CYCLING OF XENOBIOTICS THROUGH MARINE AND ESTUARINE SEDIMENTS

Extracted from cited papers by

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ACKNOWLEDGMENT

The cooperation and help of the staff at the Gulf Breeze Environmental Research Laboratory is gratefully acknowledged. Facilities in which experiments were completed were made available to the University of West Florida through the kind assistance of the Laboratory Director, Dr. Thomas W. Duke, and the Project Officer, Dr. Frank G. Wilkes.

FIGURES

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is monitored by two pairs of photo-transistors and infrared light emitting diodes.

28. An example of an activity graph indicating time in light beams (0.33 sec/h) during each hour of the 6-day test. On days 3 and 4 shrimp were exposed to 2.0 ppb methyl parathion and carrier. Light and dark bars indicate photo-period.

29. Mean increase in length by cultured Arenicola cristata during spring and early summer; 95% confidence belts are indicated.

ABSTRACT

The results of five broadly defined projects are reported.

Cycling of xenobiotics was studied with a photo-bioassay system, which used time-lapse photography to evaluate effects of Kepone and sodium pentachlorophenate on feeding activity of the lugworm, Arenicola cristata. Radio-labeled methyl parathion was used to demonstrate fate and effect in microcosms inhabited by lugworms. Uptake and depuration of chrysene by lugworms was evaluated in a flow-through system.

A toxic sediment bioassay system was developed to provide a means to test effect of dredge spoil. The system included microcosms that held mysid shrimp, Mysidopsis bahia; oysters, Crassostrea virginica; and lugworms, Arenicola cristata. Effect was tested by using survival of mysids, shell deposition and bioaccumulation by oysters, substrate reworking and bioaccumulation by lugworms, and settlement of zooplankton as criteria. Kepone-sorbed sediment and dredge spoil from James River and Houston Ship Channel were tested for 28 days. Long term tests (100 days), with the same systems, were used to evaluate effect of a specific drilling mud from an active exploratory platform.

Predator-prey tests of sublethal effects of xenobiotics demonstrated effect in one prey and two prey systems. The effects of methyl parathion on predator-prey relationships between grass shrimp, Palaemonestes pugio; juvenile sheepshead minnows, Cyprinodon variegatus; and gulf killifish, Fundulus grandis were demonstrated. The relationship between Palaemonetes pugio and pinfish, Lagodon rhomboides was also demonstrated. A method that could be used to evaluate effect of xenobiotics on predator-prey relationships between cryptically shaded flounder and pinfish prey was developed.

Evaluation of sublethal effects, such as avoidance of pollution gradients was studied in a trough-type avoidance response system. The system was developed

to be independent of an observer. It was tested with pinfish to demonstrate that they will avoid chlorine-produced oxidants. The system was modified to demonstrate toxicant induced changes in cyclic burrowing activity by pink shrimp, Penaeus duorarum, exposed to methyl parathion.

Usefulness of small scale microcosms was evaluated by developing methods to culture polychates and crustaceans. Various aspects of the biology of selected species were studied.

INTRODUCTION

Five broadly defined projects were included in the project goals of Grant R804458, "Cycling of Xenobiotics through Marine and Estuarine Sediments." Two addressed primary goals that were:

(1) to evaluate cycling of selected xenobiotics or uptake and effect of selected energy related compounds in experimental systems that included the lugworm, Arenicola cristata; and

(2) to develop a toxic sediment assay system involving the lugworm and other species.

The remaining projects were directed toward developing methods to provide more realistic evaluators, other than acute and chronic toxicity tests, for a xenobiotic's fate and effect in estuarine and marine ecosystems. Specifically these were:

(1) development of tests involving estuarine and marine crustaceans and fishes designed to evaluate how exposure to xenobiotics can alter predator-prey relationships

(2) development and testing of behavioral assays that would provide reliable means to evaluate sublethal effects such as avoidance; and

(3) establishment of small scale microcosms that could be used to test fate and effect.

Although the five broadly defined projects are divergent, commonalities included either use of systems dominated by lugworms or evaluation of sublethal effects in small scale microcosms.

CYCLING OF XENOBIOTICS BY THE LUGWORM, ARENICOLA CRISTATA

The impetus to design an assay system involving a lugworm resulted from development of culture methods for that species and recognition that toxicity tests employed by EPA for estuarine and marine species do not include an infaunal organism.

BETHIC PHOTO-BIOASSAY SYSTEM

The first test to include an infaunal representative was Rubinstein's (1979) benthic bioassay which uses time-lapse photography to measure effect of toxicants on feeding behavior of lugworms (Fig. 1). That organism is ideal for this type of test because it is widely distributed in littoral habitats and has major ecological impace due to its ability to recycle sediment and transport xenobiotics into the substrate. The photo-bioassay system was constructed based on the lugworm's habit of creating feeding funnels on the surface of sediment it occupies. Under normal circumstances, active worms, unperturbed by xenobiotics in the water column or sorbed on the sediment, create enlarge, and recreate obvious funnels. This pattern on the surface of the substrate, which indicates activity of the worm, was monitored by Rubinstein with time-lapse photographs taken at 12-hour intervals for 72 hours. Areas of feeding funnels in exposed and control aquaria calculated and compared initial trials demonstrated that there was no significant difference in reworking activity between replicates under control conditions (Fig. 2). As worms were influenced by xenobiotics, their activity, when compared to controls kept under the same environmental conditions, decreased. For these experiments the xenobiotic tested was Kepone at measured concentrations of 2.8, 4.5, 6.6, 7.4, and 29.5 ug/l.

Results indicated that A. cristata was sensitive to Kepone at all concentrations tested (Fig. 3). The highest concentration was acutely toxic. Lugworms appeared to be more sensitive to Kepone than many other species normally used in toxicity tests. It appeared that in Kepone effected habitats the ability of lugowrms to reqork sediment would be markedly decreased.

CYCLING OF METHYL PARATHION BY LUGWORMS

A second evaluation of cycling of xenobiotics by lugworms (Garnas, et al. 1977) was directed toward determing compartmentation and degradation dynamics of methyl parathion in a small scale microcosm occupied only by the wor, and microorganisms associated with the organic material on which it feeds. Ninety percent of radio-

labelled methyl parathion disappeared from the water column in aquaria after 14 days. Movement into the sediment proved to be the major compartmentation phenonomon, with over half of the total radioactivity residing in the sediment after two weeks. The lugworm inhanced movement of radioactivity into the sediment and caused dispersion throughout the sediment. While volatilization losses were negligible, steadily decreasing mass balance of radioactivity in the system suggested accumulation of unextractable residues in the sediment. Analysis of extractable radioactivity in the sediment and water compartments by thin layer chromotography and autoradiography demonstrated rapid degradation of methyl parathion into a number of more polar products, including P-nitrophenol and amino-methyl parathion. While A. cristata was shown to metabolize methyl parathion readily to P-nitrophenol, microbial activity accounted for the majority of biological degradation in the system.

EFFECT OF SODIUM PENTACHLOROPHENATE ON LUGWORM ACTIVITY

The third analysis of effect of xenobiotics on activities of the lugworm was Rubinstein's (1978) evaluation of effect of sodium pentachlorophenate on feeding activity. Na-PCP was used because it is an energy related compound (oil well drilling fluids) and because it enters estuarine and marine systems occupied by lugworms from numerous non-point sources. Photo-bioassay methods developed by Rubinstein (Fig. 1) were used in this study. Stock solutions of Na-PCP were prepared from a commercial bactericide and introduced into experimental aquaria at 45, 80, 156, and 276 ug/l. Comparisons were made between the areas of feeding funnels in exposed and control aquaria. Na-PCP had no marked effect on Feeding activity at the lowest concentration tested; however, at the other concentrations there was significant decrease in activity (Fig. 4). Some mortality occurred at the higher concentration.

UPTAKE AND DEPURATION OF CHRYSENE BY LUGWORMS

The final analysis of cycling of xenobiotics by lugworms evaluated uptake 1980a and depuration of chrysene, another energy related compound (Rubinstein et al. 1980a).

Worms were exposed to chrysene at measured concentrations of 0.07, 0.69, and 2.76 ug/l in large wooden tanks in an open system that simulated ambient conditions and the natural habitat (Fig. 5). After 14 days, exposed worms were moved to uncontaminated systems and allowed to depurate for 14 days (considerable mortality was encountered due to handling in cold weather.) From lowest to highest exposure, lugworms accumulated 65, 516, and 682 ug/l in 14 days (Fig. 6). There was a continued increase in accumulation during that period so it is probable that had exposure time been increased, higher levels of chrysene would have been encountered before equilibrium was reached. Little depuration was observed. This suggested that lugworms do not have the ability to degrade chrysene; thus there is a good possibility that they have the potential to introduce chrysene in various food chains utilized by man.

TOXIC SEDIMENT BIOASSAY SYSTEM

Many xenobiotics in marine environments have a high affinity for particulate material (especially organics) and thus become sequestered in bottom sediments. Due to increased dredging and maintenance of navigable water there is a greater need to evaluate impact of toxic sediments on the biota. For that reason, grant related activities were directed toward developing a flow-through toxicity test that could be used to determine biological effects of contaminated sediments on representative estuarine organisms and to evaluate resiliency of benthic communities exposed to contaminated sediments. The test developed (Rubinstein et al. 1980b) incorporated several established toxicity tests that were modified to examine acute and sublethal effects of dredged sediments on the biota. It was designed to serve as a screening tool to detect potential hazards of dredge spoils prior to disposal in the marine environment.

METHODS DEVELOPMENT WITH KEPONE-SORBED SEDIMENT

The approach was to simulate and then compare certain aspects of the marine environment before and after deposition of spoil material. Small scale estuarine microcosms were assembled in 10-gallon aqauria receiving flowing, unfiltered

seawater. Three aquaria received different concentrations of test sediments, while three others remained unperturbed and served as controls. Comparisons were made after 28 days. Organisms included in the test are representative of three environmental compartments affected by dredging activities. Included were mysid shrimp, Mysidopsis bahia; oysters, Crassostrea virginica; and lugworms, Arenicola cristata. Test criteria used to identify effect were: (1) survival of mysids; (2) shell deposition and bioaccumulation of known contaminants by oysters; (3) substrate reworking and bioaccumulation by lugworms; and (4) resiliency of the benthic community in terms of numbers and variety of macrofaunal organisms that settled onto test sediments as planktonic larve within 28 days.

The exposure system employed is shown in Figure 7. Sediments exposed to Kepone at 0.1, 1.0, and 10.0 ug/l were used during evaluation of the method. This was followed by tests with actual dredge spoil material from the James River and Houston Ship Channel.

Effect of Kepone-sorbed sediment and mysid survival was time and dose dependent (Fig. 8). Oyster shell growth was significantly inhibited (Fig. 9). Lugworms had an increasing dose-dependent relationship in concentration of Kepone. Whole-body residues were 0.043, 0.46, and 1.1 ug/l 19 macrofaunal species were found (Fig. 10). In terms of test criteria, only polychaetes were effected at the highest exposure.

TESTS WITH DREDGE SPOIL

James River sediment did not affect mysids significantly although there was some effect on oysters (Fig. 11). Lugworm substrate reworking was reduced in experimental aquaria. Oysters and lugworms concentrated Kepone (Fig. 12). Little difference was seen in survival of recruited larvae perhaps because few larvae entered the system during the winter when it was operational.

Houston Ship Channel sediment did not significantly affect mysid survival or oyster shell deposition; nor did lugworm activity or macrofaunal composition

vary significantly between control and experimental units.

TESTS WITH DRILLING MUDS

Since the toxic sediment assay system was proven to be effective, a long term (100 day) toxicity test was conducted to determine effect of a specific drilling mud (Rubinstein et al. 1980c). Drilling muds were obtained weekly from an active exploratory platform and tested within one week of collection in the system, previously described (Fig. 7). Three dilutions were tested: 10, 30, and 100 ml/l by volume. These concentrations represented those expected at intervals of several meters to several hundred meters from a point source. Mud was added to test aquaria to simulate periodic discharge. The same species previously employed were included in this test, but mysids were exposed only 10 days.

Mysids exposed in the system were not acutely affected (Fig. 12). Oyster shell growth was significantly inhibited at concentrations of 30 and 100 ml/l (Fig. 14 & 15), but there was no mortality. Lugworms were severly effected by exposure to the mud (Fig. 16). Mortalities observed were 75% at 100 ml/l, 64% at 30 ml/l, and 33% at 10 ml/l. Twenty recruited species were present after 100 days (Fig. 17). There was no significant difference between populations in the aquaria. Ba, Cr, and Pb were found to have accumulated significantly in oyster tissue (Fig. 18).

The results indicate that physical as well as chemical properties must be considered before environmental impact of drilling fluids can adequately be assessed. It was also recognized that composition of drilling muds in highly variable; thus impact should be considered on a case by case basis.

PREDATOR-PREY TESTS

Sublethal concentrations of xenobiotics, expecially pesticides, may be expected to affect various aspects of behavior. This was demonstrated by Farr (1977) (partly funded by this grant) who demonstrated that methyl parathion impairs the ability of grass shrimp, Palamonetes pugio, to escape predation by

the gulf killifish, Fundulus grandis. Although F. grandis ate no more exposed than unexposed shrimp, the predators took less time to capture exposed prey. If pesticides have different effects on species in a multiprey systems, predators may be expected to consume a higher than normal proportion of affected species. The result would be more rapid accumulation of a xenobiotic.

TWO PREY SYSTEM

Palaemonetes pugio and juvenile sheepshead minnow, Cyprinodon variegatus were exposed to methyl parathion for 24 hours before introduction of Fundulus grandis, the predator (Farr 1978). Two experiments were run for five days: a preliminary experiment at 0.475 ug/l, and a definitive experiment which included a carrier control and methyl parathion concentrations of 0.024, 0.119, and 0.475 ug/l.

In the first experiment when the prey were exposed to the pesticide, gulf killifish consumed a greater proprotion of grass shrimp relative to sheepshead minnows (Fig. 19). Predation was also relatively greater on P. pugio than on C. variegatus as compared with controls (Fig. 20). The second experiment tested effect of a range of methyl parathion concentrations and of acetone (carrier) on prey consumption. In both control and acetone-control aquaria, the ratio of shrimp to fish increased rapidly during the test and did not differ, indicating strong predator preferences for sheepshead minnows and no acetone-related effect (Fig. 21). As the concentration of pesticide was increased in test aquaria, the ratio of grass shrimp to sheepshead minnows decreased with time (Fig. 22). Increasing the concentration resulted in increased consumption of grass shrimp relative to fish prey, an obvious example of how a pesticide can alter relative proportions of prey in a predator's diet.

EXPOSED AND CONTROL PREY IN THE SAME SYSTEM

Test systems were modified from the work of Farr (1978) and focused on the effect of xenobiotics on exposed and control prey in the same systems (cripe 1979) Equal numbers of pinfish, Lagodon rhomboides, and toxicant exposed and control

grass shrimp. Palaemonetes pugio, were placed in two replicate tanks containing removable dividers. Approximately 20 minutes after the dividers were removed, surviving shrimp were counted to determine differential predation between exposed and control prey. Prey were pleopod clipped for identification. Clipping was emonstrated to have no significant effect on predation.

Significantly fewer shrimp survived predation after exposure for 24 hours to 1.2 ppb methyl parathion. Exposure to 1.3 ppb Trithion for 24 and 72 hours produced to significant difference in predation.

CRYPTIC SHADING AND PREDATION

The behavior between a bothid flounder, Paralichthys albigutta, and its prey the pinfish, Lagodon rhomboides, can be exploited to evaluate how a xenobiotic could alter predatory strategy of flounder or avoidance response of pinfish. Before the relationship could be tested it was necessary to determine what the prey's normal response is to flounder exhibiting various degrees of cryptic coloration.

For these experiemtns, models of flounder prey were used (Ashton 1980). These were black and white photographs laminated between plastic and attached to a plastic outline of a flounder. A circular tank was used as the arena (Fig. 23). Ten prey were released from a central holding chamber and photographs were taken at 0.5, 1.0, and 1.5 minutes to record response to the flounder model. Ten trials were completed for control, dark model, and light model treatments. Position of the school of prey relative to the predator model was calculated. The group response for ten trials at each time interval was combined for each treatment group and random versus non-random distribution was tested.

Control data indicated that pinfish were randomly distributed in the absence of a model (Fig. 24). In the case of the light model that represented a cyptically shaded flounder there was no significant avoidance (Fig. 24). Pinfish swam directly over the model. In the case of the dark model, the pinfish preferred

the opposite side of the tank from the model (Fig. 24). Pinfish did not swim around the tank as they did in control and light model experiments.

This system is now ready to be tested to determine how sublethal exposure to xenobiotics can modify the antipredator response of the pinfish.

EVALUATION OF SUBLETHAL EFFECTS IN SPECIAL TEST SYSTEMS

AVOIDANCE OF POLLUTION GRADIENTS

It has often been observed that fish and invertebrates avoid pollution gradients. Most apparatus designed to detect avoidance of pollutants by aquatic organisms require visual observations of the test organisms in steep pollution gradients. The aquatic Gradient Avoidance Response System (AGARS) was developed to eliminate these limitations (Cripe, 1979a). This system (Fig. 25) allows animals to choose between one uncontaminated zone and three increasingly toxic zones in a gradient trough that is monitored for extended periods by infrared light sources, sensor, and a microprocessor. Data are accumulated hourly and processed by a paper tape reader/calculator/plotter system that records the time test animals remain in each zone and compares behavior before and during test exposures. Initial tests in AGARS indicated that pinfish, Lagodon rhomboides will avoid chlorine-produced oxidants at concentrations of 0.02-0.04mg/l (Fig. 26). The system is a prototype that can be enlarged by using more powerful lights and greater microprocessor memory capacity. In addition to several species of fish, baseline data have also been obtained with blue crabs, Callinectes sapidus, and penaeid shrimp. The system could also be used to test thermal or salinity preferences.

TOXICANT INDUCED CHANGES IN CYCLIC BURROWING PATTERNS

The pink shrimp, Penaeus duorarum, is a species that is very sensitive to xenobiotics. Since no life-cycle toxicity test exists for penaeid shrimp, the only criterion of effect that has been used for hazard assessment is death. Pink shrimp normally remain buried in substrate during the day and emerge at night. Stress from both lethal and sublethal pesticide exposures

disrupt this pattern and may result in the shrimp's continuous presence above the substrate. Such activity would increase predation and cycling of xenobiotics. To evaluate the effect of toxicant-induced disruptions in the cyclic burrowing pattern, an apparatus was constructed (Cripe 1979b) from a modified AGARS system. Two troughs were employed with sensors only in the upper level. Each trough was partially filled with sand and compartmentalized into four areas by plastic screen (Fig. 27). Shrimp were placed in each compartment on a 12L-12D cycle and monitored for six days. One trough was exposed to 2 ppb methyl parathion on days 3 and 4 of the test.

The results indicated variability in absolute activity level of a particular shrimp on different days as well as between shrimp. An activity index was calculated by dividing the mean of the hourly light beam interruptions for each dark period into the mean hourly counts for the succeeding light period. The index was lower for controls that exposed shrimp. On a daily basis there was significant difference in activity between days when toxicant was added and days when it was not (Fig. 28).

In conjunction with the development of trough systems a device to detect potentially dangerous electrical currents in saltwater holding tanks was developed (Cripe & Stokes 1978).

SMALL SCALE MICROCOSMS

The usefulness of microcosms in evaluating fate and effect of various xenobiotics is well documented. Several of tests developed under grant auspices were actually completed in laboratory microcosms. Bourquin et al. (1979) redescribed these as well as three other types. A part of the grant effort was directed toward evaluating various aspects of the biology of selected species that could be used in microcosms.

POLYCHAETES

Pond culture of lugworms (D'Asaro, in manuscript) was directly linked to development of techniques to use lugworms in small scale systems. The results

demonstrated rapid growth rates of lugworms over a 90-day period at densities of 60 or more worms per square meter when ground seagrass (Thalassia) was used as a food (Fig. 29). These data were used by Rubinstein (1979) to develop various toxicity tests in which lugworms were used as a primary component in the system.

White (1978) used microcosms to evaluate the impact of three predators (Neanthes succinea, Glycera americana, and Callinectes sapidus. The blue crab, C. sapidus was the most effective predator especially on juvenile lugworms that do not burrow deeply.

Lasfargues (1980) examined the role of bacteria as a food source for lugworms in microcosms. Lugworms were allowed to consume composted seagrass; then comparisons were made between biomass of bacteria and yeast in the grass and feces. There was a significant reduction in the population of bacteria but not in the population of yeast in the feces. There was also evidence of selective digestion of bacteria. A gram negative bacterium, isolated from composted seagrass, was cultured and used to enrich compost fed to worms. The enrichment caused a significant increase in growth.

Redig (1980) examined culture methods that could be used to rear Polydora ligni, a species that can be easily included in microcosms.

ISOPODS

Ligia exotica is a semiterrestrial isopod restricted to the immediate supralittoral zone, an area often heavily impacted by oil spills. Orientation and social behavior in L. exotica was evaluated by Farr (1978). The tendancy of L. exotica to aggregate and orient to enviornmental stimuli was examined in circular outdoor tanks or small aquaria.

In the circular tanks, experimental animals released in the center of the arena were allowed to aggregate for 24 hours under clay saucers placed around the periphery of the arena. The resulting aggregations were not random indicating that L. exotica actively seeks conspecifics. In tests in aquaria, L. exotica significantly selected shelters containing conspecifics or a shelter conditioned

by previous occupancy by a conspecific. Other experiments demonstrated that distribution of L. exotica appears to be influenced initially by raised landmarks on the shoreline. Observations on social behavior were also reported.

Levy (1980) described the breeding habits and brood pouch development of Erichsonella altenuata, an isopod ideal for microcosm studies because it is easy to culture in closed systems, and it is a representative of marine grassflat communities.

MYSIDS

Plaia (1980) described the complete embryogenesis and organogenesis of Mysidopsis bahia, a species presently used as a standard organism in toxicity tests.

ANOSTRACANS

Logue (1980) examined the effects of temperature and diet on growth of a freshwater anostracan, Streptocephalus seali. This species wer found to be easy to culture. It matures rapidly in two weeks thus it may be useful for life-cycle tests.

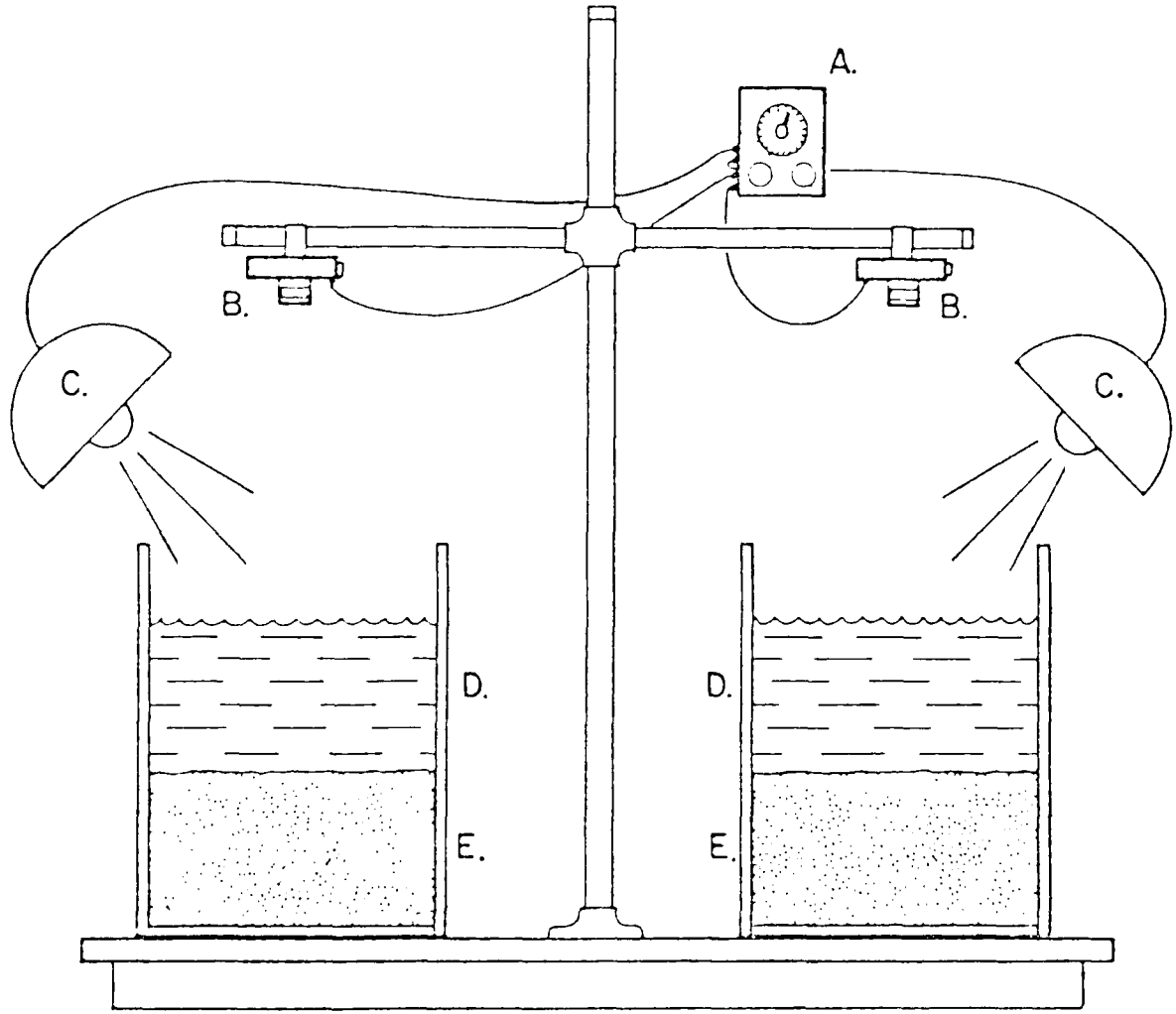


Fig. 1. Photo-Bioassay System (A - 24-hour timer; B - 35 mm camera with automatic advance; D, E - aquaria with 25 cm of sand and 75 l of seawater).

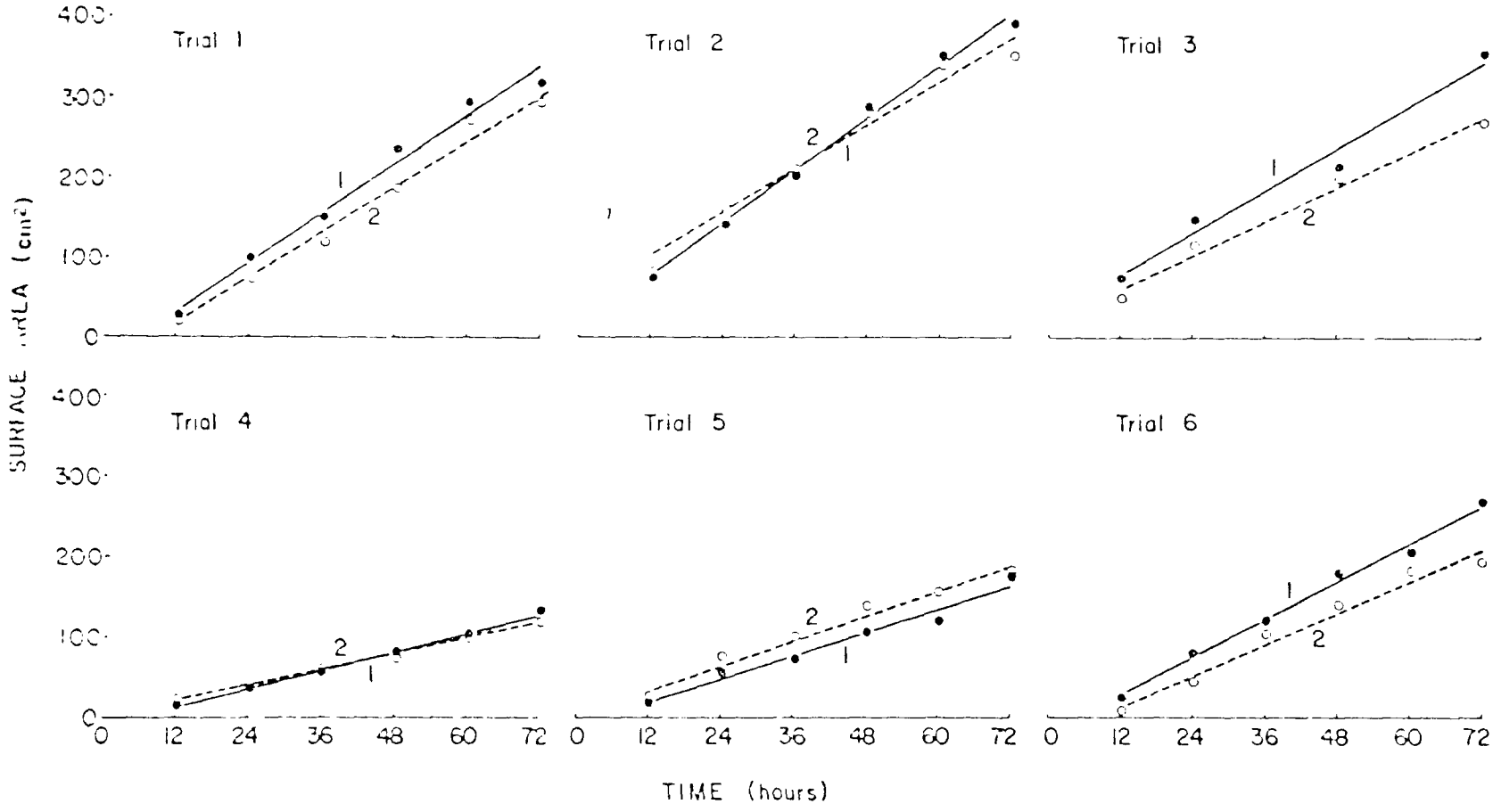


Fig. 2. Comparison of the rates of sediment turned under by group of similar size. A different group of lugworms was used for the six replicate tests.

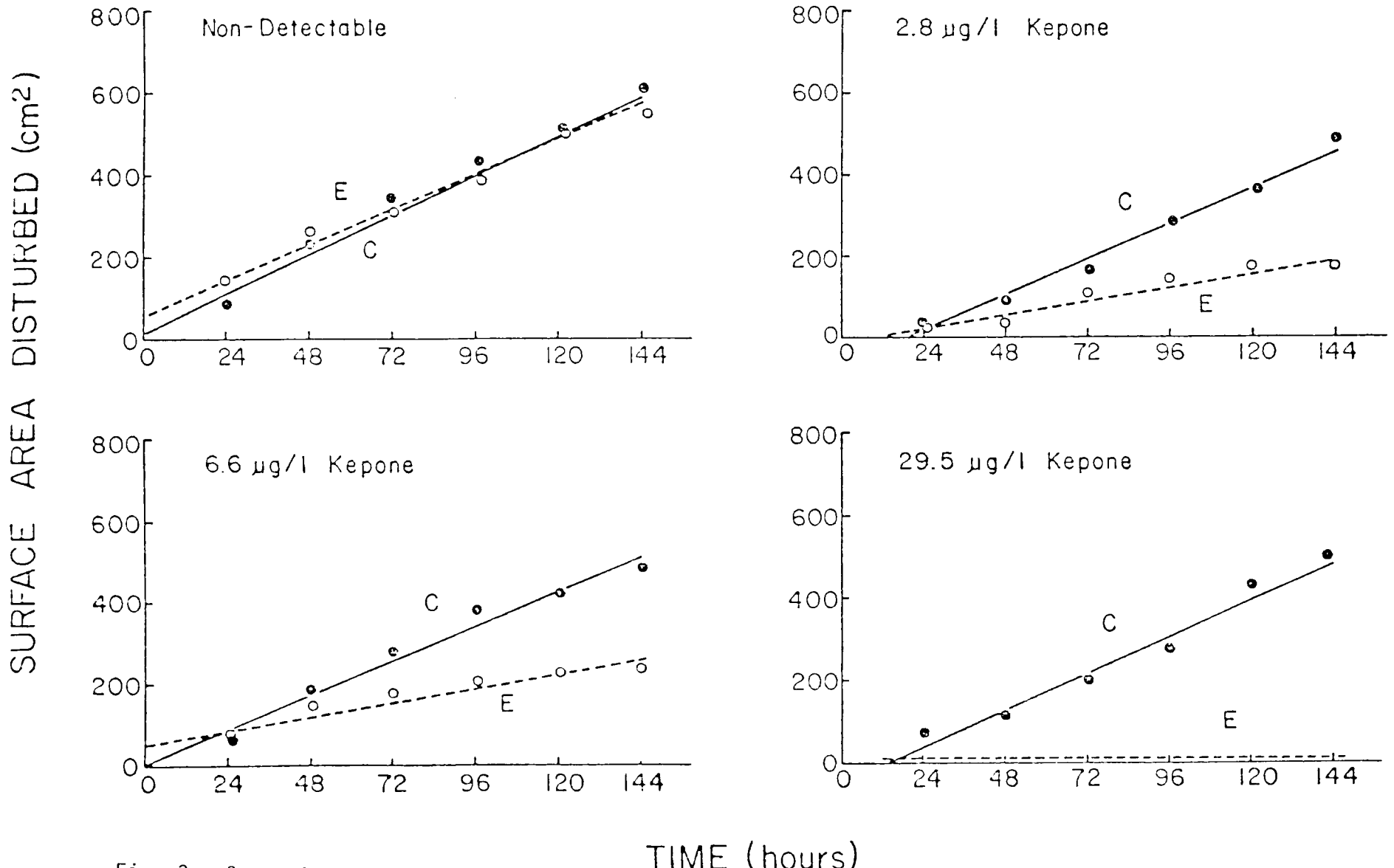


Fig. 3. Comparison of the rates of sediment turned under by lugworms. C-control; E-experimental group exposed to Kepone. Each group consisted of six lugworms.

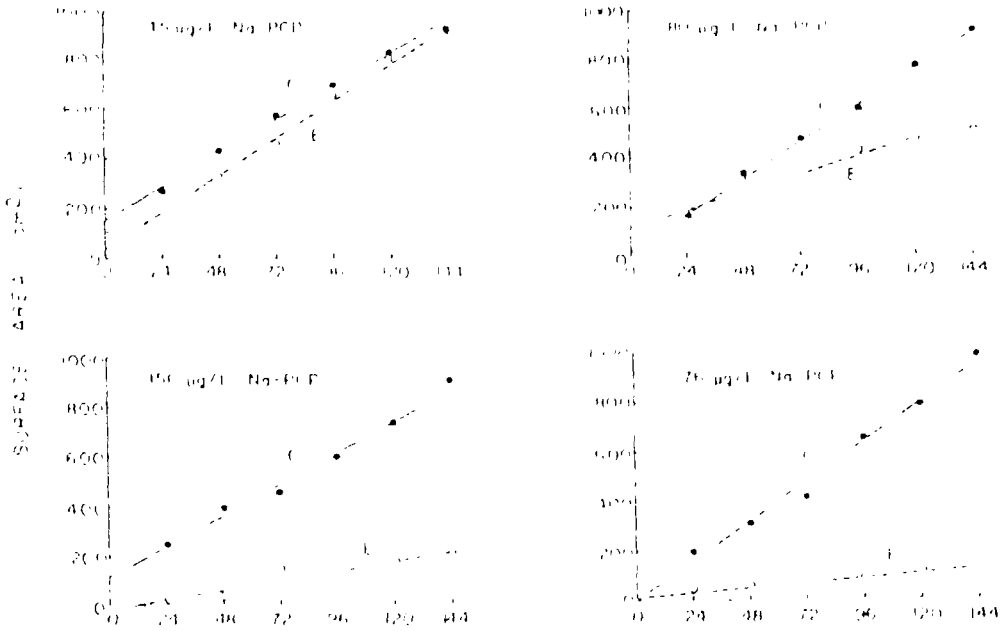


Fig. 4. Comparison of the rates of sediment turned under by the lugworm, Arenicola cristata, C-controls; E-experiment group exposed to sodium pentachlorophenate. Each group consisted of six lugworms.

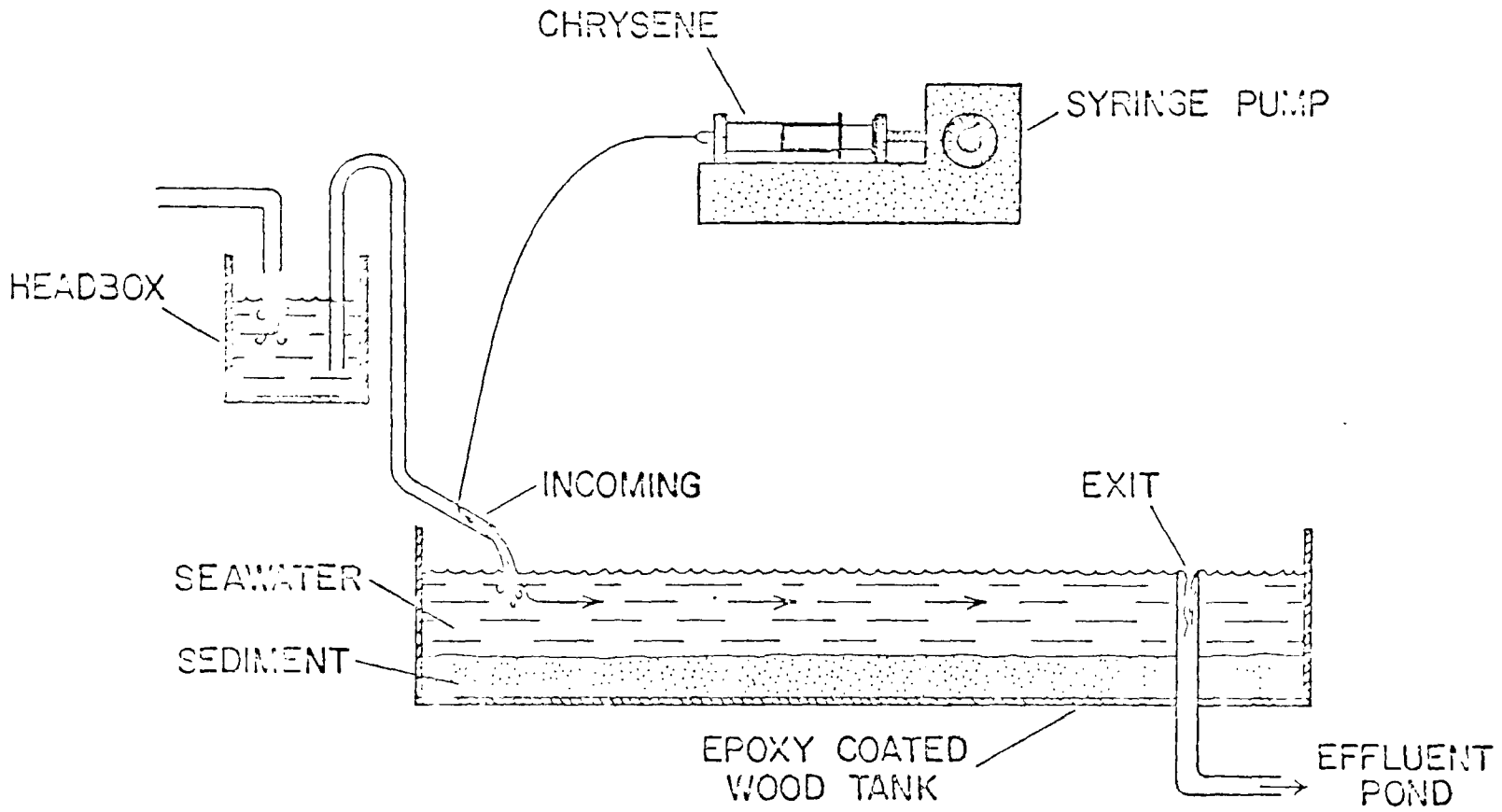


Fig. 5. One tank in the exposure system for chrysene.

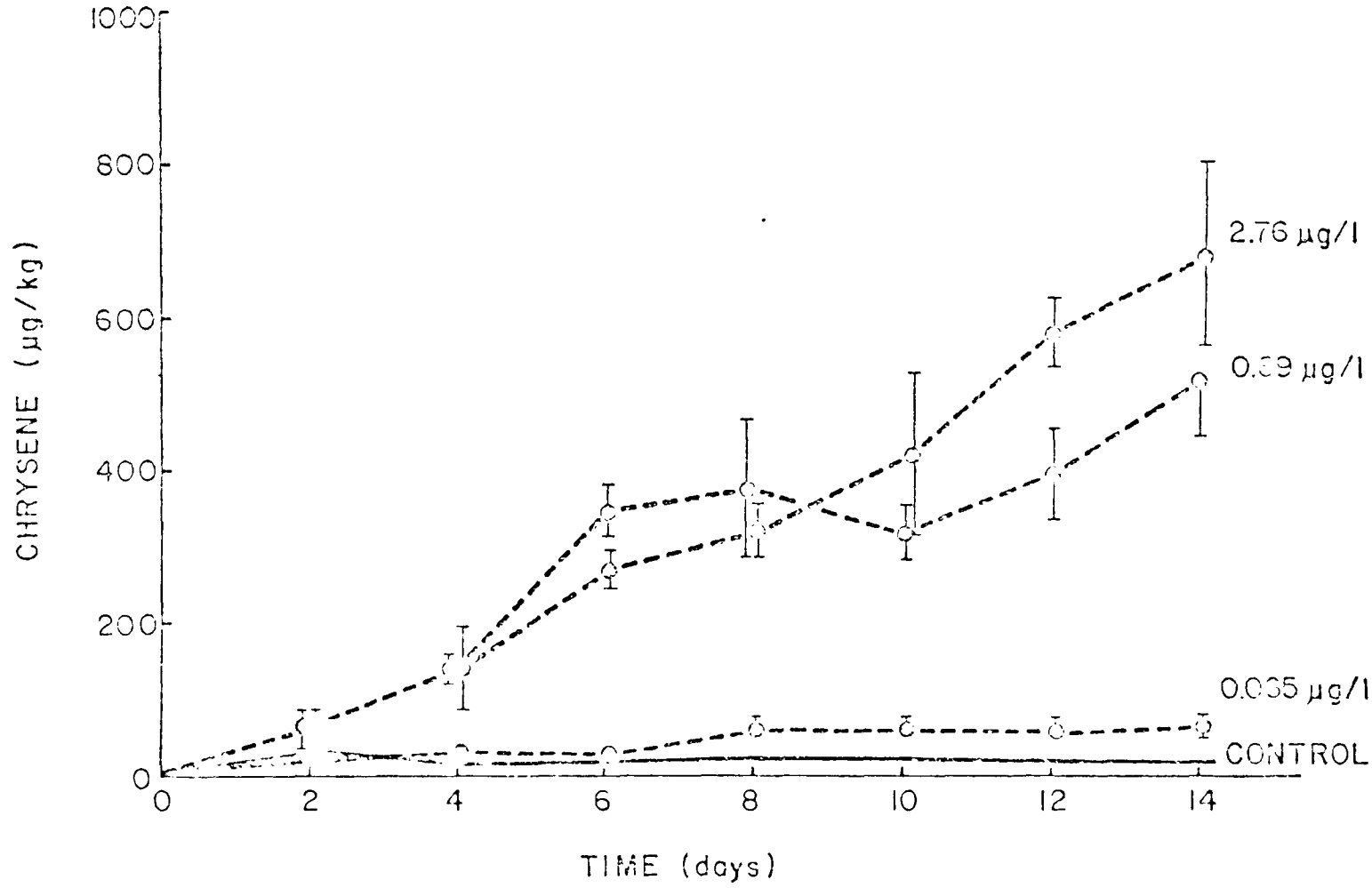


Fig. 6. Accumulation of chrysene by lugworms. Each data point is based on average accumulation of five worms.

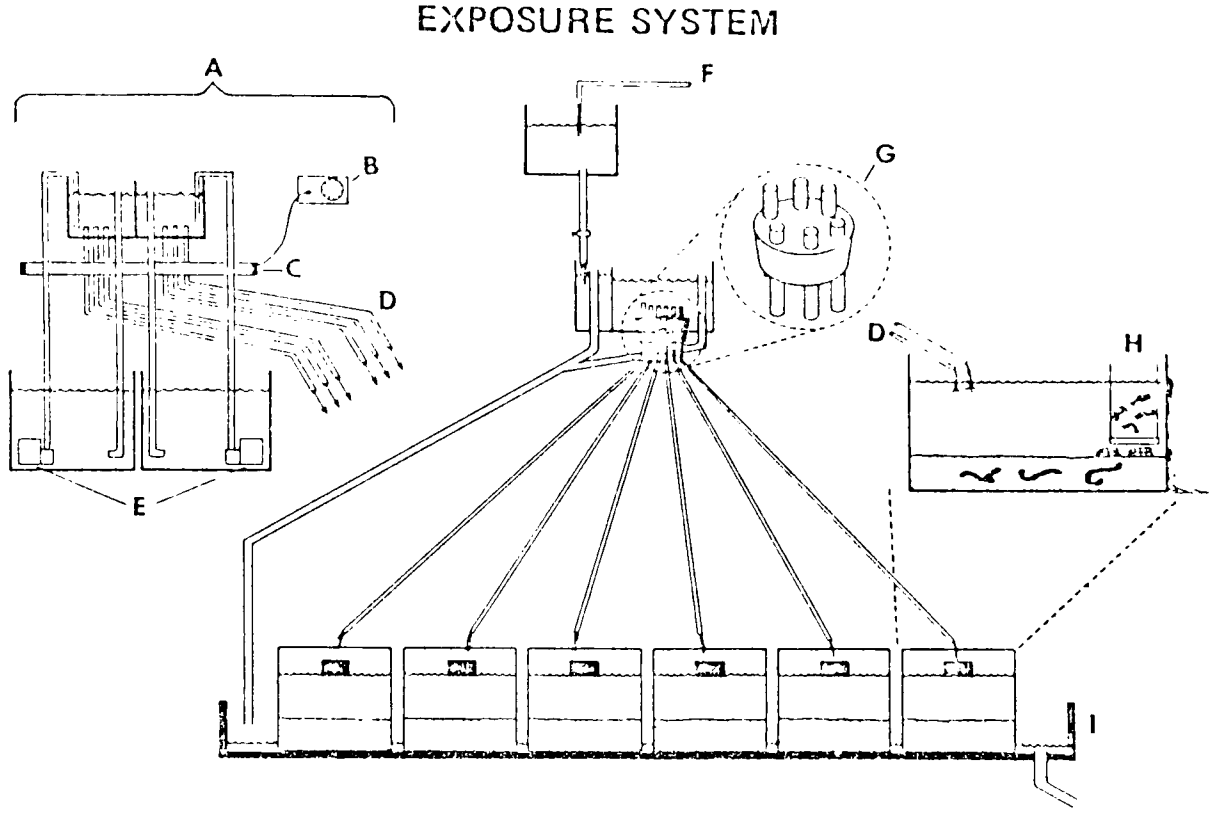


Fig. 7. Exposure system. A-suspended sediment dosing apparatus; B-timer; C-crimping bar and solenoids; D-delivery tubes, E-submersible pumps to recirculate suspended sediment to the delivery box (not labeled); F-seawater headbox; G-s;litter box stand pipes; H-mysids, oysters and lugworms in exposure tanks on a water table.

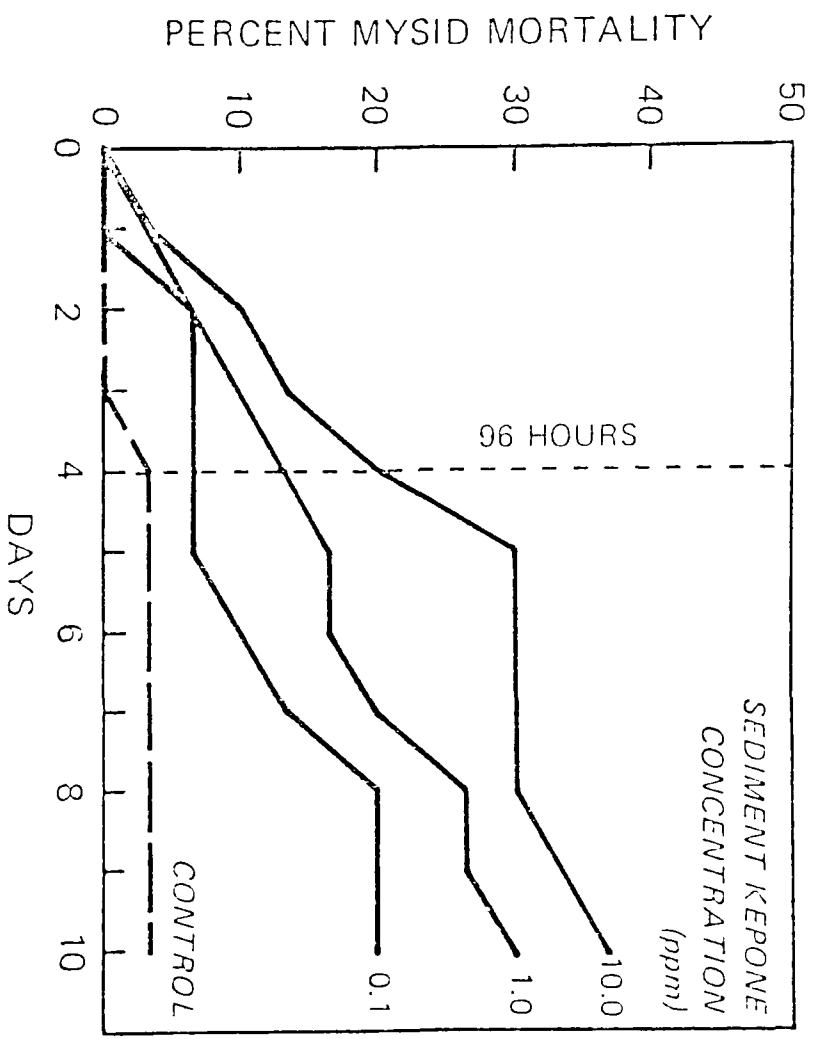


Fig. 8. Percent mortality of mysids exposed to control and Kepone-sorbed sediments for 10 days.

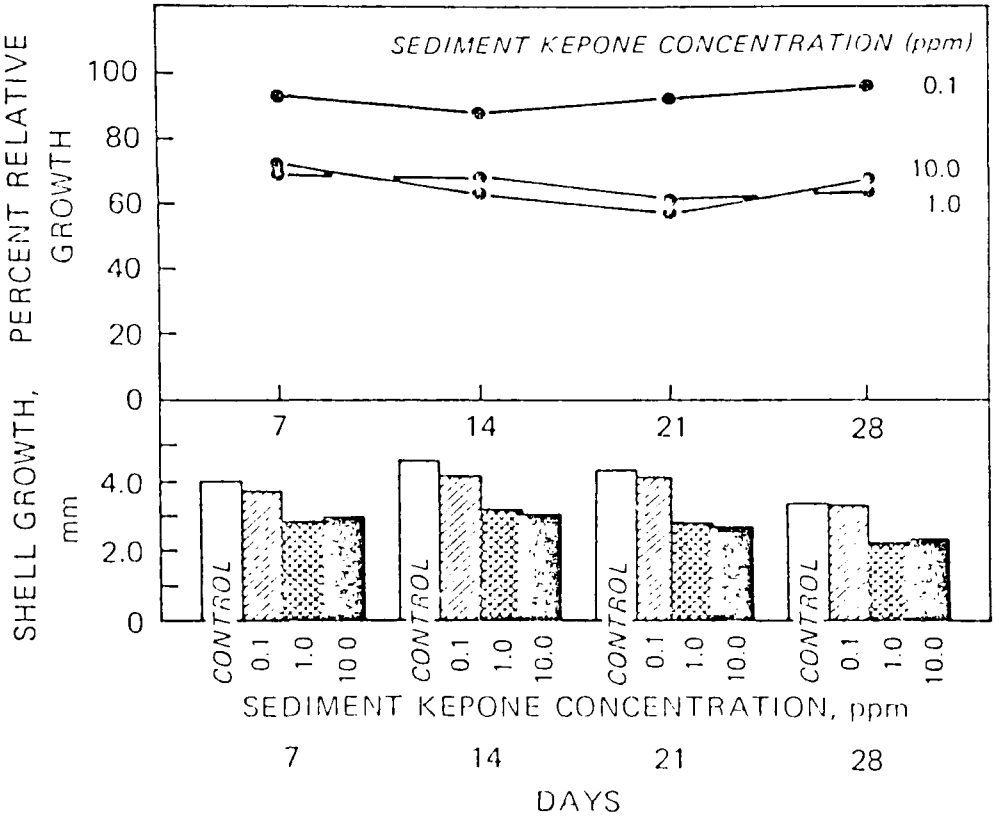


Fig. 9. Effect of Kepone-sorbed sediments on oyster shell deposition (percent growth is relative to controls).

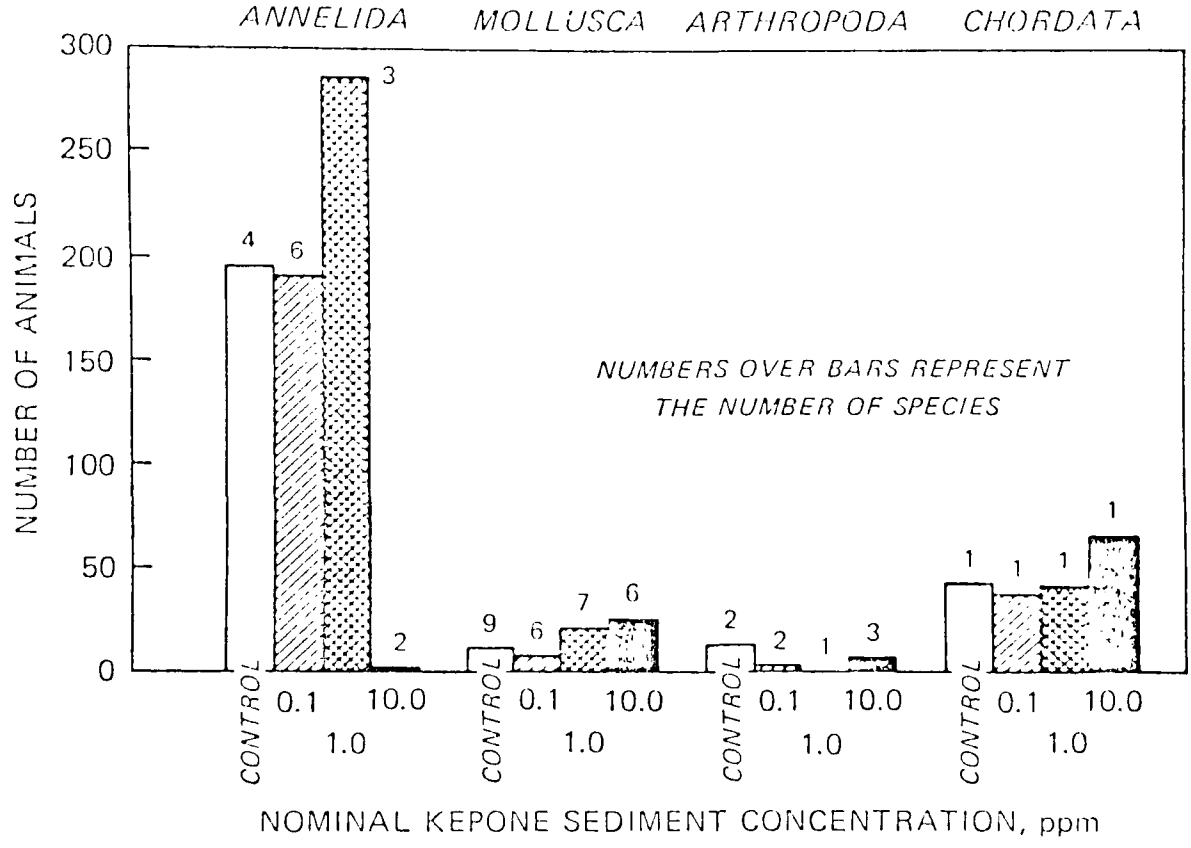


Fig. 10. Number of individuals and species collected from exposed and control aquaria after 28 days.

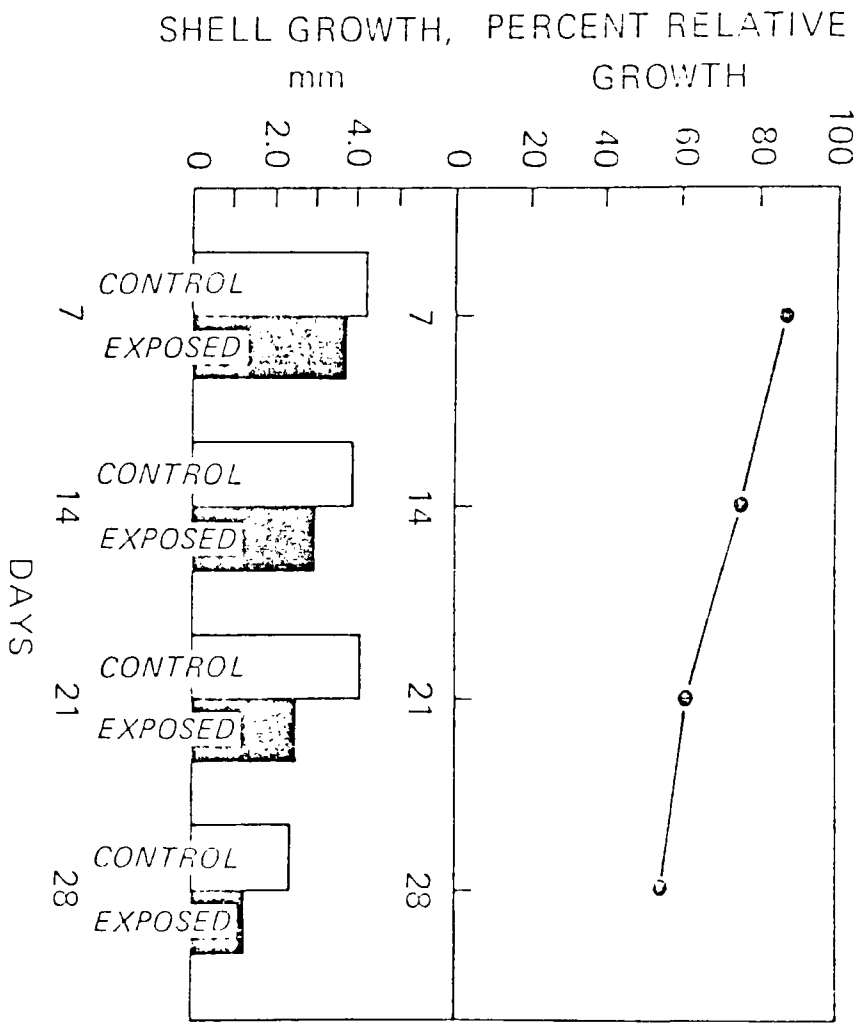
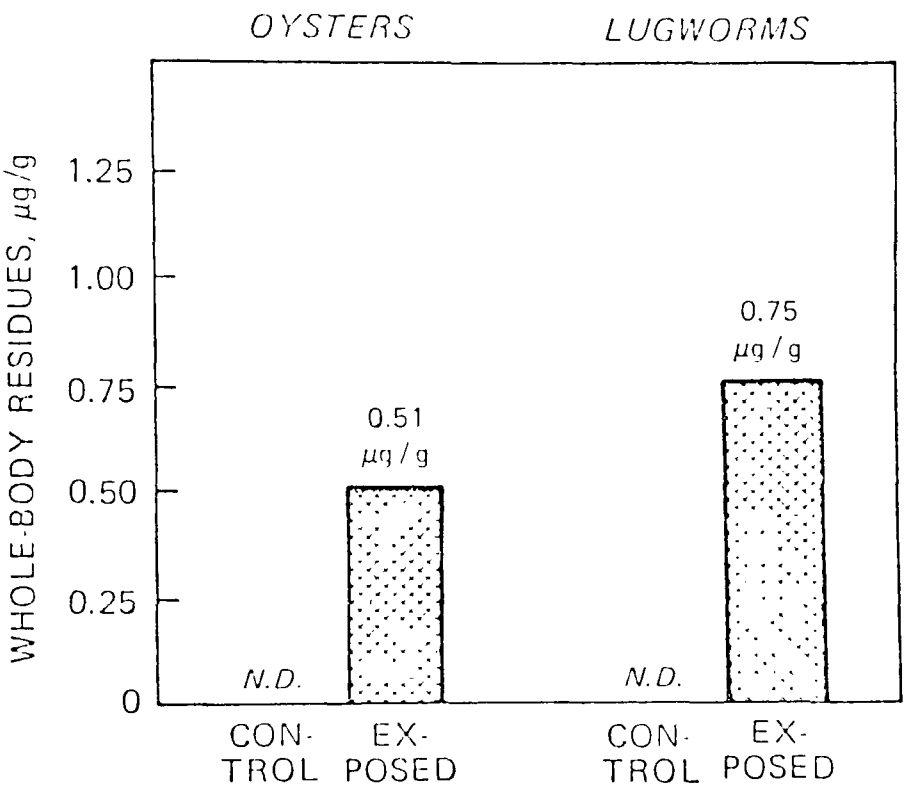


Fig. 11. Effect of James River sediment on oyster shell deposition.



N.D., NON-DETECTABLE (<0.02 µg/g).

Fig. 12. Kepone residues in oysters and lugworms following 28 days of exposure to James River sediments.

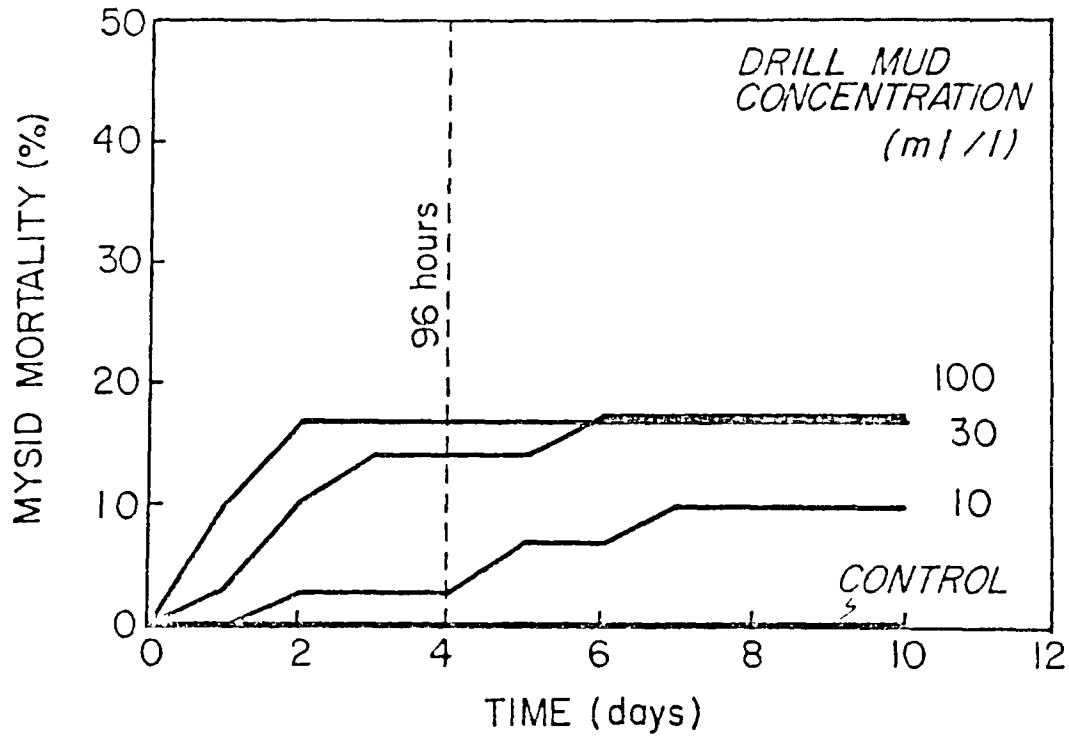


Fig. 13. Percent mortality of mysids exposed to control and three concentrations of drilling muds for 10 days.

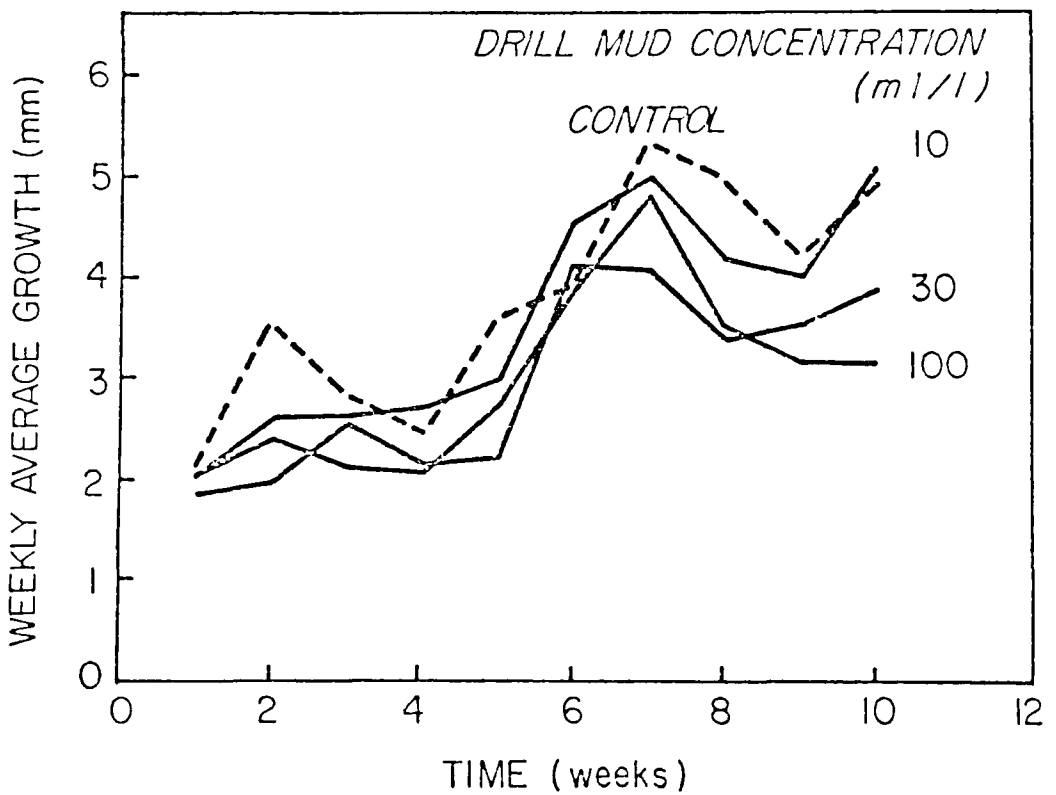


Fig. 14. Weekly average oyster growth (N=15).

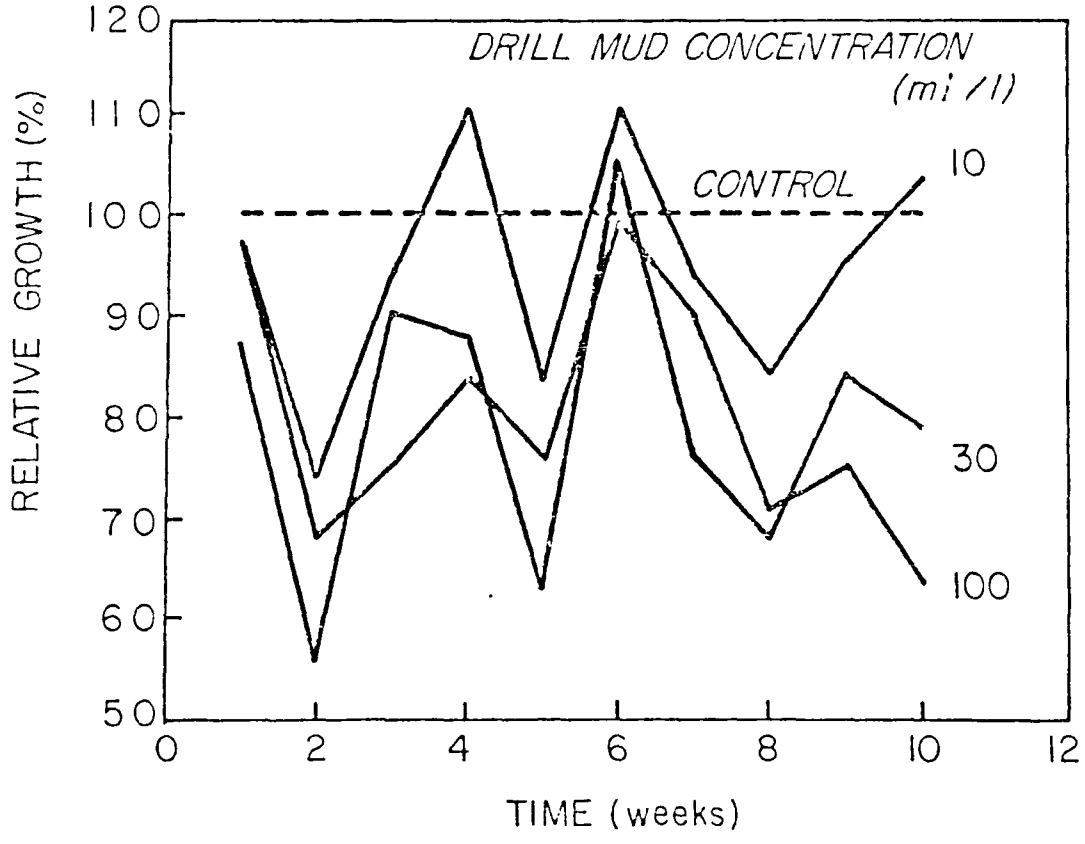


Fig. 15. Oyster shell deposition relative to controls.

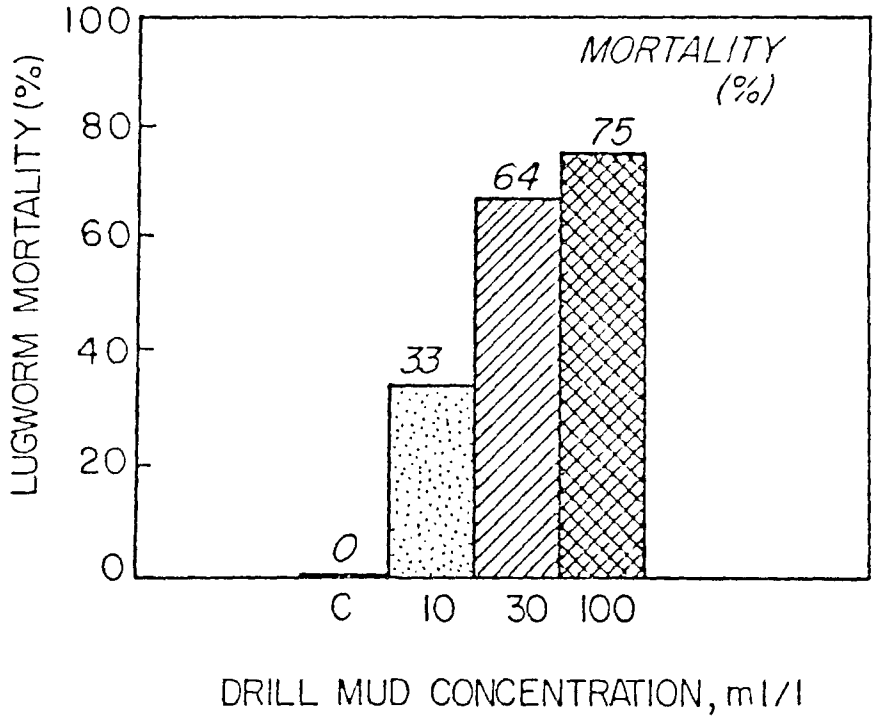


Fig. 16. Percent mortality of lugworms in control and exposed aquaria.

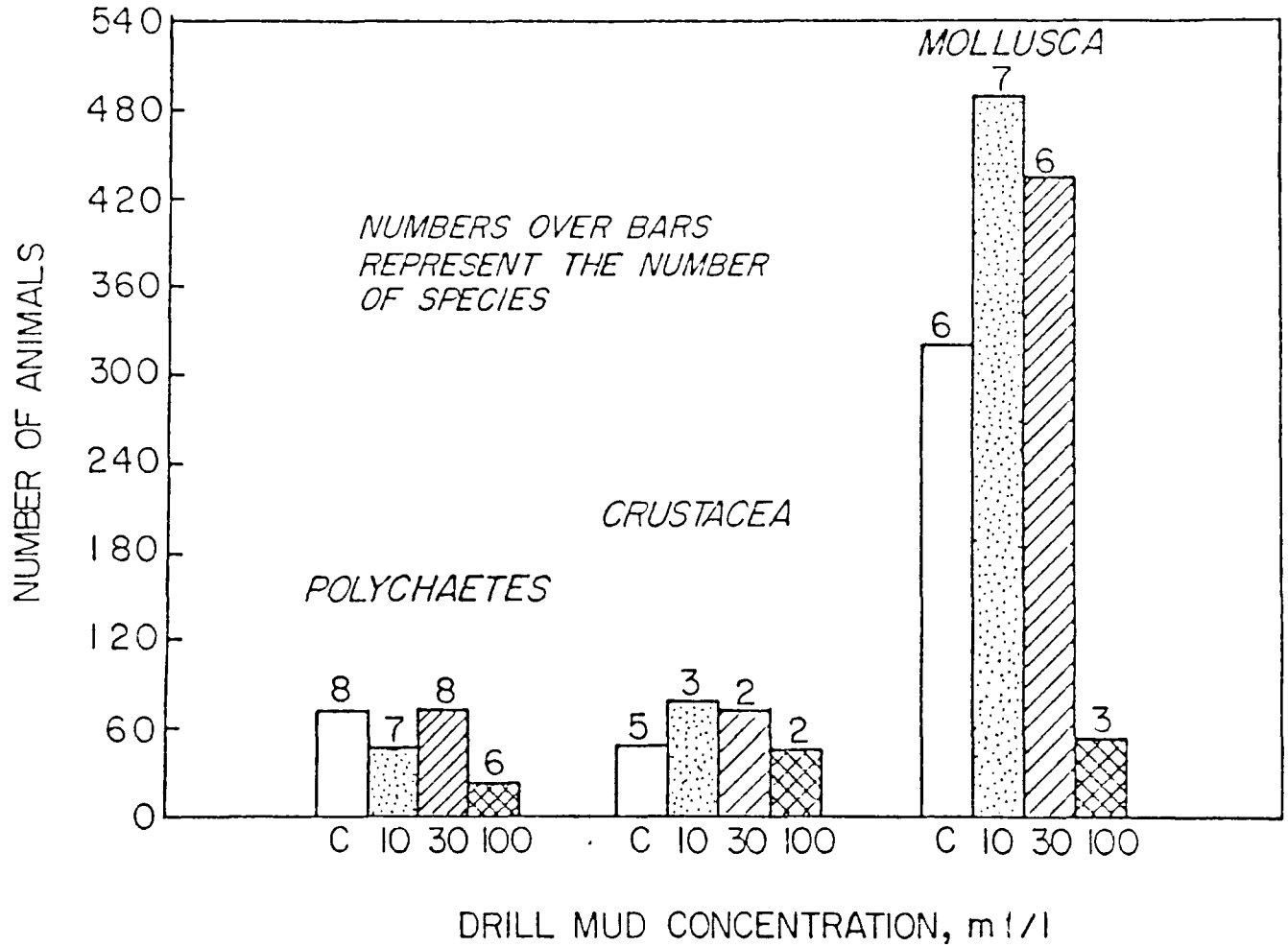


Fig. 17. Number of individuals and species collected from exposed and control aquaria after 100 days.

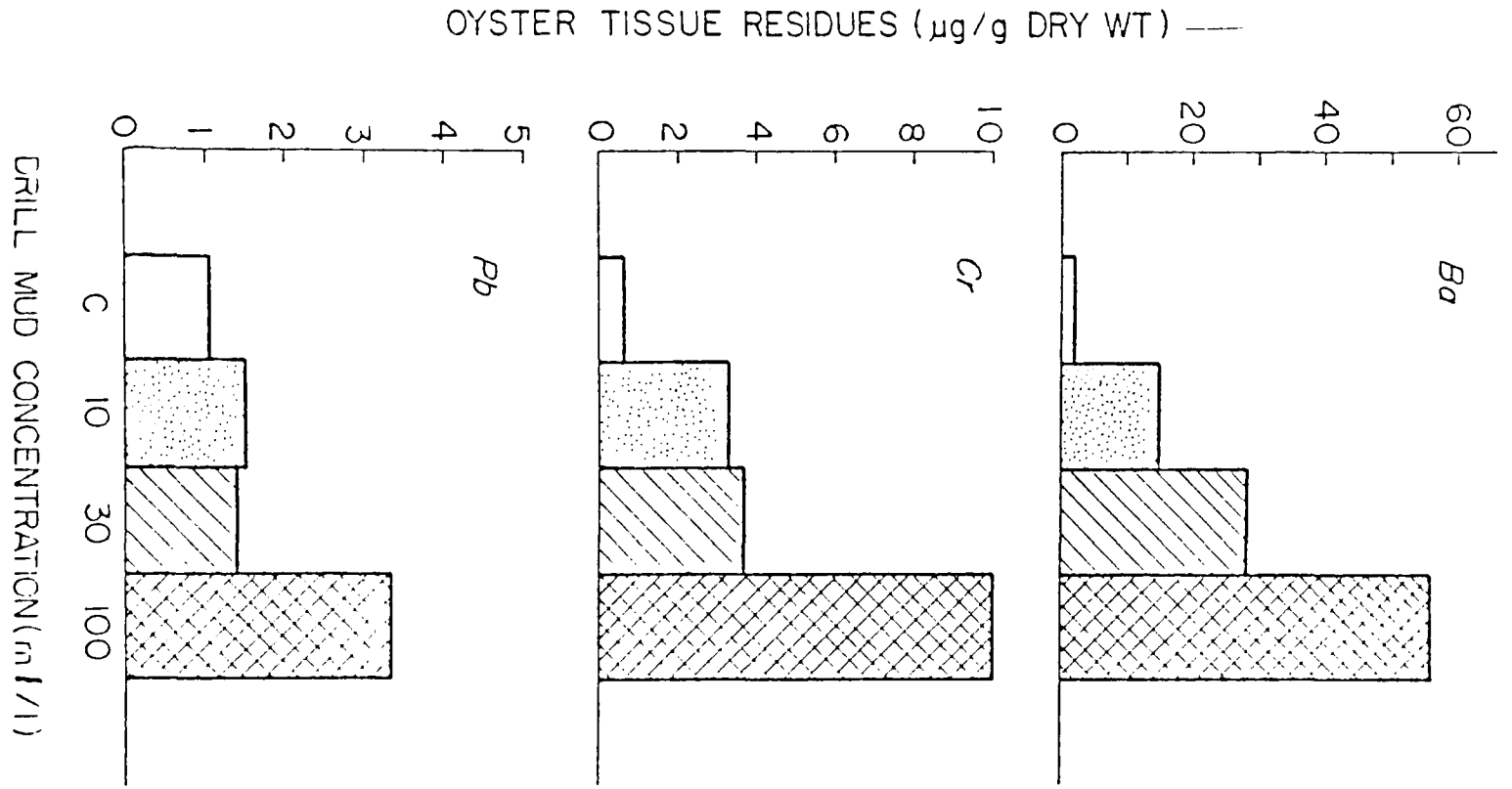


Fig. 18. Ba, Cr, and Pb concentrations in oysters exposed to control and three concentrations drilling muds for 100 days.

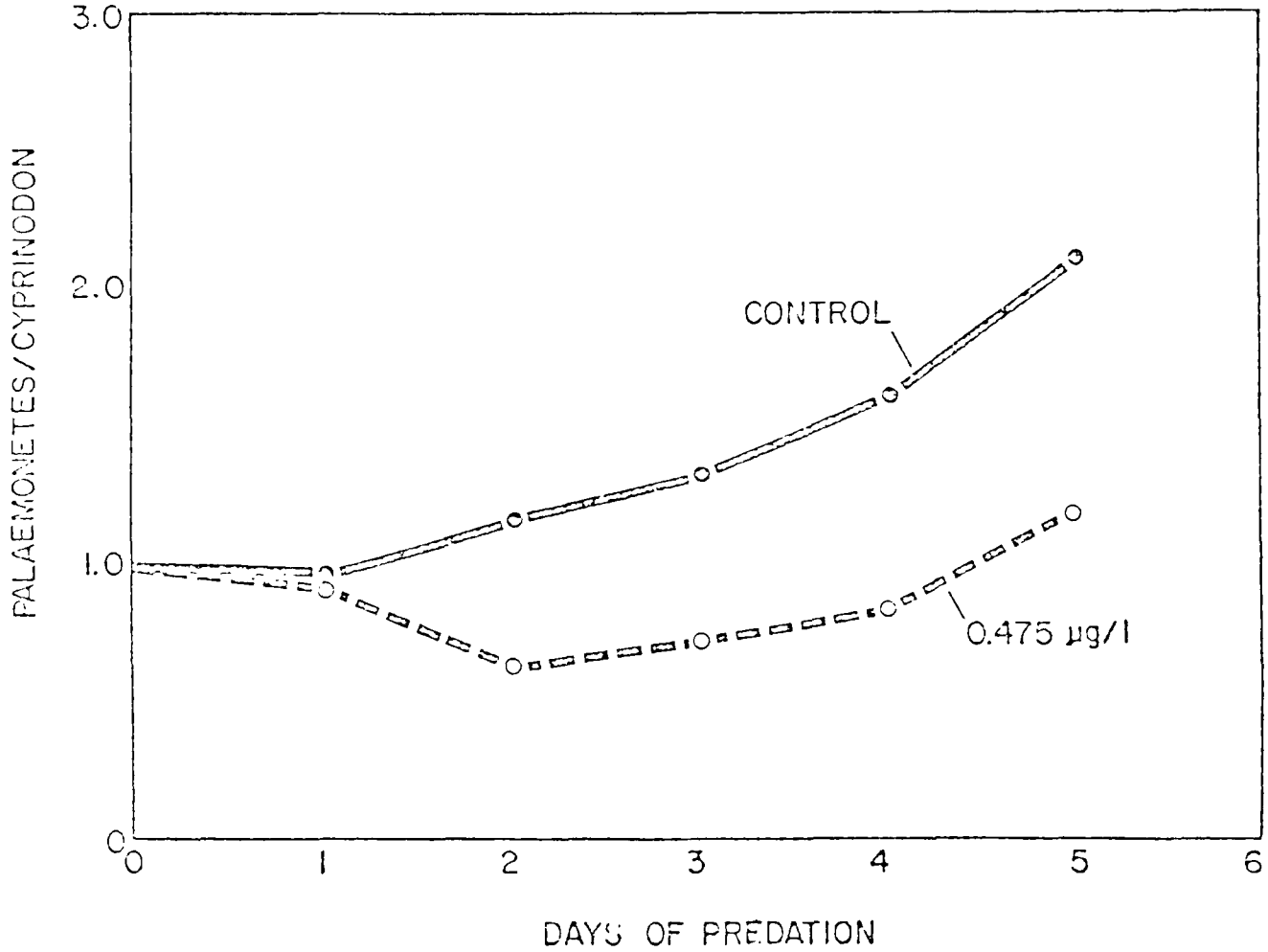


Fig. 19. The ratio of Palaemonetes pugio to Cyprinodon variegatus surviving after each of five days of predation by Fundulus grandis in control and 0.475 mg/l methyl parathion exposed aquaria. The lower ratio in the exposed aquaria indicated greater predation on P. pugio.

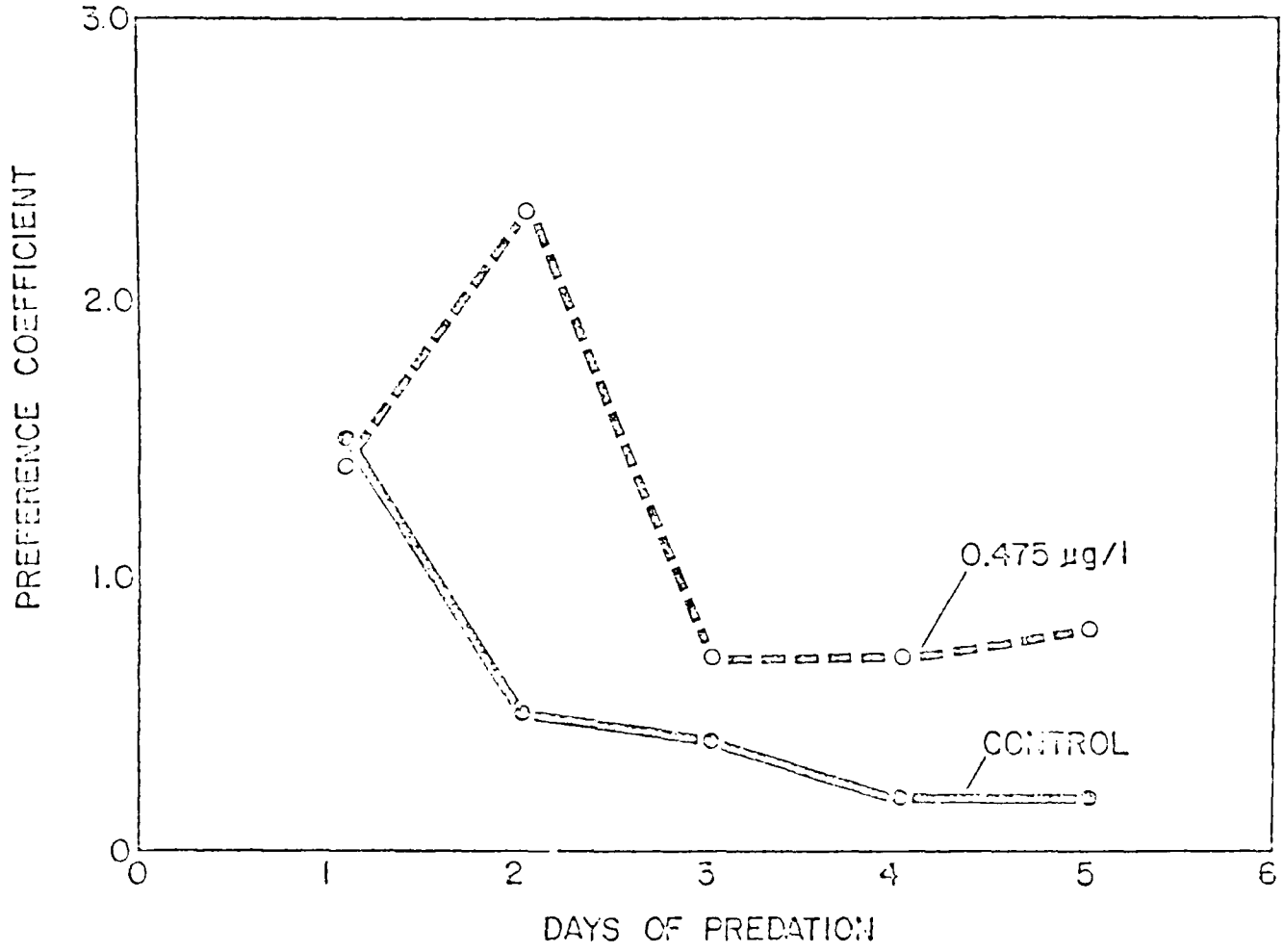


Fig. 20. Preference coefficients for F. grandis predation on P. pugio and juvenile C. variegatus during five test days in control and 0.475 mg/l methyl parathion-exposed aquaria. Higher coefficients indicate greater predation on P. pugio. See Farr (1978) for method of calculation.

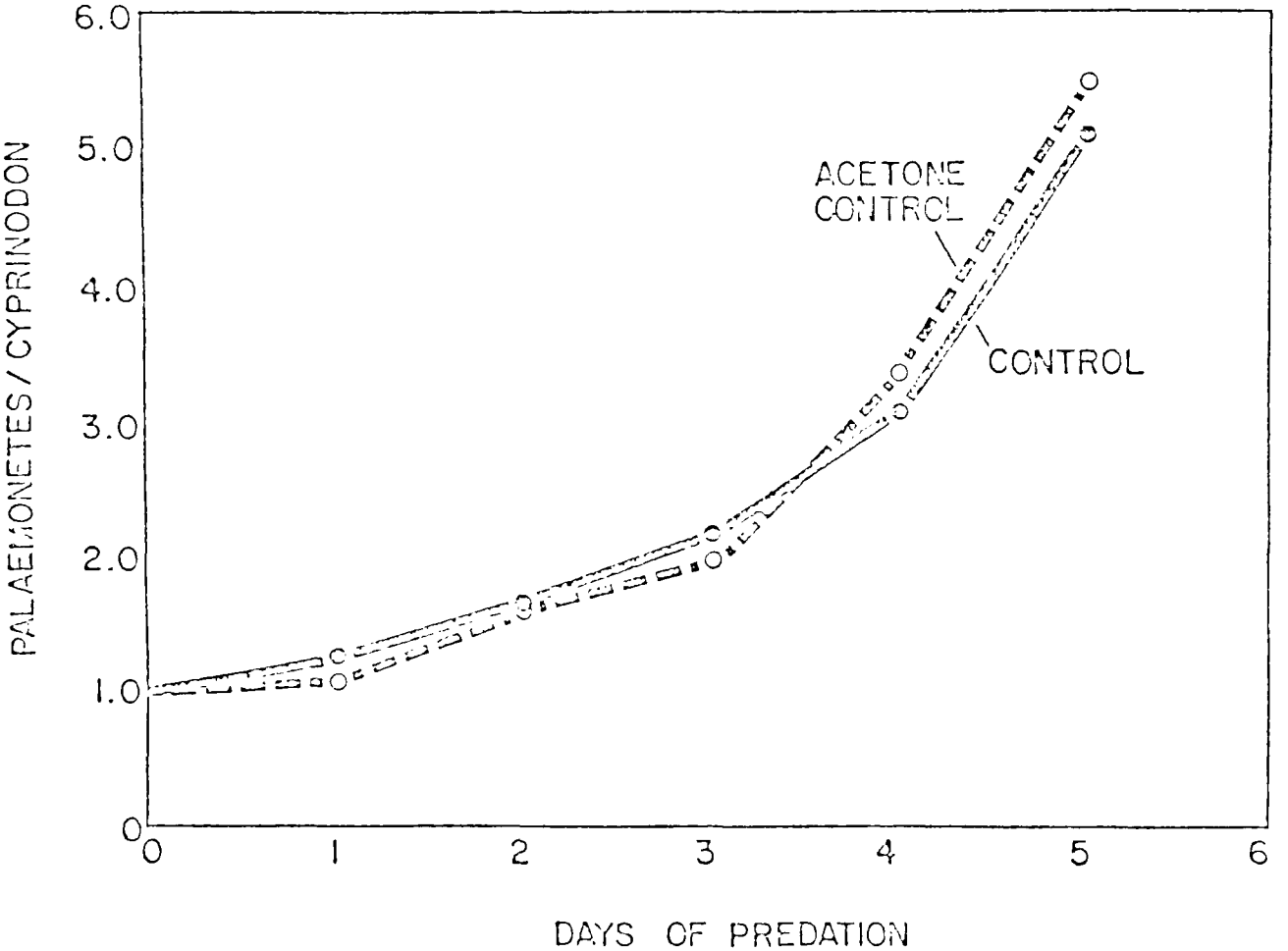


Fig. 21. The ratio of P. pugio to C. variegatus surviving after each of five days of predation by F. grandis in control aquaria and in three concentrations of methyl parathion.

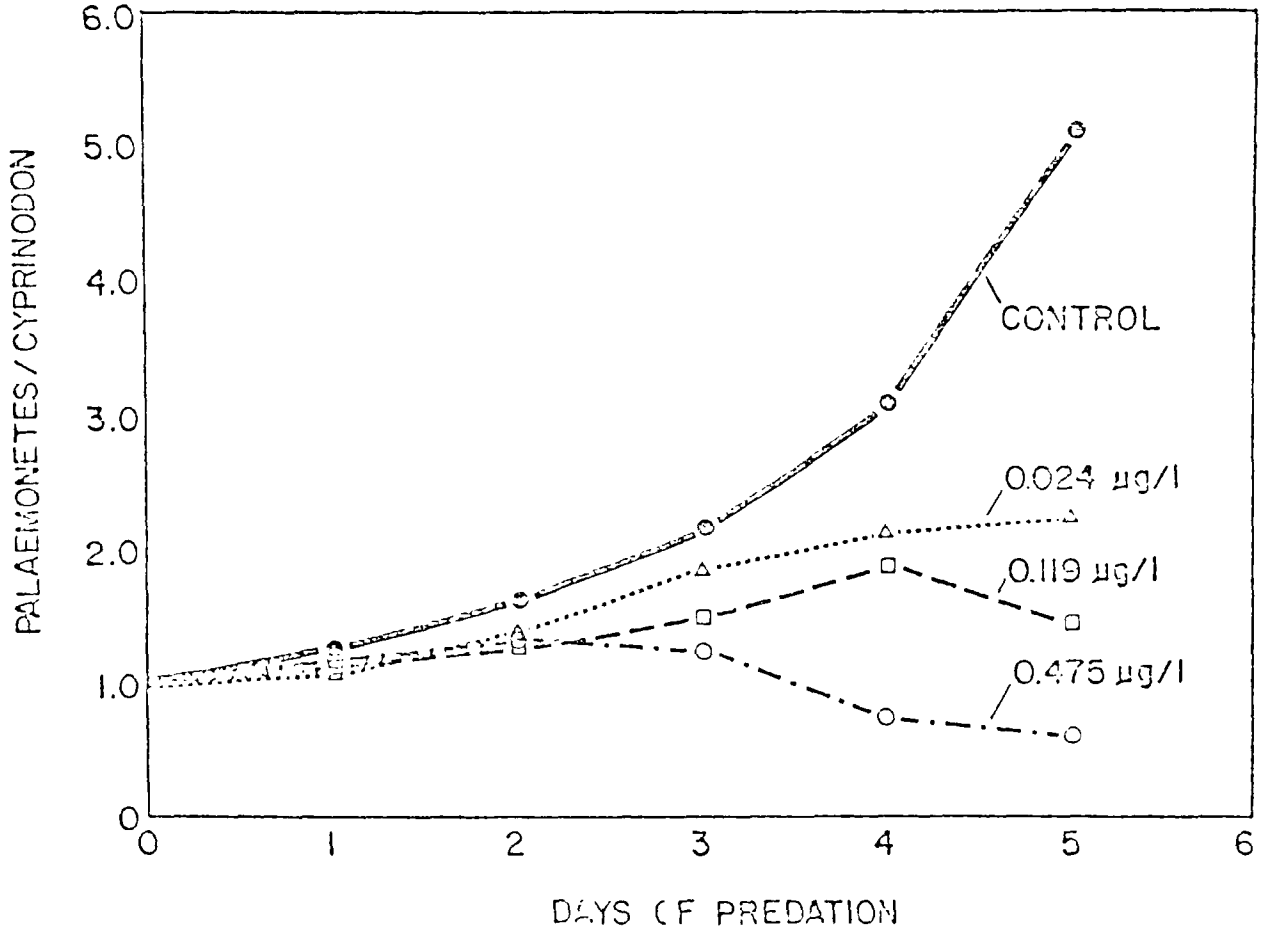


Fig. 22. The ratio of P. pugio to C. variegatus surviving after each of five days of predation by F. grandis in concentrations of methyl parathion.

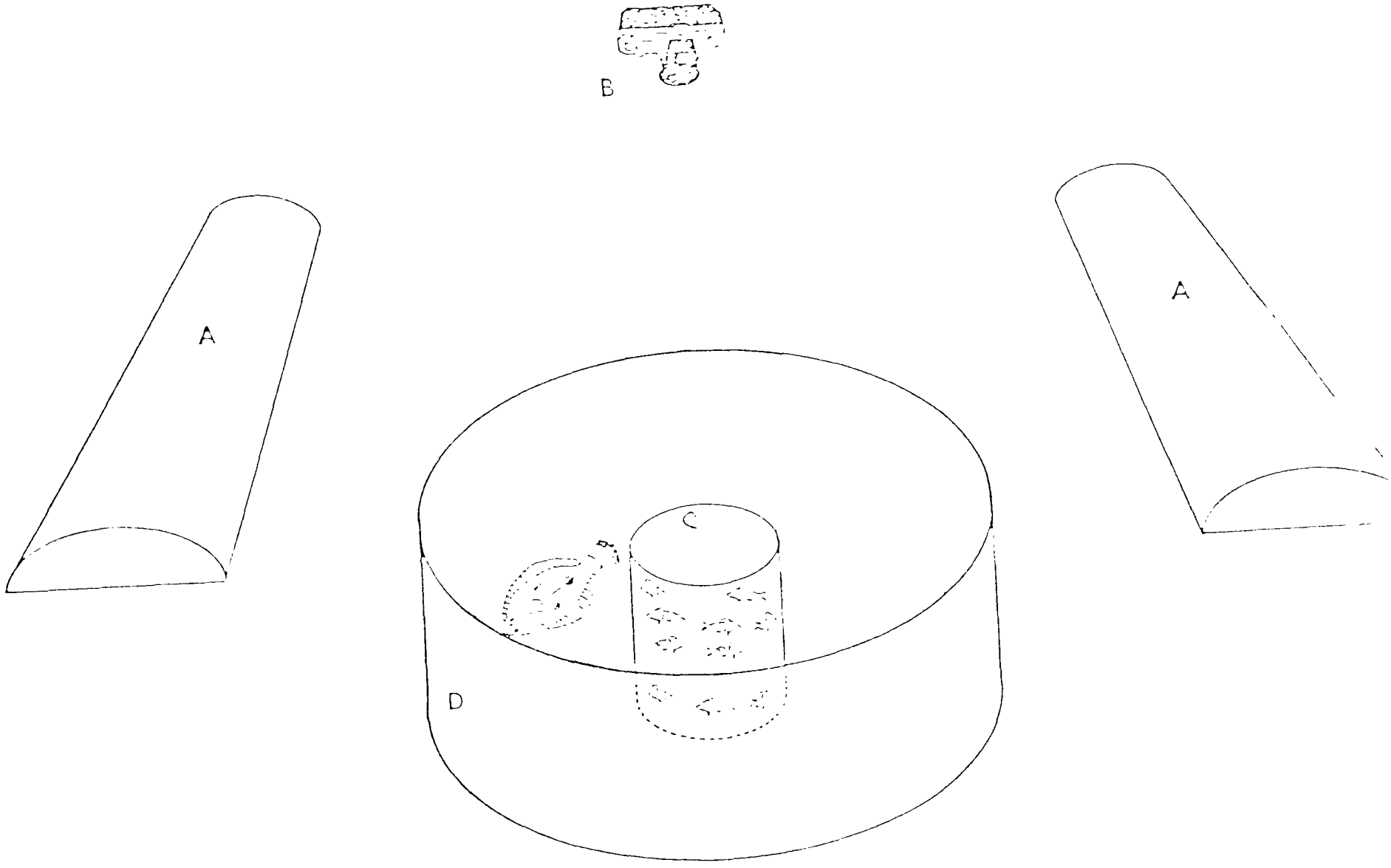


Fig. 23. Test apparatus used to observe pinfish reactions to flounder models: A-fluorescent lights; B-automatic advance camera; C-release chamber; D-circular test tank.

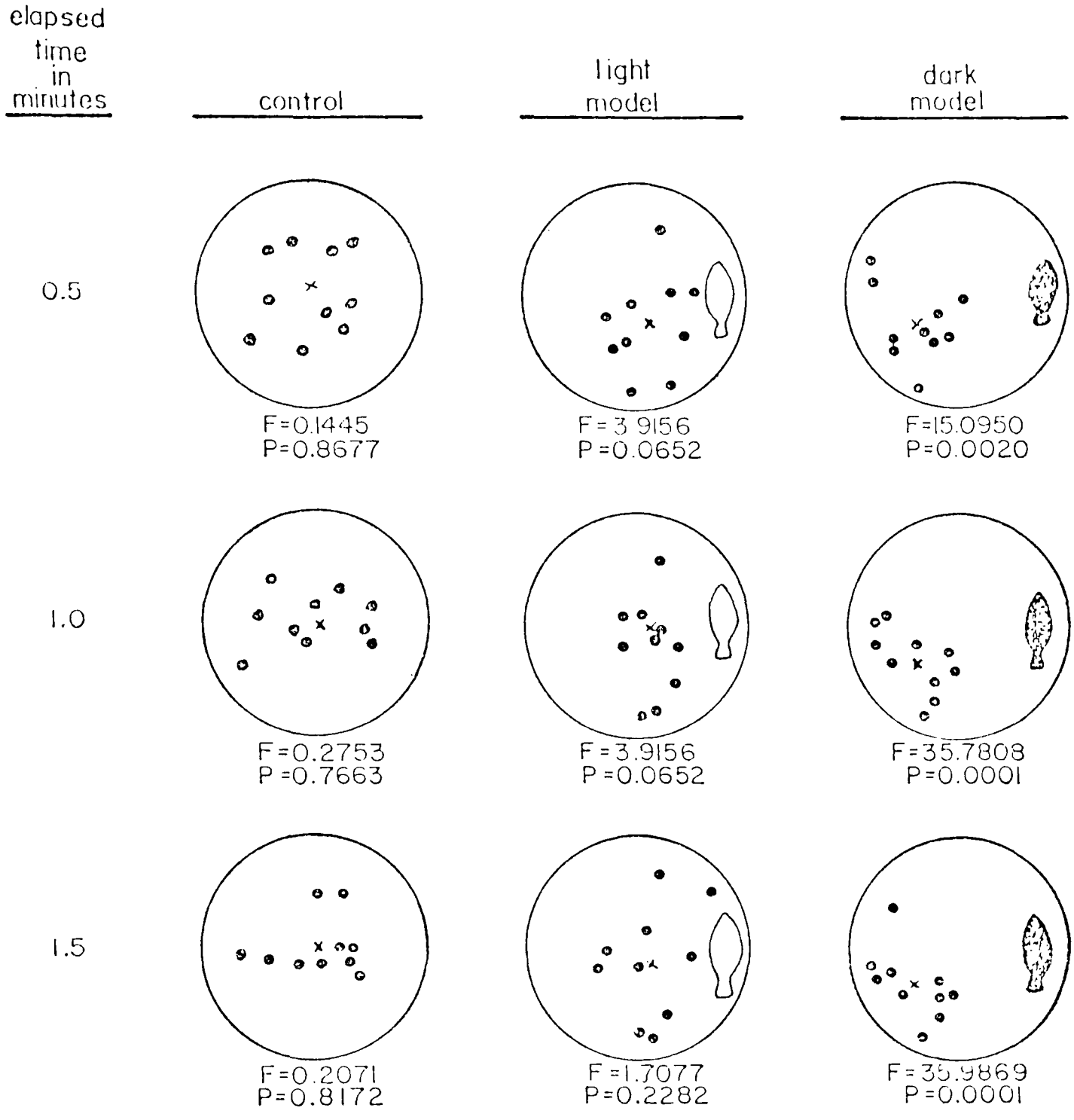


Fig. 24. Diagrams of pinfish positions for combined trials 1-10 for each time interval of control, light flounder model, and dark flounder model. Each point represents the mean position of 10 pinfish for each trial, and the X represents the mean of all 10 points. The F values shown below the diagram were calculated by Hotelling's one-sample test. P values correspond to the probability at the given F value.

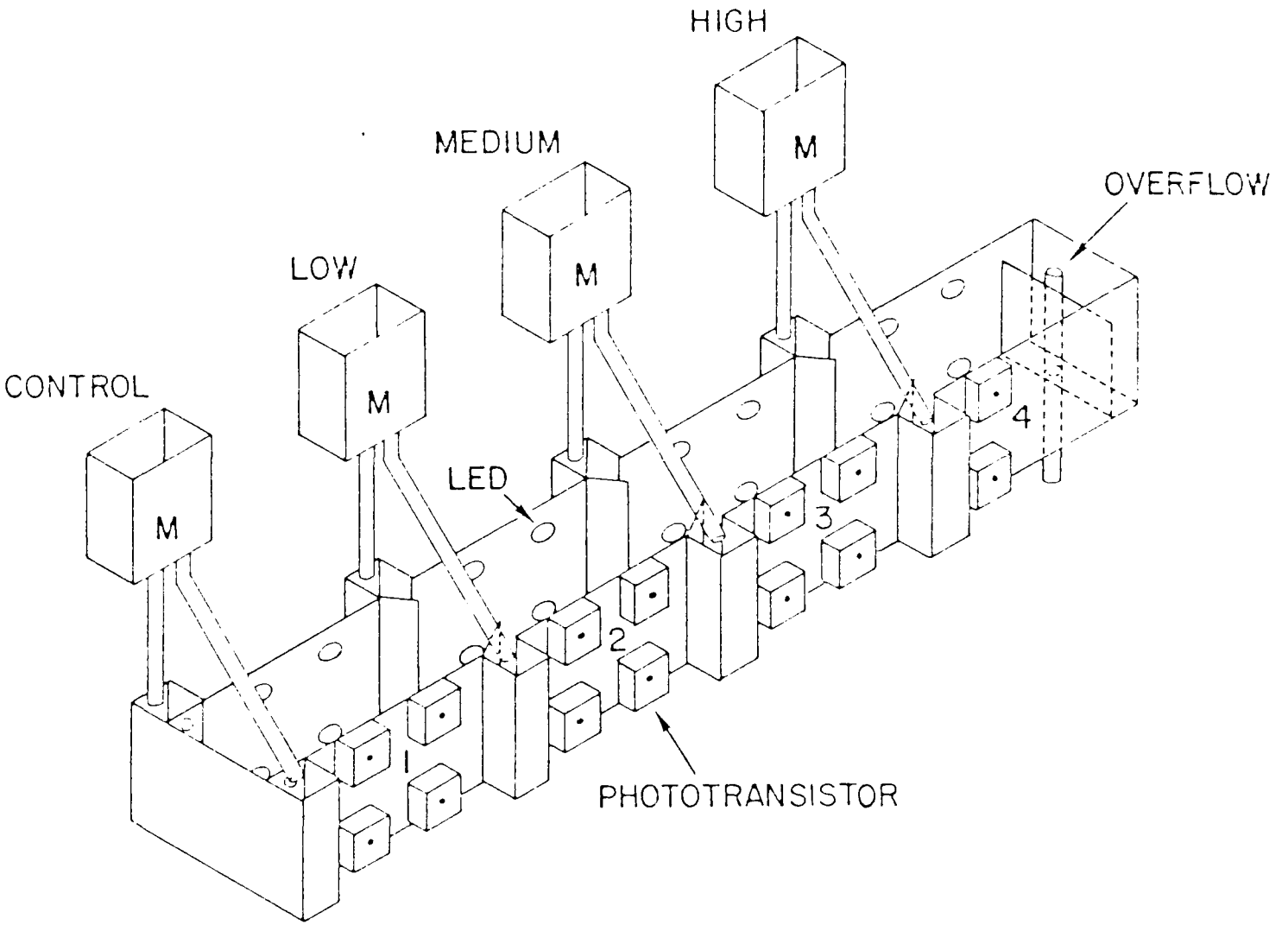


Fig. 25. Diagram of AGARS trough. Trough is 125 x 17 x 15 cm high and constructed of 6 mm clear plexiglas. "M" denotes mixing boxes where 1.5 l min clean water and test compounds or carriers are combined. The flow is divided evenly between pairs of small chambers on each side of the trough. Water exits from the chambers through a row of 7 mm holes. Water flow maintains a gradient of a control zone and three increasing toxicant concentrations (areas 1-4). Organism position can be monitored in both the upper and lower half of each area by pairs of infrared light emitting diodes and photo-transistors.

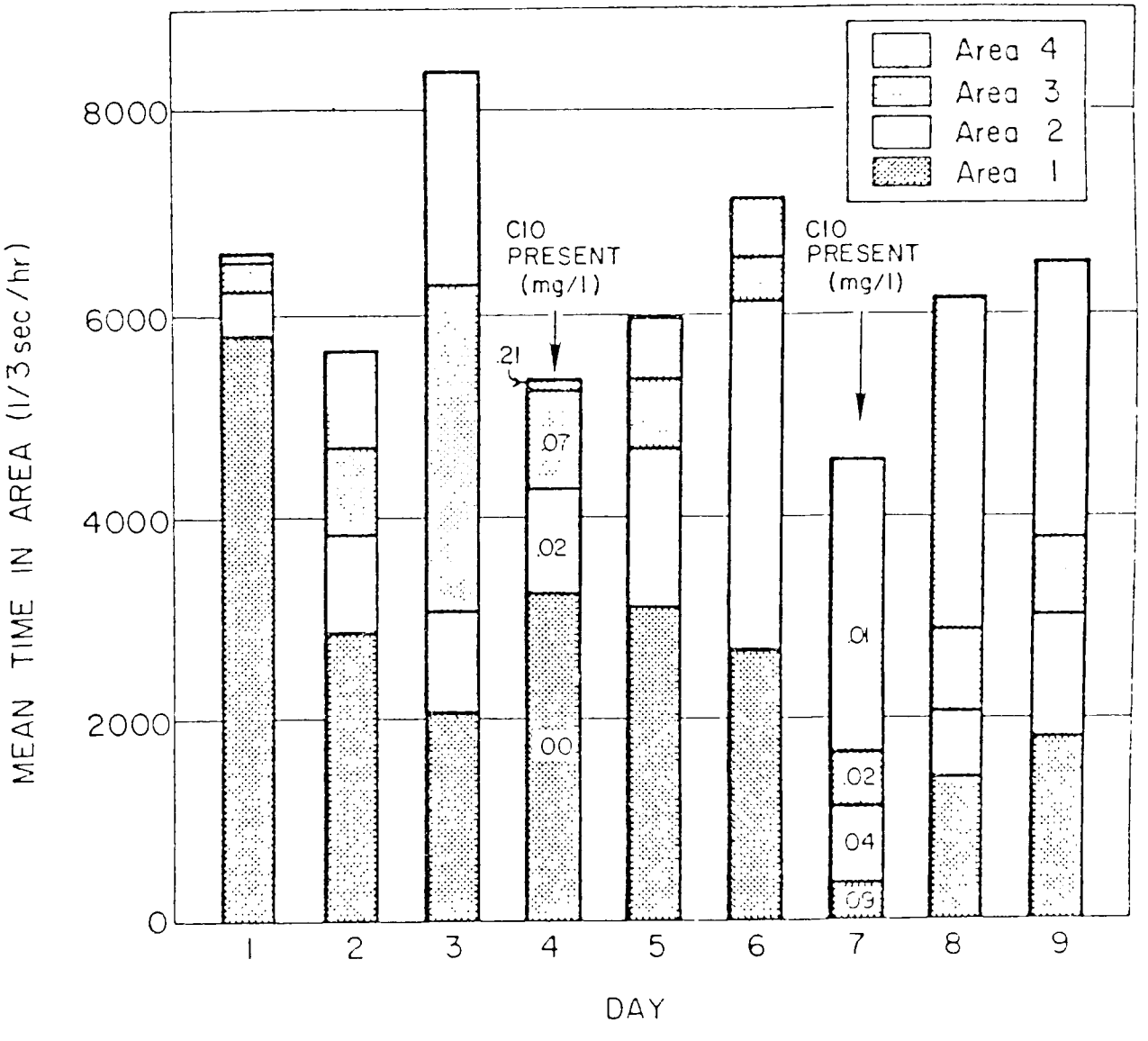


Fig. 26. Results of a 9-day AGARS test with a group of 4 pinfish. Mean of 24 hourly totals of time spent in each of 4 areas of trough versus elapsed time of test. Chlorine produced oxidants were present on days 4 and 7 only.

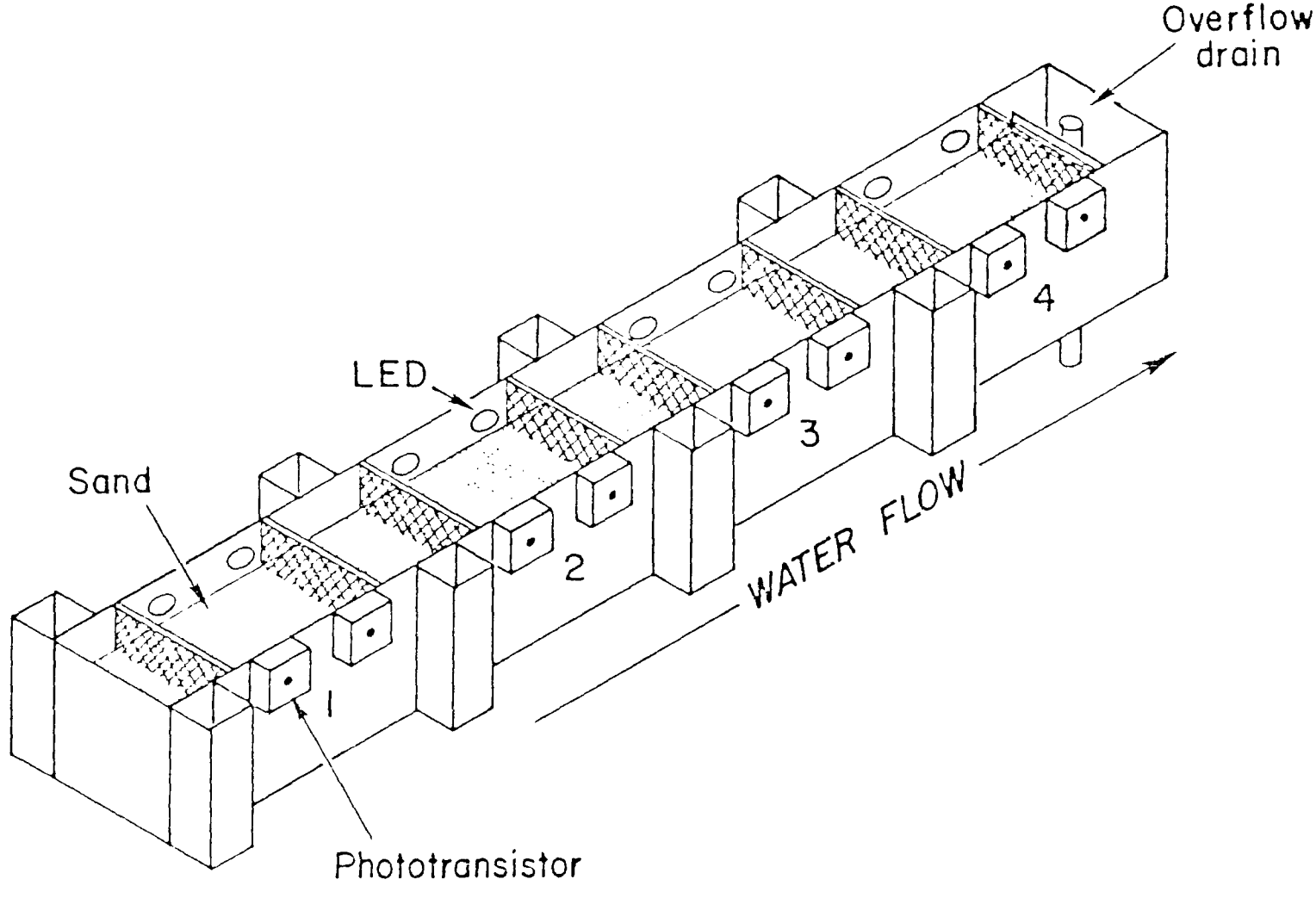


Fig. 27. Diagram of one of two replicate troughs used to study pink shrimp behavior. The trough was modified from that shown in Figure 26 in that it is partitioned with barriers of plexiglas and plastic screen and contains sand. The presence of each shrimp above the sand is monitored by tow pairs of photo-transistors and infrared light emitting diodes.

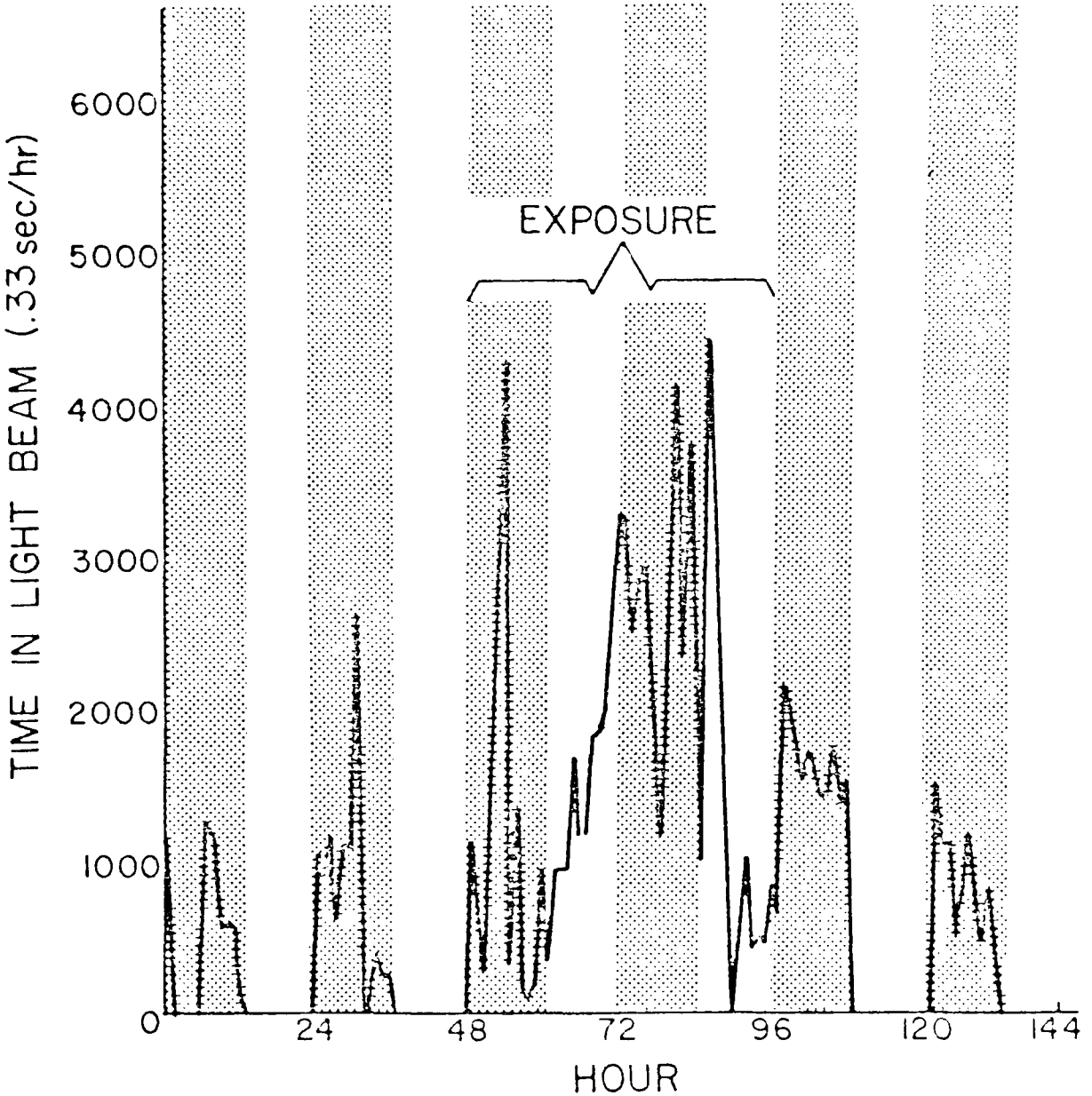


Fig. 28. An example of an activity graph indicating time in light beams (0.33 sec/h) during each hour of the 6-day test. On days 3 and 4 shrimp were exposed to 2.0 ppb methyl parathion and carrier. Light and dark bars indicate photo-period.

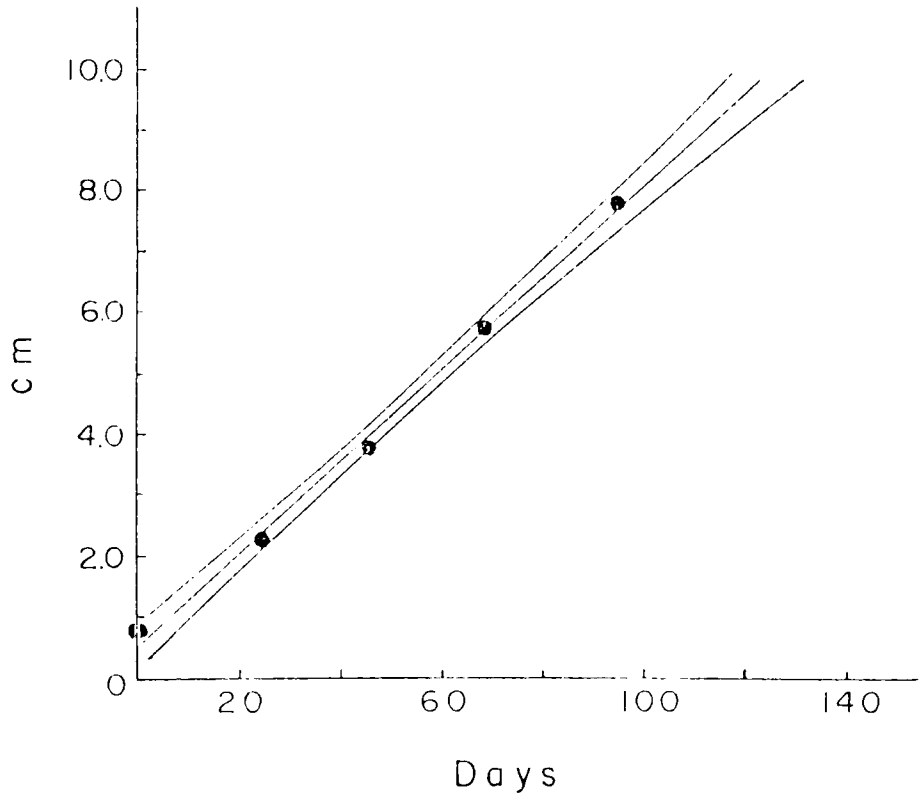


Fig. 29. Mean increase in length by cultured Arenicola cristata during spring and early summer; 95% confidence belts are indicated.

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