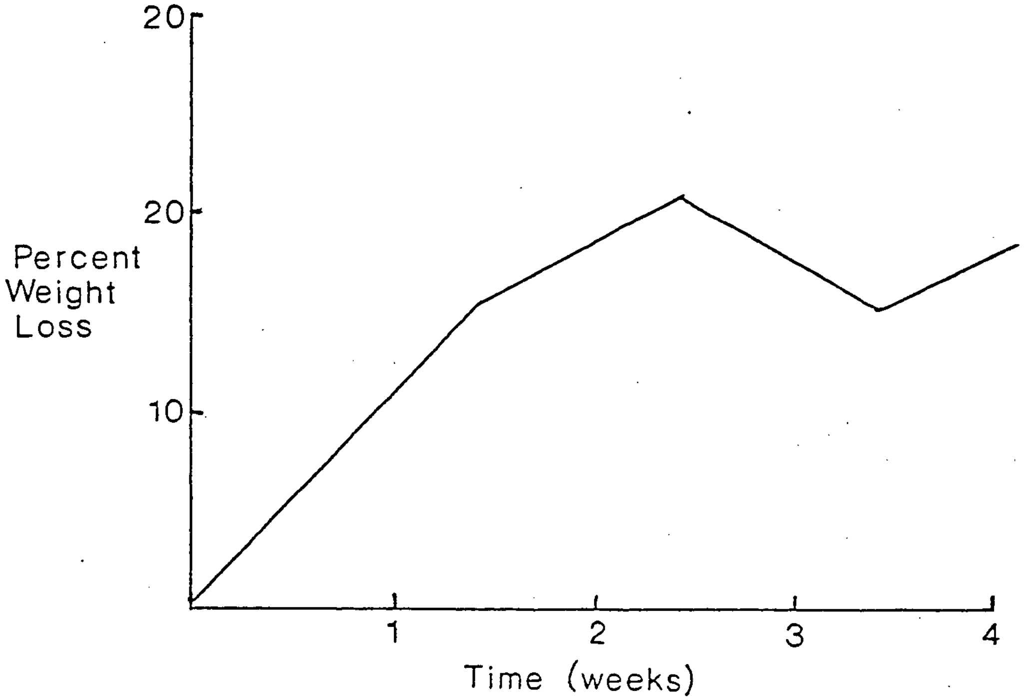


Fig. 6. Weight loss of plastic samples of various shapes incubated with Pseudomonas (Osmon et al., 1971).

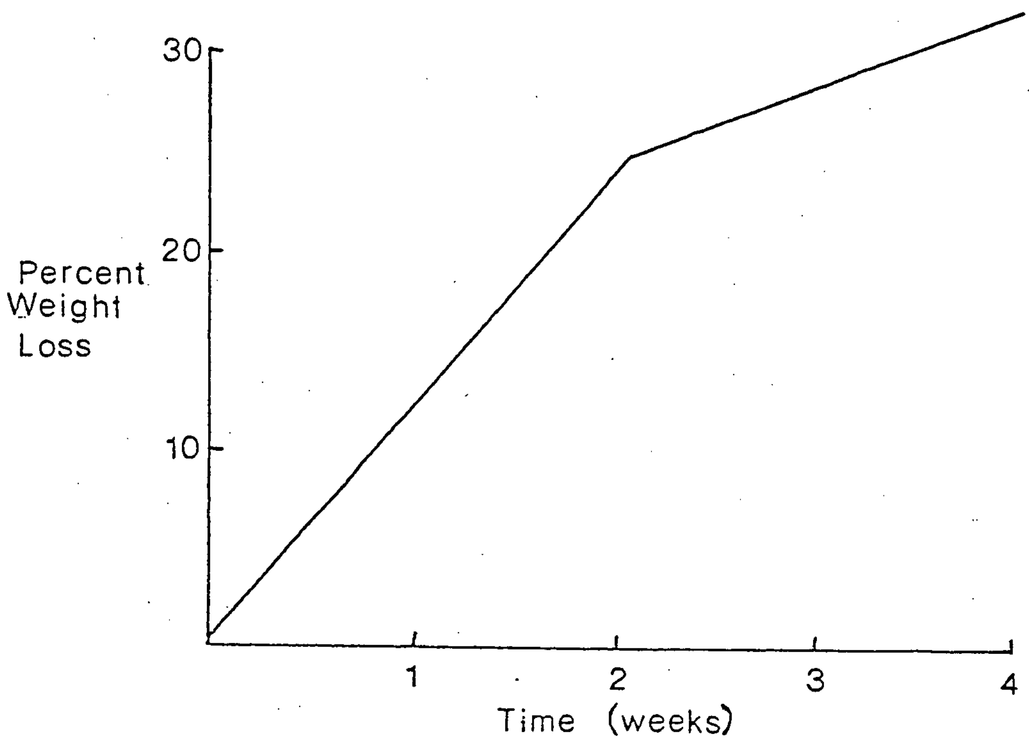


Fig. 7. Weight loss of plastic samples of various shapes incubated with fungi(Osmon et al., 1971).

tenacity and good abrasion resistance(Brydson, 1975). Polypropylene net has been tested by UMASS Aquacultural Engineering Lab in the marine environment and did not deteriorate in strength in over a year's exposure to salt water(Zahradnik, 1973).

E) Polyethylene

Polyethylene is a plastic with excellent toughness, being light in weight and easily processed at a low cost(Guide to Plastics, 1970). It provides good flexibility and chemical corrosion resistance. Unfortunately, the polymer has poor resistance to stress cracking(Guide to Plastics, 1970).

Mooring Lines

Lines are required as an essential component for the suspension of trays. What is needed are lines that will not stretch and possess the strength and resilience to hold the system together above and below the water. The choice of materials includes chain, metallic cable and synthetic fibers. Chain, because of its weight and low strength to weight ratio was not considered where lighter gear is required(Evan and Adamchak, 1972).

Metallic cables are susceptible to fatigue failures due to stress corrosion. Care must be taken to avoid abrasion if premature failures are to be prevented. Such cables are also vulnerable to dissimilar metal oxygen cell attack especially near terminal fittings, clamps and between wire strands. Cables formed from twisted wire strands present many opportunities for crevice corrosion which can be expected to occur with stainless steel cables in sea water. The attack often takes the form of tunnelling where individual wire strands suffer internal corrosion progressing within the wire from the first point of attack.

Most synthetic fibers are immune to fouling, decomposition and can be selected for little or no moisture absorption. They are light in weight and in the majority of cases are positively or neutrally buoyant. Synthetics are ideal for applications where shock loading and taut line constraints are present because of their elastic characteristics. Certain special braided synthetics have been developed to combat the problem of all twisted rope and cable, that of untwisting under load(Evan and Adamchak, 1972). In the application of synthetic lines to the oyster system a line is needed that has minimum elasticity and maximum tautness to maintain proper spacing between trays. Dacron, prolene(polypropylene) and manila may be of value when less elasticity is required(Wilson, 1969). Nylon can be eliminated because its wet-strength rating is 5-19% lower than the dry-strength rating(Wilson, 1969). Dacron rope has an effective quality between wet and dry weights and prolene rope has a wet-strength rating which is 5% greater than its dry-strength(Wilson, 1969).

The Tray

The continuous immersion of the tray in the marine environment makes it necessary to select materials that are able to withstand the corrosion and accumulation of fouling organisms. The severity of the marine situation dictates the elimination of metals and wood or the use of costly coatings. The tray design incorporates overlapping joints providing opportunities for starting points of crevice corrosion.

Based on the material survey of structural materials rigid PVC emerged as the best selection for frame construction. The only limit to its lifetime under such service is the deformation and loss of strength caused by the dynamic and static stresses that take place gradually with time. The life of the frame can range from 6-10 years depending on the loading rates and the character of the materials handling processes. PVC also becomes brittle while subjected to below freezing temperatures. Units would have to be handled discreetly during the winter months. While submerged the plastic would not be subjected to freezing temperatures and brittle behavior would not be a problem.

Rigid PVC forms are easily prefabricated by hot extrusion methods. Basically, the plastic material is forced through an orifice of the desired shape and the section required is obtained(figure 8). The PVC compound in granular or powder form is charged into the hopper and feeds through the hole in the barrel into the feed zone of the screw. The material is conveyed forward and at a certain stage depending on the nature of the compound, screw design and operating conditions; fuses to a continuous melt. The molten material is forced through a die to

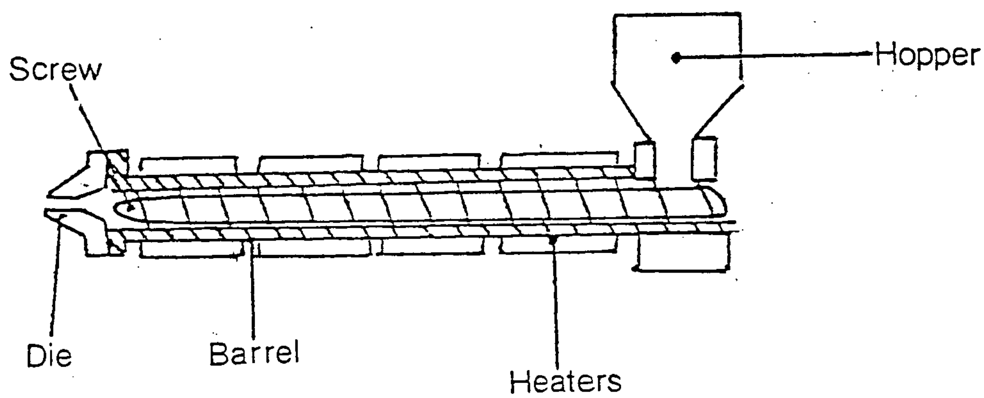


Fig. 8. General arrangement of a single-screw extruder.

form the required shape. The heat required to melt the plastic is supplied by heaters on the barrel of the machine and supplemented by the shear heat generated by the action of the screw. The dies for use with rigid PVC must be fully streamlined and free from hang-up points(Penn, 1971). Cooling, after the extrusion emerges from the die, is provided by blowing cold air over the barrel from blowers situated beneath the machine or by circulating cool water.

The most costly aspect of PVC manufacture is cutting the die($40/hr). One form requires one die, therefore the number of forms required in the tray must be kept to a minimum to reduce costs. Rectangular shaped frames involve a minimum of three dies and assembly of numerous joints. The circular frame requires only one joint and two dies. PVC is flexible enough to be formed into a circle and held in place by a copper burr riveted lap joint. The tray is composed of a rigid PVC flatbar, U-channel of PVC and 1.9 cm copper burr rivets(figure 9). The striations on the flatbar assist in securing the U-channel. The net mesh is 0.5cm polypropylene which is chemically inert, allows a free exchange of water and is inexpensive at 6 cents per square foot. Each tray requires a net mesh top to prevent spillage of young seed size oysters.

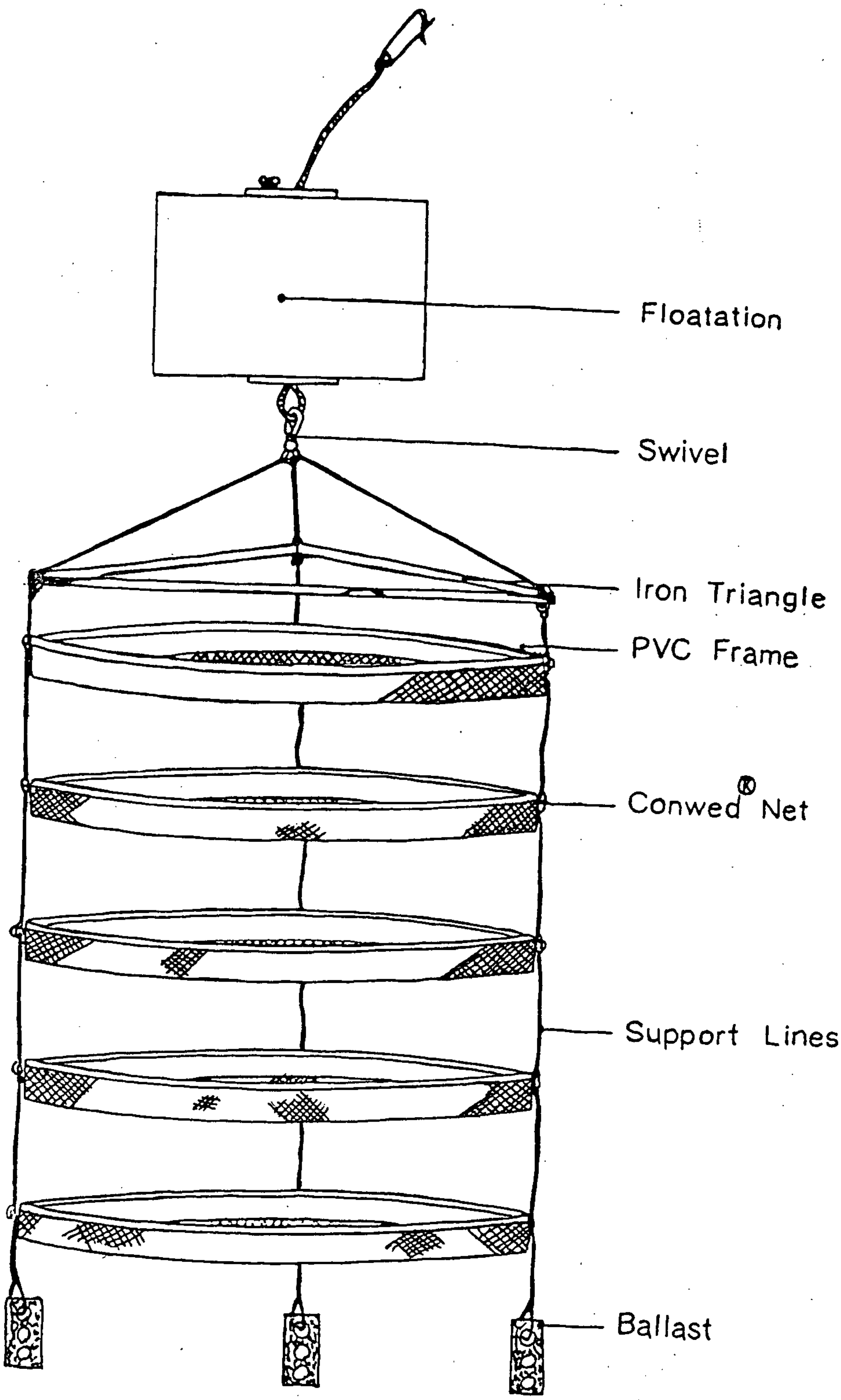


Fig. 9. The Suspension system.

The Suspension System

The assembled Suspension system illustrated in figure 11. Lines were of .64 cm polypropylene due to its low moisture absorption, high tensile strength, availability and resistance to corrosion and stretch. Connecting the tray to the lines was facilitated using nylon 5 cm cable ties(resistance to abrasion) and .95 cm corrosion resistant snap swivels. The triangular support frame topping off the structure was of plain 1.3 cm carbon steel angle(figure 10 and 11). Ballast was added to prevent tipping of the units situated in areas where currents are substantial.

The goal behind the suspension technique was to allow interaction between the facility and the environment. The incorporation of swivel connectors and spacing between trays was to enhance the passage of water, growth and waste removal and reduce the drag resistance compared to MacNicol and Nestier tray culture methods.

Fig. 10. The assembled Suspension system.

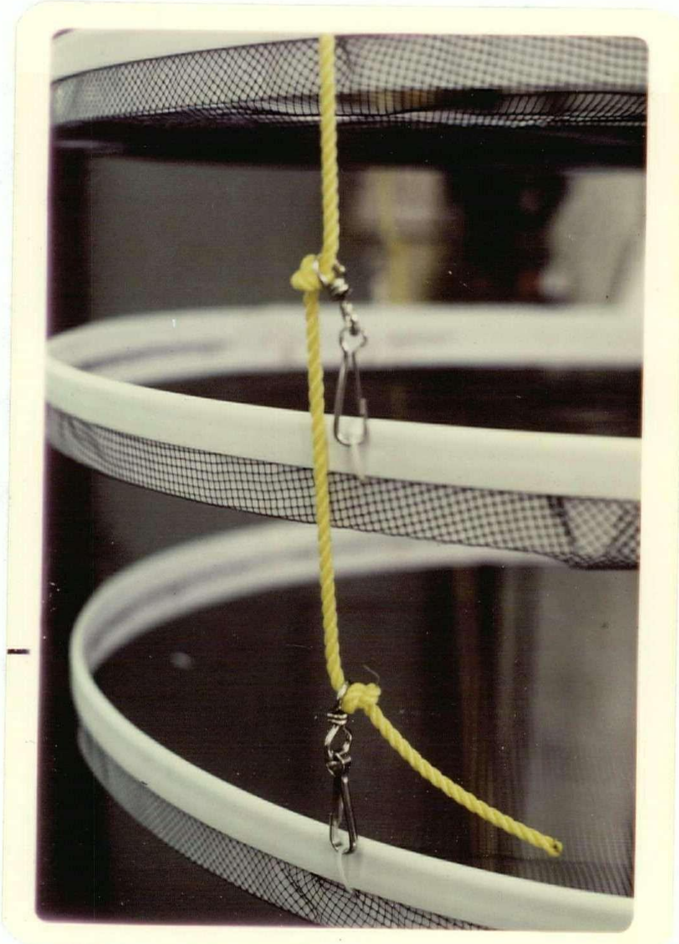


Fig. 11. Close-up of the Suspension system and attachment to the support lines.

MATERIALS AND METHODS

EXPERIMENTAL APPARATUS

The materials out of which the Suspension units were constructed consisted of copper rivets, rigid PVC, polypropylene net, polypropylene rope, nylon cable ties and galvanized halibut clips. These materials formed the six test units of five trays each(figure 10).

The Nestier trays were supplied by Mr. R. Paquin of Sunshine Seafoods Ltd.(figure 12). The MacNicol trays were supplied by the Spirit Cove Oyster Co-op(figure 13). Both tray types were manufactured out of formed plastics.

Access to the test area was accomplished using a 16 foot Bombard inflatable equipped with a 40 hp outboard. Growth was measured to the nearest millimeter using Vernier calipers.

Temperature and dissolved oxygen were measured using a YSI Model 57 Dissolved Oxygen Meter in combination with an in-situ YSI 5739 Dissolved Oxygen Probe . Salinity was determined with a YSI Model 33 S-C-T meter. The pH was measured using a Beckman pH meter(figure 14).

Nestier and MacNicol trays were lifted by hand for sampling and the experimental units were handled with the assistance of a portable davit(figure 15).

The test population of oysters (Crassostrea gigas) were composed of juvenile 30mm seed obtained from Pendrell Sound spatfall, 1977 using Chinese hat collectors. The sample juvenile population was chosen randomly from a seed population of 30,000. The adult population was selected randomly from 1000, 2 year old

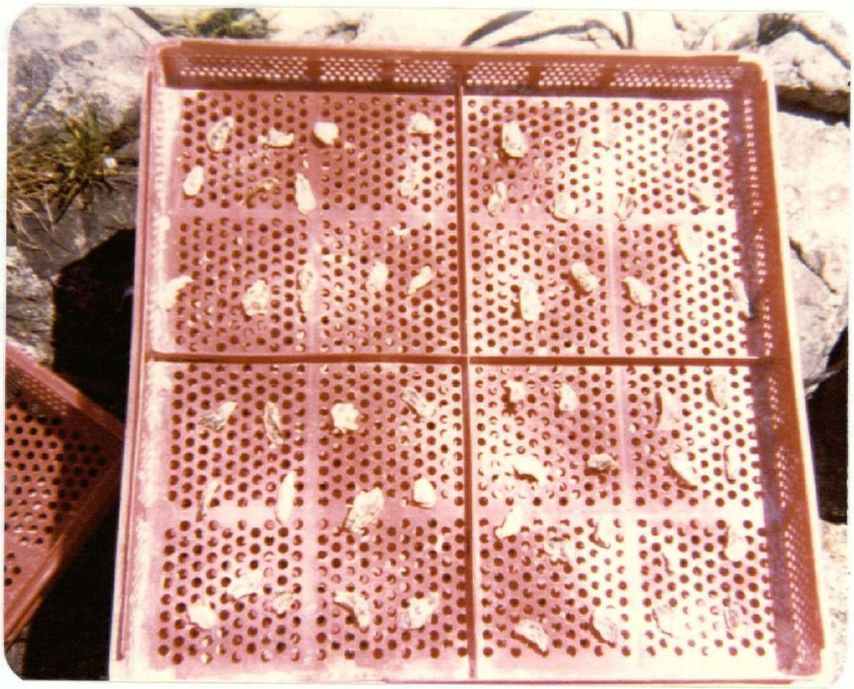


Fig. 12. The Nestier tray.

Fig. 13. The MacNicol assembly.

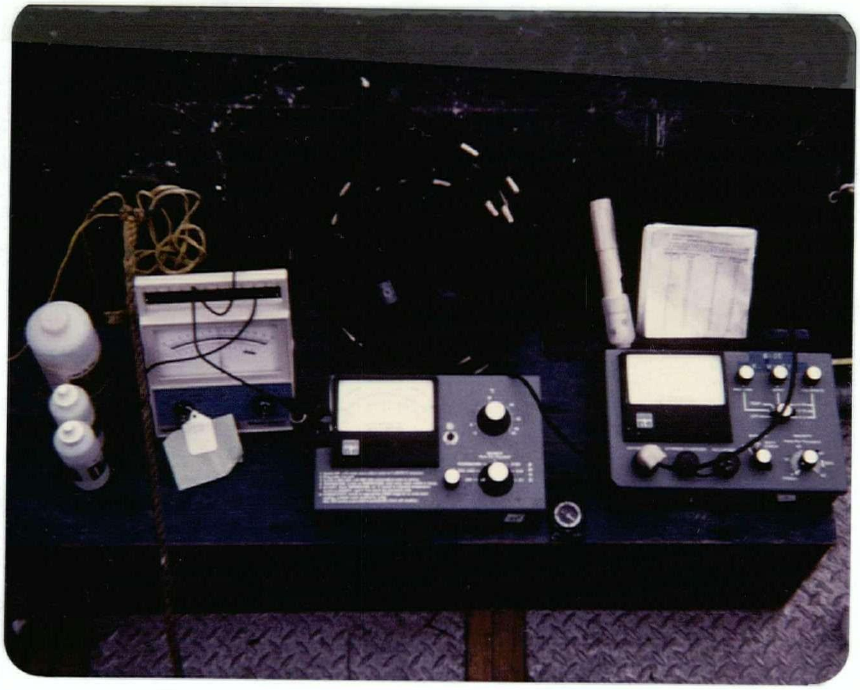


Fig. 14. Water quality monitoring devices.

Fig. 15. Davit system for handling the Suspension system.

adults grown in subsurface trays on site. Since the majority of growers in British Columbia use Pendrell Sound seed the growth characteristics obtained in these experiments are generally applicable as background information for culture system evaluation in the industry. This idea holds assumming the test population is of the same genetic stock as commercial seed obtained in the same area. It must also be kept in mind that growth characteristics are site specific and that it is indeed difficult to present a growth picture representative of all of British Columbia.

EXPERIMENTAL DESIGN

Experiments were carried out in the field on the oyster leases of the Spirit Cove Oyster Co-Op and Mr. Frank Cameron. The test areas were located in Okeover Inlet within Trevenen Bay bounded by Malaspina and Coode Peninsulas (figure 16).

Six operational units of the authors design were constructed with five trays per unit. Three units were located in the narrow channel among the Isbister Islands, where a substantial current flowed. This site is referred to as environment 2 in the following text. The remaining units were set in a calmer, sheltered area designated environment 1. At each site two Suspension units contained juvenile seed and the third assembly was stocked with adult oysters. Four Nestier and MacNicol systems also with five trays per unit were located in each type of environment along with the Suspension units for comparison. The five trays in each assembly are referred to as vertical positions 1 through to 5 numbered from top to bottom.

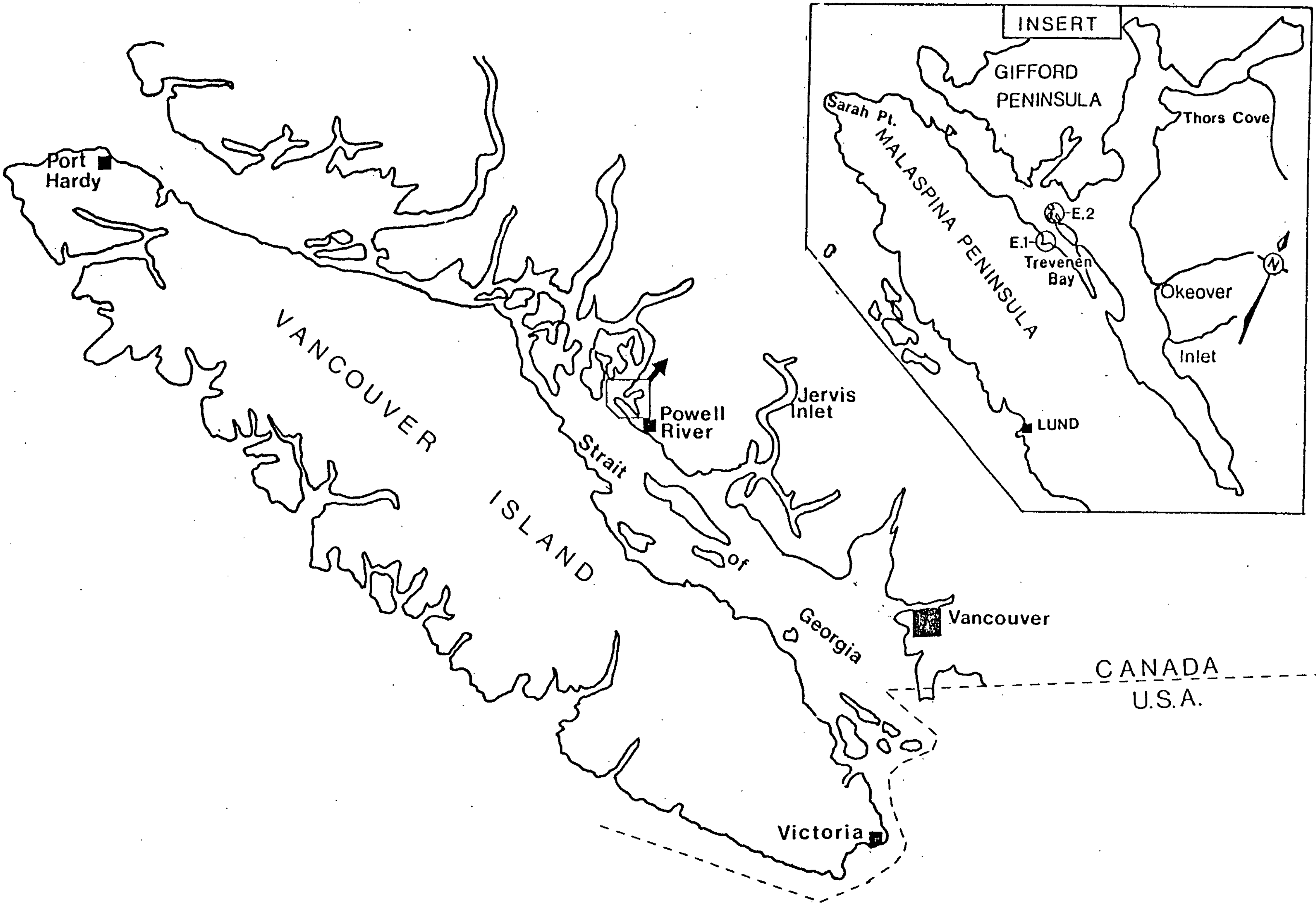


Fig. 16. Location of study areas.

Two of the four assemblies of each system type were stocked with juvenile seed and the remaining two with adult oysters. The complete array in both environments can be viewed in figures 17 and 18.

Tray performance was evaluated quantitatively by measuring growth of shell length, width and height to the nearest millimeter, monitoring meat condition index and analyzing the economics of each system. Performance was also determined qualitatively by the occurrence of fouling, material handling characteristics, system durability, oyster mortality and costs. MacNicol trays were stocked at 20 oysters per tray. The Nestiers at 52 and the Suspension units at 100. This represented a stocking density of 70 square centimeters per oyster in each system.

The entire experiment was set up as a completely randomized design to be analyzed by analysis of variance using UBC MFAV. UBC GENLIN was used to analyze condition index data. The object was to consider the effect of time, environment type, tray system and vertical position on the performance of the tray systems. Processing of the results by ANOVA indicated which factors and interaction terms were statistically significant. Those factors and interactions found to be statistically significant(alpha=.05) were further analyzed for evidence of practical significant differences. Practical significant differences were assessed by graphically plotting the mean values of the growth results for each factor and interaction term that could be plotted graphically, otherwise mean values were assessed separately. Practical significant differences were

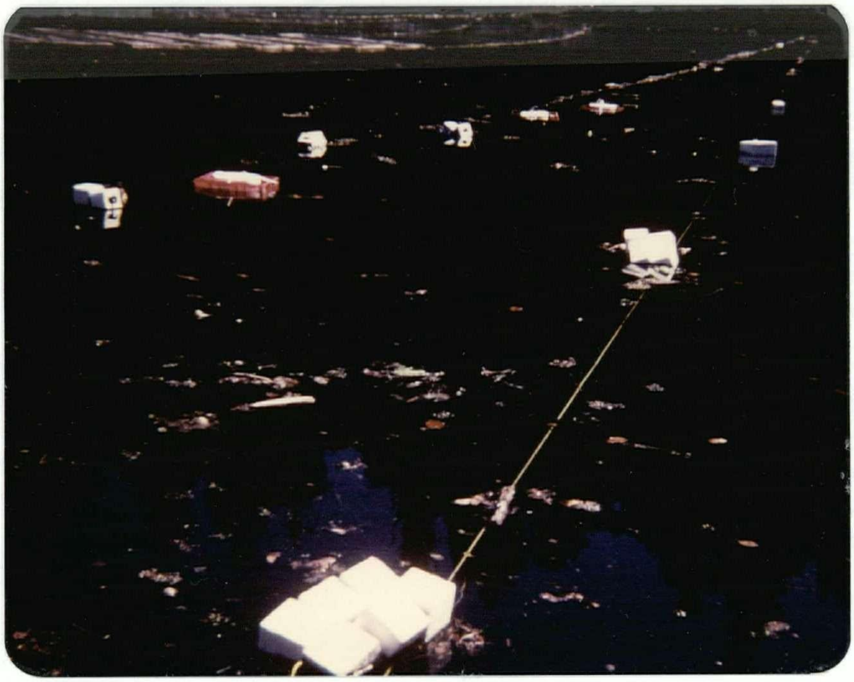


Fig. 17. The array in environment 1.

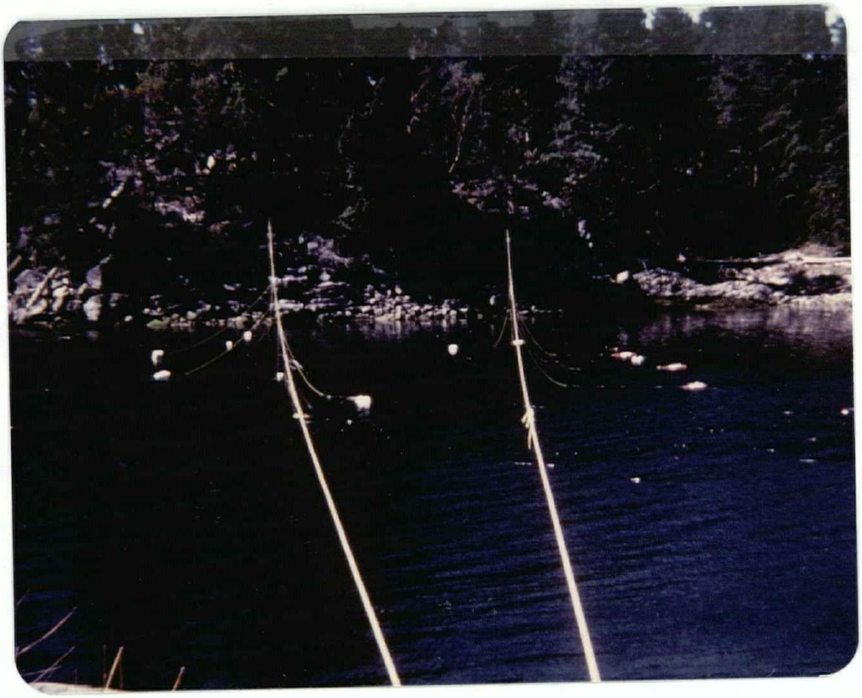


Fig. 18. The array in environment 2.

found if the mean values of plotted lines differed by more than 5 millimeters. The concept of practical significance was used to assess whether a factor and/or interaction term influenced oyster growth.

Background environmental parameters of temperature, Secchi disk, salinity, pH, dissolved oxygen, ambient weather conditions and chlorophyll levels were monitored during the sampling period. Intense sampling was carried out from June 4 to October 17, 1979. After this time units were left immersed to overwinter and subject to monthly examination. Growth measurements and environmental data were not taken during the winter due to severity and unpredictability of weather conditions and depressed shell growth in cooler water temperatures. During the winter months the goal was to observe if the test units would hold up under the stress of winter storms in the area.

DATA COLLECTION

Each tray system was subsampled at random for shell growth every second week from June 11 to October 17, 1979. Subsamples of ten oysters were taken from each of the growing systems, measured and returned to their respective trays.

Growth measurements for the Nestier and MacNicol trays were taken on Tuesdays followed by sampling of the Suspension units on Wednesdays. On occasion due to inclement weather or boat malfunctions sampling was not completed until Thursday. Condition index sampling began two weeks after adult oysters were stocked into the trays. Stocking was completed by June 11. Sampling took place every 2 weeks until mid-August. Two oysters were removed from trays in the MacNicol and Nestier systems and three were taken from Suspension trays. Oyster were bagged and placed on ice for 24 hours. Oysters were weighed unshucked on a Mettler balance then shucked with the assistance of a microwave oven. Empty shell weight was then taken and flesh was dried at 110 degrees Celsius overnight. Dried meat samples were then weighed and condition indices calculated. Condition index or condition factor was defined as the ratio of weight of dry meat to volume of shell multiplied by a factor of 1000. Trays were restocked with marked oysters of the same size and maturity to maintain stocking densities in each tray. Marking of the replacement oysters prevented them from being sampled at a later date.

Environmental data was recorded daily, Monday through Friday, between the hours of noon and 1300 hrs daylight saving time(DST). Chlorophyll samples were taken at mid-day on Wednesdays of each week from surface to 2x S.D. (Secchi depth) if depth permitted using a 3 litre Nansen bottle. If the depth was shallower than 2x S.D. The sample was taken from the surface to 1 meter off the bottom. The water samples were taken initially at just below the surface followed by 1 meter sampling intervals to the appropriate depth. With minimum exposure to light the contents of each Nansen cast was transferred to collapsible cleaned plastic water jugs(5gal cap) set within a "dark" box. Samples were kept cool and dark in this container and filtered within 3 hours. The filters used were 4.5cm Whatman GF/C glass filter paper following the method outlined in Strickland and Parsons, 1972. Upon completion of filtration, filters were placed in petri dishes; stored at -20 degrees Celsius until analysis at a later date. The chlorophylls were analyzed by November 1979 as outlined in the spectrophotometric determination of chlorophylls, Strickland and Parsons, 1972.

RESULTS

QUALITATIVE RESULTS

Fouling

All tray systems were monitored for fouling accumulation. A "quantitative" study was attempted to obtain a numerical estimate of fouling build-up in each of the environments since it was believed fouling organisms would have difficulty establishing themselves where a moderate current existed(range 0-7 knots). Unfortunately, vandals damaged the units designed to evaluate fouling beyond repair and the experiment was stopped. A qualitative visual comparison of fouling occurrence among tray units, though rough in terms of scientific approach to obtain information, did reveal a significant difference in fouling accumulation in the tray systems and test sites.

The Nestier trays during the month of July and early August suffered intense barnacle sets. This phenomenon was more apparent in environment 1. During this period tray systems were being dried out weekly and regular scraping of barnacles off Nestier trays became necessary to avoid excessive build-up. Barnacle sets on Nestier trays located in environment 2 were not as intense. Removal of barnacles in environment 2 was required only once during July and August. Mussel sets were a problem in the MacNicol trays from July through September setting at levels that required removal. Mussel sets were lighter in environment 2. Removal of mussels was needed only once in environment 2 compared to four instances in environment 1.

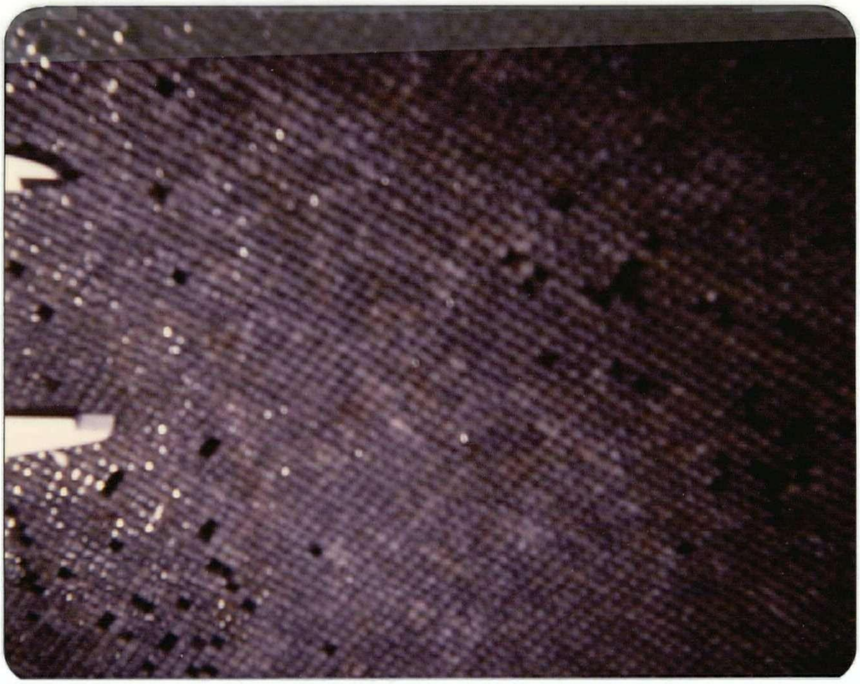
Fouling in the Suspension trays was non-existent in both test environments. Filamentous algae growth did occur on the topmost tray of the Suspension system while 1/4" Conwed mesh was used as a cover. Exchanging this for a 1/2" mesh eliminated the algae problem(figure 19). Algal growth did not occur on trays situated below the top tray. Algal growth was similar in both test environments. Filamentous algal fouling did become a problem after September 6, among Nestier and MacNicol sytems(figure 20). Algal fouling was not as significant among Suspension trays. The topmost trays in all the systems were the most susceptible to algal fouling.

Floating debris such as leaves, branches, twigs, logs, etc., snagging on MacNicol and Nestier trays was a problem for the duration of field experimentation. This did not materialize among Suspension units.

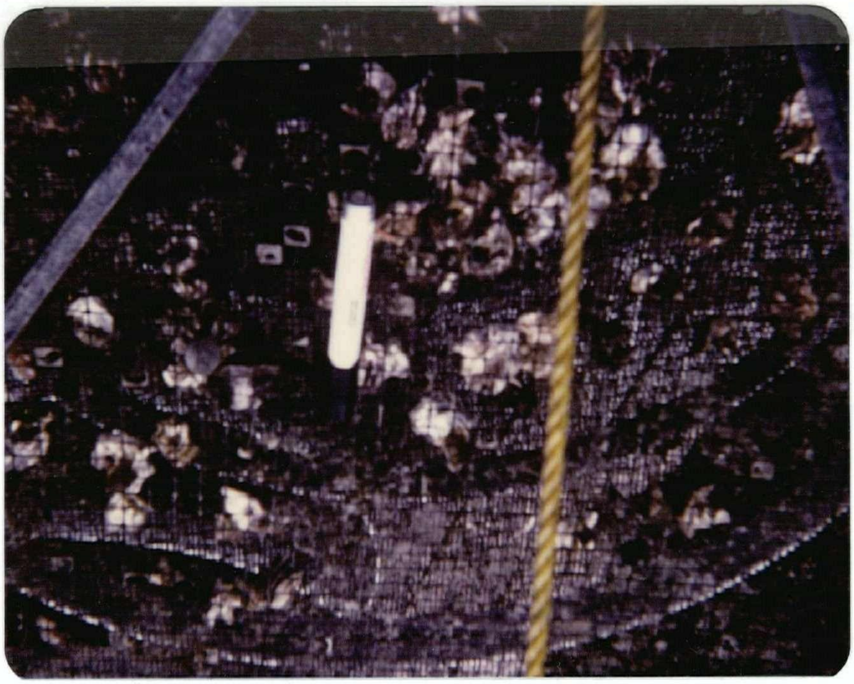
Shell Scarring

Shell scarring is a shell disfigurement caused by the growth of shell into tray materials rendering it unsuitable for the half-shell market.

Shell scarring occurred in MacNicol and Nestier trays within the two week gap between sampling for growth. Oysters in MacNicol trays tended to fuse with the flat side walls of the partitions. Oysters in Nestier units would grow shell through the circular holes in the tray. The two week inspection routine prevented permanent disfigurement that would have resulted if the oysters had not been periodically inspected. Oysters



1/4 inch mesh



1/2 inch mesh

Fig. 19. Mesh size alteration and algae control.

Fig. 20. Algal fouling occurring on MacNicol trays during the fall months.

cultured in Nestier trays did stop gowing through the tray holes after 2.5 months. The problem continued in the MacNicol trays up to the end of sampling in October.

Materials Handling

The ease with which units are handled was considered important to the success of a commercial operation. Based on the handling of units for a research operation one can only speculate as to the success or failures of a commercial system.

The MacNicol trays were light and easily lifted by a single worker provided there were only 5 to 6 trays per stack. The units must also be totally dismantled for access to individual trays.

The Nestier assembly was lifted easily by a single person until oysters attained near market size. Handling became cumbersome and two persons would be required in a commercial situation. This system also required complete dismantling for inspection, harvesting or planting. This system took longer to dismantle than the MacNicol.

The Suspension system can be lifted as a complete unit of 5 or more trays and need not be dismantled for inspection, harvesting or planting.

Material Performance

The materials of construction used in all three tray systems suffered no deterioration for the duration of the study.

The PVC and Conwed net materials comprising the Suspension tray did not suffer any loss of structural integrity. The polypropylene suspension lines suffered no chafing or loss in support strength. The triangular support frame even upon examination in February, 1980 showed no signs of serious corrosion. The galvanized halibut snaps that replaced the stainless steel swivels in the beginning of the study, would have to be replaced each year. In a commercial application the use of such snaps would not be neccessary and trays could be semi-permanently affixed to the suspension lines using nylon cable ties. The nylon cable ties endured extremely well and did not show any signs of fracture, chaffing or discolouration.

QUANTITATIVE RESULTS

Shell growth data was examined for any unique differences in the addition of shell length, width and height among the three test systems and environment types. The factors of environment type, time, tray system and vertical position were analysed separately and together as sources of variation for their influence on oyster growth. Shell height was eliminated as a measure of performance due to its insensitivity in detecting any differences as related to the four factors and their interactions.

SHELL LENGTH

The analysis of variance and follow up analysis on the data by graphics and direct examination of mean values revealed that environment type(Table 9), vertical position(Table 10) and the interactions of environment type vs time, environment type vs vertical position, environment type vs vertical position vs time and vertical position vs time did not influence growth in the practical sense(Appendix A and B).

Table 9. The mean lengths of shell attained in each of the test environments (95% confidence limits).

Environment	1	2
Mean lengths (mm)	51.0±1.0	49.0±1.0

Table 10. The mean lengths of shell attained in each of the vertical tray positions (95% confidence limits).

Position	1	2	3	4	5
Mean length (mm)	49.0±1.0	50.0±1.0	51.0±1.0	51.0±1.0	50.0±1.0

1. Environment Type Vs Tray System

The interaction of environment type with tray system proved to be statistically(Appendix A) and practically significant(Table 11). The MacNicol and Suspension systems performed on an equivalent basis irrespective of their environmental location. The Nestier trays performed the best in environment 1, but attained measurements on par with the other systems in environment 2.

2. Environment Type Vs Tray System Vs Vertical Position

This relationship was found to be statistically and practically significant(Appendix A & B). In environment 1, the Nestier trays outperformed the other systems in all vertical positions(Appendix B) and shell length measurements did not vary significantly due to vertical position. However, in environment 2 growth measurements in all vertical positions were similar but below that attained in environment 1.

Position effects in MacNicol systems were not detected in either environment locale separately. However, in environment 2 growth in positions 1 through 4 were below that achieved in environment 1. Length measurements achieved in MacNicol tray positions 2 to 4 in environment 1 exceeded levels in the Suspension system(Appendix B). Conversely, in environment 2 length measures in MacNicol tray positions 1 and 2 were below lengths noted in the Suspension units for the first two positions.

Shell growth among the Suspension trays were similar in both environments and position effects did not become apparent.

Table 11. The mean lengths(mm) of shell attained in each tray system in each of the environment types(95% confidence limits).

	Environment 1	
MacNicol	Nestier	Suspension
50.0±1.0	57.0±1.0	47.0±1.0
	Environment 2	
MacNicol	Nestier	Suspension
47.0±1.0	52.0±1.0	49.0±1.0

3. Environment Type Vs Tray System Vs Vertical Position Vs Time

This four factor term was found practically and statistically significant(Appendix A and B). There were few differences between the growth patterns among the culture systems from early June to mid July. Oyster growth among the test systems developed their own patterns after this period.

Position effects appeared in MacNicol trays after mid July. In environment 1, growth in position 1 was below that in other tray positions. This tray averaged 2mm/week until mid August and then growth rate increased to approximately 3-4mm/week up to mid September followed by a return to June-July rates. The top tray because of its slow start did not achieve measurements obtained in the trays beneath it(Appendix B). The remaining positions in the stack did not deviate from each other. Most of the oysters in the vertical series of trays had indicated a decrease in shell growth by the end of October except for position 3 with an increase in growth rate during October(Appendix B). Generally growth followed a start-up phase(June to mid-July) followed by increased growth rate until early September, followed by a decline in shell deposition rate.

Position effects among MacNicol trays in environment 2 were not as pronounced, although position 1 was still the lowest "achiever". Visually from the graphs(Appendix B), differences lay in the growth cycle over time not appearing to be as erratic. Growth curves were more closely related and the rate of shell growth was more constant from July to October(approx. 2.5mm/week)(Appendix B). Growth was minimal in October and the decrease in growth rate was much more visible than in environment 1. Growth rates in environment 2 were lower with respect to environment 1.

Shell growth among Nestier trays in environment 1 achieved more favourable results than those in environment 2. Growth rates were less erratic and measurements up to September were greater than in environment 2. Position 2 was lower than the other positions but achieved final length measurements comparable with the rest of the trays in the stack. Growth was slowed from September onward. Position effects among Nestiers in environment 2 were noted from June to the end of July. Zero growth occurred in all vertical positions from July 10 to 24. Position effects disappeared during a rapid growth phase(approx. 4mm/week) from July 24 to September 6. After these dates positions 3 and 4 were significantly higher than 1, 2 and 5 in terms of growth rate and length obtained. A decreased growth rate by the end of October was not clearly defined in this interaction.

Oyster growth in the Suspension trays were similar in both environments. Over the term of the study position effects were not clearly defined in environment 2. At certain intervals position effects were apparent but these fluctuated throughout the term. However, growth rate in the bottom tray did decrease to a low level during the fall months(Appendix B). End results in both environments did not indicate the growth rate had levelled out by the end of October. Besides this slight position effect the overall growth rate remained fairly constant in both environments for the duration of sampling(approx. 3mm/week). The Suspension system also did not show marked fluctuations in growth rate as was the case with the other systems.

4. Environment Type Vs Tray System Vs Time

This relationship was statistically and practically significant(Appendix B). Among tray systems in environment 1, growth in Nestier units was superior over time. Growth curves describing MacNicol and Suspension trays were closely related. Growth rate in the Nestier increased rapidly after June 26 maintaining a fairly constant growth rate until September 6. Growth rates in other systems did not increase substantially until July 10 and did not match the rates attained in the Nestier trays. Growth rates decreased in all systems after September 6 but curves did not indicate that a plateau had been reached by the end of October. Growth rate in the Nestier did not increase significantly until July 24. From September 19 to the end of October growth measurements in the Nestier were greater than in the other tray types.

Growth rates in Suspension trays were similar in both environments. In environment 2 greater lengths than in MacNicol trays were achieved after August 7. Growth measurements linked to environment 2 located MacNicol trays were lower than in environment 1. MacNicol units also showed zero growth for the month of October. The other systems displayed a gradual decrease in growth rates such that via extrapolation, growth would reach a zero rate by the end of November depending upon ambient water temperatures.

5. Tray Type

Table 12. The mean lengths(mm) of shell attained in each tray system (95% confidence limits).

MacNicol	Nestier	Suspension
48.0±1.0	54.0±1.0	48.0±1.0

Results indicated a significant statistical difference among tray systems(Appendix A). Practical differences did not appear between MacNicol and Suspension units, but the mean shell lengths among Nestier systems were greater(Table 12).

6. Tray Type Vs Time

The Nestier tray generated significantly better growth over time than the other two systems(Appendix B). The MacNicol and Suspension tray results were similar(Appendix B). Growth rate in Nestier trays ranged from 0.5 mm/week to 3 mm/week versus 0.5 to 2.6 mm/week in Suspension and MacNicol trays. Suspension and MacNicol trays did achieve a rate of 3.7 mm/week for a short period of time. Growth rate in the MacNicol trays had begun to decrease to 0.5 mm/week by mid-October, however shell was still being added among Suspension and Nestier tray cultured oysters. Shell length at the end of October for the Nestier stood at 78 mm versus 69 mm in the other systems.

7. Veritical Position Vs Tray Type

Among tray types, a position effect appeared in the Nestier with the second tray in the column performing the lowest. Significant practical differences were not detected between MacNicol and Suspension trays or between their vertical positions(Appendix B).

8. Vertical Position Vs Tray Type Vs Time

Differences were not detectable in the first two weeks of the study. Growth rate differences surfaced after July 10.

The growth curve associated with the top tray of MacNicol units was the lowest from late July to early August. Other trays in the column did not show differences(Appendix B).

Position 2 of the Nestier was the lowest from July 10 to August 7, otherwise vertical position did not appear as a contributing factor. Growth rates decreased after the first week in September, but oysters were still showing an increase in shell length by the end of October.

The Suspension trays displayed little variation in growth rate attributable to vertical position.

9. Time

Shell growth followed a sinusoidal type curve(Appendix B). Growth began with a start-up phase from mid-June to the end of the month. This was followed by an increase in growth rate until early September. After this time growth rate tended to decrease during the fall months.

SHELL WIDTH

The factors of environment type(Table 13), tray system(Table 14) and vertical position(Table 15) did not account for any practical significant differences among growth in oyster shell width.

1. Environment Type Vs Time

After the second week of July significant differences arose between growth characteristics in the two environments. The growth rates in environment 1 were higher from the end of June until early September. Growth curves began to level off in both environments after this time. Growth in environment 2 was the same as in environment 1 until July 10 then the growth rate decreased lagging behind measurements obtained in environment 1(Appendix C). Despite this lull in growth, the actual growth rates were similar in the two locations. The final width measurements were similar in both environments.

2. Environment Type Vs Tray System

This interaction contributed significantly to growth(Appendix A). Oysters in Nestier and MacNicol trays in environment 1 grew better than those in the Suspension units. Environment type did not significantly influence growth in the Suspension trays. Growth in Nestier and MacNicol trays were depressed in environment 2 below levels in environment 1 to a point where all the systems performed on a equal basis(Table 16).

Table 13. The mean widths(mm) of shell attained in each environment type(95% confidence limits).

Environment	1	2
Mean width	42.0±1.0	38.0±1.0

Table 14. The mean widths(mm) of shell attained in each tray system (95% confidence limits).

MacNicol	Nestier	Suspension
39.0±1.0	42.0±1.0	39.0±1.0

Table 15. The mean widths(mm) of shell attained in each of the vertical tray positions(95% confidence limits).

Position	1	2	3	4	5
Mean width	39.0±1.0	40.0±1.0	41.0±1.0	41.0±1.0	40.0±1.0

3. Environment Type Vs Tray System Vs Time

Growth curves of oysters in Nestier and MacNicol trays was favourable in environment 1 than environment 2. Growth curves for the Suspension units were similar in both environments(Appendix C).

Nestier trays in environment 1 had two periods of "rapid" growth, one from June 26 to July 10 and the second from August 7 to September 6. After September 6 growth rate decreased but did not show signs of approaching zero by the end of October(Appendix C).

Growth curves associated with MacNicol and Suspension trays were closely related in environment 1. Both systems illustrated a uniform rate from June 26 to September 6 followed by a reduction in growth rate.

In environment 2 growth was hampered in the Nestier trays until August, the point when growth rate increased drastically and then dropped after September 6(Appendix C). Growth was superior in the other two systems.

Growth curves for MacNicol and Suspension trays in environment 2 were similar except growth in the MacNicol tray was approaching zero faster by the end of October. The Suspension trays did not indicate a levelling off or drop in rate in October. Their performance was depressed between August 7 and September 19, although final width measurements did not differ significantly at the two environments. Growth rates in the MacNicol trays was depressed in environment 2. Their final width measurements were less in this environment. Generally, growth curves for the MacNicol and Suspension trays displayed a

Table 16. The mean widths (mm) of shell attained in each tray system in each of the environment types (95% confidence limits).

Environment 1

MacNicol	Nestier	Suspension
41.0±1.0	45.0±1.0	40.0±1.0

Environment 2

MacNicol	Nestier	Suspension
37.0±1.0	40.0±1.0	38.0±1.0

more constant growth rate over time in environment 2 than in environment 1. Growth curves for the Nestier trays in environment 2 were more erratic than at the other location.

4. Environment Type Vs Vertical Position

Environment 2 seemed to cause a debilitating effect on growth in the top tray. Practical differences did not materialize among the other vertical positions in either environment type(Appendix C).

5. Environment Type Vs Vertical Position Vs Time

A position effect did not occur in environment 1 over the term of the study. Growth rate in position 1 in environment 2 was below that of the other vertical positions. Growth rates among other vertical positions in environment 2 was maintained on a uniform magnitude until the end of October.

6. Environment Type Vs Tray System Vs Vertical Position

The MacNicol and Suspension units did not display any practical differences among growth in vertical positions in either environment type. Vertical positions in Nestier trays in environment 1 outperformed the other systems with the exception of position 4 which was only marginally better than the MacNicol, position 4. Growth characteristics in environment 2 were similar among the three systems. Growth in Nestier positions 1,2 and 3 was depressed below that achieved in environment 1. Positions 4 and 5 in the Nestier were similar in both environments(Appendix C).

7. Time

Growth rates described a sinusoidal curve consisting of the three phases as per discussion for shell length growth.

8. Tray System Vs Time

Growth differences among the trays surfaced after July 24. From that point, growth rate in the Nestier system increased and mean widths attained were higher than in other tray types. Growth curves describing MacNicol and Suspension units were almost identical(Appendix C).

9. Vertical Position Vs Time

The growth curve for the topmost tray appeared conspicuously lower than curves for the other positions. Growth curves of positions 2 to 5 were almost identical in appearance(Appendix C).

10. Tray System Vs Vertical Position

Evidence of an effect by this interaction term did not occur among the MacNicol or the Suspension units, however it did contribute to better growth in Nestier tray positions 4 and 5. Position 1 of the Nestier was the lowest among the stack of trays(Appendix C).

11. Tray System Vs Vertical Position Vs Time

Position effects appeared in all of the tray systems over time. After the first three weeks, growth curves in position 1 of MacNicol units were lower than curves associated with position 4. Little practical difference existed between the fourth tray and remaining vertical positions. Position 1 in the Nestier was the lowest with other tray positions being closely related. A position effect shift occurred among Suspension units. After the third week, position 1 and 3 were operating lower than positions 2 and 5 until the fourth week. Beginning in the fifth week positions 1 and 5 were lower than 4 and 2.

Balancing the tray systems against each other, differences between Nestier and Suspension units arose after the second week. From that point to the end of sampling, with the exception of the topmost Nestier tray, the Nestier system had the more favourable growth. Against the MacNicol tray the first two positions results were similar, while position 3 achieved better results in the Nestier after August 7, position 4 after July 24 and position 5 after the end of June.

12. Environment Type Vs Tray System Vs Vertical Position Vs Time

Among Nestier trays in environment 1 growth curves were closely related not showing any position descrepancies over time. Growth rates decreased after September 6 to 19 followed by a slight increase in rate until October 2, then levelling off. The top tray in environment 2 was lower in performance than other positions. There was little difference among the remaining vertical positions. Environment 2 did cause more variation among growth rate over the season. Growth rates in environment 1 were not as erratic(Appendix C). However, the final width measures were similar in both environments for the Nestier system, except for position 1 being lower in environment 2.

MacNicol trays situated in environment 1 had closely related growth curves in all positions and a uniform growth rate from mid-June to early September. In environment 2 the curve associated with position 1 was the lowest while other positions displayed no such difference. Shell growth remained at a consistent rate between end of June to early August followed by curves approaching zero growth by the end of October.

Changing position effects were noted in Suspension units in both environments. Among units in environment 1 position 2 performed the best from July 10 to September 6 followed by declining rates in positions 1,3 and 5 after this time. Positions 2 and 4 maintained a constant rate. Growth rate in position 4 decreased to zero after September 19 followed by decreasing rates in positions 1,2 and 5 after October 2. Growth was still occurring in position 3 in October but the growth curve did indicate a levelling off. The end of the study found position 3 greater than 1 and little difference among shell widths in other tray positions.

Differences appeared in vertical positions of the Suspension units in environment 2 after the end of June. Tray positions 2, 4 and 5 growth rates were greater than the other positions and zero growth occurred in position 5 between July 24 and August 7. Positions 2 and 4 were at their highest levels until early September. Growth rates then declined until October 2. During the month of October growth rates increased in all positions; position 1 especially improved(Appendix C). Comparing the two environments position 3 had the lowest growth curve versus an absence of significant differences among the other positions. Growth rates were generally uniform and consistent in both the environments.

In environment 1 the Nestier performed better than the Suspension units at all positions, while there was little difference between growth characteristics of the Suspension and MacNicol units.

In environment 2 position effects were minimal in Suspension units with respect to the Nestier system. With the exception of position 1 in the Nestier tray growth rates between the systems were close in magnitude.

MEAT CONDITION

At a 5% level of significance the analysis of variance did not reveal any significant differences among higher level interactions involving two or more factors. Statistically significant differences were found only among factors of time and tray type(Appendix D). Multiple range tests(Neuman-Keuls and Tukey) revealed an increase in the condition index from June 21 to a peak by July 19; falling off by August 7. The condition indices from July 19 to August 17 were higher than those encountered in June and early July(Appendix E).

The MacNicol trays sustained a significantly higher condition index than the Suspension or Nestier systems. Condition indices of Nestier and Suspension systems were not significantly different at a 5% probability level.

ECONOMICS

Each system was broken down into component cost. The

MacNicol and Nestier assemblages required six trays in each stack. One additional tray was used as a cover. The price of Nestier trays was found to vary depending upon whether the purchase source was corporate or private. Based upon a cost/oyster evaluation, assuming a lifespan of 5 years for each system, the MacNicol and Suspension are the cheapest at a cost of \$.02/oyster/year versus \$.04/oyster/year for the Nestier system. The MacNicol appears the least expensive purchase, however use of such a system would invoke a \$.01/oyster for every hour the system is handled. Handling costs applied to the Suspension system were essentially nil(Table 17).

Table 17. Economic analysis of the half-shell tray culture systems tested(5 trays/unit).

1.MATERIALS

A. Suspension System

PVC flatbar @$1.05/m	X 15.2m	= $16.00
PVC U-channel @$0.33/m	X 15.2m	= $ 5.00
Conwed^r Net @$0.65/m^2	X 10.2m^2	= $ 6.60
Polypropylene rope ¼" @$0.10/m	X 5.6m	= $ 0.56
Iron angle ½" @$0.76/m	X 2.5m	= $ 1.88
Cable ties @$0.30	X 30	= $ 0.90
Swivel @$2.65	X 1	= $ 2.65
Styrofoam @$177/m^3	X .03m^3	= $ 5.31
Copper rivets @$0.03	X 10	= $ 0.30
	Total	$39.20

B. McNicol System

McNicol tray @$1.10	X 6	= $ 6.60
Styrofoam @$177/m^3	X .014m^3	= $ 2.50
Center piece @$2.50	X 1	= $ 2.50
	Total	$11.60

C. Nestier System

Nestier tray @$7.00 - $10.00	X 6	= $42.00
Banding and clips @$3.00	X 1	= $ 3.00
Styrofoam @$177/m^3	X .014m^3	= $ 2.50
	Total	$47 - 50.00

table 17 continued

2. HANDLING(labour rate $6/hr and using 2 units)

Procedure	Suspension	McNicol	Nestier
lifting	10min	10min	12min
dismantling	-	5min	12min
re-assembly	-	5min	5min
re-setting	8min	5min	5min
TOTAL	18min	25min	36min
# of oysters	1000	210	520
$ cost/oyster	neglible	.01	.10
system cost/oyster (5 year lifespan)	.02/yr	.02/yr	.04/yr

DISCUSSION

QUALITATIVE

Fouling

The compactness of the Nestier assembly, the small openings and angled edges on each tray provided a favourable environment for barnacles. The barnacles setting in crevices, corners and under the ledges suggests these creatures sought out and found the dead water locations in this system. Barnacles did not set in the open areas of the tray occupied by oysters. The current regime in environment 2 reduced barnacle sets on the Nestier trays below that occurring in environment 1. The intertidal zone of environment 2 was relatively free of barnacles compared to environment 1.

Mussel preference for MacNicol trays is a difficult phenomenon to explain. It may be due to material of construction, perforation size, depth or spacing of trays and/or the circulation patterns through the system. The absence of barnacles may be due to the freeswimming larvae avoiding the materials of construction or the environmental conditions in the system. The more open nature of the MacNicol tray may reduce the stagnant water areas within the system to eliminate barnacle fouling.

The absence of mussel and barnacle fouling in Suspension trays could be caused by the openess of the design maximizing the exposure of all surfaces. The materials of construction may possess fouling retardant properties that are as yet not documented.

Regular drying of the trays each week did control algal fouling on all trays. Ending the drying routine in the fall caused algae to build-up on Nestier and MacNicol trays. Algal fouling on the Suspension trays was not a problem after mesh size of the cover was increased from 1/4 to 1/2 inch. The smaller mesh size allowed algal filaments to weave a barrier over the entire net. The larger mesh prevented the filaments from attaching in such a manner. The absence of algae on lower trays in the stack was probably due to insufficient light conditions caused by the shading effect of the top tray. The control of algal fouling in the Suspension system prevented one source of restricting water circulation. Algal growth on the other systems probably hampered water circulation through the tray assemblies.

The control of floating debris was a floatation problem. Suspending the Nestier and MacNicol trays deeper would have reduced debris accumulation and algal growth. The units were suspended in such a manner to meet a state-of-the-art specification for tray culture in British Columbia. Snagging of debris on the Suspension system was not a problem. The entire system was set deeper in the water.

Shell Scarring

The material hardness and the flat sides of the MacNicol tray; the arrangement of partitions and hole size in Nestier trays proved to promote shell fusion. If fusion with the tray proceeds too far removal leads to shell fracture and/or the possible death of the oyster. Regular inspection every 2 weeks during the study prevented fusion from proceeding too far. Maintaining such a schedule in a commercial operation is not feasible.

Growth into the tray sides or the net mesh of the Suspension system was never a problem. The flexibility of the net and the sagging under load eliminated pressured contact with the outer tray edges and the support mesh.

Materials Handling

The only objection to the use of MacNicol trays, from a handling viewpoint, was their low carrying capacity per tray. Commercial operations would require large numbers of trays to meet production goals. The operation would be spread over a larger area and require several man hours for inspection, harvesting or planting. Similar problems would arise using the Nestier system. The tray's capacity is greater but a large number of trays would be required in a commercial venture. This fact, combined with a more timely dismantling procedure questions the success of the system for commercial operations.

Suspension system oysters were readily accessible. Each tray was designed to hold 100 to 160 oysters reducing the number of trays required in a commercial operation and allowed the handling of a greater number of oysters per unit time.

Material Performance

Plastics are an excellent material for marine applications in mariculture. The galvanized halibut snaps attaching the Suspension trays to the support lines would have to be replaced each year. For commercial use these could be substituted with nylon cable ties. The nylon cable ties endured extremely well and showed no sign of fracture, chaffing or discolouration.

The only design fault in the Suspension system was the sagging of the net. This prevented full use of the growing area in each tray. Additional support of the net mesh should be designed into the system so as not to interfere with water circulation.

Economics

The MacNicol assembly was the least expensive from a component cost basis, but the benefits of cheaper oyster handling costs with the Suspension system made it the more attractive purchase.

The Nestier tray evolved as the poorest investment in terms of component and materials handling cost. The units were self-defeating from the way they had to be bound together. Their availability in commercial quantities was also debatable at the time of the research.

The Suspension system offered favourable costs for handling and components. The benefit of being able to handle a greater number of oysters/unit time make the investment attractive.

QUANTITATIVE

The assessment of tray performance was based upon the results from the yield variables of shell length and width. Discussions and concluding remarks are based upon shell length and width growth performance.

Single Factor Interactions

1. Environment Type

The factor environment type had little influence upon oyster growth. Environment 2 was a tidal raceway and had warmer water temperatures during the months of July and August. According to Walne(1974) the average feeding rate should increase as water flow increases, stimulating growth. The absence of such a result in this research could have been caused by an over-abundance of microorganisms passing over the oysters interfering with filtration. Part of the cause can be attributed to the trays swaying horizontally in the current stressing the organisms and restricting water circulation, causing a reduction in feeding and assimilation efficiency. The result was an inhibitive effect on the growth enhancing properties of environment 2.

2. Tray Type

The shell length yield variable indicated that the Nestier trays promoted the best growth. Results between the other systems were similar. Better growth in the Nestier system was due to its superior performance in environment 1 that biased the general conclusion that growth was better in this system.

3. Vertical Position

The vertical positioning of oysters in a column of trays did not radically alter growth. This factor became important in higher levels of interaction where tray systems and environment type were involved in the interaction term.

4. Time

Growth curves described three phases of oyster growth. Initially, a start-up phase(June 12-26) followed by a period of increased growth rates until early September; then an indication of levelling off in October.

The start-up phase, where little or no growth occurred was likely due to a combination of oyster acclimation to the culture system, low water temperatures and limited food supply. Background environmental data indicated water temperatures were approximately 12 degrees Celsius and that suspended phyto and zooplankton material in the water was low(Appendix G).

The improved growth rate following the start-up phase was closely co-related to rising water temperatures and periods of lower Secchi readings. Metabolic rates would have increased in response to the changing environment and the food supply was available to fuel the demands of shell growth.

Higher Level Interactions

1. Environmental Types Related To Vertical Position In The

Culture System

The growth curves describing oyster length growth over time were similar in both environments. However, shell width growth curves indicated that environment 2 caused a setback in July on shell deposition. The negative influence of environment 2 was clearly concentrated on shell width growth in vertical position 1 as indicated in the interaction term of environment type vs vertical position vs time and environment type vs vertical position. The two factor term, vertical position vs time, failed to indicate any significant position differences in the growth patterns of shell length and width. This suggested that the environmental term interacted with the factor of vertical position causing the position effect.

The descrepancy between no effect upon shell length and a clear effect on shell width growth reflects an alteration in the ability of the mantle lobes to secrete shell deposits along the width axis. The result was an impairment of shell width growth among top trays in environment 2. Ambient conditions at that location could be affecting mantle positioning and its ability to secrete shell width. Information was sparse about the regulatory mechanisms associated with shell deposition, but observations on growth in gastropods and lamellibranchs have shown that shell shape results from the position of the mantle edge(Galtsoff, 1964).

2. Tray System Related To Environmental Location

The Nestier tray did not perform as well in environment 2 based on final shell measurements and growth rates. Environment

2 also prolonged the start-up phase in this system until the end of July and August for growth in length and width. The combination of small openings, rigid-type construction, the tight compactness of the assembly and the units swaying horizontally probably interfered with water circulation and shell growth. A longer start-up phase may represent an extension of the organisms adjustment to the stresses imposed in environment 2. The longer start-up phase and the interference with water circulation did not allow the oysters in the Nestier system to keep up to the growth rate in environment 1.

Growth in the MacNicol system was adversely affected in environment 2, but the shell growth over time was less erratic than in the Nestier system. The start-up phase was not prolonged in this system. Results indicated that water circulation through the MacNicol units was not as severely impaired as in the Nestier system. A similar explanation accounts for the lower performance of the MacNicol trays in environment 2, but the magnitude of the effects were not as great. However, it became clearly evident that the MacNicol and Nestier systems were more suited to the calmer environment.

Growth results in the Suspension system failed to indicate any differences in oyster growth between the two environments in terms of final measurements and growth rates over time. Results were a tribute to the objective of an open design to improve exposure of the tray cultured oyster to the surrounding environment. The spacing between trays and the use of Conwed net was to allow an unrestricted exchange of water in order to maximize food availability and facilitate waste removal. It was anticipated that environment 2 would promote increased growth but the swaying of the units in the current negated the growth enhancing characteristics of the location. It was possible that the system had a baffling effect on the current fluctuations in environment 2, relieving the oyster from the direct impact of current fluctuations. Results indicated that conditions for growth were maintained almost identically to those in environment 1. The system proved adaptable to marginal conditions. The only design parameter that may account for the absence of total superior growth performance was the sagging of the net mesh under load causing oysters to be crowded at the center of the tray.

3. Tray Systems Related To Vertical Positioning

Growth performance in the Nestier tray positions 1 and 2 were lower with respect to the other vertical positions. Plots of growth over time also indicated that growth rates in these two trays were lower. The MacNicol system had a similar effect that was only visible over time. Considering only vertical position and the MacNicol tray, the mean measurements were similar among all the five vertical positions. Growth curves over time in MacNicol vertical positions 1 and 2 were also generally lower throughout the study.

The top trays were just below the surface and made them subject to the snagging of floating debris and algae growth interfering with food availability and waste removal caused by the restriction of water flow. The improved growth characteristics among lower tray positions(vertical positions 3, 4 and 5) is probably due to less build-up of flotsam and lower light levels controlling excessive algal growth. Adequate circulation was maintained. Performance data indicated that these systems failed to provide uniform growth through a column of trays.

Spacing of trays in the Suspension system, the net mesh retainers and the top tray located 50cm below the surface seems to have ensured an even circulation. Floating debris could not attach and fouling was controlled. The restrictions of fouling and debris that interfered with oyster growth in the other test systems did not occur. Position effects were minor.

The Nestier trays did not cope favourably with the conditions in environment 2. Vertical positions 1 and 2 were the lowest performers, growth rates were more erratic and not as consistent over time and length growth ceased completely for two weeks in July. The system swayed horizontally in the current, the problems of being close to the surface and the compactness of the design could have prevented the penetration of adequate water flow into the trays. Growth characteristics were quite similar between the two environments among lower trays in the Nestier stack. The impact of the environmental effect seems to have been concentrated in the top trays.

In the MacNicol units a consistent growth rate over time, closely related growth curves for the vertical positions and a depressed growth in length but not width in environment 2 reaffirmed that the current regime did not have as severe an impact upon this system performance as it did in the Nestier system. Growth was depressed in the top tray of the MacNicol in environment 2, but the discrepancy between growth in length and width reiterates that conditions probably altered the mantle ability to secrete shell length. The circulation, food acquistion and waste removal problems postulated as the cause for hampered growth in the Nestier may not be the case in the MacNicol system.

The performance of the Suspension system was similar among all vertical positions in each of the environments. Position effects were apparent in both situations but an alteration in which position(s) were on top in terms of growth performance tended to balance out in the end result. Growth curves applying to the vertical positions were closely related and were generally constant at each growth phase. These oysters were not subjected to the conditions that created anomalies in the growth performances in the other two systems.

MEAT CONDITION

The condition index proved not to be as sensitive to the effects of the interactions between the organism, the culture system and the environmental conditions at the test sites. Results did indicate that the time of year and the type of culture system influenced meat condition.

Based upon earlier research by Federal and Provincial Environment Ministries, the condition index usually decreases during the summer months after spawning has occurred in late July or August. The release of gametes is induced by ambient water temperatures greater than 19 degrees Celsius. Water temperatures never reached a warm state for a sustained period of time in Trevenen Bay(Appendix F). Natural spatfall did not occur in Trevenen Bay during 1979. Meat in the oysters was plump throughout the summer and only slightly "runny". Gonadal material was extensively built-up within the flesh and the condition index was elevated for that time of year. The slight decline of the index in August could have been due to a release of gametes, although evidence of spawning was not observed.

The better condition index values attained in the MacNicol tray is somewhat of a paradox. The MacNicol system had the poorest showing in terms of shell growth but sustained a superior meat condition. Studies in British Columbia and the northwestern United States have revealed that superior meat quality/condtion does not necessarily achieve superior shell characteristics. Shell growth has been observed in emaciated oysters(Quayle, 1969). It may be that shell growth and meat condition, in this instance were mutually exclusive.

The absence of condition index variablity due to environment type, vertical positioning and among two of the tray systems may have indicated a low level of sensitivity between fleshy body growth and environmental surroundings. It may follow that the residence time of food particles and the circulation regime within the MacNicol tray was more conducive to flesh growth and not for the deposit of shell material.

CONCLUSION

1. Fouling

The Suspension system displayed superior antifouling properties. Fouling in the Suspension system was never a problem for the duration of the research. This phenomenom may have been due to possible fouling retardant properties of the materials and/or the systems design. The MacNicol and Nestier trays succumbed to mussel and barnacle sets respectively.

The reduction of fouling in the Suspension units was independent of environment location. However, environment 2(tidal raceway) reduced fouling in the Nestier and MacNicol trays below that having occurred in environment 1. Therefore, an area having a current action may reduce or eliminate the attachment of fouling organisms.

The drying out of all trays each week effectively controlled algal growth on the Nestier and MacNicol trays. Filamentous algal growth became extensive in these systems when the drying routine was stopped in the fall months. Algal growth on the Suspension trays was never a problem once the proper net mesh size was used.

2. Materials Handling and Economics

In commercial applications the Suspension system proved more favourable from the viewpoint of materials handling. The system allowed the handling of a greater number of oysters per unit time and convenient access to individual oysters in an assembly. The ease of handling traded off against a slightly more expensive design made this system worth consideration to the commercial grower.

3. Product Quality

Oysters cultured in the MacNicol and Nestier trays were prone to shell disfigurement. Shell appearance was not adversely affected among oysters in the Suspension trays. The Suspension system has the potential to maintain an atmosphere that can produce a more amiable half-shell product.

4. Material Performance

Rigid plastics are especially suited for use in the marine environment. Rigid PVC products may possess some fouling retardant properties.

5. Oyster Growth and Meat Condition

The single factors of environment type, tray system and vertical position did not influence oyster growth. Shell growth characteristics were a result of higher level interactions involving two or more factors. The following points illustrate the conclusions that were discovered surrounding shell growth in the systems tested.

A. The measurement of growth in shell height was found to be a poor indicator of performance.

B. Oyster seed stocked in culture systems exhibited a start-up or acclimation phase associated with the beginnings of shell growth.

C. The tidal raceway site had an adverse effect upon growth in shell width in the top two tray positions.

D. Results indicated that the MacNicol and Nestier systems are more suited for use in calm/sheltered environments.

E. The Nestier and MacNicol trays failed to allow uniform growth in an assembly of trays. Growth in the two top trays in the Nestier and MacNicol units were lower with respect to other remaining trays in a column. Growth rates were depressed and erratic over time in environment 2 among the two top trays in the Nestier system. This impact was less severe on the top tray positions of the MacNicol tray system. Shell growth was also erratic among MacNicol trays located in environment 2.

F. The lower trays in the column(positions 3, 4 and 5) of the MacNicol and Nestier assemblies had similar growth performance at both test sites.

G. The Suspension system offered uniform shell growth in an assembled column of trays.

H. Shell growth rate was not increased by the design specifications of the Suspension system, nor was growth stimulated to occur more rapidly under the influence of current flow in environment 2.

I. The MacNicol system maintained the highest meat condition index. Meat condition indices were similar between Nestier and Suspension systems.

J. Growth performance of the Nestier system in the calm environment was better than the other test systems. Growth performances were similar between MacNicol and Suspension trays at this site.

K. Growth performance of the Suspension system in environment 2 was greater than the other test systems which were on par with each other.

L. Graphical plots of shell growth indicated a decline in such growth beginning at the end of October.

In conclusion the design specifications, operational features and materials of construction of the Suspension system proved to be a more attractive tray culture alternative in Trevenen Bay. Table 18 illustrates indices of "favourability" based upon factors discussed that summarize the attractiveness of the Suspension system having the lowest total index value. Additional research is required at other test sites in the coastal waters of British Columbia before the system can be said to be superior for use in most site locations in the province. This suggestion seems involved but is based on the site specificity of oyster growth found to occur on the commercial oyster leases within the coastal marine environments of British Columbia.

Table 18. Indices of favourability associated with the tray systems tested.

Tray System	Fouling	Handling	Economics	Position Effects	Location Effects	Material Performance	Oysters/tray	Total
McNicol	2	2	2	2	2	1	3	14
Nestier	3	3	3	2	2	1	2	16
Suspension	1	1	1	1	1	1	1	7

FACTOR	INDEX VALUE
1. Fouling	
a) high	3
b) medium	2
c) low	1
2. Handling	
a) difficult	3
b) easier	2
c) easy	1
3. Oysters/tray	
a) high(63-126)	1
b) medium(31-62)	2
c) low(1-30)	3
4. Economic Appeal	
a) high	1
b) medium	2
c) low	3

FACTOR	INDEX VALUE
5. Position Effects	
a) yes	2
b) no	1
6. Location Effects	
a) yes	2
b) no	1
7. Material Performance	
a) excellent	1
b) good	2
c) fair	3

REFERENCES

Alcan Report. 1970. Handbook of aluminum, 3rd edition. Aluminum Company of Canada Ltd.

Andrews, J.D., D. Haven and D.B. Quayle. 1959. Freshwater kill of oysters(Crassostrea virginica) in James River, Virginia, 1958. Proc. Natl. Shellfish. Assoc. 49:29-49.

Bardach, J.E., J.H. Ryther and W.O. McLarney. 1972 . Aquaculture the farming and husbandry of freshwater and marine organisms. John Wiley & Sons.

Benjamin, B.S. 1969. Structural design with plastics. Van Nostrand Reinhold Company.

B.F. Goodrich Report. 1978. B.F. Goodrich Chemical Company.

Brydson, J.A. 1975. Plastic materials. London, Newnes-Butterworth.

Butler, P.A. 1952. Effect of floodwaters on oysters in Mississippi Sound in 1950. U.S. Fish. & Wildl. Serv. Res. Rep. 31, 20p.

Calabrese, A., and H.C. Davis. 1966. The pH tolerance of embryos and larvae of Mercenaria mercenaria and Crassostrea virginica. Biol. Bull. 131(3): 427-436.

Charman, E.M., and D.W. Smith. 1976. Shellfish resource study of Malaspina, Okeover, Lancelot, Theodosia Inlets. Mar. Res. Br., Fisheries Management Report No. 6.

Dwivedy, R.C. 1973. A study of chemo-receptors of labial palps of the American oyster using microelectrodes. Proc. Natl. Shell. Assoc. 63: 20-26.

Engle, J.B. 1966. The molluscan shellfish industry current status and trends. Proc. Natl. Shell. Assoc. 56: 13-21.

E.P.A. 1974. Preliminary assessment of environmental problems associated with vinyl chloride and polyvinyl chloride. Environmental Protection Agency, September 1974, E.P.A.560/4-74-001.

Evan, J.H., and J.C. Adamchak. 1972. Ocean engineering structures Vol. 1. Mass. Inst. Tech. Press. Cambridge Mass., U.S.A.

Fink, F.W., and W.K. Boyd. 1970. The corrosion of metals in marine environments. Bayer and Company Inc.

Galanti, A.V., and C.L. Mantell. 1965. Polypropylene fibers and films. Plenum Press, New York.

Galtsoff, P.S. 1956. Ecological changes affecting the productivity of oyster grounds. Trans. 21st N. Amer. Wildl. Conf., p.408-419.

Guide to Plastics. 1979. Guide to plastics; including handbook of charts. Editors of Modern plastics encyclopedia. New York, McGraw-Hill. 175p.

Korringa, P. 1976. Farming the cupped oyster of the genus Crassostrea. Elsevier Scientific Publishing Company, New York.

LaQue, F.L. 1969. Deterioration of metals in an ocean environment. Ocean Engin. 1, 229-312.

Lipovsky, V.P., and K.K. Chew. 1972. Mortality of Pacific oysters: The influence of temperature and enriched sea water on oyster survival. Proc. Natl. Shell. Assoc. 62: 72-82.

Loosanoff, V.L., and F.D. Tommers. 1947. Effect of low pH upon rate of water pumping of oysters, Crassostrea virginica. Anat. Rec. 99: 112-113.

Matthiessen, G.C. 1970. A review of oyster culture and oyster industry in North America. Woods Hole Oceanogr. Inst. Contrib. 2528: 1-52.

Medcof, J.C. 1961. Oyster farming in the Maritimes. JFRB Bull. 131.

Mellan, I. 1976. Corrosion resistant materials handbook. Noyes Data Corporation, New Jersey, USA.

Osmon, J.L., R.E. Klausmeier and E.I. Jamison. 1971. Rate-limiting factors in the biodeterioration of plastics. Proc. 2nd Interntl. Biodeterioration Symposium. Lunteren Netherlands, September.

Parsons, J. 1974. Advantages of tray cultivation of Pacific oysters in Strangford Lough N. Ireland. Aquac. 3, 221-229.

Penn, W.S. 1971. PVC technology. Applied Science publishers, London.

Prytherch, H.F. 1928. Investigation of physical conditions controlling spawning of oysters and the occurrence, distribution and setting of oyster larvae in Milford Harbour, Conneticut. Biol. Bull. U.S. Bur. Fish. 44: 429-503.

Quayle, D.B. 1951. The seasonal growth of the Pacific oyster(Crassostrea gigas) in Ladysmith Harbour. Rep. Prov. Dep. Fish. Br. Columbia(1950), 85-90.

-------------. 1969. Pacific oysters in British Columbia. JFRB Bull. 169.

-------------. 1971. Pacific oyster raft culture in British Columbia. JFRB Bull. 178.

------------- and D.W. Smith. 1978. A guide to oyster farming. Mar. Res. Br. Dept. Recreation and Travel.

Riddell, M.N. 1973. Application and design properties of plastics, in predicting plastics performance. Division Technical Conf. Oct. 1973, Downington, Pennsylvania.

Shaw, W.N. 1962. Raft culture of oysters in Massachusettes. U.S. Fish. Wildl. Serv. Fish. Bull. 61: 481-495.

-----------., and J.A. McCann. 1963. Comparison of growth of four strains of oysters raised in Taylor's Pond, Chatham, Mass. U.S. Fish. Wildl. Serv. Fish. Bull. 63(1): 11-17.

-----------. 1965. Pond culture of oysters; past, present and future. Trans. 30th N. Amer. Wildl. Natural Resources Conf., p.114-120.

-----------. 1966. Advances in the off-bottom culture of oysters. Proc. Gulf and Caribbean Fisheries Inst. 19th Ann. Sess. 108-115.

-----------. 1969. The past and present status of off-bottom oyster culture in North America. Trans. Am. Fish. Soc. 98(4): 755-761.

Smith, P.I. 1968. Plastics as metal replacements.

Strickland, J.D.H. And T.R. Parsons. 1972. A practical handbook of seawater analysis. Bull. J.F.R.B. 167 Ottawa.

Sverdrup, H.U., M.W. Johnson and R.H. Fleming. 1942. The Oceans.

Turner, L.S., and J.W. Zahradnik. 1975. Oyster aquaculture with submerged plastic net units. Univ. Mass. Aquac. Engin. Lab Public No. 004-04-75.

Uyeno, F., S. Funahashi and A. Tsuda. 1970. Preliminary studies on the relation between faeces of pearl oyster(Pinctada martensi, Dunker) and bottom condition in an estuarine pearl oyster area.(Jap.; Engl. Summary) j. Fac. Fish. Pref. Univ. Mie-Tsu, 8: 113-137.

Walne, P.R. 1974. Culture of bivalve molluscs, 50 years experience at Conwy. Fishing News Ltd., Surrey, England.

Walker, P.N., and J.W. Zahradnik. 1976. Scale-up of food utilization by the American oyster, Crassostrea virginica. Proc. Natl. Shellfish. Assoc. 65: 63-75.

Wilson, B.W. 1969. Elastic characteristics of moorings. In: Topics in Ocean Engineering, Charles I. Bretschneider, editor. Gulf. Publ. Co. 45p.

Zahradnik, J.W. 1973. Plastics in marine aquaculture and coastal fisheries, Nov. 30, a status report. Aquacult. Engineer. Lab. Univ. Mass. U.S.A.

APPENDIX A

TABLE A1. ANOVA table for shell length.

SOURCE	DF	SUM SQ	MEAN SQ	F-VALUE	PROB
E	1	6112.0	6112.0	183.20	0.0
C	8	0.11894E+07	0.14867E+06	4456.3	0.0
EC	8	2374.0	296.75	8.8948	0.35480E-11
T	2	46131.	23065.	691.35	0.0
ET	2	12597.	6298.4	188.79	0.0
CT	16	13681.	855.06	25.629	0.0
ECT	16	5185.4	324.09	9.7142	0.0
P	4	5196.4	1299.1	38.939	0.36789E-31
EP	4	632.15	158.04	4.7370	0.81612E-03
CP	32	2158.2	67.445	2.0216	0.59814E-03
ECP	32	1408.0	43.999	1.3188	0.10791
TP	8	3541.1	442.64	13.267	0.38255E-18
ETP	8	2402.5	300.31	9.0015	0.24103E-11
CTP	64	3706.4	57.912	1.7358	0.27831E-03
ECTP	64	3252.5	50.821	1.5233	0.47615E-02
ERROR	5130	0.17115E+06	33.363		
TOTAL	5399	0.14689E+07			

TABLE A2. ANOVA table for shell width.

SOURCE	DF	SUM SQ	MEAN SQ	F-VALUE	PROB
E	1	15097.	15097.	379.86	0.0
C	8	0.12287E+07	0.1558E+06	3864.4	0.0
EC	8	5421.1	677.64	17.050	0.29974E-24
T	2	14352.	7176.2	180.56	0.16578E-75
ET	2	1807.1	903.55	22.735	0.14791E-09
CT	16	6991.1	436.94	10.994	0.0
ECT	16	6246.8	390.42	9.8236	0.0
P	4	8056.2	2014.0	50.676	0.66709E-41
EP	4	1033.4	258.36	6.5007	0.32507E-04
CP	32	3356.4	104.89	2.6391	0.17572E-05
ECP	32	2012.9	62.903	1.5827	0.19767E-01
TP	8	3410.5	426.32	10.727	0.44609E-14
ETP	8	2144.1	268.01	6.7436	0.78990E-08
CTP	64	3756.6	58.696	1.4769	0.83248E-02
ECTP	64	3590.4	56.099	1.4115	0.17523E-01
ERROR	5130	0.20388E+06	39.744		
TOTAL	5399	0.15098E+07			

1

APPENDIX B

Plots of relationships to reveal effects of the factors environment type, tray system, time and vertical position upon growth in shell length.

Environment Type .... E

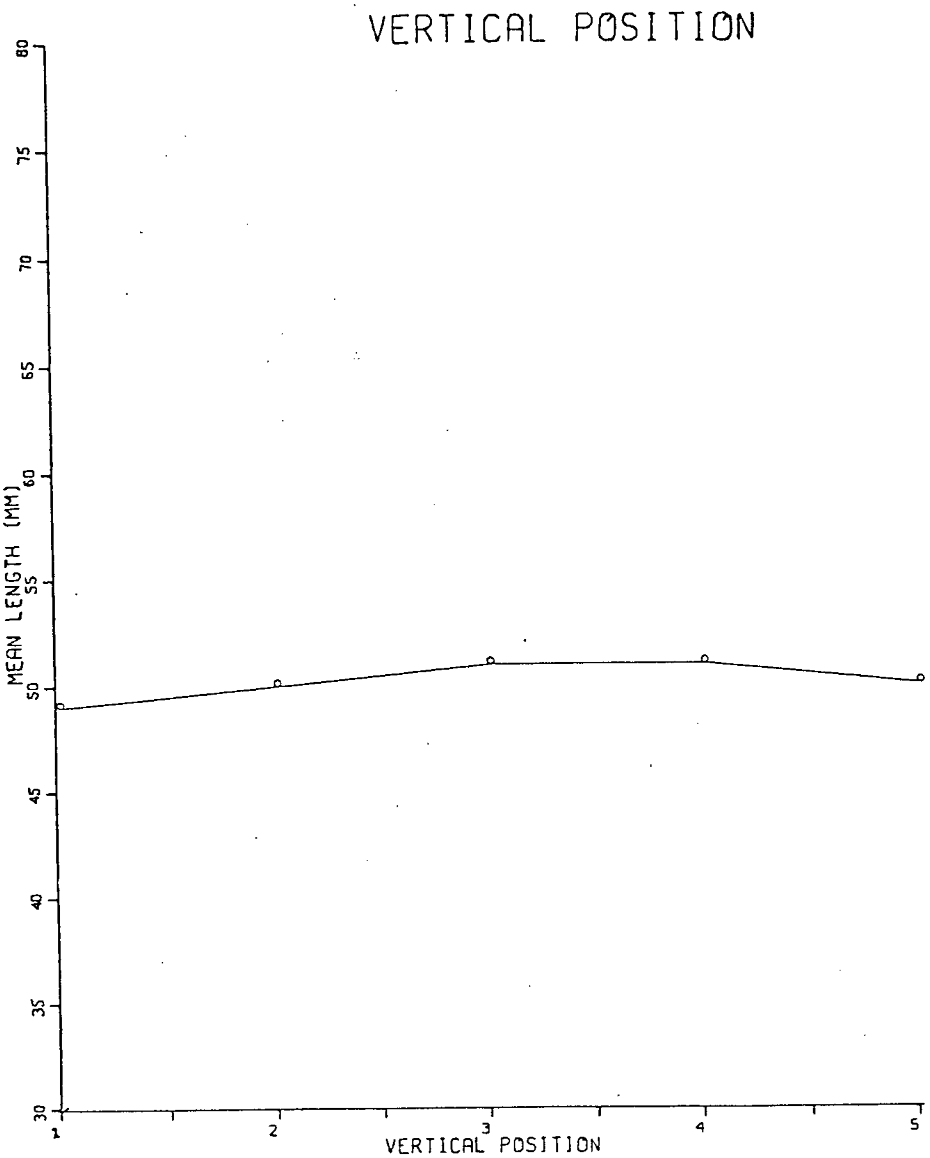
Tray System .... T

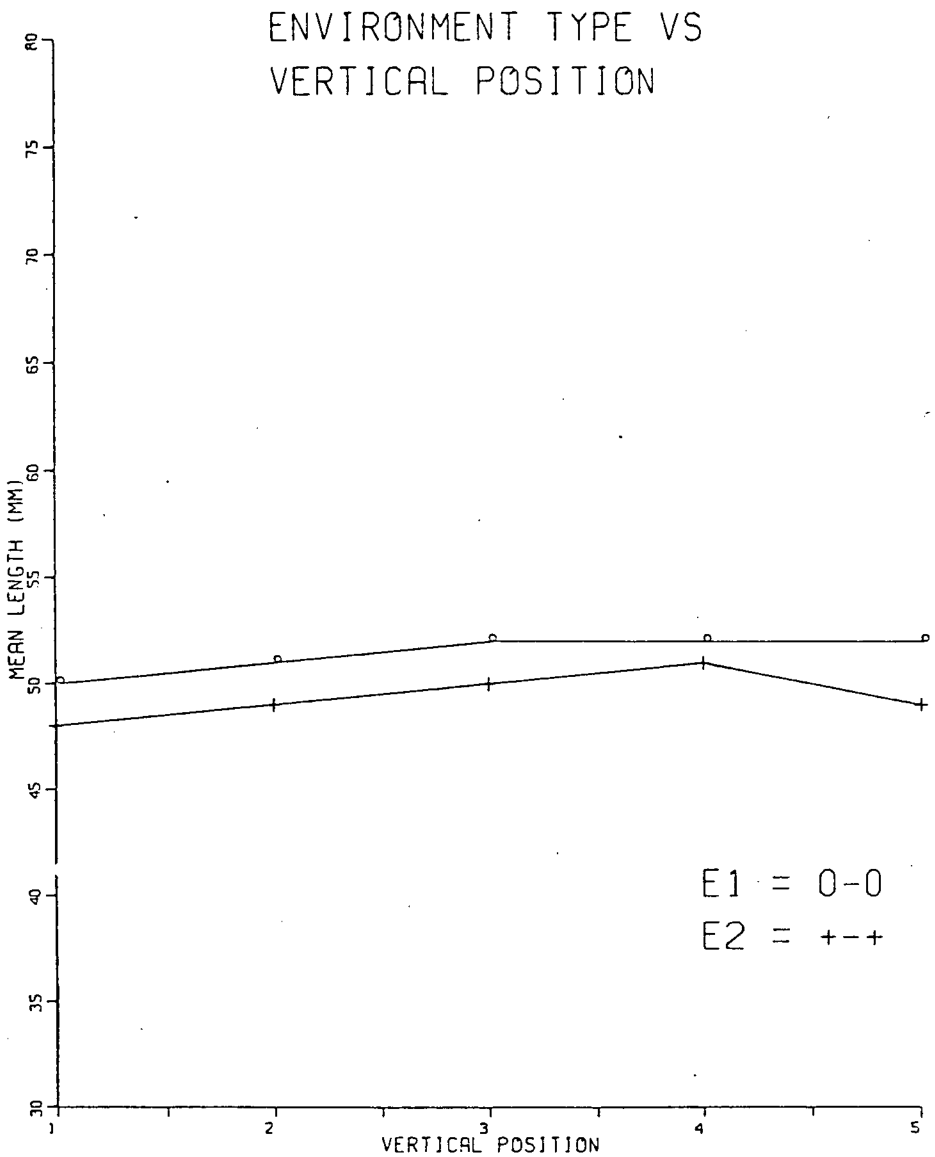
Time C

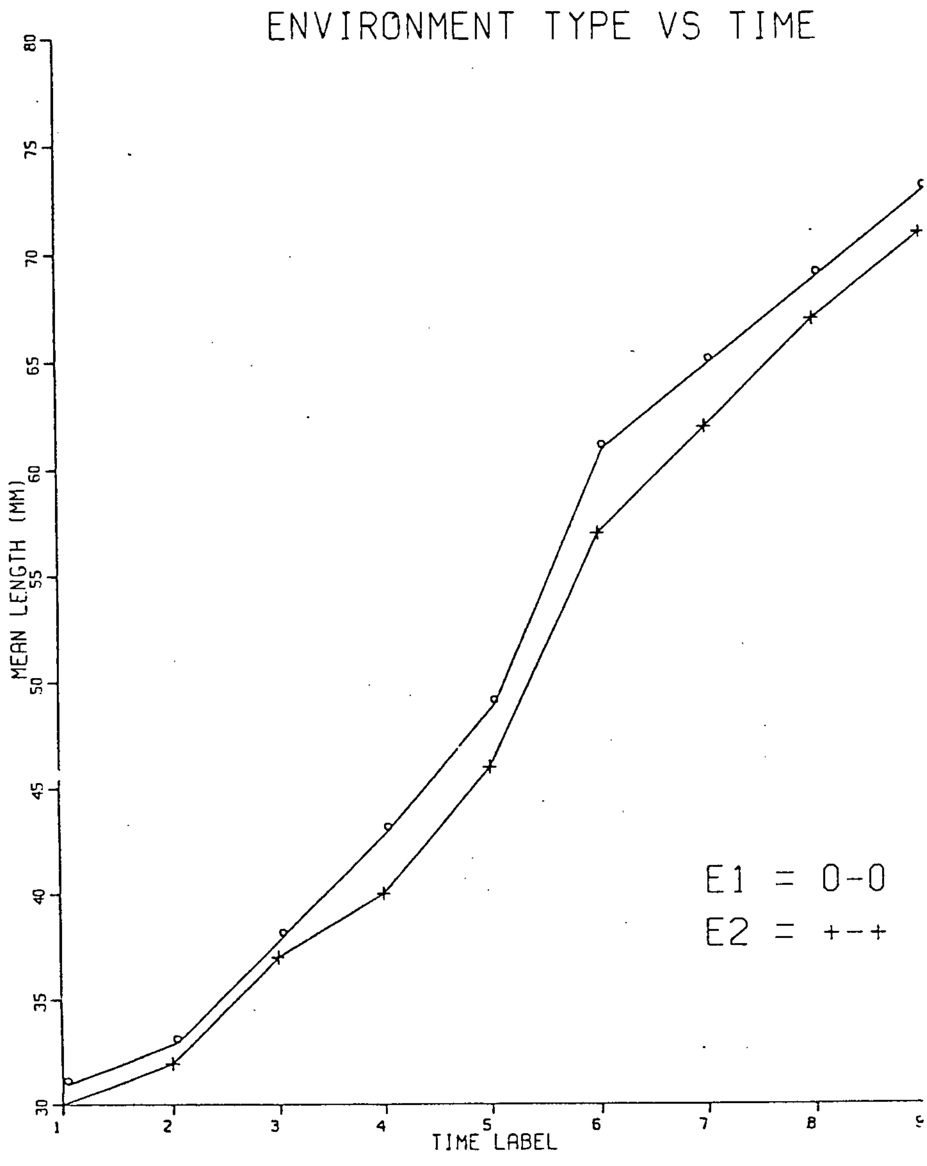
Vertical Position .... P

Time Label	Date 1
1	June 12
2	June 26
3	July 10
4	July 24
5	August 7
6	Sept. 6
7	Sept. 19
8	Oct. 2
9	Oct. 20

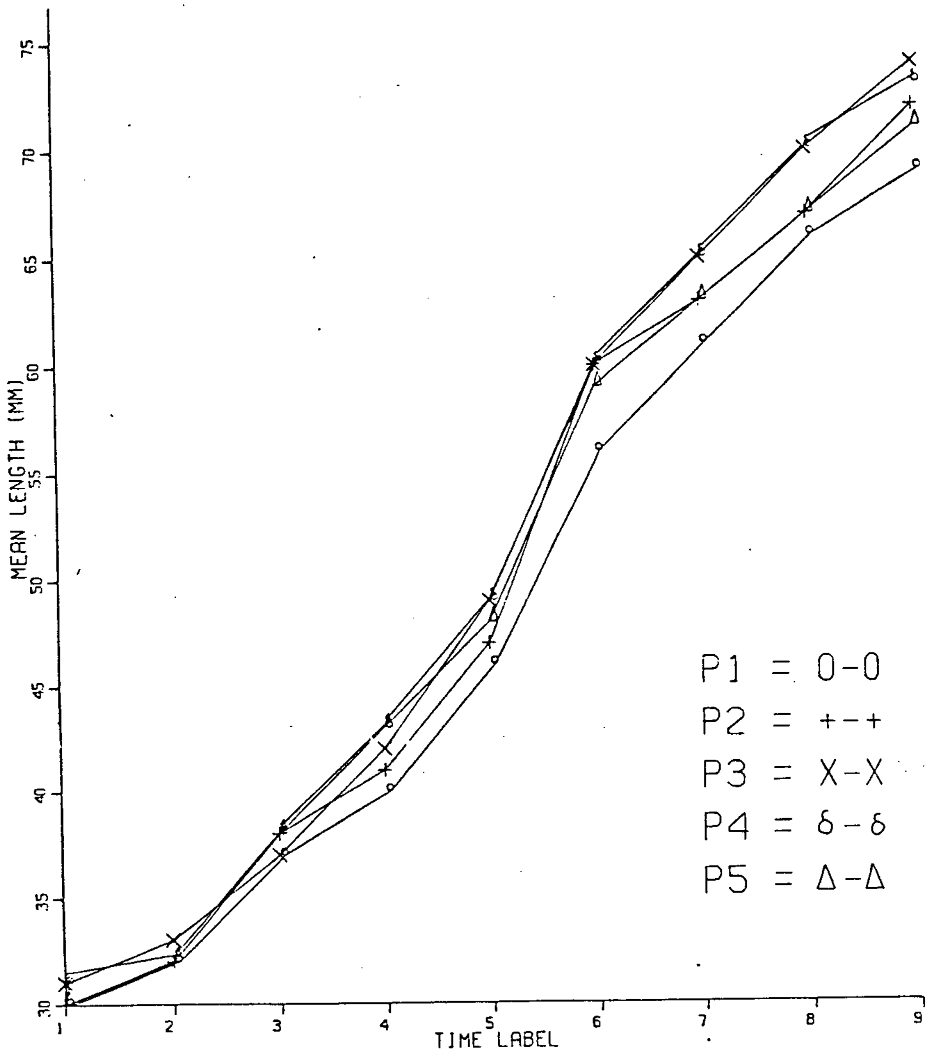
Tray Code	Tray Type
T1	MacNicol
T2	Nestier
T3	Suspension

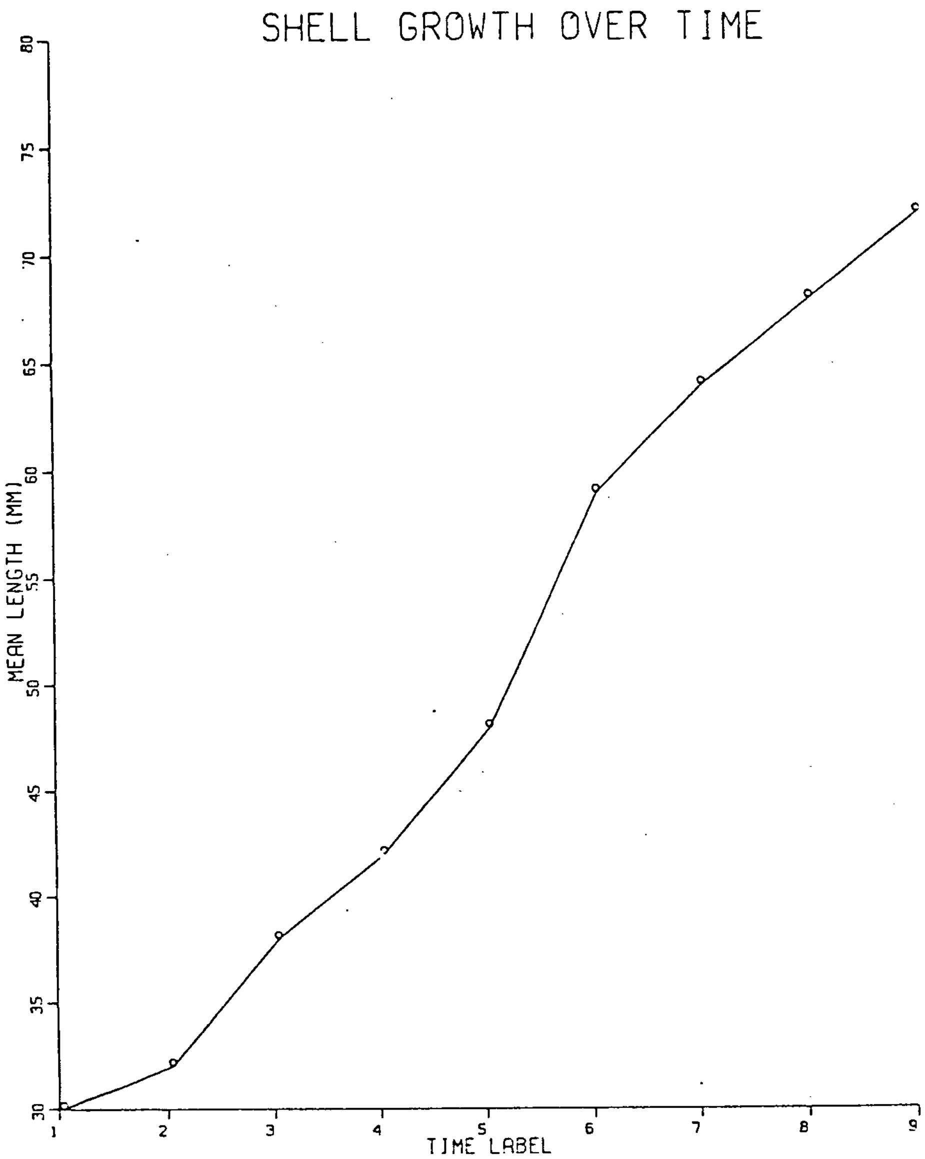

VERTICAL POSITION
MEAN LENGTH (MM)
80
75
70
65
60
55
50
45
40
35
30
1
2
3
4
5
VERTICAL POSITION

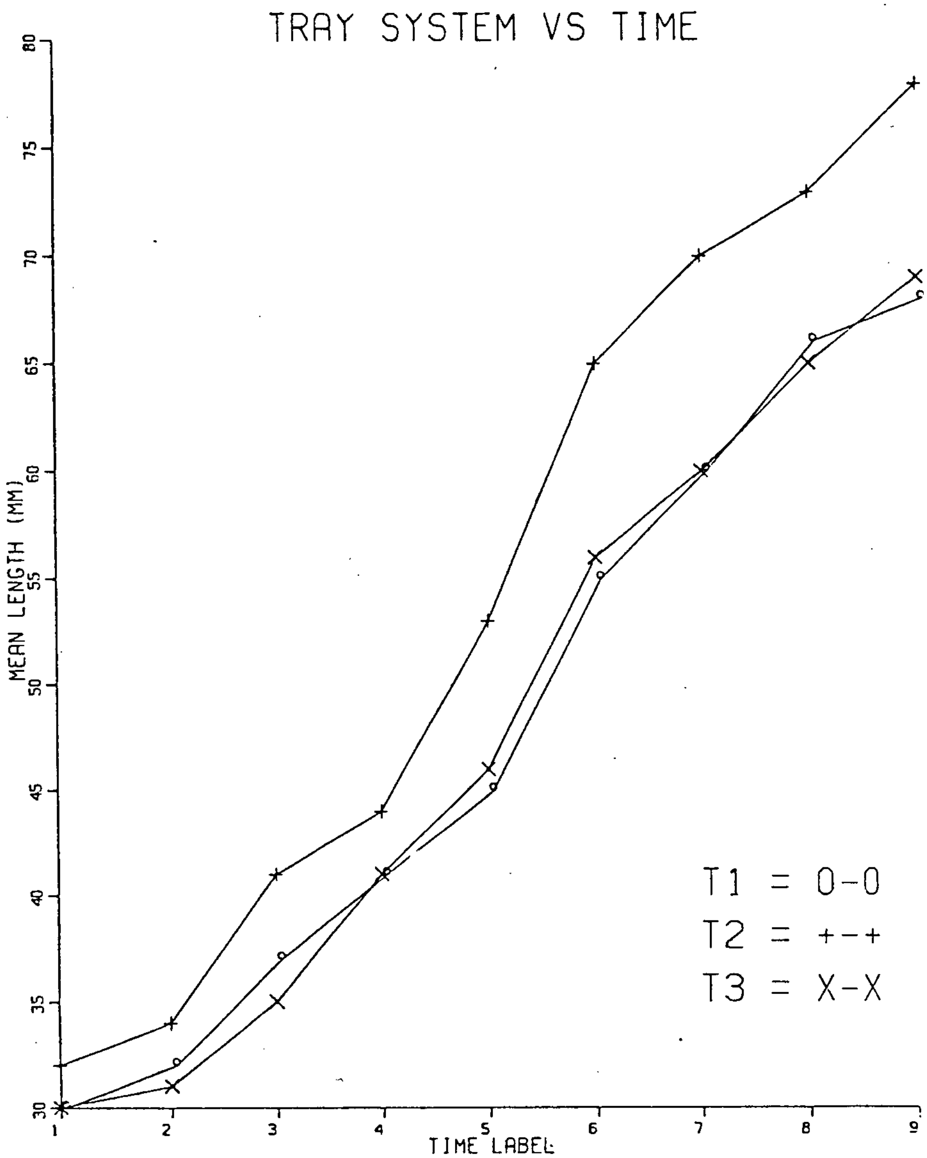

ENVIRONMENT TYPE VS
VERTICAL POSITION
MEAN LENGTH (MM)
80
75
70
65
60
55
50
45
40
35
30
1
2
3
4
5
VERTICAL POSITION
E1 = 0-0
E2 = +-+

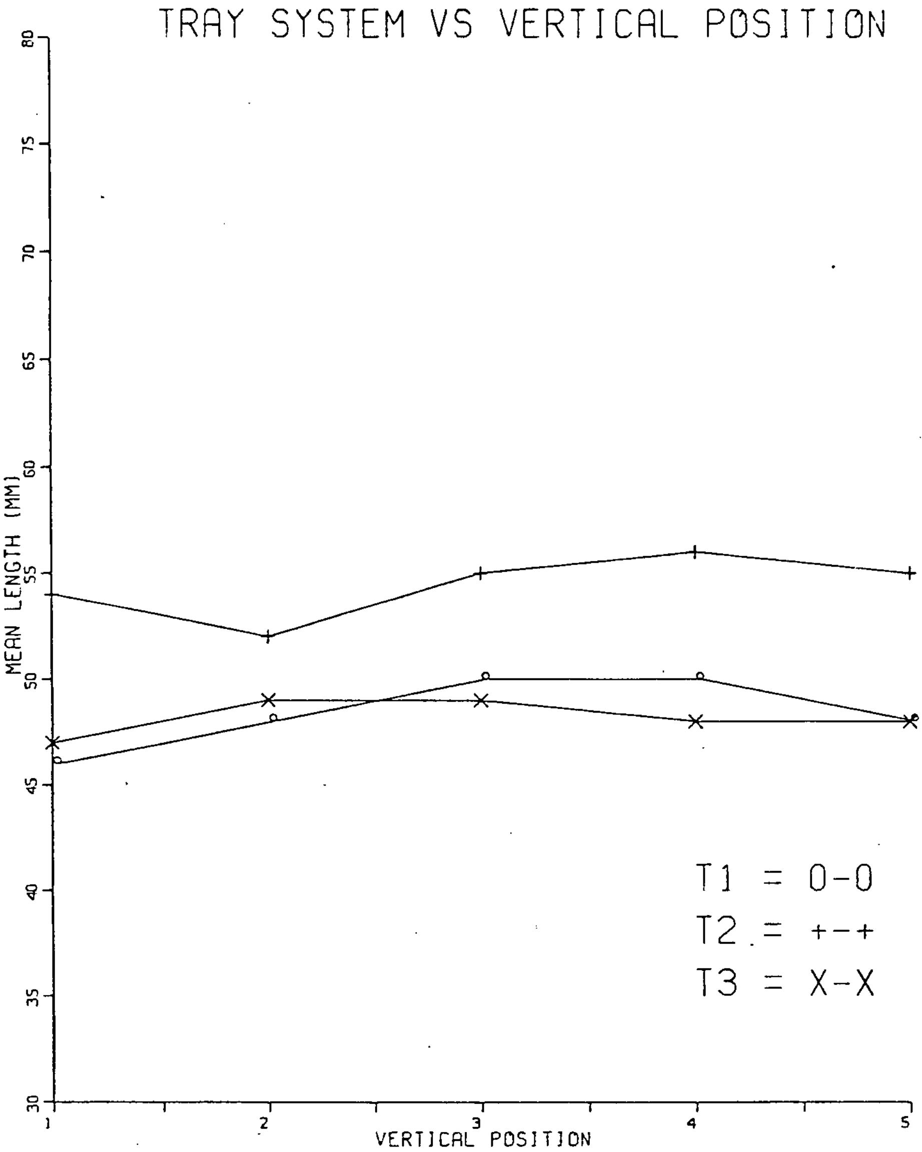

ENVIRONMENT TYPE VS TIME
MEAN LENGTH (MM)
30
35
40
45
50
55
60
65
70
75
80
TIME LABEL
1
2
3
4
5
6
7
8
E1 = 0-0
E2 = +--+

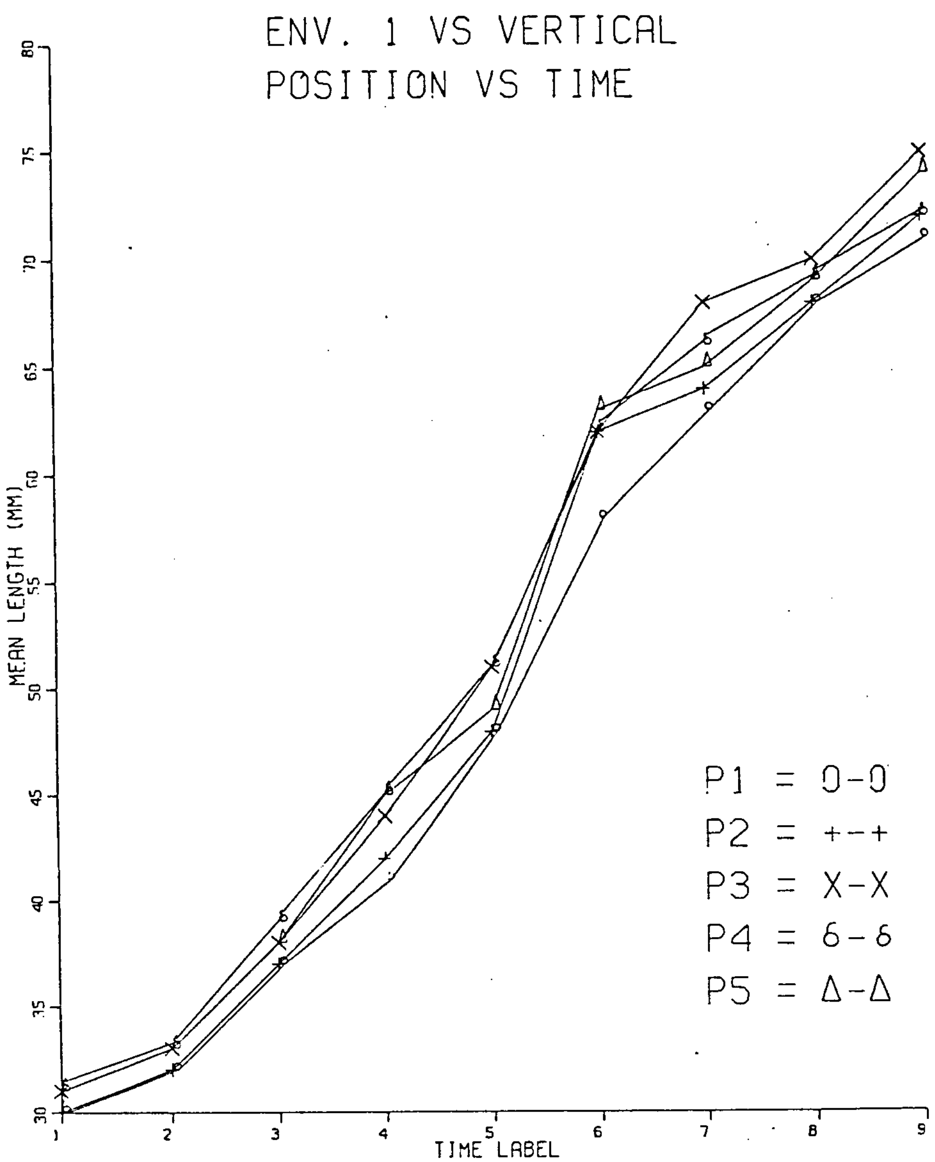
VERTICAL POSITION VS TIME

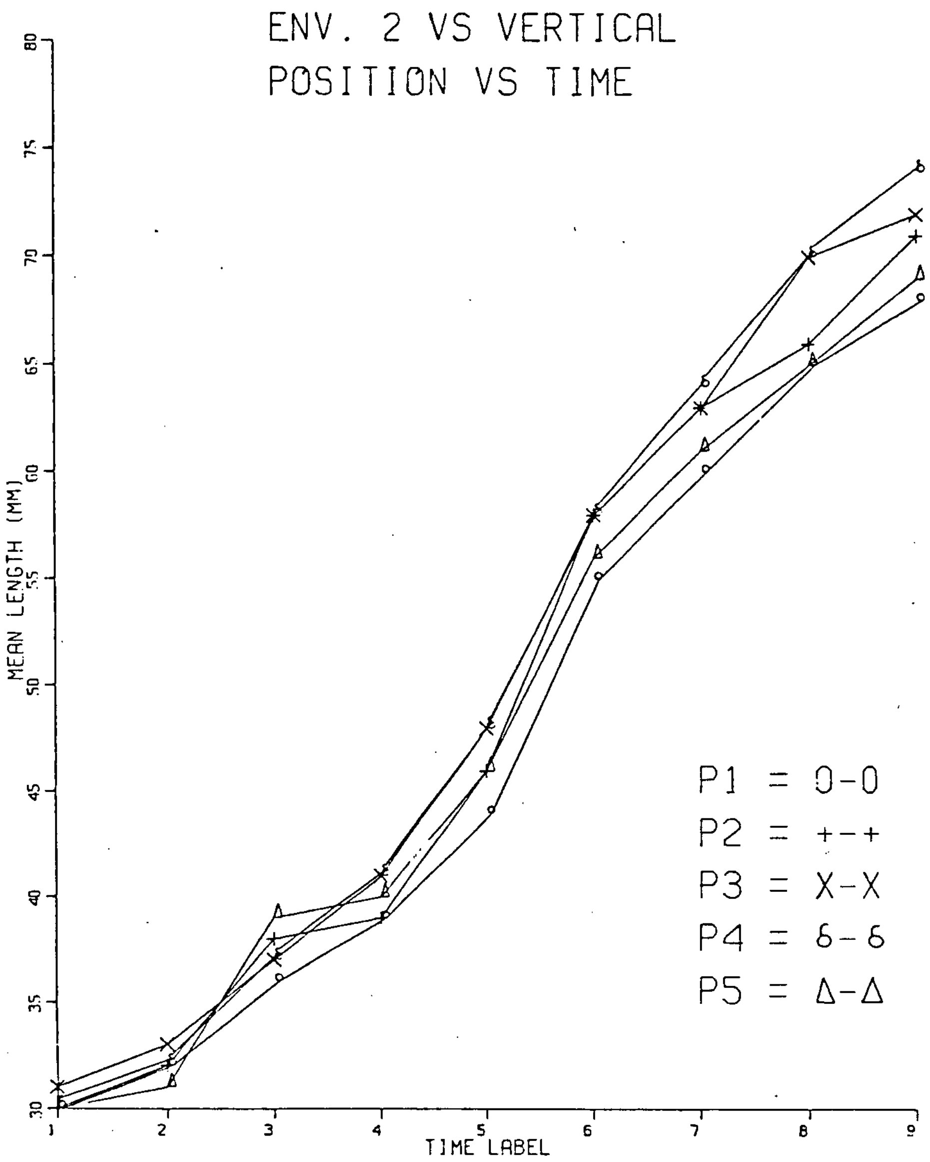


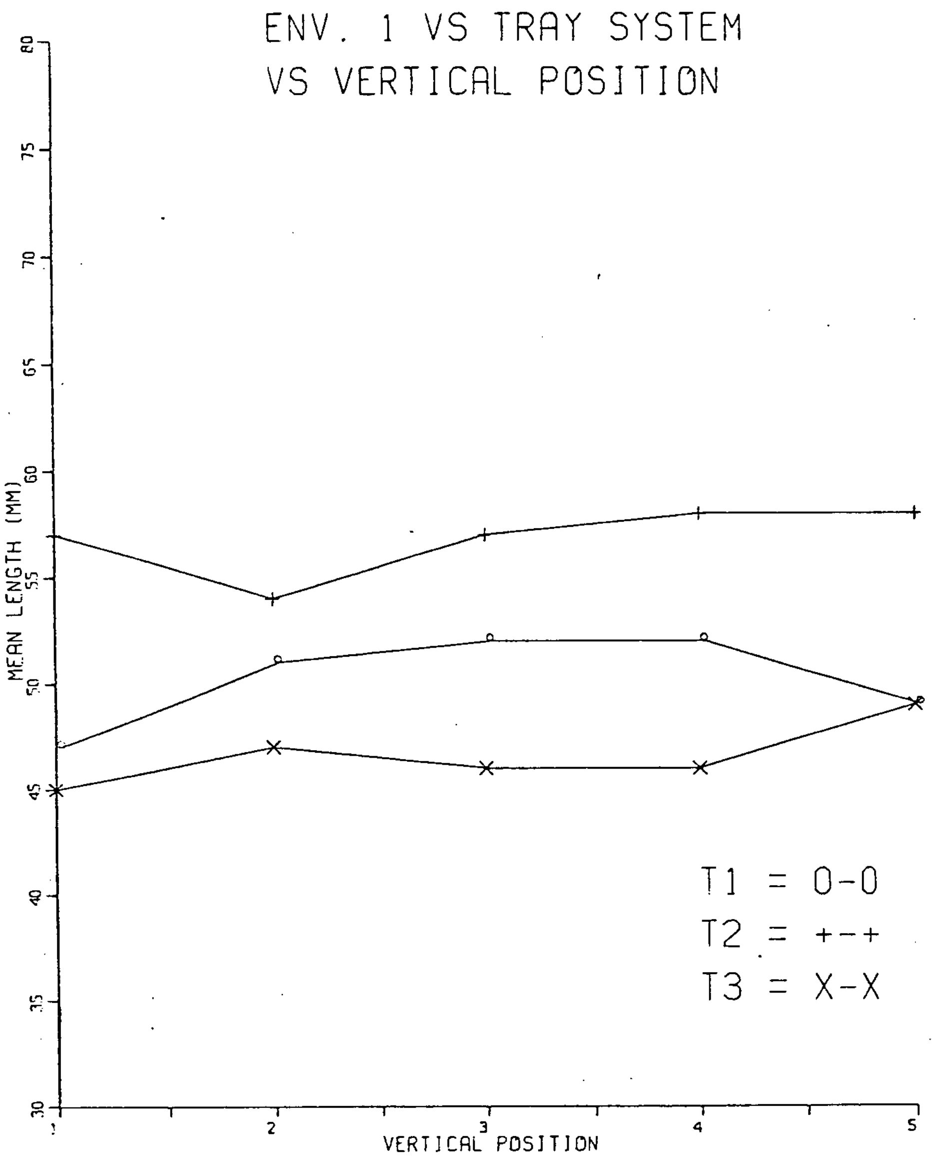

SHELL GROWTH OVER TIME
MEAN LENGTH (MM)
80
75
70
65
60
55
50
45
40
35
30
1
2
3
4
5
6
7
8
9
TIME LABEL


TRAY SYSTEM VS TIME
MEAN LENGTH (MM)
TIME LABEL
30
35
40
45
50
55
60
65
70
75
80
1
2
3
4
5
6
7
8
9
T1 = 0-0
T2 = +-+
T3 = X-X

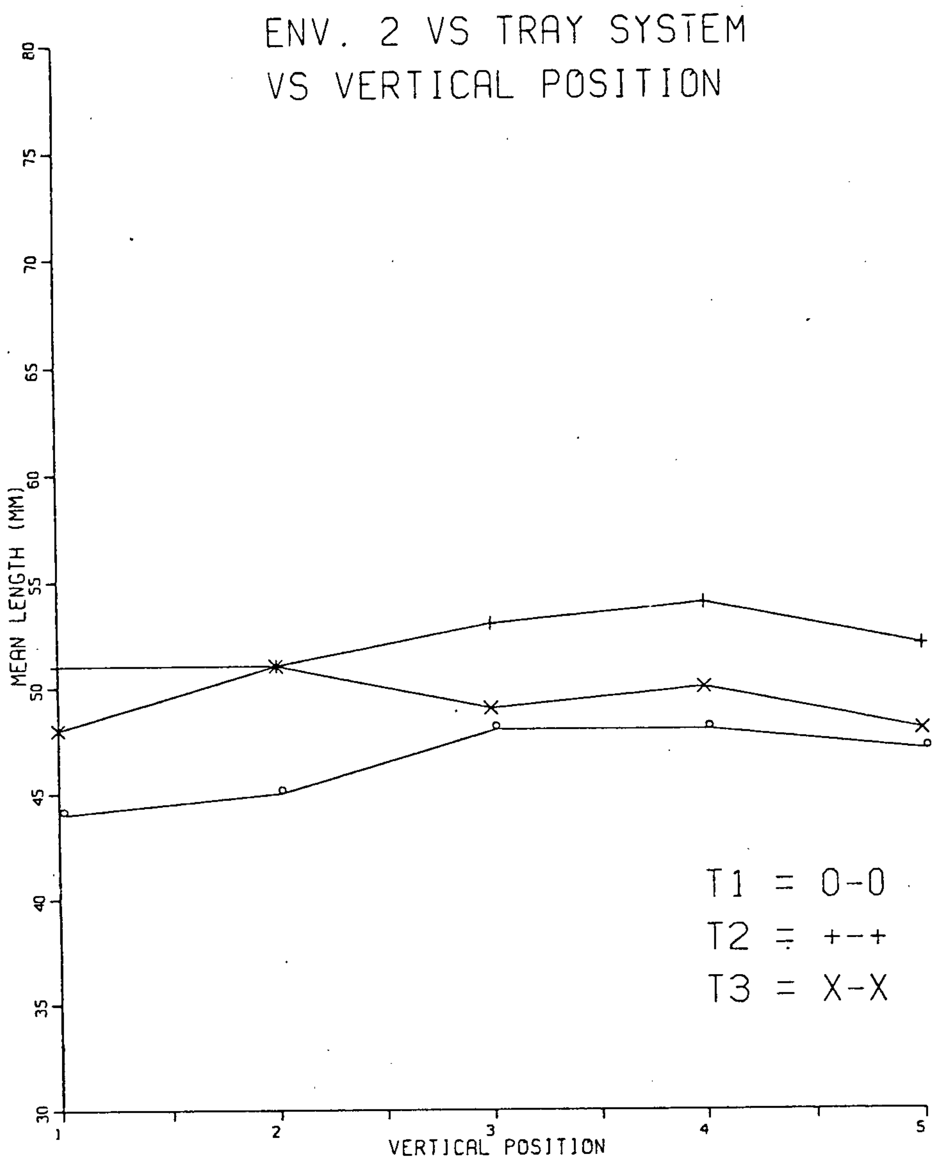

TRAY SYSTEM VS VERTICAL POSITION
MEAN LENGTH (MM)
30
35
40
45
50
55
60
65
70
75
80
1
2
3
4
5
VERTICAL POSITION
T1 = 0-0
T2 = +-+
T3 = X-X

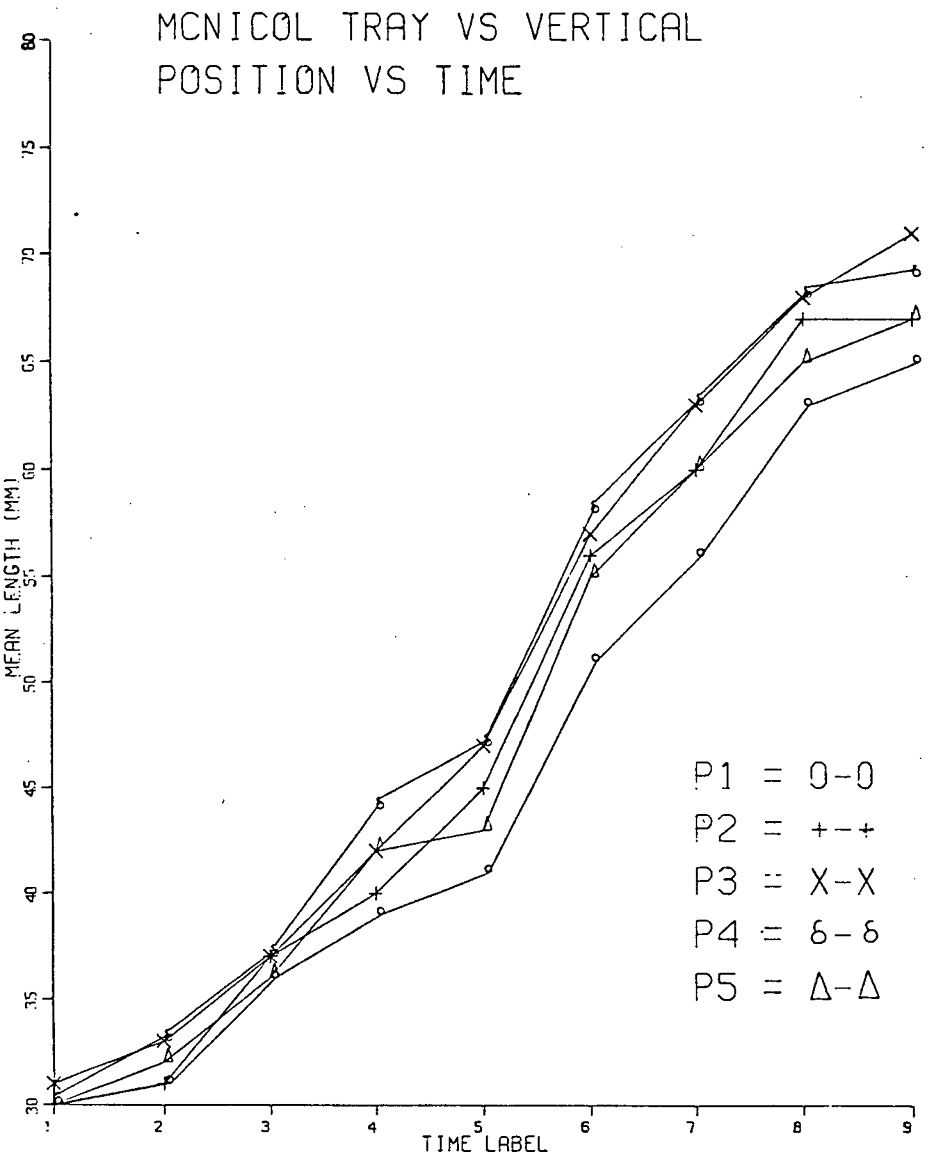

ENV. 1 VS VERTICAL
POSITION VS TIME
MEAN LENGTH (MM)
TIME LABEL
30
35
40
45
50
55
60
65
70
75
80
1
2
3
4
5
6
7
8
9
P1 = O-O
P2 = +-+
P3 = X-X
P4 = 6-6
P5 = Δ-Δ

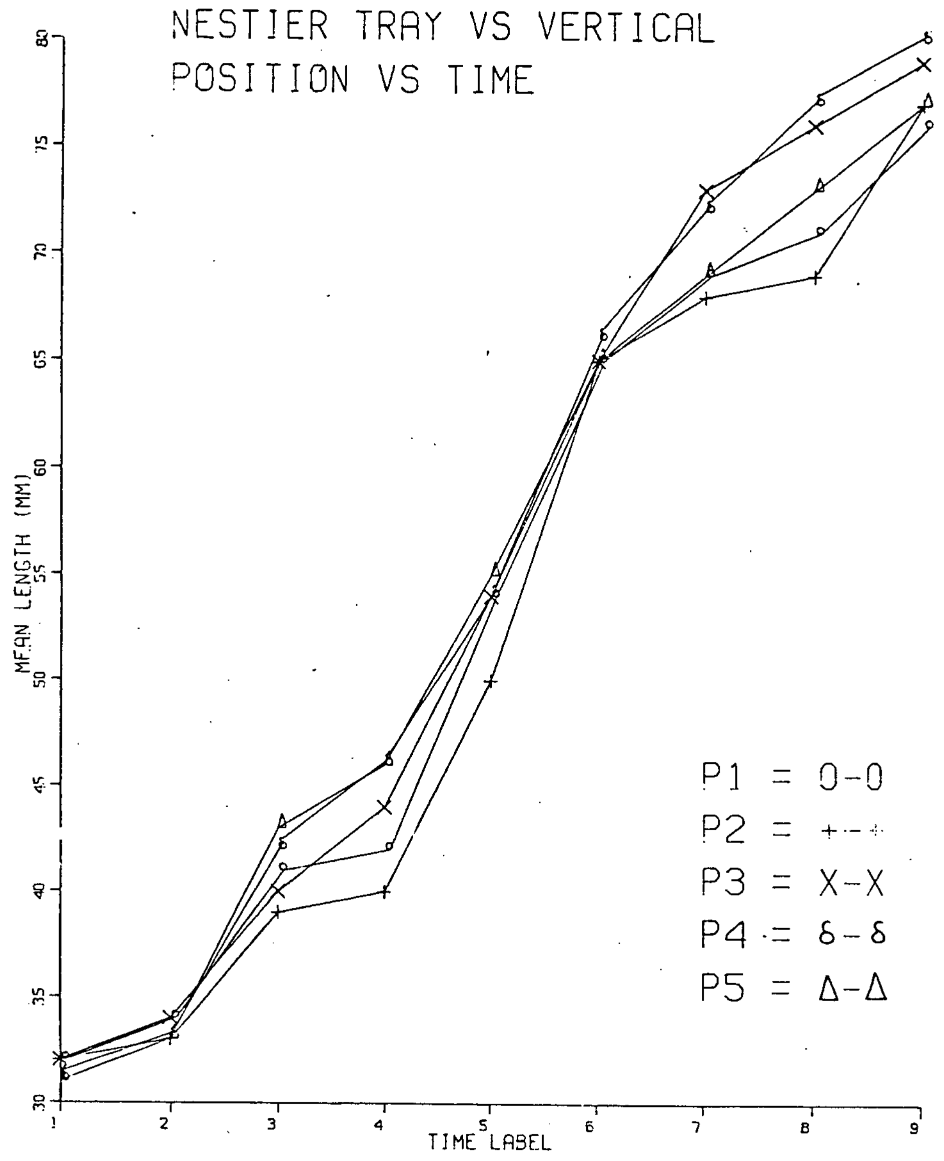

ENV. 2 VS VERTICAL
POSITION VS TIME
MEAN LENGTH (MM)
80
75
70
65
60
55
50
45
40
35
30
TIME LABEL
1
2
3
4
5
6
7
8
9
P1 = O-O
P2 = +-+
P3 = X-X
P4 = δ-δ
P5 = Δ-Δ

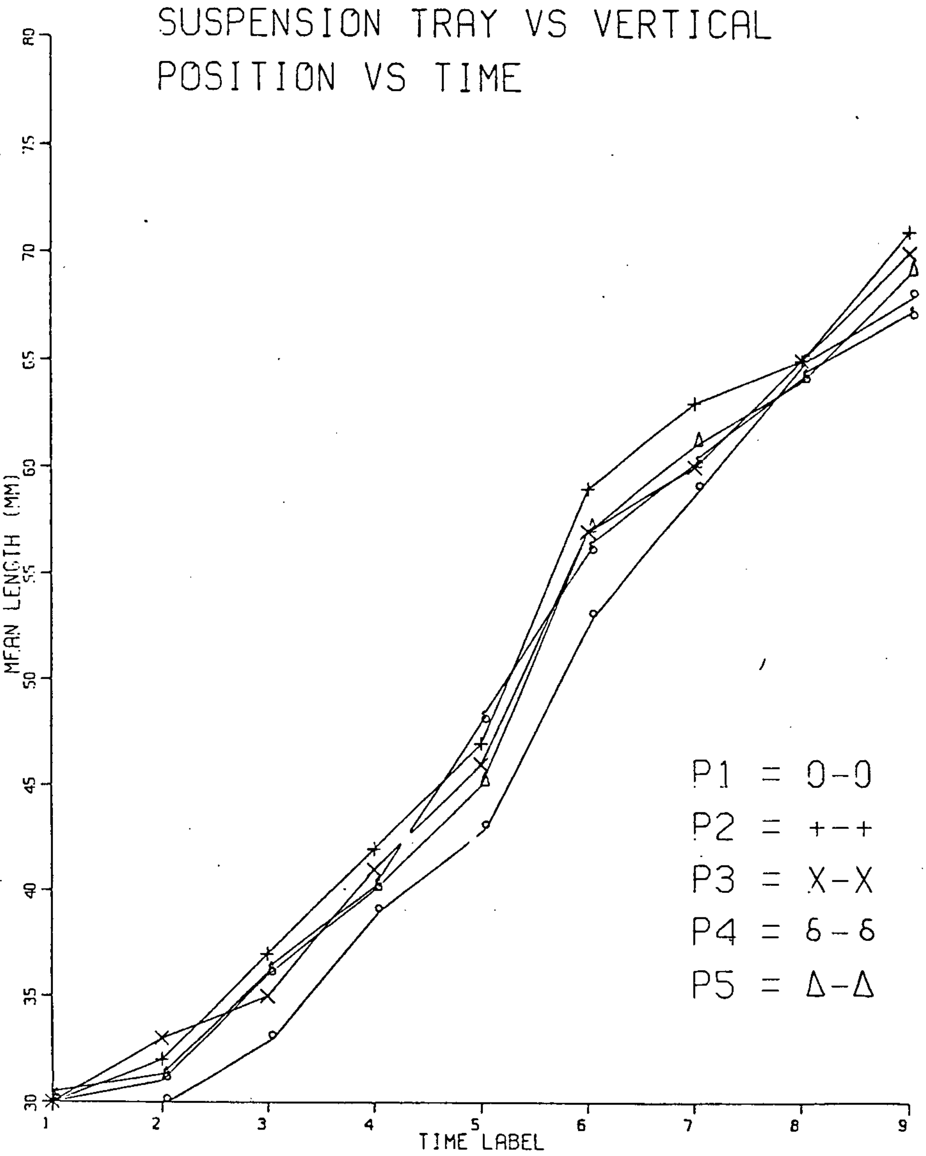


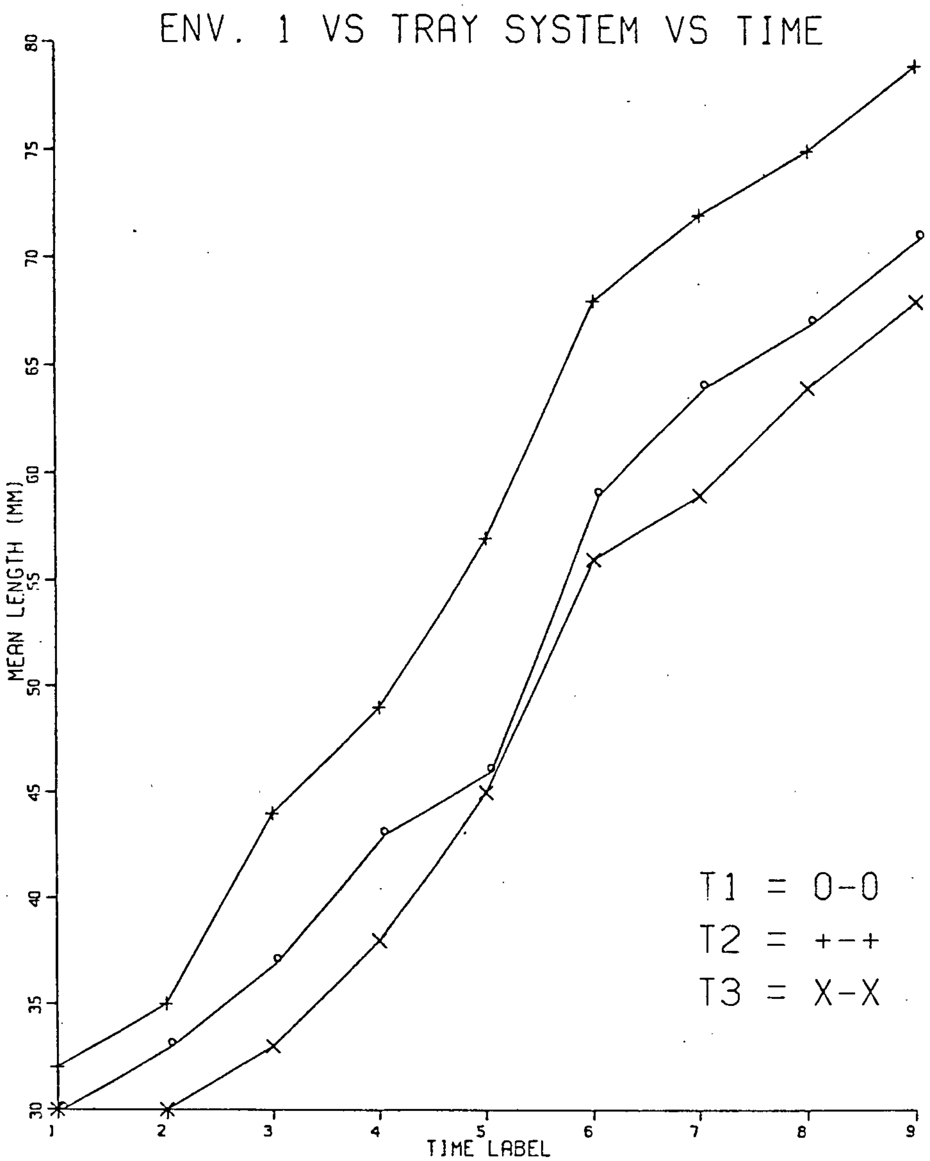
ENV. 1 VS TRAY SYSTEM
VS VERTICAL POSITION
MEAN LENGTH (MM)
VERTICAL POSITION
T1 = O-O
T2 = +-+
T3 = X-X

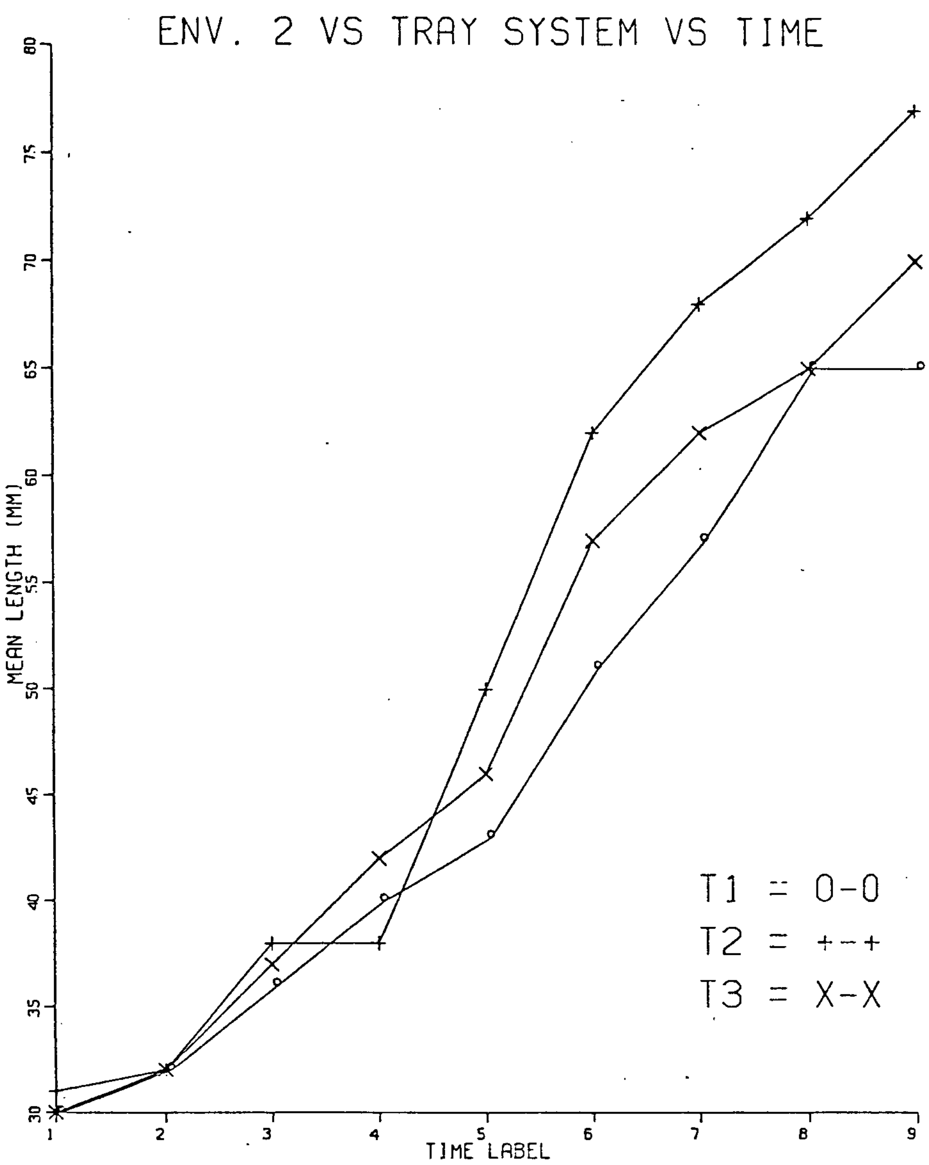

ENV. 2 VS TRAY SYSTEM
VS VERTICAL POSITION
MEAN LENGTH (MM)
80
75
70
65
60
55
50
45
40
35
30
1
2
3
4
5
VERTICAL POSITION
T1 = O-O
T2 = +-+
T3 = X-X

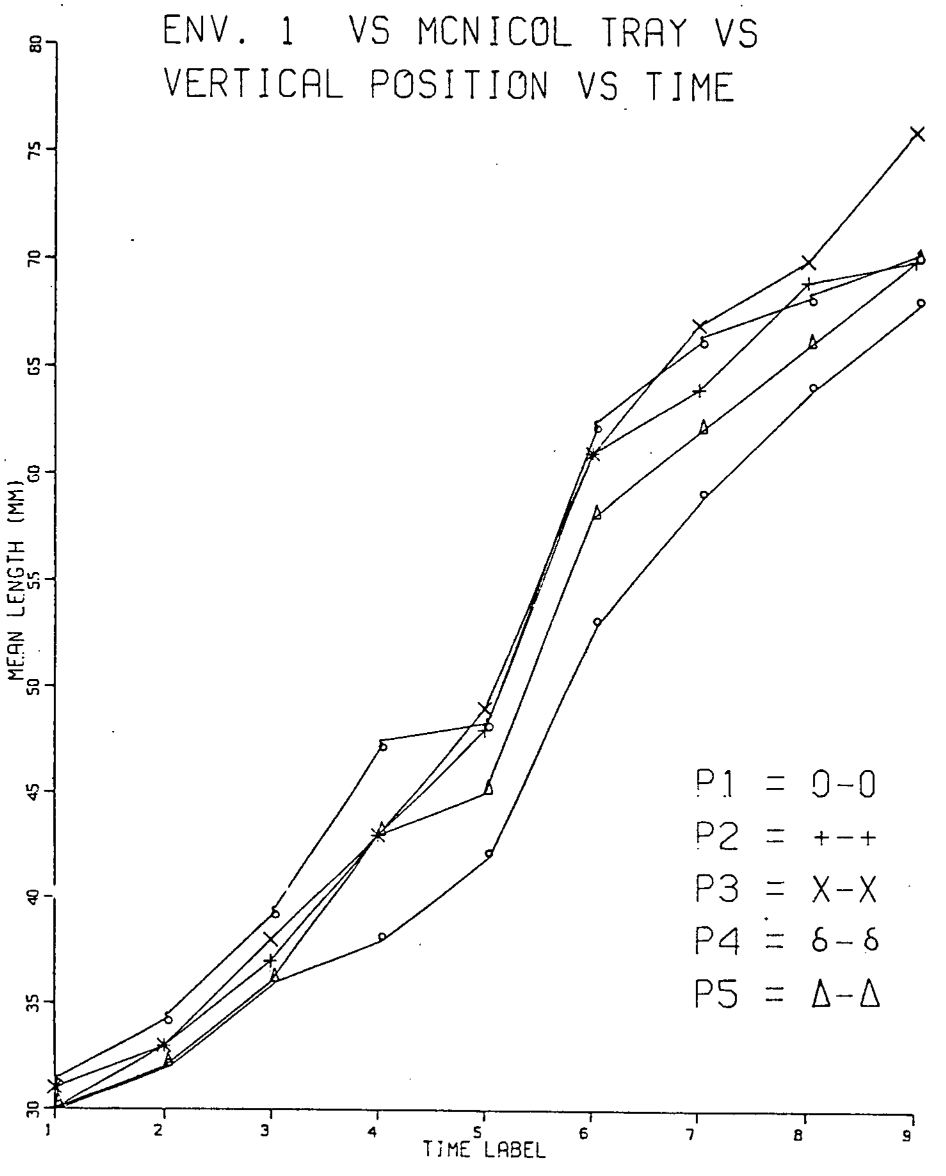

MCNICOL TRAY VS VERTICAL
POSITION VS TIME
MEAN LENGTH (MM)
TIME LABEL
P1 = O-O
P2 = +-+
P3 = X-X
P4 = δ-δ
P5 = Δ-Δ

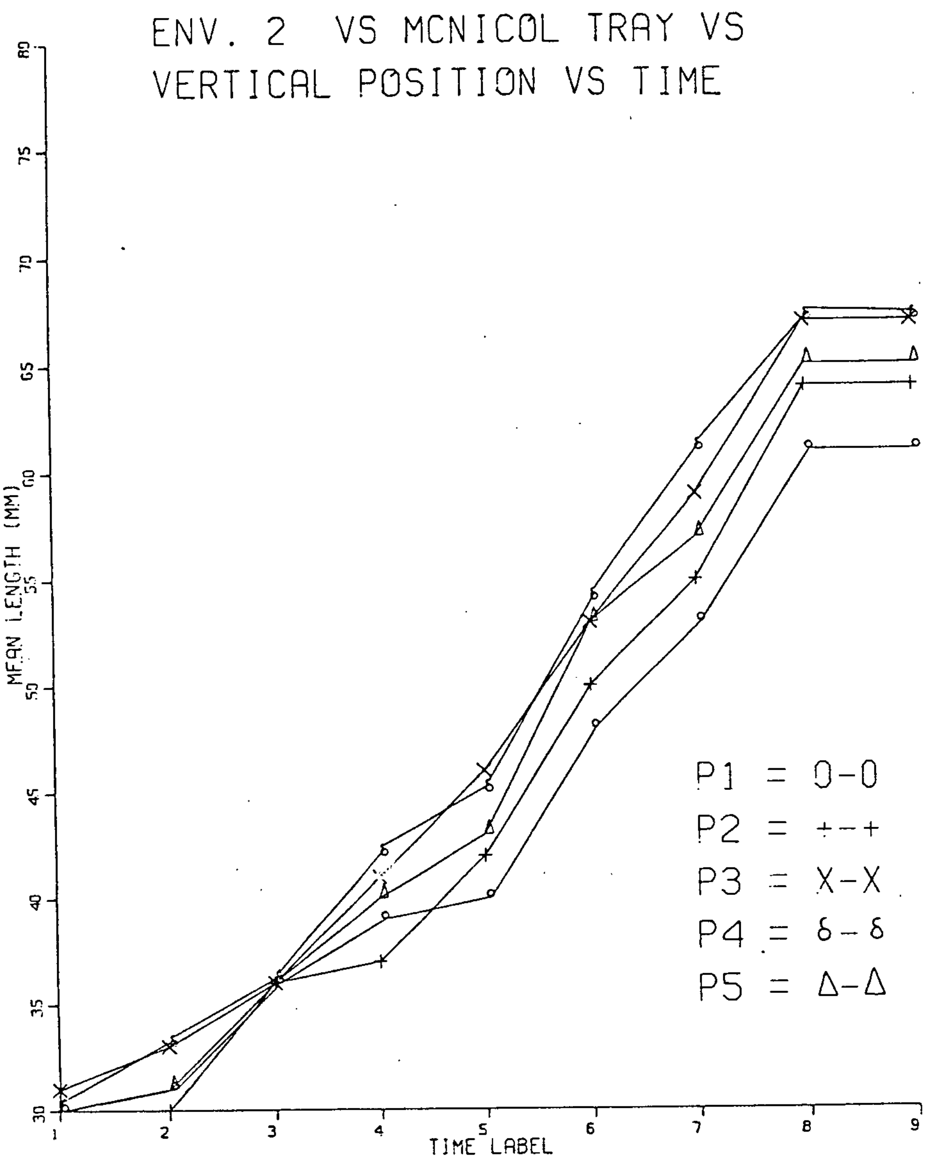

NESTIER TRAY VS VERTICAL
POSITION VS TIME
MEAN LENGTH (MM)
30
35
40
45
50
55
60
65
70
75
80
TIME LABEL
1
2
3
4
5
6
7
8
9
P1 = O-O
P2 = +-+
P3 = X-X
P4 = δ-δ
P5 = Δ-Δ

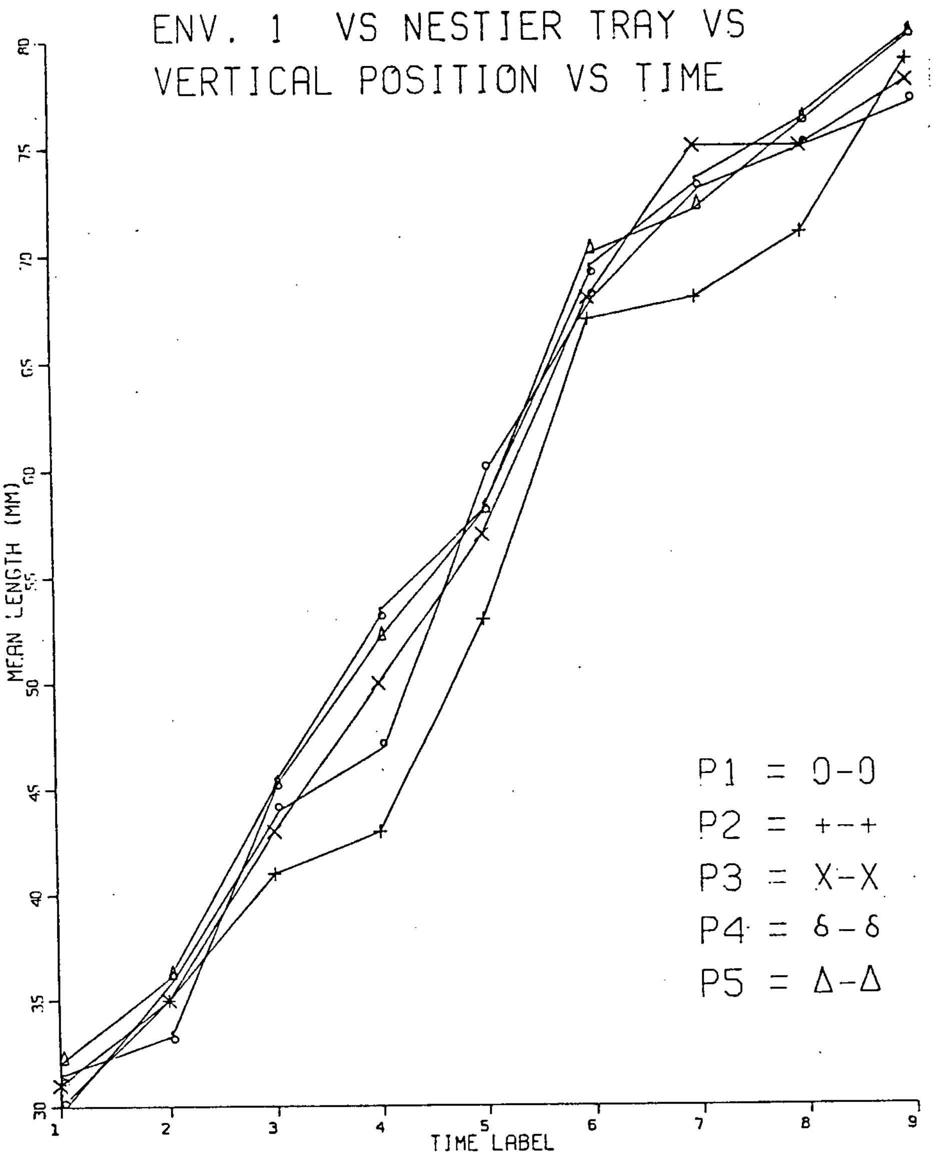

SUSPENSION TRAY VS VERTICAL
POSITION VS TIME
MEAN LENGTH (MM)
TIME LABEL
P1 = O-O
P2 = +-+
P3 = X-X
P4 = δ-δ
P5 = Δ-Δ

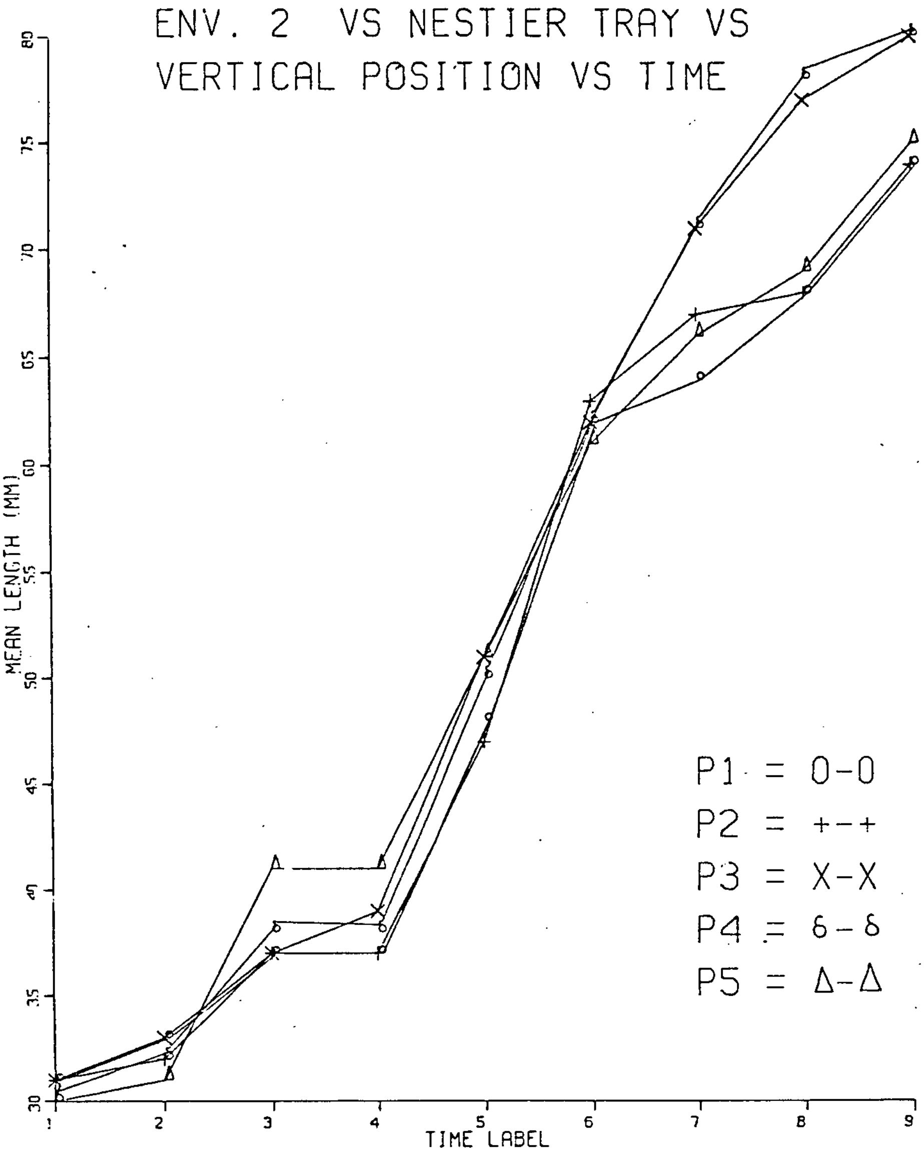

ENV. 1 VS TRAY SYSTEM VS TIME
MEAN LENGTH (MM)
30
35
40
45
50
55
60
65
70
75
80
TIME LABEL
1
2
3
4
5
6
7
8
9
T1 = O-O
T2 = +-+
T3 = X-X

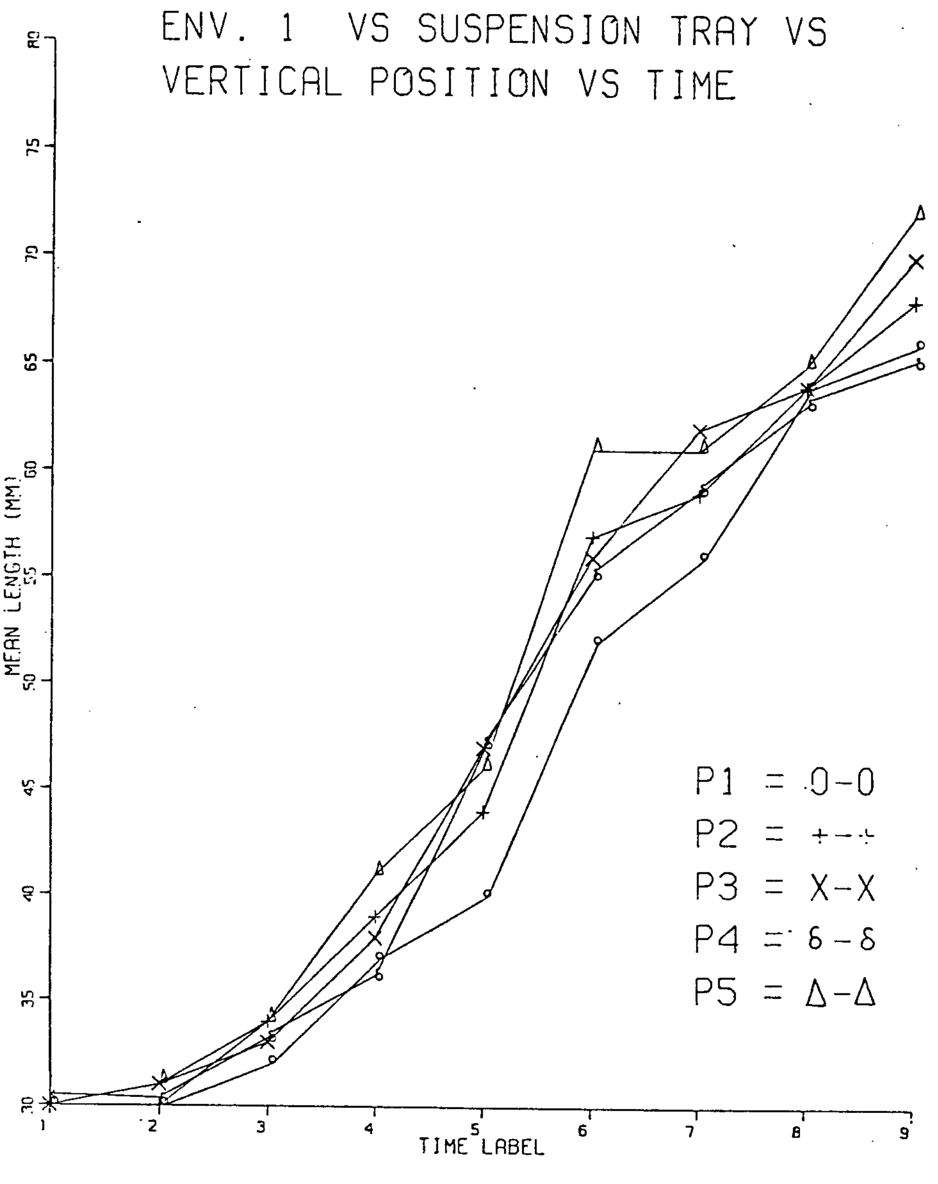

ENV. 2 VS TRAY SYSTEM VS TIME
MEAN LENGTH (MM)
30
35
40
45
50
55
60
65
70
75
80
TIME LABEL
1
2
3
4
5
6
7
8
9
T1 = O-O
T2 = +-+
T3 = X-X

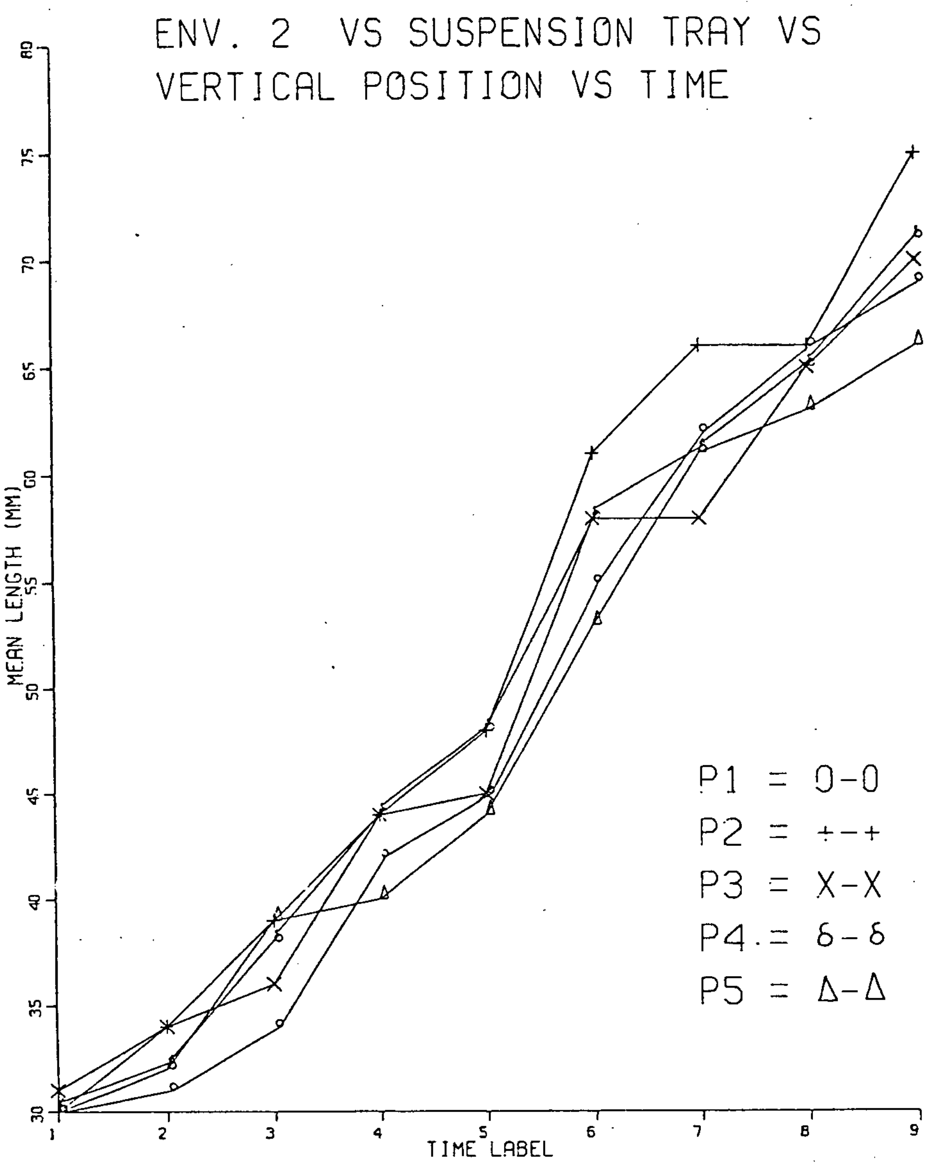

ENV. 1 VS MCNICOL TRAY VS
VERTICAL POSITION VS TIME
MEAN LENGTH (MM)
TIME LABEL
30
35
40
45
50
55
60
65
70
75
80
1
2
3
4
5
6
7
8
9
P1 = O-O
P2 = +-+
P3 = X-X
P4 = δ-δ
P5 = Δ-Δ


ENV. 2 VS MCNICOL TRAY VS
VERTICAL POSITION VS TIME
MEAN LENGTH (MM)
TIME LABEL
P1 = O-O
P2 = +-+
P3 = X-X
P4 = δ-δ
P5 = Δ-Δ


ENV. 1 VS NESTIER TRAY VS
VERTICAL POSITION VS TIME
MEAN LENGTH (MM)
TIME LABEL
P1 = O-O
P2 = +-+
P3 = X-X
P4 = δ-δ
P5 = Δ-Δ


ENV. 2 VS NESTIER TRAY VS
VERTICAL POSITION VS TIME
MEAN LENGTH (MM)
30
35
40
45
50
55
60
65
70
75
80
1
2
3
4
5
6
7
8
9
TIME LABEL
P1 = O-O
P2 = +-+
P3 = X-X
P4 = δ-δ
P5 = Δ-Δ


ENV. 1 VS SUSPENSION TRAY VS
VERTICAL POSITION VS TIME
MEAN LENGTH (MM)
TIME LABEL
30
35
40
45
50
55
60
65
70
75
80
1
2
3
4
5
6
7
8
9
P1 = O-O
P2 = +-+
P3 = X-X
P4 = δ-δ
P5 = Δ-Δ


ENV. 2 VS SUSPENSION TRAY VS
VERTICAL POSITION VS TIME
MEAN LENGTH (MM)
30
35
40
45
50
55
60
65
70
75
80
TIME LABEL
1
2
3
4
5
6
7
8
9
P1 = O-O
P2 = +-+
P3 = X-X
P4 = δ-δ
P5 = Δ-Δ

APPENDIX C

Plots of relationships to reveal effects of the factors environment type, tray system, time and vertical position upon growth in shell width.

Environment Type .... E

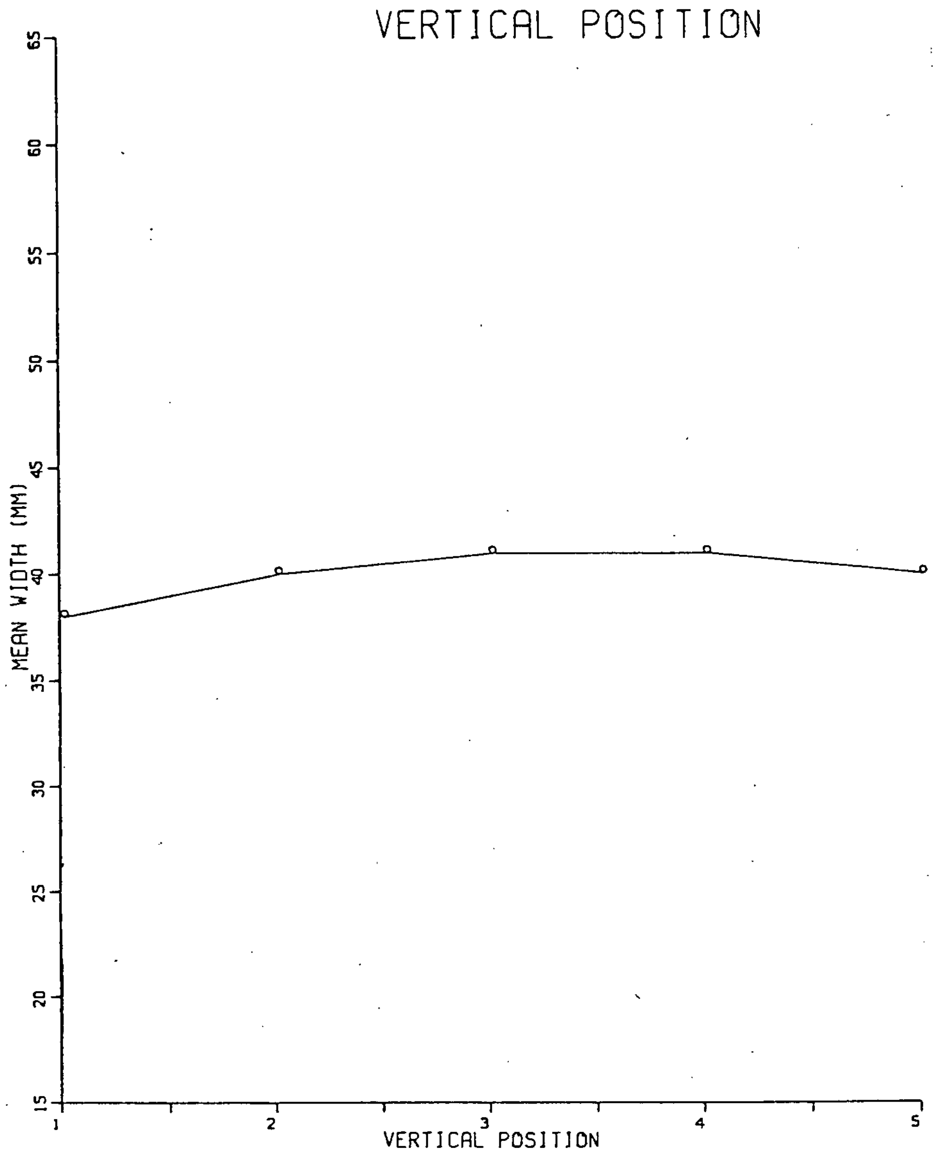
Tray System .... T

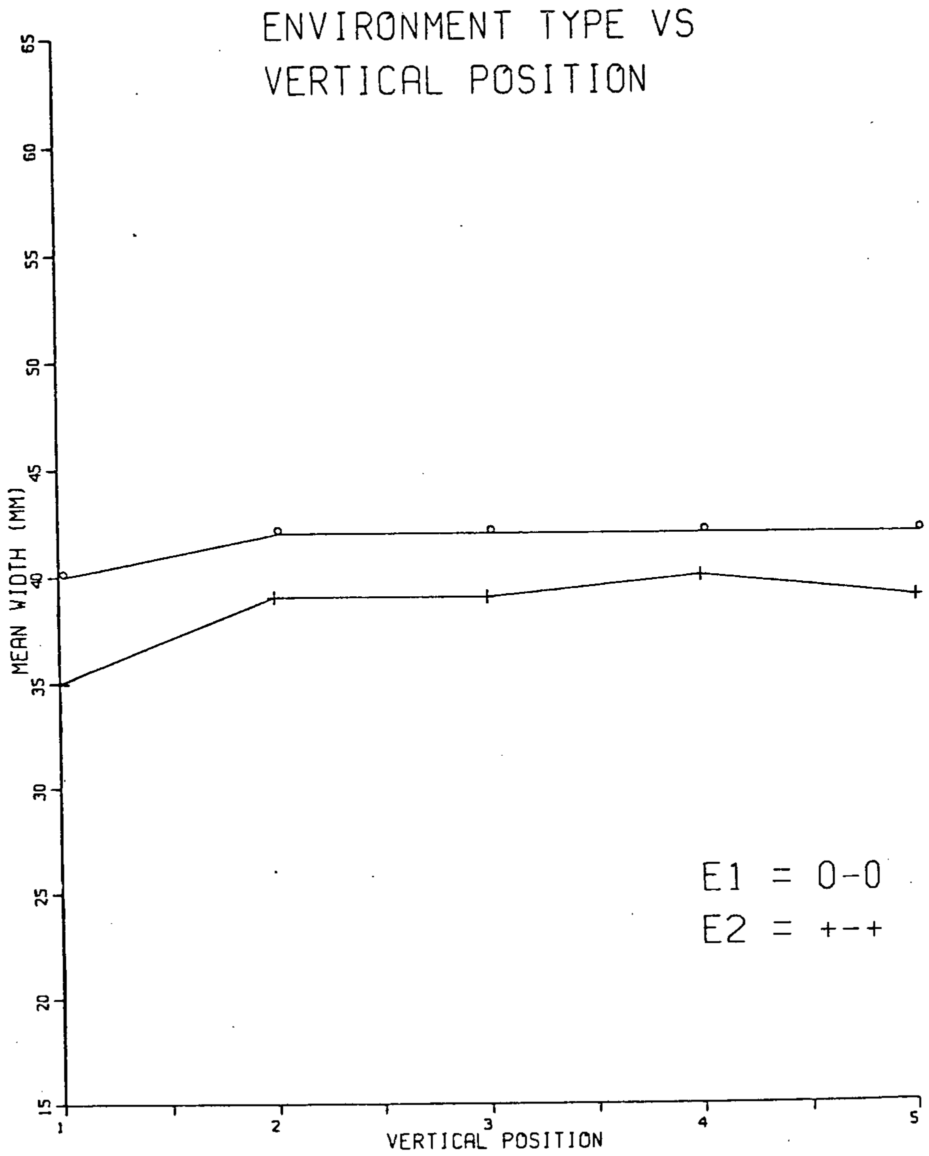
Time C

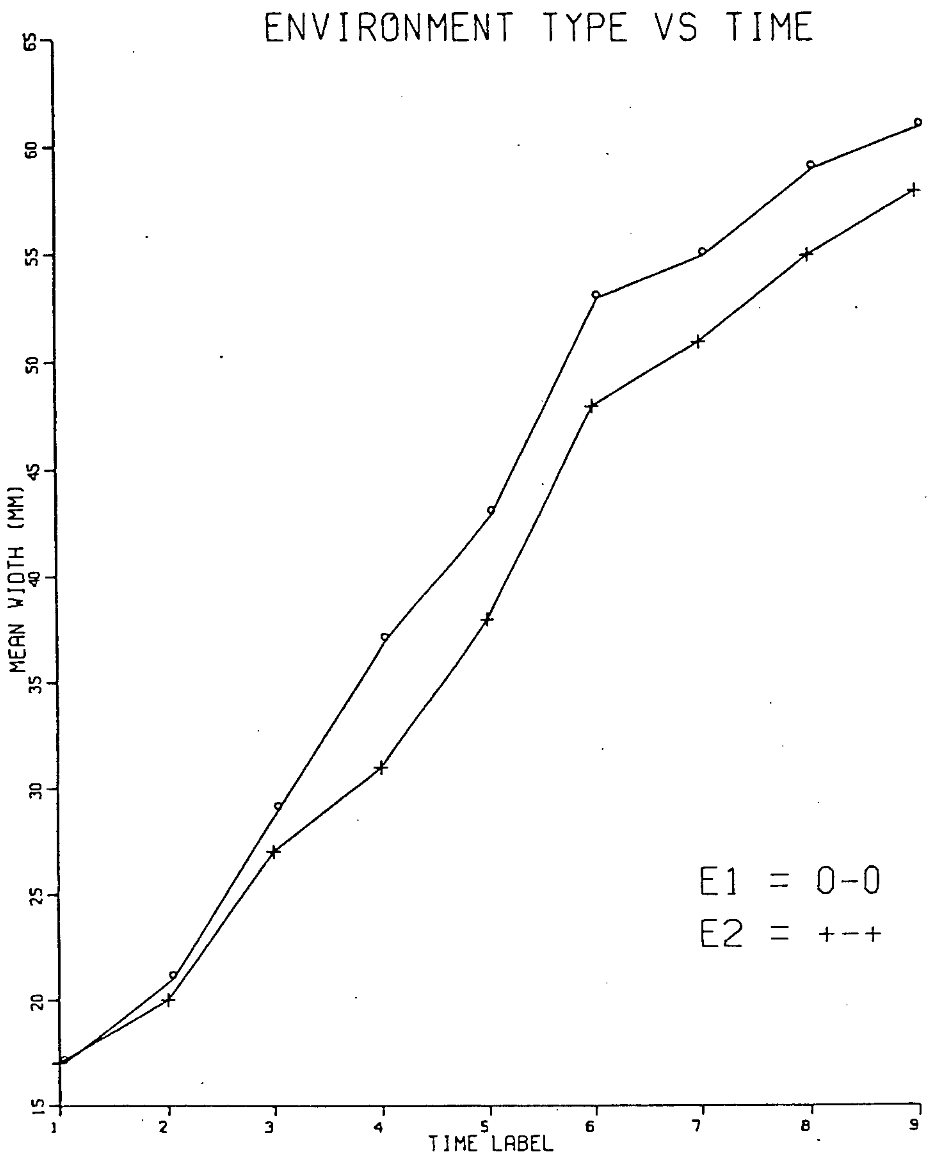
Vertical Position .... P

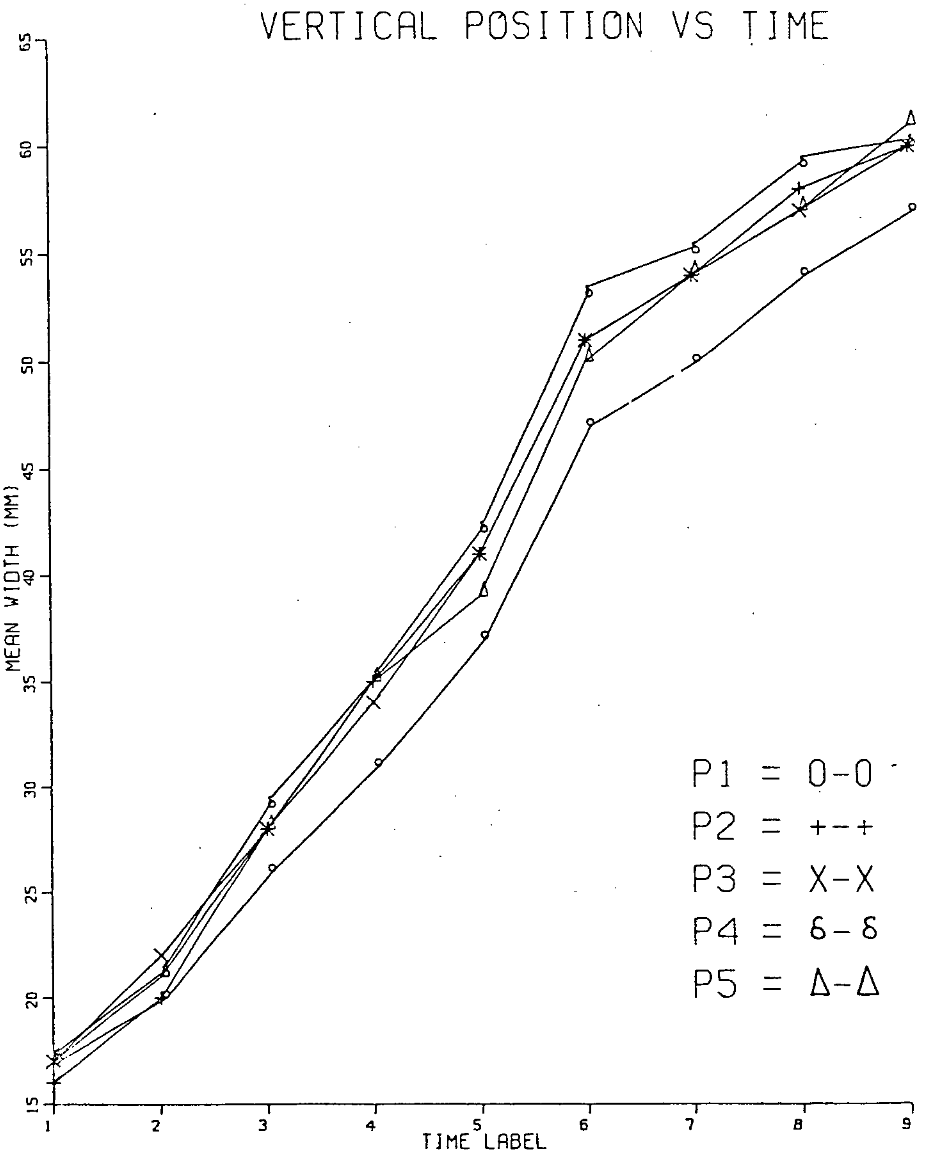
Time Label	Date
1	June 12
2	June 26
3	July 10
4	July 24
5	August 7
6	Sept. 6
7	Sept. 19
8	Oct. 2
9	Oct. 20

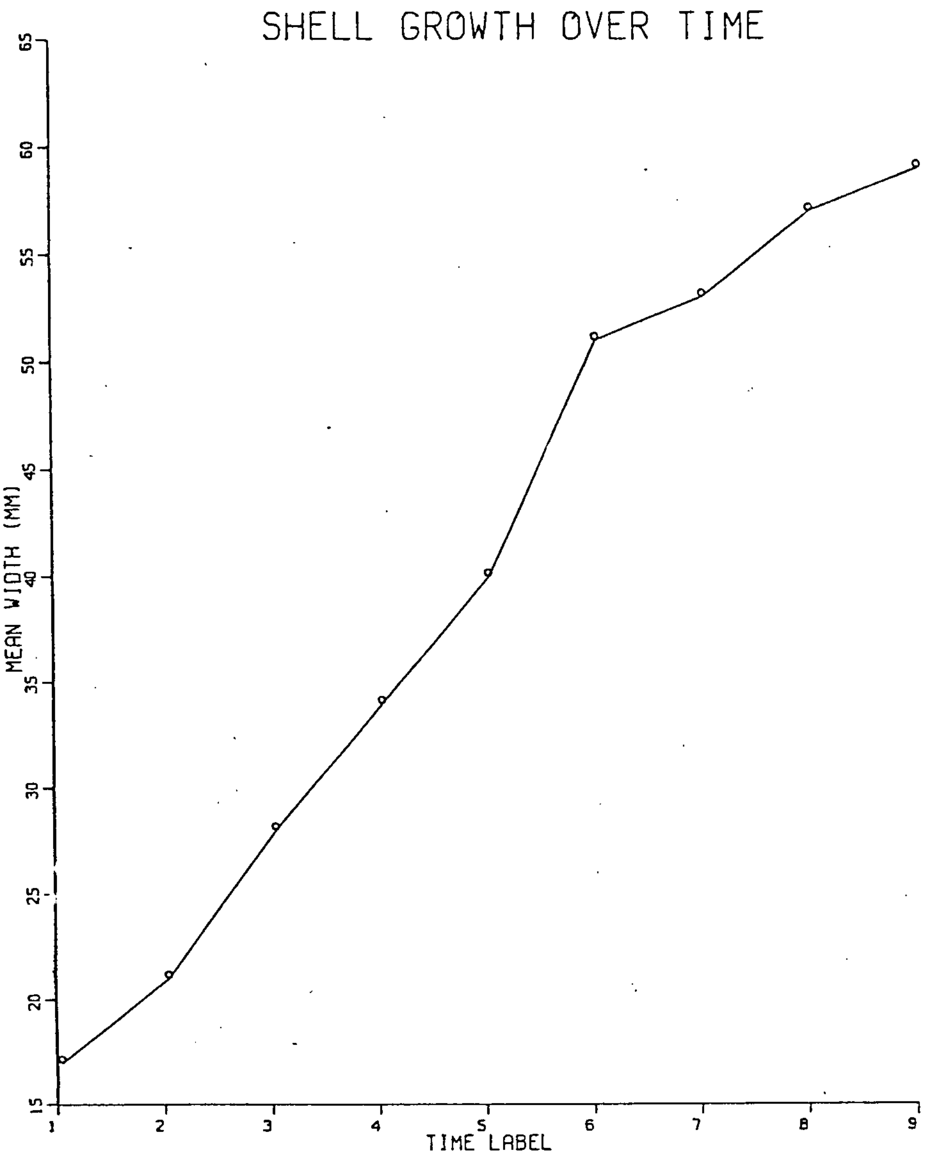
Tray Code	Tray Type
T1	MacNicol
T2	Nestier
T3	Suspension


VERTICAL POSITION
MEAN WIDTH (MM)
65
60
55
50
45
40
35
30
25
20
15
1
2
3
4
5
VERTICAL POSITION

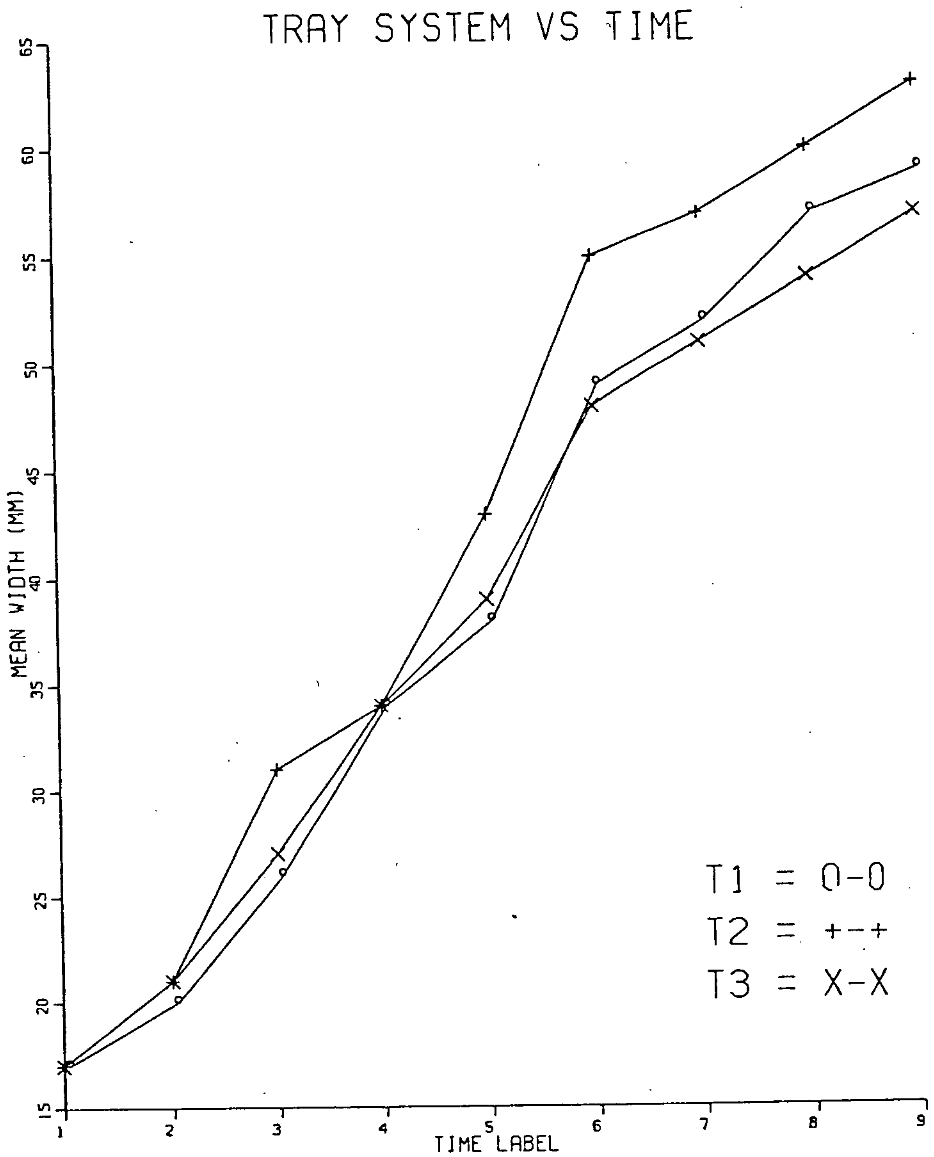

ENVIRONMENT TYPE VS
VERTICAL POSITION
MEAN WIDTH (MM)
65
60
55
50
45
40
35
30
25
20
15
1
2
3
4
5
VERTICAL POSITION
E1 = O-O
E2 = +-+

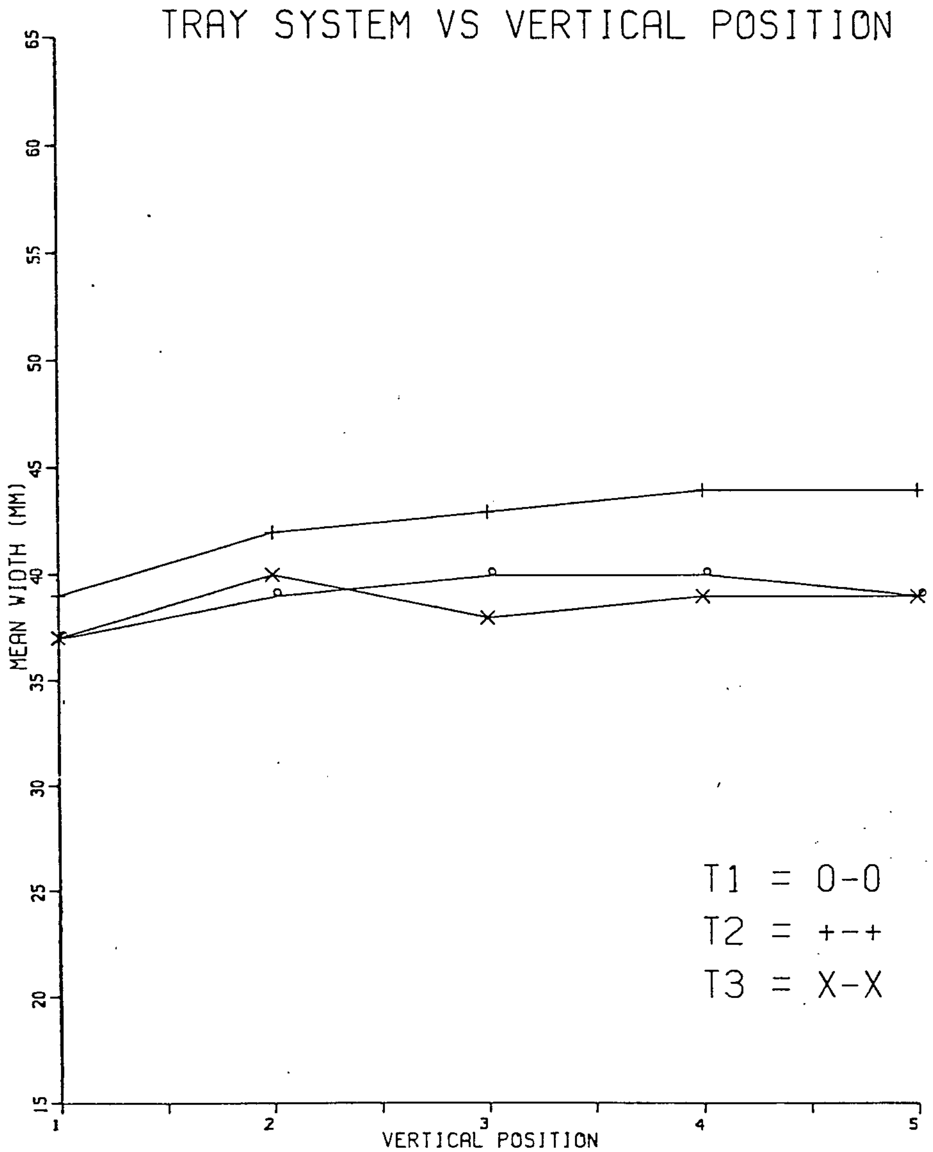

ENVIRONMENT TYPE VS TIME
MEAN WIDTH (MM)
TIME LABEL
15
20
25
30
35
40
45
50
55
60
65
1
2
3
4
5
6
7
8
9
E1 = O-O
E2 = +-+

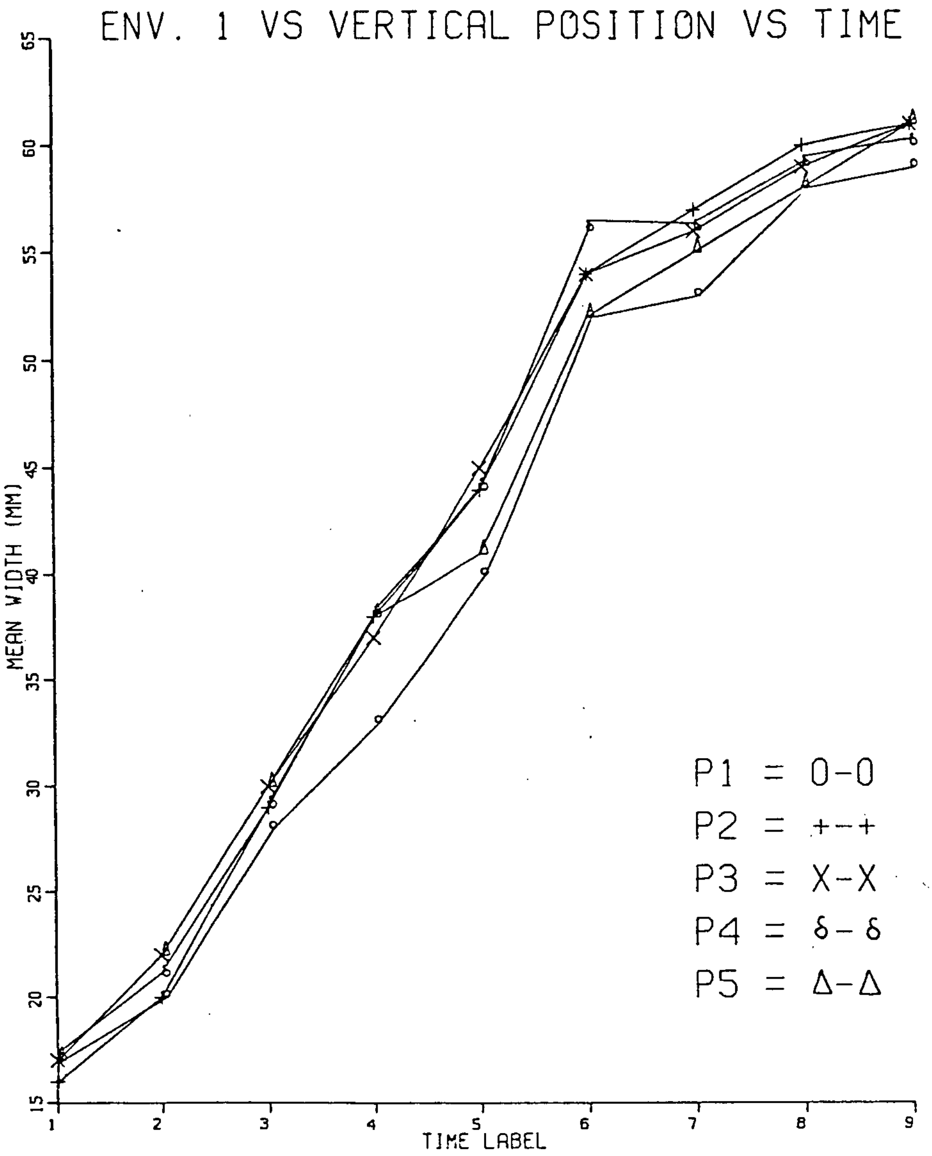

VERTICAL POSITION VS TIME
MEAN WIDTH (MM)
TIME LABEL
65
60
55
50
45
40
35
30
25
20
15
1
2
3
4
5
6
7
8
9
P1 = O-O
P2 = +-+
P3 = X-X
P4 = δ-δ
P5 = Δ-Δ

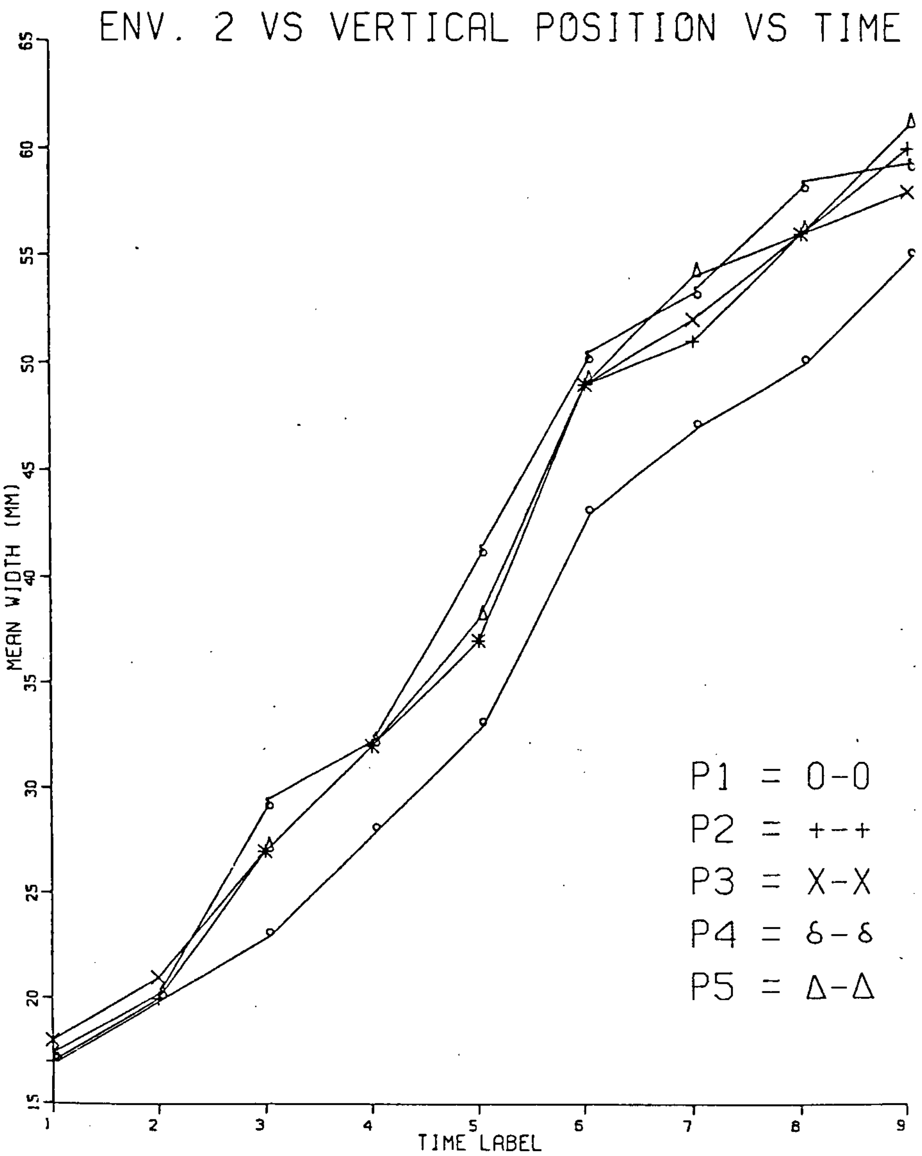


SHELL GROWTH OVER TIME
MEAN WIDTH (MM)
15
20
25
30
35
40
45
50
55
60
65
TIME LABEL
1
2
3
4
5
6
7
8
9


TRAY SYSTEM VS TIME
MEAN WIDTH (MM)
15
20
25
30
35
40
45
50
55
60
65
1
2
3
4
5
6
7
8
9
TIME LABEL
T1 = O-O
T2 = +-+
T3 = X-X


TRAY SYSTEM VS VERTICAL POSITION
MEAN WIDTH (MM)
65
60
55
50
45
40
35
30
25
20
15
1
2
3
4
5
VERTICAL POSITION
T1 = O-O
T2 = +-+
T3 = X-X


ENV. 1 VS VERTICAL POSITION VS TIME
MEAN WIDTH (MM)
15
20
25
30
35
40
45
50
55
60
65
TIME LABEL
1
2
3
4
5
6
7
8
9
P1 = O-O
P2 = +-+
P3 = X-X
P4 = δ-δ
P5 = Δ-Δ


ENV. 2 VS VERTICAL POSITION VS TIME
MEAN WIDTH (MM)
15
20
25
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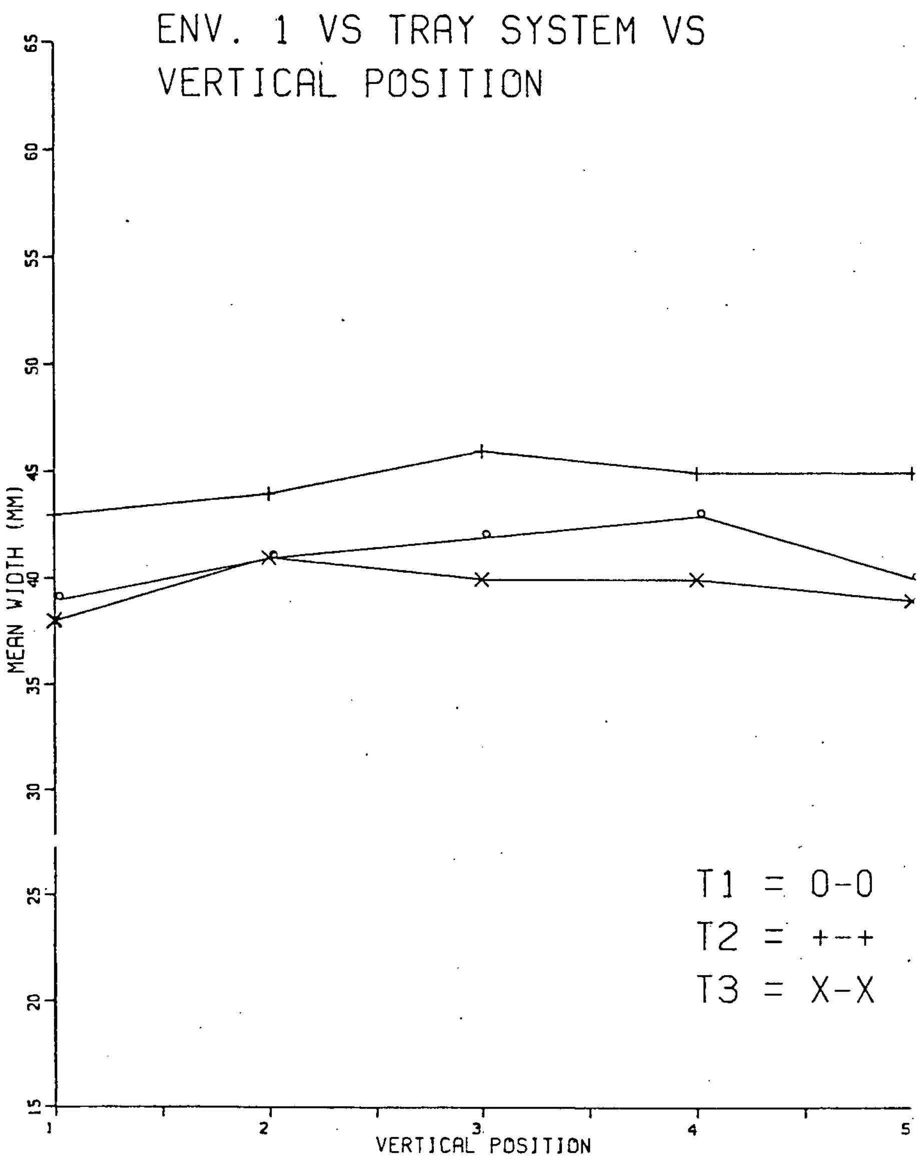
35
40
45
50
55
60
65
TIME LABEL
1
2
3
4
5
6
7
8
9
P1 = O-O
P2 = +-+
P3 = X-X
P4 = δ-δ
P5 = Δ-Δ


ENV. 1 VS TRAY SYSTEM VS
VERTICAL POSITION
MEAN WIDTH (MM)
VERTICAL POSITION
65
60
55
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45
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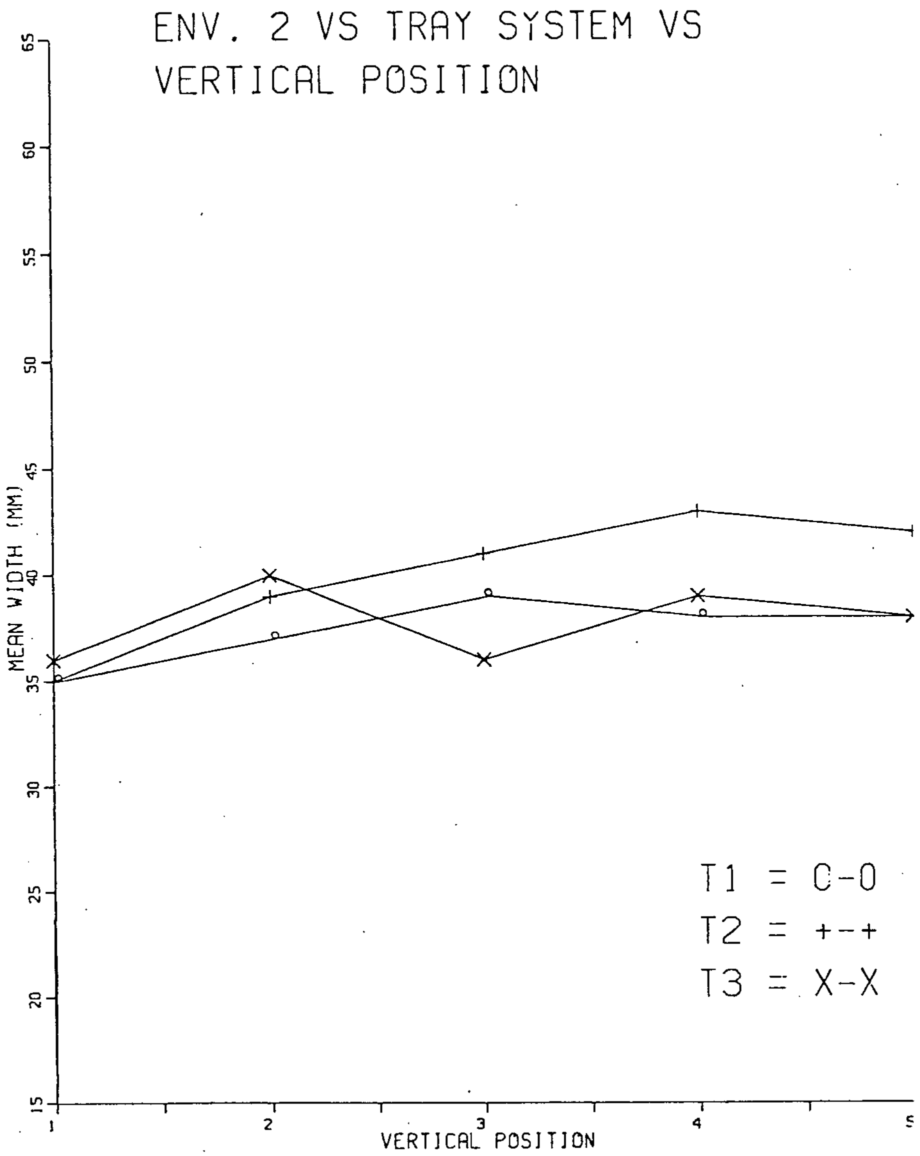
25
20
15
1
2
3
4
5
T1 = O-O
T2 = +-+
T3 = X-X


ENV. 2 VS TRAY SYSTEM VS
VERTICAL POSITION
MEAN WIDTH (MM)
VERTICAL POSITION
T1 = O-O
T2 = +-+
T3 = X-X
15
20
25
30
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55
60
65
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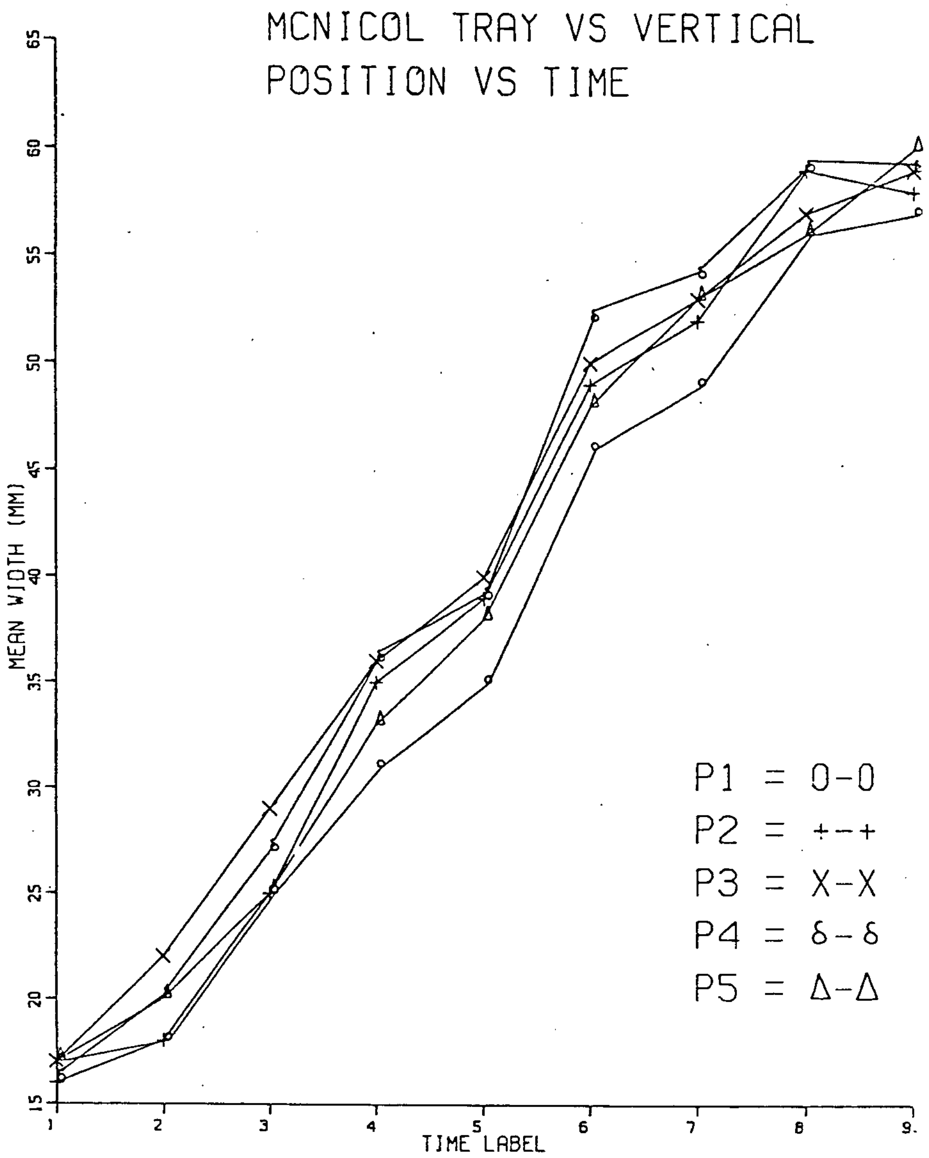
MCNICOL TRAY VS VERTICAL
POSITION VS TIME
MEAN WIDTH (MM)
TIME LABEL
15
20
25
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45
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55
60
65
1
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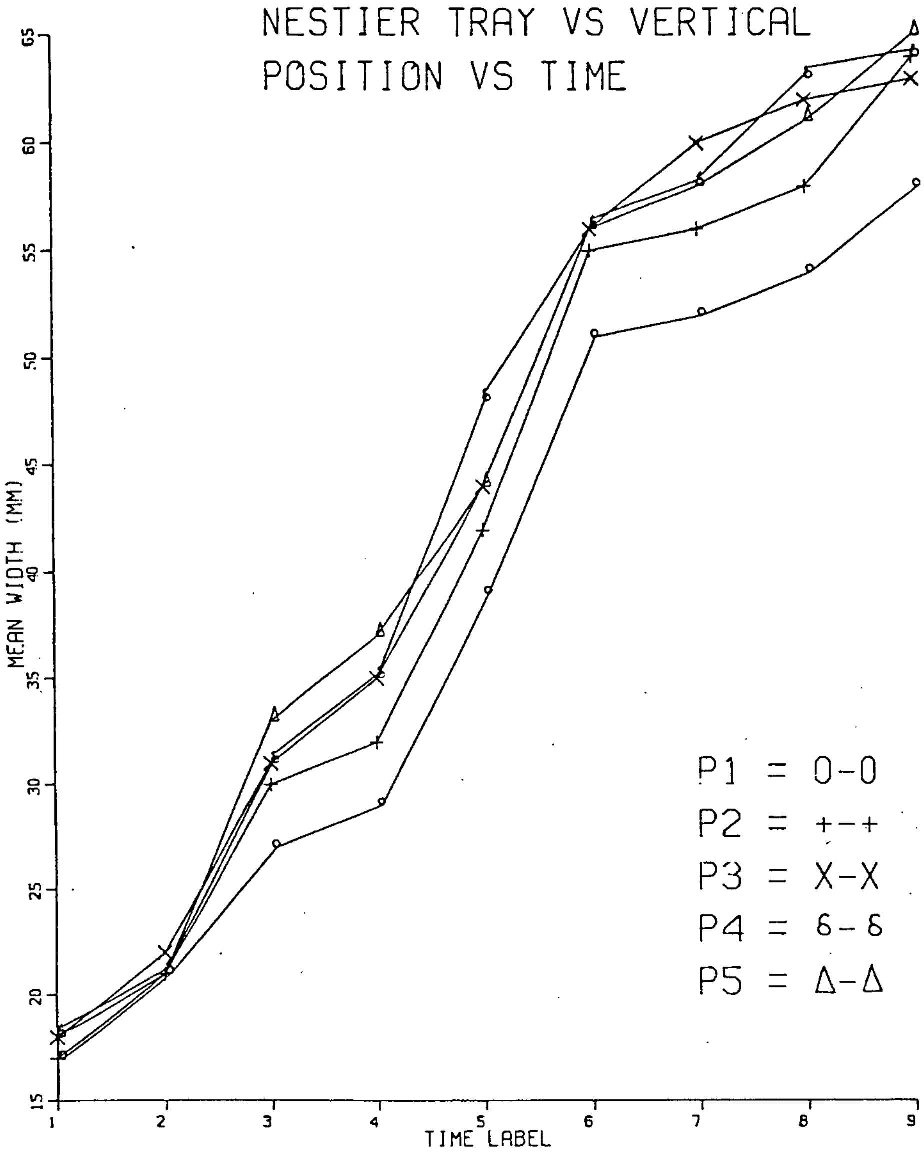
3
4
5
6
7
8
9
P1 = O-O
P2 = +-+
P3 = X-X
P4 = δ-δ
P5 = Δ-Δ


NESTIER TRAY VS VERTICAL
POSITION VS TIME
MEAN WIDTH (MM)
TIME LABEL
15
20
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65
1
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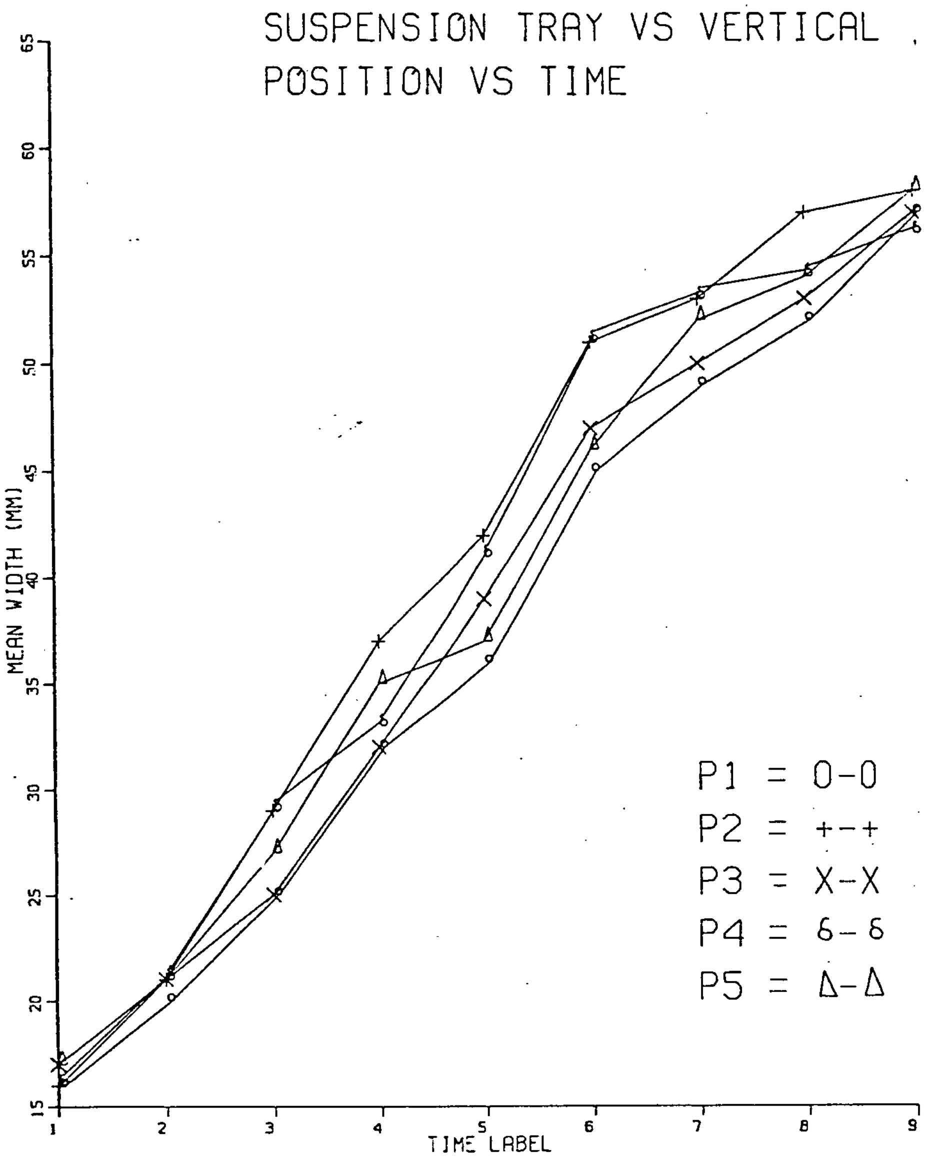
5
6
7
8
9
P1 = O-O
P2 = +-+
P3 = X-X
P4 = δ-δ
P5 = Δ-Δ


SUSPENSION TRAY VS VERTICAL
POSITION VS TIME
MEAN WIDTH (MM)
TIME LABEL
15
20
25
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35
40
45
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55
60
65
1
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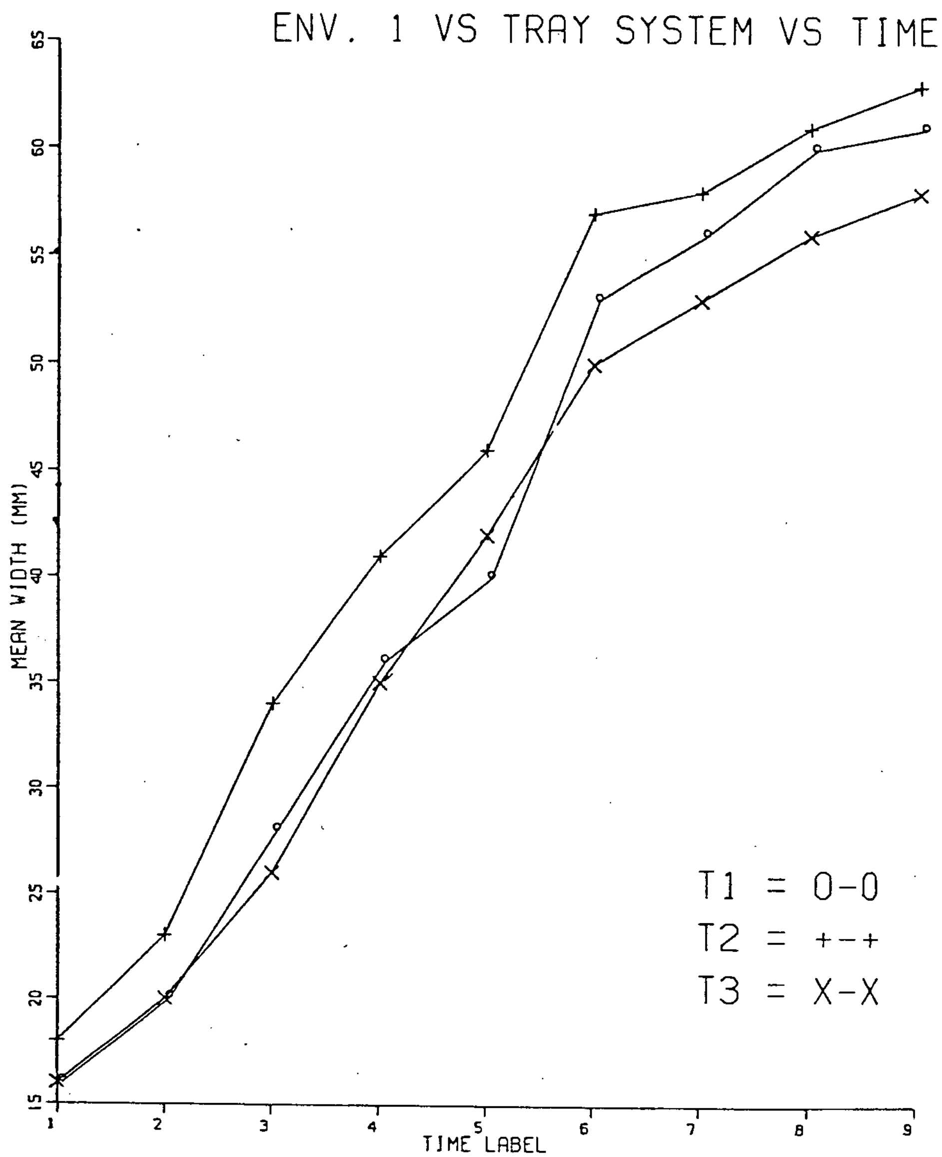
3
4
5
6
7
8
9
P1 = O-O
P2 = +-+
P3 = X-X
P4 = δ-δ
P5 = Δ-Δ


ENV. 1 VS TRAY SYSTEM VS TIME
MEAN WIDTH (MM)
15
20
25
30
35
40
45
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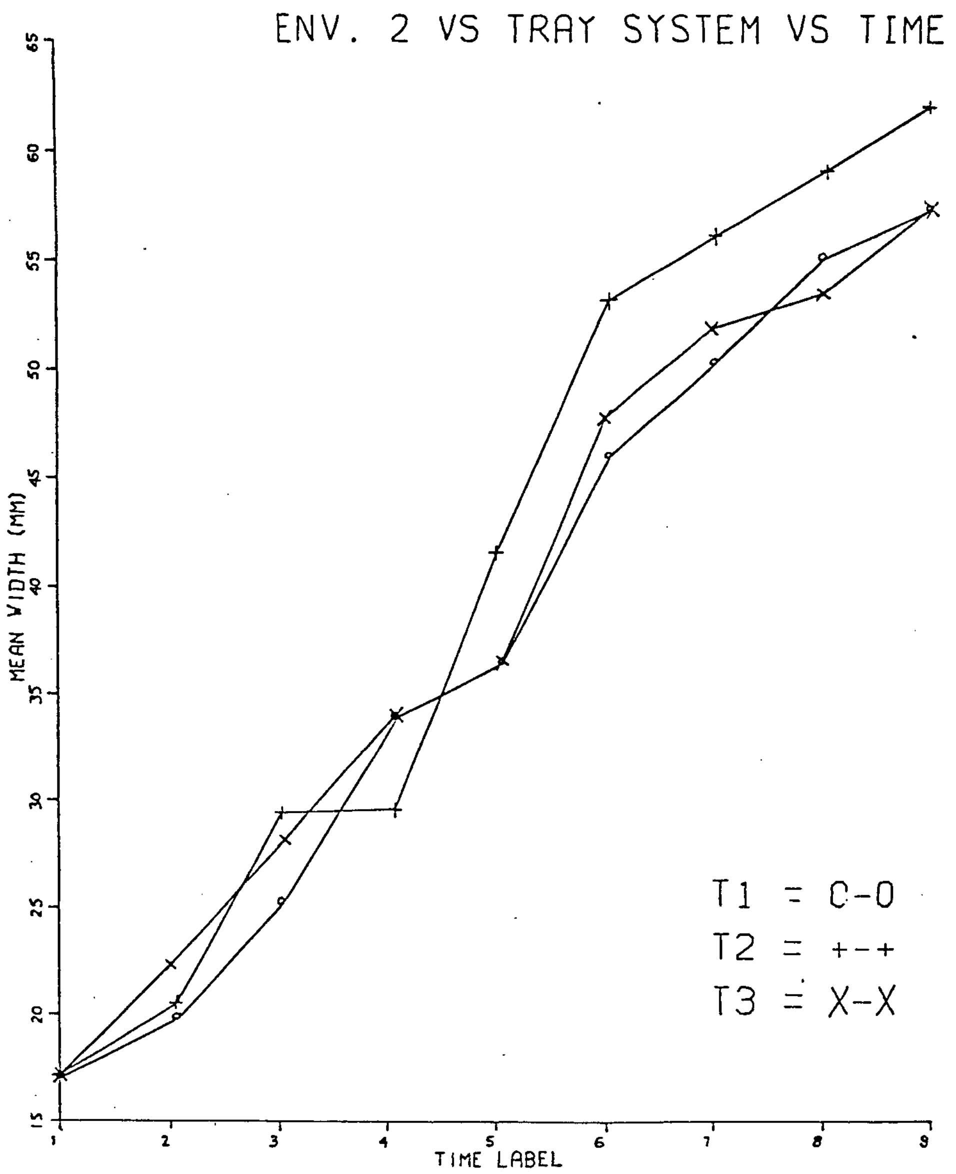
55
60
65
TIME LABEL
1
2
3
4
5
6
7
8
9
T1 = 0-0
T2 = +-+
T3 = X-X


ENV. 2 VS TRAY SYSTEM VS TIME
MEAN WIDTH (MM)
15
20
25
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55
60
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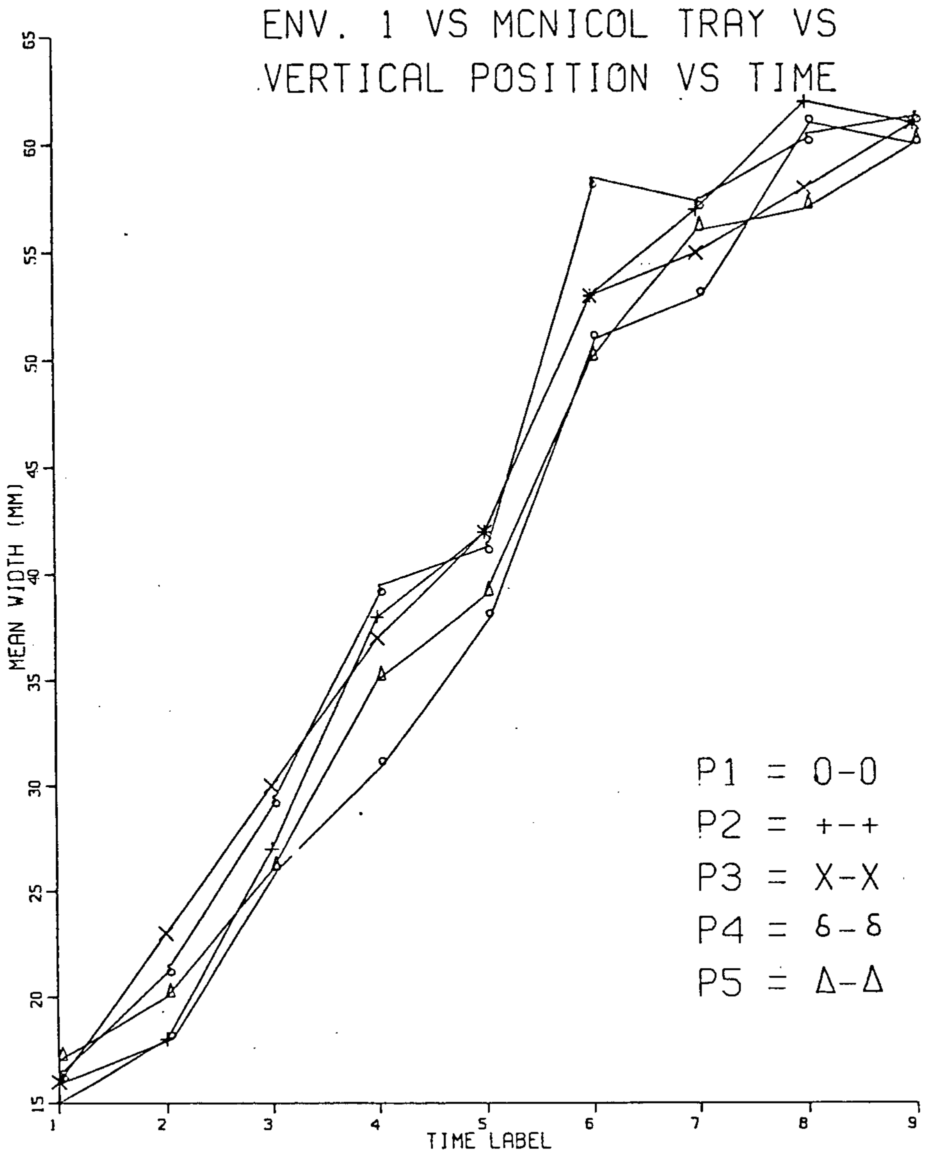
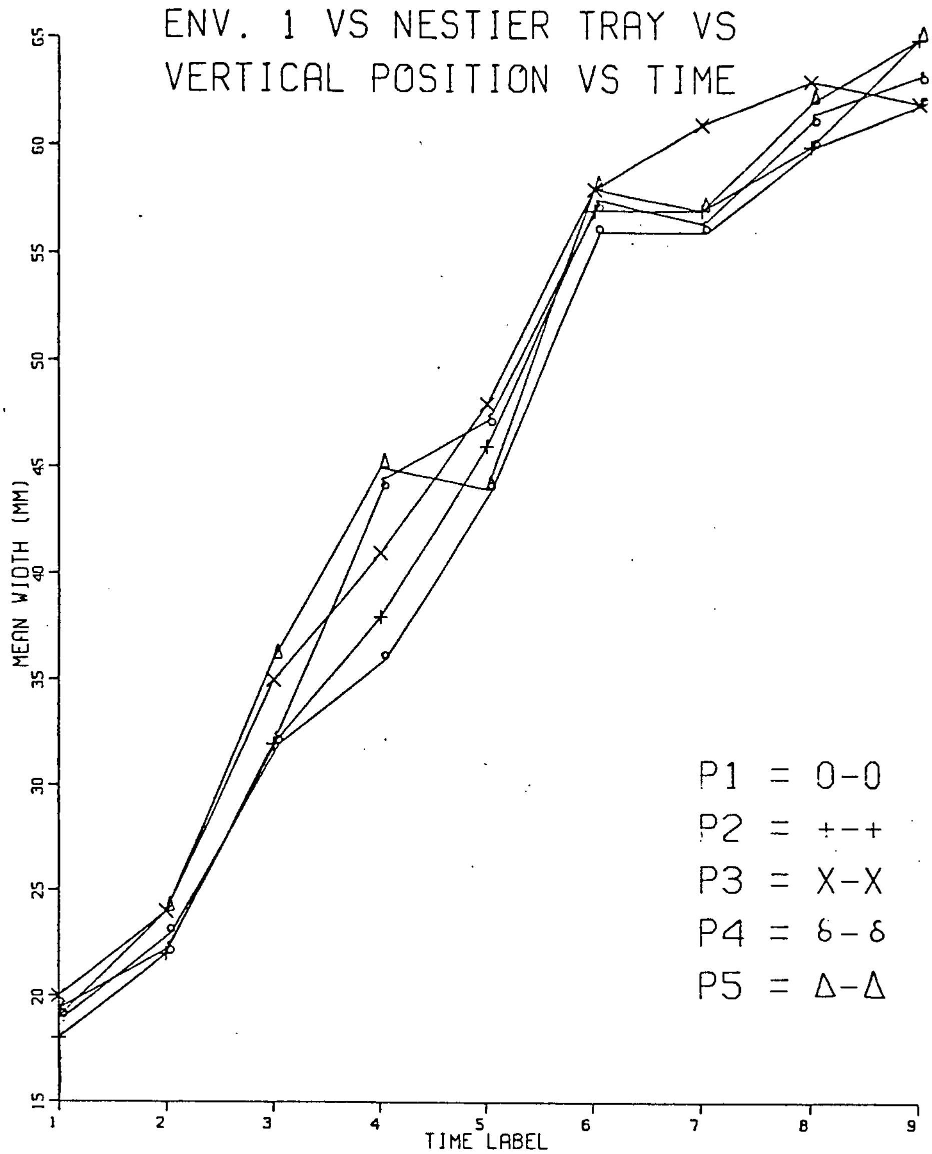
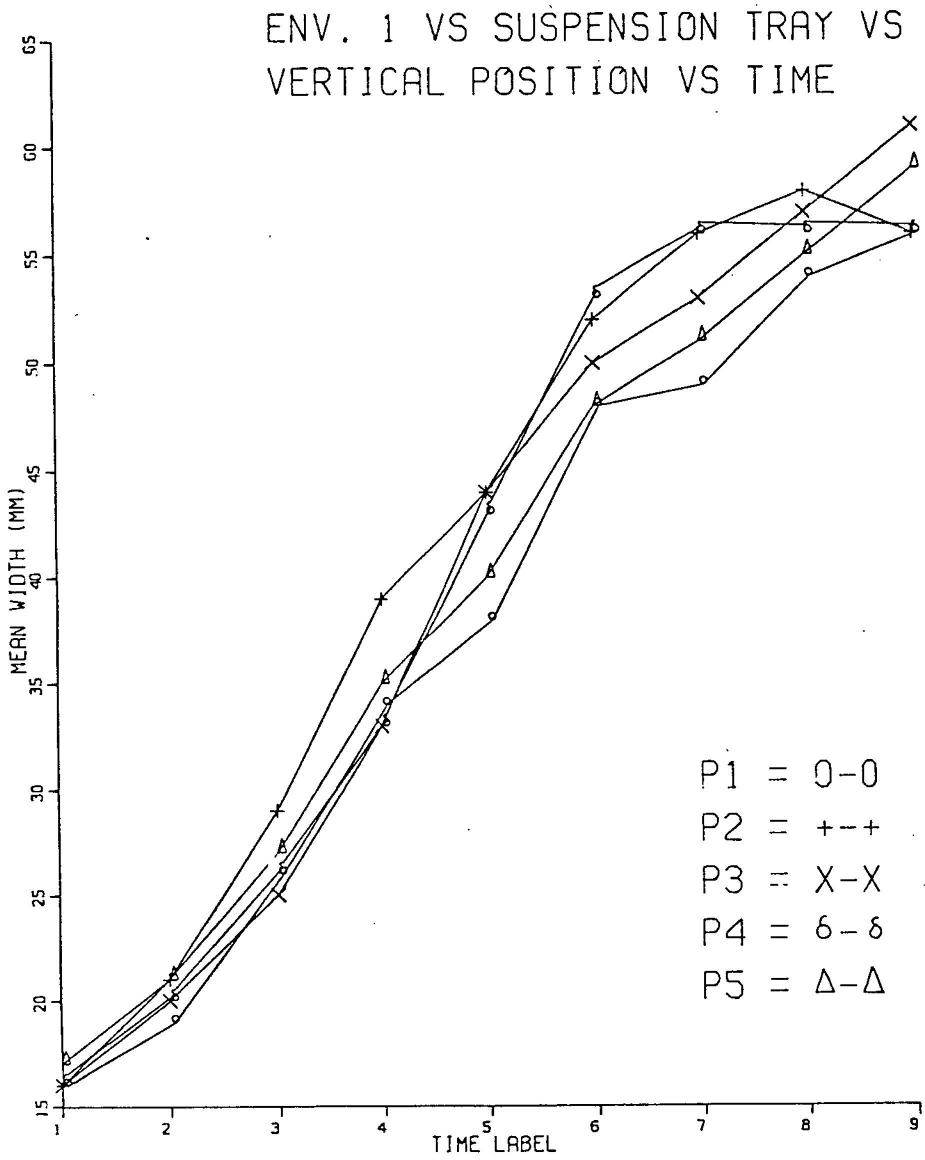
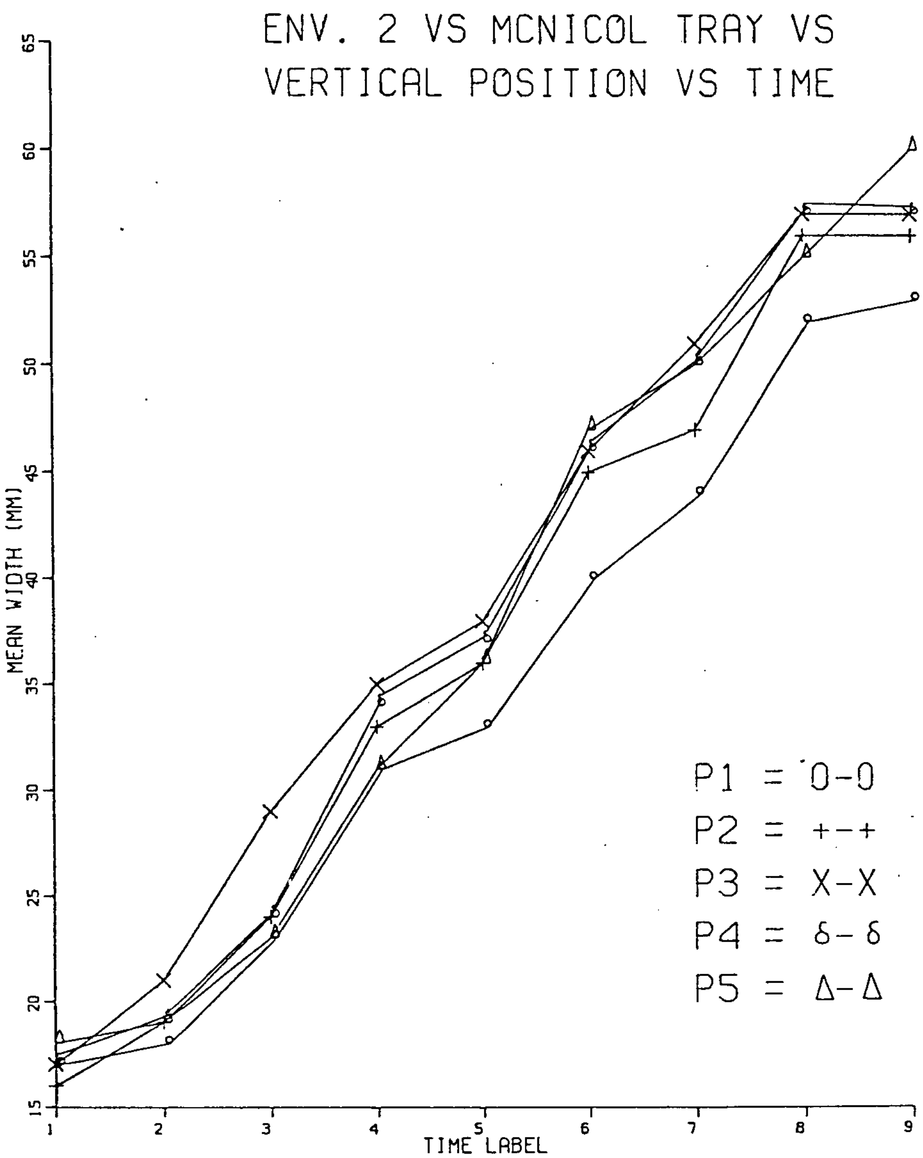
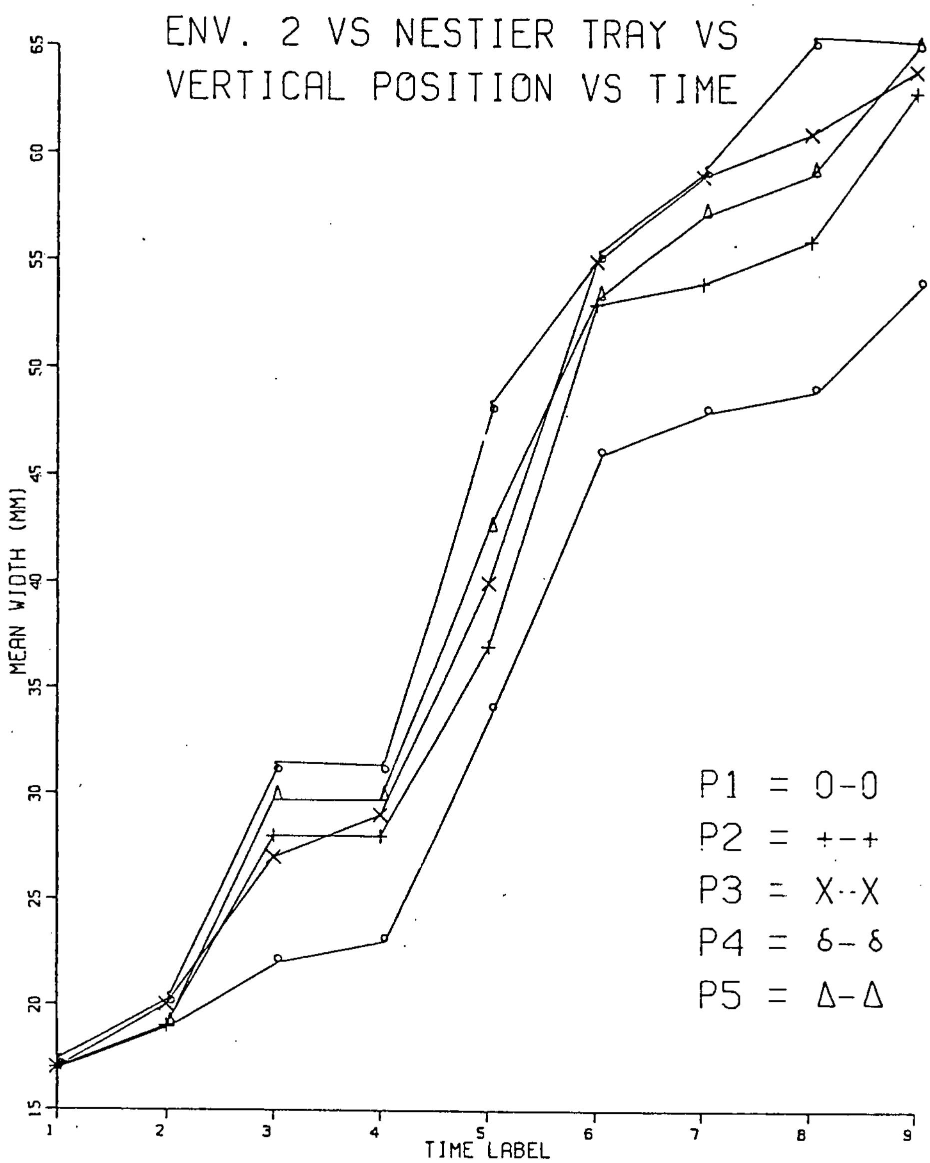
TIME LABEL
1
2
3
4
5
6
7
8
9
T1 = O-O
T2 = +-+
T3 = X-X

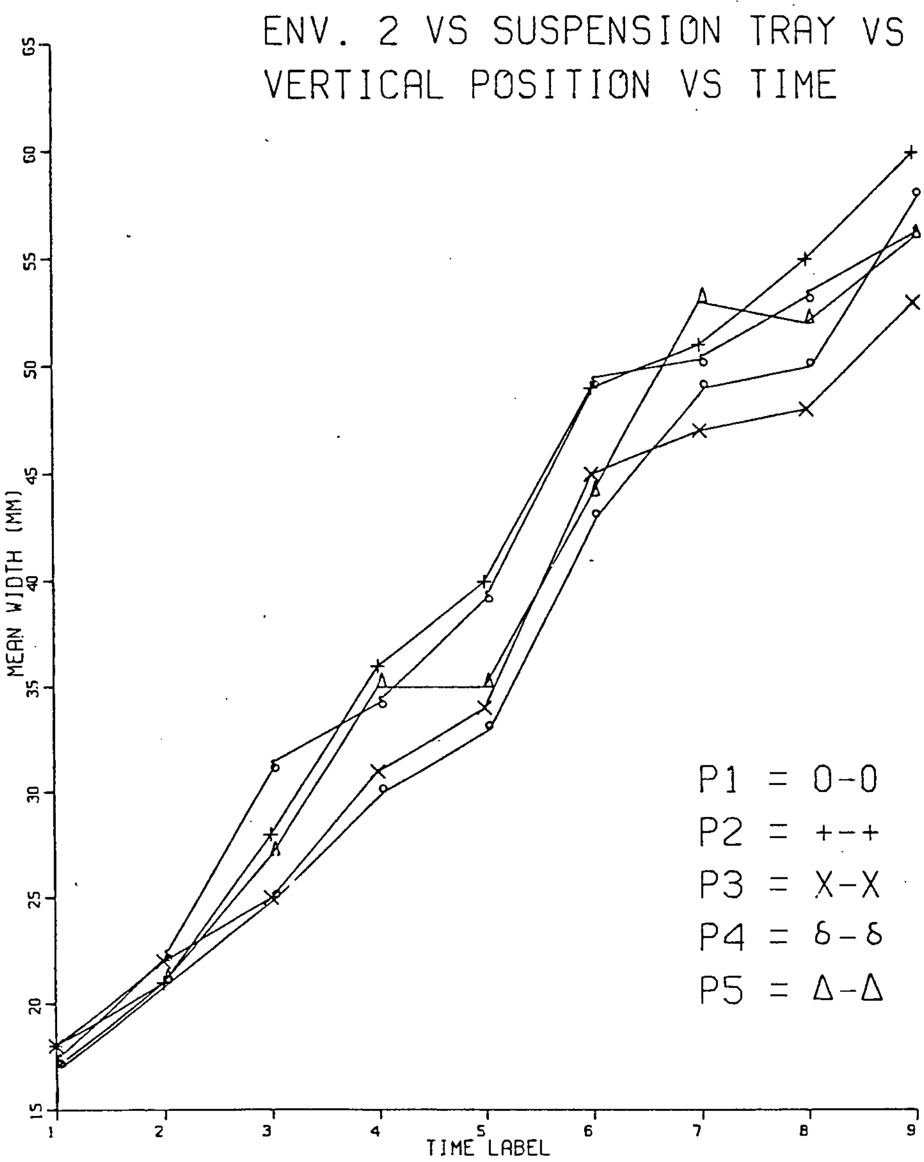

ENV. 1 VS MCNICOL TRAY VS
VERTICAL POSITION VS TIME
MEAN WIDTH (MM)
15
20
25
30
35
40
45
50
55
60
65
TIME LABEL
1
2
3
4
5
6
7
8
9
P1 = 0-0
P2 = +-+
P3 = X-X
P4 = δ-δ
P5 = Δ-Δ


ENV. 1 VS NESTIER TRAY VS
VERTICAL POSITION VS TIME
MEAN WIDTH (MM)
15
20
25
30
35
40
45
50
55
60
65
TIME LABEL
1
2
3
4
5
6
7
8
9
P1 = 0-0
P2 = +-+
P3 = X-X
P4 = δ-δ
P5 = Δ-Δ


ENV. 1 VS SUSPENSION TRAY VS
VERTICAL POSITION VS TIME
MEAN WIDTH (MM)
TIME LABEL
15
20
25
30
35
40
45
50
55
60
65
1
2
3
4
5
6
7
8
9
P1 = O-O
P2 = +-+
P3 = X-X
P4 = δ-δ
P5 = Δ-Δ


ENV. 2 VS MCNICOL TRAY VS
VERTICAL POSITION VS TIME
MEAN WIDTH (MM)
15
20
25
30
35
40
45
50
55
60
65
TIME LABEL
1
2
3
4
5
6
7
8
9
P1 = O-O
P2 = +-+
P3 = X-X
P4 = δ-δ
P5 = Δ-Δ


ENV. 2 VS NESTIER TRAY VS
VERTICAL POSITION VS TIME
MEAN WIDTH (MM)
15
20
25
30
35
40
45
50
55
60
65
TIME LABEL
1
2
3
4
5
6
7
8
9
P1 = O-O
P2 = +-+
P3 = X··X
P4 = δ-δ
P5 = Δ-Δ


ENV. 2 VS SUSPENSION TRAY VS
VERTICAL POSITION VS TIME
MEAN WIDTH (MM)
65
60
55
50
45
40
35
30
25
20
15
1
2
3
4
5
6
7
8
9
TIME LABEL
P1 = O-O
P2 = +-+
P3 = X-X
P4 = δ-δ
P5 = Δ-Δ

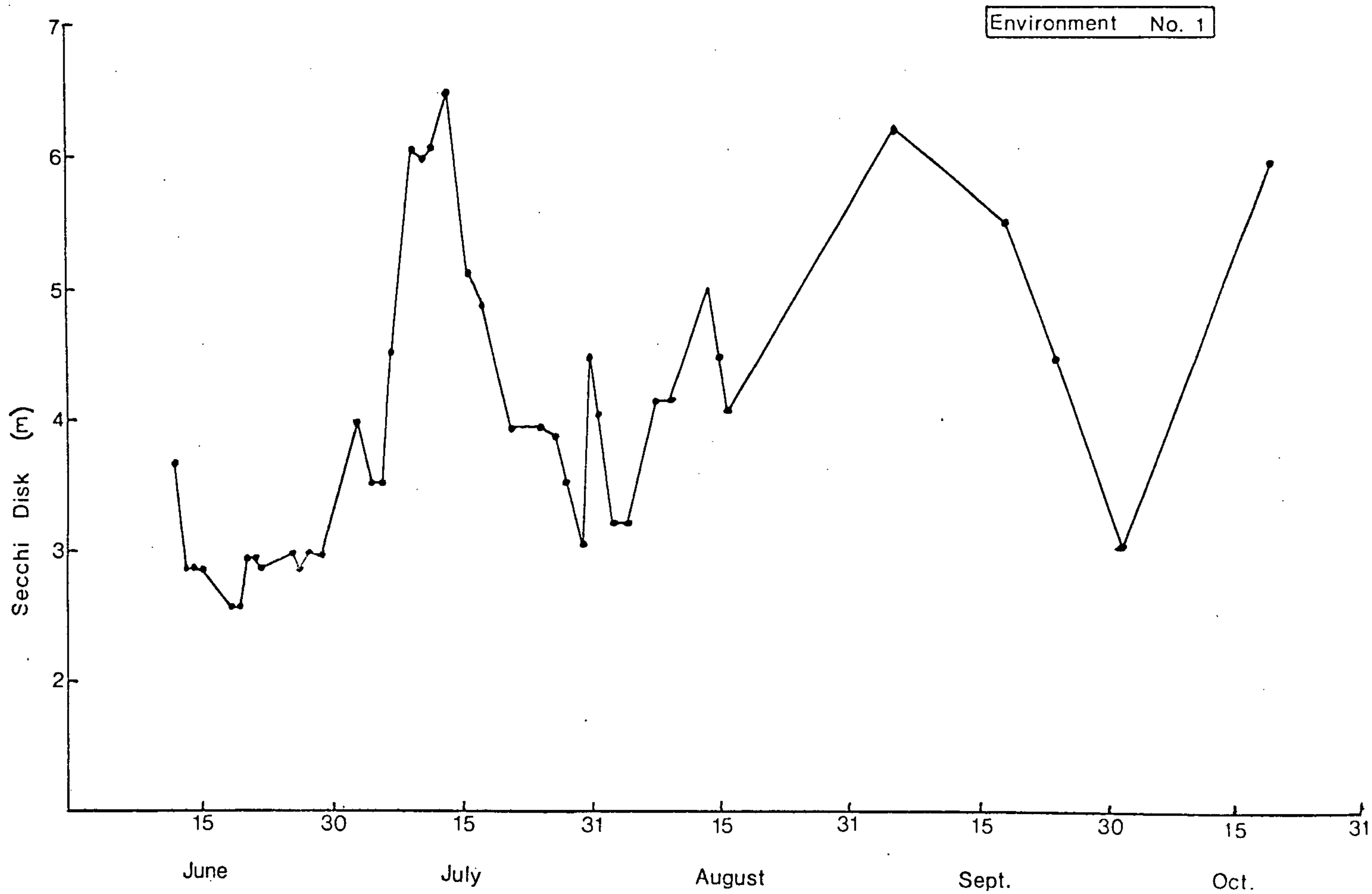
APPENDIX D

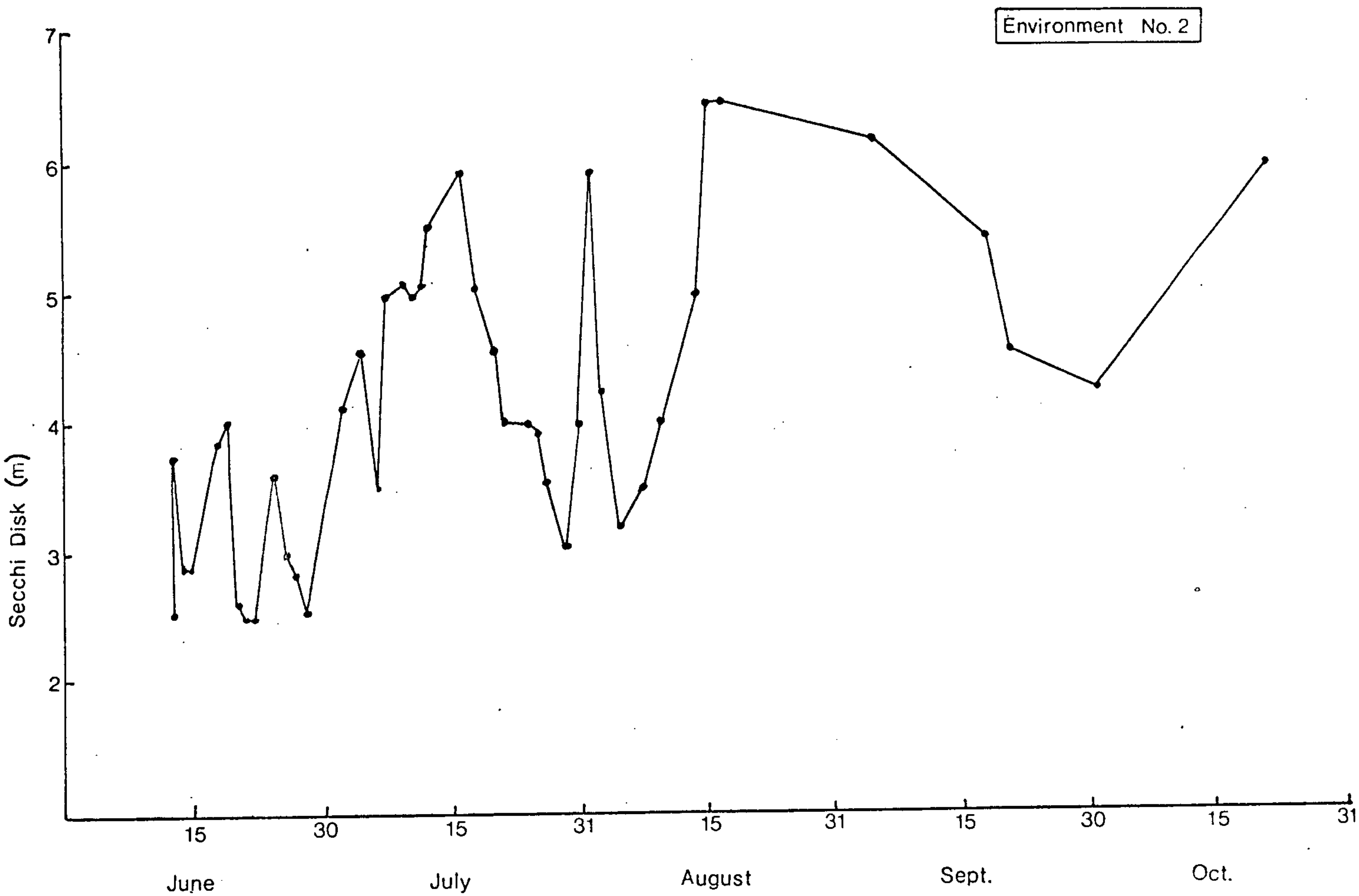
TABLE D1. ANOVA table for condition index.

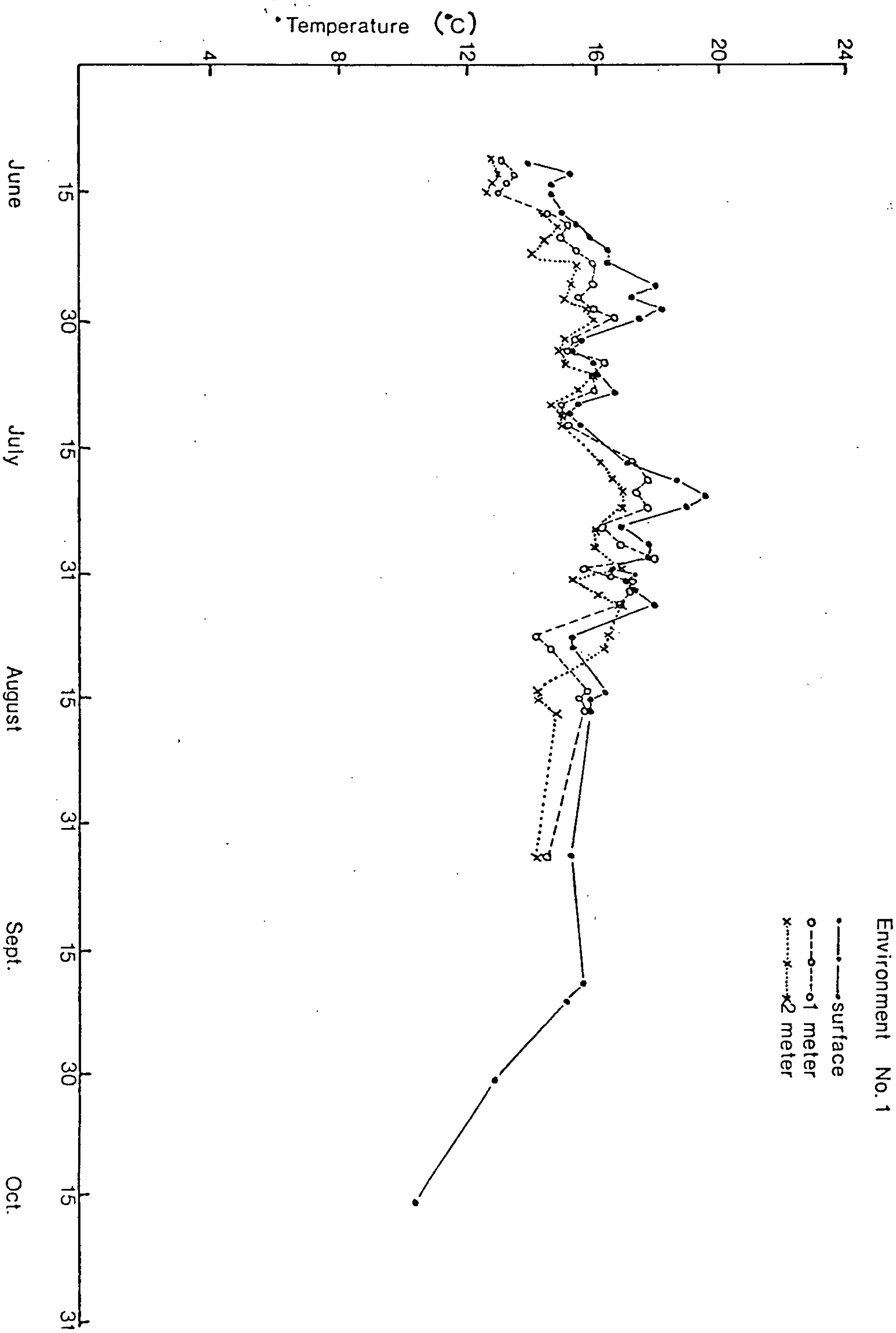
SOURCE	DF	SUM SQ	MEAN SQ	F-VALUE	PROB
E	1	4014.5	4014.5	2.5512	0.11080
C	4	0.12709E+06	31774.	20.192	0.0
T	2	22575.	11287.	7.1731	0.00084
P	4	8234.7	2058.7	1.3083	0.26571
ERROR	533	0.83870E+06	1573.6		
TOTAL	544	0.10270E+07			

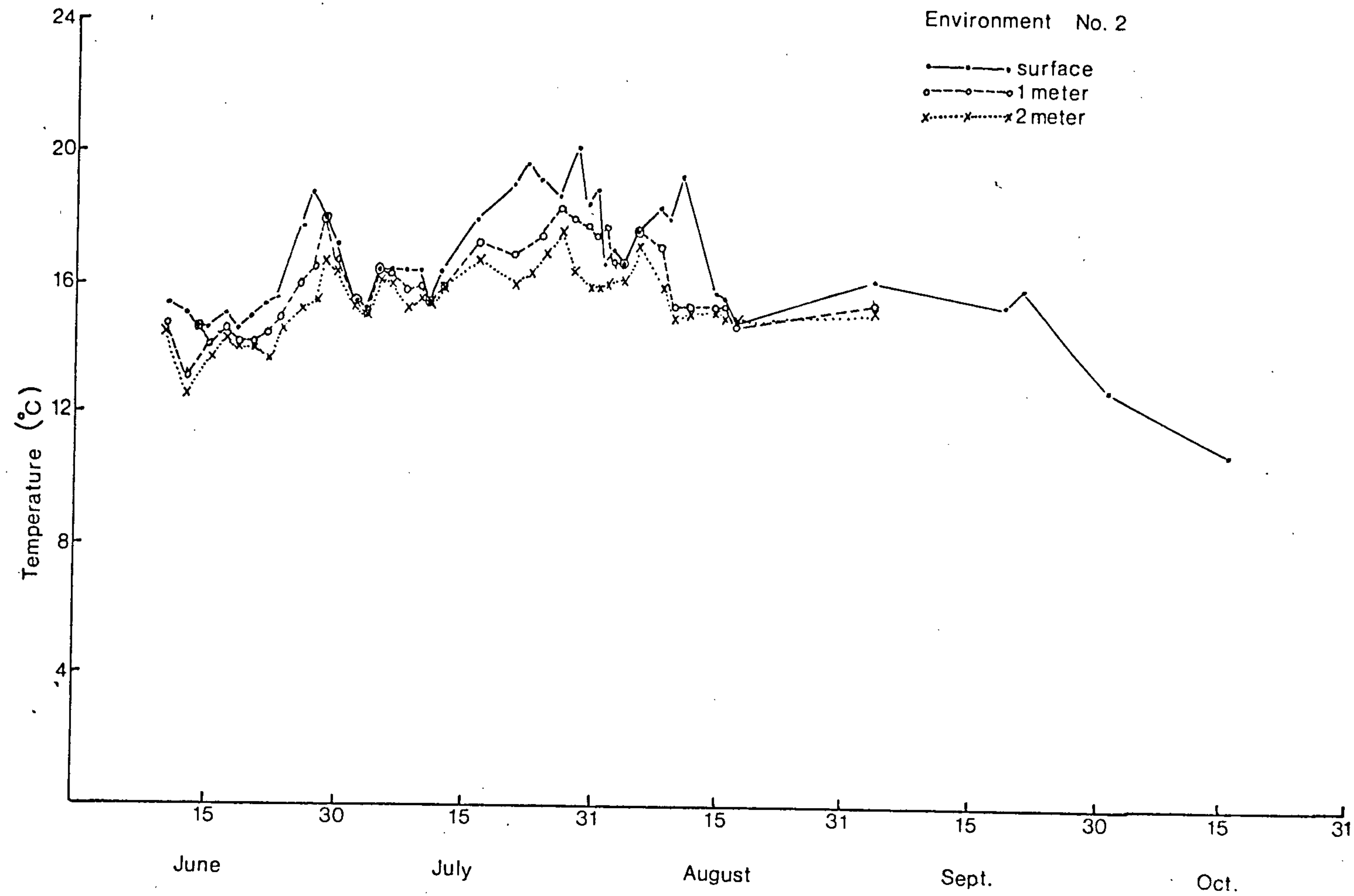
APPENDIX E

Secchi Disk and Ambient Water Temperature Measurements


Environment No. 1
Secchi Disk (m)
7
6
5
4
3
2
15
30
15
31
15
31
15
30
15
31
June
July
August
Sept.
Oct.


Environment No. 2
Secchi Disk (m)
7
6
5
4
3
2
15
30
15
31
15
31
15
30
15
31
June
July
August
Sept.
Oct.


Temperature (°C)
4
8
12
16
20
24
June 15
30
July 15
31
August 15
31
Sept. 15
30
Oct. 15
31
Environment No. 1
surface
1 meter
2 meter


Environment No. 2
surface
1 meter
2 meter
Temperature (°C)
24
20
16
12
8
4
15
30
15
31
15
31
15
30
15
31
June
July
August
Sept.
Oct.