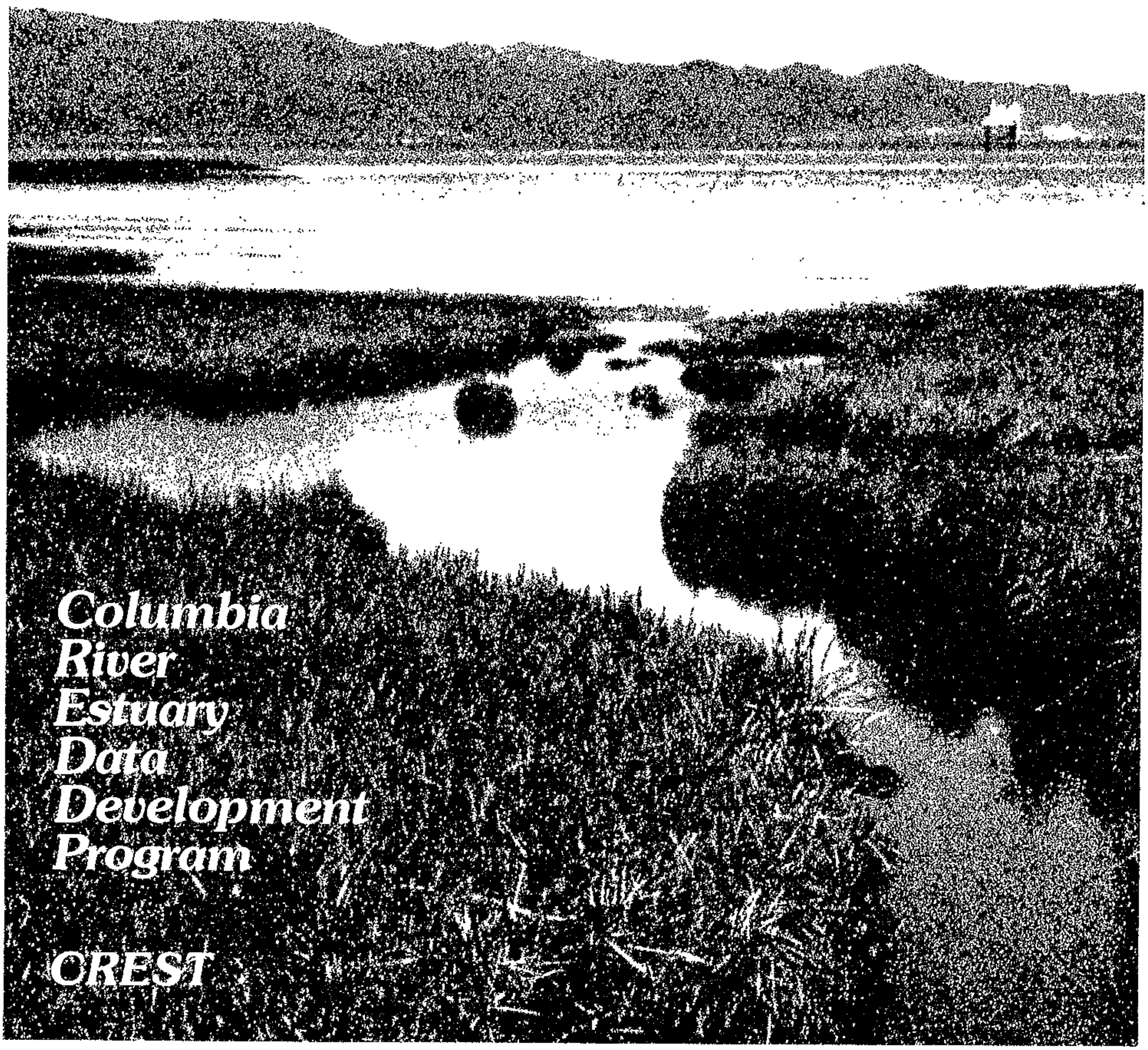
ABSTRACTS OF MAJOR C.R.E.D.D.P. PUBLICATIONS



Columbia River Estuary

Data Development Program

ABSTRACTS OF

MAJOR CREDDP

PUBLICATIONS

June 1984

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PREFACE

The Columbia River Estuary Data Development Program

This document is one of a set of publications and other materials produced by the Columbia River Estuary Data Development Program (CREDDP). CREDDP has two purposes: to increase understanding of the ecology of the Columbia River Estuary and to provide information useful in making land and water use decisions. The program was initiated by local governments and citizens who saw a need for a better information base for use in managing natural resources and in planning for development. In response to these concerns, the Governors of the states of Oregon and Washington requested in 1974 that the Pacific Northwest River Basins Commission (PNRBC) undertake an interdisciplinary ecological study of the estuary. At approximately the same time, local governments and port districts formed the Columbia River Estuary Study Taskforce (CREST) to develop a regional management plan for the estuary.

PNRBC produced a Plan of Study for a six-year, $6.2 million program which was authorized by the U.S. Congress in October 1978. For the next three years PNRBC administered CREDDP and $3.3 million was appropriated for the program. However, PNRBC was abolished as of October 1981, leaving CREDDP in abeyance. At that point, much of the field work had been carried out, but most of the data were not yet analyzed and few of the planned publications had been completed. To avoid wasting the effort that had already been expended, in December 1981 Congress included $1.5 million in the U.S. Water Resources Council (WRC) budget for the orderly completion of CREDDP. The WRC contracted with CREST to evaluate the status of the program and prepare a revised Plan of Study, which was submitted to the WRC in July 1982. In September, after a hiatus of almost one year, CREDDP work was resumed when a cooperative agreement was signed by CREST and the WRC to administer the restructured program and oversee its completion by June 1984. With the dissolution of the WRC in October 1982, the National Oceanic and Atmospheric Administration (NOAA) assumed the role of the WRC as the federal representative in this cooperative agreement.

CREDDP was designed to meet the needs of those groups who were expected to be the principal users of the information being developed. One such group consists of local government officials, planning commissions, CREST, state and federal agencies, permit applicants, and others involved in planning and permitting activities. The other major anticipated user group includes research scientists and educational institutions. For planning purposes, an understanding of the ecology of the estuary is particularly important, and CREDDP has been designed with this in mind. Ecological research focuses on the linkages among different elements in the food web and the influence on the food web of such physical processes as currents, sediment transport and salinity intrusion. Such an ecosystem view of the estuary is necessary to predict the effects of estuarine alterations on natural resources.

Research was divided into thirteen projects, called work units. Three work units, Emergent Plant Primary Production, Benthic Primary Production, and Water Column Primary Production, dealt with the plant life which, through photosynthesis and uptake of chemical nutrients, forms the base of the estuarine food web. The goals of these work units were to describe and map the productivity and biomass patterns of the estuary's primary producers and to describe the relationship of physical factors to primary producers and their productivity levels.

The higher trophic levels in the estuarine food web were the focus of seven CREDDP work units: Zooplankton and Larval Fish, Benthic Infauna, Epibenthic Organisms, Fish, Avifauna, Wildlife, and Marine Mammals. The goals of these work units were to describe and map the abundance patterns of the invertebrate and vertebrate species and to describe these species' relationships to relevant physical factors.

The other three work units, Sedimentation and Shoaling, Currents, and Simulation, dealt with physical processes. The work unit goals were to characterize and map bottom sediment distribution, to characterize sediment transport, to determine the causes of bathymetric change, and to determine and model circulation patterns, vertical mixing and salinity patterns.

Final reports on all of these thirteen work units have been published. In addition, these results are integrated in a comprehensive synthesis entitled The Dynamics of the Columbia River Estuarine Ecosystem, the purpose of which is to develop a description of the estuary at the ecosystem level of organization. In this document, the physical setting and processes of the estuary are described first. Next, a conceptual model of biological processes is presented, with particular attention to the connections among the components represented by the work unit categories. This model provides the basis for a discussion of relationships between physical and biological processes and among the functional groups of organisms in the estuary. Finally, the estuary is divided into regions according to physical criteria, and selected biological and physical characteristics of the habitat types within each region are described. Historical changes in physical processes are also discussed, as are the ecological consequences of such changes.

Much of the raw data developed by the work unit researchers is collected in a magnetic tape archive established by CREDDP at the U.S. Army Corps of Engineers North Pacific Division Data Processing Center in Portland, Oregon. These data files, which are structured for convenient user access, are described in an Index to CREDDP Data. The index also describes and locates several data sets which were not adaptable to computer storage.

The work unit reports, the synthesis, and the data archive are intended primarily for scientists and for resource managers with a scientific background. However, to fulfill its purposes, CREDDP has developed a set of related materials designed to be useful to a wide range of people.

Guide to the Use of CREDDP Information highlights the principal findings of the program and demonstrates how this information can be used to assess the consequences of alterations in the estuary. It is intended for citizens, local government officials, and those planners and other professionals whose training is in fields other than the estuary-related sciences. Its purpose is to help nonspecialists use CREDDP information in the planning and permitting processes.

A detailed portrait of the estuary, but one still oriented toward a general readership, is presented in The Columbia River Estuary: Atlas of Physical and Biological Characteristics, about half of which consists of text and illustrations. The other half contains color maps of the estuary interpreting the results of the work units and the ecological synthesis. A separate Bathymetric Atlas of the Columbia River Estuary contains color bathymetric contour maps of three surveys dating from 1935 to 1982 and includes differencing maps illustrating the changes between surveys. CREDDP has also produced unbound maps of the estuary designed to be useful to resource managers, planners and citizens. These black-and-white maps illustrate the most recent (1982) bathymetric data as contours and show intertidal vegetation types as well as important cultural features. They are available in two segments at a scale of 1:50,000 and in nine segments at 1:12,000.

Two historical analyses have been produced. Changes in Columbia River Estuary Habitat Types over the Past Century compares information on the extent and distribution of swamps, marshes, flats, and various water depth regimes a hundred years ago with corresponding recent information and discusses the causes and significance of the changes measured. Columbia's Gateway is a two-volume set of which the first volume is a cultural history of the estuary to 1920 in narrative form with accompanying photographs. The second volume is an unbound, boxed set of maps including 39 reproductions of maps originally published between 1792 and 1915 and six original maps illustrating aspects of the estuary's cultural history.

A two-volume Literature Survey of the Columbia River Estuary (1980) is also available. Organized according to the same categories as the work units, Volume I provides a summary overview of the literature available before CREDDP while Volume II is a complete annotated bibliography.

All of these materials are described more completely in this document, which serves as a quick reference for determining whether and where any particular kind of information can be located among the program's publications and archives.

To order any of the above documents or to obtain further information about CREDDP, its publications or its archives, write to CREST, P.O. Box 175, Astoria, Oregon 97103, or call (503) 325-0435.

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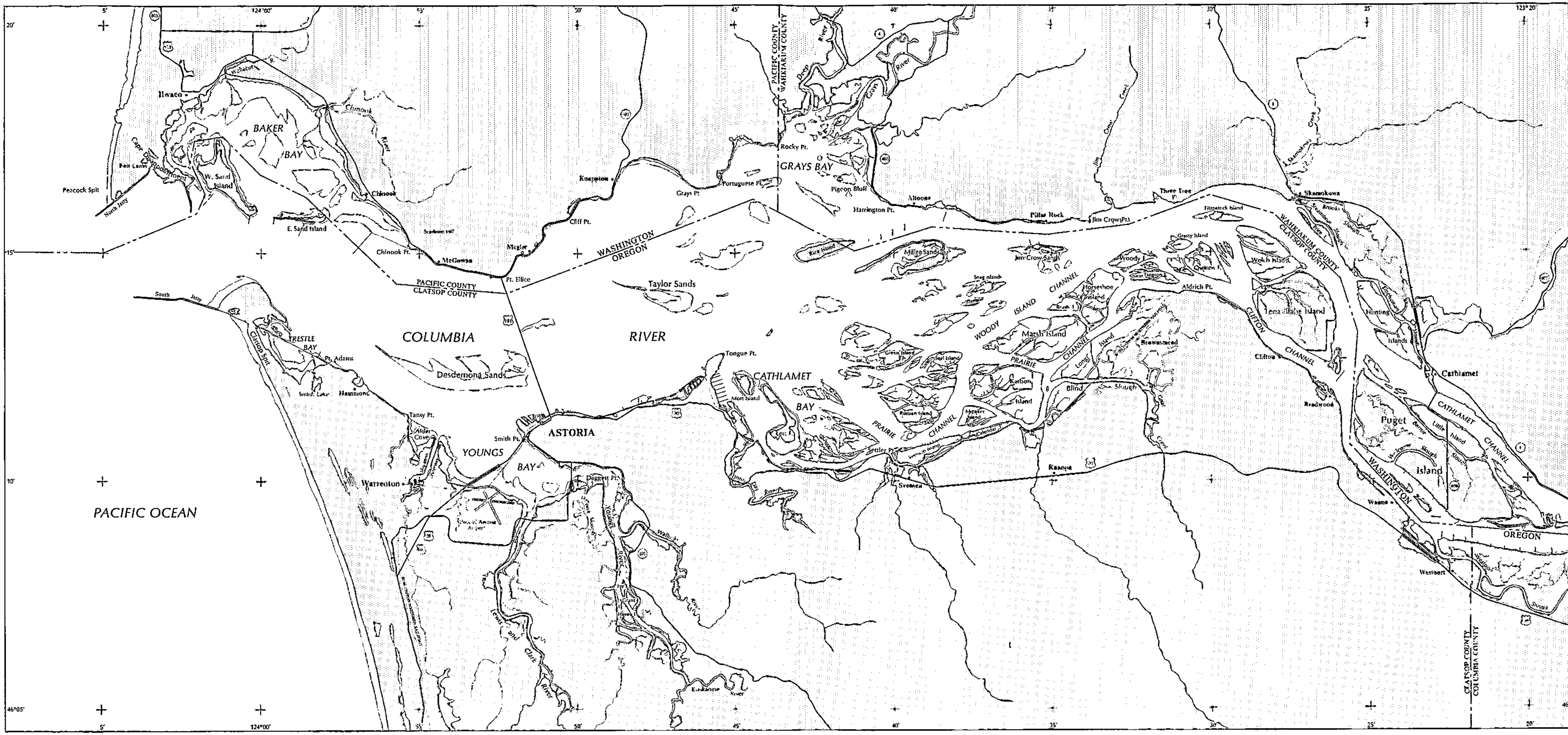

Columbia River Estuary

Scale 1:160,000

0 1 2 3 4 5 6 7 8 9 10 Kilometers

0 1 2 3 4 5 6 Miles

Map produced in 1983 by Northwest Cartography, Inc.
for the Columbia River Estuary Data Development Program

- Shoreline (limit of non-aquatic vegetation)
- Intertidal vegetation
- Shoals and flats
- Lakes, rivers, other non-tidal water features
- Major highways
- Megler Cities, towns
- Railroads
- Other cultural features

1. INTRODUCTION

The researchers working on the Columbia River Estuary Data Development Program (CREDDP) have gathered and interpreted a great deal of new information on the physical and biological characteristics of the Columbia River Estuary. This document provides brief descriptions, including major findings, of 21 major CREDDP publications resulting from this research and lists many other reports and materials produced by the program.

The major CREDDP publications, described in Section 2 of this document, include 15 technical reports (abstracts were rewritten from researchers' executive summaries), a brief cultural history of the estuary region, a literature review, an index to CREDDP data, a guide to the use of CREDDP information, and two atlases (see Preface). All but the cultural history and atlases are 8½" x 11" typewritten reports. The cultural history is a typeset report with accompanying maps and the atlases are large-format documents with color map plates.

Section 3, the annotated bibliography, lists and briefly describes other CREDDP publications, CREDDP maps and related materials, and reference collections and unprocessed samples generated by the program. The publications listed in the bibliography are mainly literature surveys, interim and annual reports produced by CREDDP researchers during the course of their research, and various publications produced by CREDDP researchers under joint funding from CREDDP and other agencies. The maps include a base map of the estuary produced by CREDDP at several scales, the source materials used to compile the base maps, and the composite negatives and offset printing plates used to produce the atlas pages and base maps. The reference collections described in Section 3 include a vascular plant herbarium and a diatom herbarium. The unprocessed samples include sediment and some biological samples obtained by researchers but not processed during CREDDP research.

The appendix to this document contains sampling site maps of each of the CREDDP research projects. These maps allow individuals interested in a particular site in the estuary to determine which of the technical work unit reports may contain information pertaining to that site.

2. ABSTRACTS

The CREDDP publications described in this section have been distributed to many federal agencies, state agencies, and universities in Oregon and Washington and to local governments and libraries in the estuary's vicinity. These publications may be borrowed from the Columbia River Estuary Study Taskforce (CREST) library in Astoria, Oregon, or purchased from CREST at the cost of reproduction, postage, and handling (see end of preface for the address and phone number of CREST).

2.1 TIDAL MARSH PLANT PRODUCTION OF THE COLUMBIA RIVER ESTUARY

Macdonald, K.B.; Winfield, T.P. 1984
108 pages

The goals of this research were to describe the species composition, standing crop, and primary production dynamics of the tidal marsh vegetation found within the estuary.

An estuary-wide field survey conducted in October 1979 confirmed the floristic diversity of Columbia River Estuary tidal marshes and suggested that their species composition reflected salinity changes from the marine estuary mouth to freshwater conditions upstream and elevation changes from low marsh to high marsh. Twenty-two broadly representative tidal marsh study sites located to examine these two environmental gradients were subsequently selected for intensive study. (Appendix A, Figure 1).

Percent species cover and aboveground biomass data sets, collected from the 22 tidal marsh study sites in both July 1980 and August 1981, yielded 67 different plant species. An additional 15 species were collected nearby but did not occur within the sample quadrats. Despite this diversity, the great majority of plant cover and biomass within the marshes was accounted for by only 20 of the total 82 species recorded. Lyngby's sedge (*Carex lyngbyei*) was by far the most abundant and widespread species throughout the marshes.

The species percent cover data were examined using both divisive clustering combined with cannonical discriminant analysis, and agglomerative cluster analysis. Both procedures yielded results in good agreement with a subjective four-fold subdivision of estuary marsh types developed from the field survey.

Brackish low marshes (567 hectares/1,400 acres) fringe much of the shoreline of Baker, Trestle and Youngs Bay. Brackish high marsh (316 hectares/780 acres) is also best developed in Trestle and Youngs Bays. Freshwater tidal marshes extend upriver from Tongue Point (RM-18). Low marsh habitats (2,268 hectares/5,600 acres) are widespread throughout the islands of Cathlamet Bay, fringe much of Grays Bay, and occur on the downstream portions of Tronson, Quinns, Grassy, and Fitzpatrich Islands, near Aldrich Point. Freshwater high marshes (576 hectares/1,400 acres) are present along the eastern shores of Grays Bay and are more broadly developed across portions of Marsh, Horseshoe and Welsh Islands.

Seasonal patterns of net aboveground marsh plant standing crop were established from replicate clip-quadrats harvested at each study site during April, May, June, July and October 1980, and August 1981. Biomass data for live shoots, attached standing dead material, and unattached plant litter, were treated separately. Mean net aboveground total (live plus standing dead) standing crop values, measured near the peak of the 1980 growing season, indicated no statistically significant differences among the four tidal marsh categories. The overall mean value (± standard error) for all marsh sites was 864 ± 41 grams dry weight per square meter (g dry wt/m^2). Comparable data collected near the 1981 growth season peak indicated that standing crop values from the freshwater low marshes were significantly lower than those from the other three marsh groups; the overall mean was 892 ± 43 g dry wt/m^2.

An estuary-wide overview of seasonal biomass changes was obtained by averaging all tidal marsh standing crop samples on a month-to-month basis. Mean net aboveground live stading crop (± stadard error) was at its lowest in April (112 ± 22 g dry wt/m^2), climbed rapidly through the end of June (735 ± 95 g dry wt/m^2), and held steady through August. By mid-October however, estuary-wide marsh biomass had declined substantially again (257 ± 34 g dry wt/m^2). Attached standing dead plant material was virtually absent in April (12 ± 5 g dry wt/m^2) but showed a steady increase through mid-October (205 ± 32 g dry wt/m^2). Detached plant litter showed little variation from month-to-month. The highest mean value was recorded in April 1980 (223 ± 69 g dry wt/m^2). Except for the April 1980 sampling period when marsh plant growth was just getting underway, these litter values represented only a small portion of the aboveground total (live and attached dead) marsh plant biomass.

Net belowground live root biomass data were collected from replicate soil cores taken at each study site in April, June, July and October 1980. Live root biomass was always substantially higher than the aboveground live biomass, and seasonal patterns of root biomass abundance were the opposite of aboveground biomass trends. Root biomass was highest in April (20 times greater than aboveground biomass), lowest at the end of June (less than double aboveground biomass values), and was on an uptrend again in July and October. The reciprocal relationship in above and belowground biomass supports the concept that late in the growing season some perennial species (Carex lyngbyei, for example) translocate biomass and nutrients from aerial shoots to overwintering root systems. Subsequently this stored material supports and accelerates the spring burst of growth typical of many marsh plants in cooler latitudes.

Net annual aboveground primary production estimates for each marsh site were calculated from the 1980 sequential standing crop harvests using the Smalley Method. Values ranged from a low of 364 g dry wt/m^2/yr at Lois Island freshwater low marsh, to a high of 1,730 g dry wt/m^2/yr for brackish low marsh Carex stands at East Trestle Bay. When production estimates were sorted among the four major tidal marsh types and pooled, no statistically significant differences were found. This suggests that all marsh types are equally productive, with an overall mean estimated net annual aboveground production value (± standard error) of 964 ± 100 g dry wt/m^2/yr.

The general absence of statistically significant differences among biomass measurements and primary production estimates from the four marsh types may be real. It could also reflect sampling problems associated with high within- and between-marsh variability. Among five indirect environmental variables tested, surface salinity regimes yielded the most significant regressions against estimated net annual aboveground primary production values from the different tidal marshes; site elevation was also important. While the relationships are clearly not simple ones, tidal marsh net aboveground primary production does exhibit significant trends, increasing both upriver from the estuary mouth and at higher intertidal elevations.

Decomposition and loss rates of plant material from the marsh surface were measured during three litter bag experiments (initiated in May, July, and October 1980) designed to measure loss rates for different plant types, marsh elevations, and estuary locations. The overall results of the experiments suggest marsh elevation has no significant effect upon decomposition rates. Some significant differences were noted among decomposition rates for differenct plant types, more succulent species decomposing faster than more fiberous species at the same location. The most striking difference was that marsh plants at upriver freshwater sites decomposed substantially faster and more completely than the same species at brackish water sites nearer the estuary mouth.

Net tidal marsh production represents a dynamic balance among several ongoing processes that account for the difference between true total, or "gross" production and the residual "net" production estimated here (964 g dry wt/m^2/yr, aboveground). Some of these processes have been tentatively quantified as follows: leaching of dissolved organic matter from live plants, 200 g dry wt/m^2/yr; utilization by herbivores (nutria, muskrat, and beaver), 145 g dry wt/m^2/yr; translocation to plant roots in the fall, 370 g dry wt/m^2/yr; and minimum detrial export, 460 g dry wt/m^2/yr.

2.2 BENTHIC PRIMARY PRODUCTION IN THE COLUMBIA RIVER ESTUARY

McIntire, C.D.; Amspoker, M.C. 1984
103 pages

The objective of the CREDDP Benthic Primary Production research was to determine mechanisms that control the production dynamics and species composition of benthic plant assemblages in the Columbia River Estuary. In particular, the work was concerned with effects of selected physical variables on structural and functional attributes of micro- and macro-vegetation, and on the productivity and biomass of benthic plants on the tidal flats of the estuary.

The sampling program was organized into two phases: (1) monthly replicated sampling at five intensive study sites from April 1980 through April 1981; and (2) a broad survey involving the collection of samples at 31 other locations in the estuary during a period from May through September 1981 (Appendix A, Figure 2). Research at the intensive study sites examined relationships between autotrophic processes and relevant physical variables. This provided the basis for predicting benthic primary production and related variables in other areas of the estuary. Data from the survey represented information about benthic autotrophy for a large spatial area, and therefore provided the basis for the development of distributional maps of plant biomass and production rates. At the intensive study sites, samples were collected for the determination of sediment grain size distribution; species composition of the flora; concentrations of chlorophyll a, phaeo-pigments, and organic matter in the sediment; and rates of benthic primary production and community oxygen uptake. Sampling at the survey sites was primarily concerned with the measurement of plant biomass expressed as the concentration of chlorophyll a.

The microalgae, which consist almost entirely of diatoms, are the most abundant group of plants on the tidal flats of the Columbia River Estuary. Along with the diatoms, blue-green algae are frequently found growing beneath emergent vascular plants in low elevation marshes in late summer. Submergent vascular plants and macroalgae are not conspicuous on the tidal flats of the estuary. Zostera marina has a patchy distribution in Baker Bay, but does not develop dense beds characteristic of other Oregon estuaries.

A quantitative analysis of the benthic diatom flora of the estuary indicated that the species compositions associated with the freshwater tidal flats of Cathlamet Bay, Grays Bay, and the region upriver from Russian Island are similar. Moreover, the flora in Youngs Bay is more similar to the freshwater floras of Cathlamet Bay, Grays Bay, and the upper estuary than to the brackishwater flora of Baker Bay, a pattern apparently related to freshwater input into Youngs Bay from the Lewis and Clark River, Youngs River, and the main channel of the Columbia River.

Mean hourly rates of gross primary production for the daylight hours at the intensive study sites in Youngs Bay, Baker Bay, Grays Bay, and on Clatsop Spit and Quinns Island for the entire period were 84, 43, 33, 5, and 30 milligrams carbon per square meter per hour ($mgC/m^2/hr$), respectively. In general, rates were lower during late fall and winter than at other times of the year, and the transects in the low marsh and upper intertidal zone were more productive than the transects in the lower intertidal zone nearer the main channel. A regression analysis indicated that there was a linear relationship between the concentration of chlorophyll a in the top centimeter of sediment and the rate of gross primary production.

Regional maps of benthic primary production in the Columbia River Estuary were developed from data collected at the intensive study sites and survey sites. Such maps indicated that in Baker and Youngs Bay there are tidal flats that support relatively high mean rates of benthic primary production, in the range of 60 to 80 $mgC/m^2/hr$. In Grays and Cathlamet Bays mean rates usually varied between 20 to 40 $mgC/m^2/hr$, although some of the sandy regions with a high degree of sediment mixing had mean rates less than 20 $mgC/m^2/hr$. Moreover, the sandy intertidal areas of the many islands in the upper estuary exhibited relatively low mean rates of primary production, usually between 10 and 20 $mgC/m^2/hr$. Annual rates of benthic gross primary production in Baker Bay, Youngs Bay, Grays Bay, Cathlamet Bay, and on the islands in the upper estuary are estimated to be about 97, 71, 26, 23, and 38 grams carbon per square meter per year ($gC/m^2/yr$), respectively. Productive capacity of the various intertidal regions of the estuary is probably determined primarily by the properties and stability of the sediment, position in intertidal zone relative to the mean lower low water level, and seasonal changes in daylength and the optical properties of the water column.

A rough estimate of the total annual benthic gross primary production for the intertidal region of the entire estuary (the CREDDP study area), excluding areas occupied by emergent macrophytes, is 2.175 x 10^6 kilograms, or 2,175 metric tons of carbon. This value corresponds to about 4,350 metric tons of organic matter per year. In comparison to the inputs of fine particulate organic carbon from upriver, the contribution of organic carbon to the estuary by resident benthic primary producers is relatively small.

2.3 WATER COLUMN PRIMARY PRODUCTION IN THE COLUMBIA RIVER ESTUARY

Frey, B.E.; Small, L.F.; Lara-Lara, R. 1984
133 pages

Primary production, or photosynthesis, is carried out in the water column chiefly by small, free-floating algal cells which constitute the phytoplankton. The overall objectives of this CREDDP research were to describe the yearly cycle of abundance and distribution of the primary food supply (particularly phytoplankton) in the waters of the Columbia River Estuary, and to assess the physical, chemical, and biological factors affecting the primary food supply.

During an eighteen-month period, ten cruises were conducted in the Columbia River Estuary. Samples were collected from up to 52 stations per cruise (Appendix A, Figure 3) using a submersible pump system to deliver the samples from depth. In addition to obtaining information on the normal cycles of events relating to phytoplankton in the estuary, data were collected concerning the effects of the May 1980 eruption of nearby Mt. St. Helens on the estuarine ecosystem.

It was determined that light is the important factor limiting primary production in the Columbia River Estuary. Both the intensity of incident light reaching the water surface, and the attenuation of light within the water column are critical in determining the rates of primary production per unit of plant biomass. Of the major plant nutrients (nitrogen, phosphorus, and silica), only nitrogen appears to ever become depleted to the point where it might limit phytoplankton growth. This occurs in late spring and summer.

Import from the Columbia River, as opposed to production within the estuary, is the most important factor in determining the abundance of phytoplankton in the waters of the estuary. On a yearly basis, an estimated 75 percent of the phytoplankton in the estuary is supplied by the Columbia River, while only 25 percent is produced within the estuary. The phytoplankton species in the estuary are dominated by freshwater diatoms. Smaller nanoplankton dominate over larger netplankton.

The concentrations of both chlorophyll a and freshwater diatoms decreased from the freshwater zone to the marine zone. Apparently as freshwater phytoplankton mix rapidly with saline water the increased osmotic pressure destroys the cells. For properties other than phytoplankton concentrations, the estuary acts as a conduit for export from the Columbia River to the Pacific Ocean, with little change occurring within the estuary itself. This is doubtless due to the low residence time of water in the estuary (one to five days), and the high turbulence of the system, which allows little sinking to occur. All measured properties were vertically homogeneous in the freshwater portions of the estuary. Where the salt wedge was encountered, properties were stratified as a result of the marine-source water intrusion at depth.

Of the total particulate organic carbon in the estuarine water column, about 75 percent is detrital and 25 percent is live phytoplankton. About 63 percent of the phytoplankton is lost within the estuary, and remainder is exported to the Pacific Ocean. Zooplankton grazing removal of phytoplankton amounts to only about 1 percent per day of the available phytoplankton biomass.

The eruption of Mt. St. Helens on May 18, 1980, added large amounts of particulate material to the waters of the Columbia River Estuary. This in turn greatly reduced the amount of primary production by reducing light penetration in the water. During the five-week period in which the estuary was unusually turbid, the primary production was reduced by an estimated 75 percent. This reduction in productivity did not measurably effect levels of phytoplankton biomass in the water. This is evidently because phytoplankton biomass levels are affected mostly by import upriver from the point where the Mt. St. Helens sediment entered the Columbia River.

2.4 ZOOPLANKTON AND LARVAL FISHES OF THE COLUMBIA RIVER ESTUARY

Jones, K.K.; Bottom, D. 1984
36 pages

This report analyzes CREDDP zooplankton and larval fish data collected by the University of Washington in 1980 through 1981. Three aspects of zooplankton and larval fish ecology were emphasized: 1) the structure of assemblages and their relationship to physical and biological factors in the estuary, 2) the life histories and ecology of abundant or important taxa in the estuarine food web, and 3) the temporal and spatial distribution and density of zooplankton and larval fish in the estuary. See Appendix A, Figure 4, for the location of sampling sites.

A few species composed most of the zooplankton in the estuary. Most of the taxa collected were copepods, cladocerans, and mysids. These taxa were grouped by distribution in the estuary: marine zone, from River Mile (RM)-5 to 10; estuarine mixing zone, from RM-10 to 18; and freshwater zone, from RM-18 to 23. Zooplankton density was high in the Columbia River Estuary during 1980 an 1981. Densities above 100,000 animals per square meter (animals/m^2) were recorded in the marine zone during late spring, in the estuarine mixing zone during late spring and early summer, and in the freshwater zone during late summer.

Four copepods species, Acartia clausi, Acartia longiremis, Centropages abdominalis, and Pseudocalanus elongatus, were common in the marine and lower estuarine mixing zones of the estuary. Eurytemora affinis was the most abundant taxon in the estuary with densities above 100,000 animals/m^2. The center of abundance of Eurytemora affinis moved from the marine and estuarine mixing zones in the spring to the estuarine mixing and freshwater zones in the summer. The copepod Cyclops bicuspidatus and cladocerans Bosmina longirostris, Daphnia pulex, Daphnia glaeata mendotae, on the other hand, were abundant during summer in the estuarine mixing and freshwater zones.

Mysids were less abundant than the major copepods and cladocerans but were common throughout the estuary. Neomysis kadiakensis and Archaeomysis grebnitzkii resided primarily in the lower estuary, but extended upriver into the estuarine mixing zone during summer. Aleinocanthomysis macropsis and Neomysis mercedis resided in the estuarine mixing and freshwater zones of the estuary.

Four major taxonomic assemblages of zooplankton were identified based on their horizontal distribution in the estuary during the year using cluster analysis. Assemblage 1 was composed of taxa rarely found upriver of RM-11 and whose center of abundance was always close to the mouth of the estuary, such as Neomysis kadiakensis, Calanus spp., and Ctenocalanus spp. Assemblage 2 consisted of taxa most commonly found between the mouth of the estuary and RM-13. These taxa were usually in the marine zone of the estuary during all but the low riverflow periods and included many common marine taxa (Acartia spp. and Pseudocalanus spp.). Taxa which tended to remain in the center of the estuary, including Scottolana canadensis, were grouped into assemblage 3. Eurytemora affinis resided primarily in the central estuary, but only during winter and spring. During summer, E. affinis populations were most dense in the freshwater region. Species such as Daphnia spp., Bosmina spp., and Cyclops spp. occurred in both the estuarine mixing and freshwater zones during the year. These taxa were in Assemblage 4.

High riverflows and two-layered circulation are dominant forces on biological communities in the Columbia River Estuary. Flows varying from 75,000 cubic feet per second (cfs) in summer to 600,000 cfs during spring control the upriver extent of the salt wedge which fluctuates between RM-8 and RM-20. Composition, distribution, and density of zooplankton assemblages in the estuary also vary seasonally with riverflow. It is likely that river discharge exerts direct or indirect control over the influx of marine taxa, the distribution of plankton food resources, water temperature and reproductive rates, and the flushing rate of zooplankton through the system. These factors may all influence the survival of freshwater, estuarine, and marine species.

Marine taxa in the estuary were influenced primarily by oceanographic conditions. In the summer, taxa abundant in the northeast Pacific were carried south to the Oregon-Washington coast by southerly flowing currents. In the winter, marine taxa in the estuary were dominated by species brought north from California waters in northerly flowing currents.

Taxa in the estuarine mixing zone probably were influenced by physical processes that control the turbidity maximum in the estuary. For example, the turbidity maximum is associated with high levels of particulate organic carbon and current reversals.

High phytoplankton abundance and high temperature during summer are associated with elevated abundances of freshwater taxa in the estuary. Reservoirs created by dams along the mainstem of the Columbia River may provide good habitat for production of freshwater zooplankton populations.

High flushing rates (1-5 days) in the Columbia River Estuary may quickly transport zooplankton to the ocean. Several physical and biological mechanisms enable zooplankton to maintain populations in the estuary. Large bays in the estuary provide slower water refuges which may serve as reproductive reservoirs; zooplankton may spend enough time deep in the stratified channels to be advected upstream with the salt wedge; and zooplankton may have a reproductive rate which balances the flushing rate.

Larval fish and eggs in the Columbia River Estuary were predominatly Osmeridae species. Spirinchus thaleichthys and Thaleichythys pacificus densities peaked in March and May, respectively. Osmeridae, Clupea harengus pallasi, Cottus asper, and Leptocottus armatus probably used the estuary for spawning and rearing.

Density of fish larvae was highest during winter and spring, while abundance of fish eggs peaked in summer. Most of the taxa (13 of 18) were oceanic in origin and were collected only in the marine and lower estuarine mixing zones. The remaining five species including the numerically dominant Osmeridae were collected in the estuarine mixing and freshwater zones.

Larval fish composition in the Columbia River Estuary may not parallel that in other Oregon estuaries such as Yaquina Bay. Whereas C.h. pallasi and Leptogobius lepidus comprised 90% of all larvae in Yaquina Bay, Osmeridae taxa and Cottus asper dominated the larval fish assemblages in the Columbia River Estuary.

2.5 BENTHIC INFAUNA OF THE COLUMBIA RIVER ESTUARY

Holton, R.L.; Higley, D.L.; Brzezinski, M.H.; Jones, K.M.; Wilson, S.L. 1984
179 pages

The CREDDP benthic infauna research was designed to study the distribution, life history, and production ecology of Columbia River Estuary infauna.

The vertical distribution of infauna was investigated by collecting 30 centimeter deep cores from intertidal sites in Grays Bay, Desdemona Sands, and Baker Bay (Appendix A, Figure 5). The cores were vertically sectioned and sieved on 4.0, 1.0, 0.5, 0.25, 0.125, and 0.063 millimeter mesh-size screens. In general, amphipods, polychaetes, and small bivalves were concentrated near the surface, nematodes and oligochaetes were broadly distributed and large bivalves were deeply placed. Corophium salmonis, a numerically and trophically important amphipod, was confined to the upper 15 centimeters of the Grays Bay core. Sieve retention data generally supported the commonly used 0.5 millimeter separation between meiofauna and macrofauna.

The infauna of a Baker Bay intertidal mudflat (Appendix A, Figure 5) was intensively studied from August 1980 to September 1981. The substrate was composed of coarse silt and very fine sand with an oxygen depleted zone at about 7 centimeters, and was covered by a rich benthic diatom flora. The abundance of individual taxa changed dramatically during the year, but species richness and the relative dominance of surface deposit feeders were stable. Relative abundance of the species and species diversity were also stable except following a Hobsonia florida recruitment in June and July. Spawning periods of the dominant species were June to July for Macoma balthica, August for Pseudopolydora kempi, and May, June, and September for Hobsonia florida. M. balthica dominated biomass density and produced 13.6 grams ash-free dry weight per square meter per year (g AFDW/m^2/yr). Hobsonia florida and Pseudopolydora kempi followed at 1.4 g AFDW/m^2/yr and 1.1 g AFDW/m^2/yr, respectively. The remaining taxa together produced 2.3 g AFDW/m^2/yr for a total community production rate of 18.3 g AFDW/m^2/yr.

Year-round studies of the benthic amphipod Corophium salmonis at Desdemona Sands and Grays Bay showed this species to have two generations per year. Spring generation juveniles were produced in May 1981 and grew throughout the summer, producing the fall generation in July and August. Fall juveniles became the overwintering population which then produced the next spring generation. The Desdemona Sands population disappeared in September 1980 and reappeared in April 1981. Early colonists were adults and subadults, which at that time characterized the year-round Grays Bay population. The Desdemona Sands population increased dramatically during early summer 1981, reaching densities of 96,000 animals per square meter (animals/m^2) in August, and then declined rapidly. At Grays Bay, density increased steadily from 10,000 animals/m^2 in August 1980 to 32,000 animals/m^2 in February 1981. Density then declined steadily to a low of 4,000 animals/m^2 in July 1981. The wintertime population increases were created by the immigration of adults and subadults. The different patterns of migration exhibited at the two sites appear attributable to higher fall salinities occurring at the Desdemona Sands site than at the Grays Bay site.

Infaunal community structure and secondary production were also investigated at the Desdemona Sands and Grays Bay study sites. Corophium salmonis dominated both biomass and production levels through the year. The species produced 13.1 g AFDW/m^2/yr at Desdemona Sands and 8.2 g AFDW/m^2/yr at Grays Bay. Respective production:biomass ratios were 12.3 and 5.5 on an annual basis, and 5.1 and 2.7 for the April to September period. Size-specific growth rates by C. salmonis (maximum 0.10 milligrams per milligram per day) were similar to values published for other Corophium species, although the production rates were higher than for these species. Other taxa (e.g., Rhynchocoela, Nematoda, Oligochaeta, Neanthes limnicola) produced just 0.5 g AFDW/m^2/yr at Desdemona Sands and 0.9 g AFDW/m^2/yr at Grays Bay, for total community rates of 13.7 g AFDW/m^2/yr and 9.1 g AFDW/m^2/yr, which were somewhat lower than the production level at the Baker Bay intertidal mudflat site.

A survey to determine the estuary-wide distribution of sediment properties and the small macrofauna was conducted in September 1981. The survey utilized a stratified-random design based on 16 strata defined according to published salinity, substrate, and bathymetric information. Sand was the dominant textural grade (mean stratum silt and clay content usually less than 25%), and organic content was correspondingly low (about 1%). Biomass means were mostly less than 0.5 g AFDW/m^2. Dominant species were brackishwater species common to other west coast estuaries, and included Macoma balthica, Neanthes limnicola, Hobsonia florida, Corophium salmonis, Eogammarus confervicolus, and unidentified oligochaetes, rhynchocoelans and turbellarians. The generally simple structure of the estuary infauna is apparently a response to habitat instability in the form of strong currents, active sediments and high tidal and seasonal variability in salinity. A few euryhaline species with opportunistic life history patterns appear to dominate biomass and production rates over the estuary, and contribute very strongly to estuarine food chains.

2.6 EPIBENTHIC ORGANISMS OF THE COLUMBIA RIVER ESTUARY

Simenstad, C.A. 1984
55 pages

This report analyzes data on epibenthic organisms of the Columbia River Estuary. Epibenthic animals in the estuary tend to fall into two categories according to their usual position within the benthic boundary layer, that region located at the interface between the water column and the bottom sediment. These include (1) the large (greater than 1 millimeter) macroinvertebrates such as shrimps and crabs and (2) meio- (1 to 0.6 millimeter) and microfauna (0.6 to 0.1 millimeter) such as harpacticoid copepods, gammarid amphipods, and cumaceans. The latter group is termed epibenthic zooplankton because of their movement in and out of the water column.

Smaller, more planktonic forms were sampled from within the benthic boundary layer of shallow habitats (less than 1 meter depth) using a 0.10 square meter epibenthic suction pump and in channel habitats using a 0.5 meter opening-closing epibenthic sled. The more evasive macrofauna were sampled with nets: a 37 meter beach seine for shallow subtidal slope habitats and a 4.9 meter bottom trawl for tidal flat and subtidal channel habitats. Sampling procedures were standardized and measurements taken which enabled estimation of the effort expended (i.e., area or volume sampled) for each sample, thus allowing estimation and comparison of epifaunal density (number of individuals per square meter or cubic meter) and standing crop (grams wet weight per square meter or cubic meter) in the different habitats. See Appendix A, Figure 6, for the location of sampling sites.

Harpacticoid (including principally Scottolana canadensis, Microarthridion littorale, and Tachidius spp.), calanoid (e.g., Eurytemora affinis), and cyclopoid copepods (e.g. Cyclops spp.), ostracods (e.g., Limnocythere sp.), cladocerans (e.g., Daphnia spp.) and rotifers were the prominent components of the epibenthic zooplankton assemblages. The sand shrimp, Crangon franciscorum, and Dungeness crab, Cancer magister, constituted the principal motile macroinvertebrates. Mysids or "opossum shrimp", Neomysis mercedis, were common to both groups.

The epifauna sampled within the estuary included components which were both indigenous to the system (i.e., their populations constituted reproductive units) and exogenous animals which were passively transported into the estuary from the Columbia River or the open ocean. Among the epibenthic zooplankters, most of the cladocerans, cyclopoid copepods, and rotifers were freshwater taxa which probably did not constitute viable populations by the time they entered the central, mixing zone of the estuary. Dungeness crabs also originated outside the estuary, including principally juveniles which settled out of the water column after metamorphosis from megalopae or migrated in as early instar stages via the benthic (bedload) transport at the mouth of the estuary. Thus, the principal indigenous epifauna were harpacticoid copepods, Eurytemora, mysids, and crangonid shrimp.

Seasonal patterns of epifauna distribution, density, and standing crop indicate higher standing stock in the tidal and shallow subtidal habitats in the mixing zone of the estuary. In the case of the epibenthic zooplankton, this involves a considerable seasonal shift in peak standing stock from the region 10 kilometers to 20 kilometers from the mouth of the estuary during the spring freshet season (e.g., approximately 160,000 animals/m^2) to the region 25 kilometers to 35 kilometers from the mouth during the summer-fall low flow season (e.g., approximately 90,000 animals/m^2). Motile macroinvertebrates maintain standing stock maxima (e.g., approximately 0.6 to 0.9 animals/m^2) in the lower region during both spring freshet and summer-fall low flow seasons but also show another, slightly lower density maximum (e.g., approximately 0.4 animals/m^2) in the upper reaches of the estuarine mixing zone during the summer-fall low flow season. These seasonal changes are correlated with circulation processes (including the location of the maximum turbidity zone and the extent of salinity intrusion) which vary spatially as a function of seasonal patterns of river discharge and neap-spring tidal cycles.

Composition of epifaunal assemblages was also seasonally dynamic. Hierarchial cluster analysis of the epibenthic zooplankton density data indicated that the reduction in water column stratification, increased mixing, and expansion of the estuarine mixing zone during the summer-fall low flow season produced a more complex structure of epibenthic zooplankton assemblages. Both the spring freshet and winter-fluctuating high flow seasons illustrated six or seven taxa clusters which tended to fall into two basic site clusters, one confined to the region upriver from Tongue Point and another in the lower reaches of the estuary. Six taxa clusters were also evident during the summer-fall low flow season but the sites were very loosely associated into at least five cluster groups. The distinguishing characteristic of these clusters is that they tended to contain both exogenous riverine as well as endogenous estuarine zooplankters and two taxa clusters contained taxa from the marine region of the estuary. This implied considerable homogeneity in the distribution of riverine zooplankters through the estuary during the low discharge season as compare to either of the high discharge seasons.

The distribution and standing stock of motile macroinvertebrates reflects the dominance of Crangon franciscorum throughout the estuarine mixing zone. The occurrence of juvenile Dungeness crab, Cancer magister, produced the slightly higher standing crop values in the more euhaline reaches of the estuarine mixing zone. Crangon populations appeared to overwinter on littoral flat habitats in the estuarine mixing zone such as Youngs Bay. Reproduction occurred in the spring and adult shrimp had disappeared from these habitats by early summer. Coincident with the start of the summer-fall low flow season, young of the year Crangon began moving up the estuary with the increased salinity intrusion and landward movement of the turbidity maximum zone and the maximum epibenthic zooplankton standing stock. Although simple salinity tolerance levels cannot be excluded as the explanation for this intraestuarine migration, it also suggests a response on the part of the shrimp population to exploit the optimum concentrations of suspended phytoplankton (diatom) cells and epibenthic zooplankton within the benthic boundary layer of the expanding estuarine mixing zone. This dramatic shift in epibenthic assemblages is also reflected in the distribution of their predators. One of the highest correlations among both physical and biological factors related to motile macroinvertebrate standing crop was the density of co-ocurring fishes. Distribution of harbor seals, also major predators upon Crangon also illustrated overlapping seasonal movement.

Although autotrophic processes, detritus availability, and other trophic factors such as predation probably are the factors limiting the production of epibenthic organisms in the Columbia River Estuary, it is obvious that seasonally dynamic circulation processes structure the composition and distribution of both epibenthic zooplankton and motile macroinvertebrates and may indirectly influence the distribution and standing stock of their predators.

2.7 FISHES OF THE COLUMBIA RIVER ESTUARY

Bottom, D.; Jones, K.K.; Herring, M.L. 1984
113 pages

This report analyzes Columbia River Estuary finfish data collected by the National Marine Fisheries Service from February 1980 through July 1981. More than 75 fish species and 148,000 individuals were collected at 49 estuarine locations using trawls, beach seines, and purse seines (Appendix A, Figure 7).

Seasonal cycles in the life history and migration of fishes influence the composition of species assemblages in the Columbia River Estuary. As the number of species and life history stages in the estuary increases from winter to summer, the composition and distribution of assemblages become more complex.

Superimposed over natural reproductive cycles are seasonal changes in riverflow and salinity patterns that affect fish distribution in the estuary. Cluster analysis was used to group survey stations with similar species composition for each of three hydrological seasons in the Columbia River: winter fluctuating (November-March), spring maximum (April-June), and summer low (July-October) flows. In each season the estuarine sampling sites were divided into three major groups. These corresponded to marine, brackish (or transition) and freshwater salinity zones. In winter and summer the marine-transition boundary was located near the mouth at approximately River Mile 7 (RM-7); the freshwater-transition was located near Tongue Point at approximately RM-18. During spring maximum flows station groups reflected increased water column stratification as the boundaries between salinity zones shifted downstream for nearshore and pelagic sampling locations. Freshwater species were captured farther downriver in shallow beach seine sites than in deeper trawl sites.

Within each salinity zone the distribution of fishes was influenced by habitat type. Slightly different fish assemblages were associated with nearshore, bay, water column, and channel bottom habitats.

Results of discriminant analysis and reciprocal averaging indicate that species assemblages are not discrete groups. Most of the fishes in the estuary are euryhaline species that can be found throughout most salinity zones and habitats. Distribution is defined along a continuum of stations that represents salinity and depth-habitat gradients. Distribution of the most common fishes in the Columbia River Estuary is governed by salinity and habitat preferences rather than absolute limits of environmental tolerance.

The distribution and abundance of fishes in the Columbia River Estuary also reflect the distribution and standing crop of invertebrate prey. During the 1980 through 1981 survey the greatest number of fish species and individuals occurred in the middle estuary and in shallow bays. These were also regions of maximum standing crop during a concurrent survey of epibenthic invertebrates. Zooplankton densities were also consistently higher in the estuarine mixing zone.

The mean weight of stomach contents for fishes (Index of Feeding Intensity) also reflects the distribution of invertebrate prey. Average feeding intensity for the entire survey was generally higher among demersal channel and nearshore habitats between RM-6 and RM-19 and in Youngs and Baker Bays. Other CREDDP researchers found epibenthic organism and zooplankton densities were maximum between RM-6 and RM-16 during high flows and between RM-16 and RM-23 during low flows. High concentration of fishes in the central estuary and protected bays is probably a response to higher food densities.

Columbia River fishes do not consume a very large diversity of prey taxa. Corophium salmonis, Daphnia spp. and calanoid copepods are among the most important prey items for a variety of fishes. Analysis of fish stomach contents discerned several pelagic and several demersal, feeding groups each season. Species classified into the same feeding group (based on similar food habits) frequently were distributed among similar regions and habitats of the estuary.

Mean weights of stomach contents for most fishes were low compared to limited data from other estuaries in the Northwest. There was a relatively large proportion of empty stomachs among all individuals for several species. Growth rates for English sole and starry flounder were low relative to several reported values, particularly during winter fluctuating flow and spring high flow periods. The Columbia River Estuary may offer a poor feeding environment relative to some other estuarine systems in the region. Diel consumption studies are needed to test this hypothesis.

The Columbia River basin has been modified from a wild to a hatchery production system for salmonids. More than 172 million juvenile salmonids were released into the Columbia River in 1981. The timing and residence period of salmonids in the estuary reflects the rearing and release strategies of hatcheries upriver and may not reflect historical patterns of estuarine rearing. Migration rates for hatchery salmonids to the lower estuary generally increase with distance of release location from the river mouth.

Yearling chinook, coho, and steelhead move more rapidly through the estuary than subyearling chinook salmon. All species released farther upriver tend to move more rapidly through the estuary than fish released downriver. Yearling chinook, coho and steelhead primarily use deeper channel habitats en route to the ocean. Subyearling chinook use a greater diversity of habitats as they linger in the estuary. Estimates of migration rates based on tag recoveries from hatchery releases suggest that the Columbia, like other estuaries in the Northwest, is used as a rearing area for juvenile chinook salmon.

2.8 AVIFAUNA OF THE COLUMBIA RIVER ESTUARY

Hazel, C.R.; Ives, J.H.; Edwards, D.K.; Tinling, J.S.; Dorsey, G.L.; Green, A.M.; Crawford, J.A. 1984
85 pages

The purpose of the CREDDP avifauna research was to determine the role of birds within the Columbia River Estuary. The study was divided into several phases to meet this objective. Initially, a literature review of previous avian research was conducted (see Section 2.21). Three initital study objectives were designed (1) identify "key" avian species and the habitats important to them, (2) identify key avian habitats and describe their avian species composition, and (3) describe the food habits of key avian species. The study design and 1979 to 1981 field work were oriented toward the first two objectives, while the third objective became the subject of the 1982 CREDDP revised Plan of Study.

To the extent possible, results of this work unit were integrated with results of related work units presented in the fiscal year 1980 annual reports and in the preliminary reports developed for the completion of CREDDP.

The literature review, interviews with persons knowledgeable about birds of the Columbia River Estuary, and a list of criteria described by the first CREDDP Plan of Study were utilized to select key avian species. A similar procedure was used to select key avian habitats.

Eighteen key avian species were selected for intensive study: western grebe, doubled-crested cormorant, pelagic cormorant, great blue heron, mallard, American wigeon, surf scoter, common merganser, bald eagle, red-tailed hawk, dunlin, sanderling, western sandpiper, western gull, glaucous-winged gull, common murre, common crow, and blank-capped chickadee. Sanderlings, dunlins, and western sandpipers were categorized as peeps, and western and glaucous-winged gulls were combined into a second group termed large gulls. Seven key habitats were studied: open-water, mudflat, marsh, marsh-shrub, shrub, tree-shrub, and forest.

Line transects conducted from a boat and point censuses from shore were used to estimate and measure seasonal changes in relative abundance and distribution of key species within the estuary. The variable-circular-plot (VCP) bird census technique was used to estimate population densities of all birds. Seventeen study sites were established and each site was sampled from spring of 1980 until winter of 1981 (Appendix A, Figure 8). Incidental bird sightings provided additional data on bald eagle, great blue heron, and other key species distribution and habitat use.

Food habits of 10 key avian species were determined by reviewing existing literature to obtain inferences about food requirements and food composition. Spatial and temporal information from other work units was used to determine likely correlations between the known abundances of birds and prey species. Where data were available, feeding rates and prey composition were estimated for the 10 species.

A survey of bald eagle, great blue heron, pelagic and doubled-crested cormorants, and glaucous-winged and western gull nests was conducted. Eagle nests were surveyed biweekly, and those of other species less frequently. The purposes of nest surveys were to locate nests and colonies within the Columbia River Estuary and to record nesting chronology and success.

Key species data from line transects and point censuses were compiled using a standard statistical computer package for the social sciences (SPSS). Data were arranged on seasonal, species, and spatial bases.

Key habitat data were analyzed using a VCP computer program. Species densities and composition were used to calculate, total bird density, bird species diversity, number of species, evenness and consuming biomass for each of the 17 study plots during each season.

Although key avian species data were derived only for a 1-year period and food habits were based on review of existing literature and cursory evaluaton of data from other work units, some trends for use of the estuary could be established. In general, the mid-estuary between Tongue Point and Aldrich Point was the most important area for key species as a group. Habitat diversity probably accounted for this since most of the major habitats within the Columbia River Estuary were represented in this area. However, there were areas of the estuary of particular significance to each species. Baker Bay and the adjacent open-water from East Sand Island to Point Ellice supported aquatic species, while shallow water and mudflats in these areas were important to great blue herons. The use trends for each of the key species are summarized in the report.

The major conclusions of this study are that although no bird species was determined to be dependent solely on the Columbia River Estuary for its existence, the Columbia River Estuary is an important area in the Pacific Northwest for wintering and migratory waterfowl, grebes, and peeps. It is an important year-round habitat for gulls, crows, chickadees, wrens, eagles, and herons and a valuable breeding site for swallows and passerines. Certain areas in the estuary are particularly important to selected species. Open-water areas, especially shallow areas of the Woody Island Channel and the zone from the Astoria-Megler Bridge to Grays Point, provided essential foraging habitat for cormorants and grebes. Mudflat habitats were least important to key species and numerically dominant species. Nevertheless, some mudflats, such as Baker Bay, were important foraging and resting habitat for peeps. The rocky cliff at Cape Disappointment, channel markers west of Miller Sands, and man-made structures in Trestle Bay comprised the only known nesting sites for cormorants in the estuary. Grays Bay and the island area are important foraging areas for bald eagles. Most eagle nests were located in coniferous stands adjacent to the estuary on the Oregon side. Approximately 95 percent of gull nesting activities in the estuary occurred on East Sand Island. The seasonal and spatial distributions of many bird species corresponded with the seasonal abundance and location of some species of fish and invertebrates in the estuary.

2.9 KEY MAMMALS OF THE COLUMBIA RIVER ESTUARY

Dunn, J.; Hockman, G.; Howerton, J.; Tabor, J. 1984
116 pages

The purpose of the CREDDP key mammal research was to examine the ecological relationships of mammals within the Columbia River Estuary. This was accomplished by focusing on four main areas of study: habitat use, period of birth, relationships to other trophic levels, and critical habitat.

A key species approach was used to examine the ecological relationships of mammals in the estuary. Key species were defined by the following criteria: 1) species that are abundant within the study area; 2) species that are rare, threatened, or endangered; and 3) species that may have significant interrelationships with other species or trophic levels. Using these criteria, ten key mammal species were identified for study: muskrat, nutria, beaver, raccoon, river otter, Columbian white-tailed deer, black-tailed deer, Townsend's vole, deer mouse, and vagrant shrew.

Habitat use of mammals was determined by foot and boat transect searches, trap line cesuses for small mammals (i.e., Townsend's vole, deer mice, and vagrant shrews), and radio telemetry for nutria, muskrat, and raccoon. Information on reproduction was gathered using radio telemetry, den searches, and reproductive tract examination. Feeding habits were determined by examining mammal stomach and fecal contents.

High marsh habitats (e.g., Lyngby's sedge/horsetail, mixed herbaceous, orange balsam, sitka willow) and low to medium elevation marshes (e.g., tall Lyngby's sedge, established soft-stem bulrush) were found to be important areas for muskrat feeding, resting, and rearing. These habitats contain Lyngby's sedge, water parsnip, and bulrush, which were also found to be important muskrat foods. Muskrats in the estuary were found to give birth from March through August.

The high marsh areas of Lyngby's sedge/horsetail, mixed herbaceous, and reed canary grass/cattail and the low elevation soft-stem bulrush habitat were found to be important nutria feeding areas. These habitats contain Lyngby's sedge, water parsnip, and soft-stem bulrush, which were found to be major food items in the nutria's diet. The high marsh sitka willow habitat associated with steep-sided tidal channels were important nutria denning and rearing areas. Nutria produce young throughout the year with a peak in production occurring during April.

Beaver were found to utilize the sitka spruce and willow-dogwood habitats extensively for feeding and denning areas. Beaver diets consisted primarily of trees and shrubs, such as sitka willow, black cottonwood, red alder, and creek dogwood. Herbaceous vegetation (e.g., sedges and horsetail) was also an important dietary component. The period of birth for beaver was found to begin in mid-April and may continue through May.

Orange balsam and sitka willow habitats were found to be important feeding areas for raccoons in the estuary. The mudflats and shallow tide channels associated with these areas provide an essential environment for raccoons foraging for crustaceans and fish common to slough and beach habitats. The willow-dogwood and sitka spruce habitats were important as resting and rearing habitats for raccoons. The period of birth for raccoons in the estuary occurs during May and June.

River otter activity was found to be greatest in the tidal sloughs and creeks of the willow-dogwood and sitka spruce habitats. These areas may also be important feeding sites as they contain substantial populations of crayfish, sculpin, and carp, all common foods of otter. The period of birth for river otter as determined from the literature occurs during March and April.

Deer activity was found to be limited to the forested habitats (e.g., sitka willow and sitka spruce) which commonly occur in the Cathlamet Bay islands and forested shorelines of Oregon and Washington. Foods found in the diet included several species of grasses and a variety of trees and shrubs. The common food species were horsetail, evergreen blackberry, Pacific ninebark, and mannagrass.

Voles and shrews were found to prefer the moist riparian habitats adjacent to non-tidal areas. Deer mice occurred throughout the estuary in moist wooded habitats. Deer mice were found to be omnivorous, commonly feeding on plants and insects. Voles fed primarily on grasses; and shrew diets consisted mainly of insect larvae, slugs, snails, and spiders.

In general, steep-sided tidal channels were important components of furbearer habitats in the estuary, particularly in the Cathlamet Bay Islands. These areas provide important denning and feeding environments for furbearers. The daily tide cycle was found to have a major effect on the activity patterns of several species (e.g., raccoon, muskrat, nutria).

2.10 MARINE MAMMALS OF THE COLUMBIA RIVER ESTUARY

Jeffries, S.J.; Treacy, S.D.; Geiger, A.C. 1984
62 pages

The purpose of this CREDDP study was to determine marine mammal abundance and feeding habits in the Columbia River Estuary. The harbor seal, California sea lion, and northern sea lion were the most frequently recorded marine mammals from the Columbia River. Sightings of the northern elephant seal were considered unusual. The California gray whale was commonly sighted near the river mouth during its annual migration along the coast.

Harbor seals were present as year-round residents, primarily using intertidal sand shoals as haulout locations. Major haulout sites were located on Desdemona Sands, Taylor Sands, and Miller Sands. Use of these and other haulout sites during winter months was associated with the period of maximum harbor seal abundance. During this season 1,000 to 1,500 seals were counted at various haulout locations. Counts decreased by spring as seals moved out of the Columbia to preferred pupping areas in adjacent estuaries. The main haulout area used during the summer was Desdemona Sands. Summer population counts showed 500 seals remained in the river. Annual pup production for the Columbia was low, with less than 10 pups born.

The California sea lion and nothern sea lion became seasonally abundant during dispersal from outside breeding areas. The only haulout site used by these species was located at the tip of the South Jetty. Counts at this site increased during the winter and reached maximum levels for both species by early spring. During this period, 150 to 200 California sea lions and 50 to 60 northern sea lions were counted at the South Jetty location. Additional animals were feeding in the river at this time, with California sea lions dispersed as far upriver as Bonneville Dam. Both species leave the area by early summer as they return to their breeding ranges. Both species begin to reappear in the region during September.

Analyses of harbor seal feeding habits were based on 436 scats collected June 1980 to April 1982 in the Columbia River. Harbor seals ate a wide variety of prey species, including a minimum of 33 species of bony fish, 3 species of jawless fish, 3 species of decapod crustaceans, and 2 species of cephalopods. These prey were mainly marine and anadromous species, most of which are indigenous to the Columbia River.

Otoliths (earstones) retrieved from food matter were used to identify prey fish. The most frequent otoliths occurred for the following families of bony fish: Engraulidae, Osmeridae, Gadidae, Stichaeidae, Cottidae, and Pleuronectidae. Longfin smelt, Pacific staghorn sculpin, Pacific tomcod, English sole, starry flounder, snake prickleback, and Pacific herring were particularly frequent year-round prey species of Columbia River seals. All these fishes were readily available at the time of consumption in the immediate vicinity of Desdemona Sands, which was the haulout site utilized by the greatest number of harbor seals in the Columbia River.

Annual abundances of northern anchovy and eulachon were preyed upon in season by almost all harbor seals in the Columbia River. These are moderately oily fishes, the consumption of which may have helped seals build up fat reserves for gestation, lactation, and molting cycles. Spawning runs of anadromous eulachon corresponded with an annual shift in harbor seal populations into the Columbia River from adjacent estuaries.

Although harbor seals of the Columbia River often competed directly for individual salmon netted by fishermen, otoliths from salmonid species did not appear often in the scats. This could be due to the fact that adult salmonids have very large heads, making it possible that harbor seals do not readily ingest that portion of the head containing the otoliths. There were no otoliths in the samples from salmonid smolts.

2.11 SEDIMENTARY PROCESSES AND ENVIRONMENTS IN THE COLUMBIA RIVER ESTUARY

Sherwood, C.A.; Creager, J.S.; Roy, E.H.; Gelfenbaum, G.; Dempsey, T. 1984
183 pages

This report summarizes the result of several years of research into the sedimentology of the Columbia River Estuary. Two major objectives were attained during the study: 1) the sedimentology of the estuary was investigated and described, and 2) some understanding of the processes important to sedimentation was gained.

As an introduction to the present study, background information on the tectonic, geologic, and oceanographic setting of the estuary are provided as well as a brief listing of previous studies performed in the estuary. The changes in relative sea-level, the hydrography of the Columbia River and the sources of sediments available to the system are considered especially important to the sedimentology of the estuary.

Several methods were utilized in the investigations of both processes and distributions in the estuary. A very large suite of sediment samples was obtained over the entire estuary and during three distinct river discharge seasons, fall, winter, and spring (Appendix A, Figure 9). These samples were analyzed to determine their grain-size distribution and some aspects of their mineralogy, and several approaches, both statistical and graphical, were taken in an effort to interpret the distributions. Information on the morphology of the estuary bottom was obtained using a side-scan sonar over various tidal stages in all three seasons (Appendix A, Figure 10). Suspended sediment processes were monitored with both fixed transmissometers and profiling nephelometers and are related to physical samples of suspended sediments (Appendix A, Figure 11). Several other sources of data were incorporated in the final interpretations, including recent bathymetry and aerial photographs.

The data served to emphasize the temporal variability in rates of processes, and the areal variations in distributions of sediments and morphology. Despite the large variance within a narrow range of sediment sizes, the grain-size data provided valuable insight into the processes that dominate sedimentation in the estuary. The statistical techniques, including factor analysis and cluster analysis, were of limited use due to the continuous nature of the sediment distribution in the estuary, but served to highlight importance of two transport modes in the estuary: bedload-intermittent suspended transport and suspended transport. The statistical techniques and the maps of conventional grain-size parameters were valuable in describing the distribution of sediments in the estuary. The side-scan sonar data enabled patterns of bedload transport to be delineated and predictions of shoaling and erosion to be made. The suspended sediment studies provided insight into the complex time-dependency of the turbidity maximum in the estuary.

The results are synthesized in a discussion that attempts to rank the various driving forces in importance and relate them first to sedimentological porcesses and second to resultant distributions and morphology in the estuary. Sections on the interpretation of grain-size and the relationship between flow, sediment-transport and sediment deposition and erosion provide a background for the process-result synthesis. The dominant influence of the fluvial system is reflected in the morphology of the estuary and in the sediment distribution, but the effects of energetic tides begin to dominate near the entrance, resulting in upriver transport of marine sediment into the estuary and entrapment of the fluvial bedload in coarse deposits within the estuary. Wave influences are important near the entrance, and the secondary influence of estuarine circulation is important in the ephemeral deposition of fine sediments in channels of the estuary. Accumulation of fine-grain sediments results in vertical accretion in the peripheral bays and is dependent on fluvial sediment supply. Most of the deposition in the estuary occurs as horizontal aggradation caused by the net seaward displacement of migrating channels and shoals of the upper estuary.

2.12 CIRCULATORY PROCESSES IN THE COLUMBIA RIVER ESTUARY

Jay, D. 1984
169 pages

This report summarizes results from a four-year study of the physical oceanography of the Columbia River Estuary. See Appendix A, Figures 12 through 15, for the location of sampling sites. Work was carried out in six areas: theory of estuarine circulation, tidal processes, system energetics, salinity distribution, salt transport, and low-frequency flow processes.

The major theoretical results are the definition of modes of estuarine circulation and an analysis of the forces maintaining the salinity distribution. The circulation modes are defined by application of a scaling analysis and a perturbation expansion. This mathematical procedure separates the primary tidal circulatory processes from secondary, modifying features. The primary tidal circulation occurs at diurnal (daily) and semidiurnal (twice-daily) frequencies. It is driven both by the surface slope and the time-varying salinity distribution. The secondary circulation modifies the primary tidal circulation. It can be divided into three modes that occur at different frequencies: the tidal overtones (that occur at frequencies higher than semidiurnal and are produced by the distortion of the tidal wave as it moves upriver), the secondary tidal circulation (at diurnal and semidiurnal frequencies), and the residual (or time-averaged) circulation, which varies during the tidal month and seasonally. The residual circulation is driven by the riverflow, the salinity distribution, tidal energy transferred from the primary tidal circulation, and, to a lesser extent, atmospheric effects.

Although a model encompassing the tidal circulation and all residual flow processes was beyond the scope of work, a one-dimensional (in the along-channel direction), numerical, harmonic water transport model was constructed that reproduced many important features of the tidal and tidal residual circulations in the presence of riverflow. This model avoids the complexities of salinity intrusion effects by treating only the transport (vertical integral of the flow). The purpose of the model was to investigate the interaction between geometric, frictional, tidal and fluvial (riverflow) effects.

Data analysis and the model show that the tidal range decreases rapidly in the upriver direction on the tides of higher range; that is, an increase in tidal range at the mouth results in a less than proportional increase upriver. Conversely, tidal range drops off slowly with river mile on tides of lesser range. This occurs because friction increases with the cube of the tidal range, but the energy supplied from the ocean by the tides varies only with approximately the square of the tidal range.

There is more energy available for mixing on the ebb than on the flood, because of the strength of the riverflow. The greater mixing on the ebb and the effects of salinity intrusion combine to make the vertical structure of the ebb currents very different than that of flood currents; this is the ebb-flood asymmetry. The vertical distribution of the mean flow is determined by the differences between the ebb and flood flows. The large shear (vertical differences in velocity) on ebb, the greater vertical uniformity of the flood flow and the salinity intrusion combine to generate net upstream bottom currents in the lower estuary.

The vertical structure of the currents is also strongly influenced by along-channel changes in depth and width. Mean upstream bottom flow associated with strong horizontal salinity gradients is not continuous from the entrance to the upstream limits of salinity intrusion. Its continuity is often interrupted by pockets of mean downstream bottom flow caused by topographic features. This suggests that the estuarine turbidity maximum, which is dependent upon the upstream bottom flow, may form preferentially in certain parts of the estuary and may be spatially discontinuous.

Tidal transports and tidal velocities are greater in the north channel than in the main navigation channel. Most of the tidal prism of the lower estuary is filled by the flow in the north channel.

Freshets reduce the tidal range and greatly increase the river stage (mean water surface level) above RM-20, because the riverflow increases the friction. Tides and stage below Tongue Point are much less affected by such changes in riverflow.

Energy budget calculations based on the tidal model show that the tidal energy entering the mouth of the estuary from the ocean is the dominant source of energy for circulatory processes in the estuary proper (below about RM-18). The dominant source of energy in the river is the potential energy released as the river water runs downhill; most of this energy is lost to friction above RM-30. Energy from the riverflow is much less important than tidal energy below RM-18, but both tidal and fluvial energy inputs must be considered in the area of minimum energy between about RM-18 and RM-30 that coincides with the islands and other depositional features of Cathlamet Bay.

The same perturbation expansion used to define modes of estuarine circulation has also been used to investigate the factors that govern salinity intrusion into the estuary. This analysis indicates that salt is maintained in the estuary primarily by the tidal currents acting on the salinity gradient (the horizontal salinity differences), not by the mean upstream bottom flow. Salt must also be transported vertically, as well as horizontally, if the salinity distribution is to be maintained. It appears that mixing and tidal transport, rather than the vertical mean flow are primarily responsible for this vertical transport, but details of salt transport processes remain unclear.

During periods of low riverflow, there is a neap-to-spring transition that changes the salinity structure from partially-mixed or well-mixed (spring tide) to stratified (neap tide). Neap-to-spring changes in salinity structure become less important as the riverflow increases. The transition may occur abruptly, because of the interaction of vertical mixing and stratification; increased stratification during the period of decreasing tidal range before the neap tide inhibits mixing which, in turn, allows a further increase in stratification. The process is reversed as the tidal range increases after the neap tide. Salinity intrusion length is greatest under low-flow, neap-tide conditions, when salinity intrusion may reach to about RM-30 in the main navigation channel, because the stratification allows upstream movement of salt without significant mixing with the overlying river water. Under the highest flow conditions, salt may be absent upriver of RM-2 for several hours at the end of ebb. Salinity intrusion into the shallower bays, and particularly into Grays and Cathlamet Bays which are at the upstream limits of salinity intrusion, is highly variable.

The high riverflow (approximately 310 thousand cubic feet per second) and low riverflow (approximately 155 thousand cubic feet per second) seasonal mean, minimum and maximum salinity distributions have been defined for north and main navigation channels. These seasonal distributions should be useful in understanding biological processes having seasonal time scales, but averaging obscures physical processes which are better understood in terms of the actual states of the system. The seasonal averages suggest that salinity intrusion into the north channel is somewhat greater than that into the main navigation channel under high-flow conditions, because of the stronger riverflow in the main navigation channel. The difference is less pronounced under low-flow conditions.

Salt and water transport calculations show that most of the net outflow of water is near the surface in the main navigation channel. Upstream bottom flow is strongest in the north channel. Salt is brought into the estuary primarily by tidal mechanisms in a near-surface jet in the north channel, at the same lateral position as the strongest tidal currents. Unlike the currents, the maximum salt transport is below the surface, because the salinity is lower at the surface. The mean upstream bottom flow appears to be important in inward salt transport only on neap tides, in those parts of the estuary where horizontal salinity gradients are strong. Salt transports near the bottom are otherwise small. The large, near-surface, mean outflow (primarily riverflow) in the main navigation channel transports salt out of the estuary.

The response to changes in riverflow, atmospheric effects (wind and pressure) and tidal range of that part of the residual or mean flow which is driven by the slope of the water's surface (the barotropic residual flow) was investigated by use of the statistical properties of the atmospheric data, tidal heights and surface slopes in the estuary and river. Record lengths of up to two years were used.

The primary conclusions of the residual flow work were that atmospheric pressure fluctuations, wind-driven changes in elevation of the coastal ocean, and winds over the estuary all influence tidal heights in the estuary, but this atmospheric forcing is too weak to dominate the residual currents in the estuary. The dominant factors controlling the residual circulation (slopes, currents and salinity) in the estuary proper (below Tongue Pt.) are the tidal range and river inflow. Tidal processes and riverflow are about equally dominant in controlling residual flows in the Wauna-Tongue Pt. reach. Riverflow is dominant above Wauna.

2.13 HYDRODYNAMIC MODELING IN THE COLUMBIA RIVER ESTUARY

Hamilton, P. 1984
411 pages

This final report of the simulation work unit of CREDDP consists of two volumes bound in one set. The first volume presents the results of applying a two-dimensional tidal-storm surge model to the Columbia River Estuary. The second volume presents the results of applying a depth-dependent, laterally averaged channel model in a specially developed multi-channel form to study the salinity and depth-dependent hydrodynamics of the estuary.

The purpose of the study was to use modern hydrodynamic models to simulate the tidal and tidal-residual circulation of the estuary and to assist in determining the physical processes responsible for the major circulation modes of the estuary. It is recommended that this report be read along with the CREDDP report entitled "Circulatory Processes in the Columbia River Estuary" (Section 2.12) in order to arrive at a comprehensive picture of the circulation and the physical oceanography of the estuary.

Volume I discusses the application of the U.S. Army Corps of Engineers Waterways Experiment Station Implicit Flooding Model (WIFM) to the Columbia River Estuary. WIFM is a two-dimensional model employing the depth-integrated equations of momentum conservation and continuity. It has a number of special features including provision for sub-grid scale barriers, and the flooding and dewatering of grid cells with changing water levels. The model was forced by tidal elevations offshore and at Eagle Cliff at the head of the estuary. The tidal elevations and depth mean currents simulated by the model agreed well with tide gauge and current meter data obtained by the Corps of Engineers during their March 1978 field program. The maps of current vectors showed that the tidal currents were largely constrained by the channels though substantial currents could occur over the sand banks. The model was used in a series of experiments to determine possible effects of the wind on the non-tidal flow. Since the model includes a portion of the inner shelf off the river mouth, upwelling and downwelling lowering and raising of sea level by longshore winds was approximately simulated. It was found that strong longshore winds were effective in changing water levels within the estuary and altering the distribution of residual currents but the changes predicted were small compared with the amplitude of the tidal elevations and currents.

Volume II contains the results from the multi-channel model. The model was developed using as a basis previous channel models developed by Hamilton, Blumberg, Elliott, and Wang and Kravitz (see report for references). The model solves, by time-stepping finite difference methods, the laterally averaged equations of along-channel momentum and salt conservation and continuity. The model thus includes the important vertical dimension and is able to calculate currents, salinity and elevations as functions of time, depth, and along-channel position. The extension of the model to multiple interconnecting channels allows the complex channel topography of the Columbia River Estuary to be efficiently schematized. It is found that simulations of horizontal currents and tidal elevations are almost as good as the WIFM results even though the horizontal grid was much more sparse than the WIFM rectangular grid. Inclusion of a relatively fine resolution depth grid ensures that the vertical exchange processes of mixing and advective fluxes as well as the combined interaction of current shear and stratification are taken into account in determining the salinity field and interaction of the salinity field with the currents. These important processes are excluded from depth-integrated models. Other features of the model include the provision for interchannel exchanges of water and salt across sandbanks when the water level exceeds the crest of the sandbank, a numerical advection scheme which minimizes numerical dispersion, and an efficient semi-implicit numerical method.

Two periods with extensive data from the CREDDP and NOS field programs are simulated: a 10-day period of low flow in October 1980 and a 60-day period of high flows in May and June of 1981. The latter includes a freshet which peaked at about 15,000 cubic meters per second (m^3/s). The reproduction of the observed current and salinity time series is good for both periods, establishing the model's ability to reproduce the main features of the circulation under two different riverflow forcings. The stratification and salinity intrusion differences between neap and spring tide caused primarily by increased vertical mixing on the spring tides are simulated as well as the differences in the salinity intrusion characteristics between the north channel and the main navigation channel. Mean circulations revealed intermittent weak upstream bottom density-current flows as being more prevalent on neap than spring tides. The intermittency is suspected to arise from non-linear tidal residual effects due to shoals and constrictions in the channels.

The model was then used to predict the circulation and salinity intrusion for a constant riverflow of 2,000 m^3/s. Historical riverflow records have shown that prior to dam construction on the upper Columbia River, such low riverflows have occurred very occasionally. The main result is that the Cathlamet Bay Channels would only expect a small rise in salinity, to generally less than 5 parts per thousand ($^o/oo$), if such an event occurred in the future.

As part of a desire to assess the impact of dredging and jetty construction on the hydrodynamics of the estuary, the model was used to predict the circulation that existed for the bathymetry of 1868. The model was reconfigured to represent the different channel networks of the estuary at that time. Three runs were performed for riverflows of 12,000, 4,000, and 2,000 m^3/s. The results show that despite the generally shallower channel depths, the tidal flows were stronger than today and with more asymmetric floods and ebbs in the major channels. Residual flow also greatly favors the north channel rather than Astoria channel west of Tongue Point. This results in increased salinity intrusion for all riverflows compared with the present day. The Astoria channel is predicted to be more saline for low riverflows than the north channel, which is opposite to that found today. The very low riverflow case showed that Cathlamet Bay would have been quite saline on presumably rare occasions, with some areas showing salinities greater than 10 $^o/oo$. The other feature of the salinity field not observed today is the presence of strong well-mixed vertical fronts over the major interior bars of the estuary at river end of the salt intrusion, particularly at high tide. These predictions are not intuitively obvious and show the value of a comprehensive model to simulate estuarine conditions not encountered or not measured.

2.14 THE DYNAMICS OF THE COLUMBIA RIVER ESTUARINE ECOSYSTEM (2 VOLUMES)

Simenstad, C.A.; Jay, D.; McIntire, C.D.; Nehlsen, W.; Sherwood, C.R.; Small, L.F. 1984
500 pages

This report presents an ecological synthesis of the physical and biological studies carried out by CREDDP. It is written primarily for estuarine scientists and resource managers with training in the physical and biological sciences. However, some sections will be of interest to resource managers, planners, and others whose training is in other fields.

There have been few comprehensive ecological studies of the Columbia River Estuary. Most studies have been either site-specific or focused on target organisms. Although there may be considerable data on physical and biological characteristics of the estuary, little information is available on relationships among biological processes and physical processes. This report, which focuses on physical-biological relationships and other ecological processes, provides a major advance in the understanding of the Columbia River estuarine ecosystem.

Chapter 2 of the report provides the background and regional setting for the more detailed discussions of physical processes presented in Chapters 3 through 5. It includes a review of the tectonic setting of the estuary and long-term sea level trends. An extensive discussion of the hydrography of the Columbia River is included. The sources of sediment input into the estuary are discussed, and the local atmospheric and oceanic conditions which affect the estuary are summarized. Finally, a brief review of previous studies of the physical aspects of the estuary is presented.

Chapter 3 uses as a framework a definition of estuarine flow modes based on an analysis of the equations of motion. This analysis is designed to determine the importance of tides, riverflow, topography, bottom friction, and density structure. The topics considered within the framework of this analysis are the tidal circulation and its interaction with the riverflow; system energetics; the salinity distribution and the transport of salt and water; the response of the system to storms; and changes in riverflow and tidal range. These problems are analyzed using time series and vertical profile data, and three different circulation models.

Chapter 4 continues the discussion of the physical environment of the estuary with an analysis of the CREDDP sedimentology data. Research into the ongoing processes of erosion, transportation, and deposition of sediment is presented, along with an interpretation of the morphologic characteristics of the estuary. Chapter 4 draws on the results presented in Chapter 3 and the sedimentation research to complete the physical description of the estuary and its subtidal and intertidal habitats.

In Chapter 5, a chronology of the physical changes in the estuary that have occurred in historic time is listed and the results of two approaches to an historical analysis of the evolution of the modern estuary are presented. Modeling results are interpreted in light of the knowledge gained in the studies of currents and sedimentation, and historical bathymetric charts and area/volume calculations are presented and discussed. Trends which appear as the estuary and the river have developed are evaluated in terms of the changes in the physical environment and the habitats of the estuary. Collectively, Chapters 2 through 5 present the physical background for the ecosystem approach taken in Chapters 6 through 8.

Chapter 6 presents a conceptual model of the complex interrelationships among biological processes in the Columbia River Estuary. This model has a hierarchical structure which identifies the coupling variables, state variables, and system inputs and outputs that are relevant to the research products of CREDDP. The conceptual model also provides an organizational structure for the synthesis of physical and biological data obtained at many different levels of temporal and spatial resolution. In the chapter, the theoretical basis for the synthesis of CREDDP scientific information is stated, and the systems and subsystems corresponding to the theory are diagrammed and described in detail.

In Chapter 7, relevant biological processes and associated state variables are discussed in relation to the physical processes that influence their dynamics. First, the taxonomic structure of the assemblages of organisms involved in each process is described, and in some cases, the physical and biological variables that determine the distribution of these organisms are identified. Next, mechanisms that control process rates are explored relative to system inputs and outputs, and within the coupling structure of the hierarchical conceptual model introduced in Chapter 6. Chapter 7 also identifies deficiencies in the CREDDP data, an evaluation that can help establish priorities for future research.

Chapter 8 provides a regional and habitat summary of information presented in Chapter 7. The estuary was divided into eight regions on the basis of physical properties. Some or all of six identified habitat types were found in each region. Tables were prepared to show, as far as the data would allow, the abundant taxa associated with the biological producers (phytoplankton, benthic algae, and vascular plants) and consumers (wetland herbivores, deposit feeders, suspension feeders, and predators) found in each region/habitat combination. In addition, tables were developed to show the biomasses, numbers of organisms, and production of the producers and consumers found in each region/habitat combination.

Conclusions resulting from this synthesis of the CREDDP data are presented in Chapter 9. This chapter evaluates (1) the ecological importance of habitats, regions, and estuarine zones to the primary and secondary production processes and (2) the role of circulation and sedimentation in structuring and limiting the ecological processes. Given these interpretations and the results of simulation modeling of circulation under historic bathymetry conditions, the ramifications to the estuarine community and processes of anthropogenic changes such as dredging and filling, diking, jetty construction, and exploitation or protection of key species are hypothesized. These conclusions end with an analysis of the adequacy of the understanding of the Columbia River estuarine ecosystem after the CREDDP research, focusing upon persistent data gaps and recommending specific directions for the next generation of research. Chapters 8 and 9 may be of special interest to planners and resource managers.

2.15 INDEX TO CREDDP DATA

Mercier, H. 1984
101 pages

Extensive data concerning the Columbia River Estuary were collected between 1979 and 1981 by scientific investigators working under contract to CREDDP. In addition to the reports described in this section of the Abstracts a total of 32 data sets were assembled from 13 work unit contractors. The purpose of the Data Index is to describe these data sets and to tell how they may be obtained. The descriptions are detailed and are intended to provide all the documentation that would be necessary to potential users of the data.

All but six of the data sets had been put in machine-readable form by the work unit contractors. These machine-readable data sets are now stored on six reels of magnetic tape maintained at the U.S. Army Corps of Engineers North Pacific Division Data Processing Center in Portland, Oregon. The Data Index explains how printed or magnetic tape copies of these data sets can be requested from the Corps of Engineers. The remaining data sets are housed in various locations; each description of such a data set includes information on how and where to request it.

Each subdivision in the Data Index deals with an individual work unit and its associated data set(s). There are from one to five data sets per work unit. Each work unit section begins with an overview of the work unit goals and the methods used to achieve those goals. Subsections on each of the data sets associated with the work unit follow the introductory overview. Each data set subsection begins with a statement describing the data collection effort represented. After this statement comes the following information on the data set:

a. Variables - the principal variables of interest. Each data set contains other descriptive or subsidiary data.

b. Data Set Description - the extent and form of the data set and, if the data set resides in the magnetic tape archive, a complete column-by-column description of the format and contents of the various types of records, referencing code tables where necessary.

c. Sampling - information concerning the sampling program represented by the data set.

d. Processing - information concerning any processing of the data by either the work unit contractor or the CREDDP data manager which may have occurred prior to archiving.

e. Quality Control - steps that were taken to ensure the quality of the data.

f. Data Set Request Information - tape and file numbers if the data set resides in the magnetic tape archive. For data sets not adaptable to magnetic-tape storage, names and addresses of contacts are given.

g. Alternate Sources - a few data sets are available from alternate sources.

Code tables referenced in the data set descriptions are grouped at the end of each work unit section following the last data set subsection. These code tables are often referenced in more than one of the data set descriptions in a given work unit section.

2.16 GUIDE TO THE USE OF CREDDP INFORMATION FOR ENVIRONMENTAL ASSESSMENTS

Nehlsen, W.; Bell, S.; Blomberg, G. 1984
60 pages

One of the purposes of CREDDP was to provide information useful in making land and water use planning decisions. The Users Guide explains how the CREDDP technical reports can be used in preparing environmental assessments. This Guide was prepared for people who do not necessarily have special training in estuarine science, but who need to understand the effects of proposed development projects on the estuary. The Guide explains the principles on which environmental assessments are based and presents some necessary scientific background.

Development projects (including construction, diking, filling, dredging, riverflow management, etc.) have a range of effects on the estuary. Some have direct effects reaching primarily the development site itself. (Indirect effects exist but are assumed to be negligible.) Others have both direct and indirect effects, extending from the development site to larger areas of the estuary. To understand the potential direct and indirect effects of development projects, it is necessary to appreciate the ways in which the estuary's circulation, sediments, plants, and animals interact. Chapter 2 of the Guide describes these complex relationships, and also presents a system for dividing the estuary into regions and habitat types.

Chapter 3 of the Guide presents a general approach for using CREDDP information in environmental assessments. This approach may be applied to small scale projects, such as diking or filling small areas, construction of docks, bulkheads and pilings, and small dredging projects. The effects of such projects are mostly direct. The approach in Chapter 3 may also be applied to large scale projects such as major fills or dredging projects and alteration of the flow volume of the Columbia River. Such projects have both direct and indirect effects.

Chapter 4 of the Guide describes how CREDDP information and the approach in Chapter 3 may be used in the local permit process for small scale projects. Most small development projects on the Columbia River Estuary are permitted through the mechanism of what is generally known as an impact assessment. An impact assessment is an assessment of the impact of the proposed development on the area's resources.

Chapter 5 of the Guide presents three example environmental assessments for large scale projects. These examples show some approaches used by scientists to evaluate the effects of major development projects.

2.17 BATHYMETRIC ATLAS OF THE COLUMBIA RIVER ESTUARY

CREDDP 1983
16 pages

This atlas is a large-format (26½" wide by 13½" high) document produced by CREDDP in conjunction with the U.S. Army Corps of Engineers Portland District and the Corps' Waterways Experiment Station. Its purpose is to provide an overview of sediment erosion and accretion patterns in the estuary.

Three bathymetric surveys are mapped at a scale of 1:60,000: 1935, 1958, and 1982. Bathymetric differencing maps designed to show areas of accretion and erosion are included for the periods of 1868 to 1935, 1935 to 1958, and 1958 to 1982. The atlas also describes the methods used to produce the maps. An interpretation of the maps is not included in the atlas; however, "Sedimentary Environments of the Columbia River Estuary" (Section 2.11) and "The Dynamics of the Columbia River Estuary" (Section 2.14) provide an analysis of accretion and erosion patterns based, in part, on the bathymetric differencing maps.

2.18 THE COLUMBIA RIVER ESTUARY: ATLAS OF PHYSICAL AND BIOLOGICAL CHARACTERISTICS

Fox, D.S.; Bell, S.; Nehlsen, W.; Damron, J. 1984
90 pages

This atlas is a large format document (page size 26" wide by 18" high) containing 28 color map plates and an interpretive text. The maps show the distributions of the estuary's major physical and biological characteristics, including salinity, sediment types, and abundant plants and animals. The atlas text summarizes the major findings of CREDDP with emphasis placed on interpreting the maps. The text is illustrated with numerous figures to help explain important estuarine characteristics.

The atlas describes the Columbia River Estuary ecosystem for readers who do not necessarily have a background in science. It is detailed enough, however, to be useful to estuarine scientists and resource managers and to act as an introduction to the CREDDP technical reports.

2.19 CHANGES IN COLUMBIA RIVER ESTUARY HABITAT TYPES OVER THE PAST CENTURY

by Thomas, D.W. 1983.
51 pages

This study compares information on the Columbia River Estuary from a time predating most human impacts with corresponding information derived from recent sources. The methods and materials section describes the selection and use of materials to achieve this comparison.

Surveys conducted from 1868 to 1873 are the source of the historical materials selected. These materials permitted the mapping and measuring (in acres) of five estuarine "habitat types": deep water, medium depth water, shallows and flats, marshes, and swamps. Also, the areas removed from the estuarine system since the 1868-73 surveys were classified into five additional categories according to current use. Separate maps of seven subareas were constructed to permit a more detailed analysis of changes in acreage. Each subarea was mapped twice, one for the past, the other for the present.

The results section presents the acreage data obtained and gives an account of the changes revealed by the maps. The data show an overall reduction in the estuary's area from 156,190 acres in 1870 to 119,220 acres in the present, a loss of 24 percent of the historical total. The greatest change, both in acres and as a percentage, is in the tidal swamp category, which shows a 77 percent loss. Swamps and marshes together lost 65 percent of their former area; deep and medium depth water acreages were reduced by 16 percent, while shallows and flats show a 10 percent increase in area. The distribution of these changes among the seven subareas is highly uneven.

The discussion and conclusions sections interpret the results in the light of the author's background in estuarine ecology and personal knowledge of the estuary. The discussion addresses two questions: what factors have caused these changes, and what is the significance of the habitat types in terms of estuarine "values" (i.e., habitats, resources, functions, and processes)?

In regard to causes, an attempt is made to distinguish between a natural estuarine "aging" process (in which shoaling is the primary factor) and changes that have resulted from human intervention. Diking and fills that create artificial uplands remove area directly from the estuary. Other human factors tend to cause shoaling in excess of that which would occur naturally, thus accelerating the natural aging process, reducing water volume, and changing the proportions among the habitat types, but without removing area from the estuary.

To estimate the ecological significance of the changes measured, the values associated with each habitat type are discussed. Also, the causes and extent of changes in salinity and in values important to salmon are estimated.

Finally, some general conclusions are attempted relating the various causes with the various effects, focusing on the question of whether and to what extent human intervention has caused the gain or loss of habitats, resources, functions or processes. The conclusion is drawn that those human activities which have increased the rate of shoaling may have been ecologically beneficial, at least in the short term, while diking and fills that create artificial uplands have resulted in a substantial loss of estuarine values.

2.20 COLUMBIA'S GATEWAY, A HISTORY OF THE COLUMBIA RIVER ESTUARY TO 1920

Oregon Historical Society. 1980.
65 pages

This document is a two-volume cultural history of the estuary area to 1920. Volume I is a narrative and Volume II is a set of unbound maps, including 39 reproductions of maps originally published between 1792 and 1915 and six original maps illustrating aspects of the estuary's cultural history. A limited number of Columbia's Gateway are available to be purchased from CREST.

The document summarizes the history of the Indians of the lower Columbia, early explorations of the river, the Lewis and Clark expedition, the founding of Astoria and settling of the north shore of the estuary, the development of the salmon and logging industries, war-time harbor defenses of the Columbia, and the history of navigation on the estuary.

2.21 A LITERATURE SURVEY OF THE COLUMBIA RIVER ESTUARY (2 VOLUMES)

CREDDP. 1980.
482 pages

CREDDP investigators conducted a review of scientific literature on the Columbia River Estuary before initiating their research. The investigations represented in the literature survey include emergent plant primary production, benthic primary production, water column primary production, zooplankton and larval fishes, benthic infauna, epibenthic organisms, salmonid and non-salmonid fishes, avifauna, marine mammals, wildlife, current studies, and sedimentation.

This document compiles the reviews of the investigators into a two-volume set. Volume I provides a summary of the literature and the results of past research on the estuary. Volume II is an annotated bibliography. The bibliographic volume is indexed by subject matter.

3. ANNOTATED BIBLIOGRAPHY OF OTHER PRODUCTS

3.1 PUBLICATIONS

The publications listed below have not been produced in quantity nor have they been widely distributed. These publications may be borrowed from the CREST library in Astoria, Oregon, or purchased from CREST at the cost of reproduction, postage, and handling (see end of preface for address and phone number of CREST).

Beyer, D.; Zamber, D.; Lawley, G. 1980. Literature review of reptiles and amphibians in the Columbia River Estuary. Vancouver, WA: Pacific Northwest River Basins Commission. 15 pages.

> This paper contains a brief summary and an annotated bibliography of scientific literature concerning reptiles and amphibians in estuaries.

Beyer, D.; Zamber, D.; Lawley, G. 1980. Literature review of seed production in the Columbia River Estuary. Vancouver, WA: Pacific Northwest River Basins Commission. 11 pages.

> This paper contains a brief summary and an annotated bibliography of scientific literature concerning seed production in estuaries.

Brzezinski, M.A.; Holton, R.L. 1980. Appendix A. Key species report: harpacticoid copepods. Vancouver, WA: Pacific Northwest River Basins Commission. 40 pages.

> This report reviews the morphology, reproduction, and physiology of harpacticoid copepods and summarizes the results of several benthic infauna studies conducted in the Columbia River Estuary prior to CREDDP investigations.

Butts, J.E.; Kadeg, R.D.; Kingsbury, P.A.; Duncan, P. 1980. Columbia River Estuary Data Development Program: Task B 3.1-2, characterization of water quality, 2 volumes. Vancouver, WA: Pacific Northwest River Basins Commission. 845 pages.

> This report reviews literature and data concerning present and historical water quality and sediment chemistry conditions in the Columbia River Estuary. The report also summarizes the results of a short-term water quality monitoring program (24 May to 18 June 1980) established to assess the impacts of Mt. St. Helens volcanic ash and mud flows on the water quality of the estuary. Volume I is a summary document and Volume II consists of appendices containing water quality data tables and figures, an annotated bibliography, and a summary of Washington and Oregon State water quality standards.

Cardwell, R.; Zamber, D.; Lawley, G. 1980. Literature review of terrestrial insects of the Columbia River Estuary. Vancouver, WA: Pacific Northwest River Basins Commission. 22 pages.

This paper contains a brief summary and an annotated bibliography of scientific literature concerning terrestrial insects in estuaries.

DeLapa, M.D.; Damron, J.; Fox, D.S.; Thomas, D. 1982. Plan of study for the completion of the Columbia River Estuary Data Development Program. Astoria, OR: Columbia River Estuary Study Taskforce. 136 pages.

This document details the plans for the completion phase of CREDDP (September 1982 through June 1984). It includes revised goals of the program, work programs for the CREDDP contractors, a summary of final products, and a summary of program management activities.

Durkin, J.T.; Blahm, T.; McCabe, G.; Coley, T.; McConnell, R.; Emmett, R.; Muir, W. 1981. Columbia River Estuary Data Development Program report: Salmonid and non-salmonid fish. Vancouver, WA: Pacific Northwest River Basins Commission. 146 pages.

This document summarizes some preliminary results of the CREDDP salmonid and non-salmonid fish work unit (September 1979 to September 1981). It includes summaries of fish catch data for the period from February 1980 to July 1981 and growth and feeding data for selected fish species.

Envirosphere. 1981. The status of knowledge on the effects of log storage on the Columbia River Estuary. Vancouver, WA: Pacific Northwest River Basins Commission. 78 pages.

This study summarizes the potential impacts of in-water log handing and storage activities and presents a survey of log raft storage areas in the Columbia River Estuary. An annotated bibliography of related literature is included.

Everitt, R.D.; Beach, R.J.; Geiger, A.C.; Jeffries, S.J.; Treacy, S.D. 1981. Marine mammal - fisheries interactions on the Columbia River and adjacent waters, 1980. Olympia, WA: Washington State Department of Game. 109 pages.

This report summarizes the results of the first year of a three-year marine mammal study conducted on the Columbia River and adjacent coastal waters and bays. The report's major purpose is to present information on the interactions between marine mammals and commercial and sports fisheries. Also included are preliminary results of a marine mammal population survey.

Higley, D.L.; Wilson, S.L.; Jones, K.K.; Holton, R.L. 1983. Distribution and community structure of benthic infauna in channel and protected flat habitats of the Columbia River Estuary. Corvallis, OR: Oregon State University. 81 pages.

This document summarizes the results of selected portions of the CREDDP benthic infauna distributional study. Much of the information in this report is included in more detail in "Benthic Infauna of the Columbia River Estuary" (see Section 2.5).

Jay, D. 1983. Interim report: Circulatory processes in the Columbia River Estuary. Astoria, OR: Columbia River Estuary Data Development Program. 521 pages.

This report presents a preliminary summary of the CREDDP circulation investigation. It consists of a summary document of the results and extensive appendices presenting field sampling locations, harmonic analyses of tidal height data, tidal constants, tidal inundation plots, daily riverflow estimates, salinity distribution statistics and plots, and velocity-conductivity-temperature-depth profile data. Much of the information in the summary document is included in more detail in "Circulatory Processes in the Columbia River Estuary" (see Section 2.12); only selected portions of the appendices are in the report described in Section 2.12.

Jay, D.; Jamart, B.; Kachel, N. 1980. A review of the U.S. Army Engineers Waterways Experiment Station sediment transport model. Vancouver, WA: Pacific Northwest River Basins Commission. 52 pages.

This report reviews the U.S. Army Corps of Engineers Waterways Experiment Station (WES) Sediment Transport program for the Columbia River Estuary. The modeling strategy is described and evaluated with regard to the methods used, the results obtained, and possible relationships to CREDDP research.

Jones, K.K.; Brzezinski, M.A.; Higley, D.L.; Holton, R.L. 1982. Vertical distribution of benthic infauna in the sediments of the Columbia River Estuary, with notes on the selectivity of screen mesh sizes. Corvallis, OR: Oregon State University. 38 pages.

This report describes the vertical distribution of benthic infaunal species in the Columbia River Estuary. Much of the information in this report is contained in "Benthic Infauna of the Columbia River Estuary" (see Section 2.5).

Jones, K.K.; Holton, R.L. 1980. Appendix E. Key species report: Platichthys stellatus (Pisces). Vancouver, WA: Pacific Northwest River Basins Commission. 18 pages.

This report reviews the life cycle and feeding of Platichthys stellatus (starry flounder) and summarizes results of several fish studies conducted in the Columbia River Estuary prior to CREDDP investigations.

Lawley, G.; Zamber, D. 1980. Literature review of nitrogen fixation in the Columbia River Estuary. Vancouver, WA: Pacific Northwest River Basins Commission. 14 pages.

This paper contains a brief summary and an annotated bibliography of scientific literature concerning nitrogen fixation in the Columbia River Estuary.

Lewis, J.K.; Hamilton, P. 1980. A review of numerical models of the Columbia River Estuary. Vancouver, WA: Pacific Northwest River Basins Commission. 19 pages.

This report reviews numerical hydrodynamic models which have been applied to the Columbia River Estuary. It was used to help design the CREDDP hydrodynamic modeling research.

Llewellyn, J.G.; Holton, R.L. 1980. Appendix B. Key species report: Macoma balthica (Bivalvia). Vancouver, WA: Pacific Northwest River Basins Commission. 15 pages.

This report reviews the habitat, reproduction, growth, and feeding of Macoma balthica and summarizes results of several benthic infauna studies conducted in the Columbia River Estuary prior to CREDDP investigations.

Loch, J.J. 1982. Juvenile and adult steelhead and sea-run cutthroat trout within the Columbia River Estuary, 1980. Olympia, WA: Washington Department of Game. 84 pages.

This report analyzes the CREDDP fish distributional and feeding study results for steelhead and sea-run cutthroat trout.

McConnell, R.; Blahm, T.; McCabe, G. Jr.; Clocksin, T.; Coley, T.; Durkin, J.; Emmett, R.; Muir, W. 1983. Columbia River Estuary Data Development Program data report: Salmonid and non-salmonid fish, 4 volumes. Astoria, OR: Columbia River Estuary Data Development Program. Vol. 1 - 105 pages; Vol. 2 - 88 pages; Vol.3 - 10,000 pages; Vol. 4 - 18 pages.

The data used to compile much of the report entitled "Fishes of the Columbia River Estuary" (see Section 2.7) are contained in this data report. The first volume is a tabulated print-out of fish density and standing crop by month, site, and gear for all fish species caught in the distributional sampling. Data for eight of the ten key species are separated into life history stages. The second volume is a compilation and analysis of physical and biological information. The third volume is a large computer printout of data on the food habits of fish in the Columbia River Estuary. The fourth volume contains growth information on American shad, Pacific herring, longfin smelt, English sole, and starry flounder. Volumes 2 and 4, along with a description of methods employed, are bound together.

McIntire, C.D. 1982. The diatom flora as a salinity indicator in the Columbia River Estuary. Corvallis, OR: Oregon State University. 150 pages.

This document describes the species composition of the benthic diatom floras of several sites in the Columbia River Estuary. The use of the species composition data as an indicator of salinity levels is explored. Much of the infomation in this report is summarized in "Benthic Primary Production in the Columbia River Estuary" (see Section 2.2).

Merker, C.; Fenton, G. 1984. Key mammals of the Columbia River Estuary - density, food consumption, and limiting factors. Astoria, OR: Columbia River Estuary Data Development Program. 70 pages.

This document supplements the report entitled "Key Mammals of the Columbia River Estuary" (see Section 2.9). The purpose of this supplemental report is to make estimates of key mammal densities and food consumption rates for use by the team of CREDDP scientists who wrote "The Dynamics of the Columbia River Estuarine Ecosystem" (see Section 2.14).

Northwest Cartography, Inc. 1983. Columbia River Estuary bathymetric data development, 5 volumes. Astoria, OR: Columbia River Estuary Data Development Program. 2,500 pages.

This document consists of computer printouts of historical and recent bathymetric data for the Columbia River Estuary. Volume I contains depth data for the 1868, 1935, 1958, and 1982 bathymetric surveys; volume II contains depth differences for 1868 vs. 1935, 1935 vs. 1958, 1958 vs. 1982, and 1868 vs. 1982; volume III contains estuarine surface areas for the 1868, 1935, 1958, 1982 bathymetric surveys, volume IV contains estuarine volumes for the 1868, 1935, 1958, and 1982 bathymetric surveys; and volume V contains the same information as volumes I through IV for bathymetric surveys at the mouth of the estuary conducted in 1852, 1868, 1885, 1895, 1902, and 1935. There is no explanatory text with these volumes.

Northwest Cartography, Inc. 1980. Summary of contemporary bathymetry for the Columbia River Estuary. Vancouver, WA: Pacific Northwest River Basins Commission. 9 pages.

This report reviews selected hydrographic surveys and mapping projects conducted on the Columbia River Estuary prior to CREDDP mapping.

Pacific Northwest River Basins Commission. 1980. Columbia River Estuary Data Development Program 1979-1980 annual data report, 2 volumes. Vancouver, WA: Pacific Northwest River Basins Commission. 1,650 pages.

This document is a compilation of fiscal year 1980 data reports produced by CREDDP research contractors.

Pacific Northwest River Basins Commission. 1979. Columbia River Estuary Data Development Program Plan of Study. Vancouver, WA: Pacific Northwest River Basins Commission. 132 pages.

This document is the original plan for CREDDP. It includes a description of the program scope, organization and management, work elements, and products. It was replaced by the 1982 Plan of Study (DeLapa et al. 1982).

Pacific Northwest River Basins Commission. 1980. Columbia River Estuary Data Development Program, Procedures Manual. Vancouver, WA: Pacific Northwest River Basins Commission. 420 pages.

This document describes the planned field sampling, laboratory processing, and data processing methods to be employed by the CREDDP researchers. Some of the described methods were modifed as CREDDP field sampling progressed in 1980 and 1981.

Richter, J.E.; Holton, R.L. Appendix D. Key species report: Corophium spp. (Amphipoda). Vancouver, WA: Pacific Northwest River Basins Commission. 15 pages.

This report reviews the feeding, physiology, and reproductive biology of Corophium spp. and summarizes the results of several benthic infauna studies conducted on the Columbia River Estuary prior to CREDDP research.

Show, I.T. 1980. Literature review and annotated bibliography of historic and contemporary research on modeling estuarine processes. Vancouver, WA: Pacific Northwest River Basins Commission. 34 pages.

This report briefly reviews scientific literature concerning estuarine ecosystem modeling. An annotated bibliography is included.

Thomas, D.W. 1980. Study of the intertidal vegetation of the Columbia River Estuary. Vancouver, WA: Pacific Northwest River Basins Commission. 17 pages.

This report summarizes the results of an intertidal vegetation classification and mapping study. A brief description and area measurement is given for each of the estuary's marsh and swamp communities. The maps developed from this study are described in Section 3.2.

Thomas, D.W. in press. The vascular flora of the Columbia River Estuary. Wassman Journal of Biology. 20 pages.

This paper lists 165 species of vascular plants found in the estuary. The distribution of each species by broadly defined vegetation type is given.

Wilson, S.L.; Holton, R.L. 1980. Appendix C. Key species report: Neanthes limnicola (Polychaeta). Vancouver, WA: Pacific Northwest River Basins Commission. 11 pages.

This report reviews the life history and trophic position of Neanthes limnicola and summarizes the results of benthic infauna studies conducted in the Columbia River Estuary prior to CREDDP investigations.

Wilson, S.L.; Jones, K.K.; Higley, D.L.; Holton, R.L. 1982. Seasonal changes in community structure of benthic infauna at six stations in the Columbia River Estuary. Corvallis, OR: Oregon State University. 95 pages.

This report summarizes the results of the portion of the CREDDP benthic infauna study designed to document monthly and seasonal changes in the estuary's infauna communities. Some of the information in this report is summarized in "Benthic Infauna of the Columbia River Estuary" (see Section 2.5).

Of the reports annotated above, the following summarize research that was sponsored jointly by CREDDP and other agencies.

Funding Agency	Reports
U.S. Army Corps of Engineers, Portland District	Higley and Holton (1982) Jay (1983) Jones et al. (1982) McIntire (1982) Northwest Cartography (1983) Wilson et al. (1982)
NOAA, National Marine Fisheries Service, Northwest and Alaska Fisheries Center	Durkin et al. (1980) Everett et al. (1980) Loch (1982)
NOAA, NMFS, National Marine Mammals Laboratory	Everett et al. (1980)
Washington Department of Game	Everett et al. (1980) Loch (1983)
NOAA, National Ocean Service	Jay (1983)

3.2 MAPS AND RELATED MATERIALS

Historical Bathymetry and Bathymetric Differencing Maps of the Columbia River Estuary

This set of maps was produced using historical bathymetry data and maps. The maps are at a scale of 1:20,000 and consist of seven overlapping segments showing the entire estuary. The following surveys are represented:

Bathymetric Maps	
1868-1877	(estuary-wide, seven segments)
1926-1937	(estuary-wide, seven segments)
1950-1958	(estuary-wide, seven segments)
1852	(approach and mouth, segments one and two)
1868	(approach and mouth, segments one and two)
1885	(approach and mouth, segments one and two)
1895	(approach and mouth, segments one and two)
1902	(approach and mouth, segments one and two)
1935	(approach and mouth, segments one and two)

Differencing Maps	
1868 vs. 1935	(estuary-wide, seven segments)
1935 vs. 1958	(estuary-wide, seven segments)
1852 vs. 1868	(approach and mouth, segments one and two)
1868 vs. 1885	(approach and mouth, segments one and two)
1885 vs. 1895	(approach and mouth, segments one and two)
1895 vs. 1935	(approach and mouth, segments one and two)

These map sets are available for use at the CREST office in Astoria, Oregon. A limited number are available for purchase.

Vegetation Maps and Color Aerial Photos

These maps show the distribution of the vegetation communities described in Thomas (1980) (Section 3.1). The maps consist of mylar overlays and color aerial photos at scales of 1:12,000 and 1:9,600. They are available for use at the CREST office in Astoria, Oregon.

Offset Printing Plates and Press-Ready Flatted Forms of the Composite Negatives for the Map and Text Pages in the "Bathymetric Atlas of the Columbia River Estuary"

The original plates and negatives used for producing the Bathymetric Atlas (see Section 2.17) are stored at:

NOAA Library
7600 Sand Point Way
Bin C-15700
Building 3
Seattle, WA 98115

Arrangements for the use of these plates and negatives may be made through the CREST office in Astoria, Oregon.

Orthophotos of the Columbia River Estuary

These are a set of 1:12,000 black and white aerial photos covering the entire estuary. They were taken by the U.S. Army Corps of Engineers in 1981. The orthophotos were produced by CREDDP for compiling the CREDDP base maps. They are available for use in the CREST office in Astoria, Oregon.

CREDDP Base Maps

The base maps of the Columbia River Estuary were produced by CREDDP at scales of 1:12,000 (9 segments) and 1:50,000 (2 segments). They are available for use at the CREST office in Astoria, Oregon.

CREDDP Base Map Composite Negatives

The original negatives used for producing the CREDDP base maps are stored at:

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Building 3
Seattle, WA 98115

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Offset Printing Plates and Press-Ready Flatted Forms of the Composite Negatives for the Maps and Text of "The Columbia River Estuary: Atlas of Physical and Biological Characteristics"

The original plates and negatives used for producing the estuary atlas (see Section 2.18) are stored at:

NOAA Library
7600 Sand Point Way
Bin C-15700
Building 3
Seattle, WA 98115

Arrangements for the use of these plates and negatives may be made through the CREST office in Astoria, Oregon.

Place Names Maps of the Columbia River Estuary

CREDDP produced 1:160,000 scale maps of the Columbia River Estuary showing commonly used place names (map size 11"x17"). An example of this map precedes page one of this report. These maps may be purchased from CREST.

3.3 REFERENCE COLLECTIONS AND UNPROCESSED SAMPLES

Herbarium of Vascular Plants of the Columbia River Estuary

This herbarium consists of dried and mounted specimens of vascular plant species found in tidal and non-tidal wetlands of the Columbia River Estuary. The collection is arranged by plant family. The herbarium is available for use at the CREST office in Astoria, Oregon. A key to the collection is available on loan from the CREST library.

Diatom Herbarium

This is a collection of Columbia River Estuary diatoms mounted on microscope slides. It is housed at Oregon State University. For more information contact:

David McIntire
Department of Botany and Plant Pathology
Oregon State University
Corvallis, OR 97331

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David McIntire
Department of Botany and Plant Pathology
Oregon State University
Corvallis, OR 97331

Fish Collected during the CREDDP Epibenthic Organism Field Sampling

These are preserved fish collections captured in beach seines and bottom trawls at several sites in the Columbia River Estuary. Their shelf-life is approximately 5 years from the collection date (1981). The species and numbers of fish collected appear on the epibenthic organism portion of the computer archive (see Section 2.15). The preserved fish are stored at the Fisheries Research Institute, University of Washington. For more information contact:

Charles Simenstad
Fisheries Research Institute
University of Washington
260 Fisheries Center
Seattle, WA 98195

Fish Stomachs Collected During the CREDDP Fish Field Sampling

These are preserved fish stomach samples collected at several sites in the Columbia River Estuary. They are stored at the National Marine Fisheries Service, Northwest and Alaska Fisheries Center, Hammond Field Station, Hammond, Oregon. For more information contact:

Robert McConnell
NOAA/NMFS
P.O. Box 155
Hammond, OR 97121

Sediment Samples Collected During the CREDDP Sedimentation Field Sampling

Approximately 2,000 sediment samples collected in the Columbia River Estuary are stored at the University of Washington. They are catalogued in the appendix of "Sedimentary Processes and Environments in the Columbia River Estuary" (see Section 2.11). For more information contact:

Dr. Joe Creager
Department of Oceanography
University of Washington
Seattle, WA 98195

APPENDIX A

Columbia River Estuary Data Development Program

Sampling Site Maps

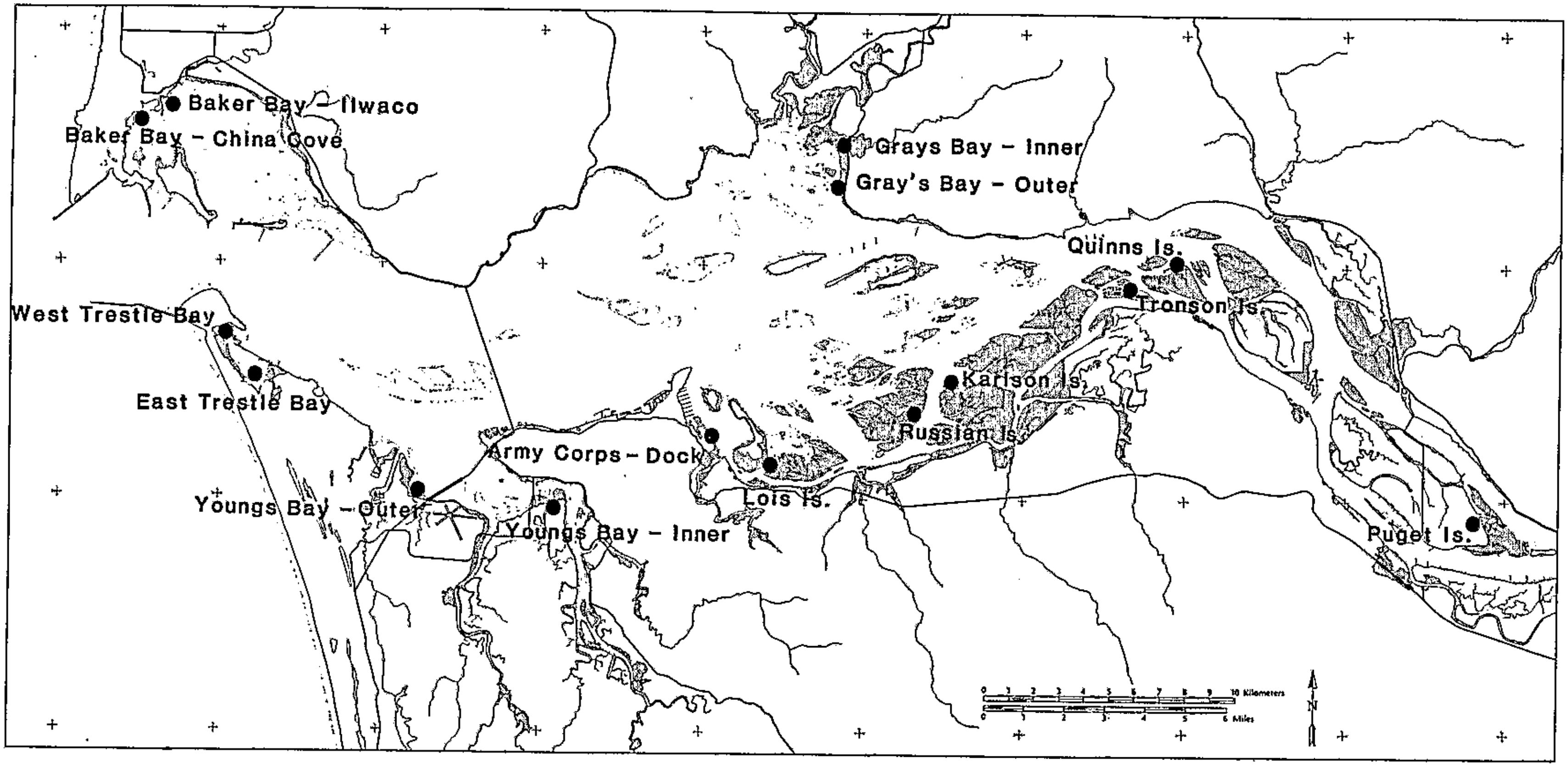


Figure 1. Sampling sites of the CREDDP tidal marsh plant production investigation.

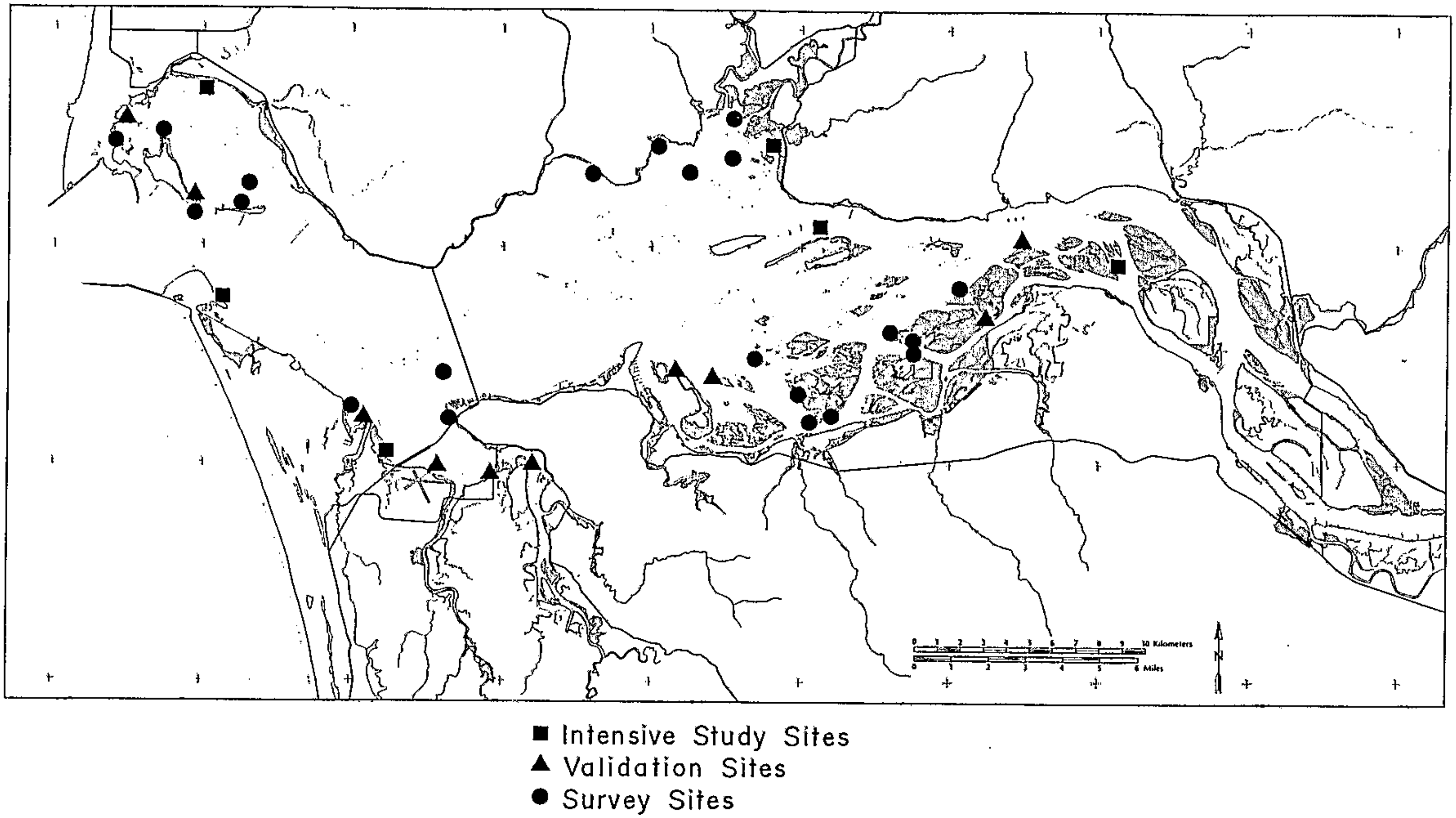


Figure 2. Sampling sites of the CREDDP benthic primary production investigation.

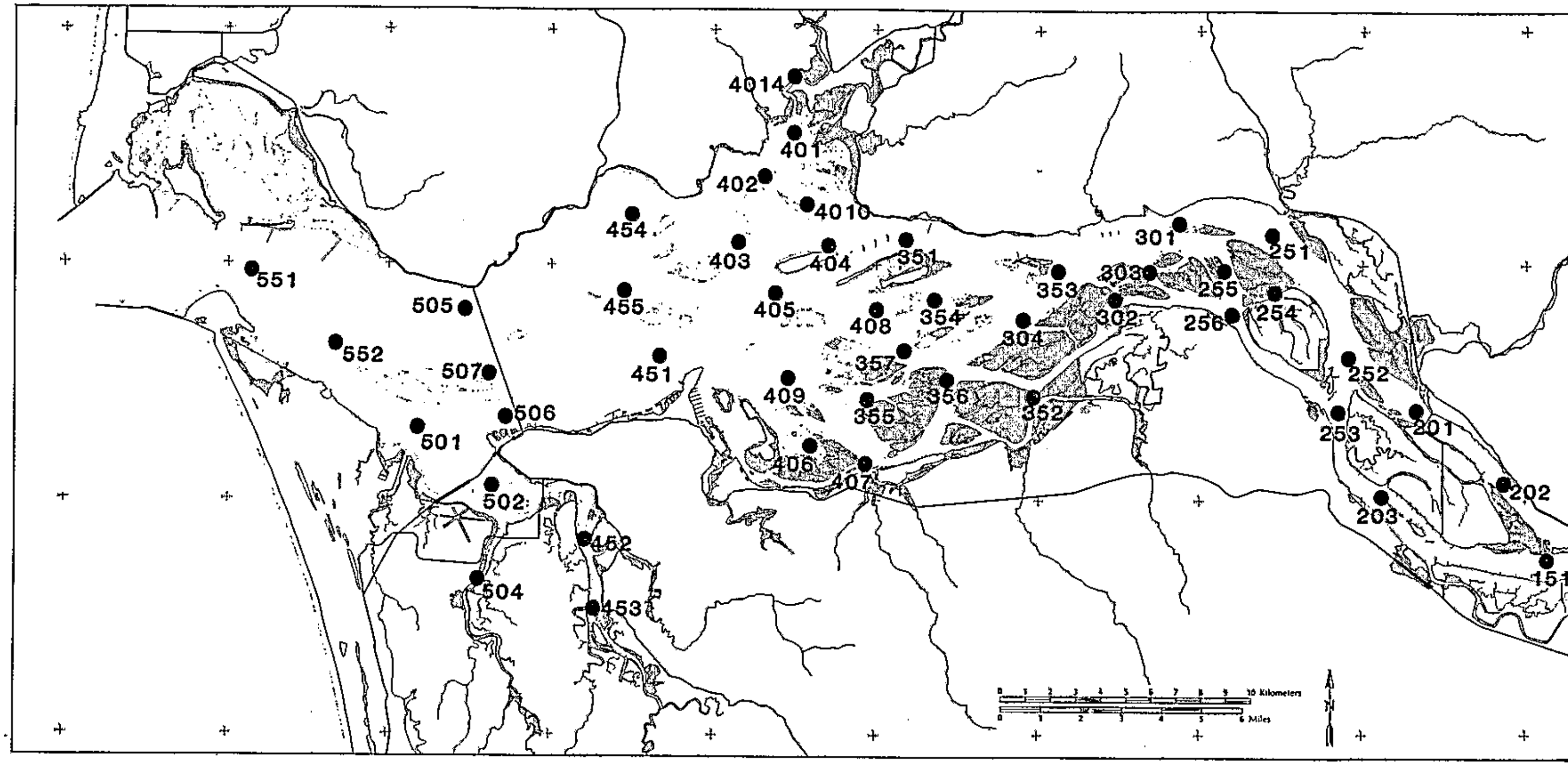


Figure 3. Sampling sites of the CREDDP water column primary production investigation.

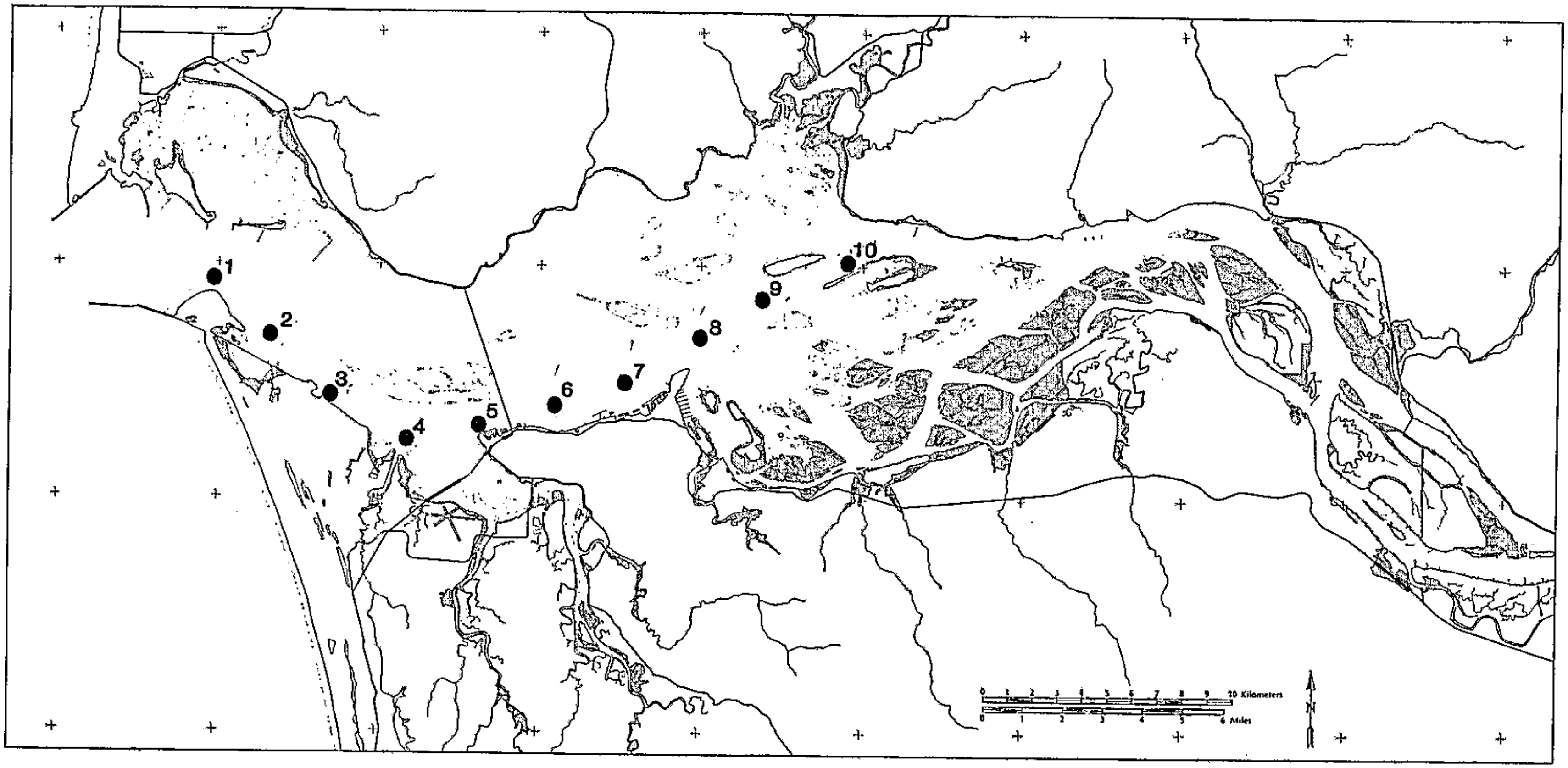


Figure 4. Sampling sites of the CREDDP zooplankton and larval fishes investigation.

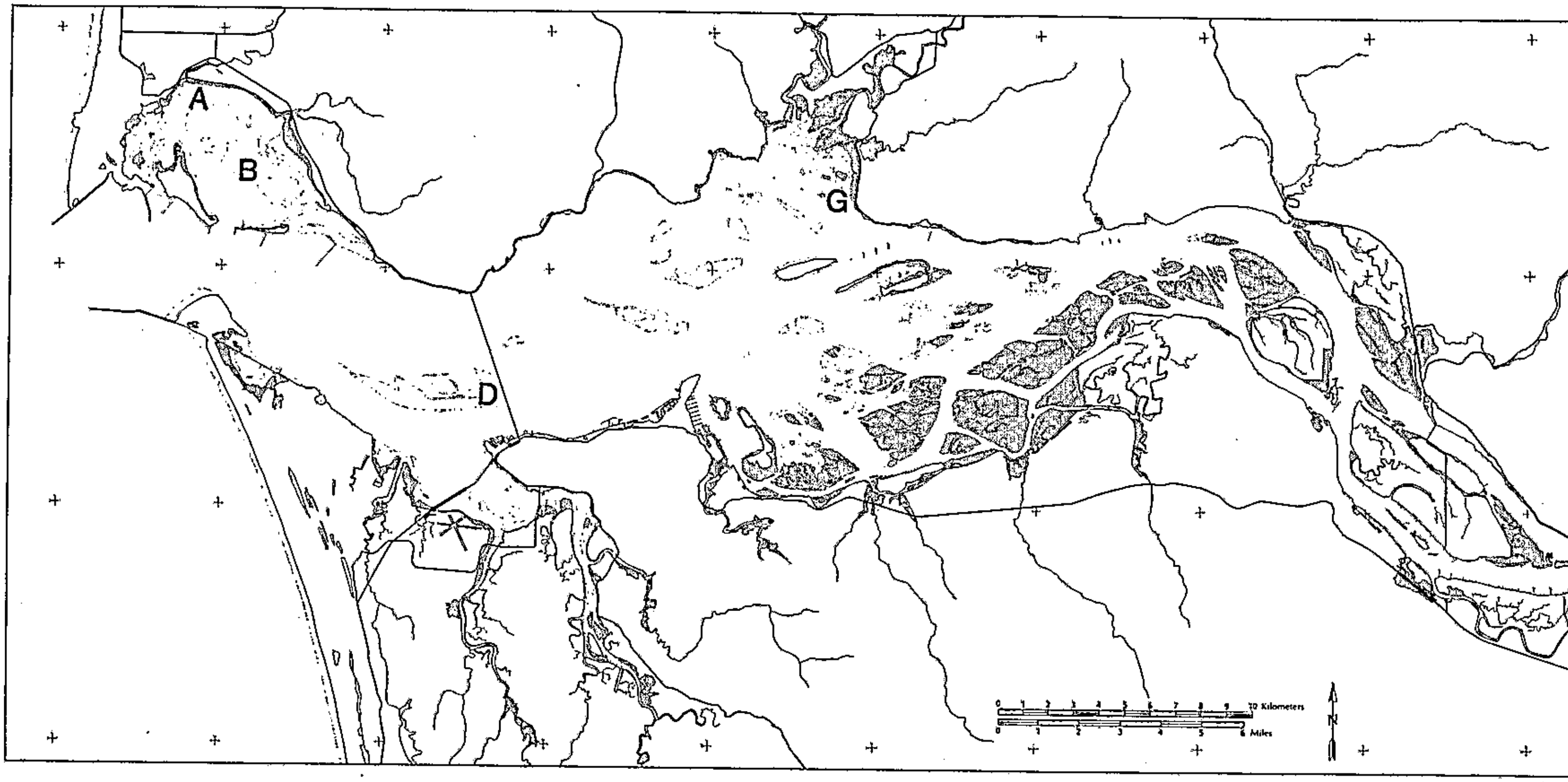


Figure 5. Sampling sites of the CREDDP benthic infauna investigation. The vertical distribution study was conducted at sites B, D, and G; the Baker Bay intensive study at site A; and the Corophium salmonis life history and community dynamics studies at sites D and G. The estuary-wide distribution study was conducted at 194 sites distributed throughout the estuary (sites not shown on the map).

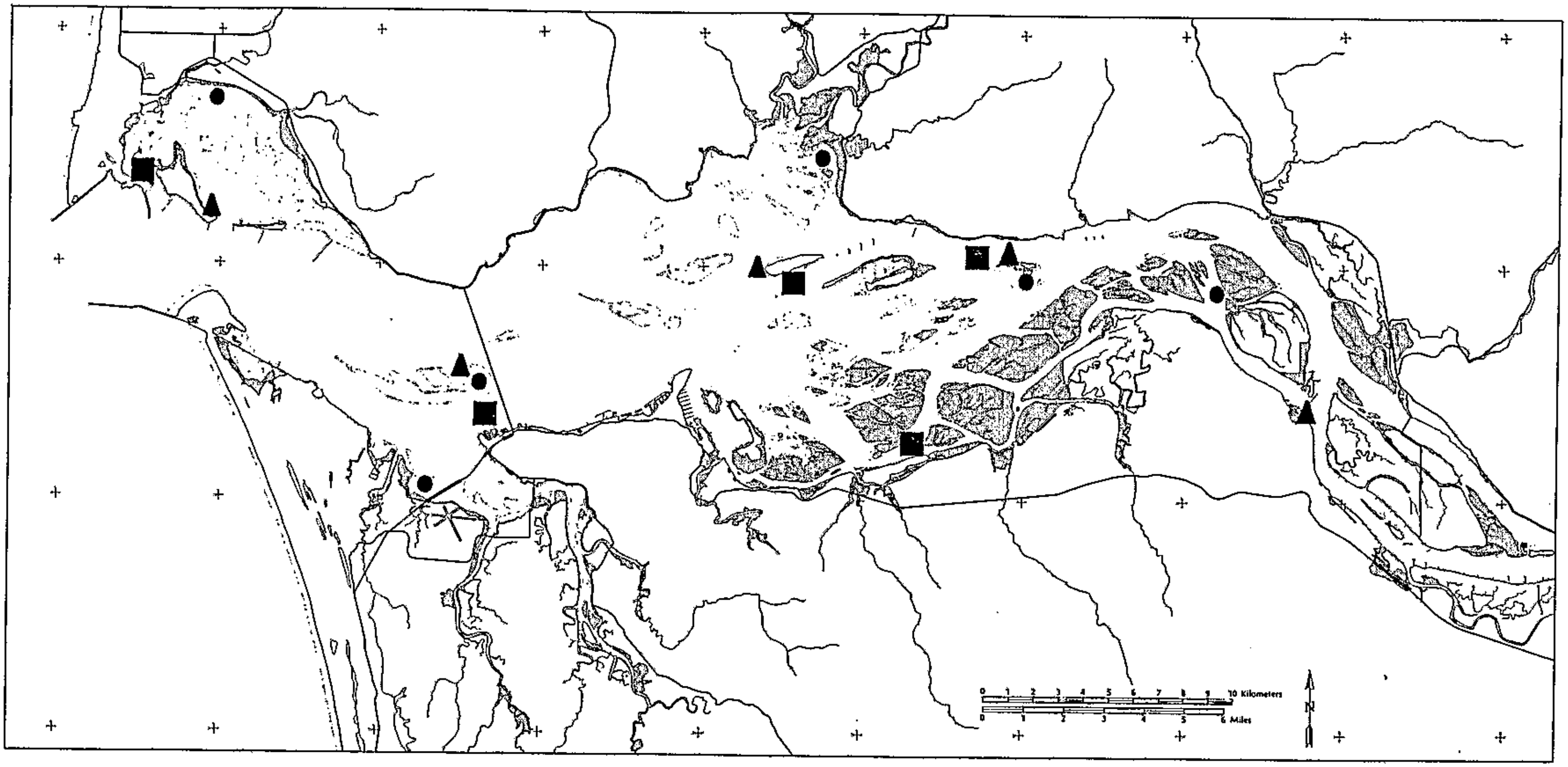


Figure 6. Sampling sites of the CREDDP epibenthic organisms investigation. Circles represent tidal flat sites, triangles represent subtidal slope sites, and squares represent subtidal channel sites.

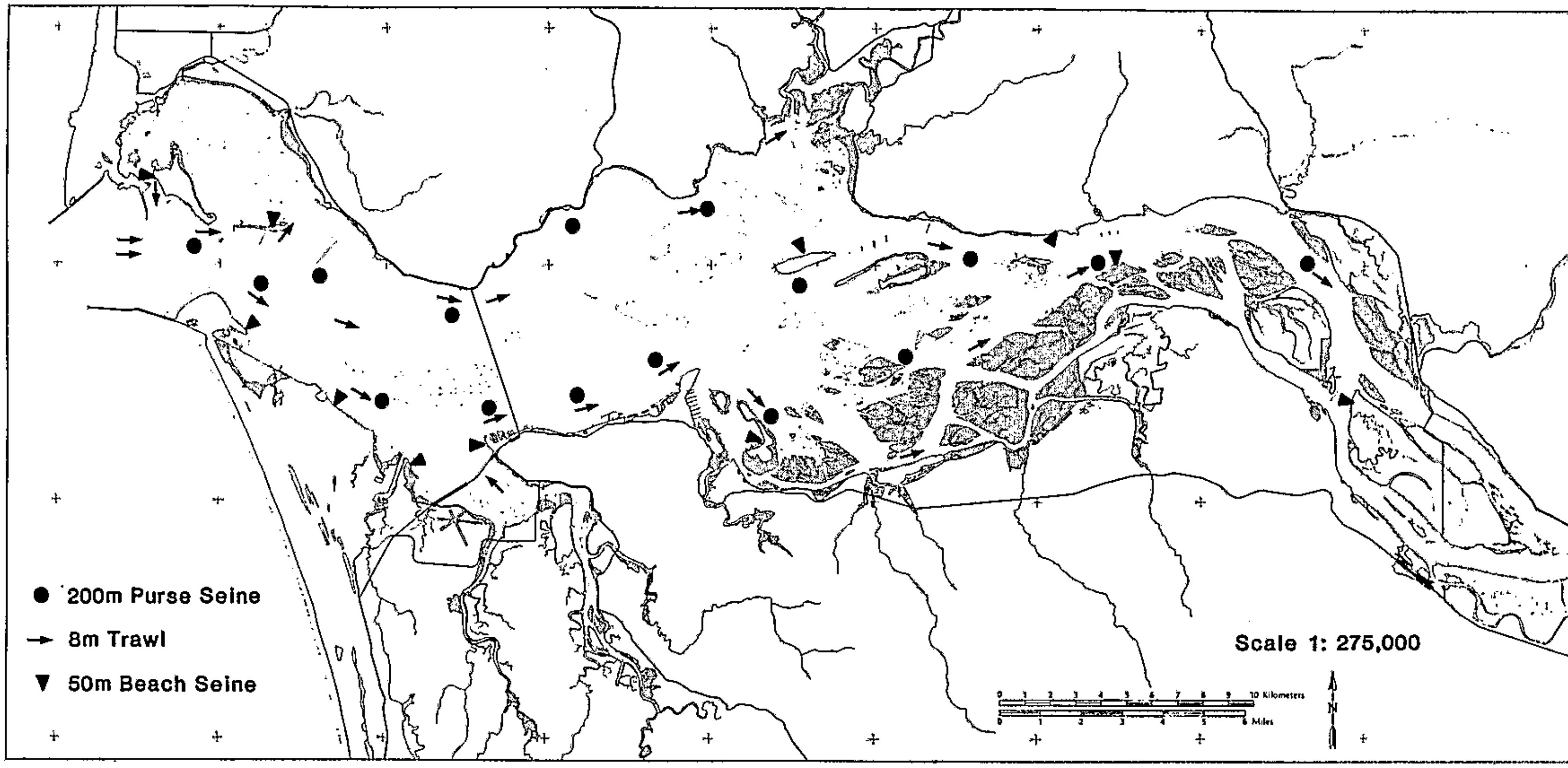
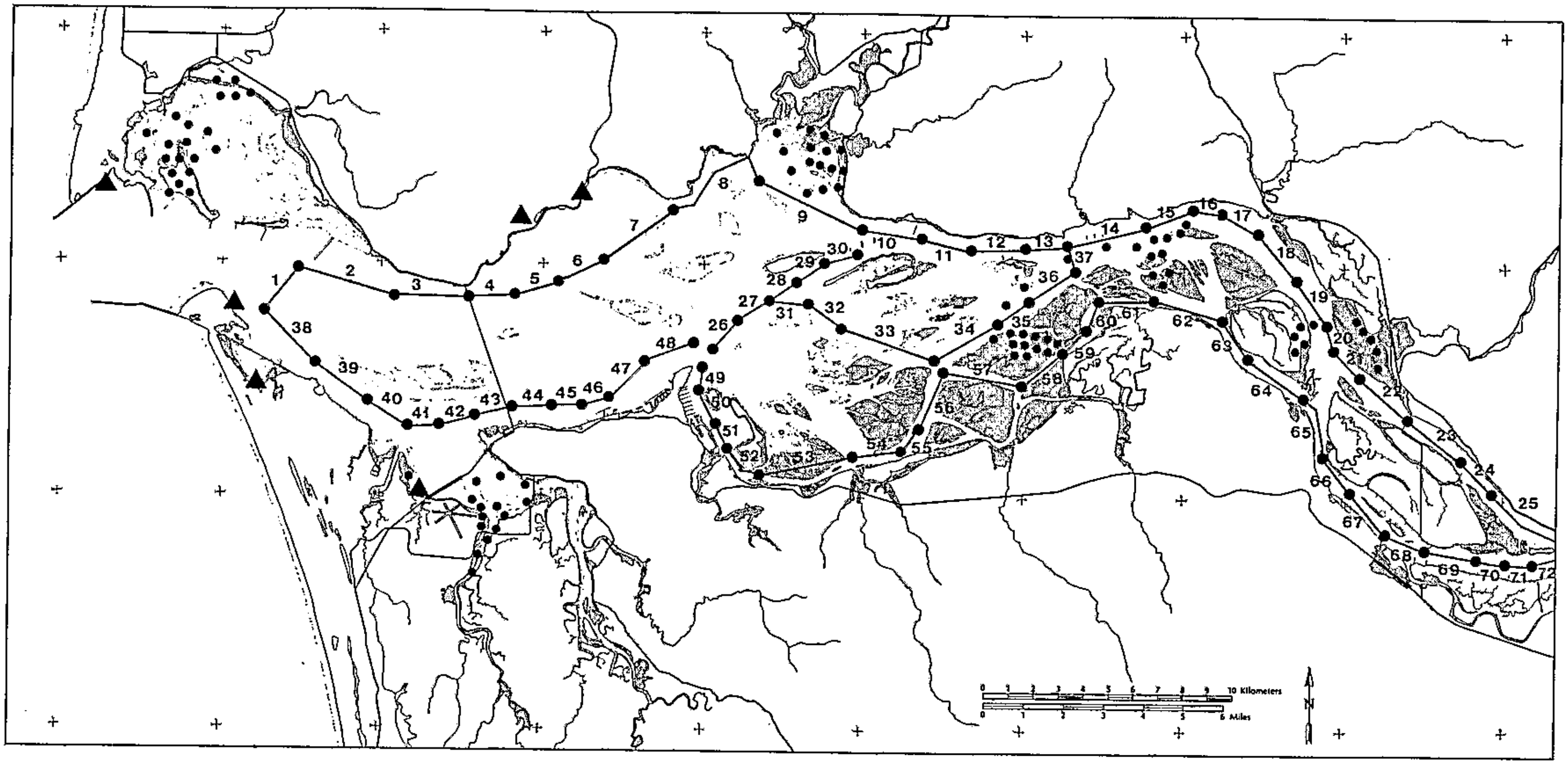


Figure 7. Sampling sites of the CREDDP fish investigation.



KEY:

- Variable Circular Plot
- ▲ Point Census
- •—1—• Boat Transect

Figure 8. Sampling sites of the CREDDP avifauna investigation.

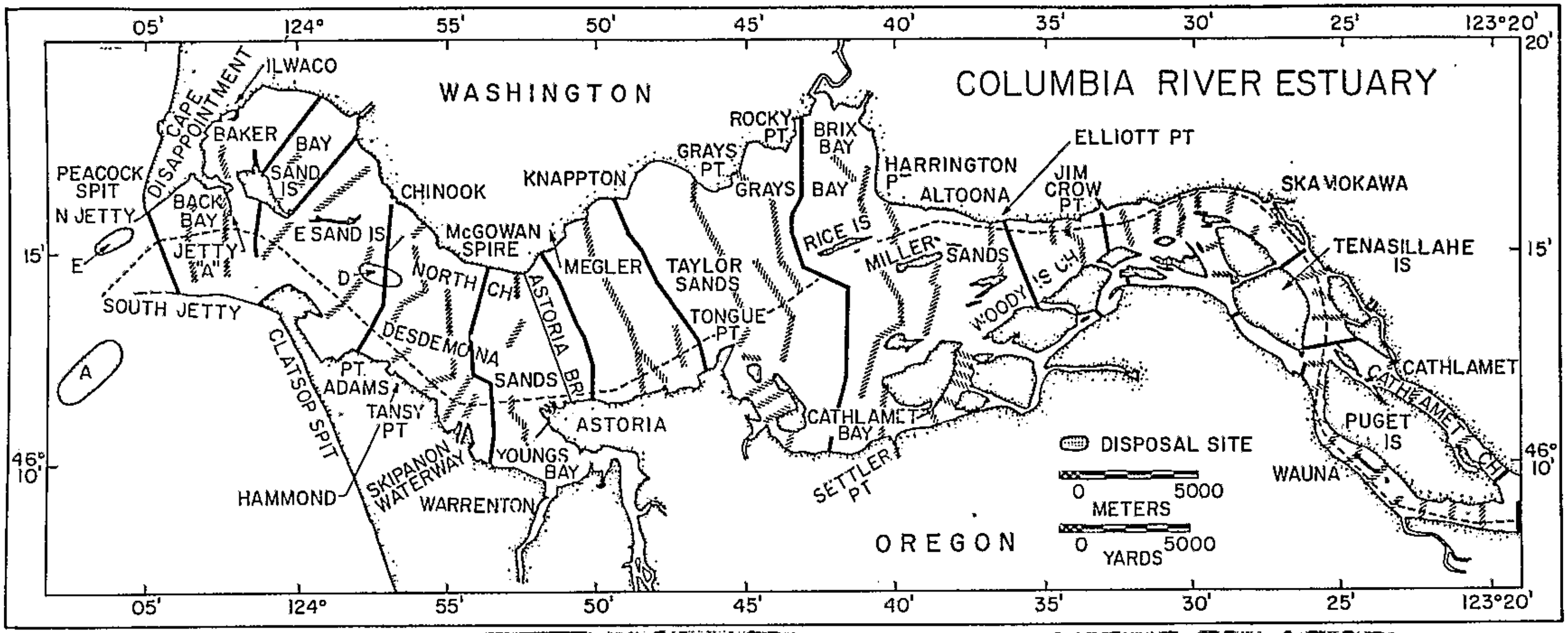


Figure 9. Sediment sample transects of CREDDP sedimentary processes and environments investigation. Dark lines were sampled in September 1979 and February, June, and October 1980. Hatched lines were sampled only in September 1979.

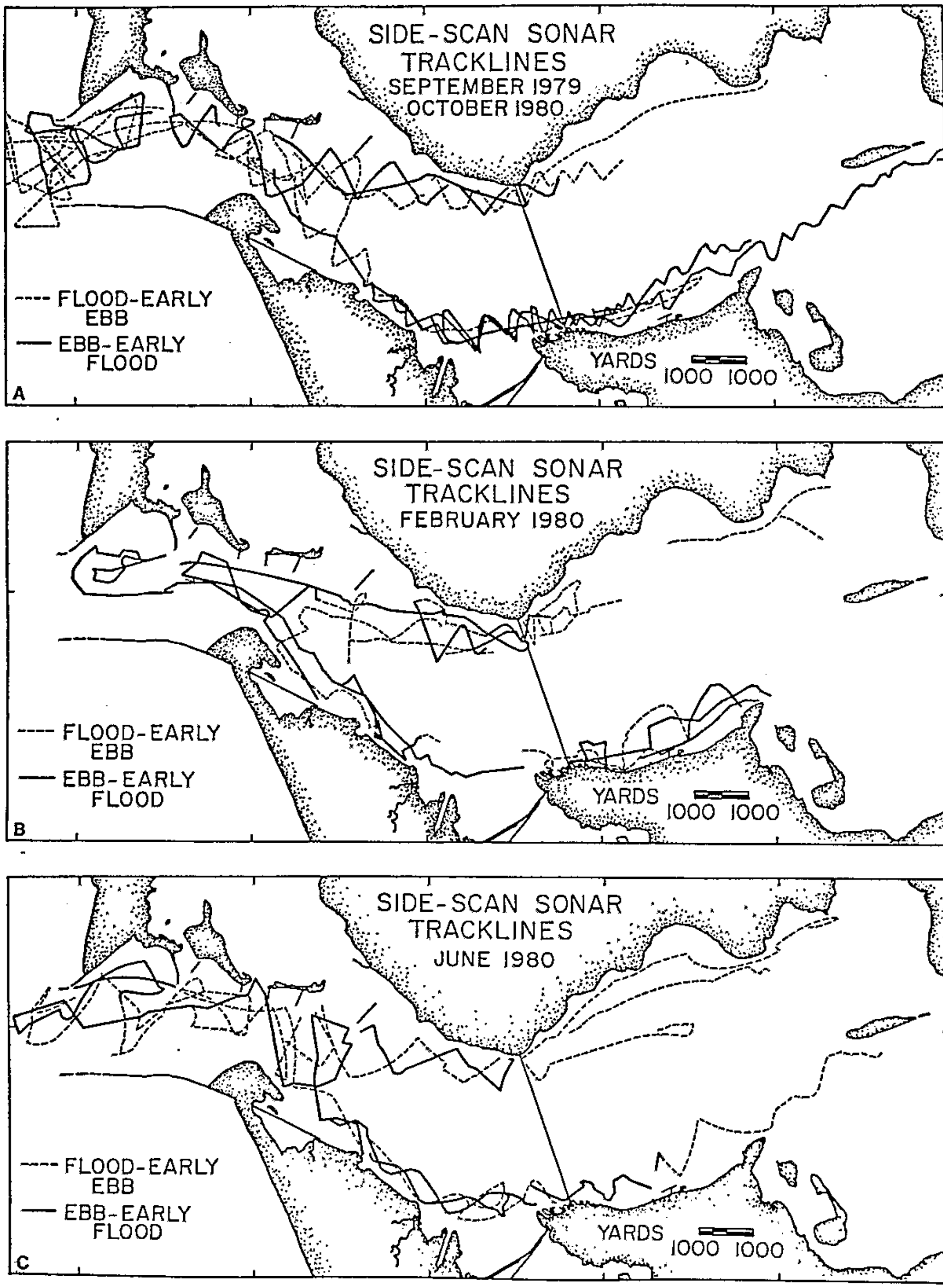


Figure 10. Side-scan sonar survey tracklines of the CREDDP sedimentary processes and environments investigation.

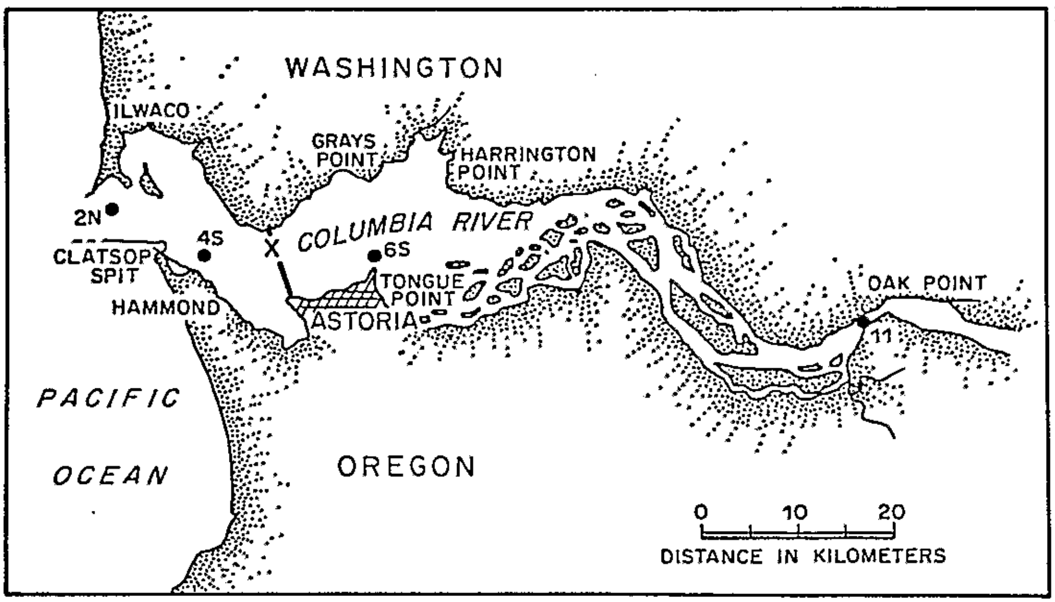


Figure 11. Profiling nephelometer (2N, 4S, 6S, 11) and bridge-mounted transmissometer (indicated by "X") sites of the CREDDP sedimentary processes and environments investigation.

(a)

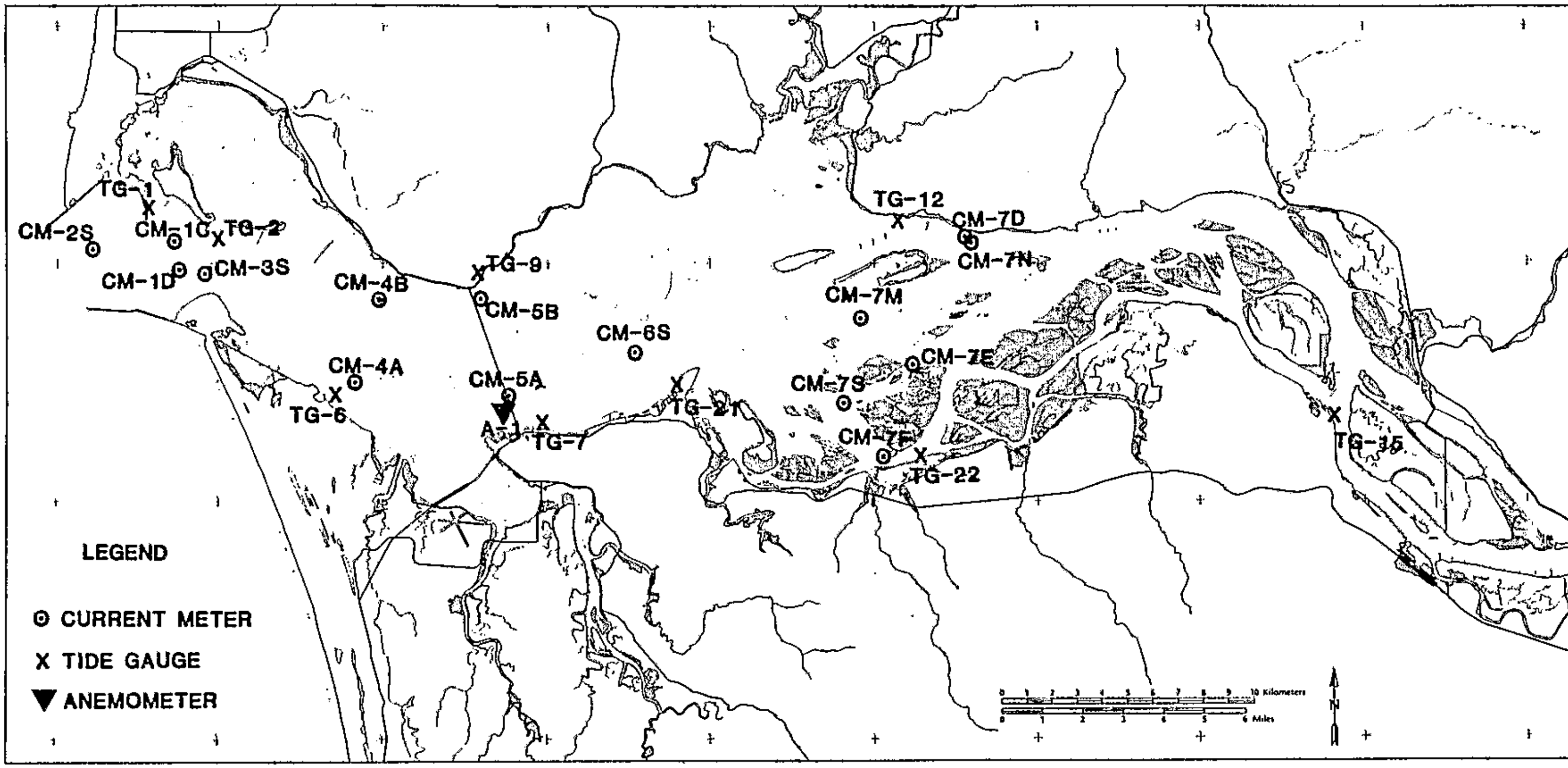


Figure 12. Current meter, tide guage, and anemometer sampling sites of the CREDDP circulatory processes investigation, (a) mouth to RM-47 and (b) above RM-47. Stations CM-5A, CM-5B, TG-1, TG-21, TG-19, and TG-20 were included in the continuous monitoring program. These and all other stations were used in one or both intensive cruises. Two additional tide gauge stations, TG-21 (National Ocean Service) and TG-1 (Geological Survey), are also shown.

(b)

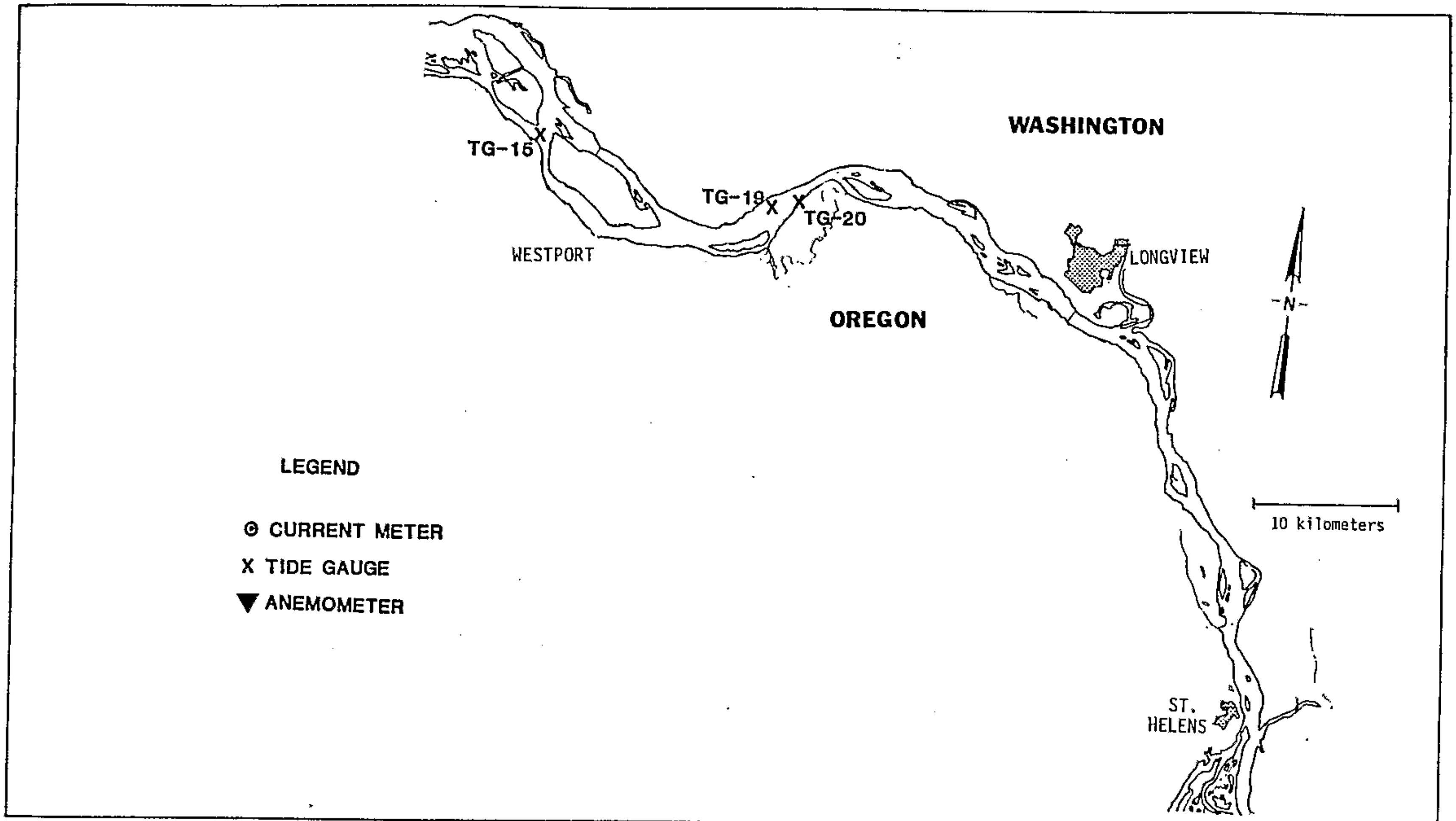


Figure 12. (continued).

(a)

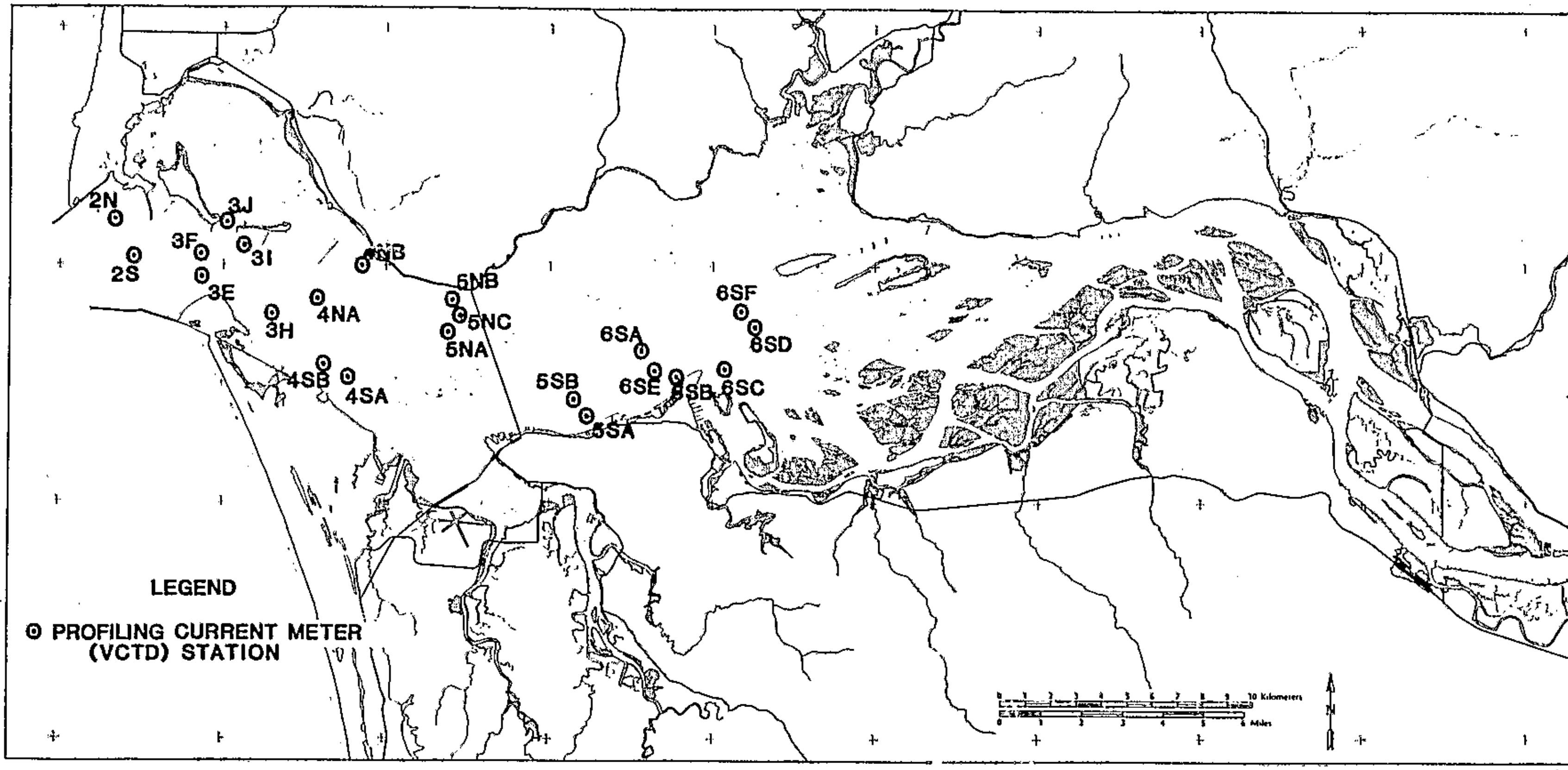


Figure 13. October 1980 VCTD profile sites of the CREDDP circulatory processes investigation, (a) mouth to RM-47 and (b) above RM-47.

(b)

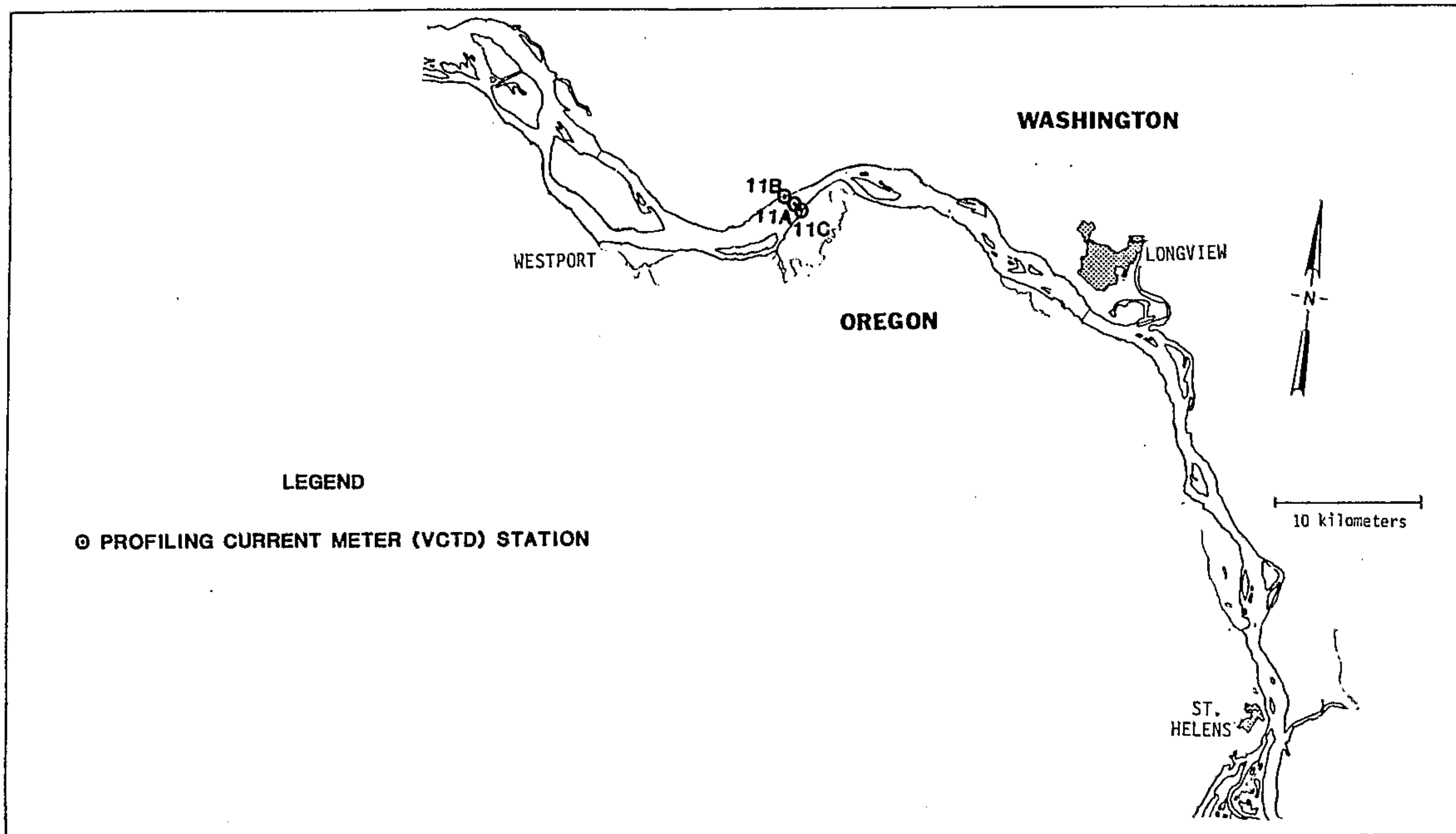


Figure 13. (continued).

(a)

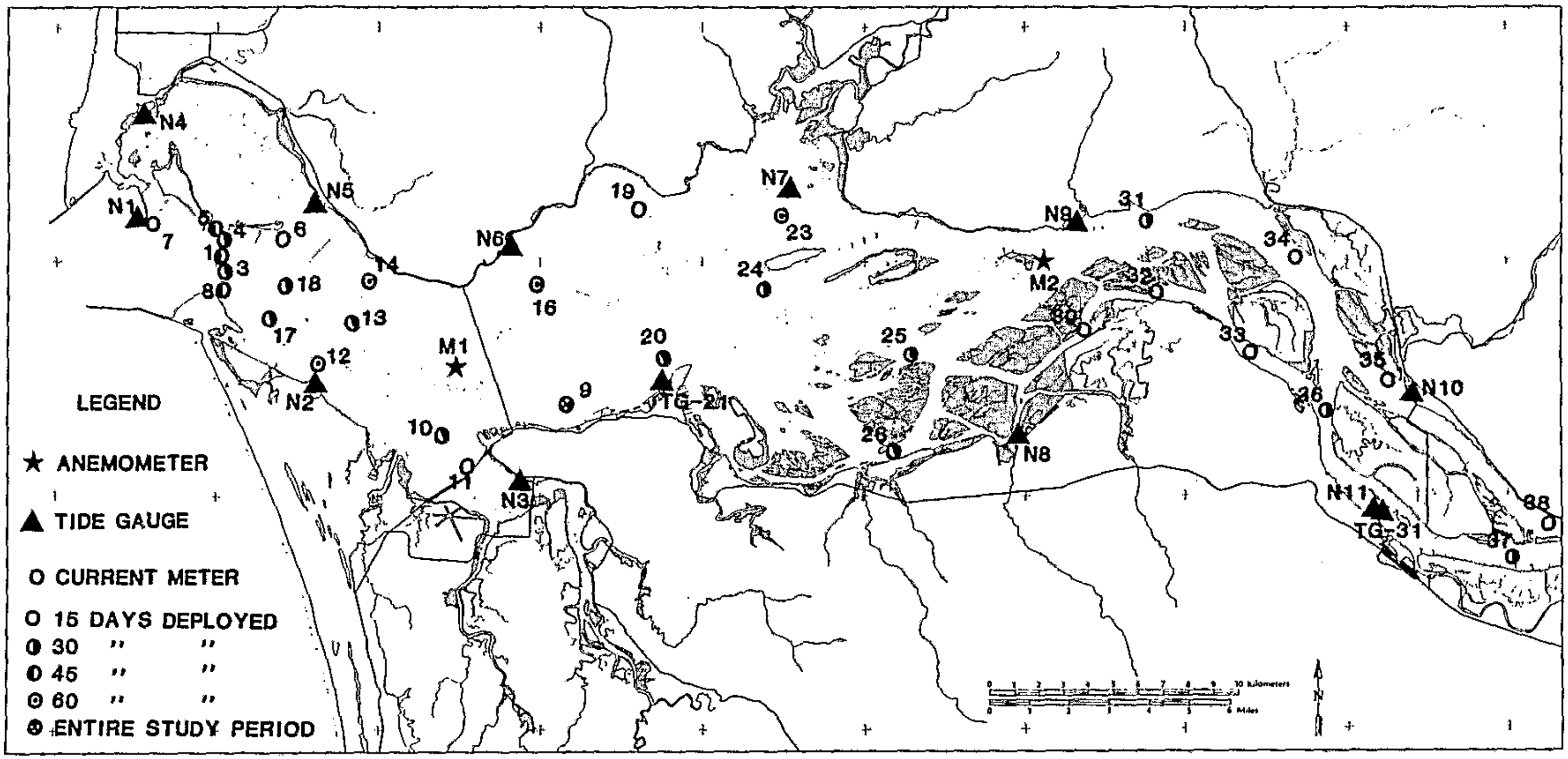


Figure 14. National Ocean Service 1981 current meter, tide and anemometer sites, (a) mouth to RM-47 and (b) upriver of RM-47. Two additional Geological Survey tide gauge stations are shown: TG-31 and TG-41.

(b)

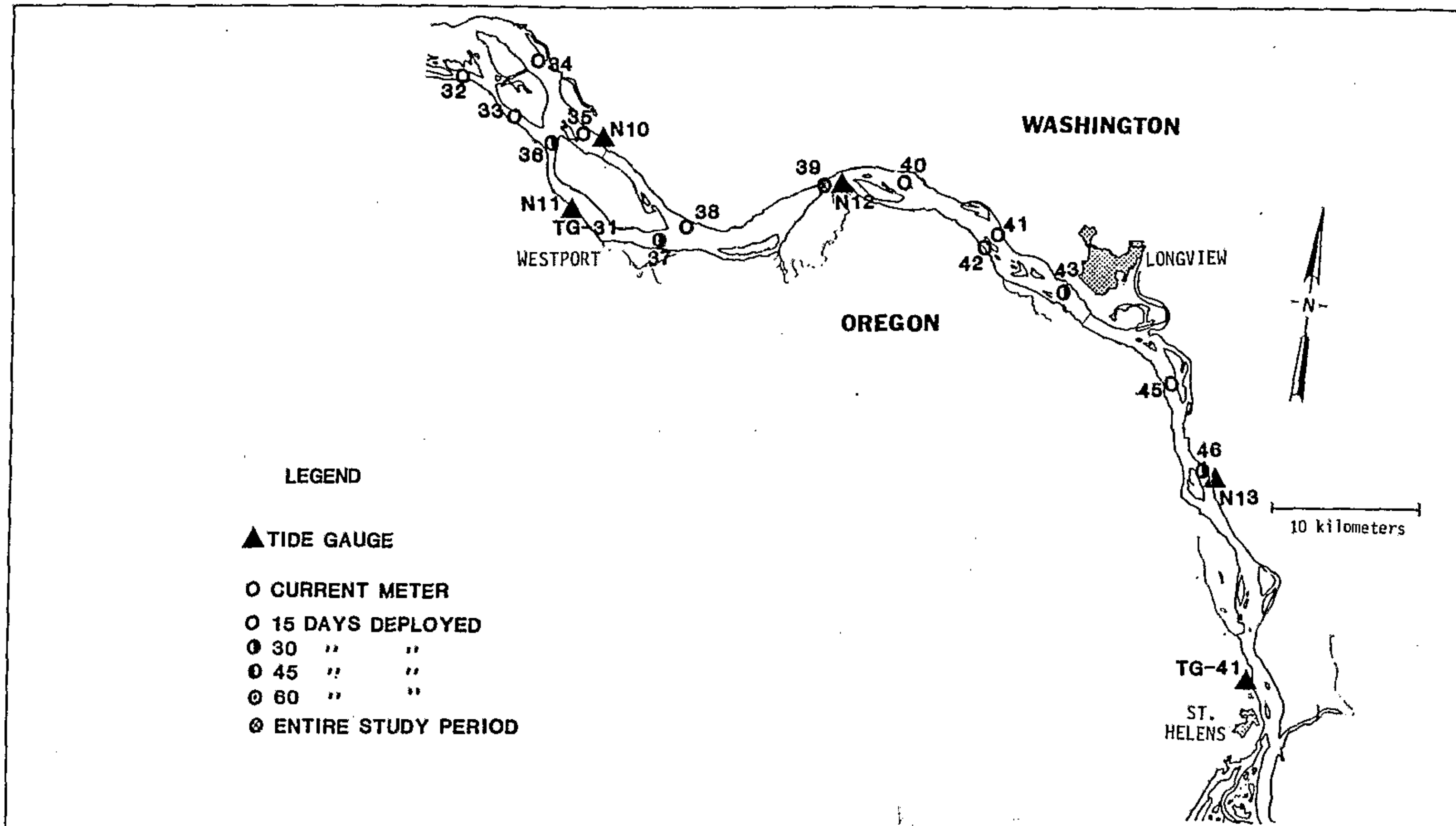


Figure 14. (continued).

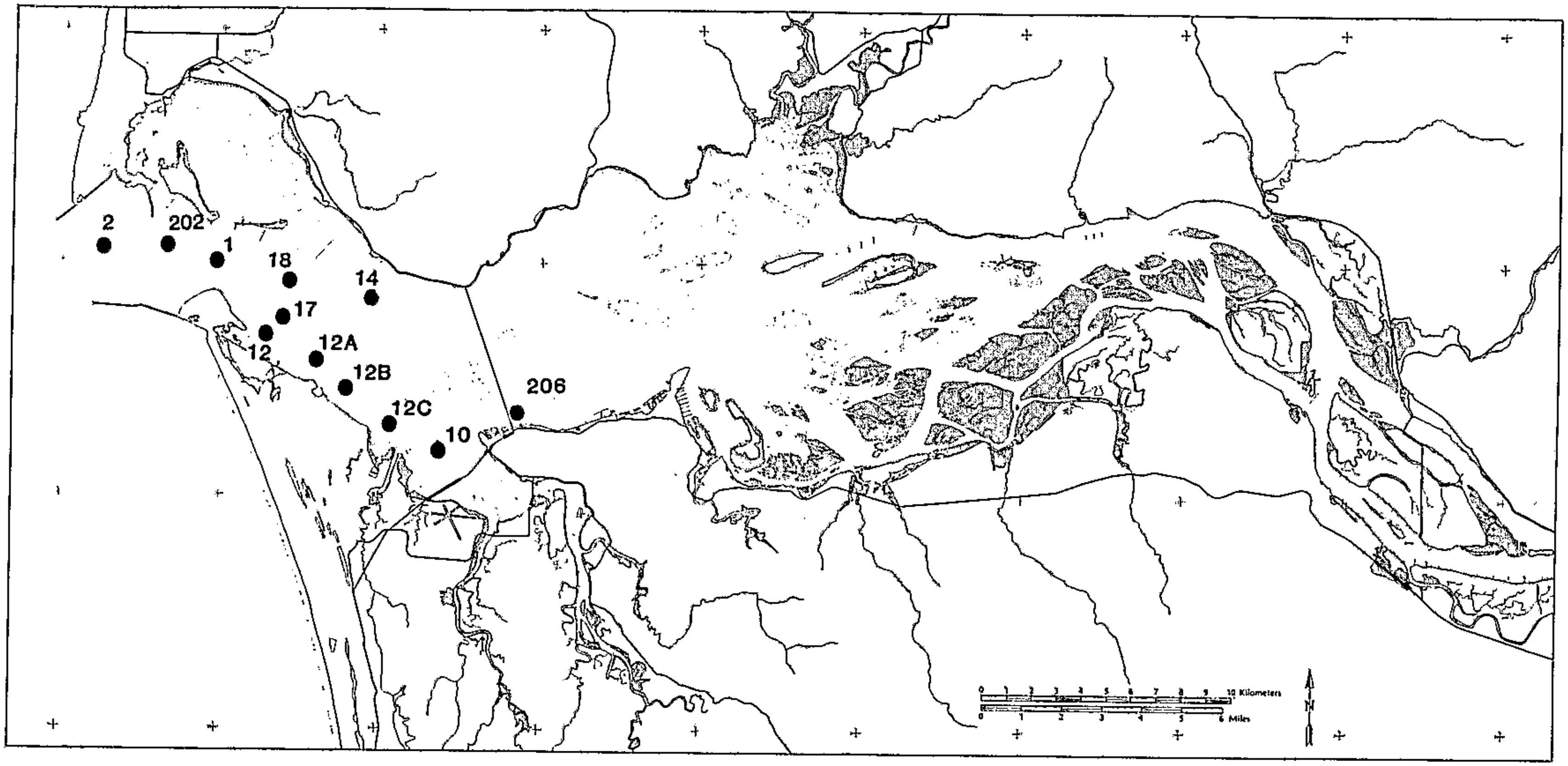


Figure 15. National Ocean Service 1981 Conductivity-Temperature-Depth (CTD) profile sites.