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Gas Exchange Rates at the Air-Water Interface in Coastal Waters (R/EQ-26)

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INTRODUCTION

Sensible management decisions regarding the water quality of coastal aquatic systems cannot be made without knowledge of the gas exchange rate across the air-water interface. The direct measurement of gas exchange is not easy; thus the common alternative is to compute the exchange rate as the product of the measured concentration gradient of the gas of interest and a proportionality constant (the gas transfer coefficient). The gas transfer coefficient cannot be measured directly and is generally estimated from a predictive model.

The problem with this approach is that the agreement between values of the transfer coefficient given by currently available models and values observed in natural systems is generally not good. Comparisons between predicted and observed exchange rates indicate that values predicted from the models are at best within a factor of two of the actual values. While this level of agreement is often considered quite good from a scientific viewpoint, it is generally not acceptable for making management decisions, where errors of a factor of two can have serious economic or environmental ramifications.

To be useful, a predictive model must give accurate values for the transfer coefficient, be applicable to a variety of aquatic systems, and be expressed in terms of easily measured parameters. The development of such models requires an understanding of the physical process(es) of gas transfer and the identification of the environmental parameters which control gas transport in natural settings.

This report presents the initial results from a Sea Grant supported research program designed to study these problems. The ultimate goal of this research effort is the formulation of a predictive model for gas exchange rates in natural systems.

* Worked with Tommy D. Dickey, Assistant Professor. Institute of Marine and Coastal Studies, and Geological Scientist, University of Southern California.

METHODS AND RESULTS

Laboratory Experiments

Laboratory experiments provide the controlled conditions under which the physical process of gas transfer can be examined. Gas transport across the air-water interface occurs by molecular diffusion across the interface and by turbulent mixing within the water below the interface. The past year of laboratory effort has concentrated on exploring the relationships between gas exchange and the parameters that characterize these processes. i.e., the molecular diffusivity of the gas of interest and the turbulent velocity near the interface.

These relationships were investigated by generating turbulence in a tank (60 cm x 60 cm x 60 cm) and measuring the properties of the fluid turbulence and the exchange rates of five gases (O_2, N_2, CO_2, CH_4, Rn). Turbulence was generated by oscillating a grid in the water column. Tracer beads added to the water were illuminated and photographed. The resulting photographs consist of an assemblage of streak images (Figure 1) from which the turbulent properties can be deduced. Gas exchange rates were determined by measuring the change in the gas concentration in the tank water during the time period of turbulence generation.

During the past year, experiments were performed at five different turbulence conditions. The relationship between the gas transfer coefficients for the five gases and the turbulent velocity near the interface is shown in Figure 2. These data indicate that gas exchange is linearly related to the turbulent velocity and dependent on the molecular diffusivity raised to some power between 0.3 to 0.7. Additional measurements are required to further quantify these relationships however, these preliminary results indicate that both of these parameters are important in the gas transfer process.

Field Measurements

A model of gas exchange expressed solely in terms of the fluid turbulence is not practical at present becuase measurements of the fluid turbulence in the field are not possible. Until methods to make such measurements are developed, it is necessary to relate gas exchange to the environmental processes that generate turbulence in the water column. In aqueous systems, turbulence is induced primarily by the wind, by currents and by breaking waves. One or more of these processes may dominate depending upon the system of interest and environmental conditions. The goal of the field experiments was to identify the important processes controlling gas exchange in an estuarine system.

Exchange rates of an inert gas, radon-222, were determined for a section of south San Francisco Bay by two independent methods:

1. By constructing a mass balance for radon in the water column, and

2. By direct measurement using floating domes.

The relationships between the gas transfer coefficients determined by each method and wind speed and current velocity are illustrated in Figures 3 and 4. The general conclusions from both methods are identical. Gas exchange is linearly dependent upon the wind speed, but shows no significant relationship with current velocity. The lack of a dependence with current velocity is surprising because currents in the study area appeared to generate turbulent mixing based upon visual observations.

Comparison of the transfer coefficients determined by the two methods suggests that the domes yield values that are higher than values from the mass balance approach at a specified wind speed. The reason for this discrepancy is not clear.

SUMMARY AND FUTURE WORK

The results of the past year of research are encouraging. Gas exchange rate appears to be a function of the molecular properties of the gas and the turbulence velocity in the water column. Additional experiments should enable the formulation of a predictive relationship based upon these parameters.

Turbulence in estuarine systems appears to be generated primarily by the wind, at least until the onset of wave breaking. Until direct measurements of the fluid turbulent velocity can be made in natural systems, reasonable estimates of the gas exchange rate may be possible from measurements of wind speed. Future field studies will attempt to quantify this relationship.

COMMUNICATION OF RESULTS

The following manuscripts are presently being prepared.

Hartman, B. Processes Controlling Gas Exchange Across the Air-Water Interface. Ph.D. thesis, USC.

Hartman, B., and D. E. Hammond. Gas Exchange Rates Across the Air-Water and Sediment-Water Interfaces in South San Francisco Bay.

Hartman, B., T. D. Dickey and D. E. Hammond. The Relationship Between Gas Exchange Across the Air-Water Interface and Fluid Turbulence.

Dickey, T. D. and B. Hartman. Studies on the Diffusion and Decay of Turbulence in the Water Column.

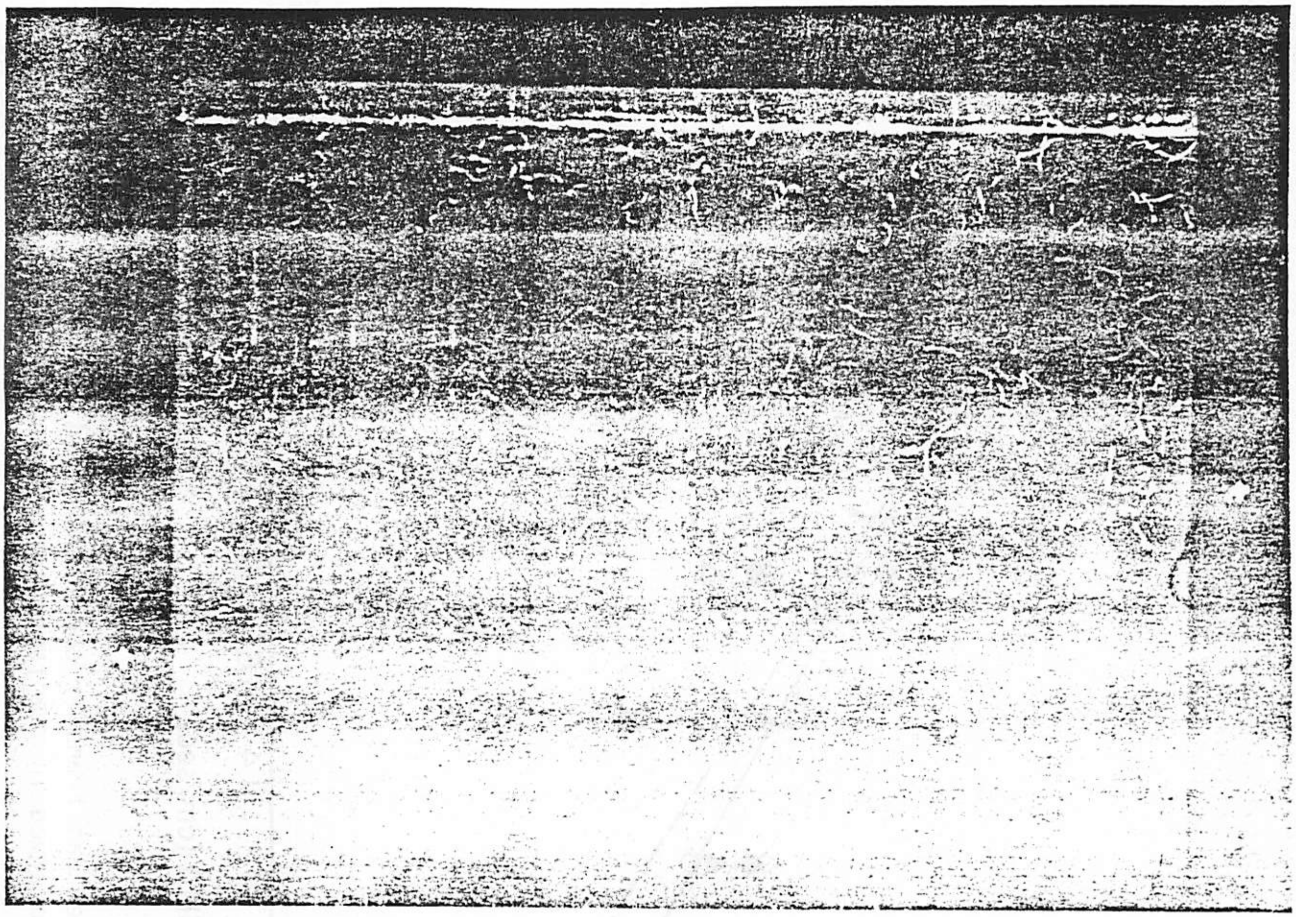


Figure 1. Streak photograph from one of the experimental runs.

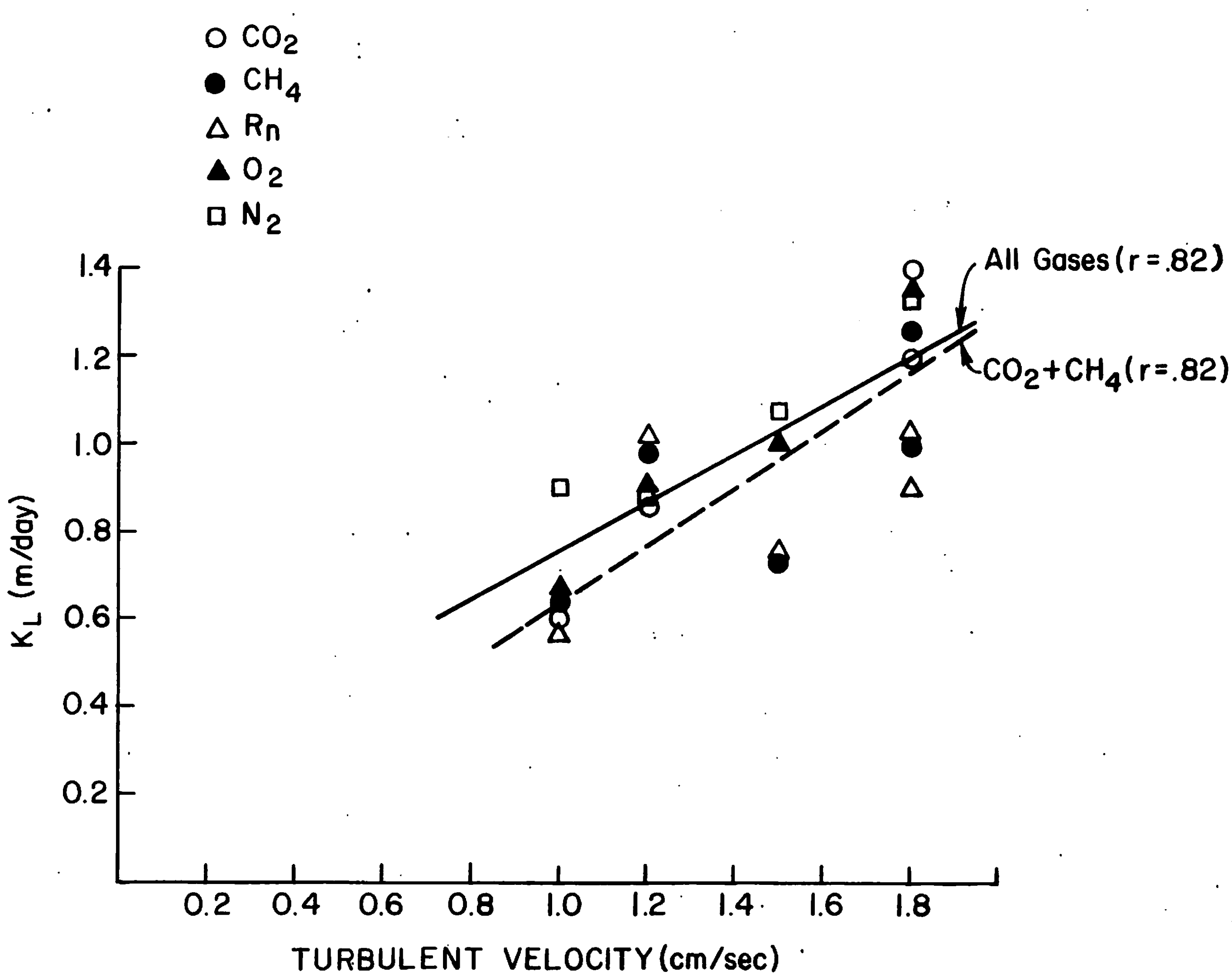


Figure 2. Relationship between the gas transfer coefficient and the turbulent velocity observed in the laboratory experiments.

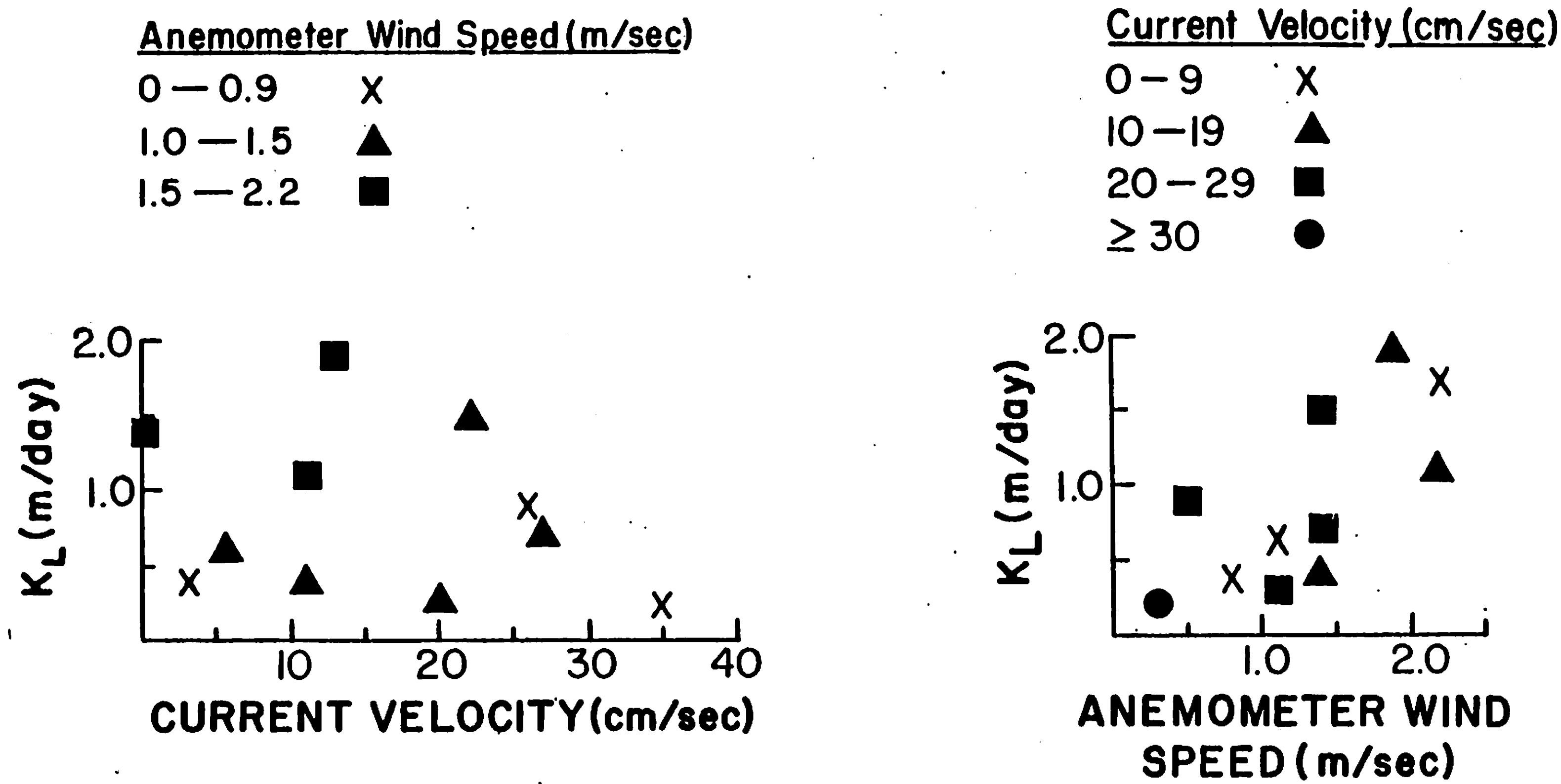


Figure 3. Relationships between the gas transfer coefficient (K_L) with current velocity and with wind speed for exchange rates determined with floating domes.

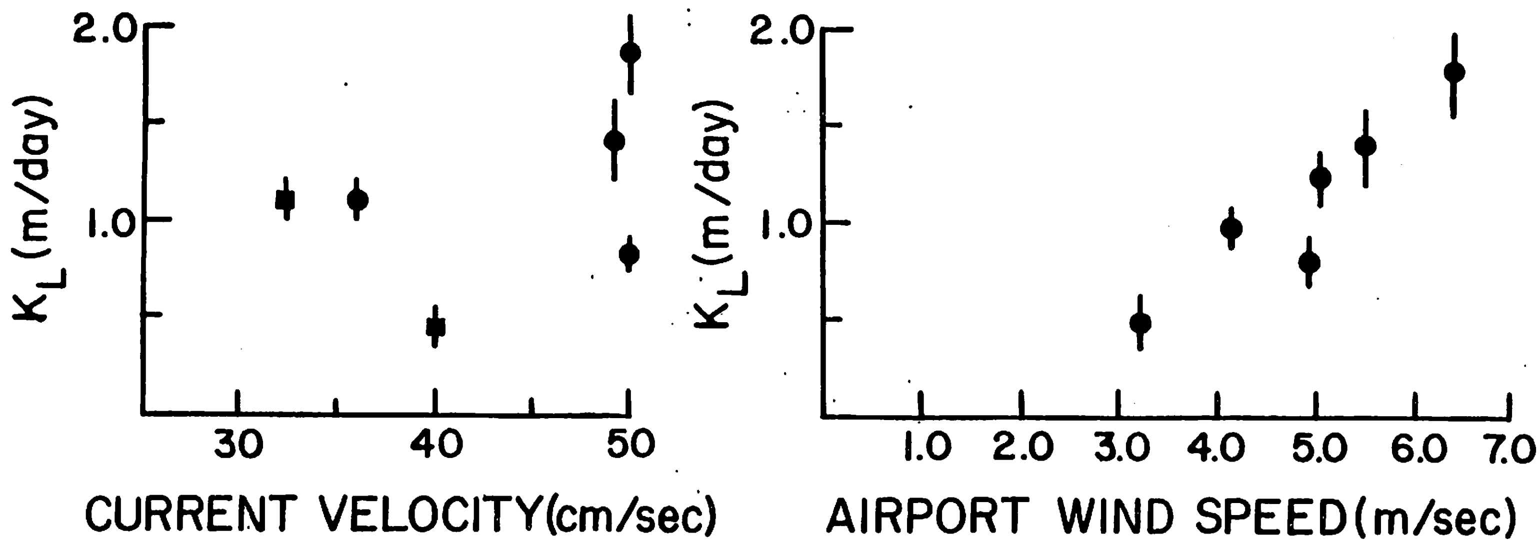


Figure 4. Relationships between the gas transfer coefficient (K_L) with current velocity and with wind speed for exchange rates determined from construction of a radon mass balance.

Wave Uplift Pressure on Horizontal Platforms (R/CE-7)

Kamram Iradjpanah*, Department of Engineering

INTRODUCTION

The need for a method to calculate wave forces is clearly illustrated by offshore construction activities which continues to grow because of mineral and other resources located beneath the ocean surface. This is a particular problem for piers and nearshore and offshore platforms.

There have been numerous reports of structural failure due to wave uplift forces not previously accounted for.

To avoid the high costs of structural failure and overestimated structures, a precise understanding of the interaction of structure and wave is needed. In a storm, waves can interact with these structures, even if they are built above the still water level, producing large uplift pressure. There have been previous analytical and experimental studies of the problem. However, a precise analytical model has never been developed because of the non-linear relation between water particle velocity and surface displacement.

Figures 1-A through 1-C show the sequence of wave impact on a horizontal platform as a solitary wave approaches from sea to the shore.

GOALS AND OBJECTIVES

The objective of this work is to develop a reliable model to define the uplift pressure that occurs when large incident waves impact fixed and rigid platforms. To define the uplift pressure as a function of time and location, the water particle velocities in the fluid domain near the platform must be computed. The accurate prediction of wave forces on a structure can only be made after the water particle velocities to which the structure may be exposed are estimated. This is usually done by adopting a wave theory which predicts a wave profile similar to that of the observed or assumed wave. The results of that wave theory are used to compute the kinematic properties

* Worked with Jiin-Jen Lee, Professor, and Landon C. Wellford Jr., Associate Professor, Civil Engineering, University of Southern California.

of the design wave. A solitary type of wave is chosen as the incident wave for this analysis because it represents a finite-amplitude ocean wave propagating through shoal water. A solitary wave has a symmetric profile; it propagates without change of form. There have been a large number of theoretical studies on the properties of the solitary wave, which provide a good comparative base. The profile celerity and other characteristic of the solitary wave have been theoretically analyzed by Boussinesq (1871).

METHODS AND RESULTS

In the first part of this work the problem of propagation of a solitary wave into still water is considered. It is assuemd that fluid is inviscid, incompressible, irrotational with a free surface. The domain can be described by a boundary-value problem composed of Laplace equation with a mixed boundary condition on the free surface. In addition a homogeneous Newman condition helds at the bottom of the ocean isoparametric mapping and finite element techniques are used in this model. The continuum is divided into many small elements of convenient shape. Certain points within the elements are chosen as nodes. The variable in the differential equation is written as combination of appropriately selected interpolation functions and the value of the variable or its derivatives at the nodes. Using weighted residual methods (Galerkin methods), the governing differential equations are transformed into finite element equations and then all elements are collected together to form a global system of algebraic equations. An iterative method is used to obtain the solution to the system of linear equation resulting from the finite element descretization. A Gauss-Seidel iterative method is employed in this work.

In the second part of this work a platform is inserted in the model. A propagating wave hits the platform whose soffit is above the still water level.

Governing Equations. Assuming inviscid, incompressible and irrotational flow, one can obtain the following potential flow equations:

$$\phi_{xx} + \phi_{yy} = 0 \qquad \text{in } \Omega$$

$$\eta_t + \phi_x \eta_x - \phi_y = 0 \qquad \text{in } \partial\Omega_1$$

$$\phi_t + \tfrac{1}{2}(\phi_x^2 + \phi_y^2) + g\eta = 0 \qquad \text{in } \partial\Omega_1$$

$$\phi_n = 0 \qquad \text{in } \partial\Omega_2 \;\&\; \partial\Omega_3$$

These equations represent the Laplace equation defined in the interior, and the free surface boundary conditions and the natural boundary conditions defined on the bottom and on the platform. "η" represents the displacement in the Y direction of the free surface from its initial position. "ϕ" is the potential function which is used as a measure of velocity.

Numerical Model. The governing equations are not solvable analytically. To treat this free surface problem, isoparametric mapping with Lagrange tensor products are used to transform the physical domain to a regular model domain.

In this plane the governing equation becomes more complicated but the model domain takes a regular shape which makes it easier to divide into many smaller elements of convenient shape (like retangular elements). In general, the choice of a finite element model depends on the geometry of the global domain. Then, a Galerkin method is used to obtain approximate governing equations in the subdomain (local elements).

These discrete equations are assembled to form a system of linear algebraic equation which in this work is solved by Gauss-Seidel iterative method.

Because the boundary conditions are time dependent, this model is based on a semidiscrete explicit method in which the time derivative of a variable at nodes is replaced on a temporal operator (finite difference). Now, the boundary and initial conditions can be applied in a manner similar to steady state problems. Recursive solution for water height and potential function can be carried out in terms of the previous history of their values.

The Courant-Friedrichs-Lewy convergence condition is used to test for the stability of the time integration algorithm. It is found that the algorithm is conditionally stable since for a given "DX" increment there exists a bounded "DT" increment outside of which stability can no longer be maintained.

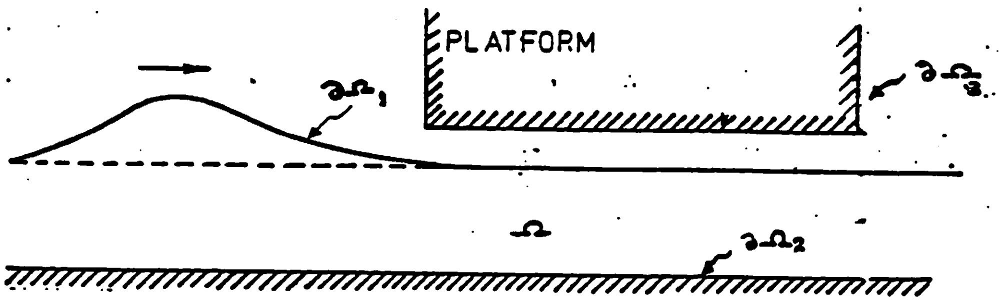
A Boussinesq profile is used as an initial wave height profile and second order theory is used to integrate the Boussinesq particle velocity to obtain an initial profile for the potential function at the free surface.

Numerical Results. In Figure 3, the numerical results are presented for the propagation of a solitary wave in a uniform region. It is found that the solitary wave height decreases by one to two percent of its original height at the first few time steps and then it remains constant as it propagates. That was because of the approximation that is used to specify the potential function at the free surface. A measure of the accuracy of the numerical scheme is the accuracy with which quantities which are conserved analytically also are conserved numerically. In our case, the volume of the wave is to be conserved as the wave propagates. Good agreement is achieved as the ratio of the wave is propagated without change of shape. In Figure 4, a wave is compared with the initial Boussinesq profile after propagating 480 time steps.

Figures 5a-5c show the numerical result of the sequence of wave impact on a horizontal platform as a solitary wave approaches the platform.

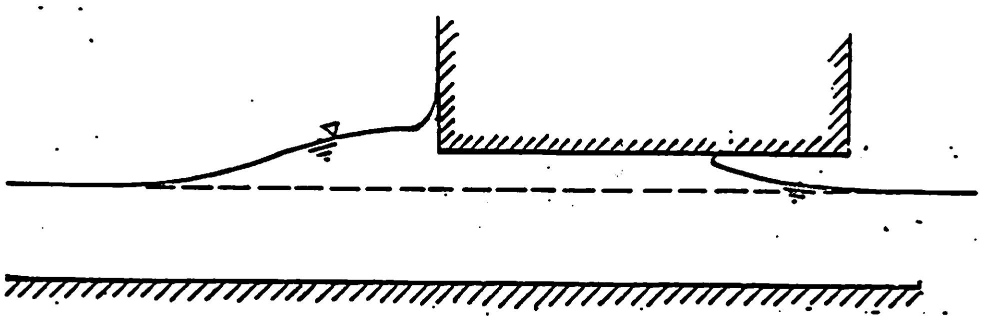
It is evident that the wave front propagates beneath the platform, while the high vertical front face of the platform causes a jet of fluid to shoot upward. As the wave propagates, the vertical jet grows no taller, but decends to form part of a reflected wave train. At this instant, the water depth at the front of the platform is less than the undisturbed bed water.

It is proposed that a model of finer mesh be used and that artifical viscosity be used to smooth the free surface in the front of the platform. The final segment of this work is to relate kinematic behavior of the flow near the platform to dynamical behavior of the flow in order to be able to compute the uplift pressure on the platform.



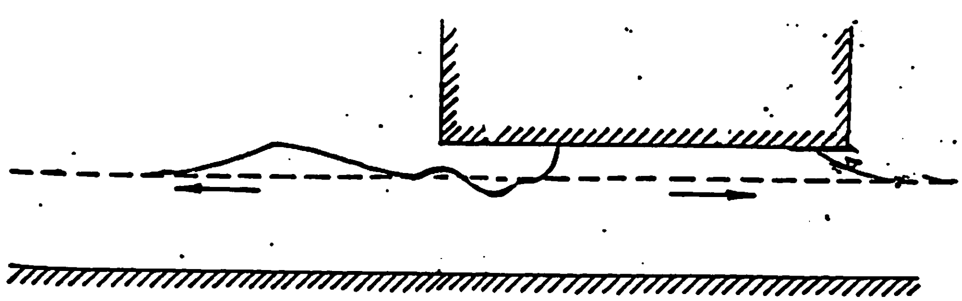
Solitary wave approaching the platform.

FIG. 1-A



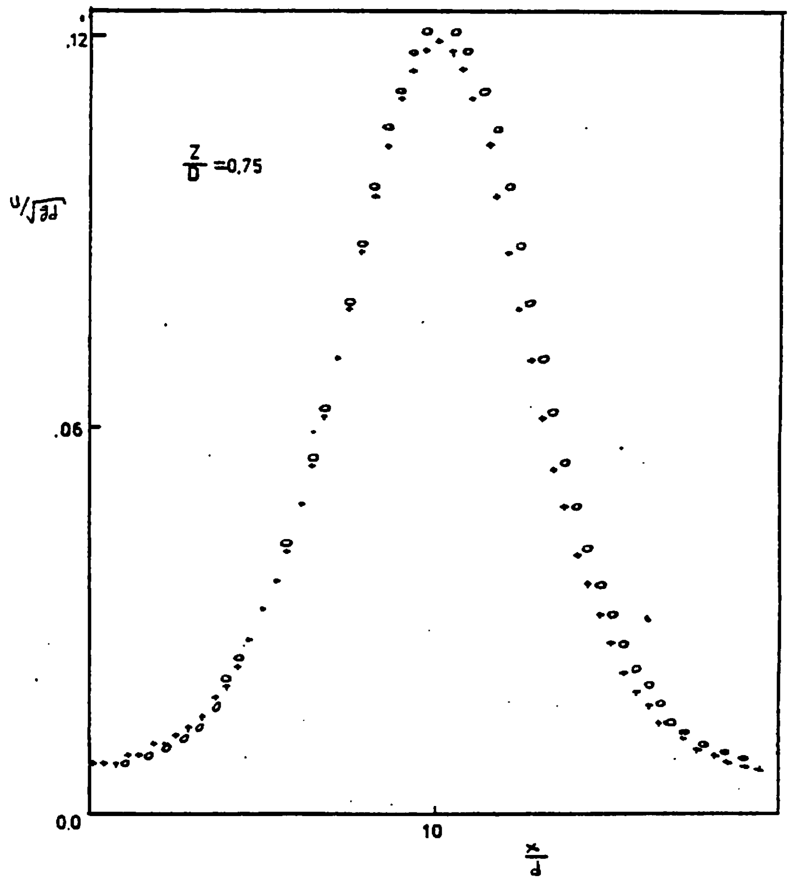
Wave striking the platform.

FIG. 1-B



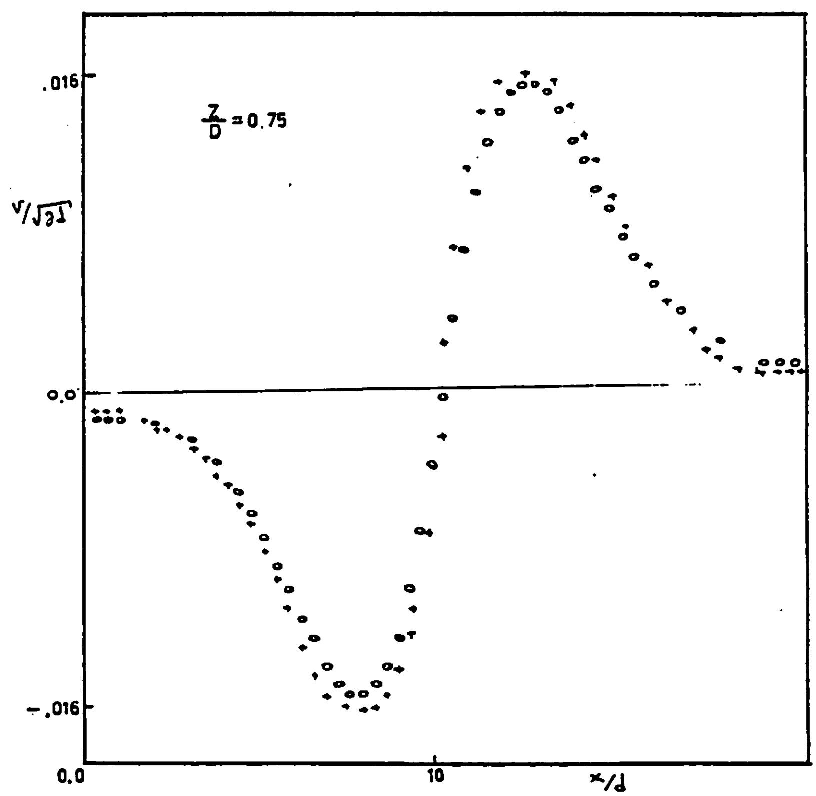
Reflected and transmitted waves.

FIG. 1-C



COMPARISON OF HORISONTAL PARTICLE VELOCITY

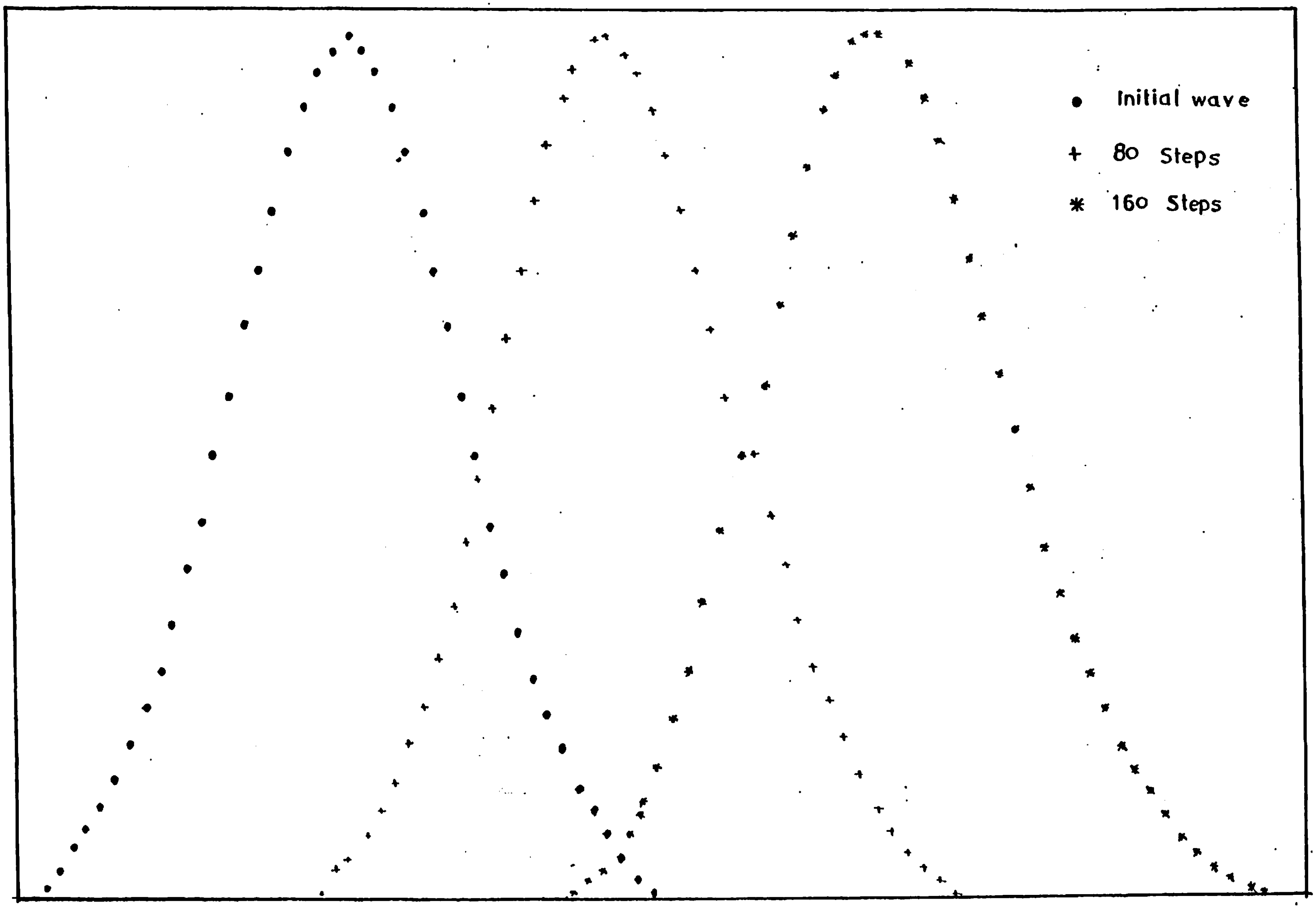
FIG. 2-A



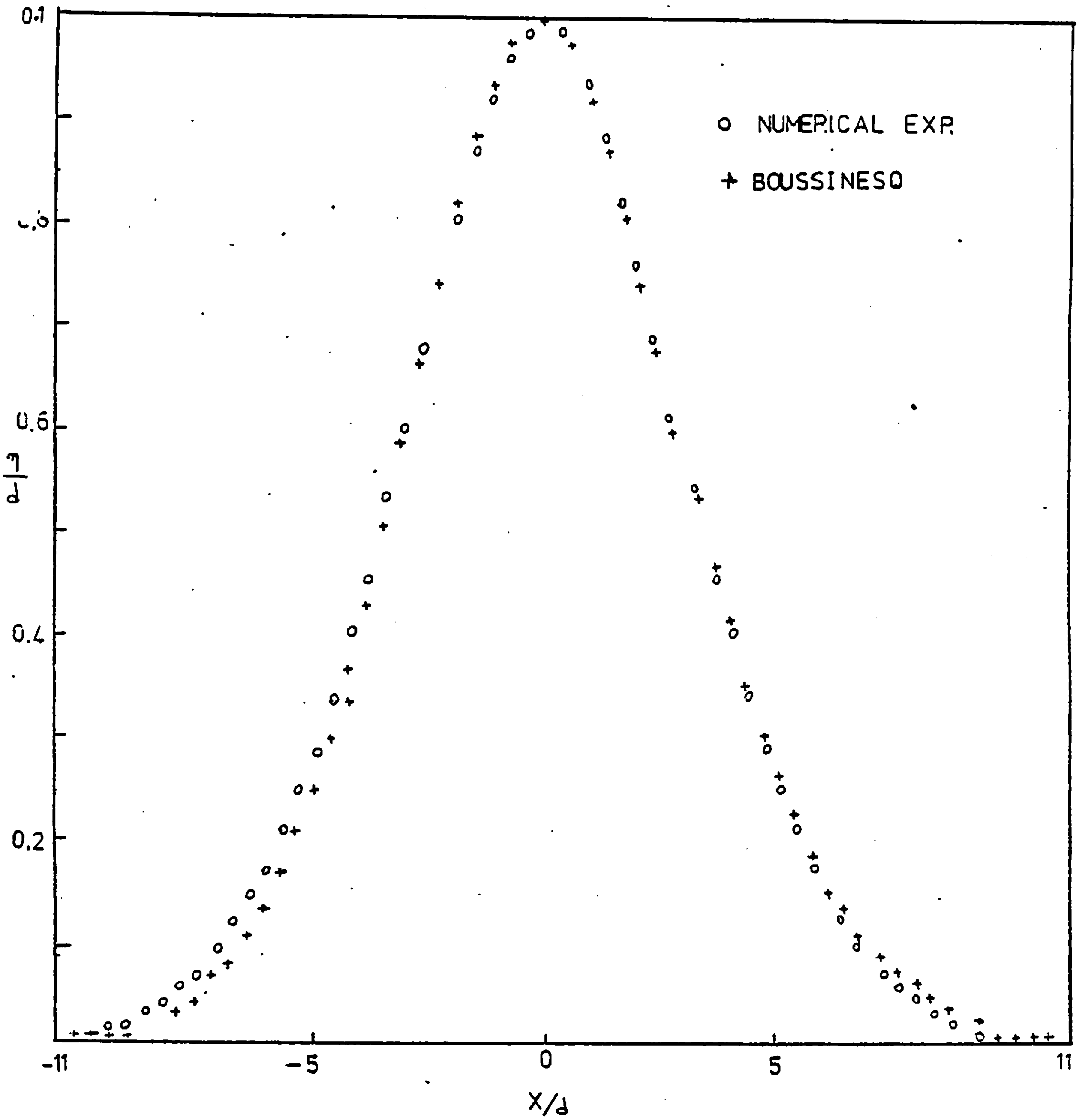
COMPARISON OF VERTICAL PARTICLE VELOCITY

O = NUMERICAL EXP.
+ = BOUSSINESQ

FIG. 2-B

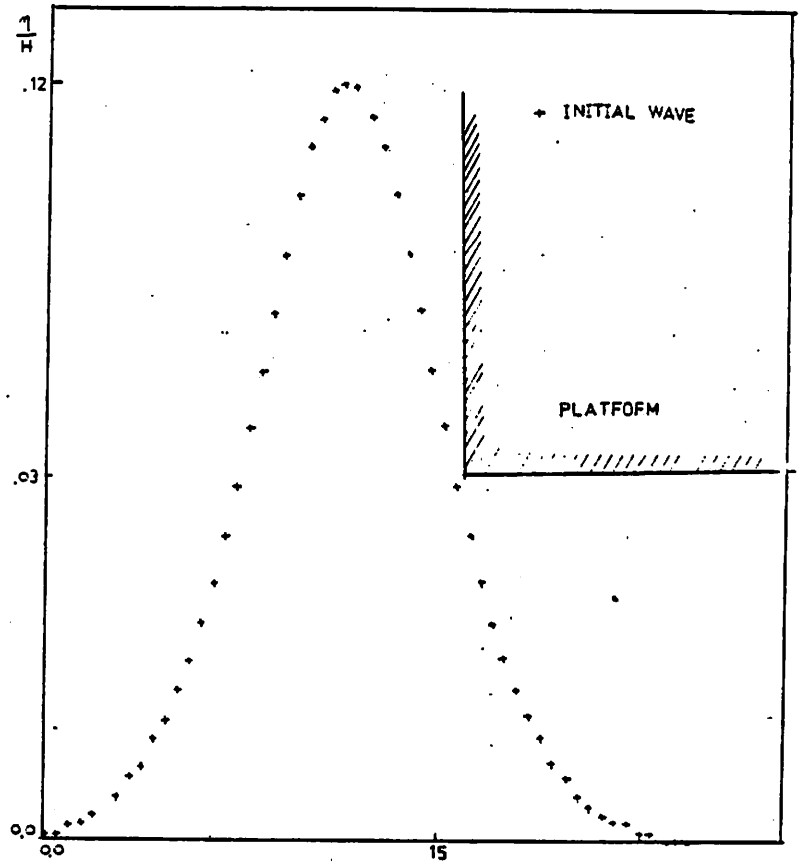


NUMERICAL RESULTS FOR THE PROPAGATION OF A SOLITARY WAVE FIG. 3



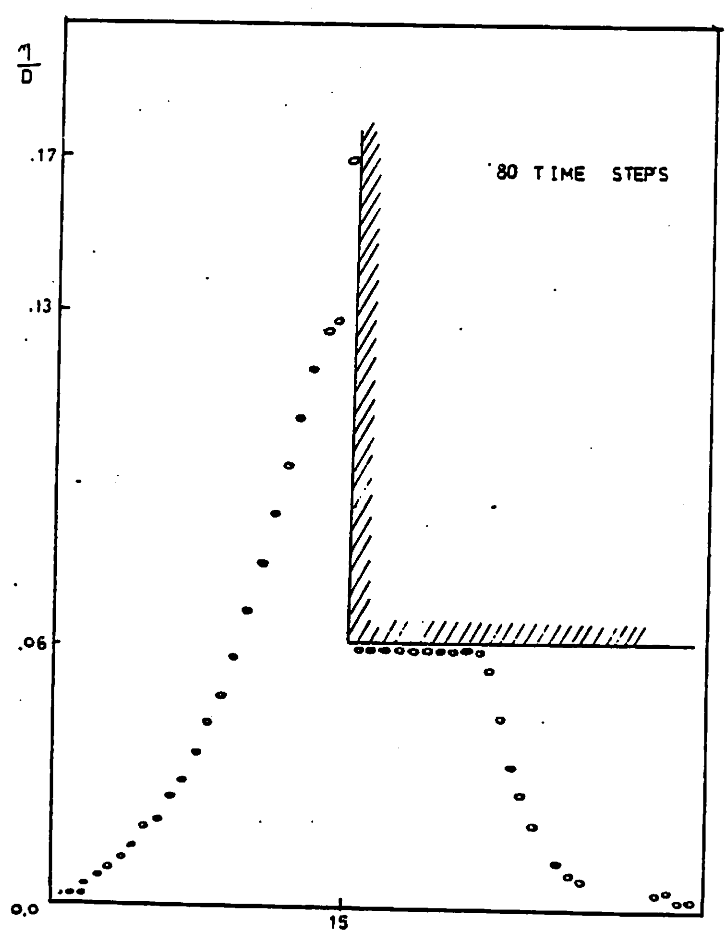
COMPARISON OF WAVE PROFILE

FIG. 4



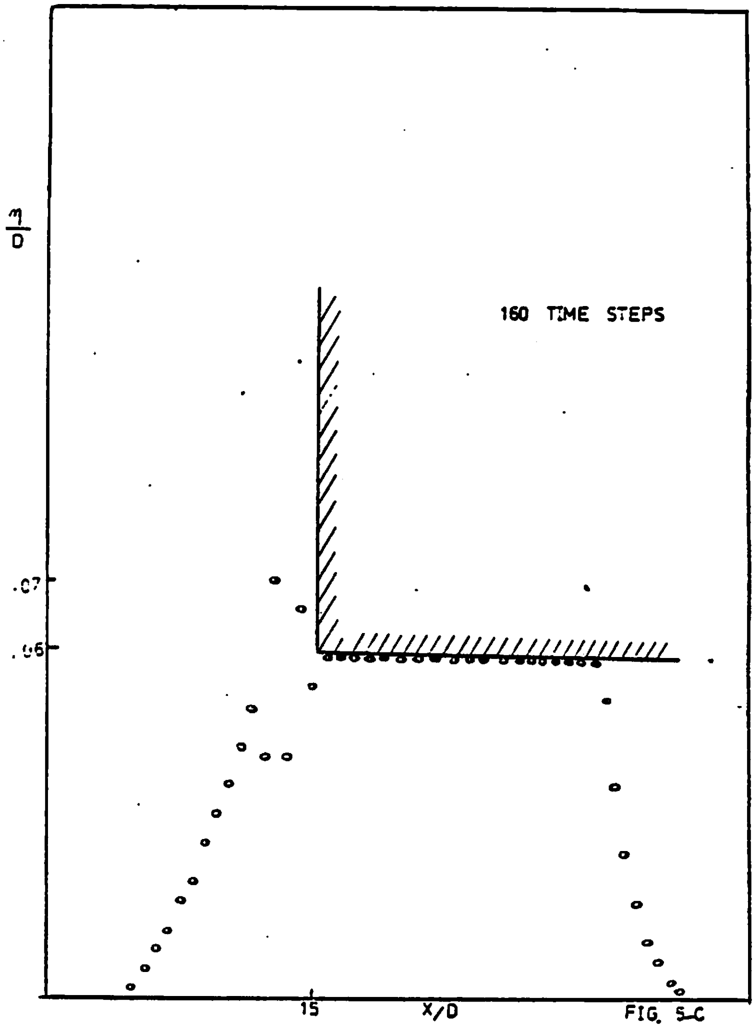
η/H
.12
.03
0.0
0.0
15
X/D
+ INITIAL WAVE
PLATFOFM

FIG. 5-A



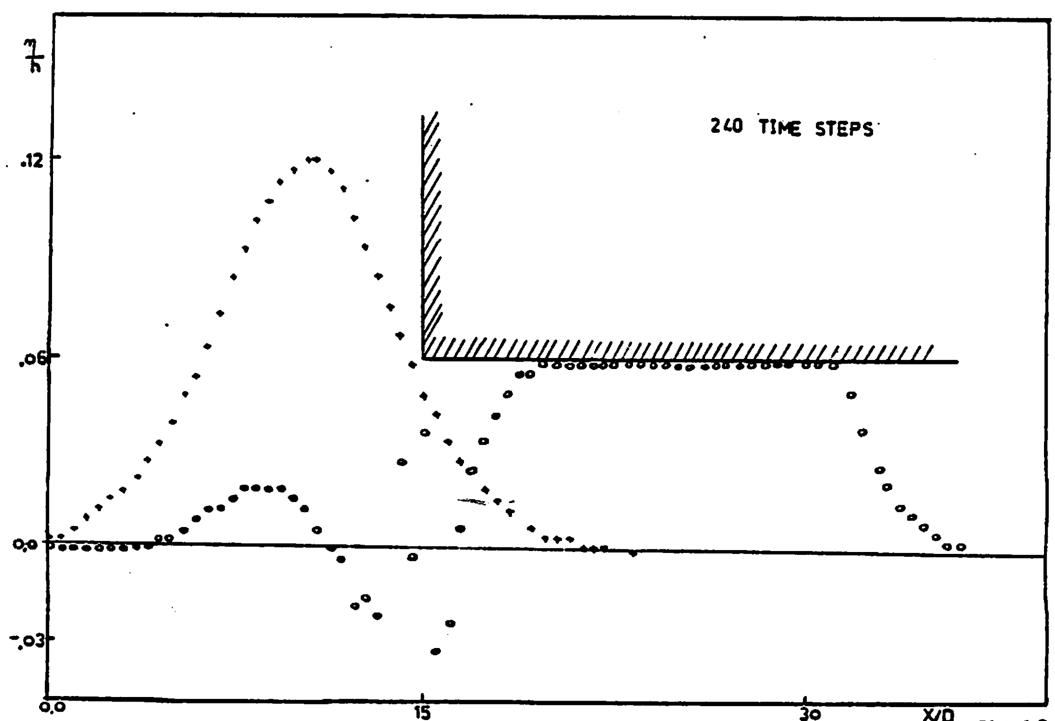
η/D
.17
.13
.06
0.0
15
X/D
80 TIME STEPS

FIG. 5-B



η/D
160 TIME STEPS
.07
.06
15
X/D

FIG. 5-C



η/D
240 TIME STEPS
.12
.06
0.0
-.03
0.0
15
30
X/D

FIG. 5-D

Evaluation of a Masters of Public Administration Curriculum Specialization in Port/Harbor Management (E/CD-1)

Peri Muretta*, Department of Urban and Regional Planning

INTRODUCTION

The curriculum development research project in seaport management has completed its third year and its basic objective to develop a concept of seaport management and curriculum specialization, conduct initial course offerings, prepare selected teaching materials and generally evaluate the potential for this field of study at the University of Southern California. A grant to develop the curriculum in seaport management began during grant year 1978-1979.

In the first grant year, the course "Introduction to Seaport Policy and Management" was prepared and was offered during the next year through USC's School of Public Administration. In the two subsequent grant years, two additional courses were offered: "Port Performance and Financial Management" and "Seaport Planning and the Coastal Zone." Students completing the 12 unit series were awarded a certificate in Seaport Management.

The current funding (1981-82) is a continuing grant to further refine the seaport management curriculum and, specifically, to develop an additional course syllabus on the application of systems analysis to seaports. This course is being developed because it is hypothesized that port operations could benefit from the application of systems analysis and operations research techniques. Although these techniques are readily available from consultants and discussed in the literature, port managers are often not familiar with these techniques. In spite of this void, it is suggested that seaport managers believe that such techniques would be useful.

* Worked with Willard Price, Associate Professor, School of Public Administration, University of the Pacific; Adjunct Research Associate, Institute for Marine and Coastal Studies, University of Southern California.

METHODS AND RESULTS

In developing a systems analysis and operations research course for seaport managers, the seaport is first conceived of as a system. The "systems approach" applies general systems theory and systems analysis to seaport systems, including the use of quantitative models and analytical methods to help seaport managers with decision-making and resource allocation. These techniques include:

1. Simple input-output models
   A. Benefit-cost analysis
   B. Cost-effectiveness analysis
   B. Multiple attribute analysis

2. Seaport system models
   A. Materials and transportation models
   B. Simulation models

3. Planning models
   A. Decision theory, with risk and uncertainty analysis
   B. PERT/CPM or network analysis
   C. Forecasting and regression analysis
   D. Linear programming, including the transportation and assignment models

4. Additional techniques
   A. Queuing or waiting line theory
   B. Markov analysis
   C. Dynamic programming
   D. Inventory models
   E. Replacement theory

The major task in creating a seaport systems course was the formulation of a syllabus to include: objectives, topics, readings, cases and excercises and a bibliography. The first step involved a detailed literature review of key journals, as well as a well-defined computer search of more than 15 Dialog data bases.

The next activity involved discussions with individual port managers at most West Coast seaports. This effort intended to locate real applications of systems techniques. In addition, these managers were queried about the potential use of methods that are not currently being used.

Because this program in seaport management is one of the very few graduate offerings available on the West Coast, another task of the current grant is to evaluate the relationship of the course to the experience of the offering of the entire curriculum.

Two of the first three courses were offered again during 1980-1982 and the third will be offered in the spring of 1983. Input for evaluating the curriculum will be sought by students who come to the courses, and seaport practitioners and national academics involved in seaport research. These evaluations will help in determining whether the systems course should be offered as a separate course or whether it should be integrated with the content of the existing three courses.

Discussions with West Coast seaport managers have yielded valuable insight on the viability of a seaport systems course. There is currently a limited use of these systems techniques by practitioners on the West Coast. The techniques more frequently used by port practitioners include economic analysis and capital budgeting techniques. Some ports have used simulation and queuing. Project management techniques such as PERT/CPM are frequently used because ports are continually developing new facilities and terminals. A matrix showing the application of these techniques by the West Coast ports is presented below:

Systems Techniques	Application: Potential	Application: Currently Used
Benefit-cost analysis		x
Cost effectiveness analysis		x
Multiple attribute analysis	x	
Materials & transportation models	x	
Simulation models		x
Decision theory	x	
PERT/CPM or network analysis		x
Forecasting & regression analysis		x
Linear programming (including transportation & assignment models	x	
Queuing or waiting line theory		x
Markov analysis	x	
Dynamic programming	x	
Inventory models	x	
Replacement theory	x	

There are several reasons offered by port practitioners why these techniques are not more widely used.

1. One reason is that some port practitioners lack the knowledge of systems techniques. This is likely because many practitioners come from the maritime industry or from educational fields which don't emphasize systems techniques. The Port of Oakland, for example, is just beginning to computerize its financial systems.

2. Another reason systems techniques are infrequently applied is that some ports perceive little or no need for these techniques. Often when an organization is in a high growth period, as some ports are, they can afford to make decisions without the benefit of analytical models. There may be little organizational pressure to optimize performance when financial slack is available. The Port of Seattle, among others, contends that investment decisions are made on speculation rather than a cost-benefit ratio. Decision-making is often political, not economic, and although a systems course may be informative, the newly-acquired techniques would probably not be used.

Most ports acknowledge the benefits of a systems knowledge but say that the techniques are applied so infrequently that it is more cost-effective to rely upon outside consultants rather than to internalize staff expertise. An ongoing in-house capability would not be fully utilized. Given the development of micro computers and many software packages, there is now less need for a fully trained systems analyst. Nonetheless, some professionals will need training to be able to deal with consultants and the available systems programs. Therefore, some education preparation is desirable for many existing and future seaport managers.

CONCLUSION

The insights gained through discussions with port practitioners may mean that a separate systems course is not warranted, although the market is not yet tested. If systems analysis techniques should be incorporated in the curriculum, it may be desirable to provide an overview in the introductory course or to discuss systems analysis more fully in the Port Performance and Financial Management course.

We do propose a test of this content in a separate offering, suggesting its more attractive content than general overview, planning, environmental or coastal zone topics. Because the finance course drew more enrollment than the other offerings, we believe this system analysis content will also be attractive. But, ultimately, we would prefer to integrate the material in order to strengthen the previous curriculum. The test of a separate offering will help make that decision.

The format may also be evaluated with other than regular graduate courses:

1. Seminar/workshop for no credit;
2. Offering at several sites close to each port region;
3. Offering both credit and no-credit, depending on needs of the students; and
4. Continue current method of credit options of either two or four units.

In sum, this research is both determining relevant content for application of the academic subject of the systems analysis/operations research as well as a testing of the nature of university offerings which would provide educational outputs for professional seaport managers. While using both the literature and practitioners in developing this syllabus, future interaction through educational programs will determine the valadity of systems techniques for seaport managers and the usefulness of the university to transfer this knowledge.

Aspects of the Biology of the Sea Cucumber, Parastichopus parvimensis: A Developing Commercial Fishery (R/RD-14)

Ann Muscat*, Department of Biology

INTRODUCTION

Recently, a new fishery has developed in Southern California for the sea cucumber, Parastichopus parvimensis. Although this animal is common in many subtidal habitats in the area, there is little known about its life history, behavior or population dynamics. This information is necessary to establish management guidelines; as of now, there is not enough known about this species to make regulatory decisions.

A study of this newly exploited resource offers a rare opportunity to accrue information of theoretical interest to marine ecologists, as well as to supply needed information on an economically important species. This present study is examining certain aspects of the life history and population dynamics of P. parvimensis, especially those which pertain to its successful utilization as a marine resource.

METHODS AND RESULTS

The first year's data indicate that there are dramatic seasonal fluctuations in population densities, with nearly complete disappearance from shallow waters (less than 40 feet) from August through November. There appears to be a migration downslope from the warmer, shallower areas, which occurs on both hard rock and soft sand substrates, and sampling continues in different habitats and at different depths to more precisely define these patterns. Densities of cucumbers increase on hard substrates, being up to ten times higher than on soft bottoms. However, the largest individuals are found on sand and an intermediate size class on the the surfaces of rocks. The preferred habitats of

* Worked with Jon Kastendiek, Assistant Professor, Biological Sciences, University of Southern California.

adult and juvenile cucumbers also appear to differ, with juveniles found almost exclusively in kelp holdfasts and under rocks. This difference in distributional pattern between adults and juveniles is probably due to predation pressures. Although I have already proven that fish will eat juveniles but not adults, experiments are underway to examine more closely the relationship between size and escape from predation.

Sea cucumbers have a definite reproductive cycle, with spawning in May and June. There is also an annual pattern of intestinal growth and development, with cucumbers undergoing spontaneous evisceration during September and October. They can regenerate the lost parts in one or two months, reaching a maximum overall body weight during the winter, presumably when they are again capable of feeding and are producing gonadal material. Comparative data are now being collected to examine these phenomena in terms of depth (shallow and deep populations) and habitat (soft and hard bottoms).

There are different movement patterns on soft and hard substrates, with cucumbers on the sand moving significantly more than those on the rocks. There is little mixing between populations on soft and hard bottoms, and mark-recapture studies are being done to more precisely demonstrate and document these differences.

It is difficult to measure growth in sea cucumbers because they are soft-bodied and can contract and expand at will. An experimental tagging method, using tetracycline, is being developed. Tetracycline is taken up when plate material is laid down in the calcareous ring. When the ring is examined under an ultraviolet light, growth lines will fluoresce yellow. If this method works, I will begin large scale tagging of cucumber populations to determine growth rates and age structure.

Information on recruitment is being collected bimonthly by sampling juvenile habitats in kelp holdfasts and under rocks. So far, very small individuals (1-2 cm) have been found only in kelp holdfasts, and those under rocks are in the 5-8 cm range. However, individuals in these size ranges are not common.

A long-term field experiment was conducted to determine the impact of cucumber deposit-feeding on the infaunal populations of soft substrates.

These samples are still being analyzed.

Concurrent with these natural history studies and laboratory analyses, I have contacted commercial fishermen and buyers along the West Coast to gather information on their fishing and processing methods.

Waves and Currents in Coastal Regions of Sharply Changing Water Depth (R/CE-6)

Seyed Mehdi Sobhani*, Department of Engineering

INTRODUCTION

In any ocean and coastal engineering problem, it is necessary to know the behavior and characteristics of waves in the regions of interest. Once wave characteristics are known, however, the need of providing some shelter from waves is another problem to investigate. There are some techniques to define wave propagation when the water depth is constant; however, in most cases, water depth changes rapidly -- especially near the coastal regions as shown in Figure 1. It is possible to use different numerical methods for each special region and then match that solution at the commom boundaries to give the final solution. In Part I of the current work, a finite element model has been developed where the solution is matched at the commom boundaries. Then in Part II, the problem of floating breakwater -- which can be used as a shelter from waves -- has been analyzed by using the finite element method (developed in Part I) together with the dynamic equation of motion of the floating breakwater.

Part I: Application to Inclined Wave Generators.

In this part, the problem of inclined wave generator has been studied, using both eigen function expansion and the radiation condition for the far end. The results are then compared with experimental results, as well as other theoretical techniques.

The inclined wave generator consists of a plate with one end hinged and attached to the bottom and then mounted in its at-rest position at a given angle in a constant depth tank. The plate is moved about this position with a periodic motion. Using velocity potential, some characteristics of generated waves are found. The domain are divided into two regions: region I is bounded by a plate (wave machine) at an obtuse angle with the bottom, while in region II, the plate makes an acute angle with the

* Worked with Jiin-Jen Lee, Professor, and Landon C. Wellford Jr., Associate Professor, Civil Engineering, University of Southern California.

bottom. The ratio of the wave height to the total stroke of the wave machine (H/S), versus ratio of depth to wave length (h/λ) for regions I and II are shown in Figures 2 and 3 respectively.

METHODS AND RESULTS

In the current work, a matching technique has been used for boundaries AB and CD (see Figures 2 and 3). The velocity potential of inner region is matched with solution of the outer region, which is a series expansion with unknown coefficients. A comparison is shown below between the current and the earlier work using the boundary integral equation technique. It can be seen that the matching technique has good agreement with the boundary integral method. Results were found for four different angles of inclination. As the angle of inclination is increased, the slope of the curves descreases. This is because the wetted length of the plate, relative to the undisturbed depth of water, decreases. Also for h/λ up to 0.1, the curves are almost linear. As this ratio is increased, curves of region II continue to be linear, while in region I, the wave height reaches a maximum and then declines. This is due to reflection of a portion of the wave into the triangular part above the plate. The amount of this reflection is more for certain ranges of h/λ . As far as wave generation is concerned, it can be said that efficiency is higher at certain h/λ . This phenomena does not take place when waves are generated in region II because there is no free surface above the inclined plate. Also for h/λ greater than unity -- a change in inclination from 22 to 34 degrees -- H/S of generated wave in region I can differ by a factor of two. Thus, the angle of inclination is very important in wave attenuation. The above mentioned results could be used in the design of floating breakwater.

CONCLUSION

The numerical method developed -- matching technique by making use of the finite element method -- gives a reasonable result in predicting the wave characteristics and can be used in sharply varying water depth cases.

Part II: Application to Sloping Float Breakwater.

In any offshore operation, the need of providing shelter from waves is a necessity. A light-weight breakwater (compared to rubble mounds) may be a feasible mean of wave protection. The sloping float breakwater, which is a mobile or portable breakwater, could be used over a wide range of wave periods. Application of this concept necessitates a complete understanding of the attenuation characteristics of moored sloping breakwater.

METHODS AND RESULTS

Figure 4 shows a schematic diagram of a sloping breakwater. To understand this concept, first we refer to the bouyant hinged plate. In this case, we have an inclined plate that moves due to the wave action which is not known a priori; in Part I, the inclined plate was moved manually in a controlled and known amount. Solution of this problem involves determining the velocity potentials in regions I and II and coupling it with dynamic equation of motion of the plate.

The above fluid-structure interaction problem is solved using the present method of matching the finite element method (FEM) solution with eigen function expansion. The results are then compared to the experimental and the analytical results obtained earlier by other investigators. The results are shown in Figure 5. Results show good agreement with boundary integral method (BIM).

It is interesting to note that in region I (for a sloping breakwater, this would correspond to the shoreward side), the generated wave height decreases rapidly for Kh more than .5 and for a given stroke (K is the wave number and h is the water depth).

In Figure 5, it can also be seen that the transaction coefficient (K_t) and relative generated wave height (H/S) decreases rapidly over the same range of Kh. At Kh approximately equal to unity, both H/S and K_t are minimum. Also it shows that for large wave lengths, the waves generated on both sides are equal (i.e., $K_t = 1$). Thus it is concluded that for Kh less than 0.4, the transmission coefficient can be assumed to be unity.

CONCLUSION

The present effort of combining the finite element method with other analytical procedures has shown good promise in attacking problems where matching solutions are needed. In the ensuing months, efforts will be directed to show additional applications to a number of important coastal engineering problems.

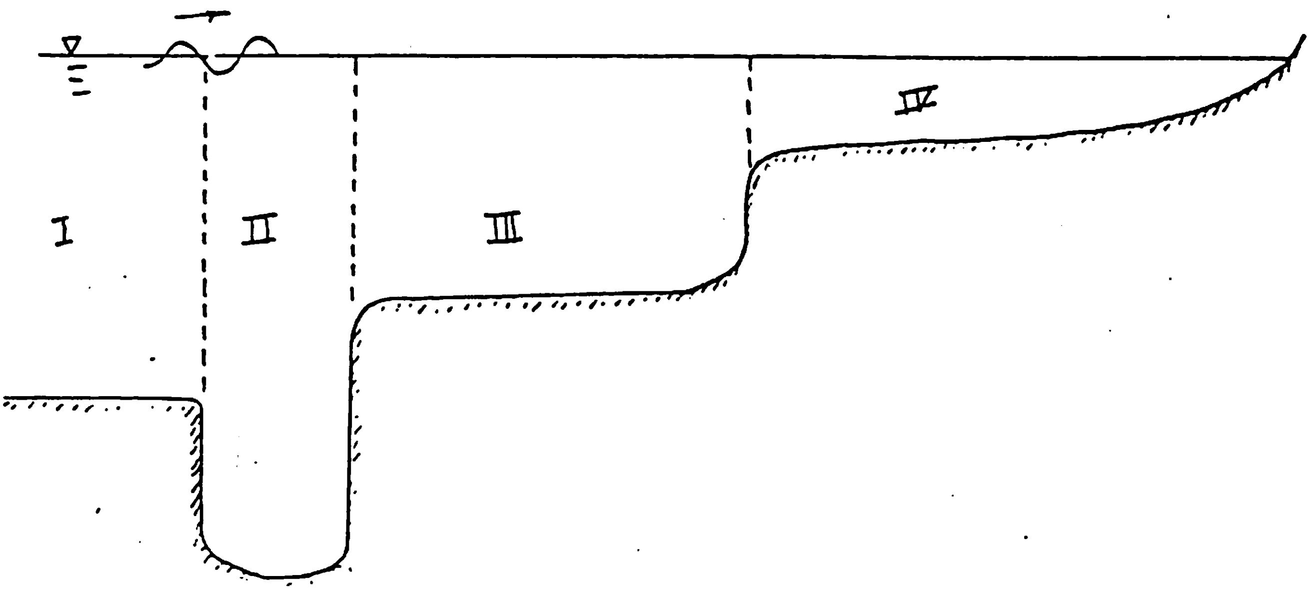


Fig. (1) Cross sectional view showing matching boundaries of various regions in coastal zone.

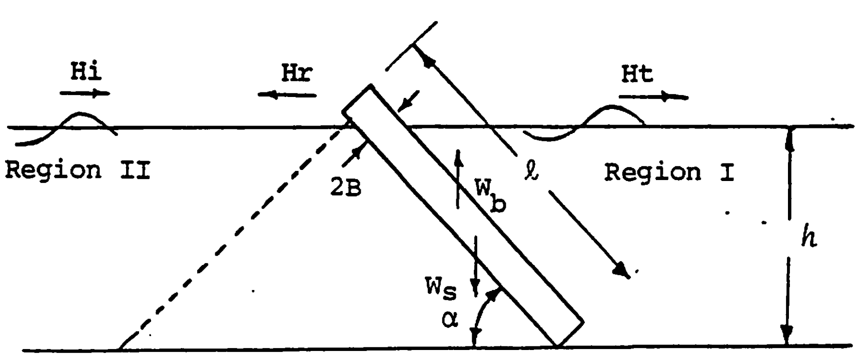


Fig. (4) Schematic diagram of a sloping breakwater.

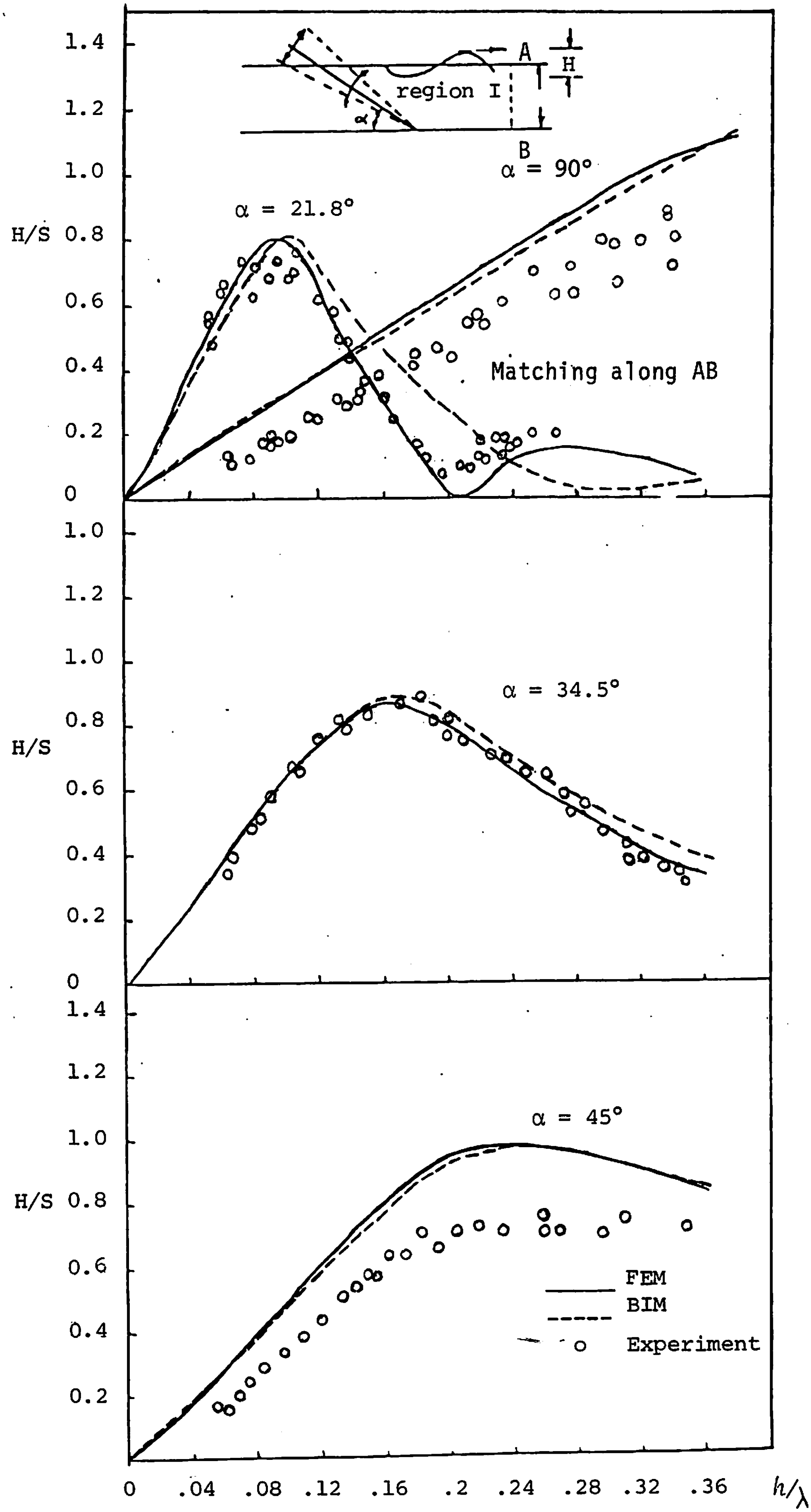


Fig. (2) Comparison of BIM, FEM (current work) and experimental results for the waves generated by an oscillating inclined plate at region I.

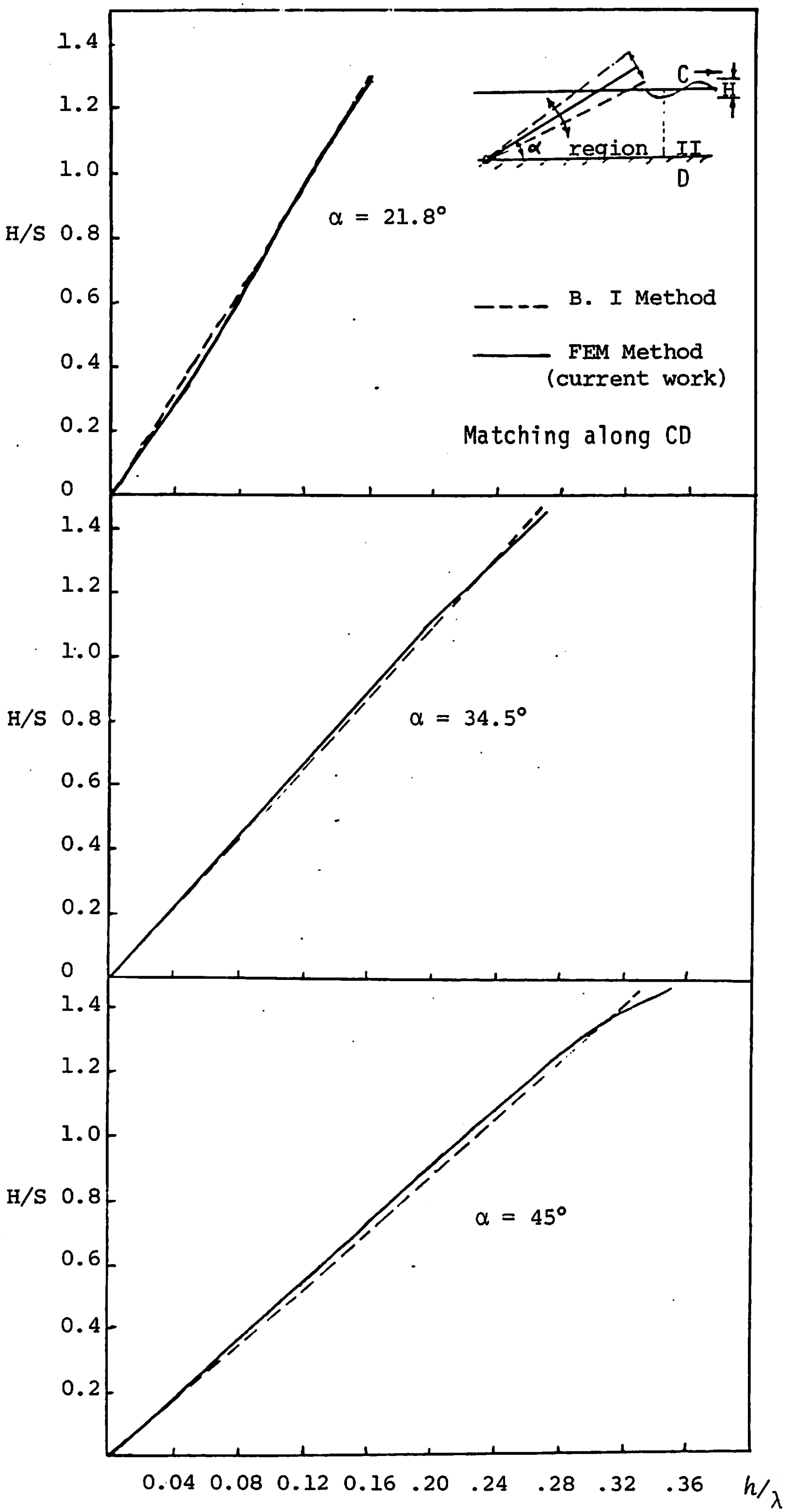


Fig. (3) Comparison of boundary integral method to FEM (current work) for the waves generated by oscillating inclined plate at region II.

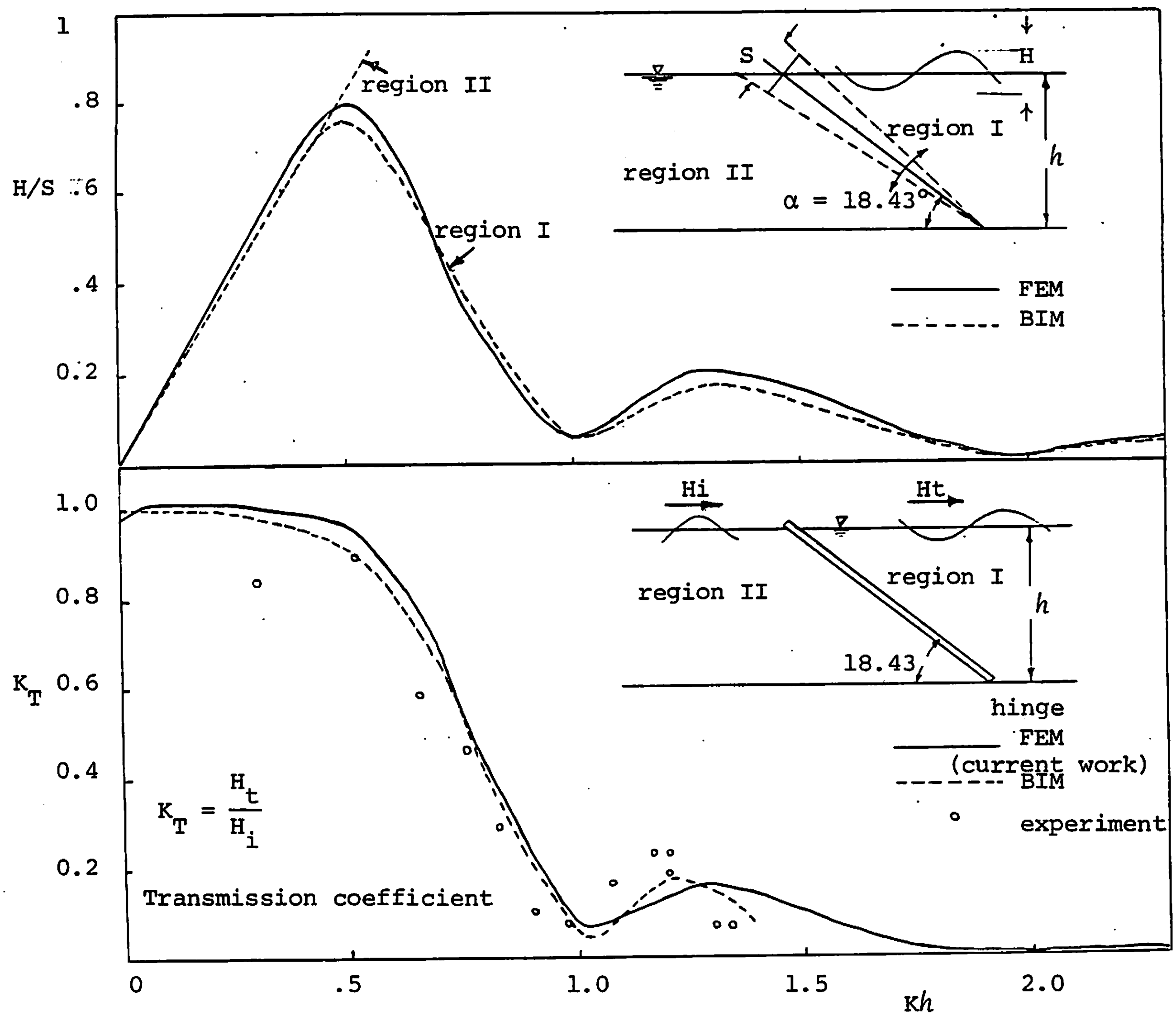


Fig. (5) Transmission coefficient for bouyant hinge plate and wave generation theory for inclined plate wave generator (FEM, BIM and experimental results.

Factors Affecting the Survival of Nearshore Larval Fishes (R/RD-13)

Carol A. Stepien*, Department of Biology

INTRODUCTION

This project dealt with the development and feeding of laboratory-reared and field-collected clinid larvae. Clinidae are an important group of fishes in the Eastern Pacific where more than 100 of the approximately 150 worldwide species are present (Springer, 1970). Of these, 12 species are found in Southern California coastal waters (Miller and Lea, 1972). Little is known, however, of their life histories and ecological roles. They are particularly abundant in algal-covered habitats in less than 200 feet of water. The giant kelpfish, Heterostichus rostratus, is the largest, reaching a length of 60 cm, and also one of the most abundant. It is a major predator of small fish and crustaceans in the kelp forest community.

A planktonic larval stage serves as the primary mechanism of dispersal in these fishes, and I have found the adults to be very territorial and to migrate little during their lives. Clinid larvae are common in nearshore ichthyoplankton samples, particularly during the spring months. Demersal eggs of Heterostichus are laid in isolated patches of algae, usually less than 60 feet deep. Nests are guarded by the male who actively defends them against predators until hatching, which occurs after approximately two weeks. Newly hatched larvae are well developed and capable of actively feeding and avoiding predators, the most critical factors for larval survival. Larvae are planktonic during the first two months, after which they become increasingly thigmotatic, feeding near kelp or surfgrass plants.

At about eight months, kelpfish juveniles begin to develop one of the adult coloration patterns. Three distinctive color morphs occur: red, green and brown. My dissertation topic is to examine

*Worked with Gary Brewer, Research Scientist, Institute for Marine and Coastal Studies, University of Southern California, and Gary Kleppel, Director, Biological Oceanography, Southern California Coastal Water Research Project.

whether these color morphs are genetically and/or environmentally determined.

I have found that adult males are always brown (this may be adaptive since their territories and nests are established in brown-dominated algal zones), while females can be either red, green or brown. Females occupy a correspondingly wider range of algal habitats and depths.

Color morphic variation may be adaptive in allowing the kelpfish to exploit a wider range of habitats, space in this highly territorial fish being potentially limiting. I have found that color does not change in either the lab or the field when background color is manipulated. I am currently testing at which stage color morphic differences begin to develop and whether juvenile color development can be artifically manipulated. I am also investigating the role that diet has in determining color and whether dietary differences between the color morphs occur.

A major part of my dissertation research is the rearing of Heterostichus larvae from known parents in the laboratory. As in any laboratory study, the major obstacle is to determine whether the results correspond to those that occur in the field. Field-collected larvae from Sea Grant Project R/RD-13, "Factors Affecting the Survival of Nearshore Fishes," have yielded valuable data on Clinid distribution, development, pigmentation patterns and feeding, which have supplemented and confirmed my laboratory studies.

A major question pertinent to fisheries stocks is whether larval fishes can obtain adequate food supplies for growth and survival while avoiding predation. Density thresholds necessary for larval survival in the laboratory have been found to be higher than food densities in the open sea. The disparity between estimates of food densities required by larvae and those available to them has led to the hypothesis that larvae may be dependent on small-scale patchiness of food (Hunter, 1981).

Whereas larvae from planktonic eggs (such as the northern anchovy, Engraulis mordac) have been widely studied, there has been little work done on the larger and comparatively well-developed larvae from demersal eggs. In nearshore waters, planktonic fish larvae from demersal eggs (such as the Clinidae) may be superior competitors for the scarce and, perhaps, patchily distributed food items. Their larger size and more advanced developmental stage at hatching may allow them to more successfully avoid predators and find food items, as compared to the generally more commercially important larvae from planktonic eggs.

In this study, I investigated feeding in laboratory-reared and field-collected larvae of the Clinid family, a prevalent group of nearshore California fishes.

Methods

Field-Collected Larvae

Larval fish from Santa Monica Bay were sampled using 335-micron mesh bongo nets. To date, only samples from the northernmost (Transect 0) and southernmost (Transect 6) sites for January 25-30 have been analyzed (Figure 1). Microplankton samples of possible larval food items were collected using a submersible pump and filtered from 35-335 microns. After identifying the larval fish species belonging to the Clinid family, I recorded data on number of vertebrae and fin-rays; measurements of total length, standard length, head length, gut length, and mouth size; and distribution of pigment to determine intraspecific growth differences as well as interspecific distinguishing characteristics. I grouped the Clinidae sampled into four types, each probably comprising a single species.

I examined the gut contents of a representative sample of each type of larvae. Under a dissecting microscope, guts were dissected away from the body and food particles teased out using a modified paint brush from which only three long strands protruded and, in some cases, using a single human hair. Under a compound microscope, the particles were identified and lengths and widths of the prey items determined. The mouth width of each larva was measured from a central view. Maximum width of prey items (including the appendages of crustaceans) has been postulated to be the major determinant of prey size consumed (Hunter, 1981).

Laboratory-Reared Larvae

I collected Heterostichus rostratus eggs while diving off Santa Catalina Island. Nests of eggs were found from February through June. Eggs were laid in algal nests in the laboratory in two cases. I suspended the nests in 20-gallon containers which were placed in a 10-foot diameter tank with running seawater at the University of Southern California's

Institute for Marine and Coastal Studies' Fish Harbor Laboratory. The nests were attached to a motor-driven stirring device so that they were constantly rotated, simulating in situ water movement. I removed some eggs every few hours for examination during the first two days of development and each day after that until hatching (Figure 6).

Eggs hatched in 12-16 days at 18°C. After the first hatching, I changed containers daily to isolate newly hatched larvae with minimal disturbance. Best results were obtained when newly hatched fish were begun on a diet of Brachionus rotifers within 24 hours after hatching. Brachionus cultures were fed Tetraselmas green algae which were thus also available as food items to the larvae. Brachionus densities in the containers were maintained at levels of 10-40 per ml.

After two weeks, larvae were also fed wild plankton, which primarily contained various developmental stages of Acartia copepods. I collected wild plankton using a submersible pump attached to a float off the laboratory pier. A light was suspended over the pump and the whole system connected to an electrical timer. Plankton was filtered into a container having two bags of 335- and 100-micron mesh to capture copepods of appropriate size. A small hose attached to the seawater system helped insure copepod survival, keeping temperature constant and maintaining oxygen levels. Best copepod catches were obtained from dusk to two hours after sunset, the copepods being attracted to the light. Brachionus food was discontinued after three weeks.

Daily for the first two weeks and biweekly thereafter, 10 larvae were removed, measured, and their development noted. I examined the gut contents of three specimens from each sample for comparison with prey items of field-collected larvae.

Results

Identification and Distribution of Field-Collected Larvae

Four types of Clinid larvae were identified, each of which is probably a separate species (Table 1). Only the identification of Heterostichus rostratus larvae is confirmed because the species has a distinctively high number of vertebrae (56-58) and specimens were directly compared to laboratory-reared larvae known to be of that species. It is probable that relatively low numbers of Clinids were collected during the January cruise due to sampling too early in the spawing season. I have observed peak larval densities for Heterostichus from early March through early May.

Most of the Clinids samples (46.5%) belonged to Type A (Figure 2). Of the genus Gibbonsia and possibly being G. elgans, Type A larvae averaged 49 vertebrae and were primarily collected in surface tows during the day (Table 1). The average size collected was 6.26 mm, and they ranged from a few days to three weeks old in developmental characteristics. Flexion of the notochord first began at an average size of 6.7 mm and was completed by 7.2 mm.

Heterostichus rostratus larvae comprised 9.3% of the Clinids collected. Most were caught near the bottom, as found in previous ichthyoplanktonic sampling. Average size was 6.77 mm and, comparing their development with laboratory-reared specimens, most also appeared to be less than three weeks old. Larger larvae may have been present but successfully avoided capture, a common occurrence in ichthyoplanktonic sampling because avoidance capabilities have been shown to increase exponentially with larval length due to improved sensory perception and stonger swimming (Hunter, 1981). Also, because it was very early in the spawing season, most Clinid larvae may have been very young.

Type B larvae, comprising 14.0% of the Clinids sampled, were all very large--averaging 12.9 mm--and comparatively advanced. They were all collected during the night and near the bottom. They may have been able to perceive the net during the day but not during the night. Type B larvae had 52 vertebrae and are probably Gibbonsia metzi (Table 1).

Type D larvae were extremely small (mean size of 2.7 mm) and less developed than the other Clinids collected (Figure 3). Their vertebrae were difficult to see, which may account for the wider variance in range (Table 1). The smallest of these larvae had yolk sacs and unpigmented eyes. Type D larvae appear to hatch at a more undeveloped stage than Heterostichus and other Clinid larvae examined. One Type D specimen had a copepod predator attached to its body wall. Predation of larvae is probably more common in the lesser-developed and slower-swimming larval fish species.

Development and Feeding in Laboratory-Reared Kelpfish

Heterostichus larvae in the laboratory hatched in 12-16 days, the mean incubation time being 14 days at 18°C. Newly hatched larvae in the 1982 experiment averaged 4.82 mm in total length (Figure 10). Newly hatched kelpfish had large yolk sacs, well-developed jaws, complete digestive systems, highly pigmented eyes, well-developed pectoral fins, and well-defined dorsal, anal and caudal fin folds (Figure 7).

Yolk sacs were present for 36-72 hours after hatching. Larvae up to four days old exhibited long periods of inactivity following short bouts of active swimming. They often appeared to "play dead" on the bottom and sides of the containers. I found that unless kelpfish larvae were given food within 48 hours after hatching, a point of no return occurred, after which they starved to death even if given food. Best results were obtained if larvae were fed within 24 hours of hatching. This point of no return appears to occur sooner in kelpfish than a pelagic-egg larvae (Hunter, 1981) and is probably related to their greater degree of development at hatching.

Brachionus rotifers and Tetraselmas algae were first found in 2-day-old kelpfish guts. The guts of 3-day-old larvae, even those which still had yolk sacs, contained an average of 5.6 Brachionus and 2.9 Tetraselmas (Table 3). Early feeding during the yolk sac period may be critical for the larvae to develop a "search image" and capture skills.

The 3-day-old kelpfish larvae averaged 5.53 mm in length and had well-developed melanin patterns, including 20 serially-arranged, post-anal ventral melanophores; a large area surrounding the anus; and two small spots on the liver. The otic region of the head was well-developed with the otoliths large and clearly visible. The liver in 0-to-2-week-old kelpfish larvae was proportionately larger than the rest of the body. High levels of mortality occurred after hatching and through Day 5. Dead larvae examined had apparently never eaten, in spite of relatively high levels of appropriately sized food in the containers.

Gill rakers had formed by Day 7 and the operculum was visible (Figure 8). Early formation of the respiratory systems allows for faster speed and increased efficiency of food-getting because the larvae are no longer dependent upon oxygen diffusion.

Mean size was 6.74 mm and maximum width of captured rotifers was only 23% of the mouth width at this time (Figure 11 and Table 3).

By Week 2, the larvae averaged 7.25 mm in length and posterior dorsal and anal fin rays were visible. The majority of larvae examined exhibited the beginning of notochord flexion, which preceeds the development of the caudal bone and musculature structures. The swimbladder had also developed, which is important in improving ability to change depths. These adaptations allow the larvae to more efficiently and actively pursue prey and may allow them to migrate in the water column, following copepod diurnal migration. By Week 2, significantly larger food items were being consumed, the largest width being 52% of the mouth size (Figure 11). This change is shown in Table 3; larger copepods were eaten more frequently than rotifers, although both food items were present.

Kelpfish larvae during Week 2 began swimming in organized schools. However, school formation is not observed in kelpfish past an age of about 2 months. Larval schooling may serve to increase the probability of locating patches of food and/or may also help them to avoid predation.

Larger copepods, up to 70% of the mouth width, were being consumed by Week 3 of development (Figure 11 and Table 3). There was a large increase in length during this period, the average size being 10.58 mm (Figure 10). A significant increase in mouth size also occurred (Figure 11).

A high mortality rate occurred at about 2½ weeks in both the 1980 and 1982 rearing experiments. During this time, I hypothesize that the larvae are switching from the smaller prey (rotifers and algae) to the larger copepods. A critical period may be reached when the larvae have to learn to efficiently capture larger crustaceans as the primary dietary component in order to obtain sufficient caloric intake. Competition for food may also have been occurring in my containers at this time. I observed one incident of possible attempted cannabalism when a 3-week-old larva I was observing in a petri dish under the dissecting microscope repeatedly "attacked" another kelpfish larva by "nipping" at it. No similar incidents were observed in the containers, however.

The 4-week-old larvae had pelvic fin buds, well-developed melanin pigmentation in the pelvic fin region, and well-developed anal and dorsal fin rays (Figure 9). Most specimens had approximately 28 post-anal ventral melanophores and pigment spots on top of their heads. Mean size was 11.02 mm (Figure 10).

The 5-week-old larvae had well-developed pelvic fins and teeth visible in their mouths. Thirty-two post-anal ventral melanophore were common. By Week 6, average length was 14 mm and orange-yellow xanthophore pigmentation had appeared. This pigment was primarily concentrated at the base of the caudal fin and on the top side of the head. Schooling behavior was no longer as prevalent. Larvae were readily observed efficiently stalking their copepod prey. Higher numbers and larger sizes of copepods were found in their guts (Table 3 and Figure 11).

Gut Content Comparisons of Field-Collected and Laboratory-Reared Larvae

I examined the gut contents of a representative sample of all four types of Clinid larvae from our field collections. I found no significant differences between the gut contents of larvae collected from the northern and southern stations (Figure 1). Gut contents of night-collected individuals contained almost no food material, with the exception of a few diatoms. Clinid larvae, like most marine fish larvae (Hunter, 1981), and as supported by my laboratory observations, feed during daylight hours only.

Type B larval specimens were only collected at night. The guts of these larvae were empty.

Type D larvae were considerably smaller and more underdeveloped than the other Clinids collected. The guts of the largest specimens of this type contained small food particles, of which 50% were dinoflagellates. Small copepod nauplii, rotifers and diatoms were also consumed (Figure 5). The diameter of the largest food item consumed was only 24% of the mouth width, indicating inability or inefficiency for capturing larger food particles.

Gut contents of Heterostichus and Type A larvae were very similar (Figure 4). Specimens of these two types of larvae were of similar sizes and developmental stages, with Heterostichus larvae being approximately .5 mm longer during comparable developmental periods. These larvae ranged from approximately 3-days to 3-weeks old.

Crustaceans composed approximately 33% of the total gut contents of Heterostichus and Type A larvae (Figure 4). Copepod nauplii and copepodites were the primary food items, as in most marine fish larvae (Hunter, 1981). They were the largest food items consumed, up to 66% of the mouth width, corresponding to the 70% figure obtained for laboratory-reared kelpfish (Figure 11). Barnacle larvae and ostracod crustaceans were also consumed in lesser but significant numbers, corresponding to their lesser concentrations in the microplankton samples.

A high number of diatoms and dinoflagellates were found in the guts. These small items may have provided some supplementary nutrition. The consumption of phytoplankton during early life history has been postulated to be an adaptation by larvae to meet maintenance metabolic requirements while they learn to feed on zooplankton (Ware et al, 1981). Rotifers (the first food given to laboratory kelpfish), tintinnids and mollusk larvae were also found in lesser but significant numbers (Figure 4 and Table 2). Many marine larvae studied have been found to be euryphagous during early stages, often eating such organisms as tintinnids, phytoplankton, mollusk larvae and ciliates, as well as copepods (Hunter, 1981).

Gut content analyses of Heterostichus Type A larvae showed fewer larger-sized food items in the field-collected specimens than laboratory-reared larvae (Table 2 and Table 3). Copepod nauplii (.068 x .134) have been shown to contain approximately 28 times the energy of a .06 diameter diatom (Ware et al, 1981). Field-collected larvae consumed proportionally more smaller-sized food items of lesser caloric values. These smaller prey items, however, may be present in significantly larger numbers in the plankton and may require less energy expenditure in search and successful capture. Although many more small prey are eaten than larger ones by most fish larvae, the larger and rarer prey probably make the major contribution to growth (Hunter, 1981).

There is a high probability that traumatization from net-catching may have caused significant loss of gut contents through defecation. This occurrence has been well documented for other species, especially those with straight guts (Sherman et al, 1981), as have the Clinids. Also, rapid digestion rates in larvae make any lag time in sample preservation critical.

Microplankton samples in this study ranged from 40-180 particles per liter. These concentrations are considerably less than minimal requirements for first-feeding larval survival in the laboratory (Hunter, 1981) and those maintained in my kelpfish rearing experiments. This disparity between estimates of food density required by larvae and densities available in the ocean has led to the hypothesis that larvae may be dependent on small-scale patchiness of food (Hunter, 1981). Patchy distribution of food items in the nearshore Santa Monica Bay, the area sampled in this study, would support the levels of ichthyoplankton we obtained.

Since Clinid larvae are efficient feeders and well-developed at hatching due to their relatively long demersal egg period (2 weeks incubation time as opposed to 72 hours for northern anchovy larvae, Engraulis mordax), they may be able to out-compete pelagic egg species, such as the anchovy, for scarce inshore resources. Nearshore fishes, such as most members of the Clinidae family, may be superiorly adapted for effectively capturing food at an early age as well as avoiding predation.

CONCLUSIONS

1. Four types of Clinid larvae were collected and described from January 1982 Santa Monica Bay ichthyoplankton samples. Most larvae were less than three weeks old.

2. Gut contents of the field-collected Clinids indicate that crustaceans, primarily copepod stages, are the principal food items. Diatoms, dinoflagellates, rotifers, tintinnid protozoans and mollusk larvae were also found in significant numbers. Gut contents of field-collected larvae contained more smaller-sized food items than laboratory-reared larvae.

3. Efficiency of capturnig larger prey items increases with growth in Clinid larvae.

LITERATURE CITED

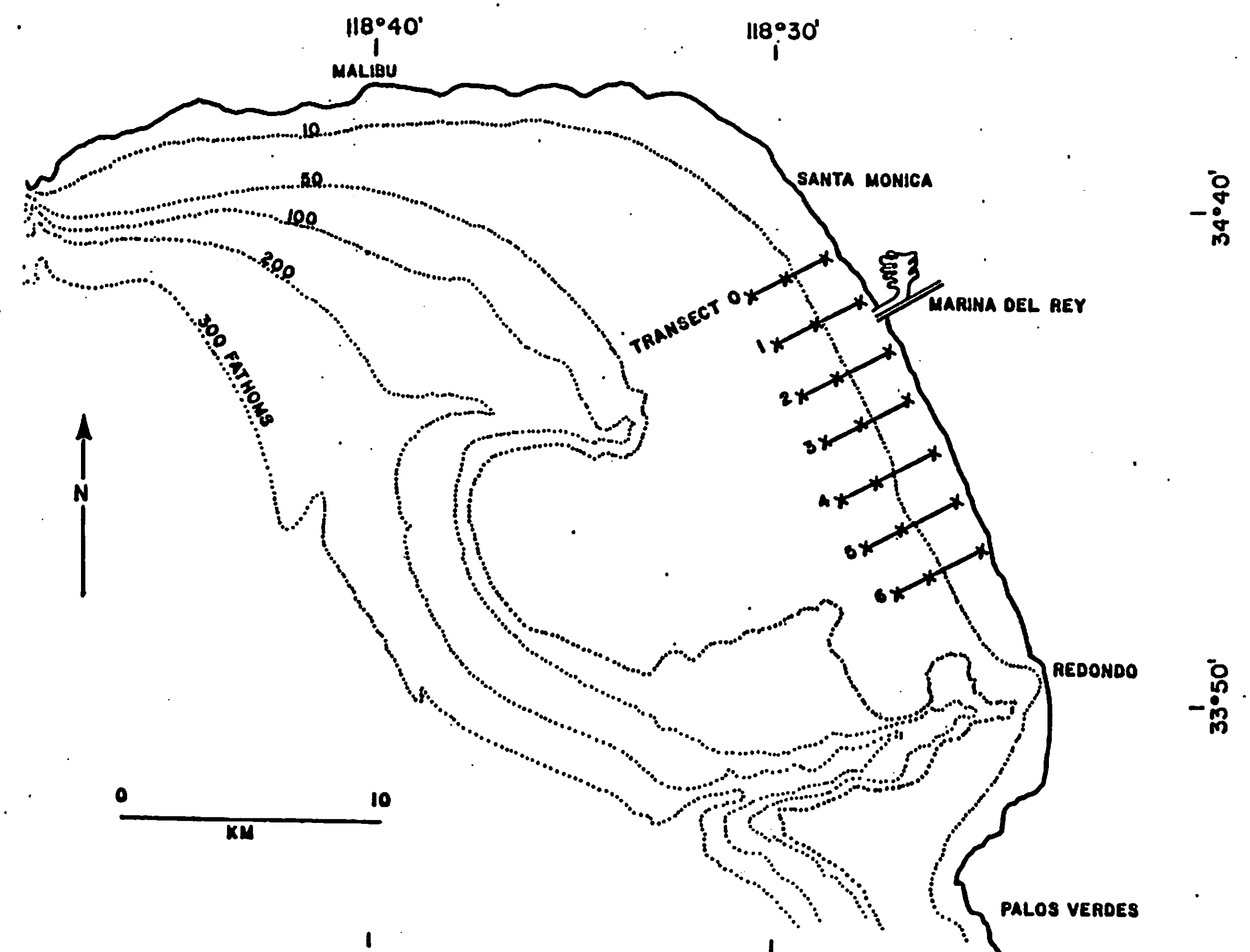
Hunter, J.R. 1981. Feeding Ecology and Predation of Marine Fish Larvae, pp. 33-77. In Marine Fish Larvae: Morphology, Ecology, and Relation to Fisheries (ed. R. Lasker), University of Washington Press, Seattle.

Miller, D.J., and R.N. Lea. 1972. Guide to the Coastal Marine Fishes of California. California Fish. Bull. 157:173-176.

Sherman, K., R. Mauer, R. Byron and J. Green. 1981. Relationship Between Larval Fish Communities and Zooplankton Prey Species in an Offshore Spawning Ground, pp. 298-294. In The Early Life History of Fish: Recent Studies (ed. R. Lasker and K. Sherman), Northwest Atlantic Fisheries Organization, Dartmouth, Canada.

Springer, V.G. 1970. The Western South Atlantic Clinid Fish Ribeiroclinus eigenmanni, with Discussion of the Intrarelationships and Zoogeography of the Clinidae. Capeia 1970: 430-436.

Ware, D.M., B.R. de Mendiola and D.S. Newhorse. 1981. Behaviour of First-feeding Peruvian Anchoveta Larvae, Engrualis ringens, pp. 467-474. In the Early Life History of Fish: Recent Studies (ed. R. Lasker and K. Sherman), Northwest Atlantic Fisheries Organization, Dartmouth. Canada.



TRANSECTS IN SANTA MONICA BAY SAMPLED DURING JANUARY 1982 CRUISE

Figure 1.

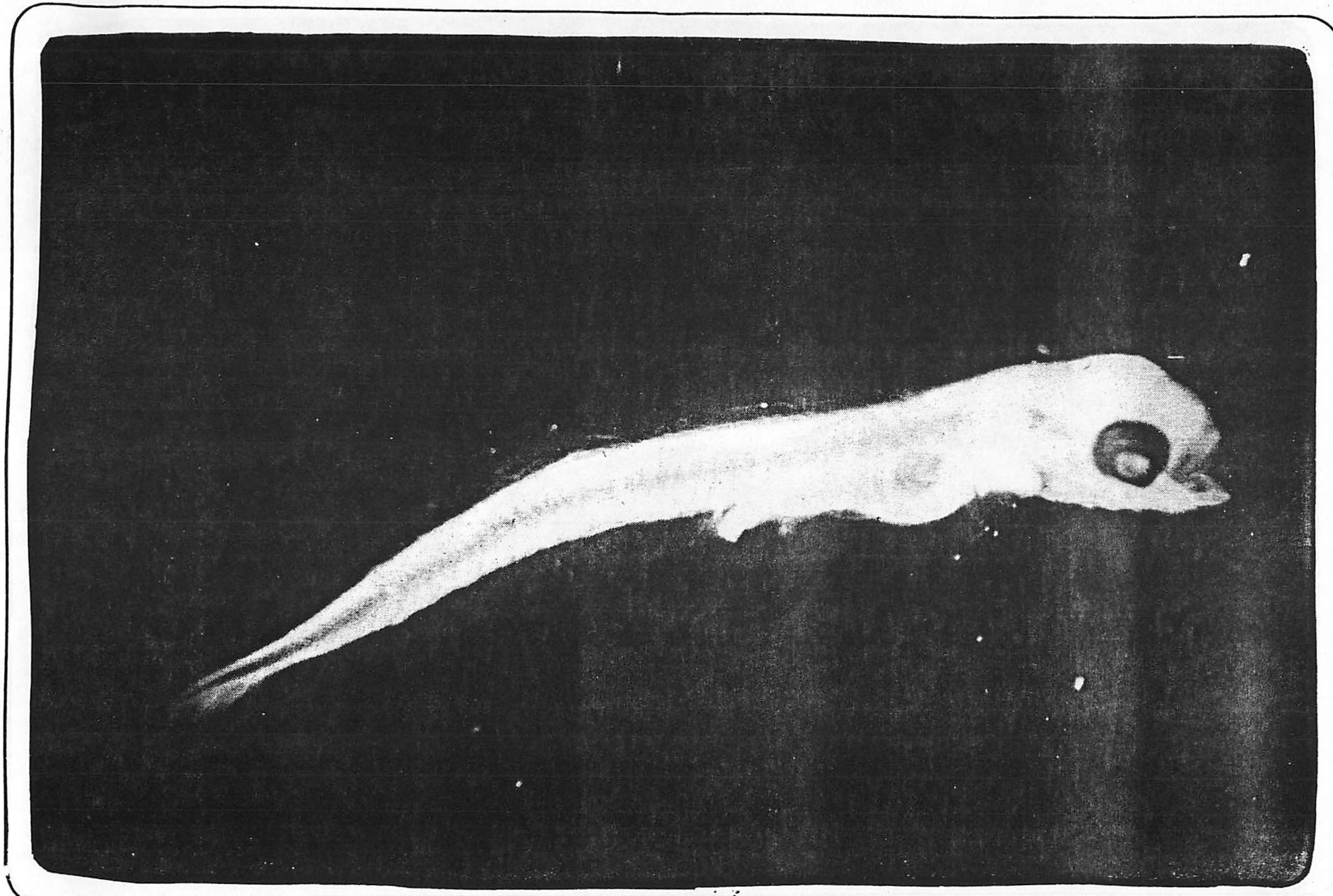


Figure 2. TYPE A CLINID LARVA. Total Length = 5.65 mm. 25 X.

Figure 3. TYPE D CLINID LARVA. Total Length = 3.08 mm. 25 X.

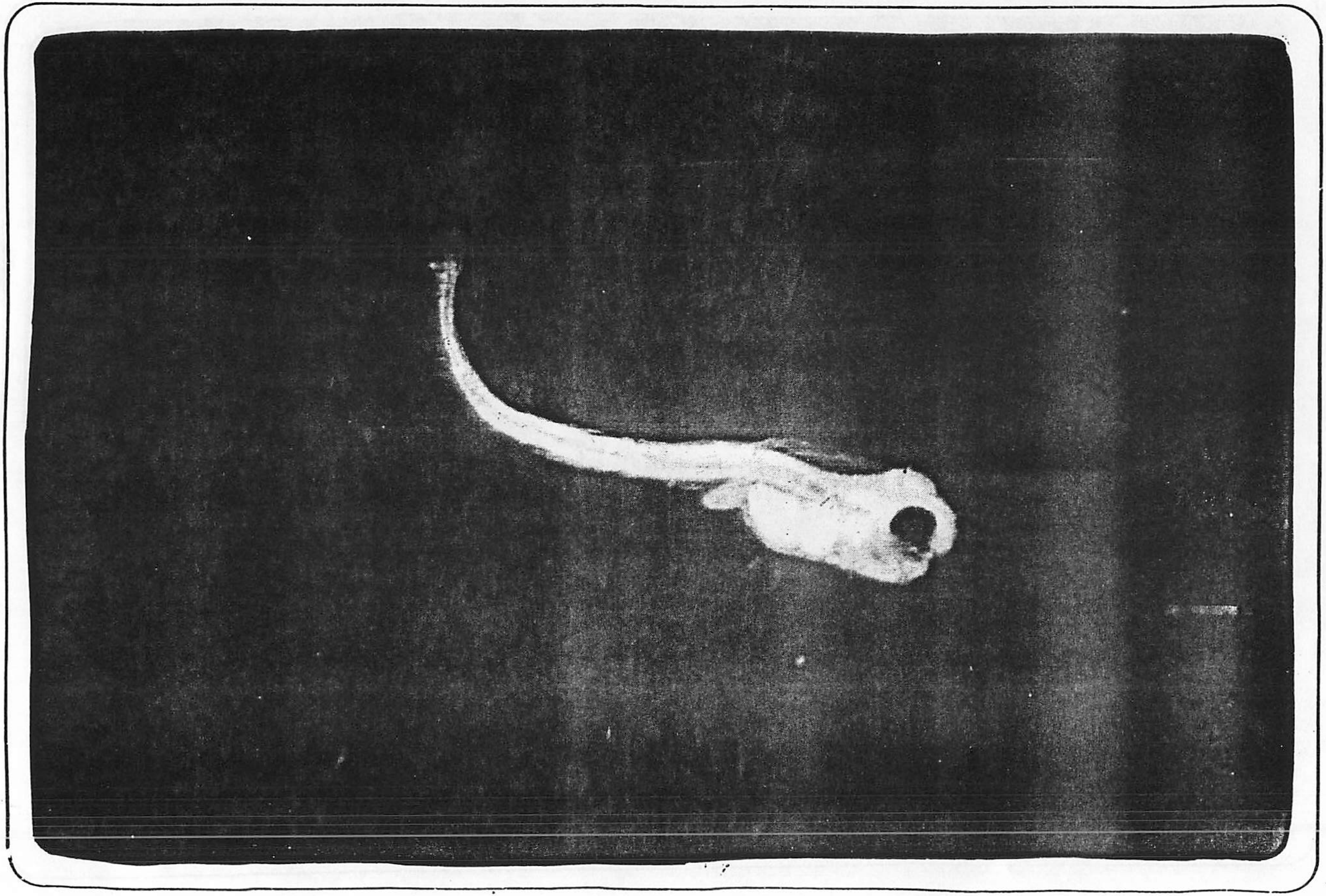
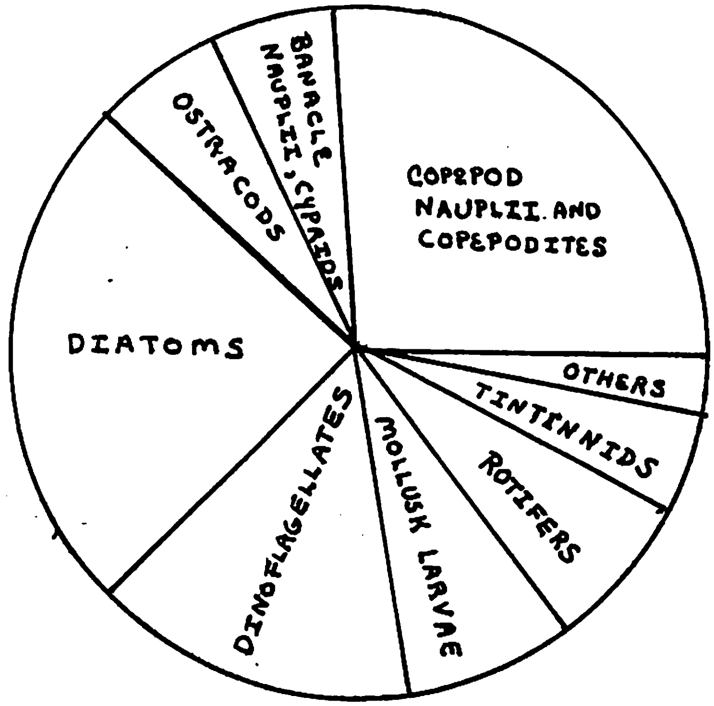
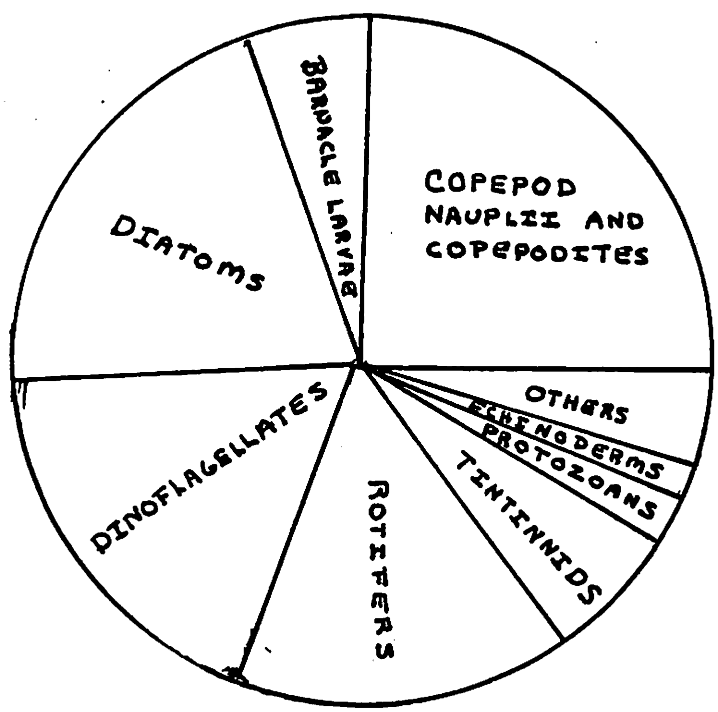


Figure 4.

MAJOR FOOD ITEMS (DAY)



Gut contents of Heterostichus rostratus larvae collected during Jan. 1982 cruise. N=4.



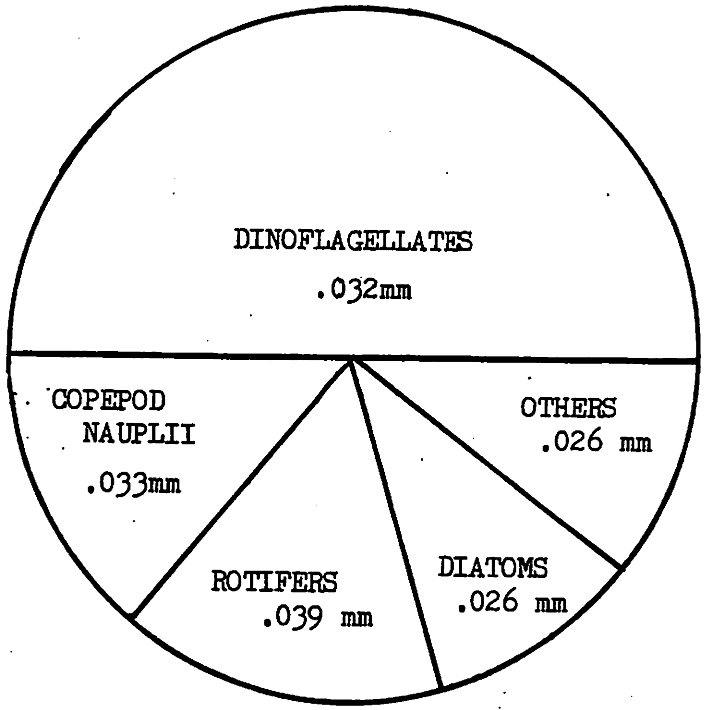
Gut contents of Type A (probably Gibbonsia sp.) larvae collected during Jan. 1982 cruise. N=10.

FIGURE 5.

MAJOR FOOD ITEMS OF TYPE D LARVAE

From Santa Monica Bay, Jan. 1982

With Mean Widths of Food



N=2, Mean Total Length= 4.49 mm.
Mean Mouth Width = .16 mm.
Largest food particle = .039 mm wide = 24% of mouth width.

Figure 6. Heterostichus rostratus egg, Day 13 (20 hours before hatching). Diameter = 1.3 mm.

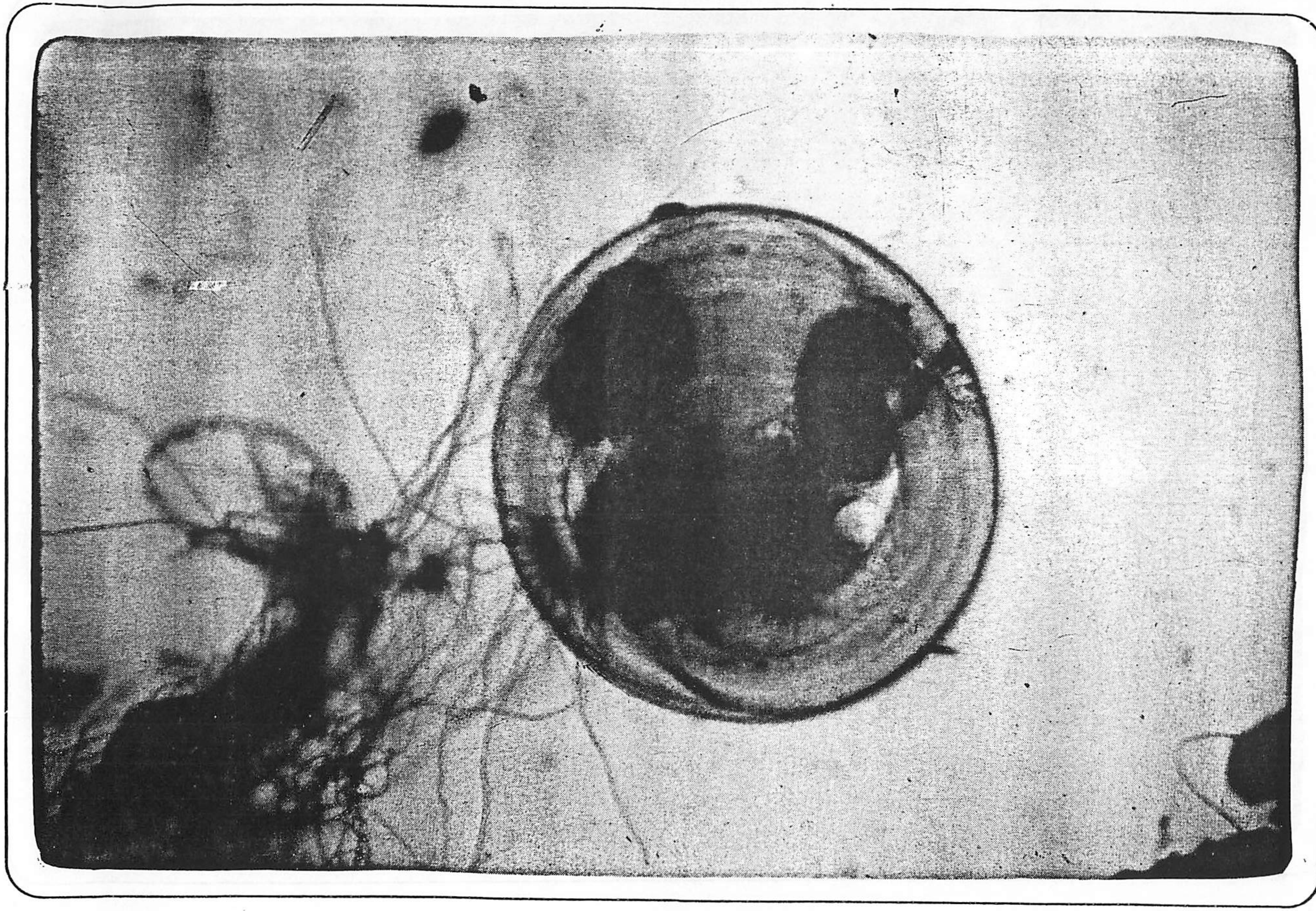
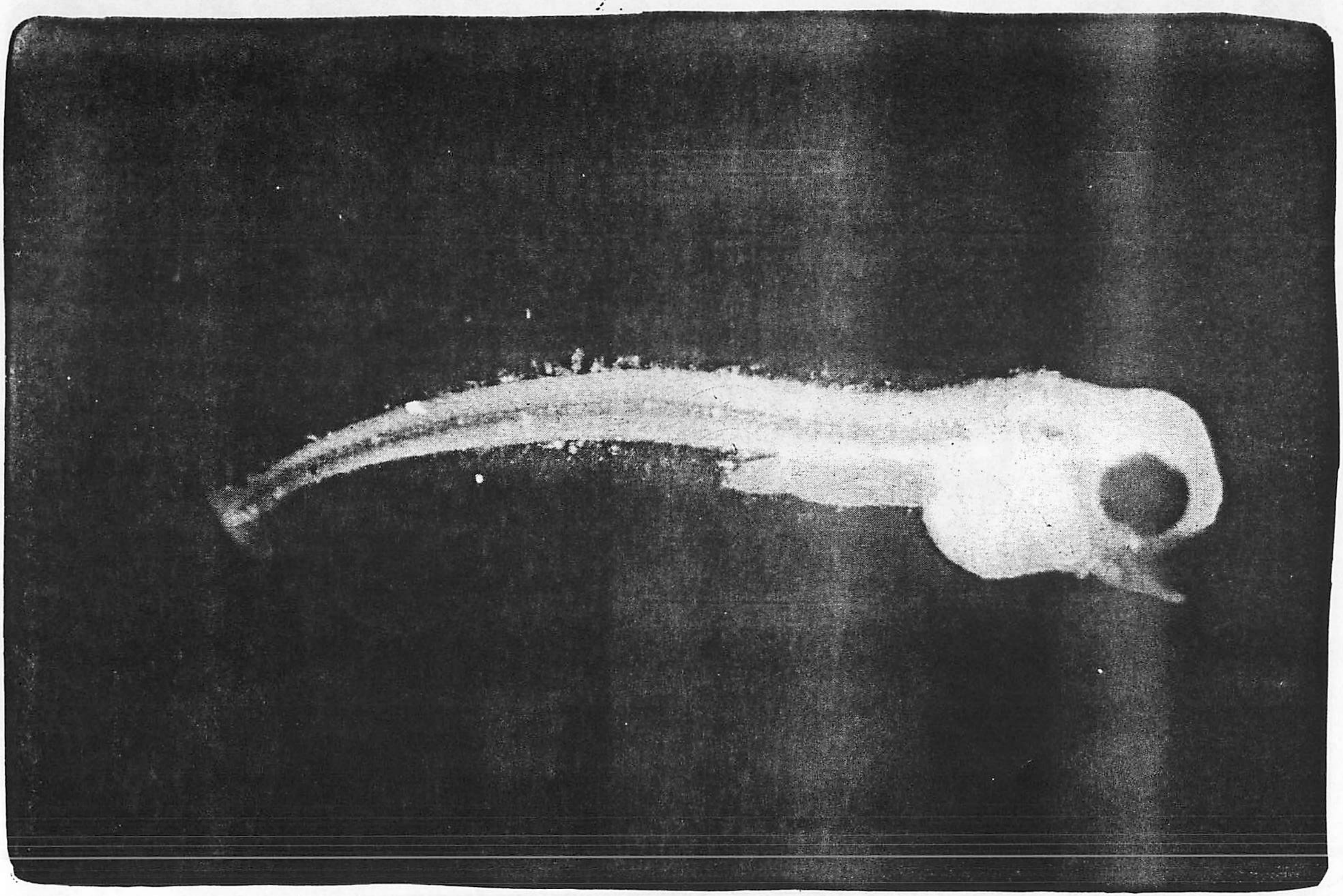


Figure 3. <u>Heterostichus</u> <u>rostratus</u> larva with yolk sac, 1 hour after hatching. Total length = 5.22 mm.



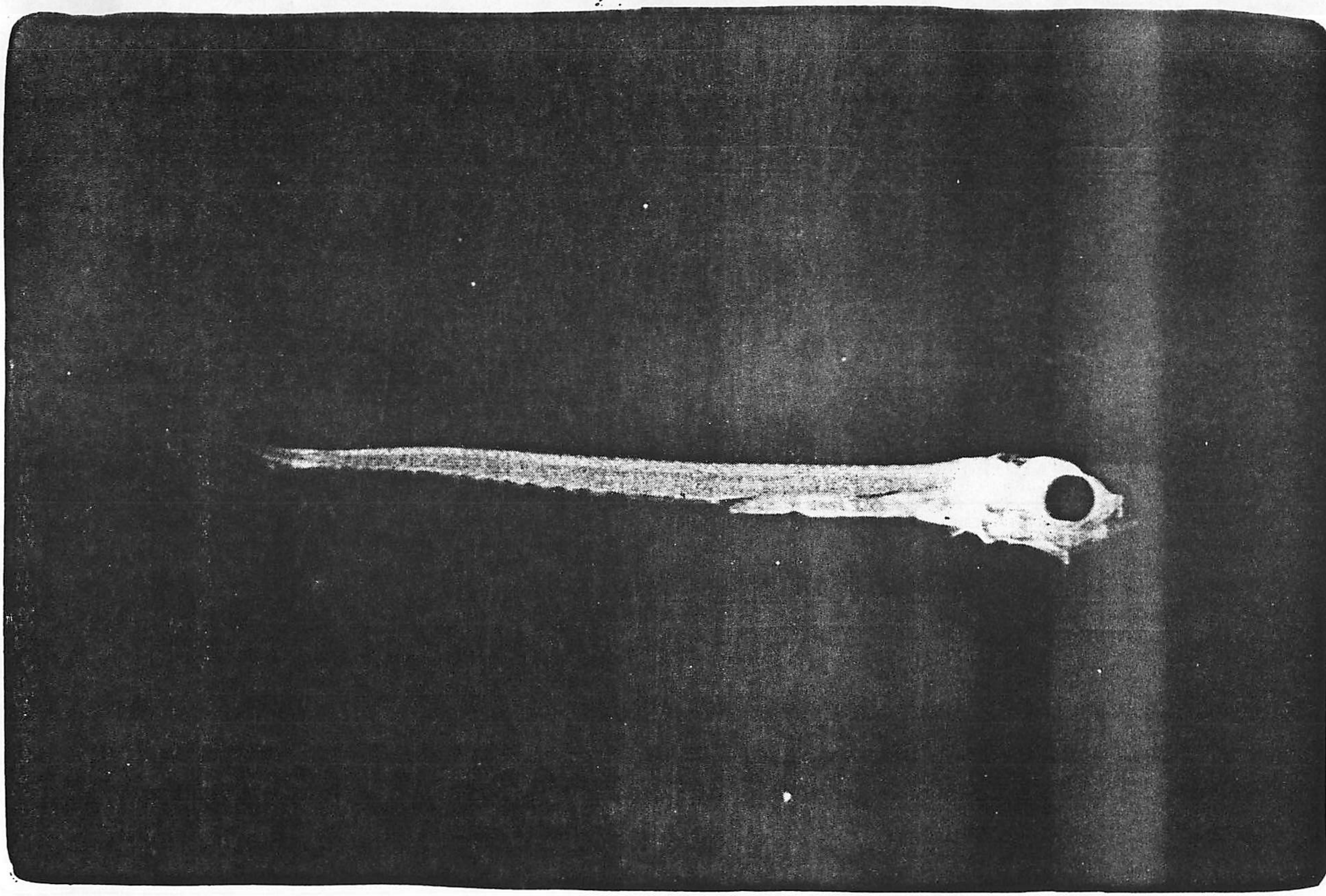


Figure 8. <u>Heterostichus rostratus</u> larva, 1 week old. Total length = 8.1mm.

Figure 9. Heterostichus rostratus larva, 4 weeks old. Total length = 11.7 mm.

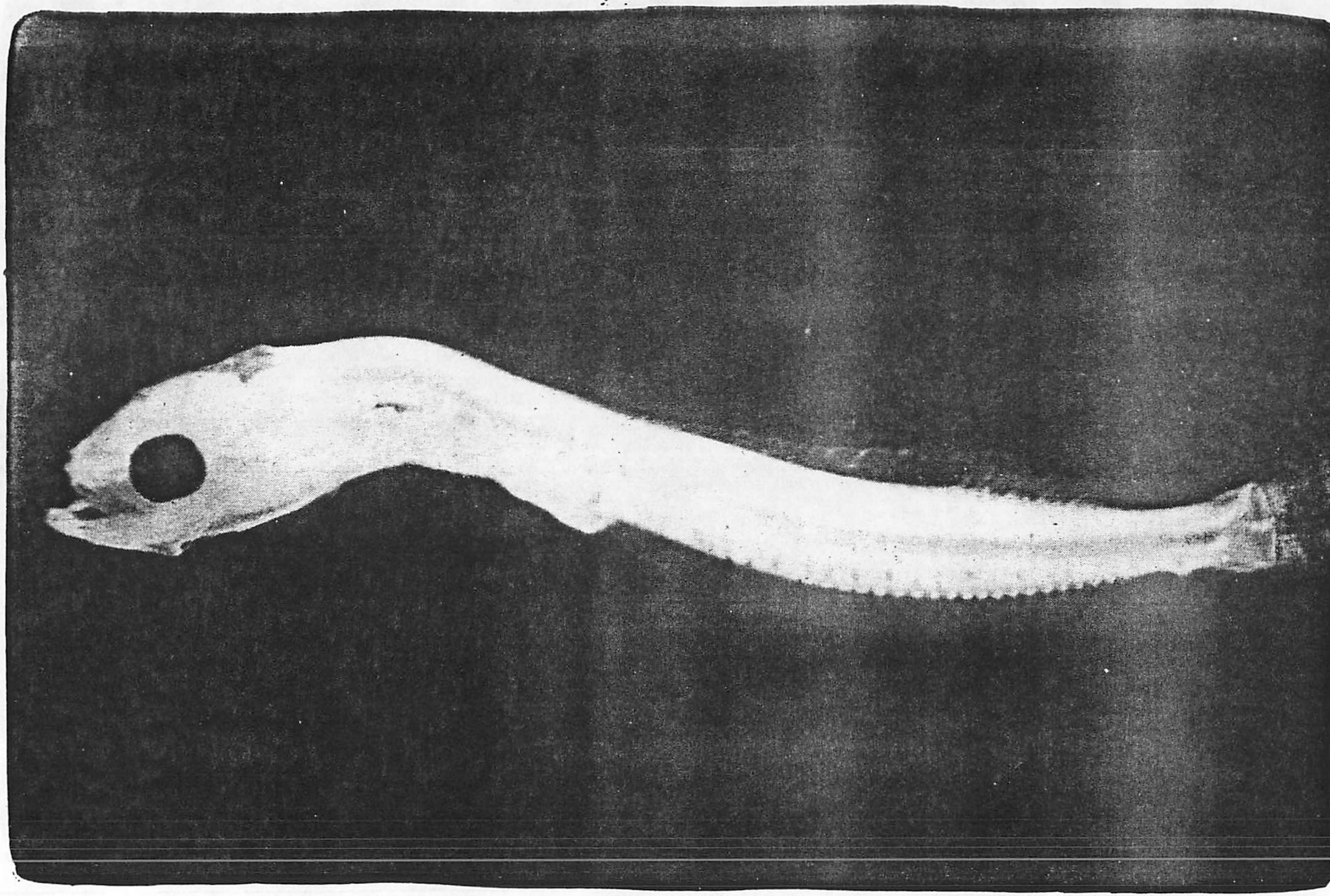


Figure 10.

GROWTH OF LABORATORY-REARED HETEROSTICHUS LARVAE

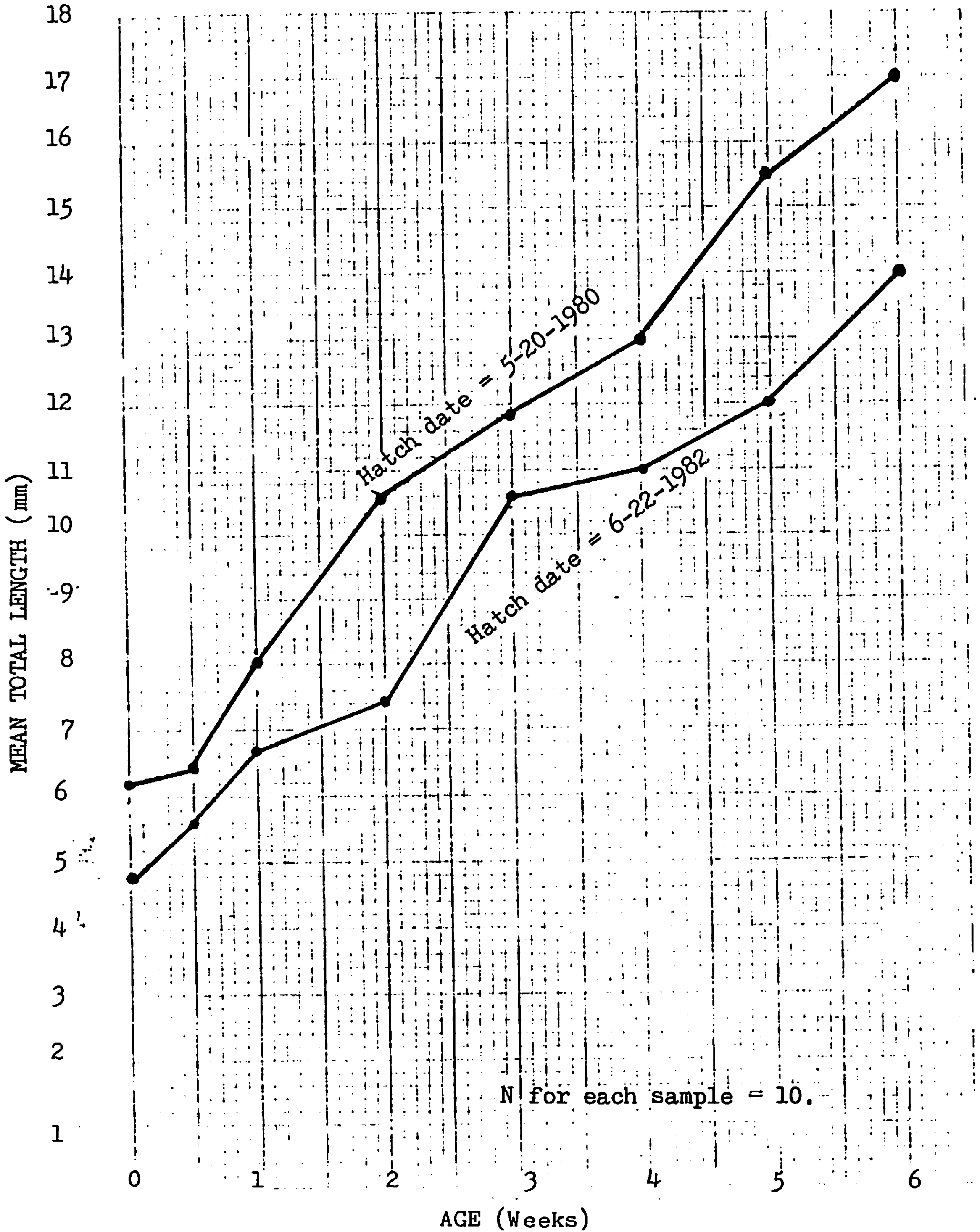


Figure 11.

MOUTH WIDTH AND MAXIMUM PREY WIDTH
IN LABORATORY-REARED KELPFISH LARVAE

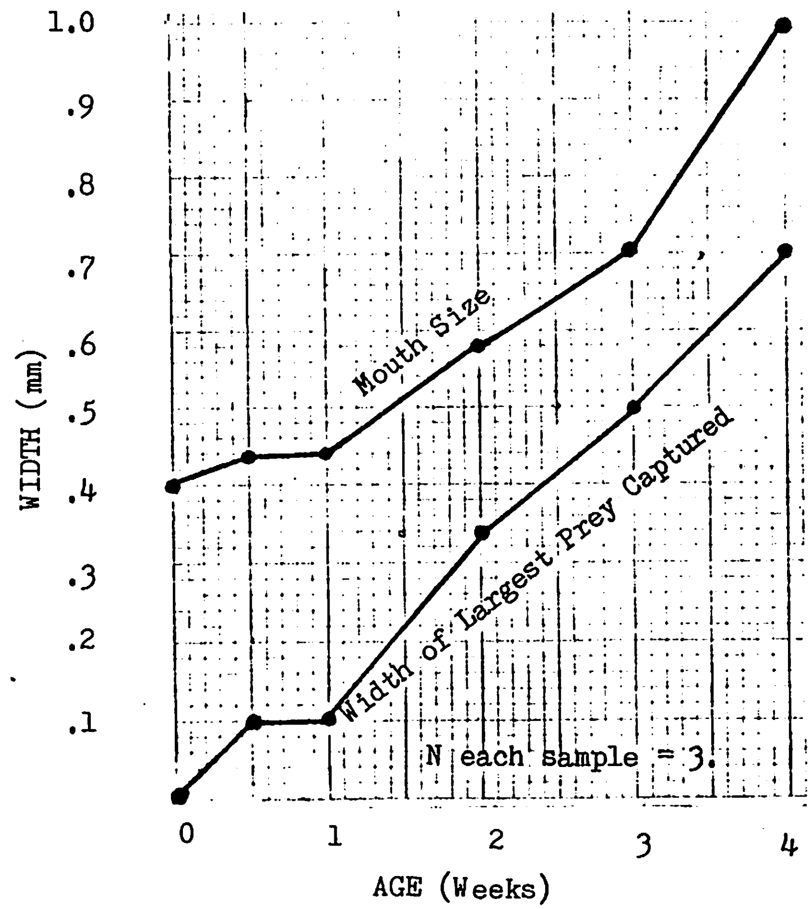


Table 1. CHARACTERISTICS OF JAN. 1982 CRUISE CLINIDS

	Clinid Type	Probable Classification	Percent of Total Clinids Collected	Distribution	Number Vertebrae	Melanophore Pattern
1.	Type A	*Gibbonsia* sp. (possibly *G. elegans*)	46.5%	Most collected on surface during day. Few during night.	49 (47-50)	7-14 post-anal ventral/ over swimbladder/ anal area/ small spots on liver/
2.	*Heterostichus rostratus*		9.3%	Most caught near bottom during day.	57 (56-58)	16-30 post-anal ventral/ over swimbladder/ anal area/ pelvic fin region/
3.	Type B	*Gibbonsia* sp. (possibly *G. metzi*)	14.0%	Caught during night near bottom	52 (51-53)	20-27 post-anal ventral/ spot under head/
4.	Type C	(Possibly *Paraclinus integripinnis*)	30.2%	Caught at surface during day and near bottom at night.	40 (36-42)	19-20 post-anal ventral/ over swimbladder/ dark line over gut/

	Total Length	Mouth Width	Ratio MW/TL	Gut Length
1.	6.26 mm (5.12-8.25)	.40 mm (.28-.56)	.06	1.43 mm (1.08-1.84)
2.	6.77 (6.24-8.82)	.42 (.40-.44)	.06	1.76 (1.44-2.05)
3.	12.90 (5.76-18.54)	.78 (.38-1.26)	.06	2.58 (1.36-4.00)
4.	2.70 (2.60-4.49)	.19 (.16-.28)	.07	.90 (.52-1.17)

MAJOR FOOD ITEMS OF JAN. 1982 CLINID LARVAE

Food Item	Mean Number per Type A Larva	Mean Number per *Heterostichus* Larva	Mean and Range of Prey Width	Mean and Range of Prey Length
Copepod nauplii and copepodites	2.90	3.50	.12 mm (.07-.21)	.40 mm (.14-.46)
Barnacle nauplii and cyprids	.70	.75	.10 (.07-.13)	.16 (.12-.23)
Ostracods	----	.75	.12 (.10-.13)	.26 (.16-.35)
Diatoms	2.40	3.00	.03 (.01-.07)	.06 (.04-.08)
Dinoglagellates	2.20	2.00	.03 (.01-.07)	.04 (.02-.20)
Rotifers	1.80	.75	.08 (.03-.13)	.19 (.08-.35)
Tintinnid protozoans	.70	.75	.04 (.03-.07)	.13 (.10-.16)
Mollusk larvae	.20	1.00	.11 (.09-.12)	.25 (.22-.29)
Echinoderm larvae	.20	----	.06 (.06-.07)	.09 (.08-.09)
Ciliate protozoans	.30	----	.02 ----	.06 ----
Nemertean worms	----	.25	.10 ----	.34 ----
Radiolarians	.10	----	.01 ----	.01 ----
Siphonophores	.00	.25	.29 ----	.30 ----

Type A Larvae (*Gibbonsia* sp.) N=10, mean total length= 6.04 mm (5.12-7.20), mean mouth width= .43 mm (.36-.48).
Heterostichus rostratus Larvae N=4, mean total length=6.93 mm (6.24-8.82), mean mouth width= .42 mm (.40-.44).

Table 2.

Table 3.

GUT CONTENTS OF LABORATORY-REARED HETEROSTICHUS LARVAE

Mean Number and Size of Prey Items

Age of Larvae	Tetraselmas Algae		Brachionus Rotifers		Copepod Crustaceans	
	No.	Size (mm)(WxL)	No.	Size (mm)(WxL)	No.	Size (mm)(WxL)
3 day-old	2.9	(.039 x .120)	5.6	(.100 x .149)	---	--------------
1 week-old	3.3	(.050 x .120)	14.7	(.103 x .157)	---	--------------
2 week-old	10.0	(.078 x .130)	10.2	(.160 x .220)	1.2	(.100 x .390)
3 week-old	----	-------------	6.8	(.130 x .195)	2.4	(.221 x .520)
4 week-old	----	-------------	.6	(.102 x .150)	3.3	(.221 x .520)
5 week-old	---	-------------	--	-------------	7.9	(.220 x .850)

N= 3 for each sample.
Laboratory Diets = Tetraselmas and Brachionus 0-3 weeks.
Wild Plankton Copepods 2-5 weeks.