PROCEEDINGS

4th annual technical conference

March 14 - 15, 1974

ESTUARIES of the Pacific Northwest

OREGON STATE UNIVERSITY
Engineering Experiment Station
Circular No. 50

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PREFACE

The technical conference series on estuaries of the Pacific Northwest has provided a forum for discussing emerging regional estuarine and coastal zone problems and for presenting recent advances and current concepts of biological, chemical and physical interactions in estuaries. Scientists, engineers, planners, governmental representatives, developers and conservationists have met and given free exchange during the conference sessions. Hopefully some progress in affecting solutions for preserving diversity of our coastal environment and for proper utilization of resources of our estuaries will be derived from these conferences.

The 1974 (IV TCEPNW) conference focused on coastal management conflicts, chemical and biological assessments of pollutants in estuaries, and hydraulic, numerical and ecological studies of estuaries.

Panel sessions were utilized to get agency and public inuut to the program. Thanks are directed to the following who gave input to these sessions: Dr. Herburt Curl, Glen Aikens, Captain Martin West, Colonel Clarence Gilkey, Don Benson, Howard Harris, Gerald Orlob, John Vlastalicia and William Hauschild. It was hoped to include the transcriptions of the proceedings of the panel sessions, but it was not possible to obtain clearance on some of the responses made during the question-answer exchange periods. It was a lively meeting.

Dr. John Byrne, Dean of OSU's School of Oceanography and William Q. Wick, Director of OSU's Sea Grant Program were able toastmasters for the luncheon and banquet, respectively, held in conjunction with the conference. Ms. Maridel Gale, University of Oregon School of Law student, provided a most challenging presentation at the noon session. Mr. Diurmuid F. O'Scannlain, Director of Oregon's Environmental Quality Commission, gave an entertaining post banquet talk. Dr. John Nath is acknowledged for providing a tour of OSU's Wave Research Facility.

The cooperative input by Dr. Herburt Curl, Dr. Robert Holton, and Edward Condon, who made up the conference steering committee is gratefully acknowledged. Without their help this conference would not have been the success it was. Thanks are extended to many who provided behind the scenes input including: Susan Ellinwood, secretary, Mr. James Folts, Sea Grant editorial staff and Janice Baker who completed copy and production of this report.

The support and cooperation of many individuals, conference participants and subscribing organizations too numerous to mention must be collectively and anonymously acknowledged here, with the committee's expression of thanks! It is hoped that the proceedings of this conference will be of significant interest and also will give encouragement for participation in future technical conferences on estuaries of the Pacific Northwest.

L.S. Slotta, Chairman
Steering Committee
IV TCEPNW

Coastal Zone Management Legislation As Seen from the Washington D.C. Perspective

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I would like to summarize briefly where we are nationally in Coastal Zone Management. Of course, the view of where we are would differ substantially depending on the perspective of the observer, and with the wide spectrum represented in this audience- a variety of local, state and federal agencies, scientists and academic representatives - there is, I suspect, a variety of divergent views on the question. The view I will give is a highly singular one, representing one person in one agency. Although I will mention other programs, I will address primarily the status of the Coastal Zone Management efforts within NOAA.

You will recognize the kinds and degree of conflicts which occur in our nation's coastal zone. The papers delivered at the last 3 Estuaries Conferences, and those on the program here, address many of those problems and conflicts. It is in the coastal zone where the problems of the oceans meet those of the land- problems involving resource use and protection, spatial competition, waste disposal, and aesthetics, among others. For a variety of physical, biological, and societal reasons, these problems are amplified severalfold within the coastal region, so that the level of conflicts between, and the impacts of, the different land and water uses far exceeds those of any other physiographic area. It is because of the magnitude of these conflicts, as well as the great importance of the coastal and especially the estuarine resources, that so much attention and effort has been placed on the coastal zone.

Past efforts at managing our coastal zone have been for the most part non-existent or unsuccessful. The sporadic management attempts have generally failed for a variety of reasons, including the type of management plan employed and the management process itself. Land and water use management plans have traditionally been short term, single-purpose plans, designed to maximize one resource, use or benefit at the expense of others. Such plans have too frequently been epitomized by public works projects, roads, canals, and even parks. The mathematical law that it is impossible to simultaneously maximize more than one variable applies as well to management choices. Our efforts to separately maximize several variables, rather than optimize them, precludes management success.

The planning and management processes themselves are also cause for failure. The stark separation of management authority and responsibility has in the past proven a major obstacle to good planning. Local government has historically exercised the primary controls over land and water use. This control might be characterized as narrow-view, self-interest, short term planning; but local governments, with few exceptions, suffer from lack of funds, expertise, and authority to do comprehensive planning and management.

On the other extreme of the management activity is the Federal Government. Although more funds and expertise are available, the Federal activity can be criticized as being removed, isolated, and unfamiliar with the local needs and problems. It suffers, too, from a diffuse bureaucracy; look at the problems which face an applicant for a dredge and fill permit: the Army Corps of Engineers, Environmental Protection Agency, Department of Commerce and Department of Interior are all involved in a substantial, diverse, and frequently conflicting review and approval process.

The result is what too frequently appears as random, uncoordinated and unbalanced planning and management efforts.

Fortunately, coastal zone management is today evolving into a more mature process. We are learning the importance - economic as well as ecologic - of planning rather than reacting. The Flood Disaster Prevention Act of 1973 is one example of this new approach. Rather than continued and costly reimbursement to individuals who unthinkingly build in flood prone areas, the Congress has acted to require some responsibility on the part of the planner, zoning body and builder to reduce the likelihood and potential damage from flooding. This kind of action will benefit everybody - the homeowner whose home is less apt to be flooded; the taxpayer, who foots the bill for flood insurance; and the environment.

Similarly, our attention is turning from costly and permanent beach restoration projects, to planning and control to avoid or reduce beach erosion to begin with. The pending Beach Protection Bill (H.R. 10394) is another example of congressional intent to plan for and protect one aspect of our coastal resources.

Such actions can have a profound effect on coastal use and resources. However, without a single unifying program, they too would be only partially effective. The unifying force is present in the Federal Coastal Zone Management Act of 1972. Enacted largely through the efforts of the two ocean benefactors, Sen. Hollings and Sen. Magnuson, this is a unique piece of legislation which becomes continually more impressive as it is implemented.

The Coastal Zone Management Act does a number of things: it defines a national interest in the effective management, beneficial use, protection and development of the coastal zone; it encourages states, through grants and other incentives, to develop and implement management programs for the wise use of coastal land and water resources; it encourages the public and local, state, regional and federal agencies and governments to participate in the development of such programs; and it requires that federal activities generally be consistent with approved state programs. There are three separate grants programs established by the Act, grants to assist states in the development of coastal zone management programs, grants to implement those programs after Federal approval, and a grant program to establish a system of estuarine sanctuaries.

Like the other sections of the Act, the management program development phase is a state responsibility. The Federal Act provides broad guidelines for the program, and establishes certain minimum requirements that must be considered during the program development process. These include such items as the identification of the coastal zone, definition of permissible land uses, inventory and designation of geographic areas of particular concern, designation of priority uses, identification of the means of control over land and water uses, and a description of the organizational structure necessary to implement the plan. However, the Act does not provide specific decisions on these or other substantive issues.

Clearly, one intent of the Act is to expand state participation in the control of coastal land and water use and resources. This is necessary to provide the wider jurisdictional range needed to cope with the broad problems of the coastal zone. However, while placing the responsibility upon the states, the Act does recognize the importance of local, regional, and public interests in the planning and management process. The state is directed to consult with and draw upon such interests in the planning process, and provides that where local programs fulfill the requirements of the Federal Act, such programs may continue to function under the state program.

The Act also recognizes a valid Federal interest and perspective in coastal zone management. Relevant Federal Agencies are encouraged to fully participate with the State during the planning process.

The overall thrust of the Act is to focus management efforts into a "systems" approach. No longer will fragmented or single-purpose planning suffice. Instead a multi-purpose effort, broad enough to encompass all integral parts of the coastal system under one management plan, is necessary and desirable.

Guidelines for application for program development grants were published last November, and states are now beginning to make formal application. In fact, just yesterday the first three grant awards - to Rhode Island, Oregon, and Maine - were awarded. It now appears as if about 23 to 28 states will have applied for development grants by the end of this fiscal year.

Following the development of a management plan, the Act authorizes grants to states to implement the program if it is approved by the Secretary of Commerce. Approval will generally be based on the development of necessary process and authority, rather than on substantive issues. The approval will in part depend on the opportunity and extent of public and private participation, as well as the participation of relevant Federal, State, regional, and local governments, organizations, and agencies. The management program must provide for adequate consideration of the national interest involved in the siting of facilities other than local in nature. Procedures for preserving or restoring specific areas for their conservation, recreational, ecological, or esthetic values must also be provided. The Act further requires that the program provide adequate authority and techniques for control of coastal land and water use. Our office is now in the process of developing the criteria which the Secretary will use to ensure that an adequate process exists in the state program.

During the review and approval process, as during the actual planning, the Secretary shall consult with, cooperate with, and to the maximum extent practicable, coordinate his activities with other interested Federal agencies. Not only will such interaction be necessary for a viable program, but the active involvement of Federal agencies during the plan development and review process should act to reduce conflict and delay during subsequent permitting actions.

Once the management program is approved, the State is eligible for implementation grants. An additional incentive for participation is provided by a Federal consistency requirement: Federal actions within the coastal zone shall be, to the maximum extent feasible, consistent with approved state management programs. This requirement at once emphasizes both the central role of the State responsibility and the need for effective State-Federal interaction.

Concomitant with the management program development and implementation, a third part of the Coastal Zone Management Act provides for an estuarine sanctuary program. As with the management program, this is primarily a state responsibility operating under Federal guidance and with a national overview. The estuarine sanctuaries program will provide grants to states on a matching basis to acquire, develop, and operate research areas which will be set aside as natural field laboratories in order that scientists and students may have the opportunity to examine over a period of time the ecological relationships within the area. The research developed in estuarine sanctuaries should generally be relevant to the coastal zone management process, and might include data and studies on natural and human processes occuring within the estuaries.

Using the guidance of the Act, as well as the Committee Reports and other relevant sources, our office has just published draft application and selection criteria procedures. Copies of this publication, which expresses the program objectives, philosophy, and procedures, were available with your registration material. The draft document is open for public comment until April 8, 1974, at which time it will be revised and finalized as necessary, and published as a final notice. I actively encourage your comments and criticisms about any aspect of the draft document or the program itself, for we would like this to be soundly based and to serve a definite need.

As we presently envision the estuarine sanctuaries program, the emphasis will be on the selection of natural areas, or areas with a minimum of human development or impact. Although we are at this time severly restricted financially, we hope ultimately to establish perhaps 12 to 15 sanctuaries carefully selected to represent the major ecological types or variations found along our coasts. A system of this sort, not chosen at random, but reflecting regional variation and a rational classification, will have the broadest usefulness at the national level.

As proposed in the draft guidelines, the sanctuaries will be used as research natural areas, set aside primarily to provide scientists the opportunity to make baseline ecological measurements, to monitor signigicant changes in the environment and as a means for forecasting future impacts. The sanctuary would serve as a control against which one could compare the impacts of man's development in other areas, and will assist biologists and planners to gain a thorough understanding of the ecological relationships within the estuarine environment.

One difficult problem which will have to be addressed on a case by case basis is the management philosophy for each estuarine sanctuary. What kinds of research and what kinds and intensity of other uses will be permitted in the sanctuary? A variety of expertise will be needed from persons like yourselves to decide which areas within a sanctuary might be suitable for what kinds of uses. The management strategy and the surrounding land and water use must be designed to ensure a reasonable stability for the sanctuary.

Several items distinguish the estuarine sanctuaries program from existing land acquisition programs. First, it is clearly and narrowly defined as for research and educational uses. Second, it is designed and will be implemented to have a direct relevance to the coastal zone management decision-making process. And third, the areas selected for sanctuaries will be chosen to be generally representative of large types of ecosystems, rather than for rare or unique features. I anticipate some problem in getting the biologists and planners to address this need for "typical" areas, for they seem by nature to gravitate toward the unique.

If all goes well, we should be able to establish the first estuarine sanctuary by mid to late summer.

The Federal Coastal Zone Management Act of 1972, then, provides the basis for long-term, broadly based planning and management efforts to provide for the optimal use of our coastal resources. The primary responsibility for developing and implementing such programs will rest with the states; the success of the program is to a large degree dependent upon the interaction and coordination with a great many governmental, public, and private entities.

The planning and management programs will require sound scientific and technical advice. They should be based on the best available knowledge, but must also recognize the gaps and weaknesses in that knowledge.

Although we have in the past experienced large-scale resource use conflicts within the coastal zone, a number of trends today will raise by an order of magnitude or more the level of those conflicts. Having destroyed so many of our nation's wetlands and polluted her estuaries, we are increasingly looking at her coasts to absorb our wastes and insults. The expansion of offshore oil activities, floating nuclear power platforms, deepwater ports, and waste and hazardous substance disposal are potential sources of conflict; floating industry, refineries, airports and even cities are being suggested or planned for our coastal zone. If we are to provide for any of this in a fashion which will maintain the other existing and potential uses of our coastal zone, then far-sighted planning and management will be required. This is something that all of you can participate in and contribute to.

Why Not Classify Estuaries?

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Estuaries belong in usufruct to all living things. Yet, the human species has asserted mastery over them and imposed upon them a rational and deceptively reasonable concept called "private property."

It has been a time of suffering for the estuaries and wetlands, the scene of battle between conflicting uses. The real conflict demanding resolution, however, is between man the conqueror and man the biotic citizen. The balance to be restored is not between uses, but between use and non-use.

Ideally, even within the context of private property rights, we might treat estuarine systems as "commons." By expanding the public trust doctrine --in concept and coverage--we could protect estuaries from any interference with common rights and manage them for the benefit of all living things. Several recent court decisions and the writings of legal theorists suggest that we may get there within a decade.

Within the next few years, however, we will have to work within several constraints: the legislative charge to the Oregon Coastal Conservation and Development Commission; Senate Bill 100; the Federal Coastal Zone Management Act; and, the traditions of local government.

As a tool for land- and water-use management, the combination of local control and state and federal single-purpose agency regulation has been a conceptual failure. The basic tool of local control is zoning. Fifty years of experience with zoning have shown it to be severely handicapped as an instrument for control of poor development practices. Two of its most serious limitations are associated with exclusive local control: susceptibility to political pressure from proposed users and lack of regional perspective.

Our environment is undoubtedly better off for the efforts of such agencies as the Environmental Protection Agency, the Department of Environmental Quality, and the Wildlife Commission. In spite of good intentions, however, agency regulation is inefficient and administrators often suffer from legislatively imposed myopia.

We seek, then, a new regime which allocates decisions about proposed uses on the basis of political responsiveness to those who feel the impact of those decisions.

We have three laws and three agencies giving us recipes for the new regime: OCC&DC and ORS Ch. 191; the Land Conservation & Development Commission and Senate Bill 100; and the federal Office of Coastal Environment and the Coastal Zone Management Act.

At first glance it might appear that our broth will be spoiled. But closer analysis of the three laws can discern a common planning approach and implementation scheme:

- the boundaries of the coastal zone must be drawn
- there must be an inventory of resources in the zone
- there must be an identification and designation of areas and activities of greater than local concern
- permissible uses in these areas must be defined
- guidelines on priorities to resolve conflicts among uses must be established
- a single state agency (LCDC) will administer the plan and be ultimately responsible for its effectiveness
- planning and review authority may be delegated to regional bodies
- the large majority of management decisions will continue to be made by local governments.

These are the bare bones of Oregon's coastal zone management program.

The OSPIRG report examined the planning approach of the OCC&DC as it stood last summer and fall and contrasted it with OSPIRG's perception of the Oregon Legislature's charge to the Commission. The report criticized the Commission for not responding to that charge and suggested an alternative approach to estuary planning.

The basic premises of the OSPIRG approach are: 1) that the present system of land- and water-use management is a failure and a new approach is needed; (2) that among proposed uses of estuarine areas many are conflicting and some are so incompatible as to be mutually exclusive on the same estuary; (3) that the vitality of ecological and economic systems can best be protected by planning for environmental diversity.

From this vantage point, the report argues that the best way to work toward the "balance" of which the Legislature speaks in ORS Ch. 191 is to classify estuarine systems and to develop policies based on those classifications.

The advantages of this approach can be demonstrated by contrasting it with what I perceive the OCC&DC's approach to be.

The Commission has completed the first draft of its estuary and wetlands policies. They are general, uniform policies applying to all estuaries and all wetlands on the Oregon coast. Dredging and filling policies, for example, apply equally to Coos Bay, Netarts Bay, and Nestucca Bay.

The "balance" which this approach imposes is coast-wide, but it is not specific to geographic areas. There will be some protection and some intensive use permitted in each estuarine system on the coast. The specific decisions on how to achieve that balance will remain in the hands of local governments.

Yet, what protection can dredging and filling policies, which must account for what is happening in Coos Bay and Youngs Bay, offer to the Salmon River estuary, where no dredging is taking place? The result of this approach in the long run will be a gradual blur of the differences which exist between developed and undeveloped estuarine areas.

A classification system does two things. First, by defining the goals of each classification it guides the development of different policies for different types of estuarine areas. The management goal in a "protection" area, for example, is to preserve the diversity and integrity of natural processes. Policies for "protection" areas are thus more restrictive than policies for other categories. Consistent with the goals of a "development" area, policies would permit activities not permitted in a "protection" area. Uses given low priority in a "protection" area would be given high priority in a "development" area.

Second, the classification system guides regional decisions concerning allocations of limited state and federal financial assistance. It does this by assigning priorities to areas designated "development" areas. For example, the classification of the Astoria-Youngs Bay area as a "development" area is an acknowledgement by coastal residents and the State of Oregon that Astoria demonstrates potential for healthy economic growth and should receive funding priority for certain kinds of assistance. In other words, the Port of Astoria should get Corps of Engineers' money to conduct an estuary and siltation study before the Port of Nehalem gets money to reconstruct its jetty system.

The heart of the classification system, however, is the development of different policies for application in different estuarine areas to preserve diversity of environment.

The next questions is: What do we do with our policies?

There will be four primary functions to be carried out in implementation: (1) continued collection of inventory data; (2) review of city and county comprehensive plans to assure consistency with the coast-wide plan; (3) review of proposed uses to assure consistency with new regulations, and (4) enforcement of compliance with plans and regulations.

Oregon must choose one or a combination of three alternatives broadly defined in Sec. 306 of the Coastal Zone Management Act if it is to receive a Sec. 306 grant. They are: (1) state establishment of criteria and standards for local implementation, subject to administrative review and enforcement of compliance; (2) direct state land- and water-use planning and regulation; (3) state administrative review for consistency with the management program of all development plans, projects and regulations with power to approve or disapprove.

The intent of the Oregon Legislature on the matter of implementation can only be found by implication in the OCC&DC's legislation. The law itself is silent. But Senate Bill 100 announces a clear intent that land- and water-use management be characterized by greater state and local sharing. Sec. 1 of the Preamble to the bill states: "Except as otherwise provided in subsection (4) of this section, cities and counties should remain as the agencies to consider, promote and manage the local aspects of land conservation and development for the best interests of the people within their jurisdictions." Then subsection (5) reads: "The impact of proposed developmnet projects, constituting activities of state-wide significance upon the health, safety and welfare, requires a system of permits reviewed by a state-wide agency to carry out planning goals and guidelines prescribed for application for activities of state-wide significance throughout this state."

Through its rule-making power the Land Conservation and Development Commission will designate certain activities as "activities of state-wide significance." LCDC will either review applications for permits for such activities or will delegate that authority to another state-wide agency.

Senate Bill 100 is not clear on the significance of "areas of critical state concern." It apparently does not require a permit for all activities in such areas. My reading of the bill is that only "activities of state-wide significance" in such areas will require permits. This would be inconsistent with the intent of the bill, which is to distinguish between "areas of critical state concern" and all other areas. I assume that the LCDC will promulgate rules articulating the significance of "areas of critical state concern."

Without question estuaries and wetlands should be designated "areas of critical state concern." There are indications in Sec. 34 of Senate Bill 100 that this will be done. That section directs the department and commission to give "priority consideration" to estuarine, tide, marsh and wetland areas in preparing state-wide planning goals and guidelines. The OCC&DC has led the way by designating estuaries and wetlands as resources of "critical environmental concern" at the Salishan Conference in 1972.

This designation can have little significance if it does not mean that there will be a greater state voice in determining the use of estuarine areas. The unanswered questions are what the scope of state review will be and whether the review function will be exercised by the LCDC itself or delegated to one or several coast-wide bodies.

Once again, the classifications system offers some guidance in resolving both issues by saying that there will be more restrictive regulation in some areas than in others.

Because of over-riding state interest, the LCDC should have a direct voice in review of "activities of state-wide significance" in estuarine areas classified "development" areas. Other activities should be subject to local review procedures with provision for right of appeal to a coast-wide for all interested persons.

"Protection" areas should be treated specially. Based on size, cost, amount of land involved, or a combination of these factors, activities of a certain magnitude should require a permit from the LCDC. The policies developed by the OCC&DC should form the basis for approval or disapproval. There are precedents for such a classification of uses and areas. The State of Hawaii classifies its land and water areas into four categories: urban, rural, agriculture, and conservation. The counties administer uses in the first three districts; in conservation districts, land uses are administered solely by the State Department of Land and Natural Resources.

With increased state authority must come increased state responsibility for the effectiveness of the plan for the coast. Part of the increased cost of environmental protection should be borne by the state as a whole. Florida shares the cost of protecting its coastal zone with a $240 million bond issue passed by the voters in the state in 1972. A tax scheme might be structured to spread some of the cost to non-residential users of the resources of the Oregon coast. This is a problem which must be addressed by the OCC&DC and the LCDC.

Metals in Estuaries

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Two questions consistently recur when metal pollution in estuarine systems is discussed. First, "What is the biological significance of a metal?" Second, "What is the rate of transport of the metal through some particular system?"

Each of these questions has several manifestations. In the former case, the primary concern may be for the health of persons eating contaminated food, for the health of the food organisms themselves, for some other species of economic importance, or even for the overall stress upon a system. In the latter case the concern may involve steady-state levels associated with constant inputs; it may involve transient, accidental spill problems, or it may involve clearance times for a system once a chronic contamination has been eliminated.

The chemist addressed with such questions instinctively responds, "What is the chemical form of the metal?" After a period of silence, the chemist begins to consider alternative means for learning the answer to his question. In a number of cases, research projects have been created to approach the question of chemical form and its corollary, "What chemical reactions are changing the form?"

My purpose here is to compare the results of several studies aimed towards answering this corollary question. I will focus primarily upon differentiation between particulate and dissolved chemical forms. Distinction between these is normally made by filtration with the portion appearing in the filtrate being called "dissolved" and that retained on the filter being called "particulate." Colloidal matter passing through the filter and dissolved matter adsorbing to the filter make the analytical distinction questionable; but, because of its simplicity, filtration continues to be an important procedure.

Each of these classes consists of many chemical forms. "Particulate" matter includes detrital and weathered mineral fragments, both living and dead organic matter, coatings of organic matter of hydrous iron and manganese oxides, and matter sorbed to one or another of these. "Dissolved" includes ions (perhaps complex) and soluble,

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but electrically neutral species, as well as colloidal forms. While there have been efforts to discern each of these forms separately, relatively few such experiments have been repeated from place to place or by different analysts. Therefore, I shall focus upon only the two broader groups.

The introduction of radioactive nuclides into the environment via nuclear detonations in the 1940's and 1950's provided awareness that local, regional and global transport systems were "operative." It was clear that matter was not only transferred from one place to another, but also that it could be passed from one component of the ecosystem to another in the normal operation of that system. Not that such knowledge is particularly obscure or difficult to comprehend, but rather that few, if any, people had consciously realized the implications until radioisotopes so clearly showed them.

Because of the hazard and the mystical, invisible nature of radiations from radioactive material, great efforts were focused upon consideration of the aforesaid implications. A particularly lucid and succinct exposition of the chemists' involvement in "radioecology" was made by Waldichuk (1961). Because of such clear recognition of important questions for radioisotopes rather earlier than for elements in general, much of the knowledge available today regarding partitioning of metals comes from studies of artificial radionuclides.

In the present report three types of experiments are discussed: those involving the analysis of sediments, those in which water is analyzed and those involving direct reaction of water and sediment in an experimental configuration.

An early "process" study was reported by Johnson (1966), and Johnson et al. (1967). Johnson recognized that although the radionuclides ^{60}Co, ^{65}Zn, and ^{54}Mn were in ionic form when released in the effluent from the Hanford, Washington, reactors, they were in particulate form by the time they reached the Columbia River estuary. He reasoned that the process of mixing with seawater in the estuary exposed the particles to a changing ionic medium and that ion exchange reactions were likely.

He sought to determine directly the "ion exchangeable" portion of radionuclides by direct leaching of Columbia River sediment with seawater. Seawater removed some 40% of the ^{54}Mn, five to fifteen percent of ^{60}Co and only one percent or less of ^{65}Zn. No ^{46}Sc or ^{51}Cr was removed. He suggested that the exchangeable portion of ^{54}Mn was displaced from particles by the abundant Na^{+} and Mg^{++} ions in seawater, but that ^{60}Co and ^{65}Zn were bound to the sediment by some more specific adsorption reaction than simple cation exchange. This experiment was later repeated by Robertson et al. (1973) with the same results and conclusions.

Because these leaching experiments allowed only one to two hours of contact, Cutshall et al. (1973) and Evans and Cutshall (1973) sought to provide a longer time period for desorption. They transferred Columbia River sediment to the non-radioactive Yaquina Bay. This time up to eleven weeks of contact with seawater was provided. Again, however, about half of the ^{54}Mn was removed by seawater and very little, if any ^{65}Zn or ^{60}Co.

In the Rhine River and its estuary de Groot et al. (1971) measured metal contents of sediments. They found that metallic contamination of sediments is greatest for fine-grained material. When the effect of particle size is removed from their data, an interesting pattern of metal contents of bed sediments of the estuary is found. For several metals the concentration is lower nearer the sea. Mercury, for example, is markedly lower. The difference in metal content is interpreted as desorption or "mobilization" of the metal from sediment during transport through the estuary. Copper and zinc appear to undergo up to 80% removal from sediments during transport downstream through the estuary. For some metals, however, no change is found. Manganese content of sediment throughout the estuary is unchanging and this metal was even used to trace Rhine River sediment along the North Sea coast. The inferences from sediment analyses agree with those from the seawater leaching experiments (Johnson 1966) in that some metals are solubilized in the estuary. The order among the various metals, however, was markedly different.

A different approach was taken by Lowman et al. (1966). They carried filtered water from the metal-rich Añasco River out to sea and artificially mixed it with offshore seawater. The metal remaining in filtered samples of the mixture was followed over the course of several hours. "Soluble" concentrations of most metals declined markedly during this time. Scandium was most rapidly lost from solution, followed by cobalt, zinc and manganese. This result contrasts with that of the sediment study because the direction of the reaction is from soluble to particulate. The relative order of solubility is similar to that of the seawater leaching experiments.

Yet another approach was taken by Evans and Cutshall (1973), again in the Columbia River. If no reaction occurs during estuarine mixing, a linear relationship between metal (or radioisotope) concentration and salinity should be found. Deviations from linearity indicate that either some reaction occurs, or there is an alternative input (output) for the substance being considered. Using this approach, Evans and Cutshall (1973) found no reaction of ^{46}Sc or ^{51}Cr in the Columbia River estuary. Zinc-65 and ^{54}Mn appear to be desorbed to the extent of 30% and 50% respectively. The authors suggested that their results for ^{65}Zn differ from those of Johnson et al. (1967) because suspended particulates and bed sediments differ in sorption-desorption properties.

Let us now recapitulate the experiments reported and summarize their results. Table 1 lists essential observations from each experiment.

There are points of contrast and points of similarity in all of the reports. Each experiment indicates that some reaction occurs. Each experiment shows that scandium, the only trivalent element common to all, is least soluble among the elements studied. Among the divalent metals Hg, Cu, Zn, Co and Mn, an order of solubility roughly parallel to the Irving-Williams (1953) order for the strength of coordination complexes is seen. That order is Mn < Co < Zn < Cu < Hg. The correspondence to coordination complex formation, plus the observation that the more tightly bound metals can be desorbed by other transition metals (Johnson et al. 1967), suggests that coordinate covalent bonding is involved in transition metal adsorption.

The "degree of solubility" varies from one experiment to another and there are minor changes in the order of solubility. Conclusions based on the Rhine River bed sediment data, however, are markedly different. While there is preservation of the Irving-Williams order, it is reversed with respect to that found in the other experiments. Manganese, with the lowest tendency to form complexes, is most securely retained, while metals high in the Irving-Williams order are substantially released or "mobilized." The contrast to other results is sufficiently striking to warrant careful examination of the unique features of the Rhine River study. The Rhine study relies upon interpretation of bed sediment data, whereas the others cited are results of water or water and sediment analyses.

De Groot et al. (1971) were not unaware of the similarity of the order of mobilization to the Irving-Williams order and they suggested that organic chelating ligands were responsible for selectively leaching metals from particles. They note that an abundance of marsh vegetation roughly corresponds in space to the apparent reaction location in the Rhine. On the other hand, almost no marsh vegetation surrounds the Columbia River estuary. Thus the Columbia would lack the source of chelating substances present in the Rhine. This conclusion would suggest that other rivers with abundant vegetation, such as those passing through salt marsh estuaries, should display the "inverse order" of solubility as compared with relatively barren systems like the Columbia.

The considerable mobilization of manganese observed in the Columbia, the Mississippi (Murata, 1939), and the Hudson (Lentsch et al. 1973) could not be explained. Manganese is low in the Irving-Williams series and therefore should not be mobilized by chelating substances. In the Rhine it apparently is not mobilized. On the other hand, perhaps manganese is also mobilized in the Rhine and subsequently reprecipitated, so that the sediment concentration does not vary appreciably. "Mobilization" or desorption of metals during estuarine mixing may be a universal, inorganic chemical process roughly following the Irving-Williams series for transition metals because binding of transition metals to sediments is dominated by coordinate bonding. Subsequent reprecipitation might occur if, for example, divalent manganese is oxidized to MnO_2. During precipitation of MnO_2, other metals would be scavenged from solution as well, unless they were sequestered as complexes by soluble ligands in the water. Such sequestering would also follow the Irving-Williams series. Thus the inverted Rhine order would be compatible with that seen in the other studies cited.

The above rationalization is highly speculative. It is, however, subject to experimental verification. First, the premise that desorbed metals reprecipitate can be checked. Were this to happen, there should be a negative deviation from linear mixing at salinities higher than those where a desorption apparently occurs. There must also be a correspondence between the apparent order of solubility in an estuary and the organic matter chemistry of that estuary. It should be fairly easy to devise experiments to uncover such correspondence. Estuaries with little organic matter like the Columbia would have Mn apparently more soluble than Zn, whereas estuaries with an abundance of organic matter like the Rhine would have Zn more soluble than Mn. Quite possibly the order would be seasonal, owing to fluctuations in the production and abundance of organic matter.

Metals appear to undergo reactions in estuaries. Whether these reactions are toward increased or lessened solubility may depend upon the specific metal and estuary. Seasonal variations are possible. Changes in physical form can be expected to affect the transport routes and rates of metals in the coastal zone and their persistance in estuaries. Changes in both physical and chemical form influence the biological significance of metals because toxicity and assimilation efficiency both depend heavily upon chemical form.

ACKNOWLEDGMENTS

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TABLE 1: RESULTS OF DESORPTION STUDIES

EXPERIMENT	% DESORBED Sc	Hg	Cu	Zn	Co	Mn	ORDER OF "SOLUBILITY"	REFERENCE
Leach Columbia River Bed Sediment in Sea Water (Radioisotopes)	0	-	-	1	10	40	Sc < Zn < Co < Mn	Johnson et al. (1967) Robertson et al. (1973)
Analyze Rhine River Bed Sediments	0	95	85	80	-	0	Sc, Mn < Zn < Co < Hg	de Groot et al. (1971)
Analyze Filtered Columbia River Water (Radioisotopes)	0	-	-	30	-	50	Sc < Zn < Mn	Evans & Cutshall (1973)
	% PRECIPITATED AFTER 2 HRS.							
Mix Añasco River Water with Sea Water	100	-	8	65	100	25	Sc < Co < Zn < Mn	Lowman et al. (1966)

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The Use of Standardized Marine Algal Bioassays for Nutrient Assessment of Oregon Coastal Estuaries

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INTRODUCTION

The need for a standardized primary producer bioassay for nutrient assessment in marine and estuarine waters has led to the development of the Marine Algal Assay Procedure (MAAP) which is capable of determining nutrient limitation and algal growth inhibition in waters varying in salinity from virtually zero to full-strength seawater (Specht & Miller, in press). The purpose of the research described herein is to show the utility and value of such a standardized bioassay in the comparative assessment of field samples from estuarine waters in terms of nutrient loading. In order to develop such information, field samples from Oregon coastal estuaries taken at various seasons were analyzed with the MAAP, compared with data produced from artificial seawater (ASW) laboratory studies, and correlated with chemical analyses of the samples.

Many assay systems have been developed for specific purposes, such as determining the toxicity of various compounds. Most have found only limited use, either because they require sophisticated equipment and professionally trained personnel to function, or do not address problems associated with the presence of nutrients. Arguments have been made for *in situ* survey type assays which can indicate community stress (Borowitzka, 1972; Valentine, Soule, and Samollow, 1973) and recognize the multiple character of pollutants imposed upon the community. The presence, absence, or alteration of the character of indicator species can demonstrate low or sublethal levels of pollutants. However, it is difficult to use these methods to ascribe the damage due to any one specific pollutant. Algal nutrient bioassays have been more successful in this respect, but most attempts have been based on toxicity-LD-50 type studies that use inocula at levels of 10^4 to 10^6 cells per ml, which exceed normal phytoplankton population levels by several orders of magnitude and pose nutrient carryover problems (Atkins, 1923; Smayda, 1970). The Freshwater Algal Assay Procedure: Bottle Test (NERP/AAP, 1971), a widely accepted standardized nutrient bioassay, has been designed to minimize most of these sources of bias. Algal bioassays that have been adapted for marine waters are limited to use over a narrow salinity range (Dierberg, 1972; Tallqvist, 1973), exclusively utilize indigenous algal populations (Goldman, Tenore and Stanley, 1973; Thayer, 1974; Burrows, 1971), and/or make excessive demands on time, sophisticated equipment, and personnel (Dunstan & Menzel, 1971); although some admirably serve their intended purpose. Except for the AAP, none of these assays made much of an attempt at standardization (Tarzwell, 1971; Fitzgerald, 1972).

EXPERIMENTAL AND DISCUSSION

Young and Barber (1973) have shown that the biomass response to natural samples by an indigenous algal inoculum was virtually the same as a pure culture inoculum of the dominant bloom organism. Since the enumeration or other evaluation of indigenous mixed populations can be laborious and time consuming or potentially misleading as with chlorophyll estimations, the use of unialgal test cultures is described. These include *Dunaliella tertiolecta* Butcher (DUN clone), a green flagellated unicellular alga, and a diatom, *Thalassiosira pseudonana* Hasle and Heimdal (CN clone) (*Cyclotella nana* Hustedt). These two algae are common laboratory types, well known physiologically and experimentally. They are particularly easy to count with an electronic particle counter, making frequent enumeration of large numbers of samples practical. In our laboratory, *Dunaliella*, particularly, grown in artificial seawater (ASW) under controlled conditions (Specht and Miller, in press), has shown wide salinity tolerance (5‰ to 35‰), critical sensitivity to phosphorus (2.5 μg P/l; 0.08 μg atoms/l) and to nitrogen (10 μg NH_4^+ -N/l; 0.714 μg atoms/l; 25 μg NO_3^- -N/l; 1.786 μg atoms/l) as shown in the three dimensional surface-response plots in Figures 1, 2, 3, and Table 1. Note that responses to nutrient increases were linear, while salinity had relatively little effect except at very low levels.

The rationale of nutrient spiking of natural samples assumes that one of several major nutrients is limiting to algal growth and that all others are in excess (NERP/AAP, 1971). One may supply that nutrient, either in excess or in increments, demonstrating statistically significant growth above the control. Since the major nutrient pollutants of concern are nitrogen and phosphorus (Ryther, 1954; Ryther and Guillard, 1959; Ryther and Dunstan, 1971; Barlow, Lorenzen, and Myren, 1963; NAS, 1971; Thayer, 1974) and are the only nutrients for which there is any real hope of controlling, it is assumed that if no response is generated by the addition of nitrogen or phosphorus, either a toxic or inhibitory substance is present or the alga is growth-limited by a micronutrient, probably iron or manganese. In many natural situations, algal growth may be light limited, especially where domestic or industrial wastes are discharged or during the winter months.

Growth of Dunaliella at various salinities and phosphorus concentrations in ASW. Dry weight at day 10.

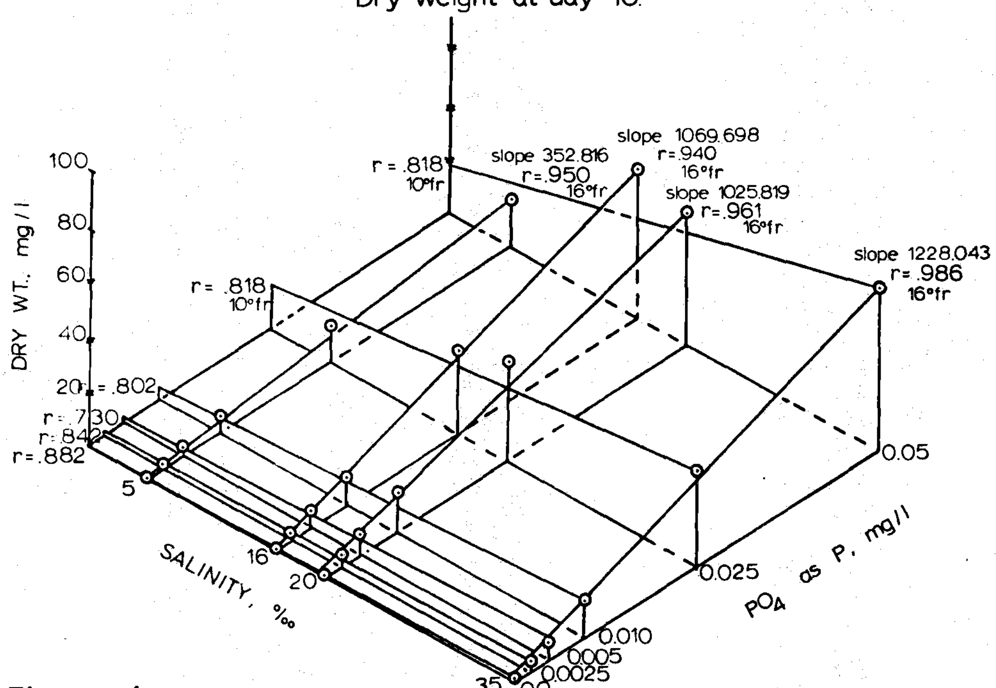


Figure 1

Growth of Dunaliella at various salinities and
nitrate nitrogen concentrations in ASW.
Dry weight at day 10.

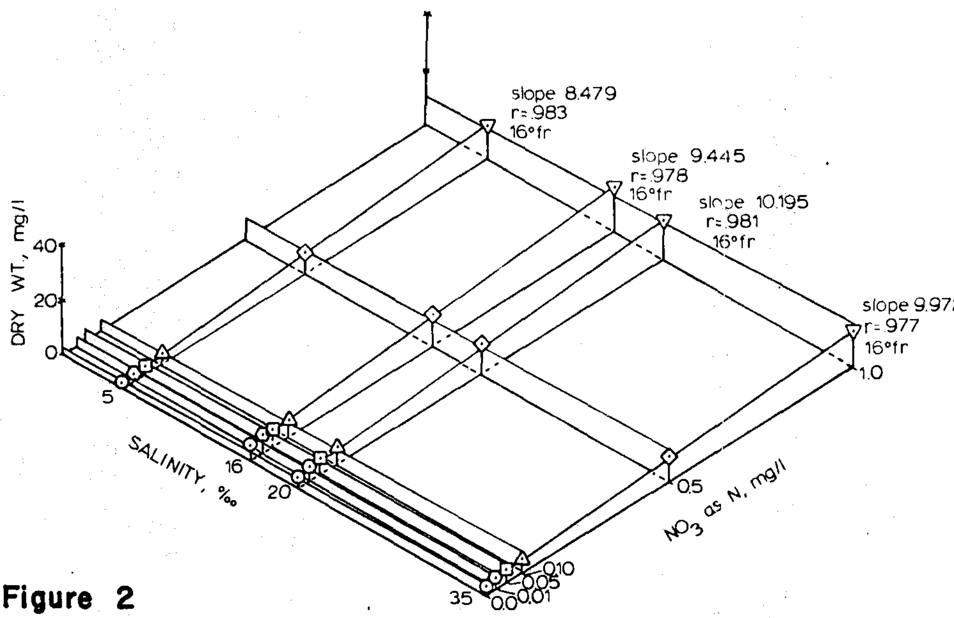


Figure 2

Growth of Dunaliella at various salinities and
ammonia nitrogen concentrations in ASW.
Dry weight at day 10.

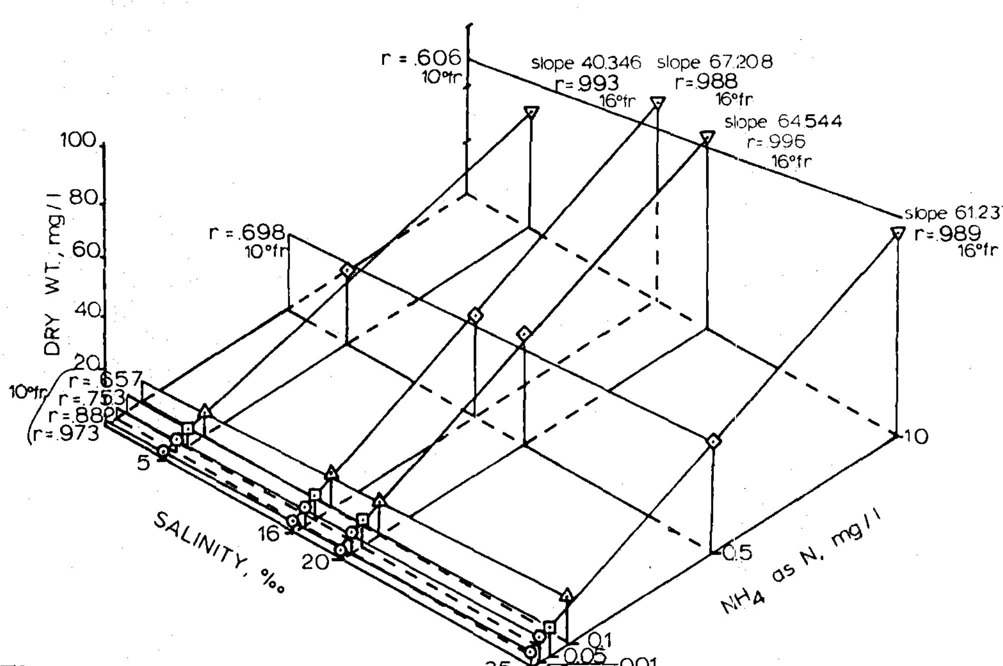


Figure 3

TABLE 1

BIOMASS PRODUCED PER UNIT OF NUTRIENT BY DUNALIELLA AT DAY 14 IN DEFINED MEDIA

Nutrient / Salinity	mg dry weight/µg of nutrient			P:N ratios	
	P	$NO_3^- - N$	$NH_4^+ - N$	$P:NO_3^- - N$	$P:NH_4^+ - N$
5 ‰	0.557 $\pm$0.158	0.0096 $\pm$0.0014	0.0747 $\pm$0.0075	1:58	1:7.5
16‰	0.930 $\pm$0.240	0.0308 $\pm$0.0394	0.0844 $\pm$0.0058	1:30.2	1:11.0
20‰	1.170 $\pm$0.164	0.0331 $\pm$0.0379	0.0766 $\pm$0.005	1:35.3	1:15.3
35‰	1.129 $\pm$0.232	0.0315 $\pm$0.0361	0.0765 $\pm$0.0193	1:35.8	1:14.8
Average*	1.076	0.0318	0.0796	1:33.8	1:13.5

*Average is calculated from the 16 ‰, 20‰, and 35‰ data only.

Some preliminary bioassays were made to determine the effect of free chlorine, ammonia and chloramine, normal products in sewage treatment chlorination procedures, on biomass production and levels of stasis and toxicity (see Figure 4) with both *Dunaliella* and *Thalassiosira*. ASW (30‰ salinity) was spiked with 1.0, 0.1, 0.01, 0.001 mg/l of free chlorine, chloramine, and ammonia nitrogen. Vitamins and silica were provided for *Thalassiosira* in the ASW.

From Figure 4, it can be seen that free chlorine was algicidal at 1.0 mg/l (but not at 0.1 mg/l or below) to *Dunaliella*, whereas chloramine was algicidal at 1.0 and 0.1 mg/l. At 0.001 mg/l or less, chloramine was not algicidal. Ammonia nitrogen was stimulatory at all levels tested.

Free chlorine was algicidal at 1.0 mg/l, algistatic at 0.1 mg/l, and not inhibitory below that level to *Thalassiosira*, whereas chloramine was algicidal at 1.0, 0.1 mg/l, but not below. Ammonia was stimulatory at all levels tested. Algistatic and algicidal concentrations were determined by removing a small inoculum from an inhibited culture after day 10 and reinoculating into fresh control media, observing for subsequent viability.

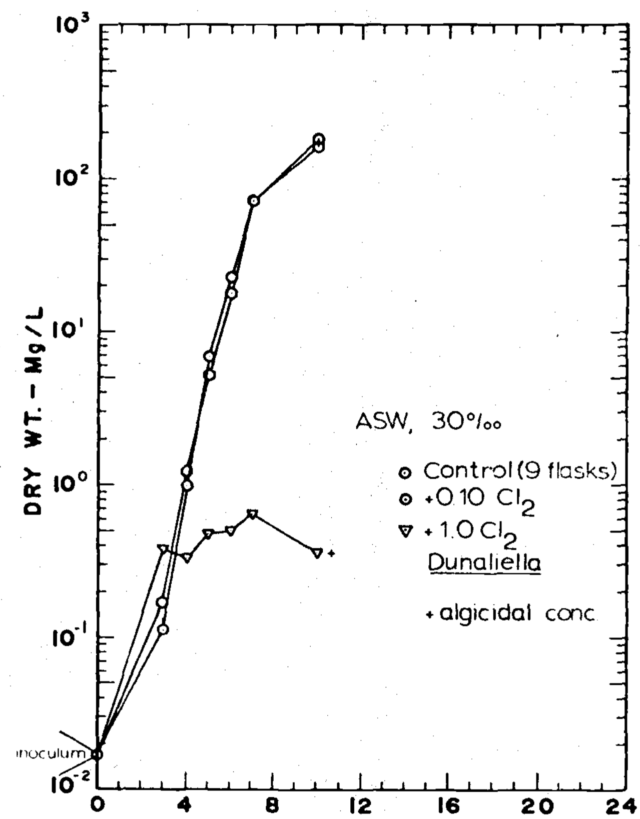


FIGURE 4A

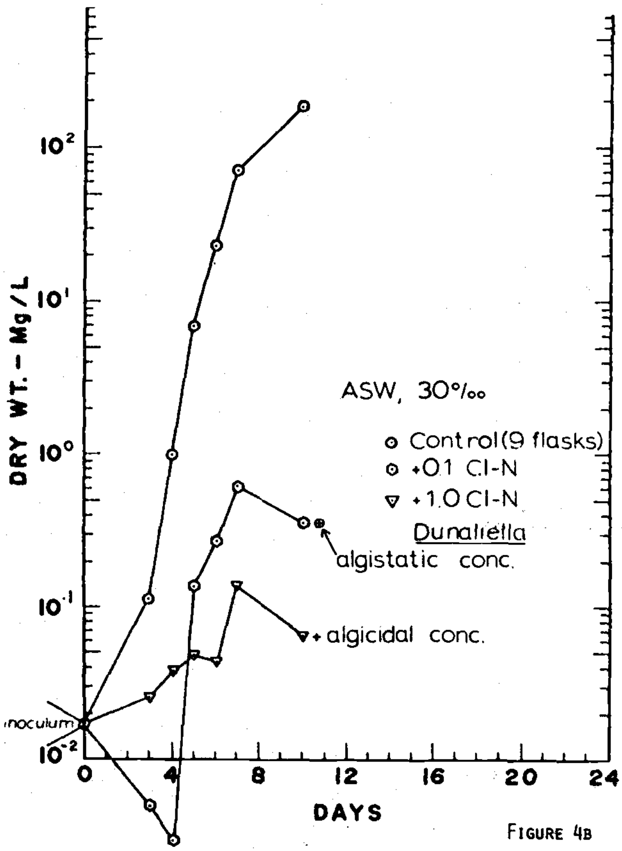


FIGURE 4B

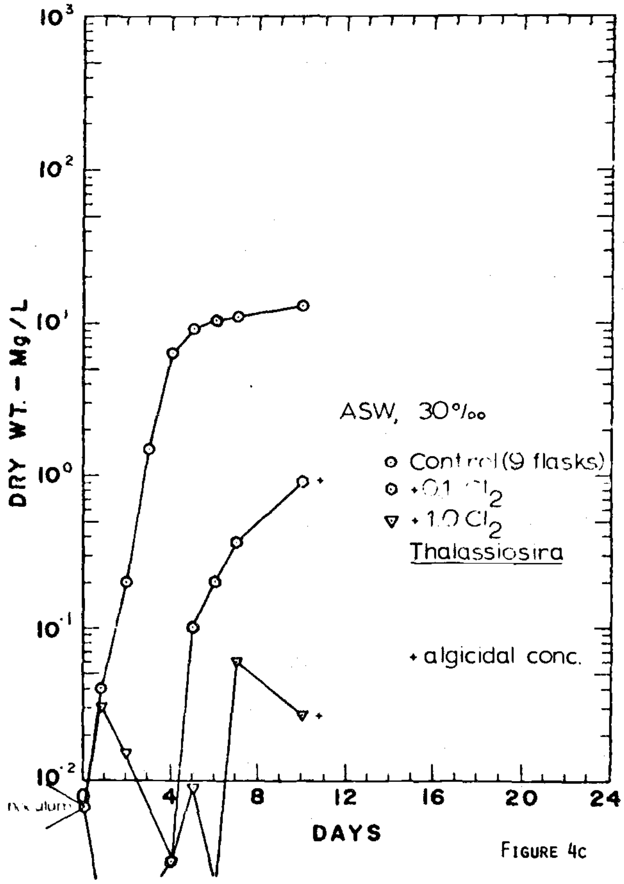


FIGURE 4C

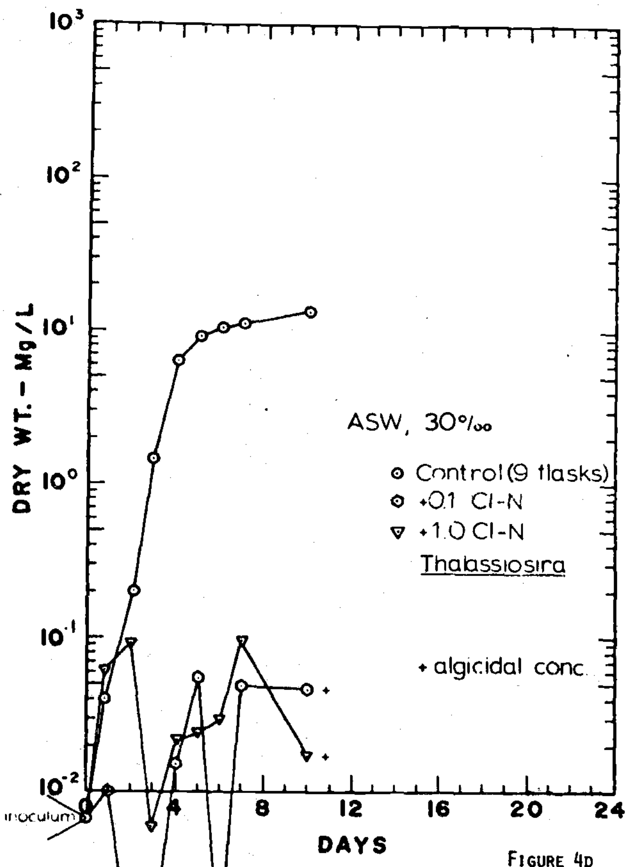
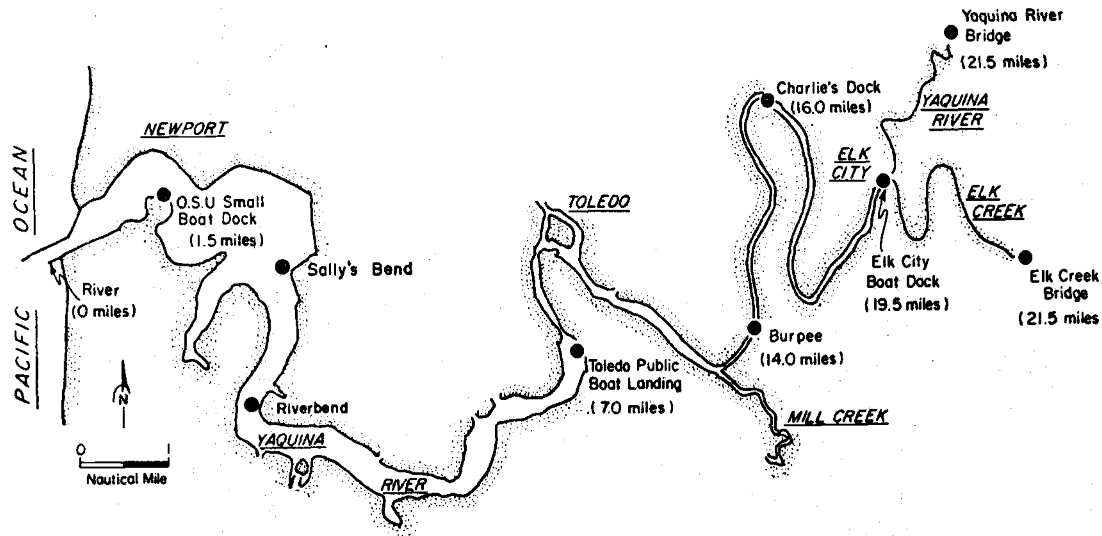


FIGURE 4D

Initial testing was done with field samples taken from various points in the Yaquina estuary, Newport, Oregon, from the Oregon State University (OSU) Dock station up to and beyond tidewater above Elk City (see Figure 5).

Initially, the assumption was made that estuaries, like coastal marine waters, would be nitrogen limited (Ryther and Dunstan, 1971; Goldman, Tenore, and Stanldy, 1973; Welch, 1968; Eppley et al., 1971). However, the assay, using *Dunaliella* defined the boundary point in the Yaquina estuary from nitrogen limited growth (seaward) to phosphorus limited growth (from tributary inflows). This changeover evidently takes place where the tributary water (phosphorus poor and nitrogen rich) meets incoming tidal water (phosphorus rich and nitrogen poor).

This interface boundary moves seaward during the winter rains as far downstream as the OSU Dock at low water and farther upstream during the dry late summer months past the Burpee station. Figures 6 and 7, illustrating growth responses of *Dunaliella* in control, phosphorus spiked, and nitrogen spiked flasks, show the alternating potential nutrient limitation at a given station on high and low tides. This documents the



MARINE ALGAL ASSAY FIELD SAMPLING SITES
YAQUINA ESTUARY, NEWPORT, OREGON

Figure 5

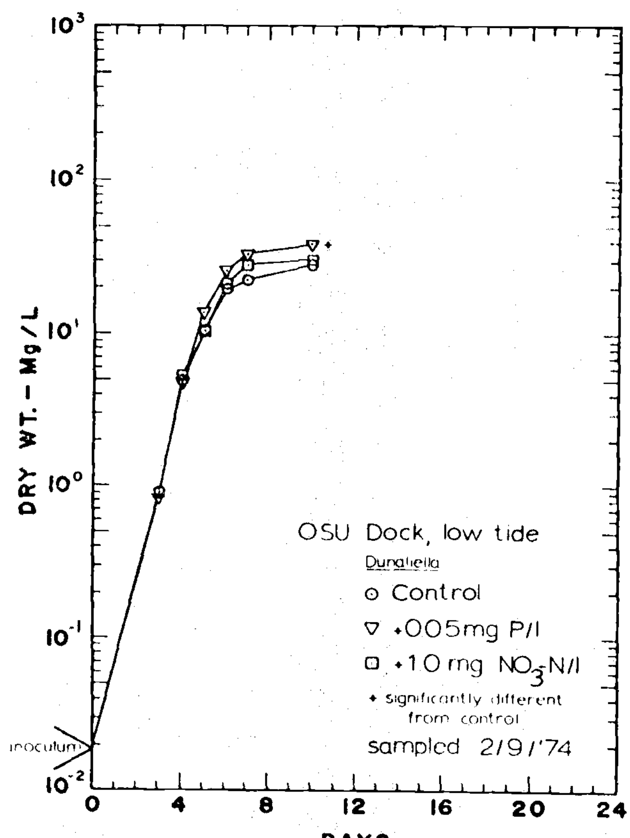


FIGURE 6A

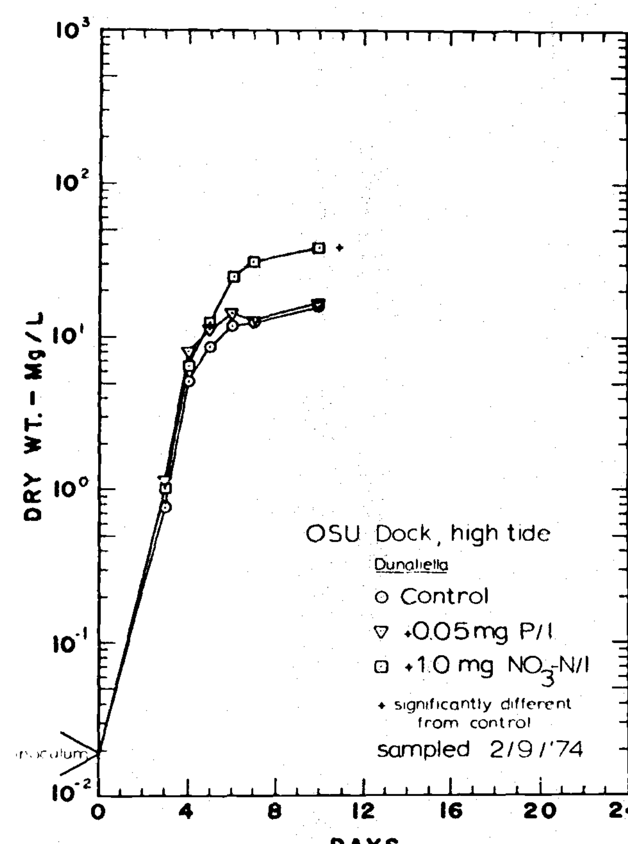


FIGURE 6B

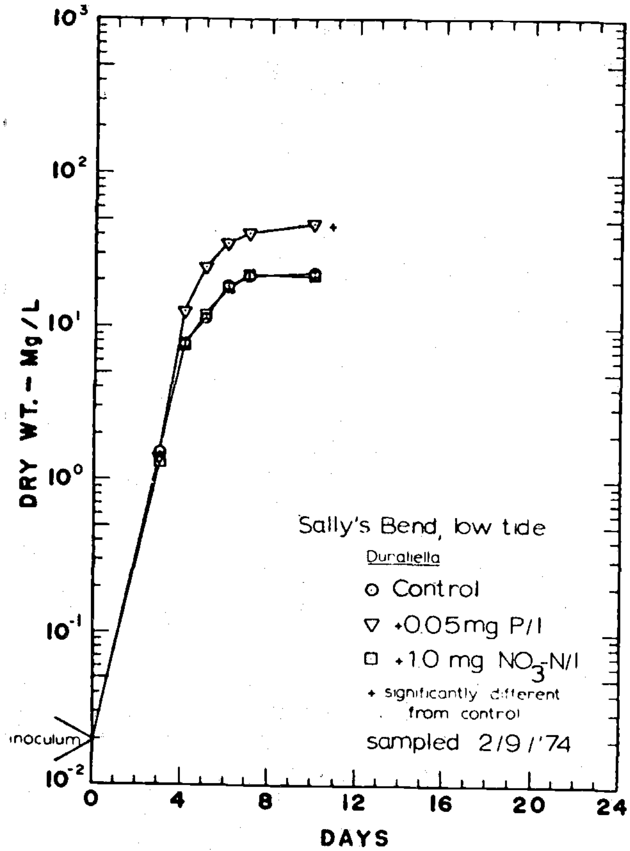


FIGURE 6C

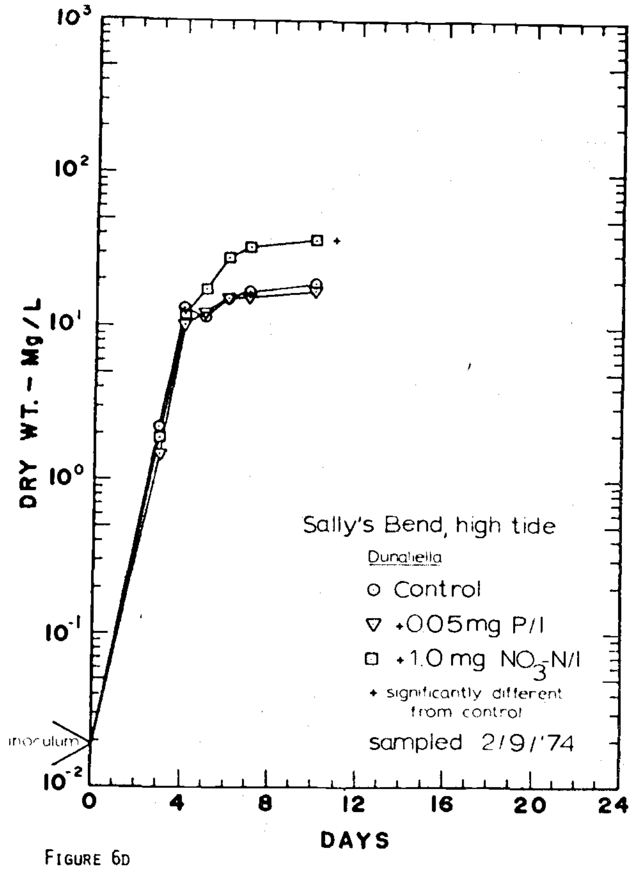


FIGURE 6D

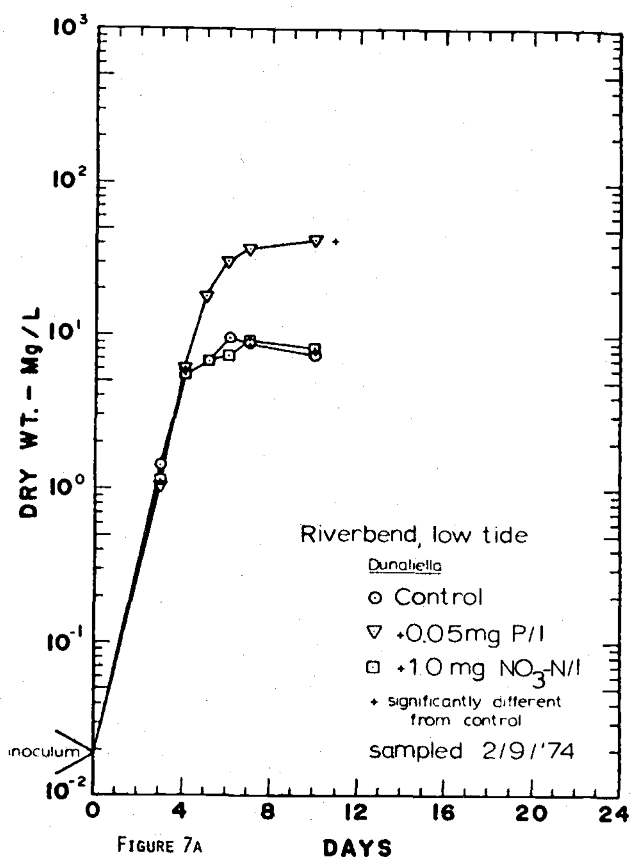


FIGURE 7A

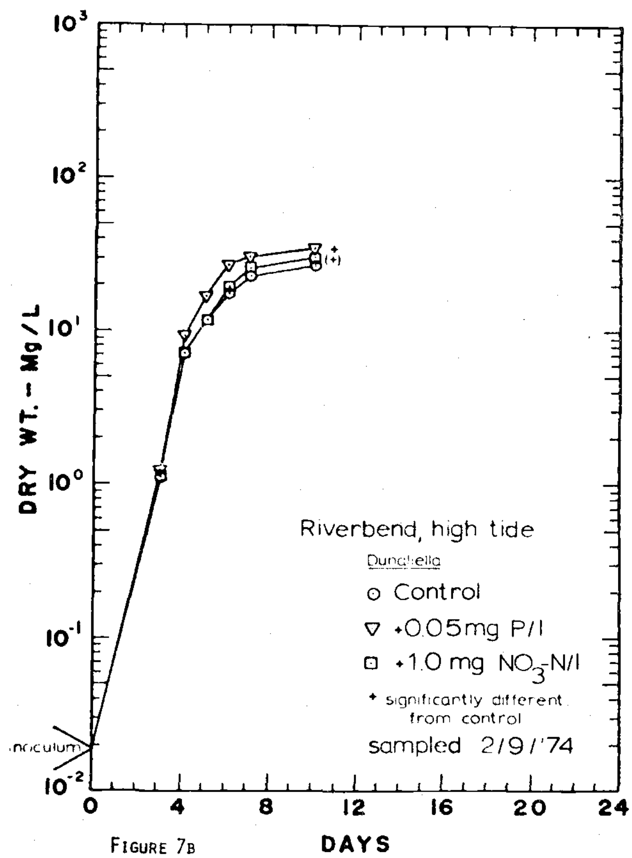


FIGURE 7B

movement of the tidal plug upstream into the estuary. Table 3 shows the control dry weights, growth limiting nutrient, salinity, phosphorus and nitrogen levels, and the dry weight produced per unit of the limiting nutrient from samples taken February 9, 1974, as compared with biomass produced in ASW shown in Table 1.

Also shown are linear regressions of the limiting nutrient against dry weight produced as opposed to the influence of salinity. It is interesting to note as in Figures 1-3, the degree of dependence and linearity of algal growth upon the limiting nutrient concentration, rather than upon salinity. As can be seen in Figures 1, 2, and 3, growth varies only slightly in relation to the salinity, especially at the lower nutrient concentration levels. This appears to hold true in this series of field samples as well. Table 2 shows similar data and calculations at the same stations for samples t taken on December 1, 1973. During that period, extremely heavy rains and flooding caused a marked flushing of nitrogen into the estuary. The heavy sediment load probably caused some light limitation.

Figure 8 shows the growth responses of control samples from midsummer, 1972, when all stations sampled were nitrogen limited. The points are plotted twice, using the horizontal axis to represent total N in the case of the upper line, and salinity on the lower line (the regression calculation has seven degrees of freedom). The plot shows the dependence of growth response on nitrogen concentration as opposed to salinity.

Figure 9 shows the ability of *Dunaliella* to respond to low level nitrogen spikes in a natural water sample and illustrates the changeover from nitrogen limitation to phosphorus limitation. In this case, in addition to the control, nitrate nitrogen was added at the levels of 0.02, 0.1, 0.2, 0.5, and 1.0 mg/l as nitrogen as well as a combination spike of 1.0 mg nitrogen and 0.05 mg phosphorus/l. As can be seen, excluding the combination spike, growth started to level off just below 0.5 mg N/l, plateauing at about 23 mg/l dry weight with the 1.0 mg/l spike. However, when 0.05 mg P/l was added in addition to the 1.0 N/l, approximately 36 mg dry weight/l was attained. If all points on the plot are considered, except the 1.0 mg N/l spike, a line of very good fit can be calculated (r=0.986, t=26.7, with 19 degrees of freedom, significant at the 0.1% level) showing that about 97 percent of the change in dry weight can be attributed to a change in the level of nitrogen present. If one considers only nitrogen, the plateau of 23 mg dry weight/l defined by the 0.5 and 1.0 mg N/l spikes demonstrates the advent of phosphorus limitation in this sample. The multiple levels of spikes also show that when nitrogen is limiting, growth responses are linear with respect to the spike level until some other nutrient or factor becomes limiting.

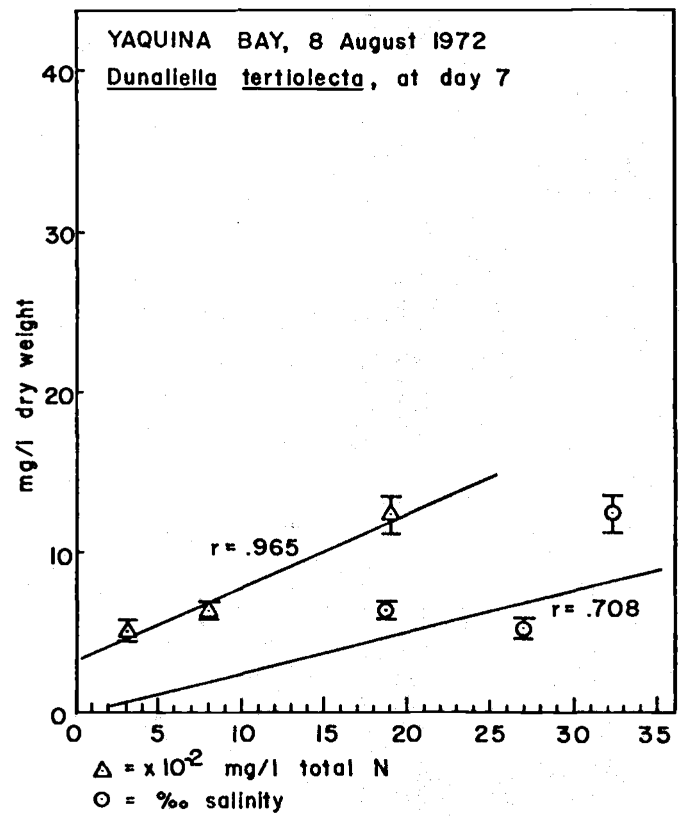


Figure 8

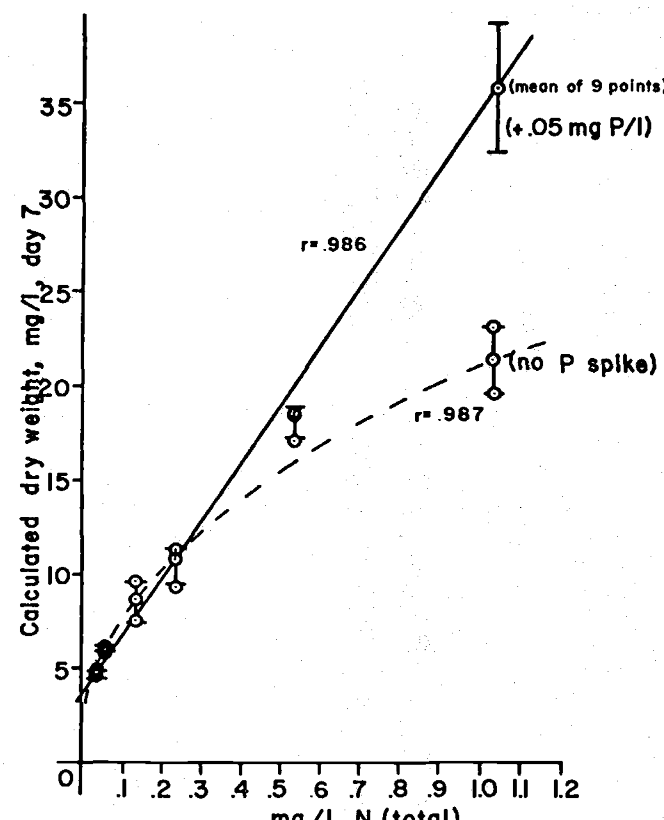


Figure 9

TABLE 2

Algal assay growth response and associated parameters from low water-high water samples collected 12/1/73
(Surface grab samples, membrane filtered)

Treatment / Sampling Station	OSU Dock low tide	OSU Dock high tide	Sally's Bend low tide	Sally's Bend high tide	River Bend low tide	River Bend high tide
Control dry wt.,[†] day 10, mg/l	32.8	33.	8.57	12.8	12.6	7.89
+ 0.05 mg P/l	37.3	36.1	44.8*	45.7*	47.2*	45.4*
+ 0.02 mg N/l	30.4	27.3	5.09	14.0	10.5	5.53
+ 1.0 mg N/l	31.5	32.8	7.31	14.1	10.6	5.72
+ 0.05 mg P/l +1.0 mg N/l	77.7*	73.1*	43.6*	65.3*	58.4*	41.9*
Growth limiting nutrient	P	(P)	P	P	P	P
Salinity, ‰	13.2	13.0	6.5	7.4	8.1	7.2
Ortho-P, mg/l	0.035	0.030	0.024	0.022	0.016	0.014
N (NO_2+NO_3+NH_4) mg/l	0.674	0.690	0.921	0.918	0.912	0.977
mg dry wt/μg P	0.911	1.1	0.357	0.582	0.785	0.563
mg dry wt/μ N	0.048	0.047	0.009	0.013	0.013	0.008
mg dry wt/μg of the limiting nutrient in ASW (Specht & Miller, in press) adj. for salinity	0.836	0.831	0.623	0.654	0.659	0.629

Linear regression of parameter vs dry wt.	Slope	Intercept	Correlation coefficient (r)	t-test, sign. of (r)	# degrees freedom
P (P limited samples)	1150.0	-6.69	0.897*	8.13	16
N (P limited samples)	-87.7	92.7	-0.964	-14.7	16
Salinity ‰	3.77	-16.6	0.959*	13.6*	16

*indicates statistically significant difference

[†] all dry weights are geometric means of triplicate samples

TABLE 3

Algal assay growth response and associated parameters from low water-high water samples collected 2/9/74
(Surface grab samples, membrane filtered)

Treatment / Sampling Station	OSU Dock low tide	OSU Dock high tide	Sally's Bend low tide	Sally's Bend high tide	River Bend low tide	River Bend high tide
Control dry wt.,† day 10, mg/l	28.9	16.8	21.8	19.2	7.35	27.5
+ 0.05 mg P/l	37.3	17.1	46.2	17.3	43.8	34.7
+ 1.0 mg N/l	30.5	38.8*	21.6	36.4*	8.1*	31.3*
Growth limiting nutrient	P	N	P	N	P	P (N)
Salinity, ‰	19.0	29.0	13.8	28.2	6.7	22.8
Ortho-P	0.024	0.027	0.021	0.027	0.014	0.024
N (NO_2+NO_3+NH_4) mg/l	0.53	0.234	0.685	0.263	0.818	0.478
mg dry wt/μg P	1.20	0.621	1.04	0.710	0.524	1.15
mg dry wt/μg N	0.054	0.071	0.031	0.072	0.008	0.057
mg dry wt/μg of limiting nutrient in ASW (Specht & Miller, in press) adj. for salinity	1.11	0.077	0.810	0.076	0.614	1.16

Linear regression of parameter vs dry wt.	Slope	Intercept	Correlation coefficient (r)	t-test, sign. of (r)	# degrees freedom
P (of P limited samples)	2090.0	-21.9	0.996*	35.5*	10
N (of N limited samples)	42.1	7.9	0.990*	19.2*	7
Salinity	0.359	13.1	0.392	1.71	16

*indicates statistically significant difference

†all dry weights are geometric means of triplicate samples

Figure 10 shows the sampling sites for the southern Oregon estuaries sampled July 25, 1973, and Figures 11 and 12 show the growth responses and the nutrient limited status of these estuaries at the time. The Umpqua River appeared phosphorus limited at the time. The last graph in Figure 12 shows the relative status of the six estuaries in unspiked controls.

Figures 13, 14, and 15 show the growth responses of *Dunaliella* and *Thalassiosira* in Yaquina Bay and four estuaries to the north sampled October 30, 1973. These included Sand Lake and Netarts Bay, which are rural unpolluted estuaries and Siletz Bay and Nestucca Bay which receive some sewage and industrial pollution (Percy, et al., 1973). Nestucca Bay was phosphorus limited, but Sand Lake showed the lowest growth in the controls. Because of scheduling problems, the *Thalassiosira* runs were terminated early but nonetheless showed the same growth responses as *Dunaliella*.

SUMMARY

The use of the described standardized Marine Algal Assay Procddure has shown that estuaries of the Oregon Coast are generally nitrogen limited in the summer and potentially phosphorus limited in the winter-spring rainy season. The assay is capable of detecting the availability of low levels of phosphorus and nitrogen to algae, as well as the presence of certain toxic compounds which mask the growth promoting effect of excessive levels of critical nutrients. This assay may be used to help predict what the potential of nutrient changes may be on a body of estuarine water.

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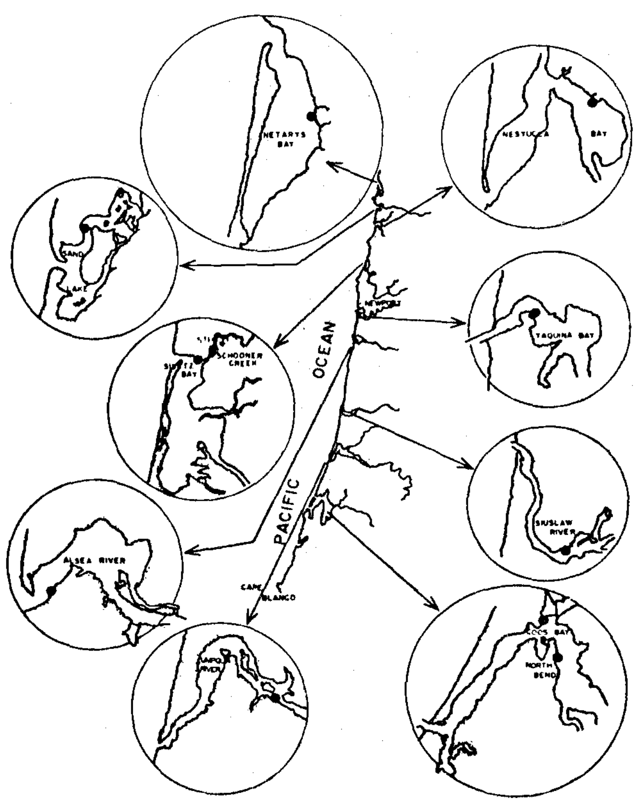
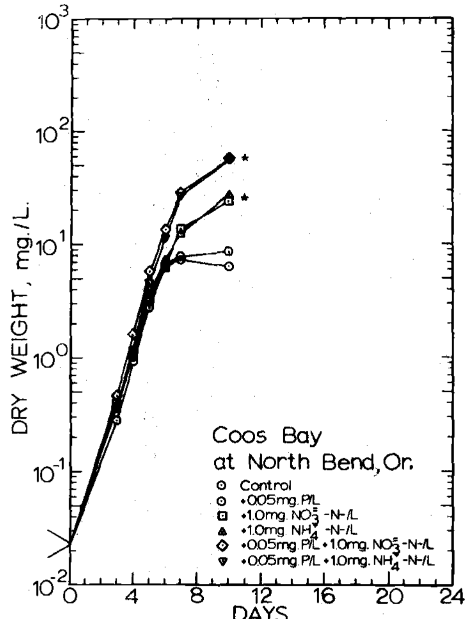
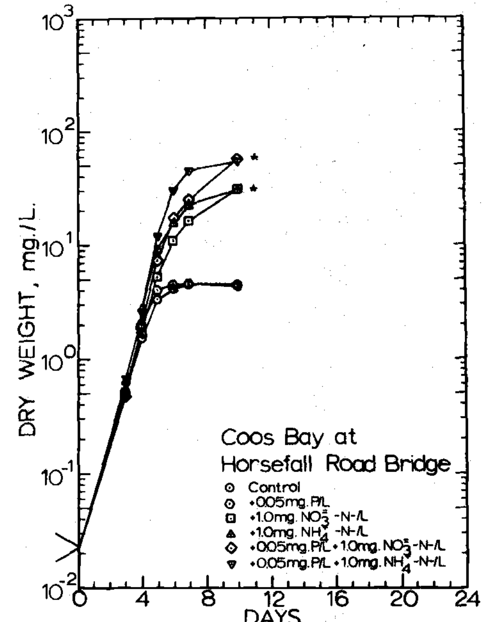


Figure 10 MARINE ALGAL ASSAY FIELD SAMPLING SITES
·OREGON COASTAL ESTUARIES·

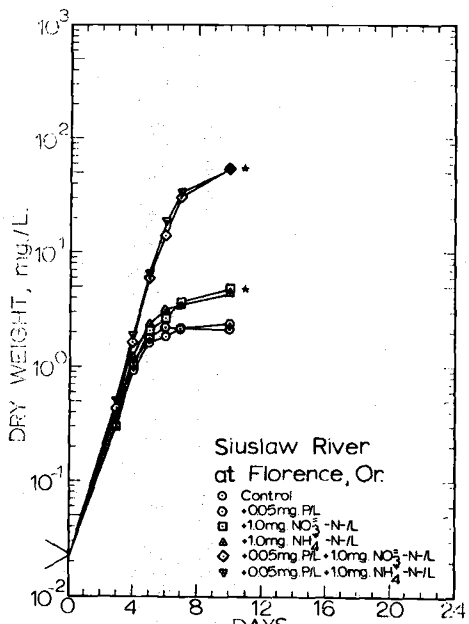
(NOT TO SCALE)



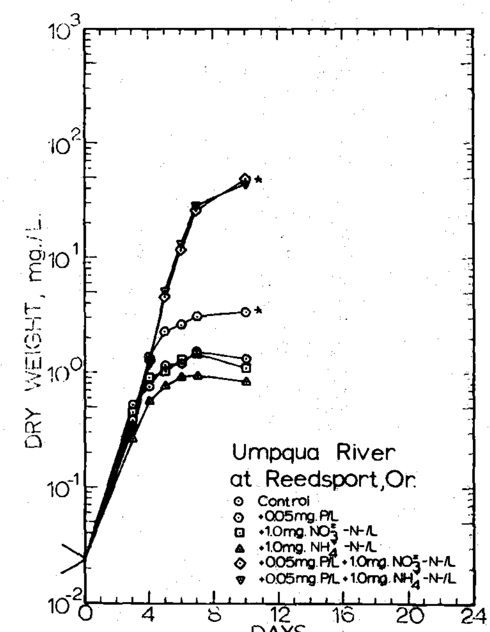
Growth response of <u>Dunaliella tertiolecta</u>



Growth response of <u>Dunaliella tertiolecta</u>

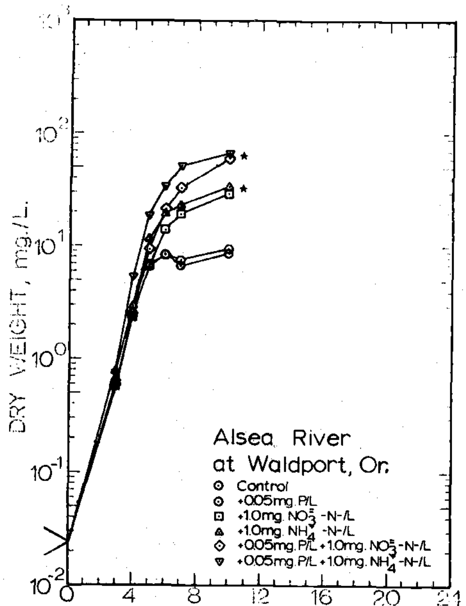


Growth response of <u>Dunaliella tertiolecta</u>

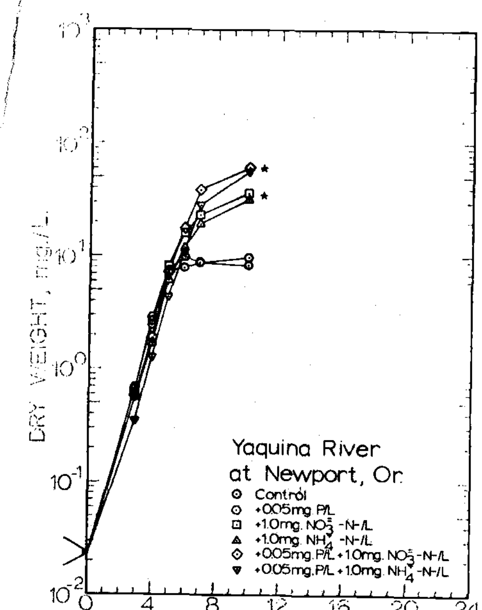


Growth response of <u>Dunaliella tertiolecta</u>

Figure 11



Growth response of Dunaliella tertiolecta



Growth response of Dunaliella tertiolecta

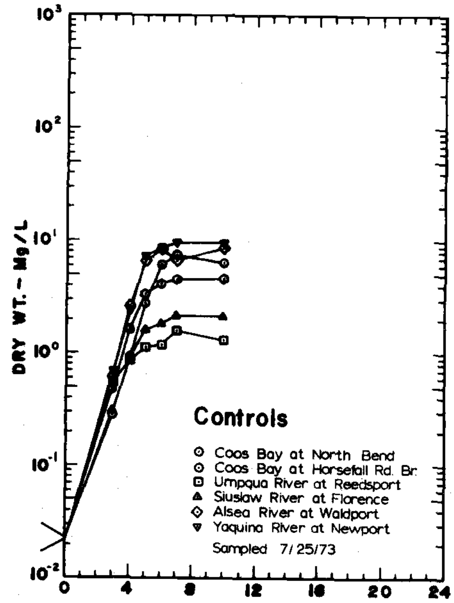


Figure 12

Growth response of Dunaliella

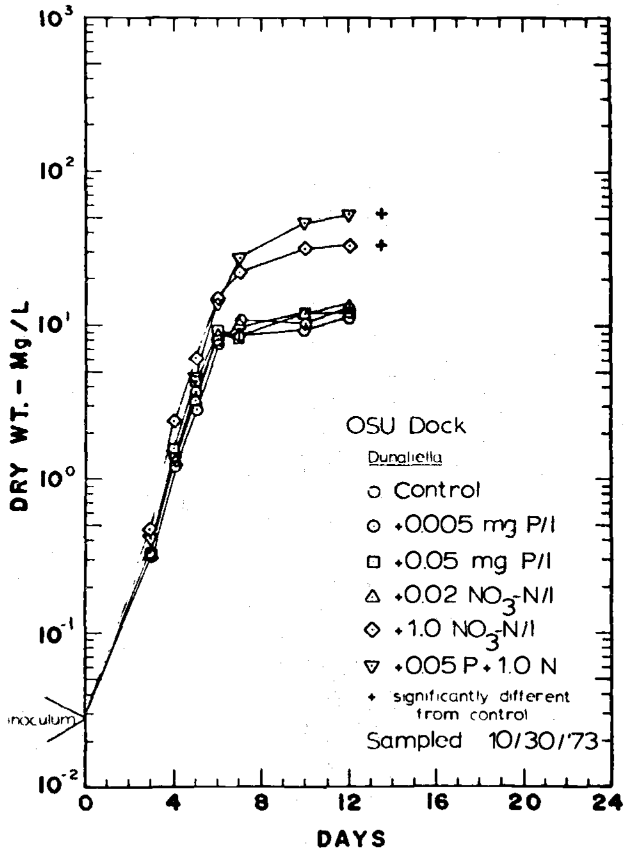


FIGURE 13A

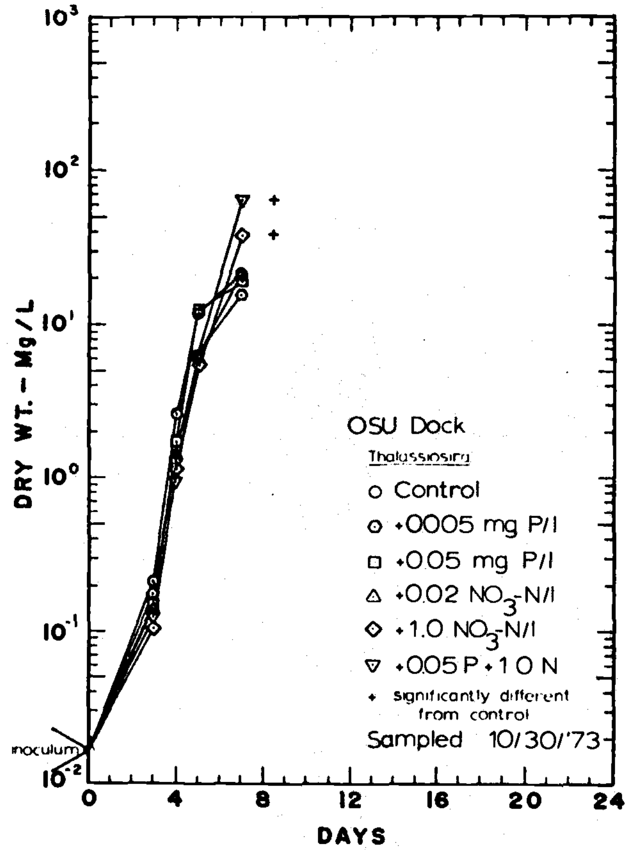


FIGURE 13B

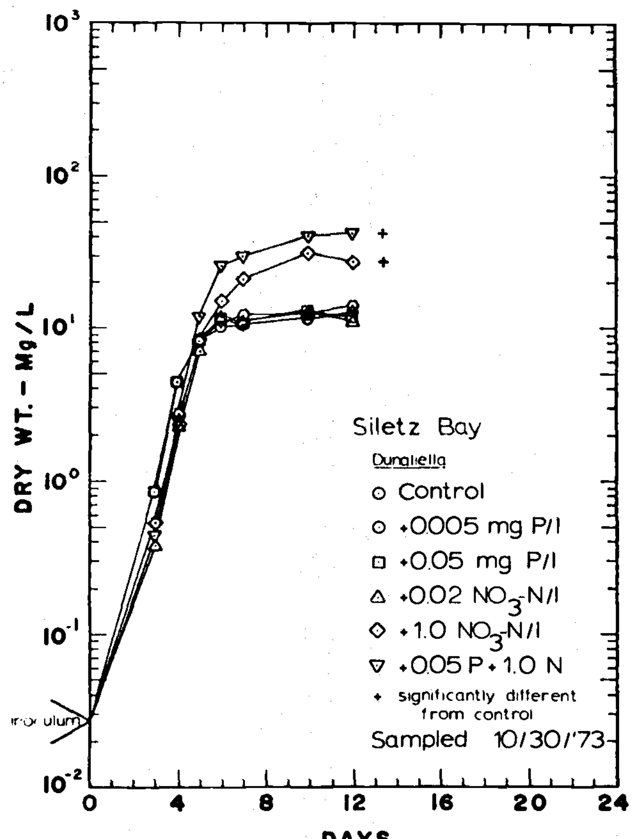


FIGURE 13C

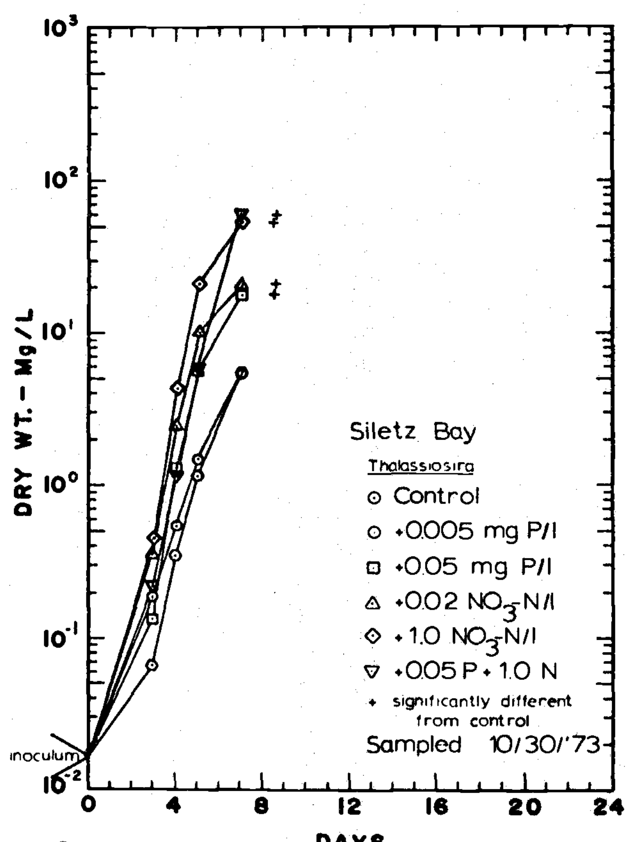


FIGURE 13D

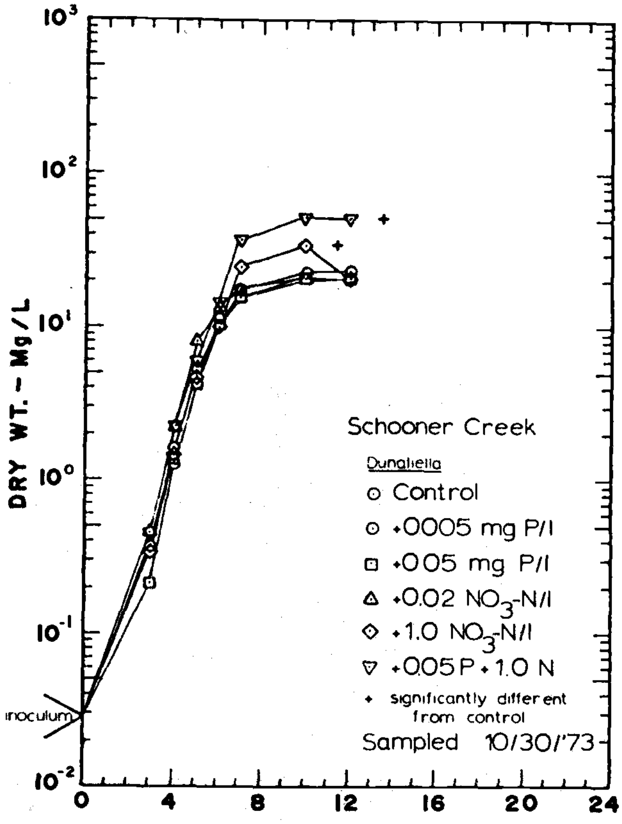


FIGURE 14A

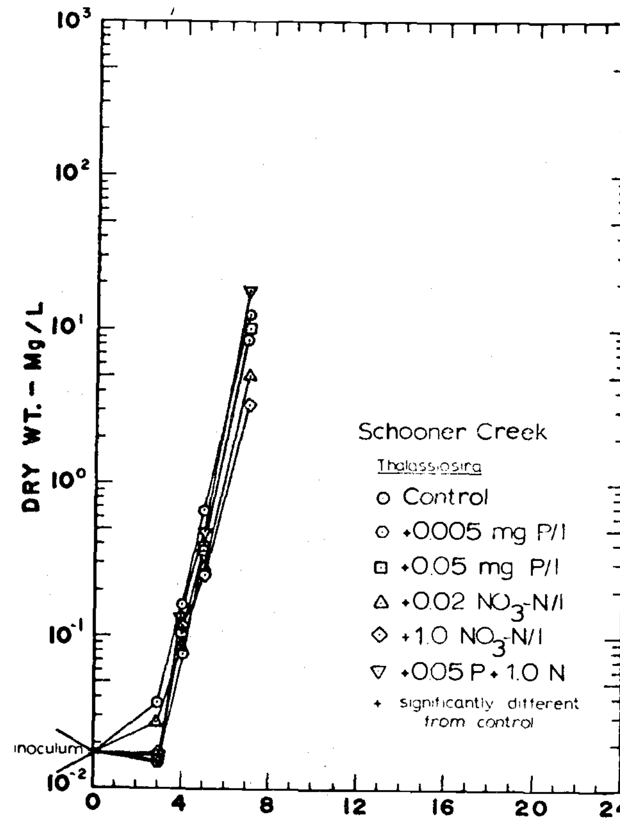


FIGURE 14B

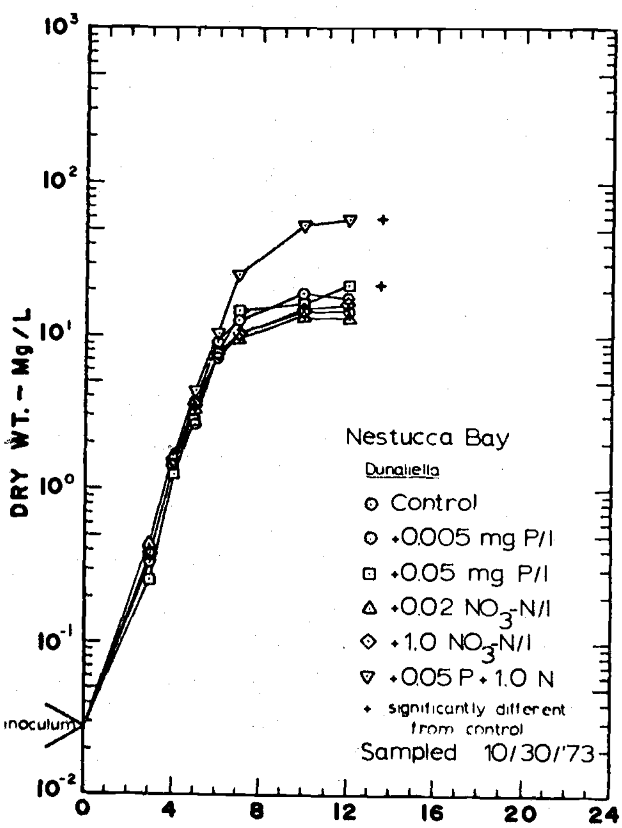


FIGURE 14C

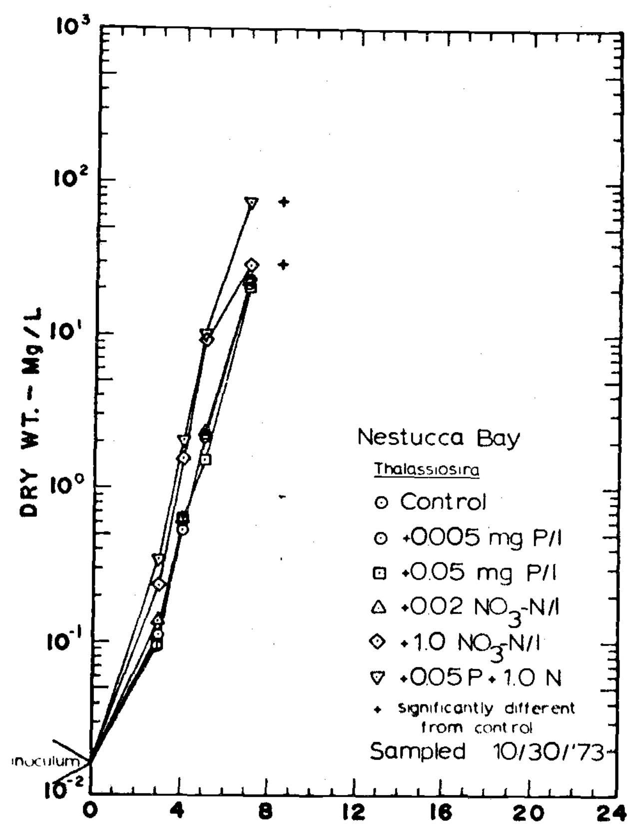


FIGURE 14D

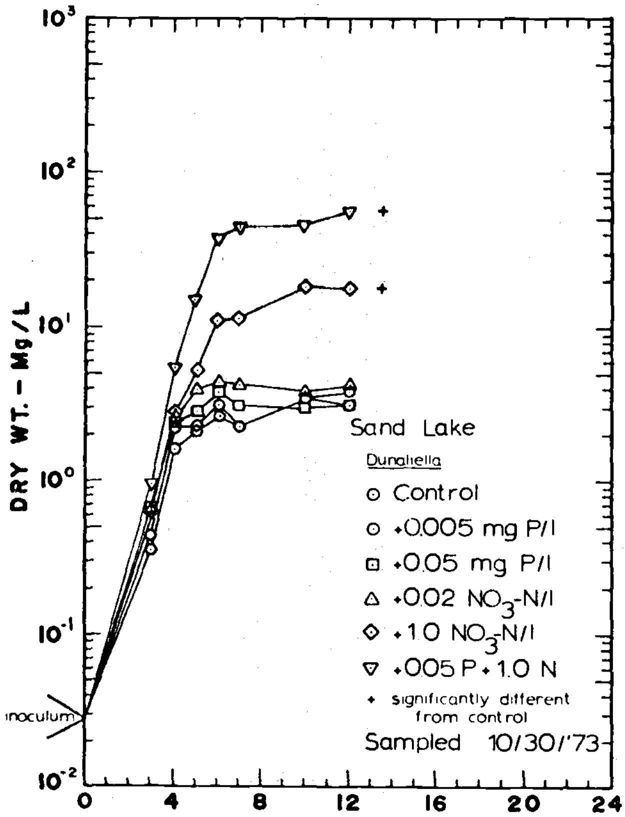


FIGURE 15A

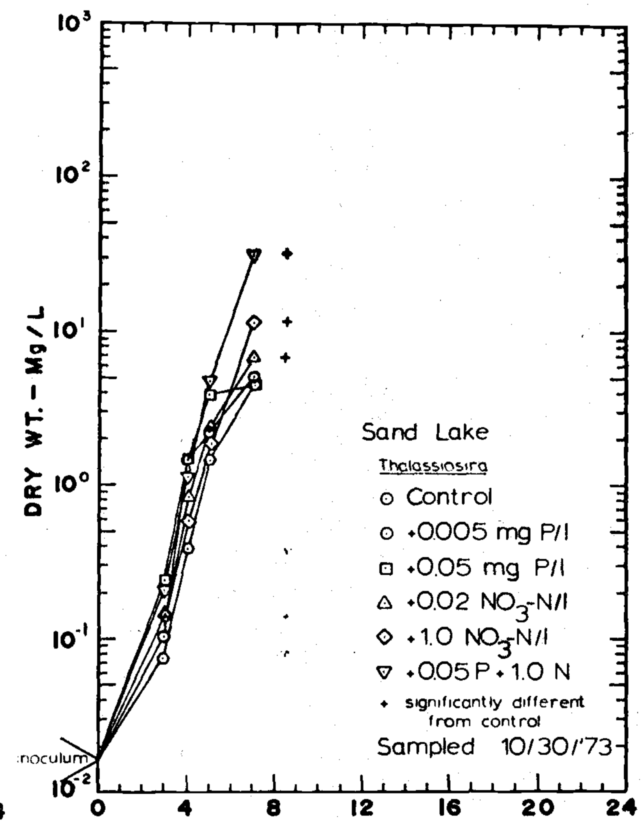


FIGURE 15B

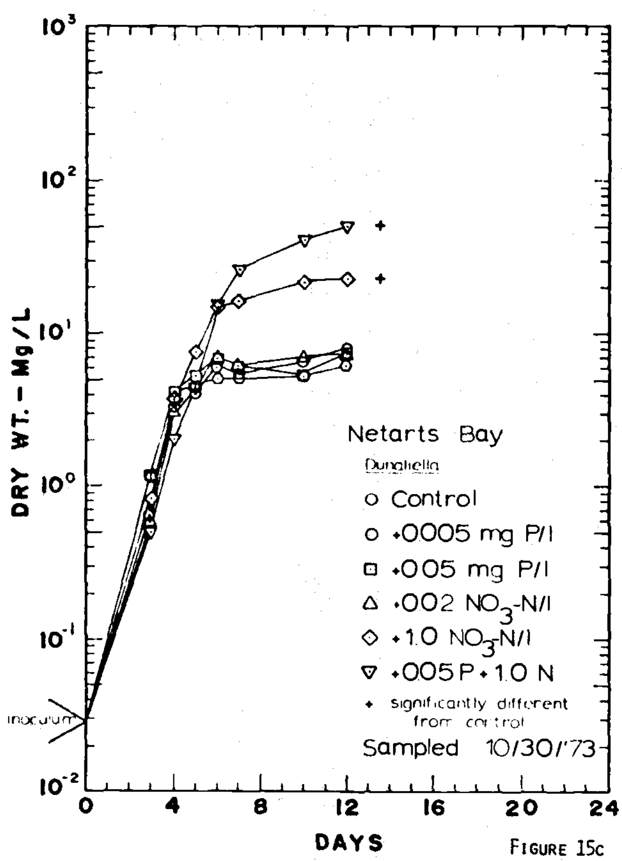


FIGURE 15C

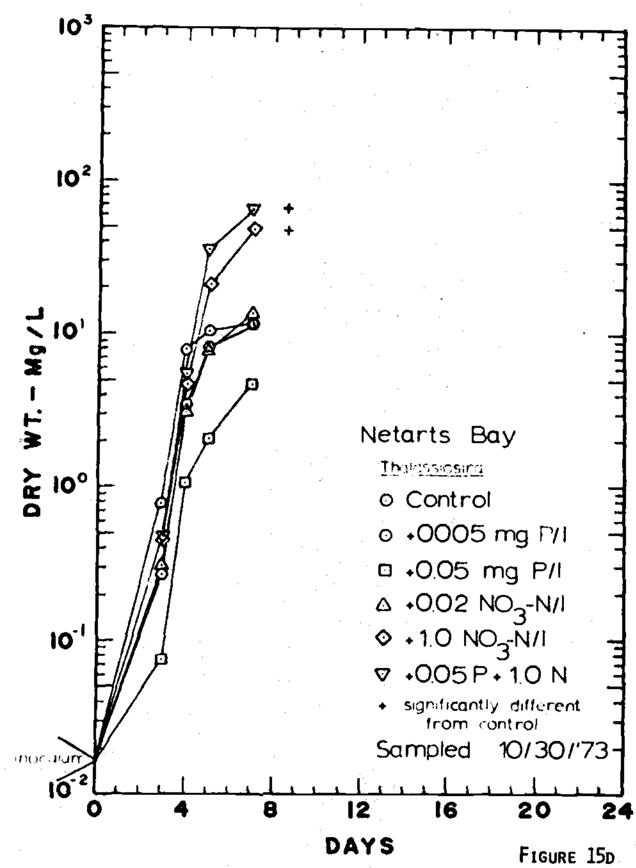


FIGURE 15D

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Digital Processing of ERTS Satellite Data for Management of Estuarine and Land Resources

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ABSTRACT

The NASA ERTS I *satellite* launched in July 1972 provides researchers and resource managers with a source of high quality radiometric data in digital form. A processing system, PIXSYS, has been developed at Oregon State University and has successfully performed in a wide range of resource classification situations. It has been used in determining water acreage, vegetation classification, geologic classification, and insect damage. It has been proven to be a viable alternative to manually interpreted aerial photography in many situations.

THE SATELLITE

Since its launch in July 1972, the NASA ERTS I satellite has been relaying high quality radiometric data to the earth for further processing. The satellite is in a 500-mile polar orbit. The orbital geometry is such that all regions of the earth are covered with a constant sun angle. Coverage is repeated every 18 days.

Using an array of sensors the reflected solar radiation in four regions of the visible and infrared spectrum is measured with a resolution of 1.125 acres. The "image" format is 100 miles by 100 miles. The region contains approximately 7.5 x 10^6 resolution elements.

The data is made available to the public through the EROS Distribution Center in Sioux Falls, South Dakota. It may be procured in the form of digital tape or reconstituted as photographic-like images. Multiple images corresponding to three of the four frequency sensitive bands may be formed into color photographs for manual interpretation.

COMPUTER PROCESSING

In many instances unique ground conditions produce a unique interrelationship among the four bands of reflected radiation. These interrelationships can be used as a means of classifying the data obtained from "unknown" ground resolution elements into one of several classes. This process is referred to as pattern recognition and has a well developed body of supporting literature.[1]

The PIXEL facility at Oregon State University has developed a complete data handling system called PIXSYS which has been successfully used in a wide variety of resource classification problem areas. The PIXSYS system integrates computerized pattern recognition techniques into a uses oriented data processing system which can be run in a time share mode on a medium-sized computer.

NATURAL RESOURCE CLASSIFICATION EXAMPLES

The following short summaries describe some of the investigations which have been performed using PIXSYS.

1) Big Summit Praire

Objective: Determine the feasibility of using ERTS data to prepare vegetation maps of natural plant communities typical of the high desert country of the Western United States.

Procedures: Big Summit Prairie, a 200 square mile region in central Oregon was selected as a test region. Ground vegetation experts using computer "gray scale" maps selected test sites for the PIXSYS classifier. PIXEL research assistants applied an early version of PIXSYS to produce vegetation classifications. Several modifications and test site evaluations were required before satisfactory results were obtained.

Significant Results: Ten natural vegetations species were classified and mapped by computer. The classes included water, sagebrush (four types), grasses, mixed conifers (trees), and Ponderosa pine. Ground truth indicated very good agreement. The results cannot be completely quantified since ground coverage of the 200 square mile test area was not possible.

Importance of Results: Natural plant communities, being highly non-homogeneous, present unique automatic classification problems. The success of this project suggests that satellite data may be used to manage the extremely large regions of natural vegetation. This vegetation is of great economic importance as grazing land and recreational land. It may be used as one component of a comprehensive environmental impact statement.

2) Mt. Washington, Belknap Crater

Objective: Evaluate the effectiveness of using ERTS data and PIXSYS processing to classify major geologic structures.

Procedure: The Mt. Washington region of the Oregon Cascades was selected as an experimental site. Cooperating with Dr. Robert Lawrence of the multidisciplinary team, test sites for lava from three distinct eruptions from Belknap Crater were selected. Additional test sites for water resources and a recent (1967) major forest fire were included.

Significant Results: Three types of lava were distinguished. The burn area was classified. Water resources were accurately mapped. Areas of forest "clear cut" logging were delineated.

Importance of Results: The results obtained were primarily of scientific importance understanding the geology of the region. Although not primary objectives the study indicated that brush and/or timber regrowth could possibly be monitored from satellite. This result has very large economic and environmental potential.

3) Salishan Spit

Objective: Evaluate the effectiveness of using satellite data for monitoring beach erosion and estuary conditions.

Procedure: In the winter of 1972, a group of vacation homes on Salishan Spit on the Oregon coast were threatened by severe beach erosion. Several homes were destroyed. A breach in the Spit threatened to greatly alter the status of Siletz Bay and the Siletz River estuary. ERTS data was used to pictorially portray the water/land interface. A poster/display was created describing the activity and results.

Significant Results: ERTS resolution was found to be too coarse to monitor the subtle effects of beach erosion. PIXSYS processing delineated several features within the Siletz estuary. Shoaling patterns in the mouth of the bay were observed.

Importance of Results: The results indicated that shoaling in bays, rivers, and estuaries could be monitored by satellite. These results were presented to the Army Corps of Engineers which is currently sponsoring additional research in this area.

4) Unity Reservoir

Objective: Determine the feasibility of monitoring water acreage from satellite data.

Procedure: Unity Reservoir in central Oregon was selected as a typical small but economically important reservoir. Proper water management is essential for irrigation and recreational activity in the region. Using PIXSYS water acreage was determined.

Significant Results: Satellite data can be used to monitor water acreage with great precision.

Importance of Results: Satellite surface surveys have great potential in accurately determining the water budget for whole regions. This information is accurate and cost effective compared to fixed wing aircraft photography.

The following activities were initiated using NASA funds but completed using other sources of funding. Their economic and environmental importance warrants their inclusion in this report.

5) Tussock Moth

Objective: Evaluate the feasibility of using ERTS data to provide management data for detecting, delineating, and monitoring insect defoliation in timber resources.

Procedure: With cooperating personnel from the Oregon State Department of Forestry and Boise Cascade Corporation, 26 test sites were established in northeast Oregon. These comprised three stocking densities (crown closure) and four degrees of moth damage. PIXSYS was used to classify a 300 square mile region. The results were evaluated using trained (Boise Cascade) personnel and low elevation aerial photography.

Significant Results: Tussock moth damage was accurately delineated for three degrees of infestation. Thus far only the 100% crown cover timber stands have been investigated. The computer results graphically show the degree of damage and calculate the total acreage infected.

Importance of Results: Nearly a million acres of forest land are defoliated by Tussock moth. Total economic/recreational impact is enormous. To our knowledge this is the first demonstration that vegetation stress can be determined from satellite data. These results strongly suggest the tremendous cost/benefit impact of using satellite data for timber resource management.

6) Rhea Creek

Objective: Determine the feasibility of separating irrigated vs. non-irrigated agricultural land.

Procedure: A test region adjacent to Rhea Creek in central Oregon was investigated. Water right maps were provided by the State Engineer's Office.

Significant Results: Inconclusive. Adequate ground truth was not available.

Importance of Results: Prudent allocation of irrigation water is essential to optimize agricultural production. Satellite data may provide data for the monitoring of irrigation and the enforcement of water rights.

7) Columbia River

Objective: Evaluate the feasibility of using satellite data to monitor shoaling and determine water depth in the Columbia River.

Procedure: With the cooperation of the U.S. Army Corps of Engineers, "super pictures" (multi-spectral enhancements of water features) were prepared for 80 miles of the Columbia River. Test sites were selected and water depths determined from survey maps. PIXSYS was used to classify the water based on water depth.

Significant Results: A principal component data transformation (super picture) offers an excellent method to enhance selected low contrast features. Shoals up to about ten feet in depth were accurately portrayed. The pictorial results offer a viable alternate to aerial photography.

Importance of Results: Dredging in the Columbia River is a multimillion dollar operation. Satellite data introduced the possibility of monitoring sediment transport and shoal build-up on a repetitive basis. This will have economic impact on optimizing the dredging and disposal operations in the river.

CONCLUSION

Satellite data sources, despite their apparent resolution limitations, may provide the most cost effective means of natural resource monitoring. The low cost of classification (ten cents per square mile) and suitability for image enhancement for manual interpretation make such data a viable alternative to aircraft photography and classical photo interpretation.

Physical Parameters Which Control Propagation of Tidal Waves in Estuaries, Verified for Three Significantly Different Oregon Estuaries

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ABSTRACT

A one-dimensional, time-dependent, implicit, finite-difference model, verified for three estuaries along the central Oregon coast, is used to generate controlled data for a large number of hypothetical estuaries.

To synthesize model results, two non-dimensional coefficients, K_F and K_I, are developed which incorporate the physical characteristics and boundary conditions of the estuary and summarize the effects due to friction and inertia, respectively. These coefficients are used to describe the variability of tidal response throughout the complete range of hypothetical estuaries investigated. A graphical algorithm, based on the derived relationships, is presented and examples of its application to real estuaries is given.

The results of this study can be used to predict changes in tide characteristics due to proposed physical changes in an estuary, such as entrance dredging and filling of tidal flats. The predictions can be made without the need for simulation modeling.

INTRODUCTION

A recent trend in estuarine tide prediction has been toward greater sophistication, such as 2 and 3-dimensional modeling, with concurrent escalation of effort and cost. Since many questions may require much simpler techniques to reach a satisfactory answer, it is worthwhile to pursue their development. This paper presents one such simplified approach.

It is the purpose of this paper to define the physical parameters which control the propagation of tidal waves into real estuaries, to group these parameters into useful coefficients, and to provide an algorithm for prediction of tide changes in estuaries.

To achieve this objective, a quasi one-dimensional model has been built to generate data on which the predictive method could be based. The model has been verified for three significantly different estuaries on the central Oregon coast.

MODEL

Basic Equations

After the development by Dronkers (1964), the following equations governing tidal flow in estuaries were chosen as the basis for this model.

The simplified equation of motion is:

$$\frac{\partial H}{\partial x} + \frac{1}{gA_C}\frac{\partial Q}{\partial t} - \frac{B_T Q}{gA_C^2}\frac{\partial H}{\partial t} + \frac{B_C}{C^2 A_C^3}|Q|\ Q = 0 \qquad (1)$$

and the continuity equation is:

$$\frac{\partial Q}{\partial x} + B_T\frac{\partial H}{\partial t} = 0 \quad \text{or} \quad Q + A_S\frac{\partial H}{\partial t} = 0 \qquad (2)$$

where:

H = the instantaneous elevation difference between actual water level and mean sea level--feet (FT)

Q = instantaneous discharge through a cross section--cubic feet per second (CFS)

x = coordinate measuring distance along the length of the estuary--feet (FT)

A_S = total surface area of a channel segment--square feet (FT^2)

A_C = cross sectional area of conveying portion of the channel--square feet (FT^2)

B_T = total surface width of both conveying and storage portions of the channel--feet (FT)

B_C = surface width of conveying portion of the channel--feet (FT)

C = Chezy friction coefficient--feet$^{1/2}$ per second ($FT/SEC^2)^{1/2}$

g = acceleration due to gravity--feet per second per second (FT/SEC^2)

t = time--seconds (SEC)

Assumptions

The major assumptions inherent in these equations are:

1. one-dimensional motion
2. homogeneous fluid
3. negligible wind stress
4. negligible Coriolis acceleration
5. no tributary inflow along the length of the estuary
6. flow to and from the tidal flat areas has no inertial effect on the motion in the main channel
7. momentum and kinetic energy correction factors have the value of unity
8. water particle velocity is less than the critical velocity, $\sqrt{gD}$, where D is the instantaneous hydraulic depth in feet
9. slope of the channel bottom within each river section is zero
10. the Chezy relationship is adequate to describe frictional effects in tidal flows.

Presentation of model details are beyond the scope of this paper. By way of summary, however, a central finite-difference scheme for approximation of equations (1) and (2) is used which produces a set of implicit equations. These equations are then solved using iterative techniques. Details of model development, input, output and other documentation is given by Goodwin (1974).

FIELD WORK

Field work necessary to calibrate and verify the model was carried out during the summer of 1969 on three central Oregon estuaries; the Yaquina, Alsea and Siletz (see Figure 1). Much of the resulting data has been presented by Goodwin, Emmett, and Glenne (1970). Additional data from this work is also given by Goodwin (1974). Information collected includes tidal stage, tidal phase, velocity, temperature and salinity at several locations and depths in each estuary.

The degree of model verification is illustrated in Figures 2, 3 and 4 for the Siletz estuary. Generally, for the three estuaries investigated, the verification achieved is within 0.15 feet for displacement, between two and six degrees for phase and less than 0.5 feet per second for velocity. This is considered adequate for the purposes of the study. Additional details of model results can be found in Goodwin (1974).

CORRELATING PARAMETERS

General Observations

The calibration, verification and testing of the Yaquina, Alsea and Siletz models indicated that the parameters of cross-sectional area, surface area and friction all play important roles in controlling the tidal phenomena. O'Brien's (1931) observations (see Figure 5) indicate a general relationship between entrance area and tidal prism. Since tidal prism, in its simplest form, can be expressed as surface area times tidal range, O'Brien's curve can be interpreted as describing the influence of surface area and cross-sectional area on the tidal range within an estuary.

The description is not complete, however, as pointed out by O'Brien (1967), Johnson (1973) and further illustrated in Figure 5 by data from Goodwin, Emmett and Glenne (1970). For "choked" conditions, where the estuary tidal amplitude is less than the ocean tidal amplitude, and for points other

FIGURE 1 Location Map

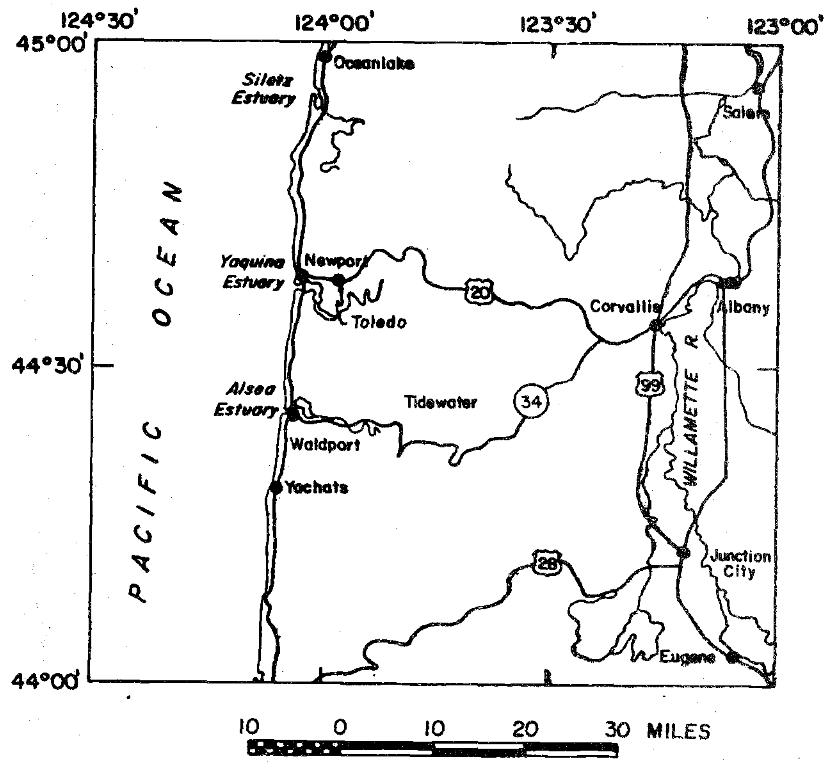


FIGURE 2 Displacement Verification - Siletz Estuary - September 12, 1969

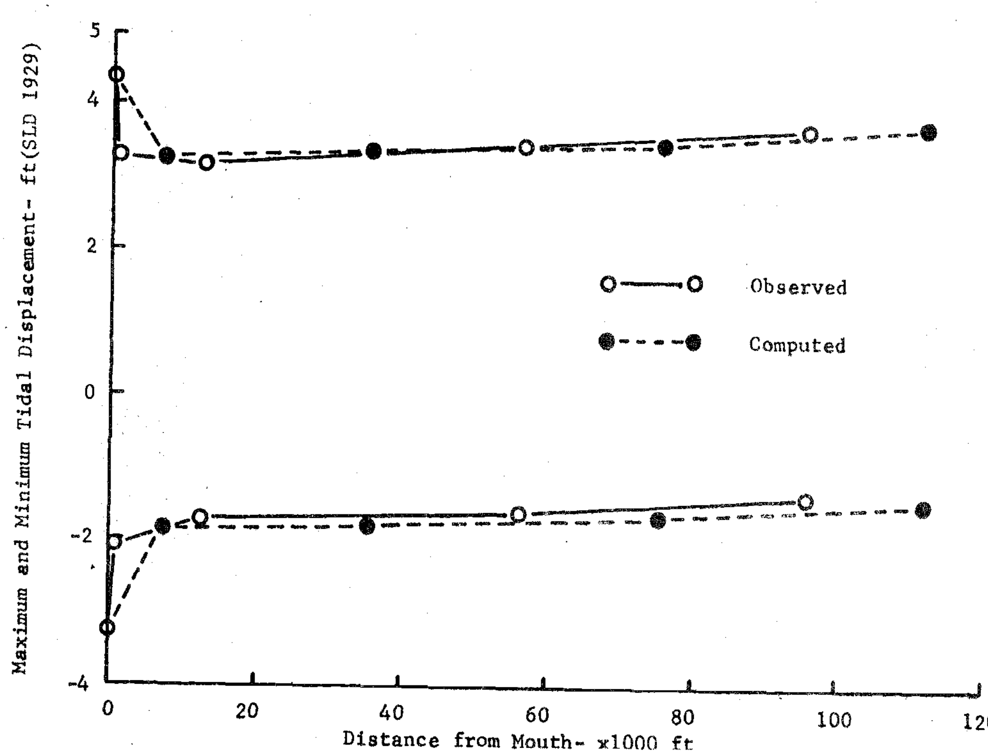


FIGURE 3 Phase Verification - Siletz Estuary
September 12, 1969

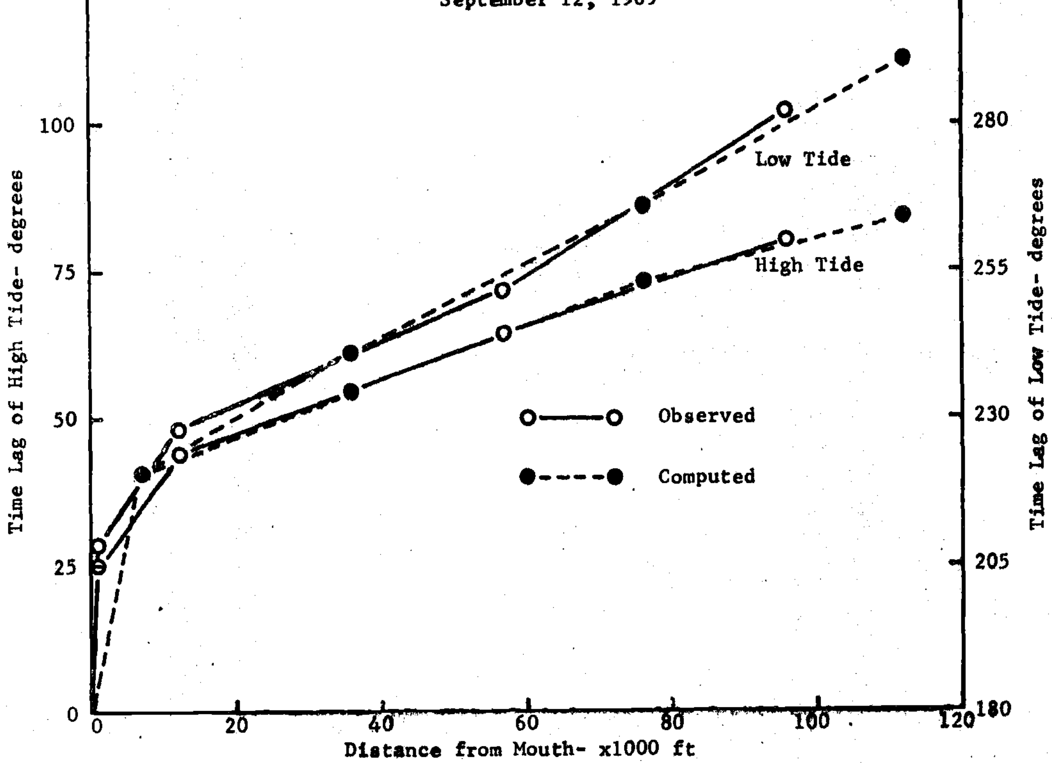


FIGURE 4 Velocity Verification - Siletz Estuary - Flood Flow
September 12, 1969

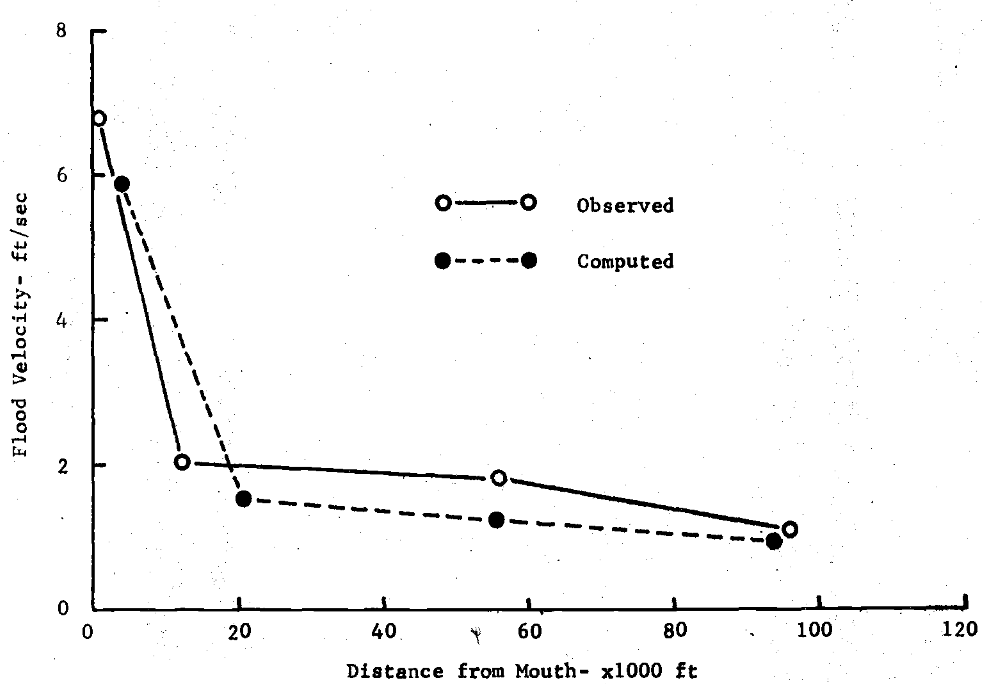
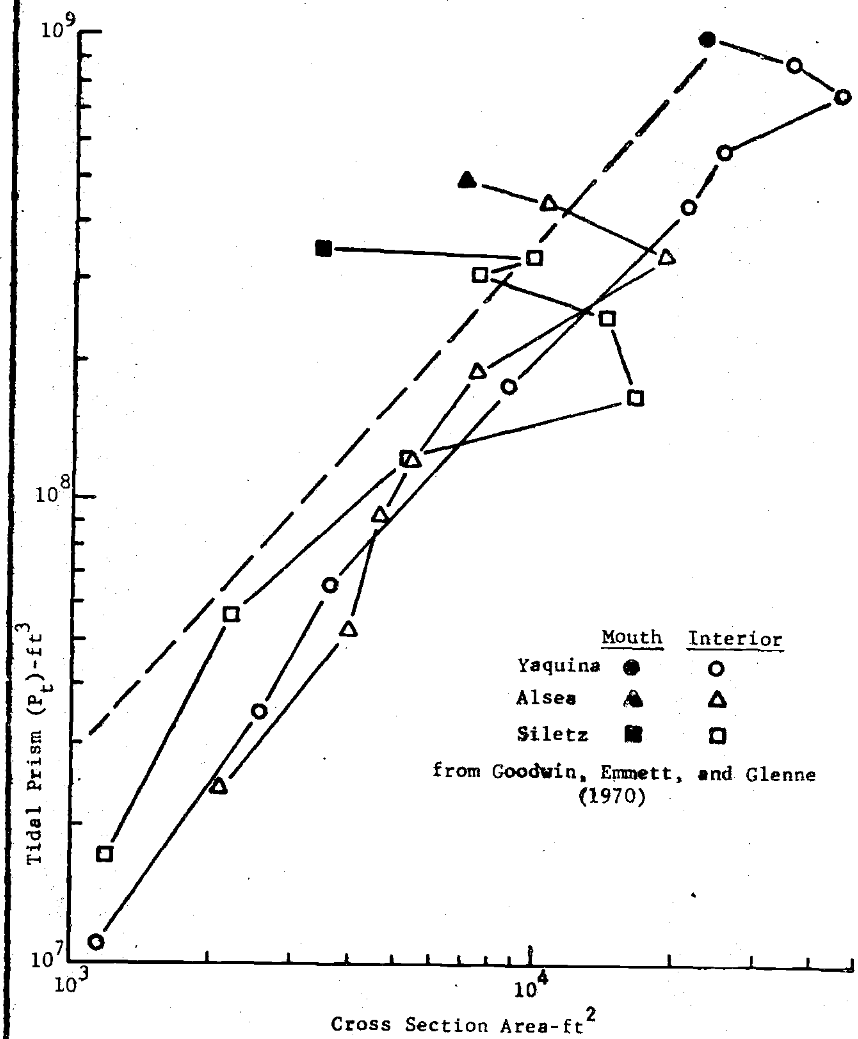


FIGURE 5 Tidal Prism vs. Cross Sectional Area



than at the mouth of estuaries, additional relationships must be found to describe the tide.

Keulegan's (1967) analysis of tidal flow in entrances introduced a parameter which he termed the "repletion coefficient." The numerical value of this coefficient is determined by the physical dimensions of the entrance and embayment as well as the amplitude and period of the ocean tide. The expression is:

$$K_R = \frac{T}{2\pi H_o} \frac{A_C}{A_S} \left[\frac{2gRH_o}{\lambda L + mR}\right]^{\frac{1}{2}} \quad (3)$$

where:

K_R = repletion coefficient-dimensionless

T = tidal period--seconds (SEC)

H_o = ocean tidal amplitude--feet (FT)

R = hydraulic radius of the entrance channel --feet (FT)

L = length of the entrance channel--feet (FT)

λ = frictional coefficient--dimensionless

m = velocity distribution coefficient at the entrance (assumed to be unity)--dimensionless

Assuming no variation of surface area (A_S) and cross sectional area (A_C) with tidal elevation, Keulegan analytically expressed tidal characteristics as a function of K_R. It is important to note that inertial effects were neglected in Keulegan's analysis.

Glenne, Goodwin, and Glanzman (1971) used numerical techniques to solve a similar problem. Their results were also expressed in terms of a coefficient directly analogous to Keulegan's repletion parameter.

Both Keulegan and Glenne assumed that the basin connected to the ocean acted as a simple integrator of entrance flows. All points within the bay were assumed to rise and fall in unison. In most natural estuary systems this assumption is violated to some degree.

The fact that amplification of the tidal wave is observed in many estuaries indicates that inertial effects cannot always be neglected. It appears that two coefficients may be required to describe tidal conditions when friction and inertia forces both play important roles.

Frictional Coefficient

The equations of motion and continuity, (1) and (2), are rewritten here neglecting the inertial term in (1).

$$\frac{\partial H}{\partial x} + \frac{B_C}{C^2 A_C^3} |Q| \, Q = 0 \quad (4)$$

$$Q + A_S \frac{\partial H}{\partial t} = 0 \quad (5)$$

For positive Q values (flooding flow), substitution gives:

$$\frac{h_i - h_o}{L} + \frac{B_C}{C^2 A_C^3} A_S^2 \left[\frac{\partial h_i}{\partial t}\right]^2 = 0 \quad (6)$$

where the space derivative is expressed in finite form with h_o representing the ocean displacement, h_i the displacement inside the bay, and L the intervening length of channel.

Assuming a cosine function for the ocean tide,

$$h_o = H_o \cos\sigma t, \quad (7)$$

and a phase shifted periodic function for the bay tide,

$$h_i = H_i f(\sigma t - \phi), \quad (8)$$

equation (6) can be rewritten as:

$$H_o \cos\sigma t - H_i f(\sigma t-\phi) + \frac{B_C \, L \, A_S^2 H_i^2 \sigma^2}{C^2 A_C^3} [f'(\sigma t-\phi)]^2 = 0 \quad (9)$$

Solving for the amplification factor gives:

$$\frac{H_i}{H_o} = \frac{\cos\sigma t}{f(\sigma t-\phi) - K_F[f'(\sigma t-\phi)]^2} \quad (10)$$

where the frictional coefficient, K_F, is defined as:

$$K_F = \frac{4\pi^2 B_C \, L \, A_S^2 \, H_i}{C^2 A_C^3 T^2} \quad (11)$$

This coefficient, aside from the different choice of resistance factors, is the inverted square of Keulegan's repletion coefficient, equation (3), except for one detail. The ocean tidal amplitude term, H_o, is replaced by the bay tidal amplitude, H_i. As a practical matter, it makes little difference whether H_o or H_i appears in the equation defining the friction parameter, K_F. The two amplitudes are related through the non-dimensional ratio H_i/H_o. Since H_o is normally a known quantity and H_i is to be determined, it is suggested that H_o be used instead of H_i in equation (11) to avoid possible trial and error situations which could inject unnecessary complications in further analyses. The suggested form is then:

$$K_F = \frac{4\pi^2 B_C \, L \, A_S^2 \, H_o}{C^2 A_C^3 T^2} \quad (11a)$$

Inertial Coefficient

Using a similar procedure to that in the previous section, the equation of motion written without the frictional term is:

$$\frac{\partial h}{\partial x} + \frac{1}{gA_C}\frac{\partial Q}{\partial t} = 0 \qquad (12)$$

The time derivative of equation (5) is:

$$\frac{\partial Q}{\partial t} = -A_S \frac{\partial^2 h}{\partial t^2} \qquad (13)$$

Combining (12) and (13) and using the same notation as in the previous section gives:

$$\frac{h_i - h_o}{L} - \frac{A_S}{gA_C}\frac{\partial^2 h_i}{\partial t^2} = 0 \qquad (14)$$

Rewriting in terms of the periodic functions, equations (7) and (8), gives:

$$-H_o \cos\sigma t + H_i f(\sigma t-\phi) - \frac{A_S\, L\, H_i \sigma^2}{gA_C} f''(\sigma t-\phi) = 0 \qquad (15)$$

and solving for the amplification factor:

$$\frac{H_i}{H_o} = \frac{\cos\sigma t}{f(\sigma t-\phi) - K_I f''(\sigma t-\phi)} \qquad (16)$$

where the inertial coefficient, K_I is defined as:

$$K_I = \frac{4\pi^2 A_S\, L}{gA_C T^2} \qquad (17)$$

This parameter is not directly dependent on either the ocean or bay tidal amplitudes.

As will be shown later, the inertial coefficient in conjunction with the frictional coefficient provides a means for analyzing tidal phenomena which has not been available before.

Displacement Curves

Figures 6 and 7 represent normalized tidal displacement curves for various combinations of friction and inertia forces acting upon the simple integrating embayment system of Keulegan and Glenne. In each instance the heavy dark line is the cosine forcing function at the mouth of the embayment.

For the case of no inertia (K_I=0), Figure 6, increasing friction values (K_F) clearly cause a reduction of the tidal amplitude in the embayment. This is the same effect reported by Keulegan and called "tidal choking" by Glenne, et al. It should be noted that no embayment amplitudes greater than the forcing function are possible under these conditions. Also, at the time of extreme conditions (high and low water) in the embayment, the water elevation in the ocean and embayment are equal. This is true for all values of the frictional coefficient.

Figure 7 shows how the embayment displacement curves are modified by increasing inertial effects. It is apparent that amplitudes in the bay can be greater than that in the ocean for some K_F, K_I combinations. The larger the inertial coefficient, the greater can be the amplification. At times of high and low water, the ocean and bay water levels are no longer equal. Also, the amplification effect is most pronounced for low values of the frictional coefficient.

The influence of K_F and K_I on tidal displacement, phase lags and maximum velocity is summarized in Figures 8 through 11. These graphs were prepared from results of hundreds of model simulations of hypothetical estuaries.

Figure 8 shows the displacement response of an estuary as a ratio of amplitudes between adjacent estuary segments. Increasing friction (K_F) causes a decreased ratio while increasing inertia (K_I) causes an increased ratio. Friction is dominant at high K_F values with inertia most important at low K_F values.

Figure 9 shows the phase difference ($\Delta\phi_I$), in degrees of a complete tidal cycle, between slack water at a segment boundary and the time of high or low water at the centroid of the adjacent downstream segment. For a simple, one-segment embayment this reduces to the difference between times of occurrence of high or low waters in the embayment and the ocean. Phase difference is an increasing function of both K_I and K_F.

Maximum velocity can be expressed in terms of a velocity coefficient, C_V, [see Keulegan (1967)].

$$V_m = \frac{2\pi}{T} C_V \frac{A_S}{A_C} H_i \qquad (18)$$

Figure 10 defines the variation of C_V for different inertia and friction coefficients. The dip observed at a K_I value of about 0.1 is unexplained.

Figure 11 defines the relationship used to determine the phase difference between times of maximum or minimum displacement in adjacent segments of a multiple segment estuary.

PREDICTIVE ALGORITHM

Assumptions

All assumptions inherent in the digital model used to develop these procedures are fully applicable. In addition, the fresh water inflow is assumed to be negligible when compared with the tidal flow at any cross section.

Physical Data

In order to apply the methods presented in this chapter, some basic information must be available. Much of this can be readily determined from published charts, maps or aerial photographs. Extensive field surveys should not be necessary in most instances.

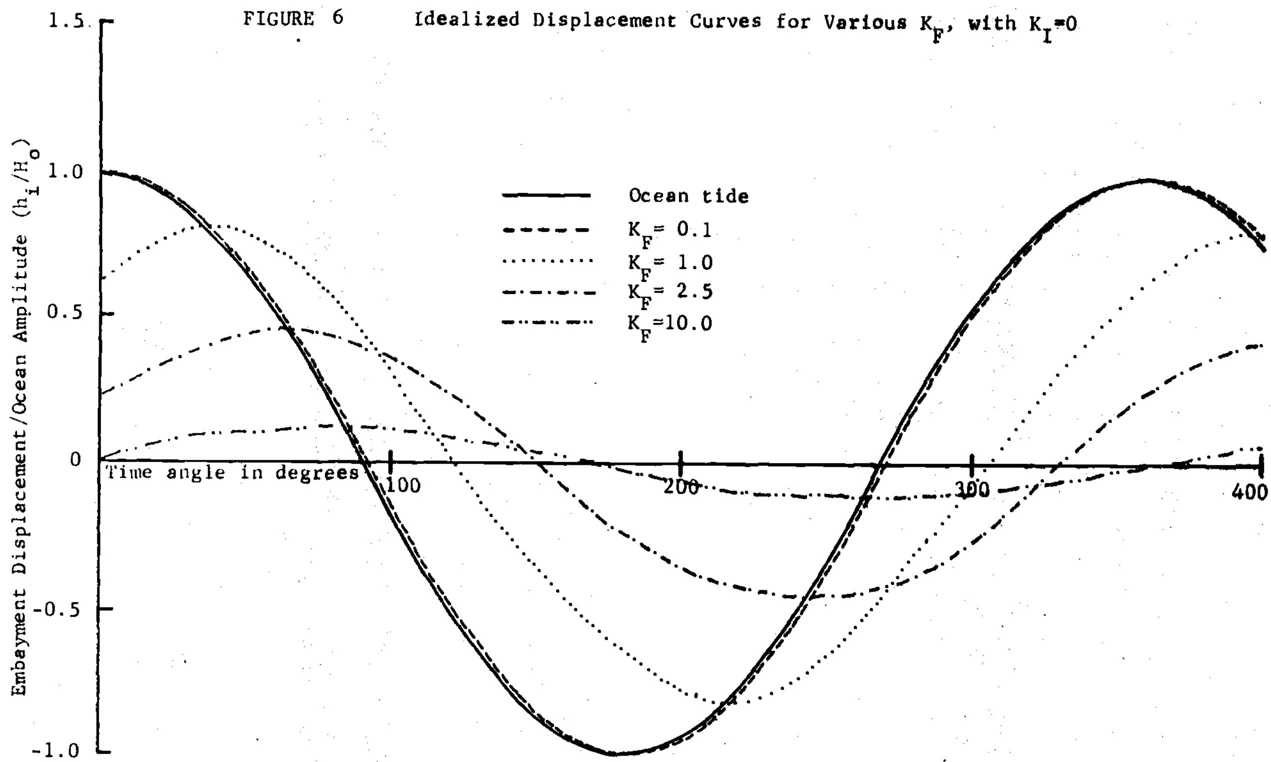


FIGURE 6 Idealized Displacement Curves for Various K_F, with K_I=0
Embayment Displacement/Ocean Amplitude (h_i/H_o)
1.5
1.0
0.5
0
-0.5
-1.0
Time angle in degrees
100
200
300
400
Ocean tide
K_F= 0.1
K_F= 1.0
K_F= 2.5
K_F=10.0

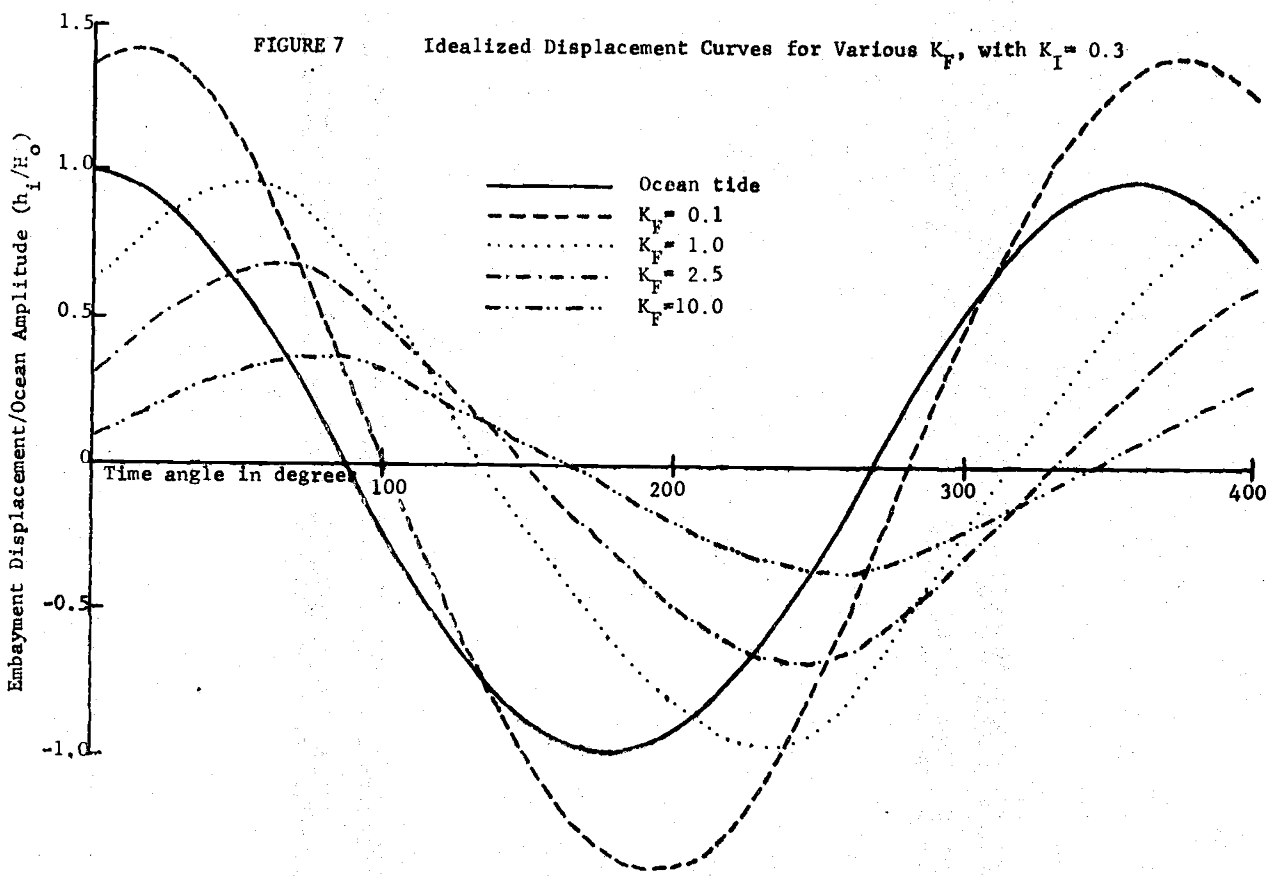


FIGURE 7 Idealized Displacement Curves for Various K_F, with K_I= 0.3
Embayment Displacement/Ocean Amplitude (h_i/H_o)
1.5
1.0
0.5
0
-0.5
-1.0
Time angle in degrees
100
200
300
400
Ocean tide
K_F= 0.1
K_F= 1.0
K_F= 2.5
K_F=10.0

FIGURE 8 Effect of K_F and K_I on Tidal Amplitude Ratio

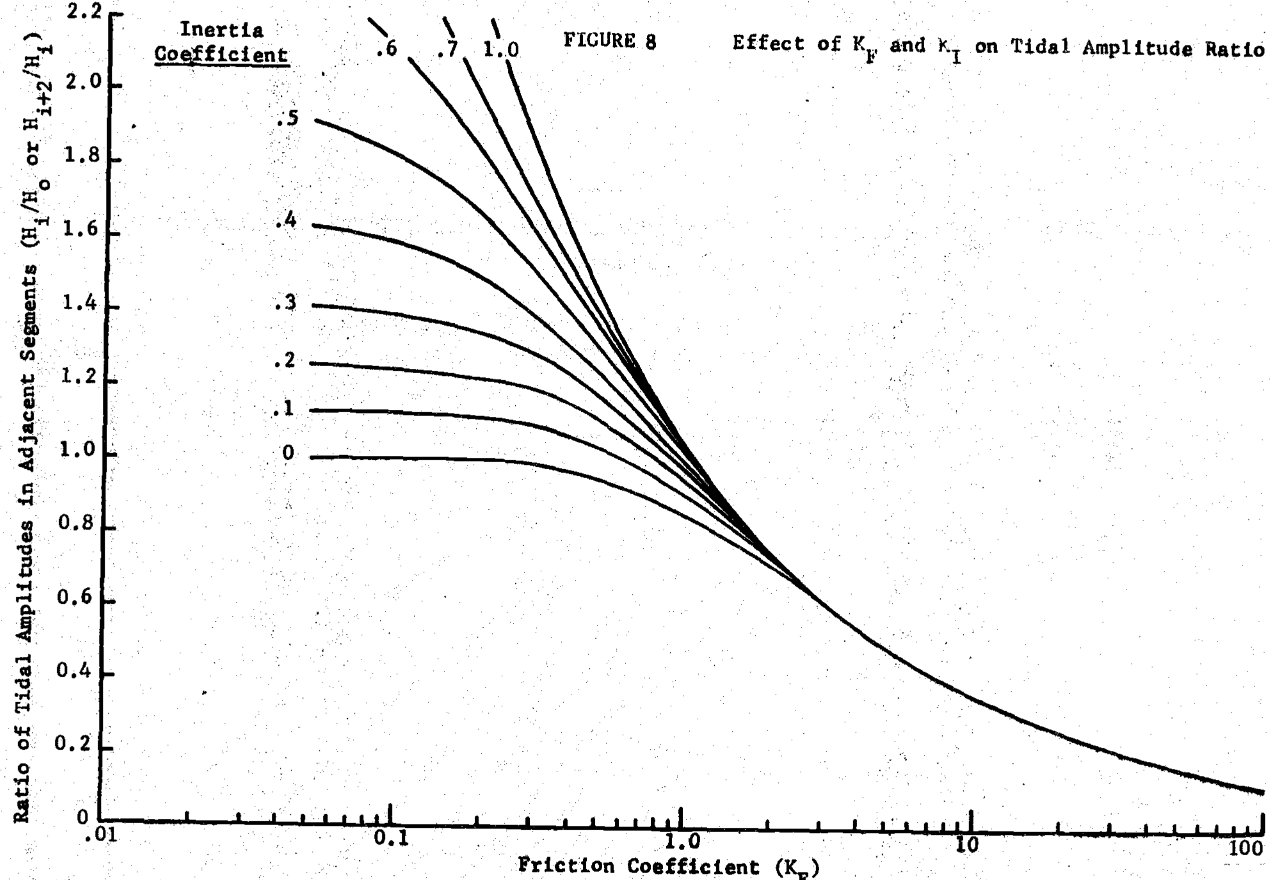


FIGURE 9 Effect of K_F and K_I on High Tide and Slack Water Phase Lag Between Adjacent Segments

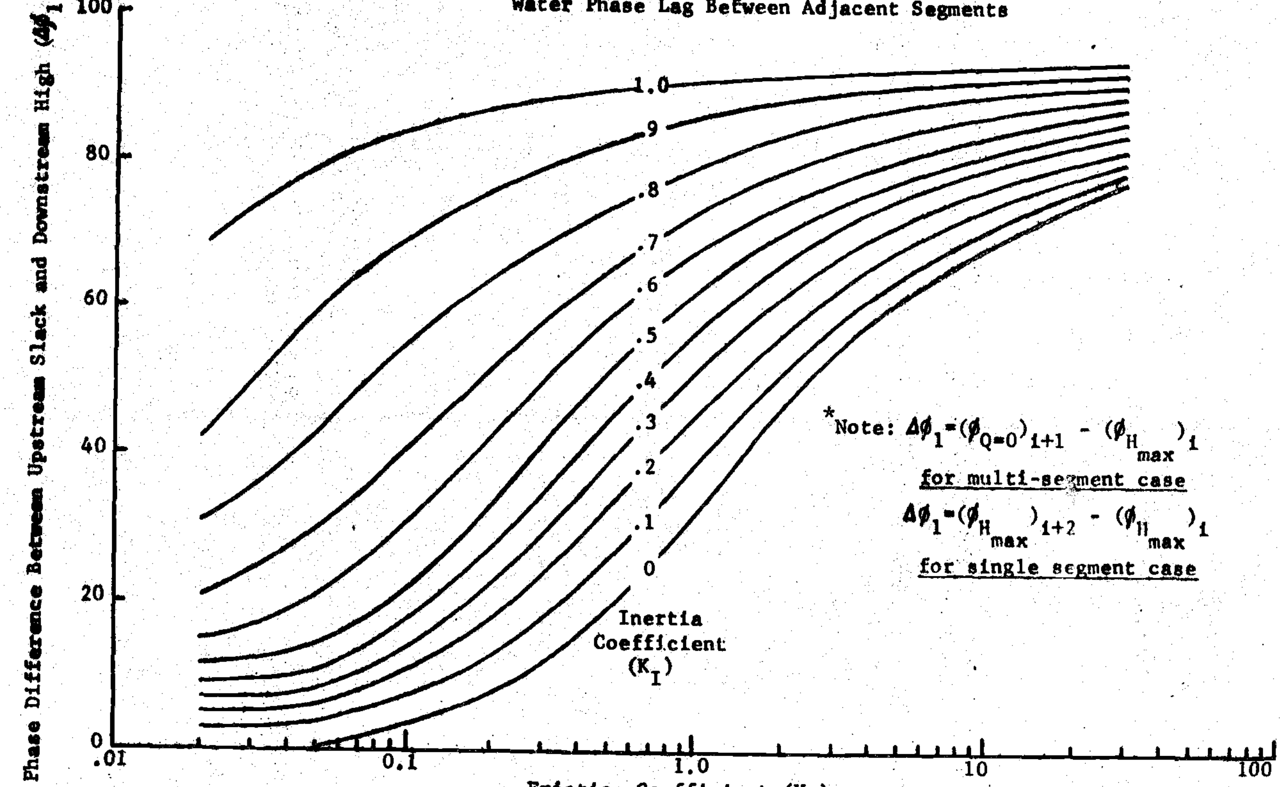


FIGURE 10 Effect of K_F and K_I on the Velocity Coefficient (C_V)

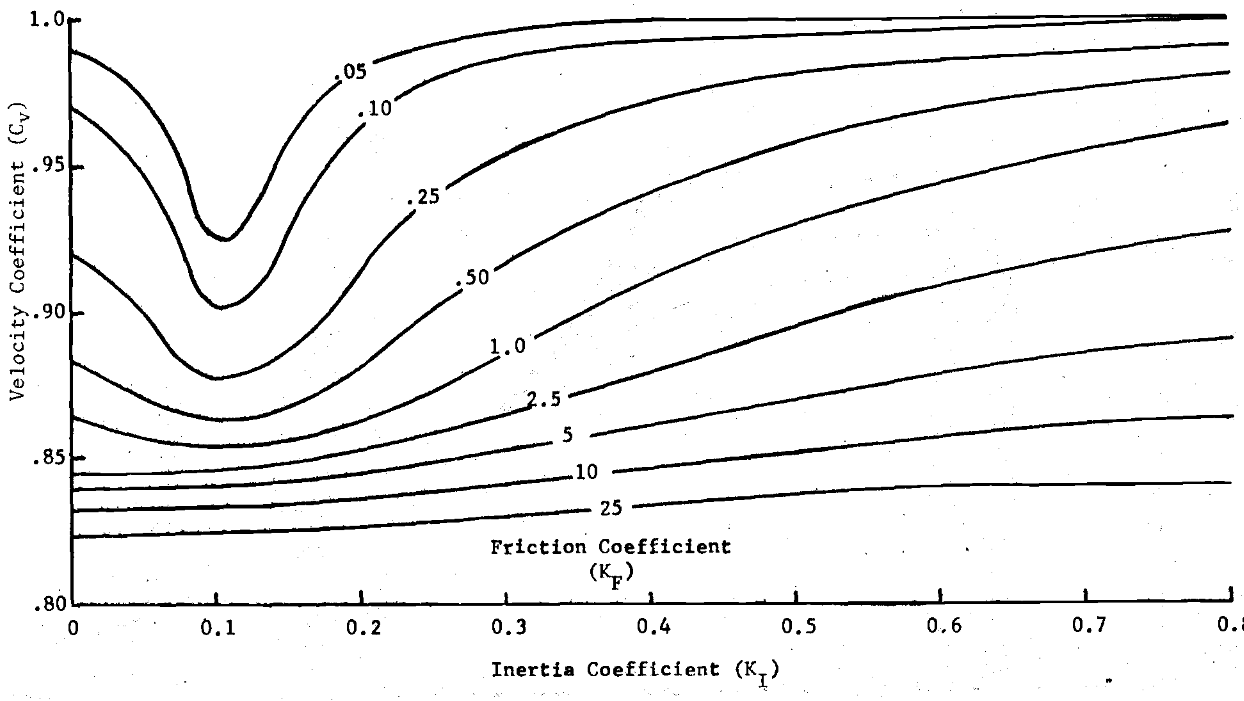
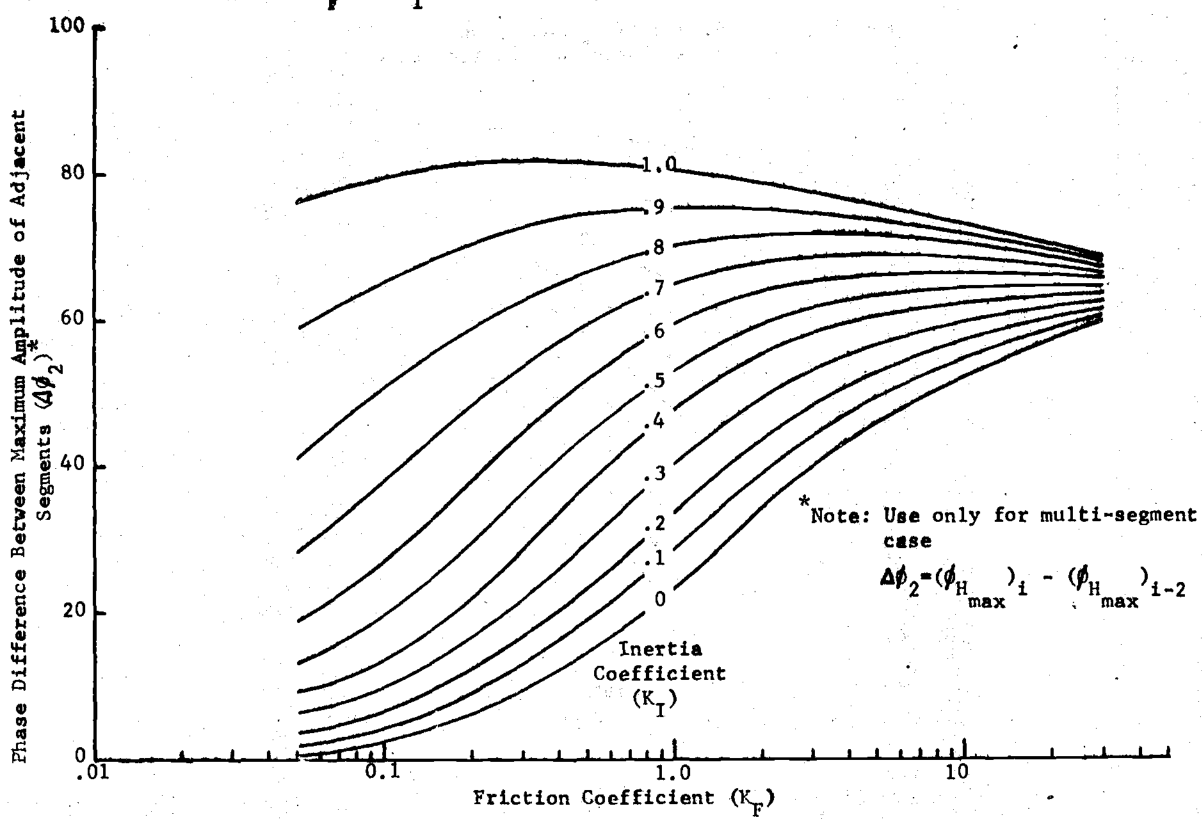


FIGURE 11 Effect of K_F and K_I on Maximum Amplitude Phase Lag Between Adjacent Segments



The following is a list of physical parameters needed for performing the necessary computations.

1) A_S, the surface area of the embayment or of each unit in the multi-segment case--FT^2

2) A_C, the entrance cross sectional area of the embayment or of each unit in the multi-segment case--FT^2

3) L, the length of the embayment entrance channel or length between segment centroids if in the multi-segment case--FT

4) B_C, the conveyance width of the entrance channel or of each channel reach in the multi-segment case--FT

Each of these parameters should be defined at the mid-tide elevation of the ocean tide, normally taken as Mean Sea Level.

Hydraulic Data

The following hydraulic parameters must also be known or estimated:

1) T, the period of the forcing tidal function at the entrance--SEC

2) C, the Chezy coefficient of friction in the entrance channel or in each channel segment if in the multi-segment case--$FT^{1/2}$/SEC

3) H_o, the amplitude of the tidal forcing function at the entrance--FT

4) H_2, H_4, H_6 ..., the initial estimate of tidal amplitude within each segment of a multi-segment estuary--FT

COMPUTATIONAL PROCEDURE

Single Segment Case

Given the data listed above, the procedure for a single segment estuary is as follows:

1) Compute the frictional and inertial coefficients:

$$K_F = \frac{4\pi^2 B_C\ L\ A_S{}^2 H_O}{C^2 A_C{}^3 T^2} \ ;\ K_I\ \frac{4\pi^2 A_S\ L}{g A_C T^2}$$

2) Enter graph 8 to determine the amplitude ratio between the embayment and the ocean, H_2/H_o.

3) Enter graph 9 to determine the phase lag, in degrees, between high tide in the ocean and high tide in the embayment ($\Delta\phi_1$). The times of high tide in the embayment (ϕH_{max}) and slack water in the channel ($\phi_{Q=0}$) are the same for this case.

4) Enter graph 10 to determine the velocity coefficient C_V. Compute the maximum velocity attained in the connecting channel as:

$$V_{max} = \frac{2\pi}{T} C_V\ \frac{A_S}{A_C} H_2$$

With this procedure it is possible to predict what effect a change in any of the physical or hydraulic parameters will have on the response of the system as defined by amplitude, phase lag, and maximum velocity.

Multiple Segment Case

The algorithm for a multiple segment estuary is more complex than the procedure just outlined for the single segment case. The reason is that downstream and upstream responses are not independent, making it impossible to compute one without knowledge of the other. This drawback can be overcome, however, if a set of initial conditions is assumed and in iterative procedure applied. The basic steps in this algorithm are as follows:

1) Assume a maximum tidal amplitude value in each of the estuary segments upstream of the mouth. Unless other information is available, segment amplitudes are normally set equal to the ocean tide amplitude.

2) Compute the frictional and inertial coefficients of the next upstream segment starting at the estuary mouth.

$$K_F = \frac{4\pi^2 B_C L (A_{ST})^2 H_O}{C^2 A_C{}^3 T^2};\ K_I = \frac{4\pi^2 A_{ST}\ L}{g A_C T^2}$$

Note: The surface area term (A_{ST}) is now defined as an amplitude weighted sum of upstream-segment surface areas.

3) Determine the first approximation to the maximum amplitude in the next upstream segment from Figure 8.

4) Repeat steps 2 and 3 for each estuary segment.

5) Repeat this procedure until satisfactory convergence of the amplitude in each segment has been achieved.

6) Once convergence is attained, use the the final K_F and K_I values for each segment to determine the phase lag of slack water from Figure 9. The phase lag of high water can be found from Figure 11.

Simple Embayment Application

Van de Kreeke (1967) supplies the following values describing the geometry and boundary conditions at Macquarie Harbour Inlet, Tasmania:

$A_S = 2.8 \times 10^8 m^2$
$A_C = 4200\ m^2$
$L = 7000\ m$

B_C = 700 m
T = 24 hrs = 86,400 sec
C = 50 $m^{1/2}$/sec
H_o = .45 m

Van de Kreeke's computed values for bay response with no fresh water inflow are:

H_i = .22 m
Q_{max} = 3,650 m^3/sec
$\Delta\phi_1$ = 4 hrs

Following the outlined procedure, K_F and K_I are found to be: $K_F = 4.95$ and $K_I = .257$. From Figure 8, the amplitude ratio between embayment and ocean is 0.50. The maximum displacement in the bay then is $H_i = H_o \times .50 = .225$ m which agrees very closely with Van de Kreeke's model results.

From Figure 9 the phase lag, $\Delta\phi_1$, is determined to be 70 degrees or 4.67 hours. This is higher than the 4 hour lag computed by Van de Kreeke using a non-inertial model. By arbitrarily setting the K_I factor equal to zero (no inertial effect) Figure 9 gives 61 degrees or 4.06 hours, which is directly comparable and in agreement with Van de Kreeke's computations. This suggests, however, that inertial forces are important in determination of phase relationships and the method presented here is to be preferred over non-inertial developments.

The maximum velocity in the entrance can be found from Figure 10 and application of equation 18. In this example, $C_v = 0.85$ giving a velocity of .865 m/sec. This represents a maximum discharge, Q_m, of 3633 m^3/sec which is nearly identical to Van de Kreeke's value.

Multiple Segment Results

The Siletz estuary was chosen as an example of a multiple segment application of the procedure. Application details are beyond the scope of this paper but can be found in Goodwin (1974).

Figures 12 and 13 illustrate the differences in displacement and phase, respectively, between observed field data and application of the predictive algorithm.

ACKNOWLEDGEMENTS

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FIGURE 12 Displacement Comparison - Siletz Estuary
September 15, 1969

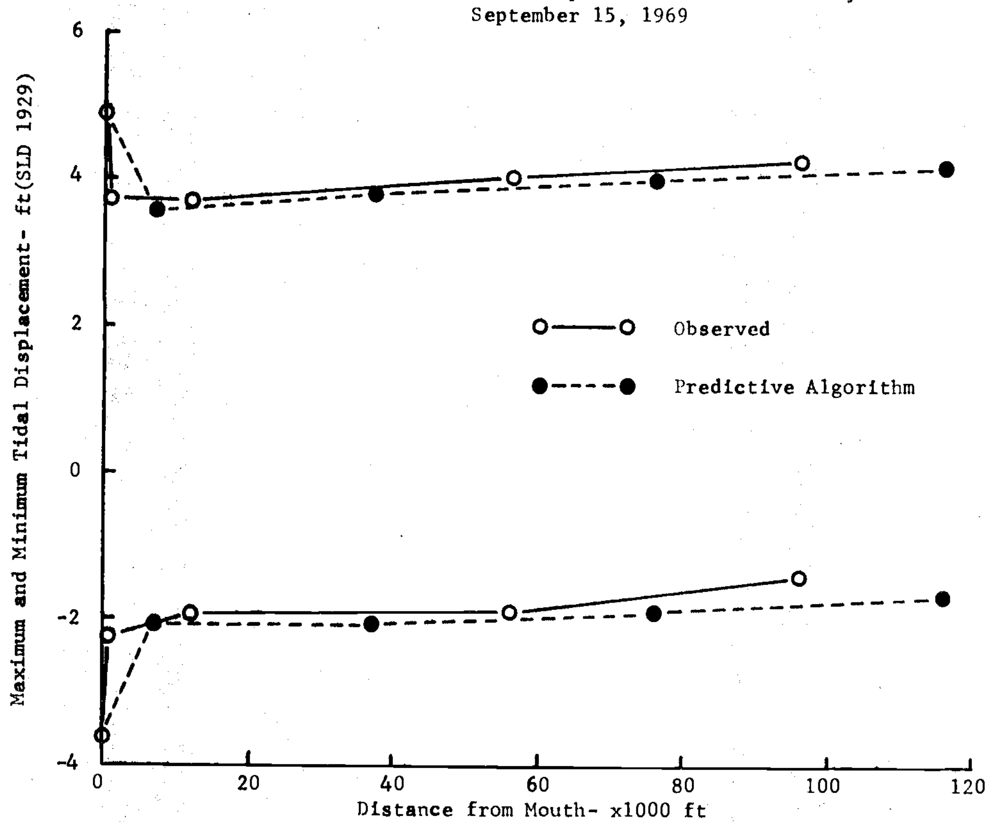
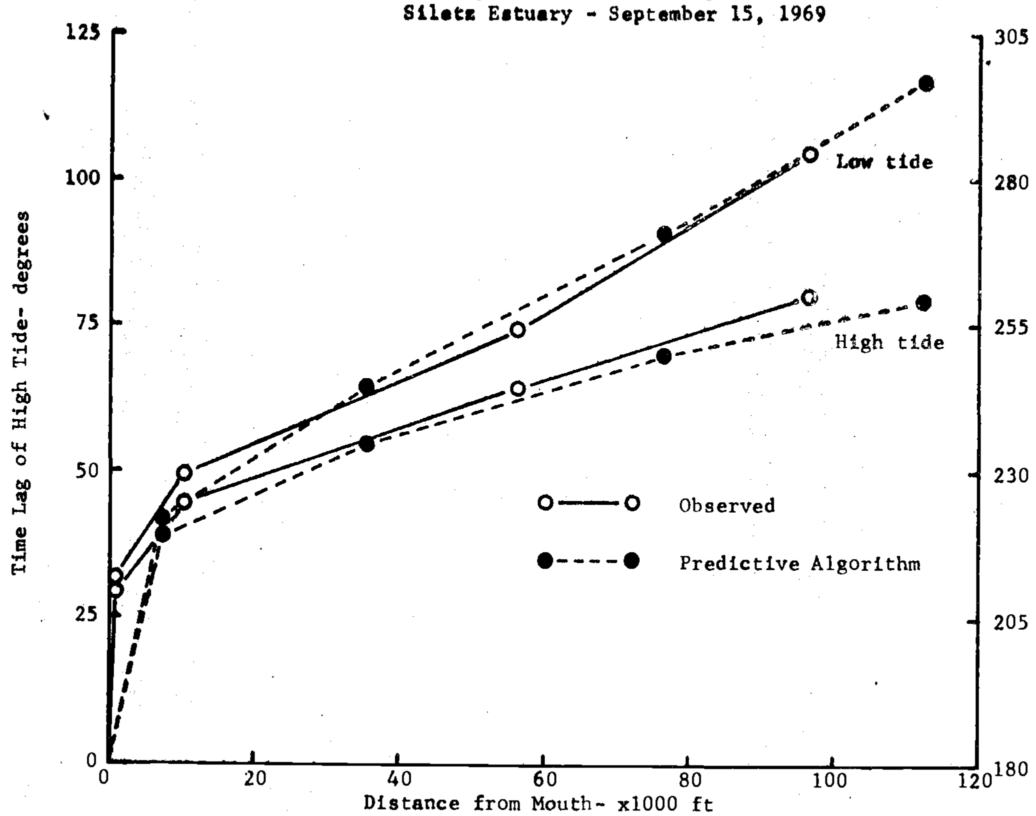


**FIGURE 13 Displacement Phase Comparison
Siletz Estuary - September 15, 1969**



Inputs and Distributions of Chlorinated Hydrocarbons in Three Southern California Harbors*

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ABSTRACT

Chlorinated hydrocarbons such as the pesticide DDT and industrial polychlorinated biphenyls (PCB) are major contaminants in southern California marine waters. As a result of a predominant DDT input from the large submarine discharge of Los Angeles County municipal wastewater, coastal mussels off Los Angeles contain up to 30 times more p,p'-DDE than do those off San Diego. Specimens of a bay mussel collected from San Diego Bay, Newport Harbor, and San Pedro Harbor also show this pattern of increasing DDT concentrations toward Los Angeles.

However, PCB 1254 concentrations are similar in mussels from the three harbors and are several times higher than in specimens collected from the nearby coastal waters. Estimates for total annual inputs of PCB 1254 to these harbors from municipal wastewater, industrial wastewater, surface runoff, aerial fallout, and vessel antifouling paints range from 1 kg/yr in Newport Bay to 150 kg/yr in San Pedro Harbor, with surface runoff and industrial wastewater constituting virtually all of the latter input.

Although antifouling paints presently constitute a completely insignificant mode for PCB input to these harbors, occasional high PCB concentrations in old paint chips and the correlation of mussel PCB concentrations with antifouling paint usage suggest that this may have been the predominant source of PCB to southern California harbors in recent years. It is not yet known how long these harbors will exhibit enhanced PCB contamination levels over those of the adjacent coastal waters.

*This paper is contribution 18 of the Coastal Water Research Project. Investigations into marine input rates of chlorinated hydrocarbons described here were supported by the U.S. Environmental Protection Agency, Grant R801152. The contents do not necessarily reflect the views and policies of the Environmental Protection Agency, nor does mention of trade names or commercial products constitute endorsement or recommendation for use. Investigations into chlorinated hydrocarbon distributions described here were conducted in conneciton with State of California Agreement M-11, with the Marine Research Committee, Department of Fish and Game.

INTRODUCTION

Chlorinated hydrocarbons appear to be one of the most important classes of contaminants yet described in the marine ecosystem of southern California. Excessive concentrations of DDT residues have been found in anchovies, sand crabs, byssal mussels, flatfish, and bottom sediments collected near one Los Angeles coastal outfall that discharges municipal wastewater, and relatively high concentrations of polychlorinated biphenyls (PCB) have also been reported (Risebrough 1969; Burnett 1971; Southern California Coastal Water Research Project 1973; de Lappe et al. 1974). In addition, reproductive failures in the brown pelican at Anacapa Island rookeries off Los Angeles have been associated with the large accumulations of chlorinated hydrocarbons in this fish-eating bird (Risebrough et al. 1971).

The coastal plain of the Southern California Bight extends from Point Conception to northern Baja California, a distance of about 500 km (Figure 1). It is inhabited by more than 11 million persons, and the intense agricultural and industrial activities of this region have constituted an ample source of chlorinated hydrocarbons to the environment. During the past 3 years, the Coastal Water Research Project has been engaged in describing (1) the input rates of DDT and PCB compounds via major routes to the coastal marine waters and (2) the distributions of these materials in several important components of the ecosystem throughout the Bight. Our studies indicate that the numerous harbors located in the Bight may be significant sources of certain trace metals and organic compounds to the adjacent coastal waters (Southern California Coastal Water Research Project 1973).

During 1973, the Project began a detailed investigation of chlorinated hydrocarbon inputs and distributions in three major southern California harbors: San Pedro Harbor in Los Angeles County, Newport Bay in Orange County, and San Diego Bay in San Diego County. Our study focused on San Pedro Harbor,* which is the largest of the three harbors and the one with the greatest variety of inputs. Most of the direct industrial discharges into harbor waters in the Bight occur here; San Pedro Harbor is also the only one of the three harbors that receives a major discharge of municipal wastewater (from the Terminal Island Treatment Plant) and a major input of surface storm runoff (from the Los Angeles River channel). All of the large shipyards in the Bight are located in either San Pedro Harbor or San Diego Bay. In contrast, Newport Bay is almost entirely composed of either recreational craft moorings (in Newport Harbor) or relatively undisturbed wetlands (in upper Newport Bay).

*San Pedro Harbor is comprised of the Los Angeles and Long Beach Harbors.

The Project studied the principal input modes--antifouling paint application, direct industrial discharge, municipal wastewater discharge, surface runoff, and aerial fallout. Previous studies had demonstrated the usefulness of the coastal intertidal mussel *Mytilus californianus* in describing the extent and degree of nearshore contamination by chlorinated hydrocarbons (Southern California Coastal Water Research Project 1973; de Lappe et al. 1974). Therefore, we selected the bay mussel *Mytilus edulis* to describe the distributions of DDT and PCB compounds within these harbors. The use of *Mytilus* allowed us to compare concentrations in harbor mussels to those found in coastal specimens, which are more directly exposed to other sources of chlorinated hydrocarbons, such as the large submarine discharges of municipal wastewater.

SAMPLING

We obtained information on typical kinds and amounts of antifouling paints applied annually to recreational, commercial, and naval vessels in the Bight during 1973 by surveying both haulout yards and paint retailers in the vicinity of the harbors under investigation. Samples of principal paint brands currently being applied and paint scrapings from drydock areas were obtained for analysis of chlorinated hydrocarbon content. The survey results were used to estimate the average annual application rate of antifouling paint per recreational craft in the marinas of the Bight; quantities of antifouling paint used annually on commercial and naval vessels were determined directly from surveys of the major shipyards in the Bight.

Industrial discharges into San Pedro Harbor were grouped into several general categories. In the summer and fall of 1973, we collected approximately 20 composites of industrial effluents, each composed of four hourly grab samples from a variety of industries in each category. Replicate 7-day samples of Terminal Island municipal wastewater were obtained in early 1974 by compositing (according to flow) three grab samples per day. These samples were refrigerated soon after collection and preserved in pesticide-grade hexane until analyzed.

Samples of surface runoff were collected a few kilometers from the mouth of the Los Angeles River during four storms of Water Year 1973-74; we usually collected about ten samples per storm. The samples were taken at the center of the channel: An all-metal, depth-integrating sampler (patterned after a U.S.G.S. suspended sediment sampling device) was raised and lowered between the surface and the bottom of the stream at a steady rate until it was nearly full. Four-liter samples were preserved with hexane until analyzed.

In addition to the storm runoff collections from the Los Angeles River, we also sampled dry-weather flows in several southern California channels during the spring and summer of 1973.

Aerial fallout was sampled at two stations inside San Pedro Harbor, one on a beach lifeguard tower and the other on the roof of a boat barge anchored near the central breakwater. The Newport Bay station was located at an ocean pier just outside Newport Harbor, and San Diego stations were located at La Jolla and Imperial Beaches, a few kilometers north and south of San Diego Bay, respectively. Replicate week-long collections were made at the stations throughout the summer of 1973 according to a technique developed by McClure (personal communication).* Cleaned glass plates 0.1 sq. m. in area were sprayed with a light coat of mineral oil and placed on unpainted surfaces approximately 4 m. above the ground. Once a week, the plates were scraped and resprayed three times in succession; this provided high recovery of the sample and left a cleaned plate for the next collection.

Intertidal mussels 4 to 6 cm. long were collected during January 1974 at ten or more stations in each harbor and also at two or more coastal sites near the mouth of each harbor. The whole soft tissues were removed and analyzed for chlorinated hydrocarbons.

LABORATORY ANALYSIS

Paint samples were extracted using two different methods. Wet paint samples were extracted with diethyl ether-hexane solutions in a separatory funnel. Dry paint samples were hexane-extracted in a Soxhlet extraction apparatus. Both wet and dry paint extracts were cleaned using Florisil columns.

All water samples (municipal wastewater, direct industrial discharge, and surface runoff) were processed using one technique: The samples were extracted with diethyl ether-hexane solutions in separatory funnels, and the extracts were then cleaned, using Florisil columns.

The aerial fallout samples were passed through a silica gel column to separate the chlorinated hydrocarbons from the rest of the sample, according to a technique developed by McClure (personal communication).

The mussel samples were extracted by covering the tissue with acetonitrile and using a high-speed blender to homogenize the sample. The homogenate was filtered into a separatory funnel, and the sample was partitioned with hexane. The hexane fraction was cleaned, using a Florisil column.

*Dr. Vance McClure, National Marine Fisheries Service, Tiburon, Ca.

The instrument used for analysis was a Tracor MT 220 gas chromatograph equipped with two ^{63}Ni electron capture detectors. The carrier gas was purified nitrogen flowing at a rate of 80 ml/min. The injector, column, and detector temperatures were 225, 190, and 285 degrees C, respectively. The column was a 1/4-x 6-in. tube packed with 3 percent OV-1 on Chromosorb W, AW, DMCS, 60/80 mesh.

RESULTS

The survey of antifouling paint application in several marinas of the Bight indicated that about 75 percent of the boats in each marina were painted once a year and that, on the average, approximately 1 gal.* of paint was used per boat.** On the basis of this relationship and small craft inventories obtained from harbormasters, we estimated the use of antifouling paints in Newport Harbor and in several marinas of San Pedro Harbor and San Diego Bay (Table 1; the table also gives estimated quantities of antifouling paint applied annually to commercial and naval vessels in these anchorages).

Concentrations of PCB 1242 and 1254 observed in the major brands of antifouling paint currently in use in southern California are listed in Table 2; data on levels found in paint scrapings at haulout yards are listed in Table 3. The upper-limit values for total DDT generally were an order of magnitude lower than those for the sum of PCB 1242 and 1254.

Tables 4 and 5 present the concentrations of PCB and DDT compounds observed in effluent composites from major representatives of direct industrial dischargers to Los Angeles Harbor and Dominguez Channel of Long Beach Harbor. PCB concentrations were highest in effluents from several shipyards, but the discharge rates of these effluents were relatively low. Significant concentrations of both PCB and DDT compounds were found in the cannery wastes, which were discharged at the rate of several million gallons per day.

The lowest concentrations were found in cooling water discharges from a power plant in the Los Angeles Harbor area; effluents of this type account for approximately 80 percent of the 1,290 mgd of industrial discharges to San Pedro Harbor. The results of the replicate analyses of Terminal Island municipal wastewater released into the outer portion of San Pedro Harbor (Table 6) revealed higher concentrations of the chlorinated hydrocarbons in this effluent than in most of the direct industrial discharges.

*One gallon equals 3.78 liters.

**Inventory records generally apply to small craft between 16 and 65 ft (about 5 to 22 m) in length.

Figure 2 gives an example of the relationship between estimated discharge rate* and concentrations of suspended sediment, total DDT, and PCB 1254 in Los Angeles River storm runoff. Although there were relatively large variations in the chlorinated hydrocarbon concentrations, these values appeared to fluctuate with concentration of suspended sediment and discharge rate. Such a relationship implies that most of the runoff transport of these trace organics occurs during periods of peak discharge. Flow-weighted mean concentrations of these chlorinated hydrocarbons for four individual storms during Water Year 1972-73 are listed in Table 7, as are the overall storm flow-weighted means for the year. For comparison, corresponding values based on analyses by Risebrough and de Lappe**for Water Year 1971-72 are also listed. These overall means are in remarkably good agreement. Table 8 presents the results of the two seasonal collections of dry weather flow in channels discharging into or nearby the three harbors under investigation.

Figures 3 and 4 illustrate weekly values for flux via dry aerial fallout of PCB 1254 and p,p' DDT***measured from July to September 1973 at or near the three harbors. During the sampling period, winds were predominantly from the west. Investigations are now in progress to determine if higher fallout values occur during the winter when the sea breezes are less persistent and occasional strong winds from the east carry dust and other materials out over the Bight.

From these data, we have attempted to estimate typical annual inputs of measurable DDT and PCB compounds to the three harbors via the five routes investigated. As seen from Table 2, PCBs were detected in only 7 of the 28 wet paint samples analyzed. With the exception of the two samples with total PCB concentrations of approximately 40 mg/l each, levels generally were the order of 1 mg/l or below; neglecting inequality signatures in Table 2, median values for PCB 1242 and 1254 were 0.3 mg/l and 0.7 mg/l, respectively. Total DDT upper limits generally were an order-of-magnitude lower. We combined these values with the estimated quantities of antifouling paint applied annually to recreational, commercial, and naval vessels in the harbors (Table 1) and obtained estimated upper limits for this annual use of PCB and DDT in these harbors.

*Preliminary values; calculated from telephonic readings of depth of flow and appropriate calibration curves.

**Bodega Bay Institute of Pollution Ecology, P.O. Box 245, Bodega Bay, California 94923.

***The predominant DDT compound observed in the fallout samples.

The estimates for industrial inputs to San Pedro Harbor were obtained by calculating flow-weighted concentrations of PCB 1254 and total DDT in three classes: power plant cooling water, fish cannery wastes, and "other industrial" discharges. These categories were initially selected* because of the relatively high flows of the power plant discharges and the relatively high DDT emissions from cannery wastes. The weighted concentrations were then multiplied by the reported total present flows for the three classes of industrial wastewaters into San Pedro Harbor;** these values are summarized below:

Class	Mean Flow (mgd)	Flow-Weighted PCB 1254	Mean Conc. (μg/l) Total DDT
Power Plant Cooling	1,021	0.01	0.002
Cannery Wastes	16	0.09	0.34
Other Industrial	254	0.10	0.02
Blank		0.004	0.002

There does not appear to be any significant discharge of industrial waste into Newport Bay;+ in San Diego Bay, some power plant cooling waters and cannery wastes are discharged,++ but these inputs have not yet been studied.

Estimates of annual PCB and DDT inputs to San Pedro Harbor via the discharge from the Terminal Island Municipal Wastewater Treatment Plant were calculated from the average concentrations listed in Table 6 and the mean discharge rate of approximately 10 mgd.

The long-term annual mean flow of surface runoff to San Pedro Harbor via Los Angeles River is 148 cu m/yr; of this, approximately 29 cu m/yr is dry-weather flow, and the remainder is attributable to storm flow.† By combining these data with the concentrations given in Tables 7 and 8, we obtain the estimated typical mass emission rates for total

*The industrial wastewater sampling and evaluation program is still in progress.

**Information supplied by Dr. Lewis Schinazi, California State Regional Water Quality Control Board, Los Angeles Region.

+Personal communication, Steven Harrera, California State Regional Water Quality Control Board, Santa Ana Region.

++Personal communication, Joseph Barry, California State Regional Water Quality Control Board, San Diego Region.

†Data provided by the Los Angeles County Flood Control District.

DDT and PCB 1254 (shown in Tables 9 and 10). Of these chlorinated hydrocarbon inputs, only about 2 percent occur via dry weather flow; thus, storm flow does appear to dominate annual runoff transport of these compounds in southern California. Although extensive records for Newport and San Diego Bays are not available, present best estimates for typical surface flow to these two bays are 7 and 12 cu m/yr, respectively. Because storm flow PCB and DDT concentrations were not obtained in these two areas, we have assumed that the dry-weather flow relationships (Table 8) for the Orange County and San Diego County channels, relative to the Los Angeles River dry-weather concentrations, may be used to extrapolate the 1972-73 Los Angeles River storm flow averages (Table 7) to the Newport Bay and San Diego Bay runoff channels.

Finally, the estimates of aerial fallout inputs of PCB 1254 and p,p'-DDT to the waters of the harbors were calculated from the waterway areas and the fluxes measured in the three regions during summer 1973:

Harbor	Area (sq km)	10^{-9} g/sq m/day PCB 1254	p,p'-DDT
San Pedro Harbor	62	99	308
Newport Bay	6	102	136
San Diego Bay	40	50	38

The resulting estimated annual mass emission rates for the five routes are summarized in Tables 9 and 10. The distributions* of total DDT (principally p,p'-DDE) measured in the whole soft tissues of the intertidal byssal mussel *Mytilus* collected from the vicinities of the three harbors are illustrated in Figures 5 to 7; corresponding distributions* for PCB 1254 are illustrated in Figures 8 to 10.

DISCUSSION AND CONCLUSIONS

Our investigation shows that negligible quantities of DDT are now entering Newport and San Diego Bays via the five major input modes under study. Because of the large input of stormwater from the Los Angeles River, surface runoff is the dominant source of DDT to San Pedro Bay; however, the estimated total annual input of about 100 kg/yr through runoff is insignificant relative to the 4,000 kg from the Los Angeles County submarine outfalls (at Whites Point, just northwest of the harbor) during 1973. (The 1971 DDT input via this municipal wastewater discharge was approximately 19,000 kg, and previous annual inputs may have been considerably higher.)

*The concentrations shown have not been corrected for chemical yield, found to be approximately 90 and 95 percent for total DDT and PCB 1254, respectively.

The distributions of total DDT concentrations in the intertidal mussels, shown in Figures 5 to 7, support the hypothesis that the Whites Point submarine outfall system has been the dominant source of DDT to the coastal and harbor zones investigated. The maximum tissue concentration of 1,500 µg/wet kg (ppb) occured on the coast near Whites Point, at the base of the outfalls. With the exception of the surprisingly high concentration (1,300 ppb) within the Long Beach Marina, the levels found inside San Pedro Harbor ranged from 120 to 640 ppb and were similar to (but somewhat lower than) those along the breakwater (range: 360 to 960 ppb).

In general, the DDT values in mussels increased with proximity to the Whites Point outfall system. Values in the coastal specimens outside Newport Harbor, 40 km to the south, were also high (concentrations ranged from 110 to 260 ppb), although inside the harbor, somewhat higher values were observed (200 to 640 ppb). As the present known input rates of DDT to Newport Bay are negligible, these high values in the harbor mussels may be due to recycling of past accumulations of DDT within the restricted waters there.

The San Diego mussels showed the lowest DDT concentrations, with coastal values ranging from 4 to 61 ppb. The median coastal value was 51 ppb compared to the median harbor values of 32 ppb. These levels, which were not significantly different, were approximately 30 times lower than the concentration observed at the base of the Los Angeles County outfalls, 150 km to the north.

The following PCB summary indicates an important difference between the relative distributions of PCB and those of DDT discussed above.

Region	Coastal Median	Coastal Range	Harbor Median	Harbor Range
San Pedro	110	80-140	160	86-480
Newport*	69	53-100	210	86-880
San Diego*	47	44-61	320	19-860

The coastal PCB medians decrease by a factor of two from San Pedro to San Diego, but the harbor medians increase by a factor of two. This pattern indicates that, in contrast to the case for DDT, there appears to be more than one important source of PCB to nearshore waters of the Bight.

Past studies have shown that in 1971, PCB inputs from Los Angeles and Orange County ocean outfalls each exceeded 1,000 kg/yr, whereas the input from the San Diego Point Loma outfall was an order of magnitude lower (Southern California Coastal Water Research Project 1973). We would therefore expect coastal mussels off San Pedro and Newport

*Excluding *M. californianus* values.

Bays to be more influenced by PCB from the ocean outfalls than are those off San Diego; the median PCB concentrations just presented are consistent with this expectation. However, in all three regions, the values of PCB in harbor mussels exceed those in coastal specimens, implying that a specific harbor-related source may have been a dominant ubiquitous PCB input in recent years.

Although the data of Table 10 does not indicate which of the potential sources investigated is most likely to have been the dominant one, the fact that the high PCB concentrations are found wherever there is intense vessel activity suggests that this may well be the key. In all three harbors, the values are highest in the confined regions where recreational or commercial and naval vessels are present. This conclusion is strengthened particularly by the fact that some of the highest PCB concentrations observed occurred in Newport Harbor, an anchorage with a high density of recreational craft and with no significant discharge of industrial, municipal, or surface runoff wastewater. The occasional very high concentrations of PCB in dried chips of antifouling paint support this hypothesis, although other potential vessel sources, such as loss of hydraulic fluid, might also be the explanation.

Samples of pre-1970 antifouling paints are now being sought to further investigate this possibility. If the tentative conclusions attributing the relatively high PCB concentrations in harbor mussels to past inputs from this source are confirmed, it could mean that the prohibition of "open" use of PCB, such as in paints, has decreased the application of PCB to vessel bottoms by up to 10,000 kg/yr in the largest harbors of the Bight. Nevertheless, the restricted circulation in these harbors, and the proximity of harbor intertidal organisms to potential PCB sources, has resulted in significantly higher contamination levels of PCB than are exhibited by coastal mussels near present major submarine discharges of these chlorinated hydrocarbons.

ACKNOWLEDGMENTS

We thank Larry Miller, Newport Beach Chamber of Commerce, and Ray Berry, California Shipyards, for help in acquiring these data. Personnel of the Flood Control Districts and the California Regional Water Quality Control Boards in Los Angeles, Orange and San Diego Counties provided important information on surface runoff and industrial discharges. We also appreciate the cooperation of most of the owners and operators of drydocks and retail paint outlets at the harbors we investigated. Elliott Berkihiser, Joseph Johnson, and Paul Smokler of the Coastal Water Research Project participated in the field collections and laboratory analyses, and Deirdre McDermott and Robin Simpson, also of the Project, assisted in preparation of the manuscript.

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FIGURES

Figure 8. Concentrations (μg/wet kg) of PCB 1254 in whole soft tissues of *Mytilus edulis* in San Pedro Harbor, January 1974.

Figure 9. Concentrations (μg/wet kg) of PCB 1254 in whole soft tissues of *Mytilus edulis* in Newport Bay, January 1974.

Figure 10. Concentrations (μg/wet kg) of PCB 1254 in whole soft tissues of *Mytilus edulis* in San Diego Bay, January 1974.

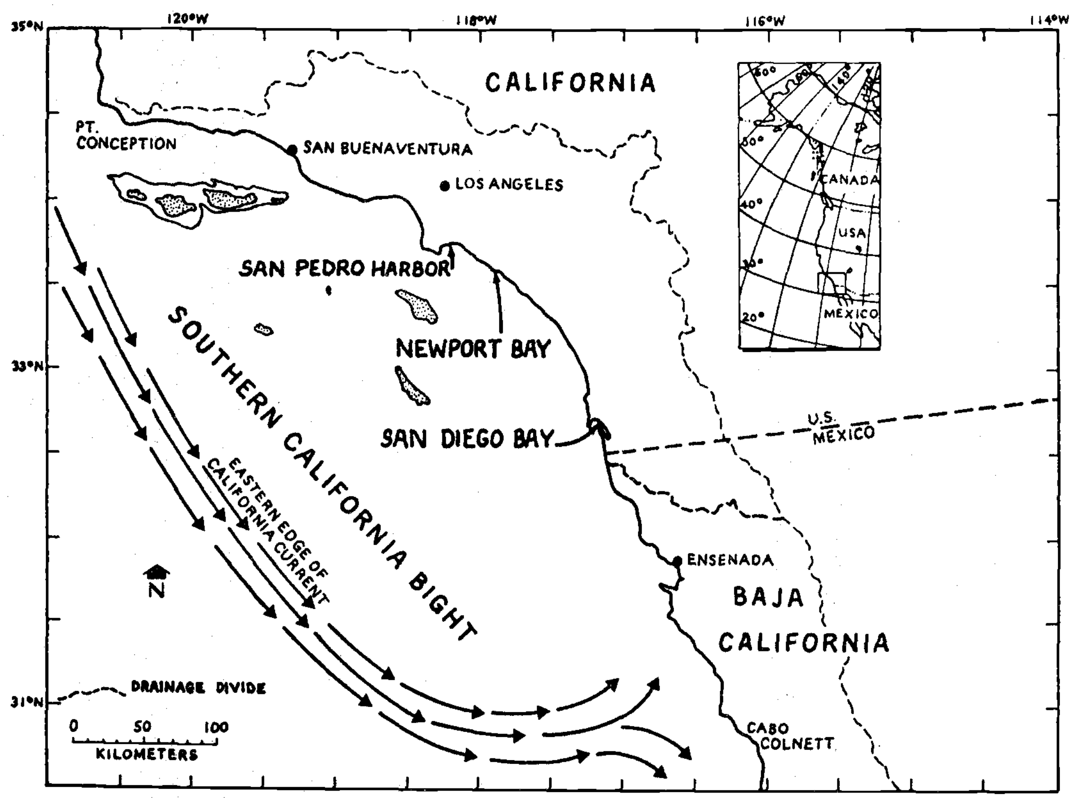


FIGURE 1.

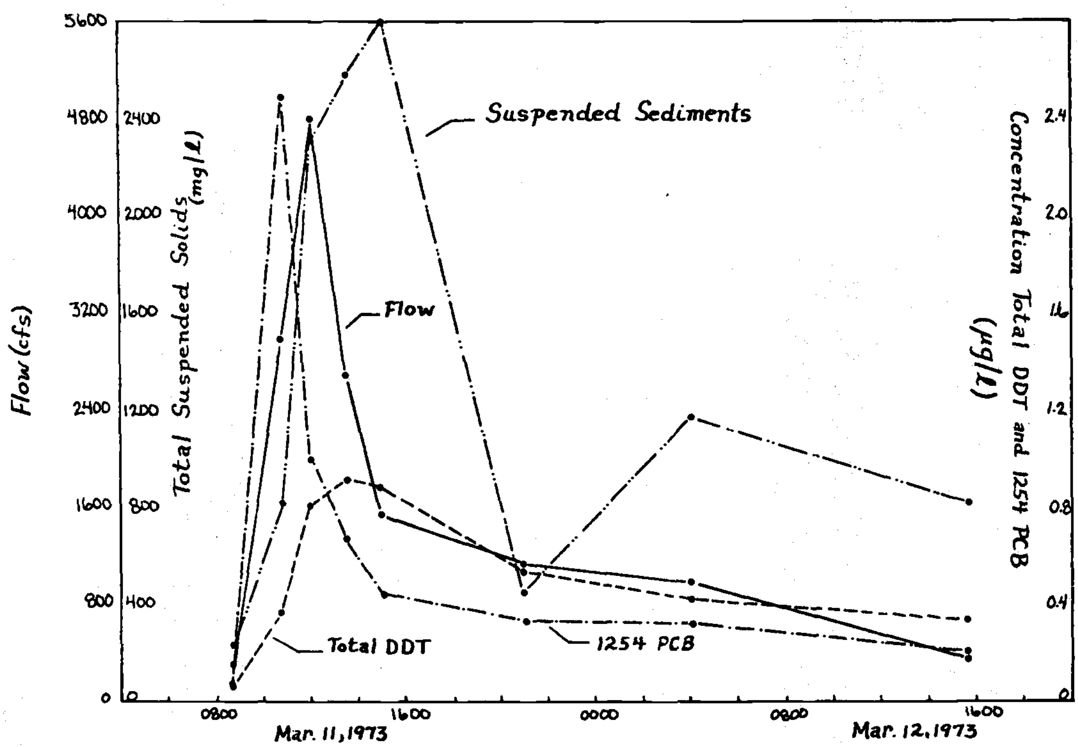
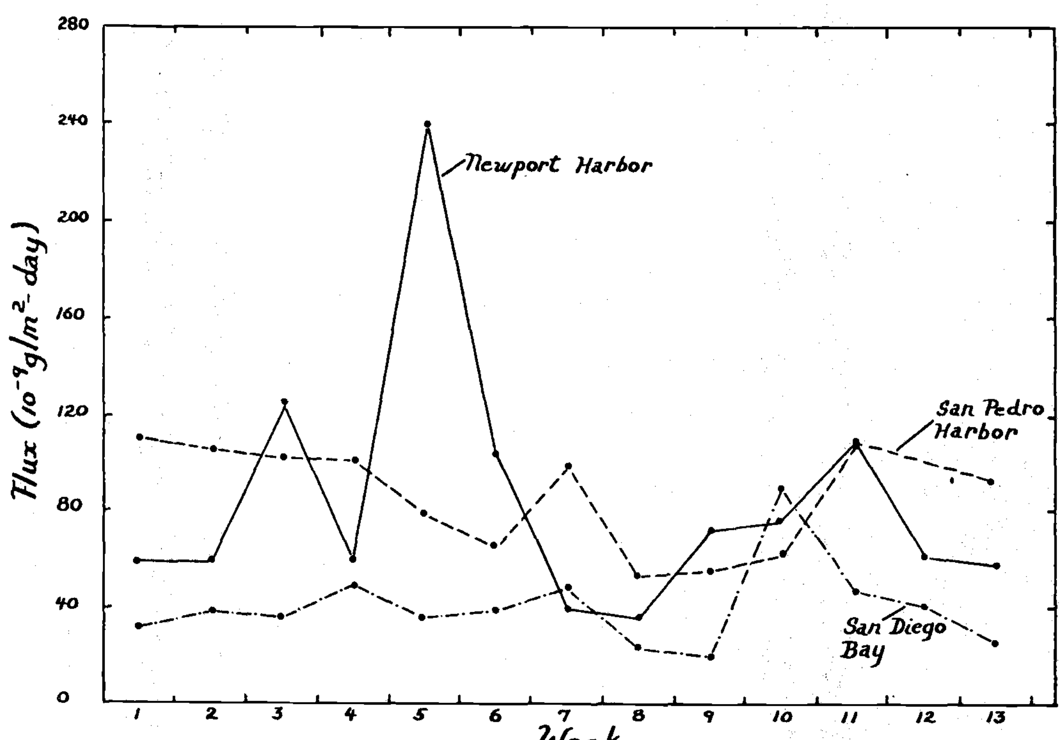


FIGURE 2.



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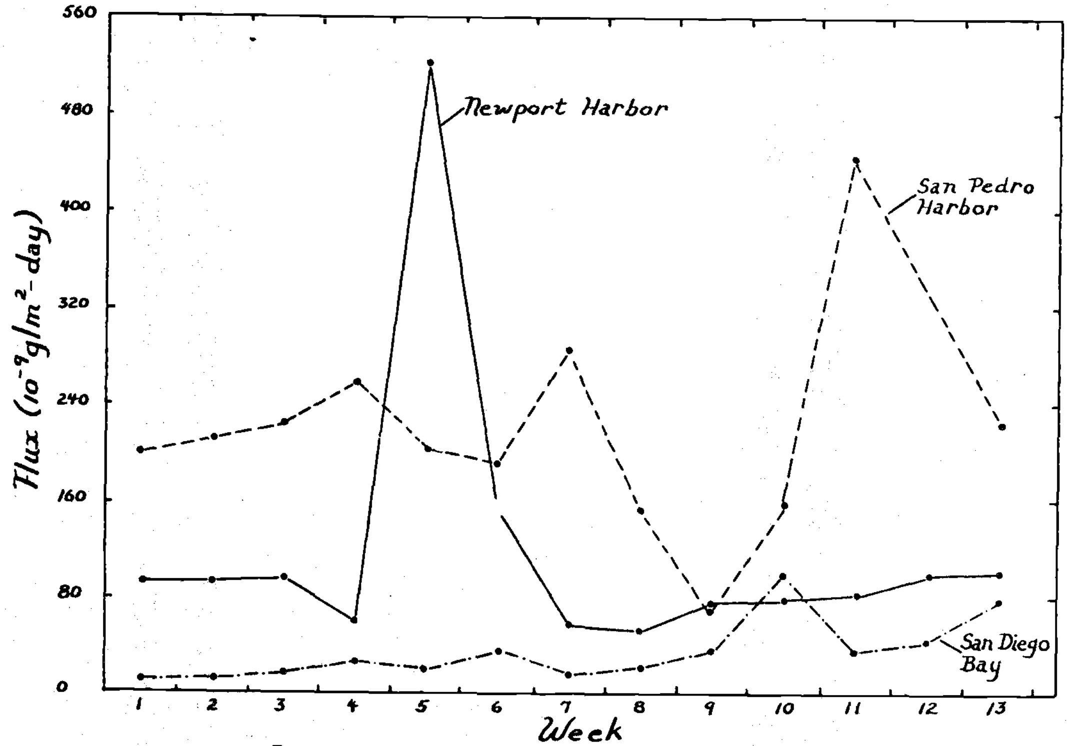


FIGURE 4.

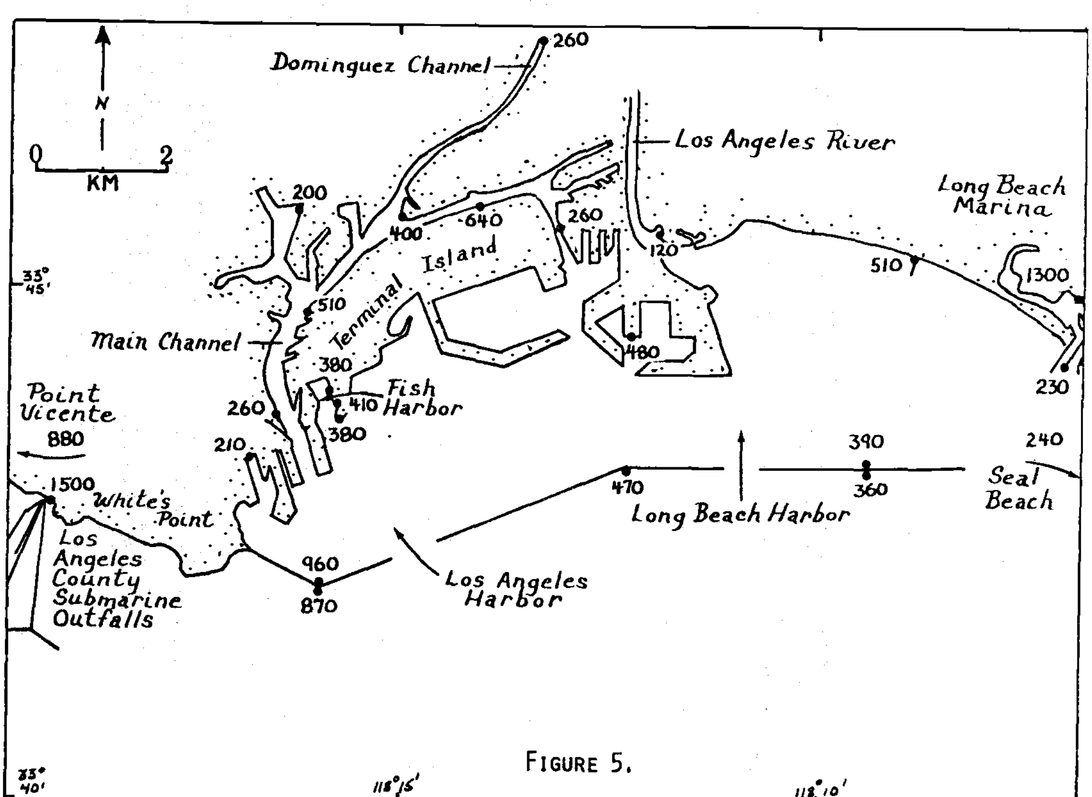


FIGURE 5.

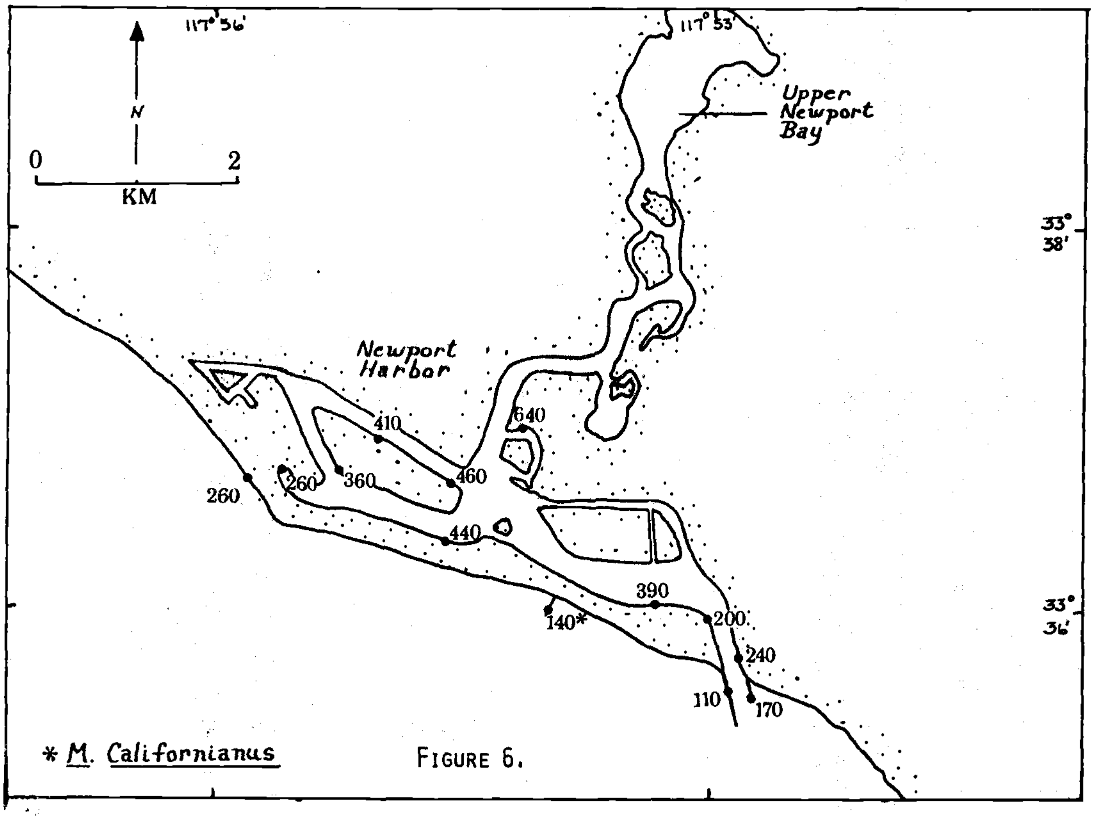


FIGURE 6.

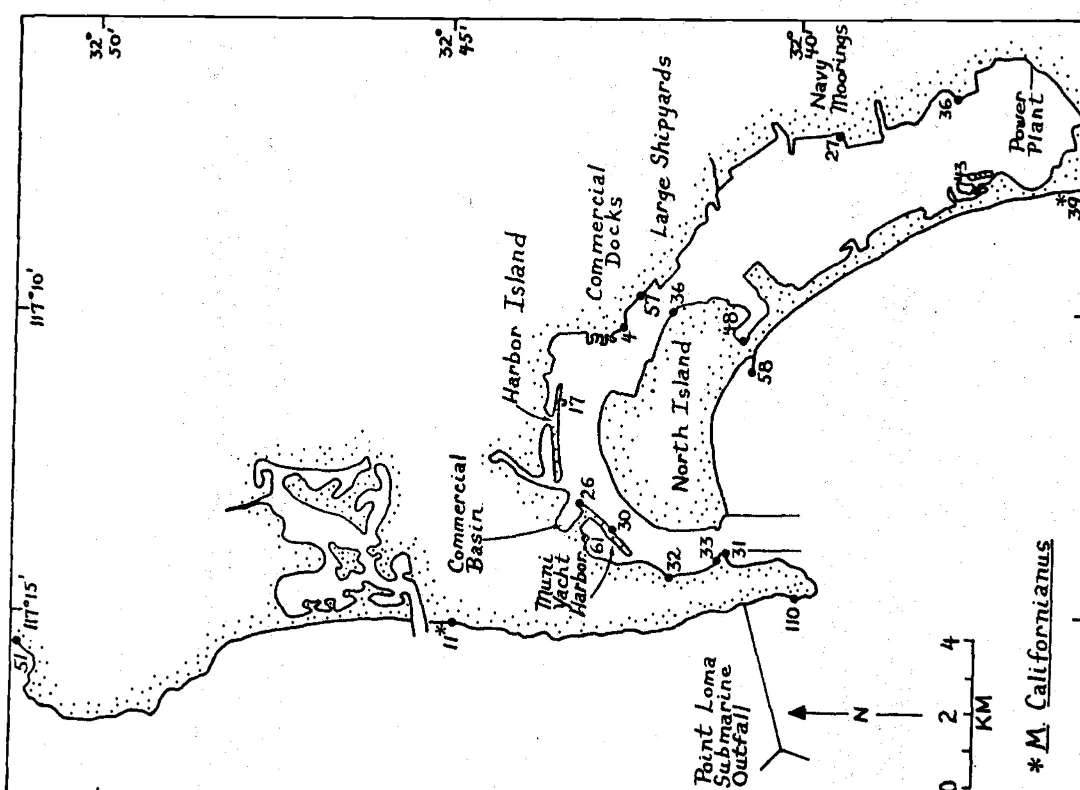


FIGURE 7.

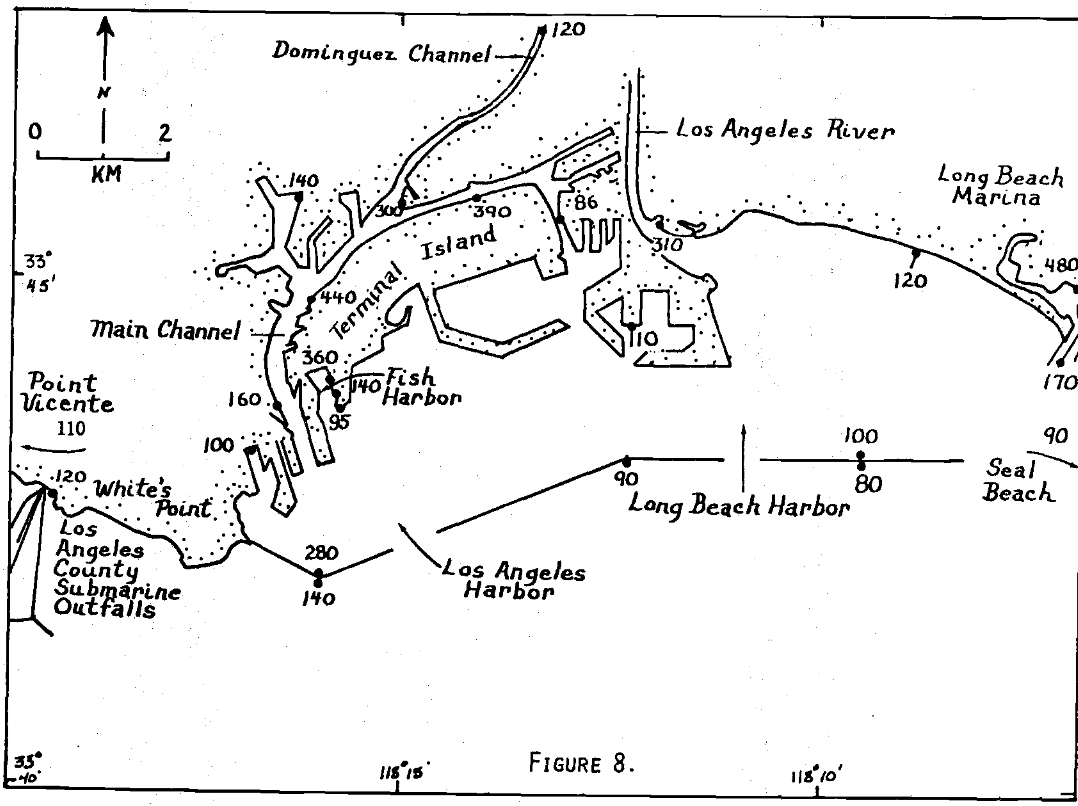


FIGURE 8.

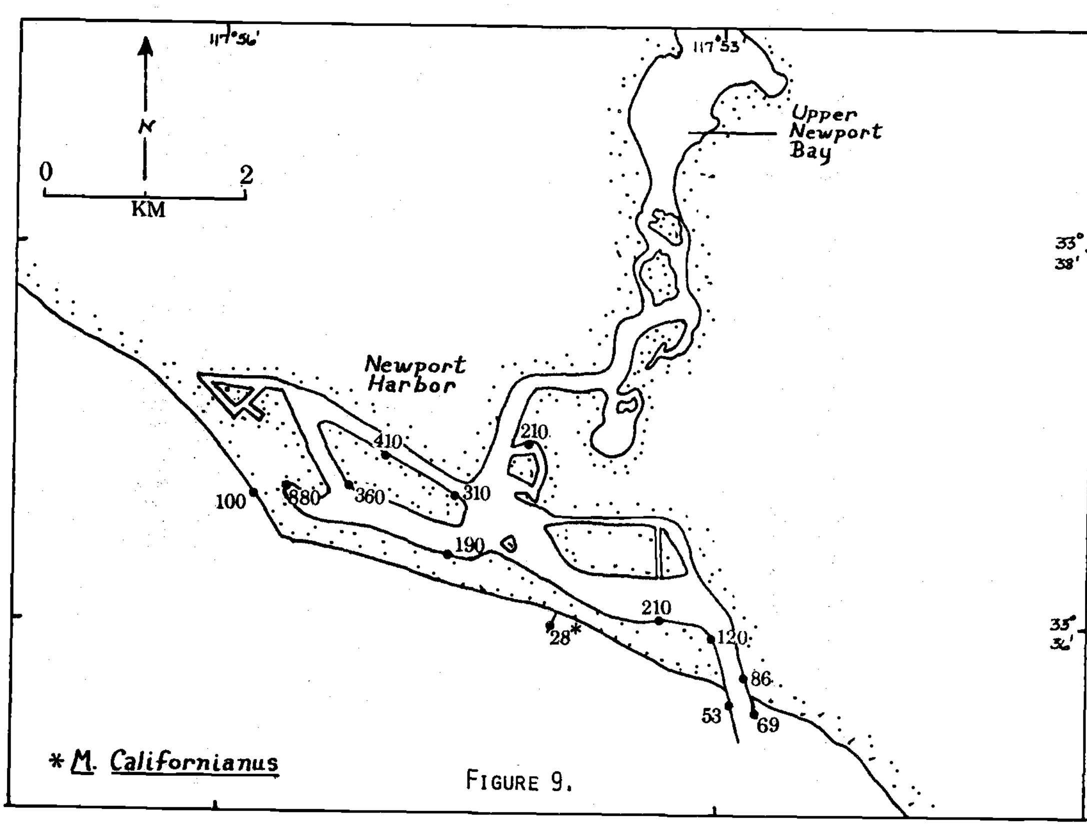
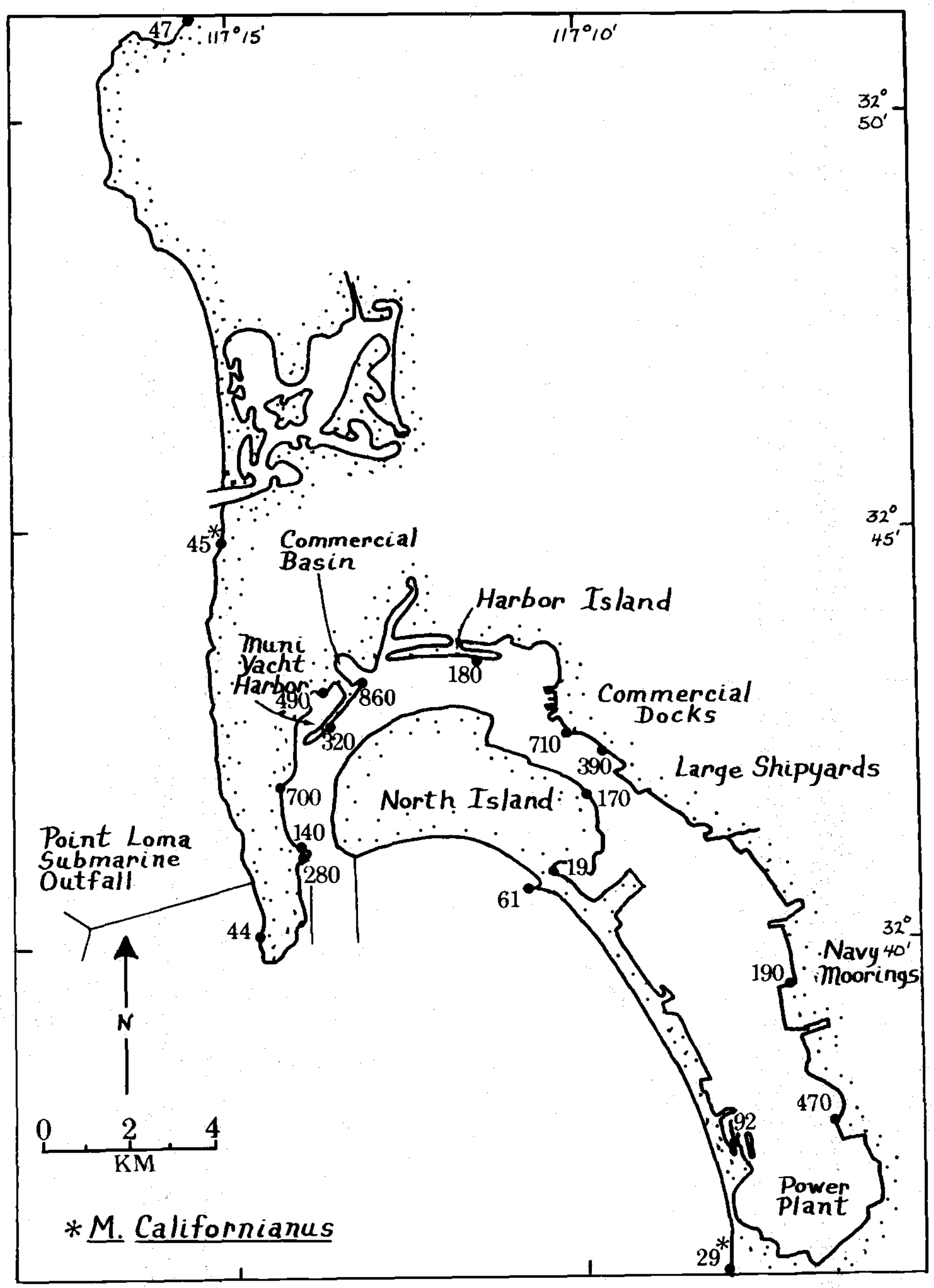


FIGURE 9.



47
117°15'
117°10'
32° 50'
32° 45'
32° 40'
45
Commercial Basin
Harbor Island
Muni Yacht Harbor
180
490
860
Commercial Docks
320
710
390
Large Shipyards
700
North Island
170
140
Point Loma Submarine Outfall
280
19
61
44
Navy Moorings
190
N
470
0 2 4
KM
92
Power Plant
* M. Californianus
29

FIGURE 10.

TABLE 1. ESTIMATED NUMBER OF RECREATION CRAFT AND AMOUNTS OF ANTIFOULING PAINTS APPLIED IN THREE SOUTHERN CALIFORNIA HARBORS.

HARBOR	NUMBER OF BOATS	ANTIFOULING PAINTS (ℓ/YR)
SAN PEDRO HARBOR		
LOS ANGELES HARBOR	3,600	
LONG BEACH HARBOR	2,700	
LONG BEACH MARINA	2,500	
SUBTOTAL	8,800	25,000
COMMERCIAL AND NAVAL	-	115,000
NEWPORT HARBOR	8,600	25,000
SAN DIEGO BAY		
MUNI. YACHT HARBOR	1,900	
COMMERCIAL BASIN	800	
HARBOR ISLAND	600	
CORONADO MARINA	200	
OTHERS	100	
SUBTOTAL	3,600	10,000
COMMERCIAL AND NAVAL*	-	75,000
TOTAL	21,000	250,000

*ESTIMATES BASED PARTIALLY ON DATA FROM Barry (1972).

Table 2. Polychlorinated biphenyl concentrations in antifouling paints used in southern California.

Code	Brand and Type	PCB (mg/ℓ) 1242	1254
RECREATIONAL			
	Brolite Z-Spar		
P23	2000	<0.06	<0.16
P48	Multitox	<0.05	1.6
P34	Colortox	-	0.29
P53	Killer (B-90)	<0.3	<0.6
P37	A-1316 (1969)	<0.4	<1.2
	Woolsey		
P24	Vinelast (Blue)	<0.3	<1.0
P39	Vinelast (Red)	<0.1	<0.3
	International		
P28	Inter-lux 62	<0.2	<0.6
P26	Bottomkote 69	<0.4	<1.1
P20	Vinyl-lux	<0.03	<0.07
P19	Tri-lux	<0.3	<1.0
P18	Copper-lux	<0.06	<0.15
	Pettit		
P25	Unepoxy	<0.01	<0.03
P51	Trinidad 75 (red)	<0.09	<0.2
P31	Pacific Special	1.7	1.2
	Mariner's		
P2	1034 Lido	<0.3	<0.6
	Singapore		
P32	696 Blue	<0.4	<1.2
	Devoe-Reynolds		
P30	Navicote	<84	<220
P63	Triple C	12.0	28.0
COMMERCIAL			
	Devoe-Reynolds		
P54	Super Tropical	18	23
P58	3407	<0.005	<0.023
P59	213	<0.92	<0.29
P64	Hot Plastic	1.30	3.00
P55	Cold Plastic 105	<1.6	<4.0
	Amarcoat		
P62	Emeron 67	1.20	2.80
	Proline		
P57	1080	<0.17	<0.72
NAVY			
	Devoe-Reynolds		
P60	121/63	<0.1	<0.4
P61	129/63	<0.1	<0.4

TABLE 3. POLYCHLORINATED BIPHENYLS IN ANTIFOULING PAINT SCRAPINGS FROM SOUTHERN CALIFORNIA DRYDOCKS

ORIGIN	PCB (MG/DRY KG) 1242	1254
FIBERGLASS HULL	.1	3.0
TRASHCAN	1.3	1.4
TRASHCAN	9.5	3.5
DRAIN 1	28	3,300
DRAIN 2	7.5	8.3
DRAIN 2	110	160
WOOD HULL		19
WOOD HULL	3,000	53,000
WOOD HULL		150,000
YARD	2.8	0.3
WOOD HULL	0.9	20
WOOD HULL	1.1	1.1
FIBERGLASS HULL	1.0	4.2
WOOD HULL	0.5	0.8
WOOD HULL	3.7	1.9

TABLE 4. CONCENTRATIONS (μg/ℓ) OF CHLORINATED HYDROCARBONS IN INDUSTRIAL DISCHARGE: LOS ANGELES HARBOR, 1973

TYPE DISCHARGE	FLOW (MGD)	PCB 1254	TOTAL DDT
FISH CANNERY			
WASTE	5.55	0.05	0.49
WASTE	3.20	0.17	0.10
RETORT DISCHARGE	0.12	0.02	0.007
SHIPYARD			
COOLING WATER	0.04	0.65	0.003
COOLING WATER	0.43	0.01	0.001
OIL TANKER CLEANDOWN	0.25	2.10	0.18
SHIP BALLAST	0.04	1.52	-
SHIP BALLAST	0.29	0.02	-
OIL REFINERY			
COOLING WATER	0.02	0.02	0.002
POWER PLANT			
COOLING WATER	257	0.01	0.002
CHEMICAL PLANT			
COMB. PROCESSES	5.51	0.03	0.002
BLANK		< 0.004	< 0.002

TABLE 5. CONCENTRATIONS (μg/ℓ) OF CHLORINATED HYDROCARBONS IN INDUSTRIAL DISCHARGE: DOMINGUEZ CHANNEL-LONG BEACH HARBOR, 1973

TYPE DISCHARGE	FLOW (MGD)	PCB 1254	TOTAL DDT
OIL REFINERY			
COOLING WATER	0.047	0.01	0.01
COOLING WATER	0.200	0.03	0.12
COOLING WATER	0.319	0.03	0.01
COOLING WATER	0.270	0.04	0.10
CHEMICAL PLANT			
COOLING WATER	0.047	0.02	0.02
COOLING WATER	0.040	0.01	0.13
COOLING WATER	0.529	0.004	0.004
MISCELLANEOUS			
AUTO WASH	0.040	0.01	0.003
YARD RUNOFF	0.004	0.18	0.09
COOLING WATER	0.125	0.16	0.13
BLANK		< 0.004	< 0.004

Table 6. Concentrations ($\mu g/\ell$) of Chlorinated Hydrocarbons in Replicate Composites of Municipal Wastewater from Terminal Island Treatment Plant,* 19-25 February 1974.

Constituent	R-1	R-2	Average	Blank
PCB 1254	0.21	0.09	0.15	<0.006
p,p'-DDT	0.14	0.06	0.10	<0.001
o,p'-DDT	0.03	0.01	0.02	<0.001
p,p'-DDD	0.15	0.09	0.12	<0.001
p,p'-DDE	0.03	0.03	0.03	<0.001
Total DDT	0.35	0.19	0.27	<0.004

*Mean annual discharge approximately 10 mgd.

Table 7. Flow-Weighted Mean Concentrations ($\mu g/\ell$) of Chlorinated Hydrocarbons in Los Angeles River Storm Runoff

Date	PCB 1254	Total DDT
1971-72 Average	1.03	0.88
1972-73 Average	0.77	0.78
4-7 Dec 1972	0.52	0.67
27 Feb-1 Mar 1973	0.85	0.99
6-9 Mar 1973	0.91	0.73
11-12 Mar 1973	0.73	0.60
Average Blank	<0.003	<0.004

Table 8 . Concentrations ($\mu g/\ell$) of Chlorinated Hydrocarbons in 1973 Collections of Dry Weather Flow.

Channel	County	PCB 1254 Spring	PCB 1254 Fall	PCB 1254 Avg.	Total DDT Spring	Total DDT Fall	Total DDT Avg.
Los Angeles R.	L.A.	0.10	0.14	0.12	0.15	0.01	0.08
San Juan Cr.	Orange	0.01	0.01	0.01	0.01	0.01	0.01
San Luis Rey R.	S. Diego	0.01	0.02)	0.04	0.02	0.02)	0.02
San Diego R.	S. Diego	-	0.08)		0.02	0.03)	
Blanks		<0.002	<0.02	<0.01	<0.001	<0.007	<0.004

TABLE 9. ESTIMATED TYPICAL ANNUAL MASS EMISSION RATES OF TOTAL DDT (KG/YR) TO THREE SOUTHERN CALIFORNIA HARBORS.

	SAN PEDRO HARBOR	NEWPORT BAY	SAN DIEGO BAY
MUNICIPAL WASTEWATER	4	~ 0	~ 0
DIRECT INDUSTRIAL	17	~ 0	-
SURFACE RUNOFF	96	0.7	2
AERIAL FALLOUT*	7	0.3	0.6
ANTIFOULING PAINTS	< 0.1	< 0.1	< 0.1
TOTAL	124	1.1	2.7

*P,P'-DDT ONLY

TABLE 10. ESTIMATED TYPICAL ANNUAL MASS EMISSION RATES OF PCB 1254 (KG/YR) TO THREE SOUTHERN CALIFORNIA HARBORS

	SAN PEDRO HARBOR	NEWPORT BAY	SAN DIEGO BAY
MUNICIPAL WASTEWATER	2	~ 0	~ 0
DIRECT INDUSTRIAL	51	~ 0	-
SURFACE RUNOFF	96	0.4	3
AERIAL FALLOUT	2	0.2	0.8
ANTIFOULING PAINTS	0.1	<0.1	<0.1
TOTAL	151	0.7	3.9

Microbiogenic Sediments and Their Use in Evaluating Estuaries of the Central Puget Sound, Washington

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AND
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During the last several years marine technicians from Shoreline Community College have been collecting bottom sediment samples and other oceanographic data from the Central Puget Sound, Washington, as part of their training in field and laboratory techniques. During this last academic quarter, Winter 1974, more than 400 bottom samples and salinity stations were taken from seven student group project areas; Shilshole Bay, Elliot Bay, Embayments of Bainbridge Island, Sinclair Inlet-Port Orchard, Dyes Inlet, Liberty Bay, and Port Madison-Appletree Cove (Figure 1). The study areas provided the students with experience in the problems with initiating scientific research, cruise planning and preparation, data collection and laboratory processing techniques, data synthesis and final report preparation which we feel enhances the technician's awareness of his role in the outcome of scientific projects. In addition, the environments sampled exposed him to the problems with working in tidal and river influenced environments, ports, marinas, and shallow environments. Although initially the data collected was not intended to be presented as a scientific contribution, we feel that the data is of interest to people involved with estuary studies.

Since most grab samples we collected in the Central Puget Sound contained few macrofauna specimens per grab sample, the more abundant microbiogenic components of the sediment such as plant fragments, diatoms, foraminifera and ostracods were used as a basis for differentiating environments. A tablespoon of the sediment sample is usually of sufficient size to obtain counts normally exceeding several hundred specimens. The higher counts per station is quite desirable when population or community variations due to man induced pollution must be distinguished from natural population or community variations caused by changes in substrate, salinity or other natural factors controlling their variation. Furthermore, the microbiogenic components are preserved in areas of sediment accumulations and make it possible to analyze ancient environments during glacial periods or before man's influence upon the environment. We will later illustrate how the information obtained in this study might be used to aid in ancient environmental interpretations or pollution studies. Another useful aspect of the biogenic sediment components is that the examined micro-organisms are readily stored and therefore available for further comparisons.

Topographically Central Puget Sound is very complex with numerous embayments with varying shapes, size of drainage areas, and varying depths. Many of the estuaries and inlets such as Dyes Inlet and Liberty Bay are distant from the main waters of Central Puget Sound and have shallow sills separating their deeper interior basins from the more oceanic waters (Figure 1). Most of the embayments were glacially carved, modified by glacial deposits, present river and wind activity. The size and shape of the estuary does not necessarily reflect the size of the drainage area or where its major runoff site is concentrated within the estuary itself. For example, many of the embayments of Dyes Inlet have no rivers emptying into them; Fletcher Bay is very small despite its large drainage area and Hidden Cove is large but has a relative small drainage area. These relationships should effect the degree rivers, tides, and sediment influence water characteristics and life within the estuaries.

The lower surface salinities of Central Puget Sound reach their lowest values after peak runoffs associated with wet winter months in contrast to Northern Puget Sound where peak runoffs are associated with glacial meltwater runoff. The deeper waters of Central Puget Sound are controlled by the shallow sill at Admiralty Inlet north of the study area. The major fresh water sources in the area are located adjacent to Seattle; the Green River emptying into Elliot Bay and the outflow from Lake Washington at Shilshole Bay. Their locations next to the industrial areas of Elliot Bay and the major sewer outfall off West Point present sources of unnatural chemical additions within their respective deeper inflowing waters.

The details of the physical features of Central Puget Sound have been reviewed by other investigators. At this point we would like to summarize some of the basic questions that we will try to consider when reviewing the data that we have collected. What is the effect of inlets isolated or distant from the main body of Puget Sound water? How does the varying drainage area size and shape relative to estuary size and shape influence the micro-organisms and bottom sediment? What similarities or differences exist in the micro-organisms adjacent to large or small rivers? Are there any basic differences among the various estuary micro-organisms? How do the micro-organisms change relative to depth of water? How does the sediment size influence or bottom substrate influence the types of micro-organisms found within the sediment? Do the ports, sewer outfalls, and marinas show signs of unnatural variation in its micro-organisms population or communities? In addition, special attention should be given to contrast: the eastern and western main sides of Puget Sound, Elliot Bay versus Port Madison, Millers Bay versus Hidden Cove, Liberty Bay-Sinclair Inlet versus Dyes Inlet, and areas of strong tidal currents such as Rich Passage, Agate Passage and channels of Dyes Inlet.

FIELD AND LABORATORY METHODS

Samples were primarily collected between January 27 and February 27, 1974; some additional samples collected during Summer 1973 and Spring 1972. The school's 21 foot motorboat is equipped with a van Veen sampler, a portable salinometer, and a recording fathometer. Stations were located principally using lines and positions from compass bearings, depths, visual sightings down the lengths of piers, or by utilizing various navigational aids as "ranges." Sampling sites were primarily chosen in order to represent as many diverse environments within the area but were mainly confined to depths less than 20 fathoms.

The sediment samples were wet sieved through a 250 Tyler mesh screen (.064 mm) in order to separate the mud from the sand-gravel fractions. After oven drying the sediment fractions were weighed for size analysis, the sand-gravel fractions were floated with perchloroethylene (density 1.613 g/cm^3) to separate the microbiogenic components. Counts were made by Harman and the students computed and plotted their data as well as aided in the drafting of the figures.

RESULTS OF INVESTIGATION

Much data could have been plotted such as number of specimens per sample for each species, number of species, or statistical methods used. Although the concentration of the micro-organisms normally help discern either high productive areas or help depict sedimentation patterns, relative frequencies were used in order to evaluate relative changes within distinct groups of micro-organisms. Many of the groupings chosen would have been grouped differently if we intended the data to be used by a specialist of micro-organisms. The species were grouped with the idea that future technicians could make counts on the micro-organisms without too much fear of placing species in the wrong group. The results confirmed our initial expectations that many more stations would have to be sampled to obtain better resolution of natural variability in both community and population in order to decipher man induced variability. However, certain trends do exist and should be kept in mind as we review the results. They are: 1) the eastern side of Puget Sound differs from the western side, 2) the width of entrances, channels, estuaries, as well as depth of water and proximity to rivers appear to influence the communities found in tidal channels and estuaries, 3) tide flats and shallow water environments vary both in dominant species and concentration in bottom sediment but still have characteristics in common, 4) the more distant deeper inlets show a sparcity in micro-organisms as compared to the main deeper portions of Central Puget Sound (except for Elliot Bay), and 5) stagnant bottoms due to man's influence should be able to be detected as well as glacial epochs from sediment cores.

Sediment Grain Size Groups

Gravels dominate current swept channels, points or banks such as Agate Passage, Rich Passage, narrow channels of Dyes Inlet, and the bank off Blakely Harbor (Figure 2). Barnacle fragments make up most of the shallow sea shell rich gravels while *Cripidula spp,* make up deeper gravels. Rocks are normally encrusted with the red algae, *Lithothamnium spp,* and bryozoans. Although not shown, gravel makes up most beaches adjacent to tidal channels, outcrop areas, and southerly wave exposed beaches.

Sands prevail along most of the offshore areas of Central Puget Sound, especially in tidal or wave swept areas such as the region from Liberty Bay to Agate Passage to Point Jefferson. Well sorted gray sands occur especially on the western side of the sound adjacent to Murden Cove and Point Jefferson and on the eastern side around Alki Point. Brown sands occur north of Meadow Point to Richmond Beach, and frequently in river dominated estuaries. Muddy green sands are more frequent in deeper samples or distant embayments of Dyes Inlet, Sinclair Inlet, Port Orchard as well as Shilshole Bay. Some of the sands off West Point showed some degree of blackening and hydrogen sulfide odor. It appears that the gray sands occur mainly in current swept areas as well as brown sands, the latter being closer to suspended river sediment. Green and black sands may suggest higher availability of organic debris.

Muds dominate the deeper areas, coastlines protected from tidal or wave activity, and adjacent to rivers. Problems in size analysis arose in samples taken near rivers where an abundance of sand-size plant fragments existed. Green muds occurred in most offshore areas and distant estuaries with some samples showing increasing blackness with sediment depth especially in Blakely Harbor, Sinclair Inlet and Liberty Bay. Black muds rich in H_2S were abundant on the eastern and southern sides of Elliot Bay although green muds were found on its western side. Other occurrences of black muds were found in the estuary of Shilshole Bay, over diatom rich banks of Dyes Inlet, on the tidal flats of Blakely Harbor, Liberty Bay and Millers Bay, next to a lumber mill in Eagle Harbor, and within current protected marinas of Sinclair Inlet, Liberty Bay, Dyes Inlet and Kingston. Marinas at Shilshole and Port Orchard appear to flush enough to prevent stagnant sediment bottoms. Samples from five fathoms (near Pycnocline) appear to increase in mud content and wood fragments and have been corroborated in some areas by our scuba divers.

Salinity Distribution

The salinity data was collected throughout the month of February and at varying conditions of ebb and flood, but still the distribution appears significant to present in order to correlate with trends found in the micro-organisms distribution. For the most part, the major outflow areas of Elliot Bay and Shilshole Bay show marked decreases in salinity about their mouths and their fresh water transported toward their eastern margins (figure 3). Northern and southern major river plumes of the eastern side of Puget Sound have lower salinities than its western side. Most smaller estuaries with restricted entrances and large drainage areas show lower salinities, such as Millers Bay and Fletcher Bay, while the more open, deeper estuaries and the estuaries with small drainage areas have higher salinities. The salinities of the distant inlets (Sinclair, Liberty and Dyes Inlets) are lower than the main Central Puget Sound salinities but suprisingly do not show larger decreases near their major river outlets. Salinity differences between surface and deeper depths decrease within narrow channels, over banks, and especially in stations south of Alki Point.

Percent Diatoms

The two most abundant groups of micro-organisms are the diatoms and foraminifera; ostracods are less abundant and are confined mainly to more brackish waters and tidal passages. The relative abundance of the diatoms increases near brackish water areas and in the deeper offshore areas (Figure 4). It should be kept in mind that marked increases in diatom percentages can be caused by either increases in sediment concentrations of diatoms or decreases in the foraminifera. The later decreases in the foraminifera are especially apparent in Elliot Bay, deeper offshore areas, in black sediment, and in most current swept gray sands off Point Jefferson. The eastern side of the Sound shows an increase in percentages toward its shorelines reflecting the increases in the diatom *Milosiranae* and *Biddulphia,* while the western side reflects the greater increases in the nearshore foraminifera, *Elphiediella hannai.* In restricted, strong current passages calcareous foraminifera increase quite markedly in their concentrations and number of species, while diatom species are kept from accumulating. Differences between the more distant inlets and embayments show marked variations and it appears that the distant embayments of Dyes Inlet are different from those of Liberty Bay and Sinclair Inlet.

Diatom Groups

The grouping of the diatom species was made with the intention that non-specialists could examine the micro-organisms and be able to properly group various species without gross error. Three groups were formed based on their outward shape; flat disc-shaped diatoms such as *Coscinodiscus* and *Asterostycus*, angular- or rectangular-shaped diatoms such as *Ischmia* and most species of *Biddulphia*, and rod-like or coherent chains of diatoms such as *Melosiranae* and one-rod shaped *Biddulphia*.

Rod- and chain-shaped diatoms dominated the shallower, brackish water areas and the eastern side of Central Puget Sound, except for the deeper areas of Elliot Bay and Shilshole Bay (Figure 5). *Ishmia*, although present on the eastern side of the Sound was especially frequent in the embayments of Bainbridge Island and Dyes Inlet. Most deeper samples of Port Madison and Elliot Bay contained *Coscinodiscus* and appear frequently in Sinclair Inlet with lesser concentration in Port Orchard and Liberty Bay while wave swept areas of Port Madison contained *Asterostycus*. In the deeper portions of the distant inlets foraminiferal faunas become sparse, *Coscinodiscus* dominates but not in concentrations that would be expected in deeper areas. This suggests the possibility that these more oceanic species are entrapped near the pynocline and explain their higher concentration in some of the shallower areas, especially in the shallow, semi-closed basin of northwestern Port Madison.

Percent Calcareous Foraminifera

Foraminifera, single-celled animals, make their sea shells (tests) out of either calcium carbonate, calcareous foraminifera, or utilize sand grains to build their tests, arenaceous foraminifera. Calcareous foraminifera dominated most of the areas, especially in narrow passages, marinas, piers and nearshore environments, except in deeper offshore areas or near river mouths (Figure 6). Low percentages of calcareous foraminifera near river mouths and tidal flats are due to increases in the brackish water arenaceous species of *Miliammina fusca, Trochammina pacifica, T. inflata, T. macrescens* and a *Reophax spp. Elphidium selseyense* which appear to be more tolerant of brackish water than *Elphidiella hannai* found more abundantly offshore (Figure 7). *Ammonium beccarri*, a warmer water species, was found only in isolated inlets of Dyes Inlet and the far extremities of Millers Bay and Sinclair Inlet. The recognition of these brackish water species is important in evaluating glacial epoch in sediment cores which will be discussed later.

The decreases in deeper water calcareous foraminifera might be related to unfavorable environment for calcium carbonate secretion by the foraminifera since many of the equivalent depth calcareous species found in the Straits of Juan de Fuca and off the coast of Washington are absent or scarce in the study area, and most specimens are partially dissolved. When calcareous foraminifera are present they generally are shallower species, legenids, and *Polymorphina charlottensis*.

Abundant calcareous foraminifera exist in tidal or current swept passages such as Agate Passage, Rich Passage, narrower channels of Dyes Inlet and Liberty Bay, banks off Blakely Harbor, and current swept shores adjacent to Millers Bay. Characteristics species in these areas are *Elphidium crispum, E. subarcticum* (Figure 7), *Glabratella ornatissima, Trichohyalus columbiensis* and rock attachers *Trochammina charlottensis, Rosalina columbiensis*, and *Cibicides lobatus*. The lack or scarcity of these species in the narrow passage of Liberty Bay suggests the possible influence of the more brackish, turbid waters.

Arenaceous Foraminiferal Groups

The arenaceous foraminifera best depict changes in micro-organism communities with depth and between areas (Figures 8 & 9). The coiled arenaceous are represented in the area by *Trochammina pacifica, T. macrescens, T. charlottensis, Discammina planissimum, Cribrostomoides columbiensis*, and *Miliammina fusca*. Spherical and elongate uniserial tests, forming a second group, contained *Legenammina atlantica, Reophax scorpiurus*, and other unidentified *Reophax* species. The third group contained elongate biserial and triserial chamber arrangements consisting of *Eggerella advena*, and other rare species of *Texturia*.

Again the east side of Central Puget Sound appeared to be different than the west side. The east side, except for portions of Elliot Bay and Shilshole Bay, were dominated by the groups *Reophax-Legenammina* and *Eggerella-Textularia*. The west side was represented more by the *Trochammina-Discammina* and *Eggerella-Textularia* groups (Figures 8 & 9). Sinclair Inlet, Dyes Inlet, and Liberty Bay contained mainly *Trochammina* species; *Trochammina pacifica* was more abundant in brackish, current swept, sandy areas, especially in Liberty Bay; *T. inflata* in Sinclair Inlet and off Shilshole Bay; *T. charlottensis* in Dyes Inlet and current swept passages. *Discammina plannisimum* is found in depths usually greater than 10 fathoms, specimens in the shallow depths of Port Orchard are dwarfed in size, while those on the west side of Elliot Bay are very large. The higher sedimentation rates from the large fresh-water outflow on the eastern side of Elliot Bay and

Shilshole Bay probably explain their absence in those areas.

Trochammina Inflata Concentrations

Trochammina inflata is a well-known shallow brackish water arenaceous species typical of mud flat environments. In central Puget Sound it is found sporadically in depths of less than 5 fathoms, especially on the tidal flats of Sinclair Inlet. Unusually high concentrations and percentages of this species occur also in the deeper water off West Point, adjacent to Seattle's major sewer outfall and to a much lesser extent over the outfall off the south side of Alki Point (Figure 10). In view of high concentrations of *T. inflata* in other parts of the Sound, the writers feel the present or former effluent was responsible for its unusually high occurrence within the region of the old and new outfall. Despite the numerous other sewer outfall sites sampled, the species was not found, suggesting the lesser influence of the smaller outfalls. However, despite the fact that care was taken to sample only the top few centimeters of the bottom sample, studies of sediment cores and distributions of the living and dead concentrations of this species should be made before one can assess whether the new sewer outfall controls its distribution.

USE OF MICRO-ORGANISMS IN EVALUATING ANCIENT ENVIRONMENTS AND POLLUTION EFFECTS

The major use of the microbiogenic components of the sediment is to interpret ancient environments since these organisms are preserved in the bottom sediment accumulations. Before adequate interpretations can be made about ancient glacial environments or polluted bottom sediment, the environmental associations of these species should be ascertained. Sediment belonging to glacial stages should be recognizable since it is generally assumed that colder, shallower water existed in Central Puget Sound. The depths and usual environmental occurrence of various species are listed below.

TIDE FLATS
(0 Fathoms)

Mud Flats

Trochammina macrescens
Trochammina inflata
Miliammina fusca
Reophax spp.
Non-ornate ostracods

Sandy Mud Flats

Trochammina pacifica
Miliammina fusca
Ammonium beccarri

Diatoms

Milosiranae
Coscinodiscus spp.
Ischmia
Asterostycus
Rod-shaped *Biddulphia*
Coscinodiscus

SHALLOW OFFSHORE
(0-5 Fathoms)

Less Saline

Elphidium selseyense
Bucella frigida (small)

More Saline

Elphidiella hannai

Strong Currents, Rocky

Elphidium subarcticum
E. crispum
Trochammina charlottensis
Trichohyalus columbiensis
Glabratella ornatissima
Rosalina columbiensis
Cribrostomoides columbiensis
Cibicides lobatus
Buccella frigida (large)
Miliolids
Ornate ostracods

DEEPER OFFSHORE
(5-30+ Fathoms)

5-10 Fathoms

Eggerella advena
Legenammina atlantica

10-20 Fathoms

Reophax scorpiurus
Discammina plannissimum
Polymorphins charlottensis
Nonoinella basispinata

10-30 Fathoms

R. Scorpiurus
Bolivina pacifica
Globobulimina auricula
N. basispinata

Glacial epochs in the sediment cores should have fewer species, in most cases fewer specimens, lower percentages of calcareous foraminifera, dominance of *Milosiranae*, and a change to shallow water species (Figure 11). Polluted bottom sediment should show most of the same changes (except diatoms) except that the location of the man-induced polluted bottom should be located at the surface of the sediment, or top of the core.

ACKNOWLEDGEMENT

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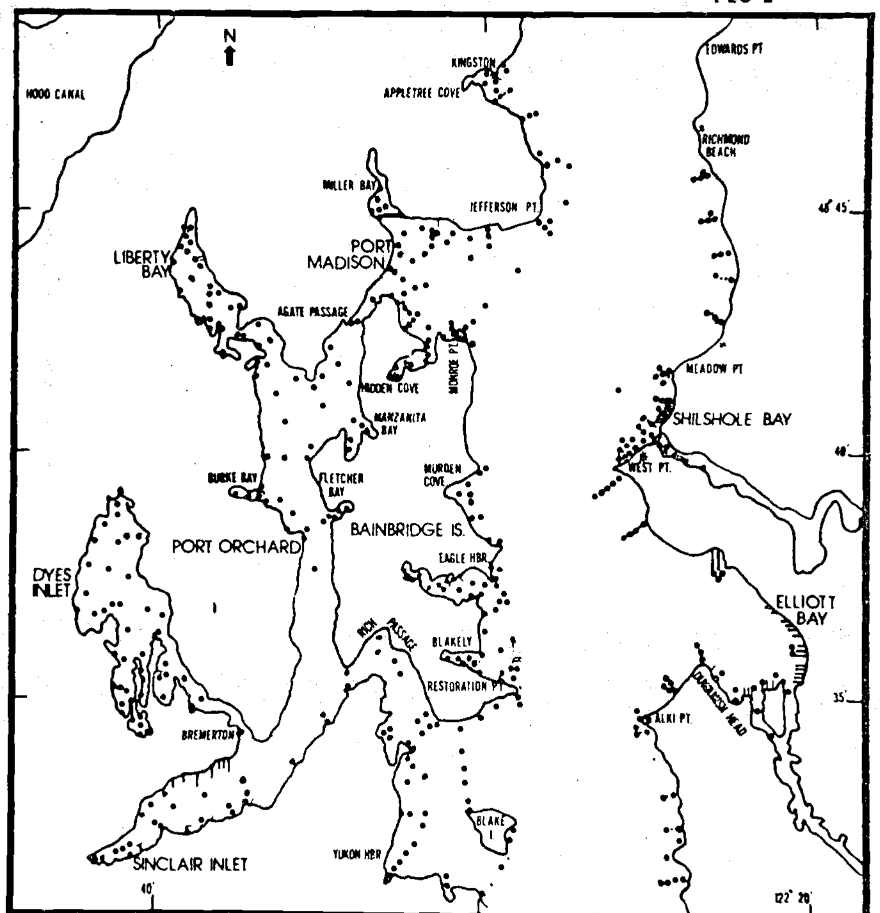
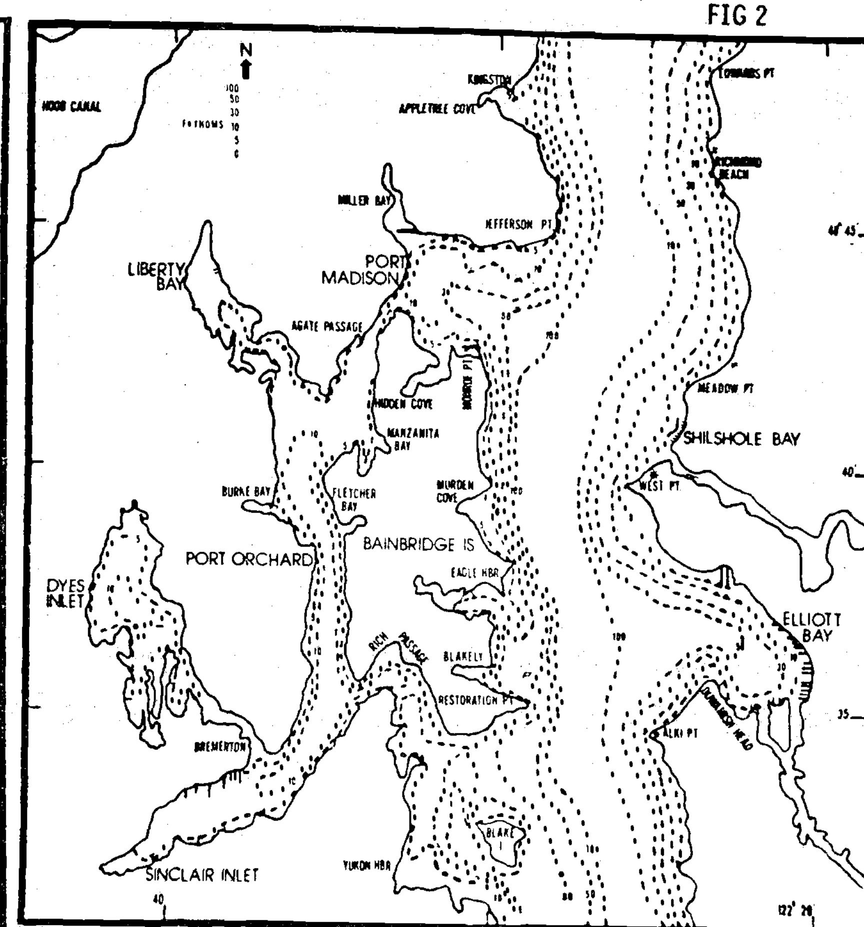
FIG 1



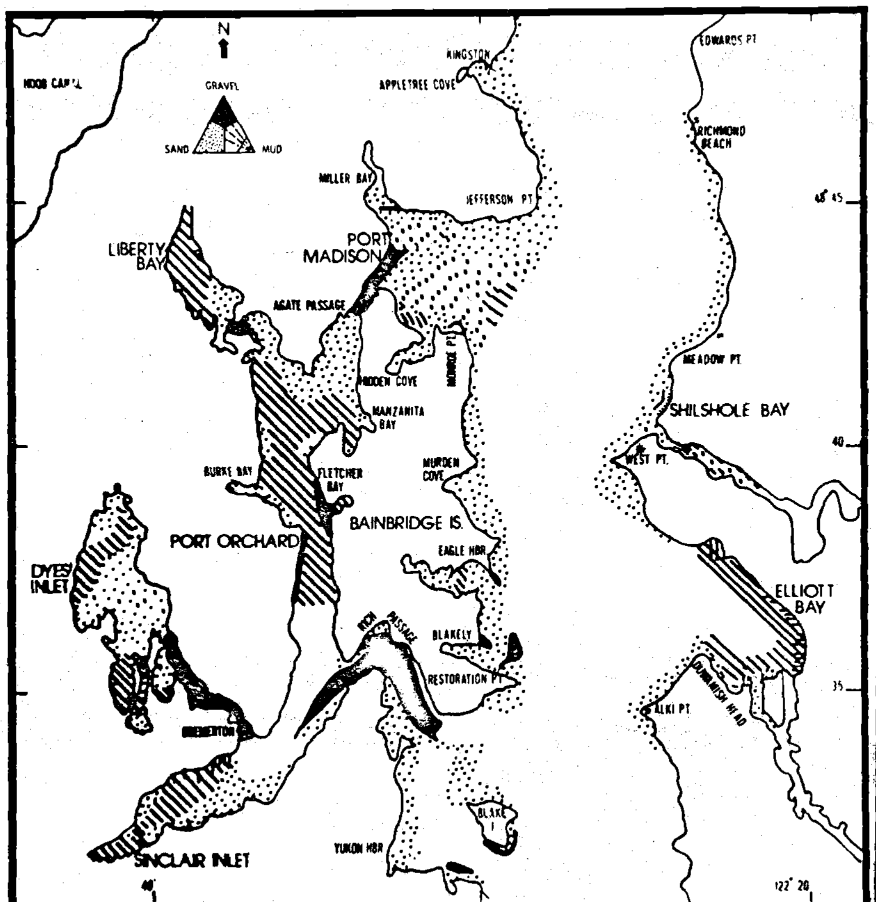
STATIONS

FIG 2



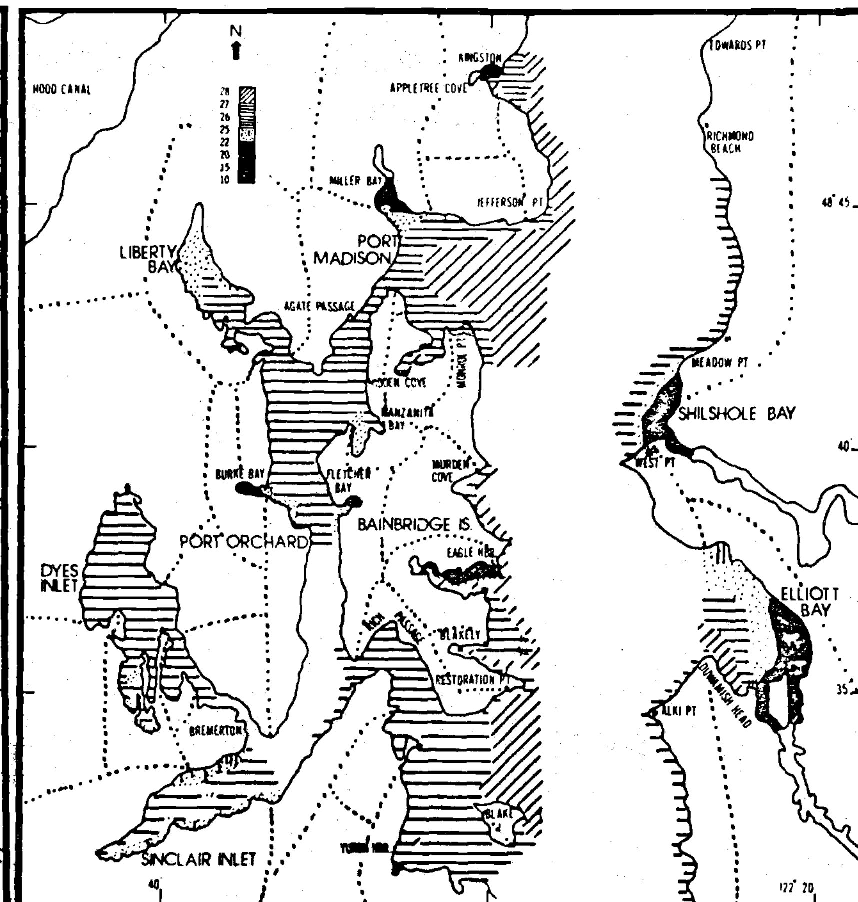
BATHYMETRY AND DRAINAGE AREAS

FIG 3



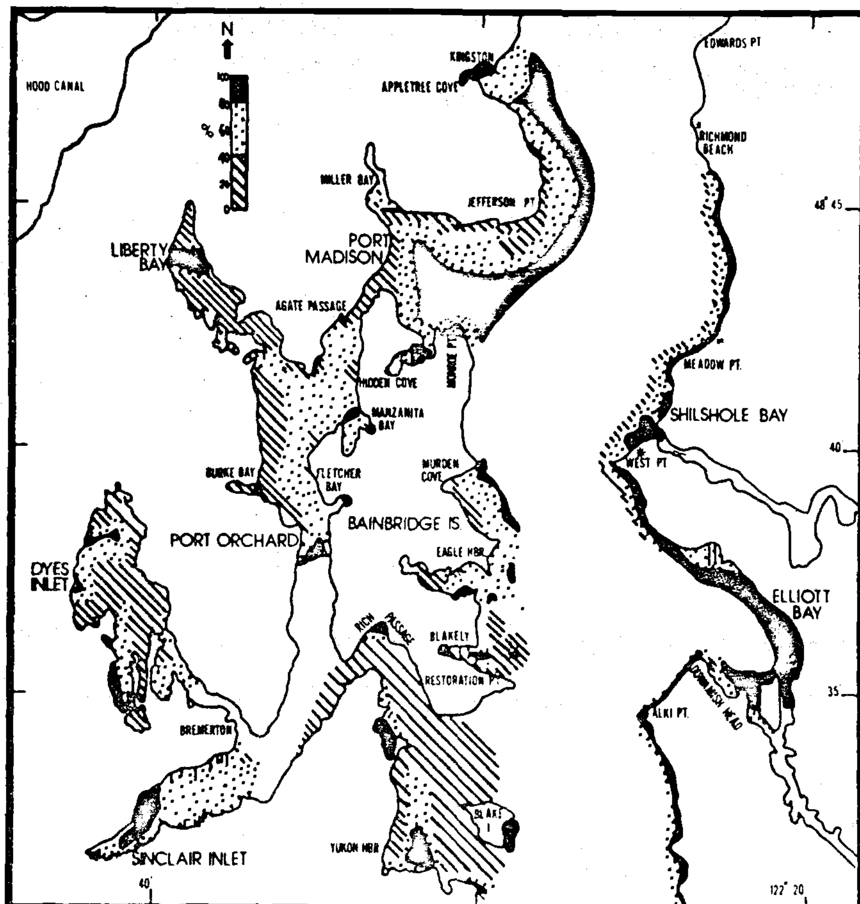
SEDIMENT DISTRIBUTION

FIG 4



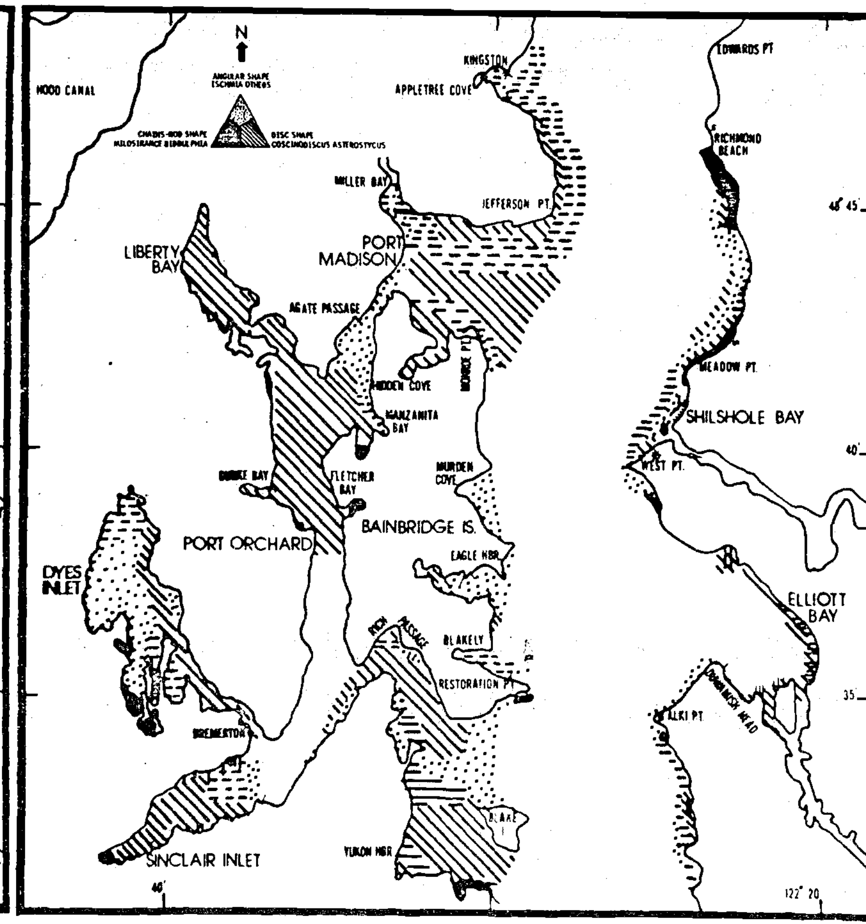
SALINITY AND DRAINAGE AREAS

FIG 5



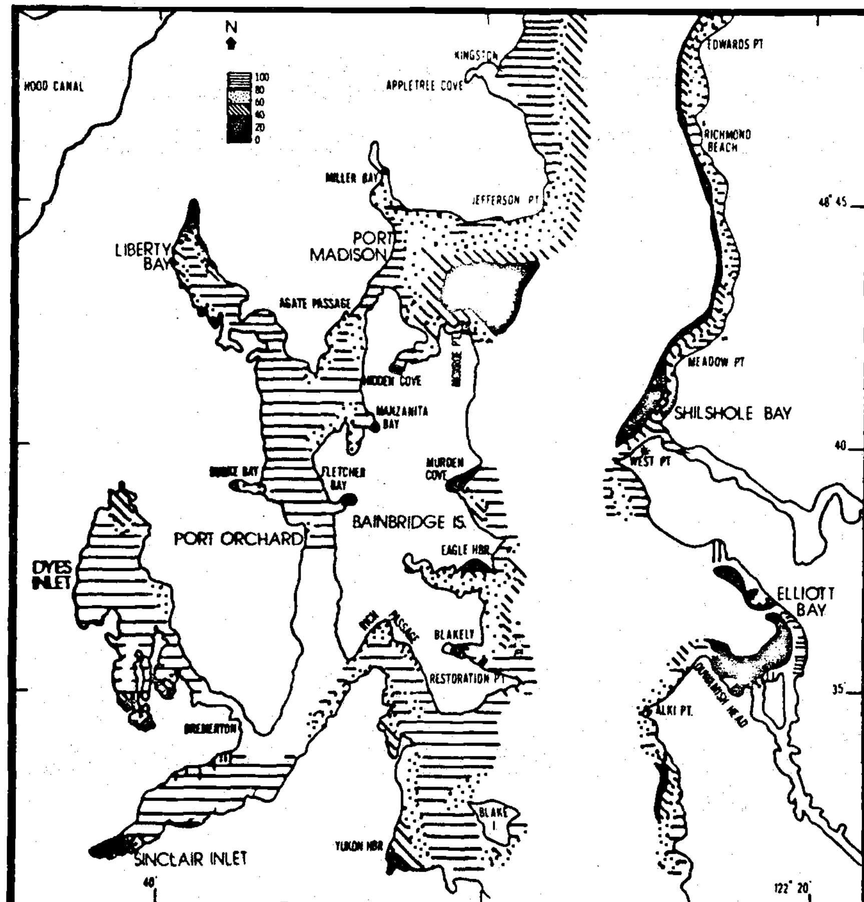
PERCENT DIATOMS

FIG 6



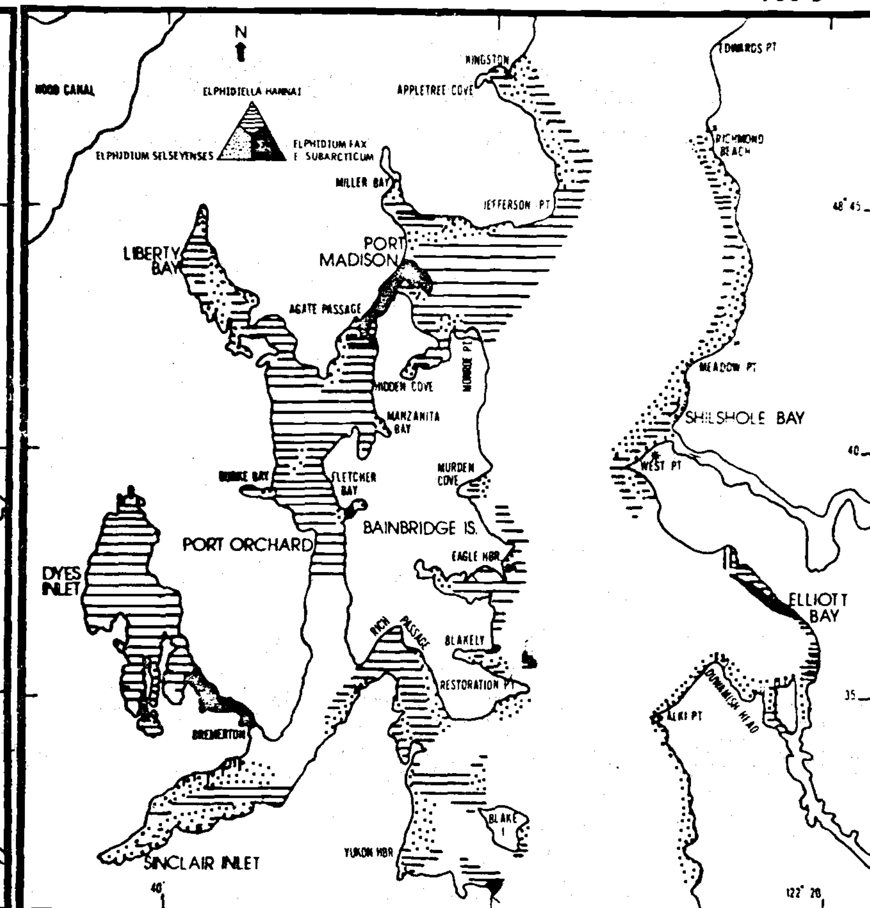
DIATOM GROUPS

FIG 7



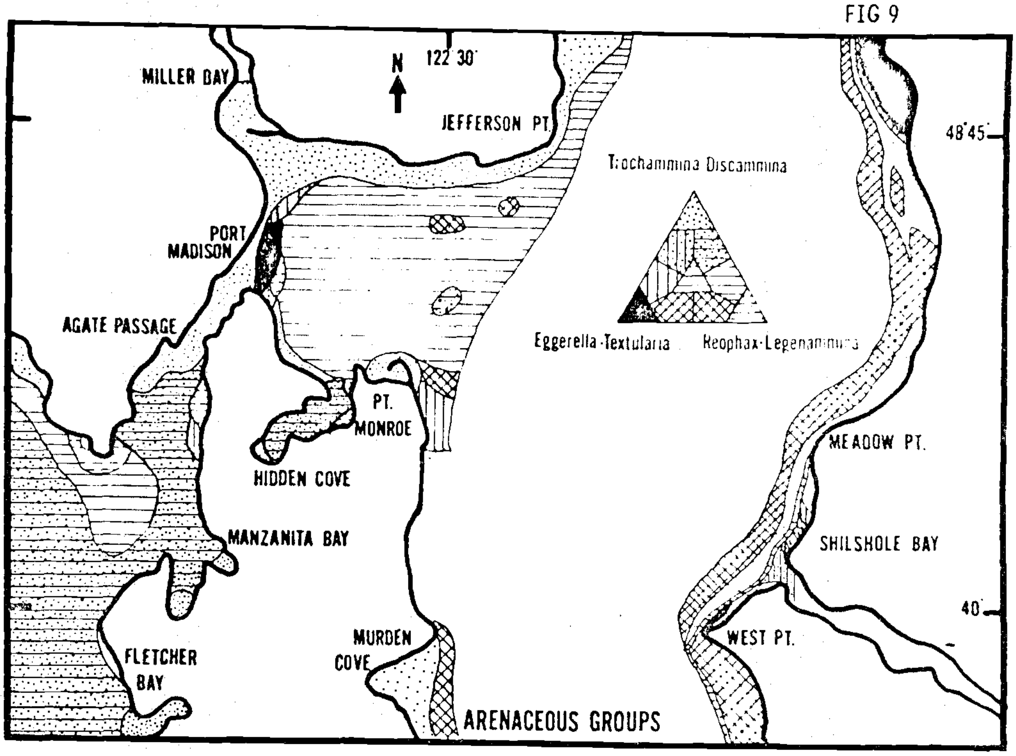
PERCENT CALCAREOUS FORAMINIFERA

FIG 8



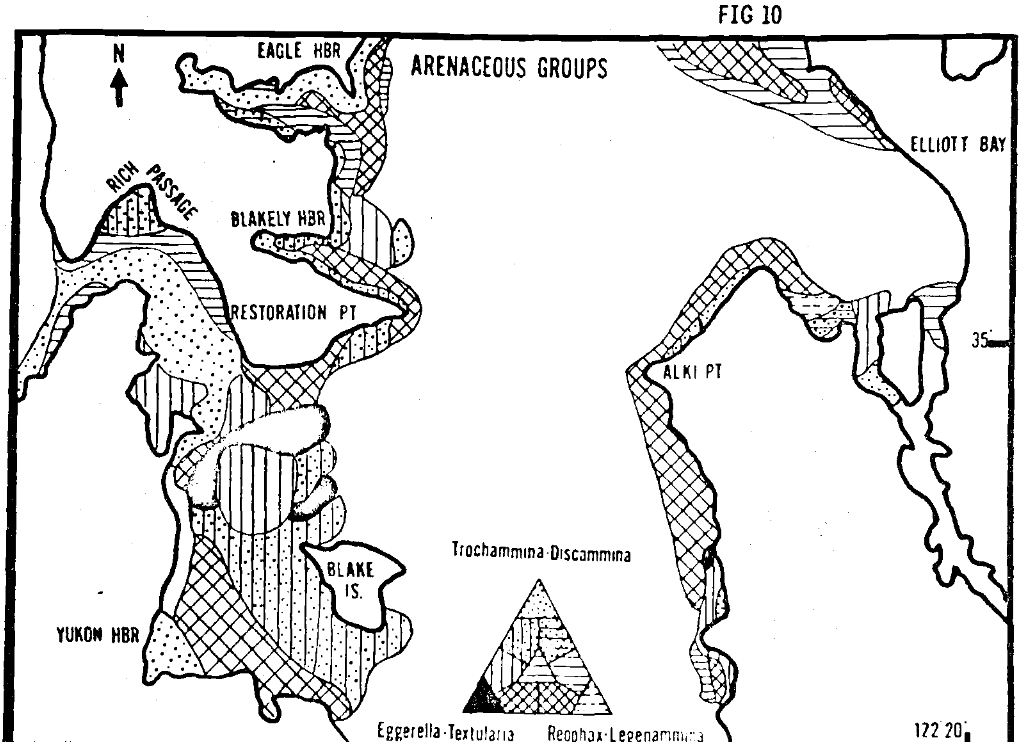
ELPHIDIIDAE GROUPS

FIG 9



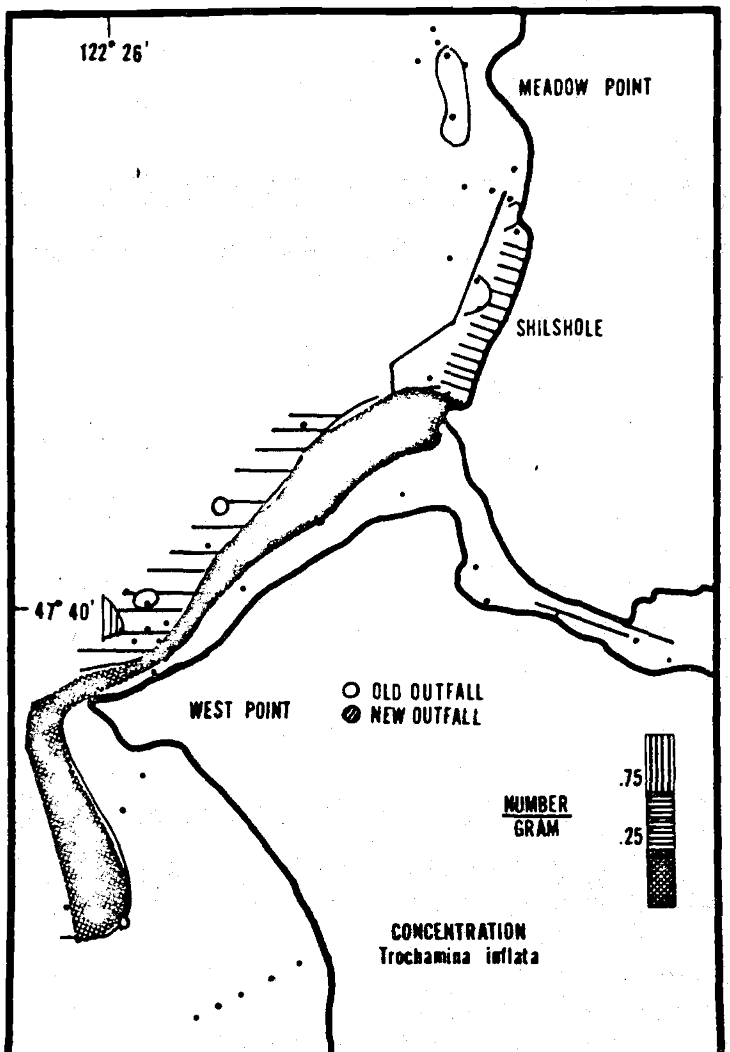
PERCENT ARENACOUS

FIG 10



PERCENT ARENACOUS

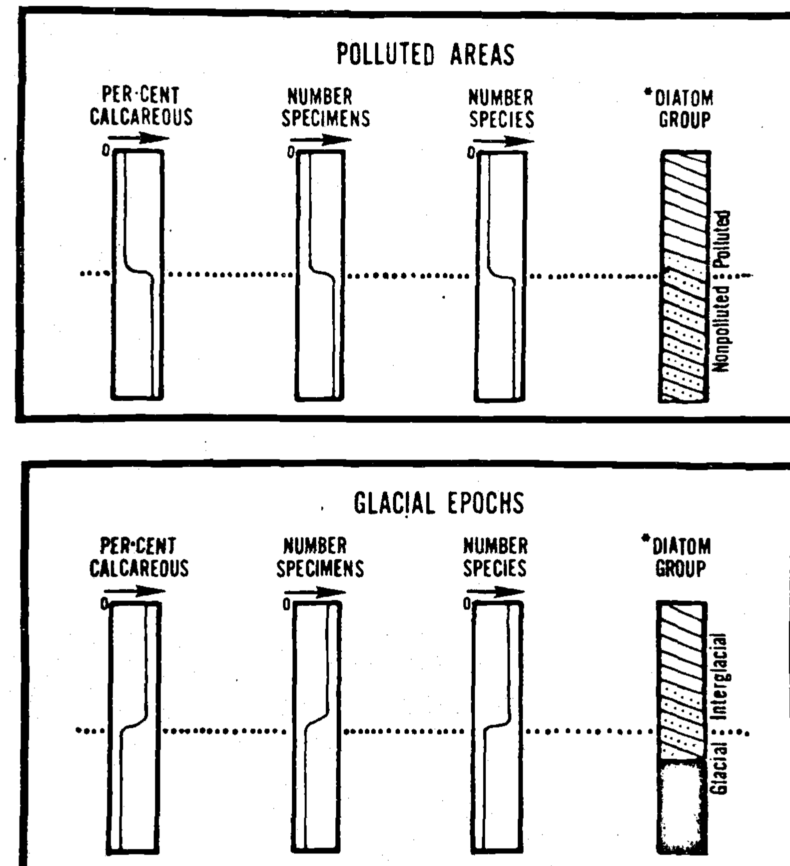
FIG 11



TROCHAMMINA INFLATA

ANTICIPATED EVIDENCE
FROM
SEDIMENT CORES

FIG 12



*Symbols as used in text