The Columbia River Estuary

Atlas of Physical and Biological Characteristics

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Columbia River Estuary Data Development Program

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Credits

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CONTENTS

Preface

The Columbia River Estuary Data Development Program

This atlas 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 in 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 for Environmental Assessments demonstrates how the results of the program 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.

This atlas is also oriented toward a general readership and is intended to provide a detailed but concise representation of the estuary. It is also intended to be used in conjunction with the *Guide,* which makes frequent reference to the atlas as well as to other CREDDP publications. 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 *Abstracts of Major CREDDP Publications.* This document 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. In addition to the abstracts, it includes an annotated bibliography of all annual and interim CREDDP reports, certain CREST documents and maps, and other related materials.

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.

Estuaries

An estuary is defined by scientists as "a semi-enclosed body of water that has a free connection with the open sea and within which sea water is measurably diluted with fresh water derived from land drainage."* It is the dilution of sea water by freshwater drainage that sets estuaries apart from coastal bays and inlets. Near the ocean the salinity (concentration of salt) of estuarine water is nearly as high as in the ocean itself. From the mouth salinity gradually decreases upriver toward the freshwater source (usually one principal river, but sometimes more than one) until eventually the water becomes completely fresh.

There is a tendency in estuaries for the denser and heavier sea water to move into the estuary below the river water. The more saline water tends to remain at the bottom of the estuary. Thus, salinity varies not only from one end of the estuary to the other but also from surface to bottom. There is a lengthwise gradient (gradual change) in salinity and a vertical salinity gradient.

The locations in the estuary of sea water, river water, and the brackish water resulting from their mixing are determined primarily by the interaction of riverflow and tides. Riverflow transports water through an estuary at a rate which may vary dramatically with the change of seasons, while the rise and fall of the tides move water both into (flood tide) and out of (ebb tide) the estuary. The interaction of riverflow and tides creates a constantly and often radically changing environment where physical properties (such as salinity, currents, and sediments) are in a constant state of flux.

Such dynamic conditions constitute a stressful and rigorous if not actually inhospitable environment for plant and animal life. Those plants and animals that are adapted to live in the ever-fluctuating estuarine environment therefore tend to be hardy, tolerating a relatively wide range of conditions.

Yet, paradoxically, estuaries are among the most biologically productive ecosystems in the world. To a great extent this is because estuaries tend to have large and concentrated supplies of the nutrients needed to support aquatic life. These important nutrients are derived from two major sources: river water, supplying nutrients leached from surrounding land areas, and ocean water. The nutrients transported into the estuary tend to be retained and concentrated within the estuarine system. The richness of the nutrient supply allows those plants and animals that are adapted to the estuarine environment to sustain high rates of productivity.

*From Cameron and Pritchard (1963)

Introduction

Purposes and Uses of This Atlas

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. The Preface on this page describes CREDDP and helps place this atlas in the context of the other publications and materials the program has produced. The purposes of CREDDP are to increase understanding of the ecology of the estuary and to provide information useful in making land and water use decisions. This atlas is intended to help serve the program's purposes in conjunction with the other CREDDP materials.

The atlas may be useful to three broad categories of people who would be interested in the results of CREDDP research. One group of potential users consists of those who are simply curious about the Columbia River Estuary and wish to learn more about it. For such readers the atlas is perhaps the most useful of all CREDDP publications. It collects the scientific information developed by CREDDP investigators and distills it into a single document, providing a concise, detailed portrait of the estuary without requiring any previous familiarity with the subjects involved.

A second group of people for whom CREDDP results are expected to be of interest consists of research scientists and academicians. For this group, the maps in the atlas may serve to provide a quick orientation to the Columbia River Estuary and may be particularly useful as indicators of the ways in which the Columbia differs from other estuaries.

The third and last group is people involved in policy formation or in a planning or decision-making process regarding a project in the estuary or an activity that could affect the estuary. This group includes elected and appointed public servants and their staffs, public or private developers with large-scale or small-scale proposals, and concerned citizens. These readers may or may not have extensive formal education in the research disciplines that were involved in CREDDP. To the extent that they do, the atlas may serve as an orientation in the same manner as for research scientists. To the extent that they do not, the atlas is the best tool for developing an understanding of helpful concepts and information concerning the ecosystem. Where specific projects or activities are involved, the atlas is designed to be used in conjunction with a related publication, *Guide to the Use of CREDDP Information for Environmental Assessments* (see Preface).

About the Maps

The physical and biological information mapped in this atlas was compiled by CREDDP researchers. These CREDDP investigators took measurements and collected samples in the estuary for 12 to 18 months between September 1979 and September 1981. For the atlas, the investigators interpreted their data to show the general extent and range of the physical and biological characteristics. The representations developed by the investigators are shown on a new base map developed for CREDDP. The sources and methods used to compile the base map are described in an appendix to this atlas.

In reading the maps in this atlas it is important to note that they are generalized interpretations of the results of specific data collection efforts that occurred at specific times. Identical collection efforts would not necessarily produce identical results. There are many limitations of the maps that are either inherent in the mapping process or specific to CREDDP's situation. Each of the following chapters includes a discussion of the limitations of the maps that accompany it. Some of the caveats that apply to all the maps are given in the following paragraphs.

First, the data that were interpreted to produce the maps were collected at specific sampling sites, and yet the maps for the most part display areas, rather than sites, as having certain characteristics. To generalize from the sampling site results, investigators had to decide which characteristics of the sampling site were primarily responsible for the results. Then the boundaries of the area sharing those characteristics had to be estimated. The area so determined may appear on the map as representing a certain range of results, surrounded by areas having different ranges of results. But this should not be interpreted as meaning that the mapped attribute was uniformly distributed throughout that area, or that the attribute changed abruptly from one range to another at the border between the two ranges.

A second caveat is that physical and biological characteristics vary through time and therefore it should be expected that all the characteristics mapped in this atlas are continuously changing to some degree. Much of the change is cyclical but conditions are never exactly the same even at identical points in a cycle. Among the cycles involved are flood-to-ebb tide (twice daily), day-to-night, the bi-monthly tidal range cycle caused by the relative positions of the moon and sun, riverflow and seasonal cycles, and the reproductive cycles of organisms.

Finally, it should be noted that the well-known explosive volcanic eruption of Mt. St. Helens, located about 90 kilometers east of the estuary's eastern limit, occurred in 1980 during the early months of CREDDP sampling. Mudflows from the eruption dumped massive amounts of sediment into the Cowlitz River, which empties into the Columbia about 40 kilometers upriver from the estuary. However, while the eruption was a very unusual event, CREDDP investigators felt confident that adequate allowances were made to account for its effects.

Chapter 1.

THE COLUMBIA RIVER ESTUARY

The Setting

The Columbia River Estuary is located on the Pacific Coast in the northwest portion of the United States and forms a part of the border between the states of Oregon and Washington (Plate 1, Map b). The Columbia River, the main source of fresh water to the estuary, is the second largest in the United States in terms of river discharge. It is 1,950 kilometers long and, along with its tributaries, drains an area of 667,000 square kilometers (Plate 1, Map a). This drainage basin includes portions of seven states and one Canadian province. The river drops from an elevation of about 800 meters at its origin in British Columbia to about 2.5 meters above mean sea level at the base of Bonneville Dam at River Mile 145 (RM-145).

The drainage basin of the Columbia River is divided by the Cascade Mountain Range into an eastern and a western region, each with different climatic and hydrologic characteristics. The eastern region has about 92 percent of the total drainage basin area but contributes only 76 percent of the total river discharge because of its drier, more continental climate. Most of the runoff from the eastern region occurs as a result of snowmelt from April to July. The eastern region accounts for virtually all of the Columbia's discharge during this period.

The western region has a wetter, oceanic climate with narrower seasonal and daily ranges of temperature. This region has only about 8 percent of the total area but contributes about 24 percent of the total river discharge, and for the period from December through March it contributes nearly half the river discharge. The major coastal tributaries to the Columbia River (the Willamette, Lewis, and Cowlitz Rivers) have discharges that are up to ten times greater from December to March than during other months.

The seasonal aspects of the climate east and west of the Cascade Mountains result in a variable discharge at the mouth of the river. From late fall to early spring, the monthly average river discharge fluctuates from about 100,000 cubic feet per second (cfs) to about 500,000 cfs and is primarily affected by runoff from the western region. As the snow melts in late spring, river discharge stabilizes at a high level, averaging about 450,000 cfs. From summer to early fall very little river discharge comes from the western region and the total river discharge drops to its lowest level, an average of 100,000 cfs.

This annual river discharge cycle strongly influences many characteristics of the estuary. To explain this, CREDDP investigators classified the annual river discharge into three seasons. The fluctuating riverflow season lasts from November through March, the high riverflow season is from April through June, and the low riverflow season is from July through October. Figure 1-1 compares the Columbia's average river discharge for two periods of time, past and present. The differences between these two periods are due to increased flow regulation by means of a series of upriver dams on the Columbia River and its tributaries.

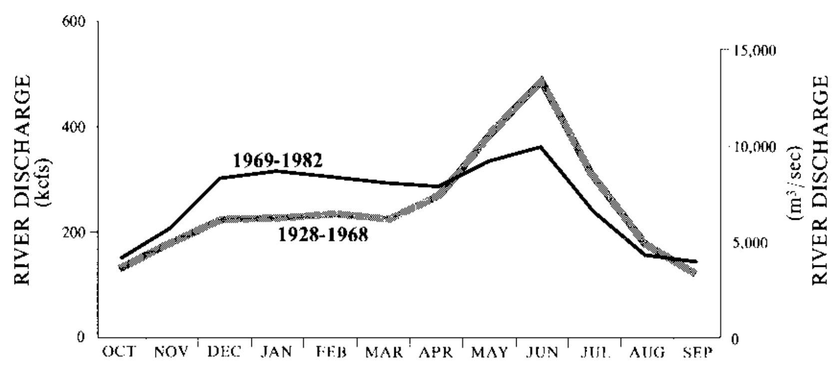


Figure 1-1. Monthly mean river discharge for the periods 1928 through 1968 and 1969 through 1982, Columbia River at Astoria, Oregon (from Jay 1984; Orem 1968; Oregon Dept. of Water Resources 1971).

The water flowing from the estuary into the ocean is called the Columbia River plume (Figure 1-2). The boundary of the plume is defined as the salinity contour representing 32.5 parts per thousand (ppt) at the surface of the ocean. The Columbia River pays a major part in the regional water properties of the northeastern Pacific Ocean, contributing some 60 percent (winter) to 90 percent (summer) of the total freshwater discharge into the ocean between San Francisco Bay and the Strait of Juan de Fuca. The predominantly freshwater plume mixes with ocean water, resulting in offshore salinities lower than commonly found in the ocean. This plume moves in response to prevailing coastal winds and currents: generally south and offshore during the summer, north and alongshore during the winter.

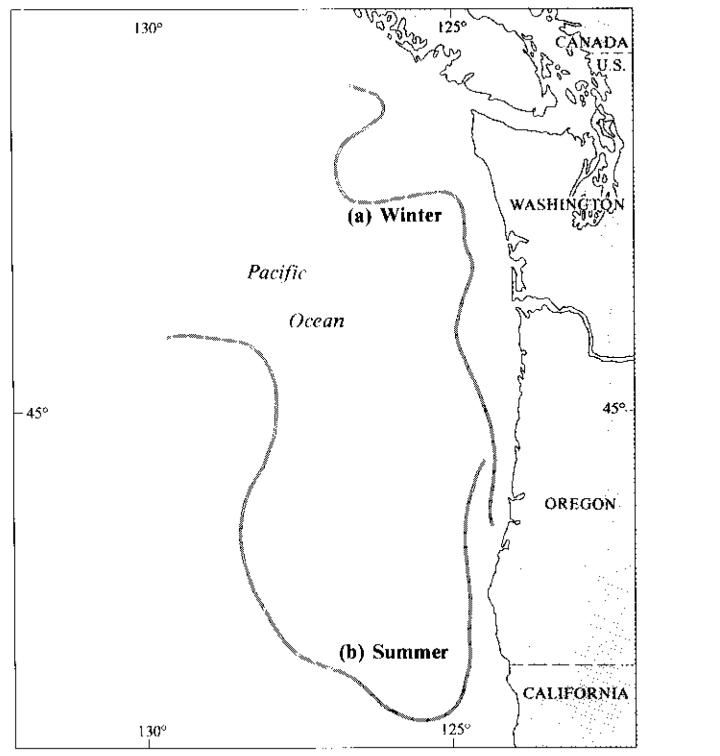


Figure 1-2. Approximate extent of the Columbia River plume during (a) winter and (b) summer (Barnes et al. 1972).

Because of the rotation of the earth, wind-driven ocean currents tend to turn to the right (in the northern hemisphere) of the wind. The northerly winds of summer therefore cause the coastal water to move offshore. This lowers the sea level alongshore slightly and allows deeper ocean water to slowly move toward the surface (Figure 1-3a). This upwelled water is typically colder, lower in oxygen, higher in nutrients, and slightly more saline than surface ocean water. Downwelling occurs in winter when southerly winter winds increase sea level slightly alongshore (Figure 1-3b). The average seasonal fluctuation in sea level resulting mainly from these factors amounts to about 20 centimeters and affects coastal tides, including those of the estuary. Storm surges during winter storms, however, can produce much greater sea level changes, occasionally raising the sea level as much as 100 centimeters.

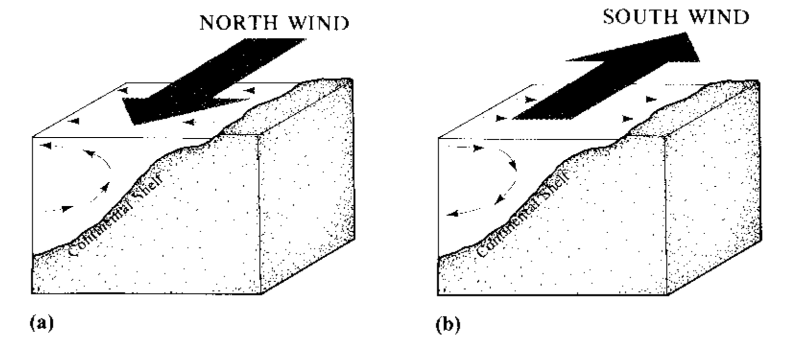


Figure 1-3. Schematic representation of water circulation patterns during periods of (a) upwelling and (b) downwelling. Large gray arrows represent wind direction and small black arrows represent water current direction.

Ocean tides at the entrance to the Columbia River Estuary are classified as mixed and semi-diurnal (twice-daily). This means that two high and two low tides occur each lunar day (24.8 hours) and the two high tides are of different heights and two low tides are also different. In the approximately six hours from the higher high tide to the lower low tide, the water level of the ocean at the entrance of the estuary drops an average of 2.4 meters. The average elevation of the lower of the two daily low tides is called mean lower low water (MLLW) and is assigned an elevation of zero by hydrologic and charting convention. The average elevation of the higher of the two daily high tides is called mean higher high water (MHHW).

The Estuary

The area of study for CREDDP was the portion of the Columbia River extending from the mouth at River Mile 0 (RM-0) to just upriver from the eastern tip of Puget Island at RM-46 (Plate 2). Along the shores and islands of the estuary, the study area extends into tidal marshes and swamps to the landward limit of aquatic vegetation. In the Columbia River Estuary, the elevation at which the transition from aquatic to non-aquatic vegetation occurs varies from about 2.4 to 3.7 meters above MLLW. Where there is no vegetation, the study area boundary was set at approximately MHHW, which is about 2.5 meters above MLLW at Tongue Point. Where tributaries enter the estuary, the study area was defined as extending upriver to the farthest extent of tidal influence (the head of tide). The shoreline was drawn according to these specifications on Plate 1, Map c and on the subsequent maps in this atlas. By this definition, the estuary has a surface area of about 41,200 hectares (101,750 acres). This includes 25,300 hectares (62,500 acres) of subtidal area (where the bottom is deeper than one meter below MLLW and is never exposed at low tide), 9,950 hectares (24,600 acres) of unvegetated tidal flats, and 5,950 hectares (14,650 acres) of tidal marsh and swamp (Plate 2). Those portions of islands that are above MHHW and have no aquatic vegetation are not included in these calculations and are not considered part of the surface area of the estuary according to these definitions.

Geologists believe that the Columbia River had established its present course by about two million years ago and possibly much earlier. The estuary occupies a valley cut by the river through sedimentary and volcanic bedrock, much of it during periods of glaciation. Since the last glacial retreat, this bedrock valley has been filling with fluvial and estuarine sediments to form the present estuary floor. During these glacial periods, sea level fluctuated often and was sometimes substantially lower (up to 100 meters) than it is today. Following the most recent glacial advance and starting about 9,000 years ago, sea level rose relatively rapidly, forming a drowned river valley estuary (Figure 1-4). Sea level stabilized about 5,000 years ago and has risen at an average rate of one or two millimeters per year since then. However, the sea level relative to adjacent land has not continued to rise along the coast of Oregon and Washington. The tectonic uplift of these coastal regions has resulted in a lowering of relative sea level. In the Columbia River Estuary the relative sea level has been falling since the turn of the last century at rates between two and five millimeters per year.

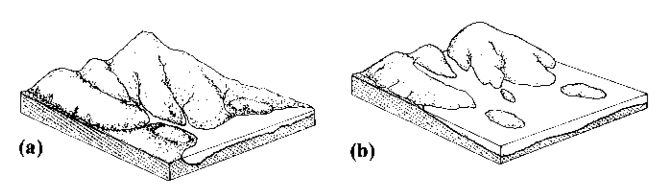


Figure 1-4. Schematic representation of a drowned river valley estuary (a) before and (b) after a rise in sea level due to glacial melt.

The climate of the Columbia River Estuary is dominated in winter by a persistent onshore flow of oceanic air masses. A series of low pressure systems from the Gulf of Alaska brings an abundance of relatively warm and moist air to the region throughout the winter months. The summer months have comparatively little precipitation and moderate temperatures characterize the estuary region all year (Table 1-1). At the latitude of the Columbia River Estuary (about 46 degrees north), daylight ranges from 8.5 hours at the winter solstice (December 22) to 15.5 hours at the summer solstice (June 21).

Month	Precipitation* cm(inches)	Temperature* C°(F°)	Number of Days*		Mean Daily Solar Radiation**
			Cloudy	Heavy Fog	BTU/ft²
Jan	24.70(9.73)	4.8(40.6)	25	4	314.7
Feb	19.85(7.82)	6.4(43.6)	22	3	545.3
Mar	16.80(6.62)	6.9(44.4)	23	2	865.9
Apr	11.70(4.61)	8.8(47.8)	22	2	1253.2
May	6.90(2.72)	11.3(52.3)	20	2	1608.3
Jun	6.22(2.45)	13.6(56.5)	20	2	1625.7
Jul	2.44(0.96)	15.6(60.0)	15	2	1746.4
Aug	3.71(1.46)	15.7(60.3)	15	5	1498.8
Sep	7.18(2.83)	14.7(58.4)	14	6	1183.1
Oct	17.26(6.80)	11.6(52.8)	19	7	713.1
Nov	24.82(9.78)	8.1(46.5)	22	4	387.3
Dec	26.82(10.57)	6.0(42.8)	25	4	260.6
Annual	**168.38(66.34)** (Total)	**10.3(50.5)** (Average)	**242** (Total)	**43**	**1000.2** (Average)

*Based on data from 1940-1970
**Based on data from 1941-1970

Table 1-1. Selected climatic data for Astoria, Oregon (U.S. Dept. of Commerce 1975).

The bathymetric map of the estuary (Plate 2) shows the main features of the present estuary floor. The Columbia River Estuary is characterized by a complex series of channels, tidal flats, and submerged sandbars and is surrounded by shallow peripheral bays. The channels seldom exceed 18 meters in depth and the tidal flats are exposed at low tide. The most prominent features of the bathymetry are the division of the main estuarine channel into the main navigation and north channels just upriver from the entrance, the tidal sandflats between RM-10 and RM-25, and the numerous channels and tidal-marsh islands in Cathlamet Bay. These complex features are major factors affecting the estuary's water circulation patterns.

One important aspect of the estuary that the bathymetric map does not show is the ever-changing nature of the bottom. Throughout the estuary's geologic history, the processes of sediment deposition and erosion have acted to continually alter bottom features. The *Bathymetric Atlas of the Columbia River Estuary* (see Preface) depicts the recent history of these changes, which have occurred as a result of both natural processes and human activities (see "Human Activities and Their Effects" below). In the recent past, there has been more deposition than erosion of estuarine sediments. While this is a normal pattern for estuaries, the current high rate of net sediment accretion is striking.

Oceanic processes and the regional climate influence the physical attributes of the estuary. Strong ocean tides and a powerful riverflow meet in the shallow, narrow basin of the Columbia River Estuary to produce turbulent and very rapid currents. This highly energetic water circulation strongly affects other important physical characteristics of the estuary such as salinity and sediment distribution. Saline ocean water moves into the estuary primarily as a result of tidal action and the upriver extent of its movement is restricted by the strong riverflow. The estuary can become completely freshwater during high riverflow seasons when strong ebb tides flush all of the saline water from the estuary.

Most of the sediments in the estuary are composed of sand rather than silt. Sandy sediments are indicative of strong, turbulent currents which tend to flush the silty sediments away. Silty bottom sediments are largely restricted to the protected embayments of the estuary. The sediments of the estuary are constantly shifting in response to the strong water flows. Sediment transport in the Columbia River Estuary involves the movement of sand waves along the bottom, a process known as bedload transport, and the movement of finer sediment (very fine sand, silt, and clay) in suspension (suspended transport). Although large quantities of sediment are transported through the estuary in suspension, the bedload transport is more important to the long term erosion and deposition of sediments in the estuary.

Generally, the physical characteristics of the Columbia River Estuary differ from those of most other estuaries. River discharge is much greater, salinities are much lower, and the sediment is less stable. Because of the large volume of riverflow into the Columbia River Estuary, its flushing time (the amount of time water takes to move through the estuary) is only about one to five days. This contrasts with many other estuaries, in which water may take weeks or months to reach the ocean. For example, the average flushing time of Chesapeake Bay is about one year.

The physical characteristics of an estuary determine the composition of its biological communities. The most biologically important physical factor of an estuary is salinity. Plants and animals are highly sensitive to the salinity of water because this has a large influence on many biochemical processes. Single-celled plants and animals shrivel and die if exposed to salinity that is too high, and more complex organisms cannot tolerate prolonged exposure to inappropriate salinity. Species are adapted to certain salinity ranges, and these salinity ranges determine where they are able to live. Species that live in the Columbia River Estuary are adapted to its particular salinity characteristics. The biological communities of the Columbia River Estuary differ from those found in many other estuaries, in part because they are composed of species able to tolerate its unusually low and variable salinities.

As is the case with all biological systems, the plants and animals of the Columbia River Estuary are members of a food web. Animals feed on plants, and are in turn fed upon by other animals. Any particular feeding sequence of plant and animal species is a food chain. The food chains are interlinked with each other and all of them together make up the estuarine food web. The components of the estuarine food web can be described in general terms as a series of feeding levels. The first level consists of plants, which convert inorganic chemicals and the sun's energy into living material. Because all living material originates with plants, they are called primary producers, and the process of plant growth is called primary production. This living material is passed on to higher levels, first through consumption of plants by herbivores (organisms that consume plants), then through consumption of these herbivores by carnivores (organisms that consume flesh), and finally through successive consumption of these carnivores by higher and higher predators. Detritivores are animals that eat particles of decaying plant or animal matter (detritus). The consumers in the Columbia River Estuary seem to be supported mostly by detritus and secondarily by living plants. For this reason, the food web of the Columbia River Estuary is said to be detritus-based.

The primary producers studied by CREDDP investigators include phytoplankton, benthic primary producers, and marsh plants. The community of phytoplankton (single-celled drifting plants) in the Columbia River Estuary is generally dominated by freshwater forms. This is probably related to the fact that the Columbia River Estuary's flushing time is so short that, unlike many other estuaries, it does not support an estuarine community of phytoplankton. Instead, freshwater phytoplankton are rapidly brought downriver, die as they reach the brackishwater area, and either settle to the bottom, are flushed out of the estuary, or are eaten. The benthic (bottom-dwelling) primary producers in the Columbia River Estuary consist almost entirely of a group known as diatoms (single-celled plants), which live among the surface sediments of the tidal flats. Large, productive beds of submerged flowering plants (for example, eelgrass) and large algae are not common in Columbia River Estuary benthic habitats, although they are in many other estuaries. It is difficult to say why this is the case. It may be related to the fact that Columbia River Estuary salinity levels are lower and sediments are less stable than in estuaries favored by these plants. The tidal marsh and swamp communities of the Columbia River Estuary show dramatic differences from many well-studied estuaries. First of all, there are no saltmarshes in the estuary; instead, all of the tidal marshes are either brackishwater or freshwater. This is due to the relatively low salinity of the Columbia River Estuary. In addition, some of the tidal swamps in the estuary are spruce swamps, a type that has become particularly rare along the coast of Oregon and Washington. Tidal swamps in the Columbia as well as other estuaries have been greatly reduced by diking, but there are still about 430 hectares of tidal spruce swamp in the Columbia River Estuary.

The higher feeding levels, or consumers, studied by CREDDP investigators include invertebrates (animals lacking backbones). The invertebrates are classified as zooplankton, benthic infauna, and epibenthic organisms. The zooplankton (the community of very small animals suspended and passively floating in the water) of the Columbia River Estuary, as in many estuaries, includes marine, freshwater, and estuarine (brackishwater) groups. The estuarine group has a complex relationship with the circulation patterns of the estuary, allowing it to be maintained in the estuary and not flushed out. The benthic infauna (the community of animals living within the bottom sediments) is dominated by organisms adapted to live in fresh water or low-salinity brackish water. The estuary's epibenthic organisms (animals living on the sediment surface and/or in the overlying water layer) are mostly mobile organisms such as crabs and small shrimp. Large beds of clams and oysters are common in many more saline estuarines but do not exist in the Columbia.

Most of the invertebrates in the Columbia River Estuary are detritivores. Very few vertebrates can consume detritus even though it is far more abundant in the estuary than living plants. Instead, many vertebrates consume invertebrate detritivores, which are therefore key links in the detritus-based food web of the Columbia River Estuary.

The vertebrate consumers studied by CREDDP investigators include fish, birds, and mammals (including terrestrial, aquatic, and marine mammals). Whereas there are many differences between the invertebrates of the Columbia and those of other estuaries, its fish, birds, and mammals seem to show close similarities to those of other estuaries. This is probably related to the fact that these more complex organisms are not as immediately affected by the physical factors as the invertebrates. As with most estuaries, the Columbia River Estuary is an important nursery area for several fish species. This is due mainly to its food supply and protective habitat. Like other estuaries, the Columbia River Estuary is a feeding ground for many birds and provides a resting point for migratory species. Terrestrial and aquatic mammals find favorable feeding and denning sites in the marshes, swamps, and associated tidal channels of the estuary. Marine mammals feed in the Columbia River Estuary as in other estuaries but do not seem to breed here. Instead, adjacent estuaries or coastal regions are used for pupping.

Human Activities and Their Effects

Human beings have inhabited the Columbia River Estuary region for thousands of years, but their impacts were negligible until relatively large numbers of settlers began arriving in the 1870's. Almost all the population growth around the estuary occurred between 1870 and 1920; little population growth has occurred since then. Of the four million people living in the drainage basin of the Columbia River, only about 25,000 live around the estuary, of whom approximately 90 percent live on the southern (Oregon) side.

The topography of the region, shown on Plate 2, is rugged, particularly on the northern (Washington) side. The land around the estuary is dominated by forests of fir, spruce, and hemlock (Plate 1, Map c). Plate 1, Map c also shows areas devoted to agriculture, mostly pasturage for dairy and beef cattle. Small rural communities are interspersed among the forested hills, particularly in the valleys of the estuary's tributaries. Astoria, a commercial and governmental center with about 10,000 people, and Warrenton (population 2,500) are the only towns with more than a thousand people.

Fishing and logging have been consistently important to the area's economy from the 1840's to the present. Harvesting and processing of both fish and lumber boomed between 1870 and 1900. Fishing and fish processing were concentrated almost exclusively on salmon until after World War II. In recent years tuna, crab, shrimp, and bottomfish have been periodically important. The forest products industry accounts for the three heavy-industrial plants in the area: a pulp and paper mill at Wauna, a plywood mill in Astoria, and a lumber mill in Warrenton, all in Oregon.

Human activities have had a substantial impact on the estuary in spite of the relatively sparse population of the area around it. Four kinds of activity in particular have had clear, if not always measurable, effects: dike construction; various activities to deepen and maintain navigation channels; dam construction upriver from the estuary; and fishing.

Dikes have been constructed in tidal marsh and swamp areas of the estuary for more than a century, primarily to provide pasturage. The early settlers, confronted by a shortage of level uplands for pasturage, grazed their cattle in the tidal marshes during mid and low tides, removing the cattle when the tide came in. Soon they began piling mud up in long narrow bands around areas of high marsh so that the cattle could graze during high tide as well. These early dikes were followed in the twentieth century by more extensive dikes which converted large areas of tidal marsh, and expecially tidal swamp, to pasture. Diked lands were drained, cleared of trees and shrubs, and planted with grass. Where a dike crossed a tidal channel, farmers installed a tidegate that would permit the channels behind the dike to drain at low tide but would prevent water from entering at high tide. By the late 1930's there were over 160 kilometers of dikes in the estuary region. Few new dikes have been added since then, but existing dikes have been improved to withstand extreme tides. They are made primarily of local estuarine and floodplain soils, and are commonly three or four meters high and several meters wide.

Figure 1-5 compares the boundaries of the estuary (as defined above) in about 1870 with its present extent. Most (85 percent) of the loss is due to diking. The other factors are fills (12 percent) and accretion of sand at the mouth of the estuary (3 percent). Most of the lost area was tidal swamp and marsh. The present area of swampland is less than one quarter of what it was in 1870, and that of marshland is a little more than half what it was then. The total surface area of the estuary, including open water, has been reduced by about 24 percent since 1870.

Major changes in the configuration of the subtidal areas, tidal flats, and mouth of the estuary and in the estuary's circulation patterns have occurred as a result of activities to deepen and maintain the main navigation channel. These activities are of two kinds: the construction of permanent channel training structures (such as jetties and pile dikes) designed to channelize currents, and dredging and dredged material disposal. CREDDP investigators concluded that the first kind of activity has had greater impact than the second.

Three jetties have been constructed at the mouth of the estuary to confine and stabilize the entrance channel. Each of the jetties consists of large stones deposited in a long arm reaching out from the shore. Before jetty construction the channel across the sandbar at the mouth of the estuary was unstable, and its depth rarely exceeded eight meters. Construction of the South Jetty (Plate 2) began in 1885. The first segment was completed in 1895, with a second segment completed in 1914. The North Jetty (Plate 2) was built from 1913 to 1917. A third jetty, Jetty A, extending south from Cape Disappointment, was added in the 1930's. Each jetty contributed to the stabilization of the entrance channel and promoted a self-scouring effect so that tidal currents deepened the channel and reduced the need for dredging.

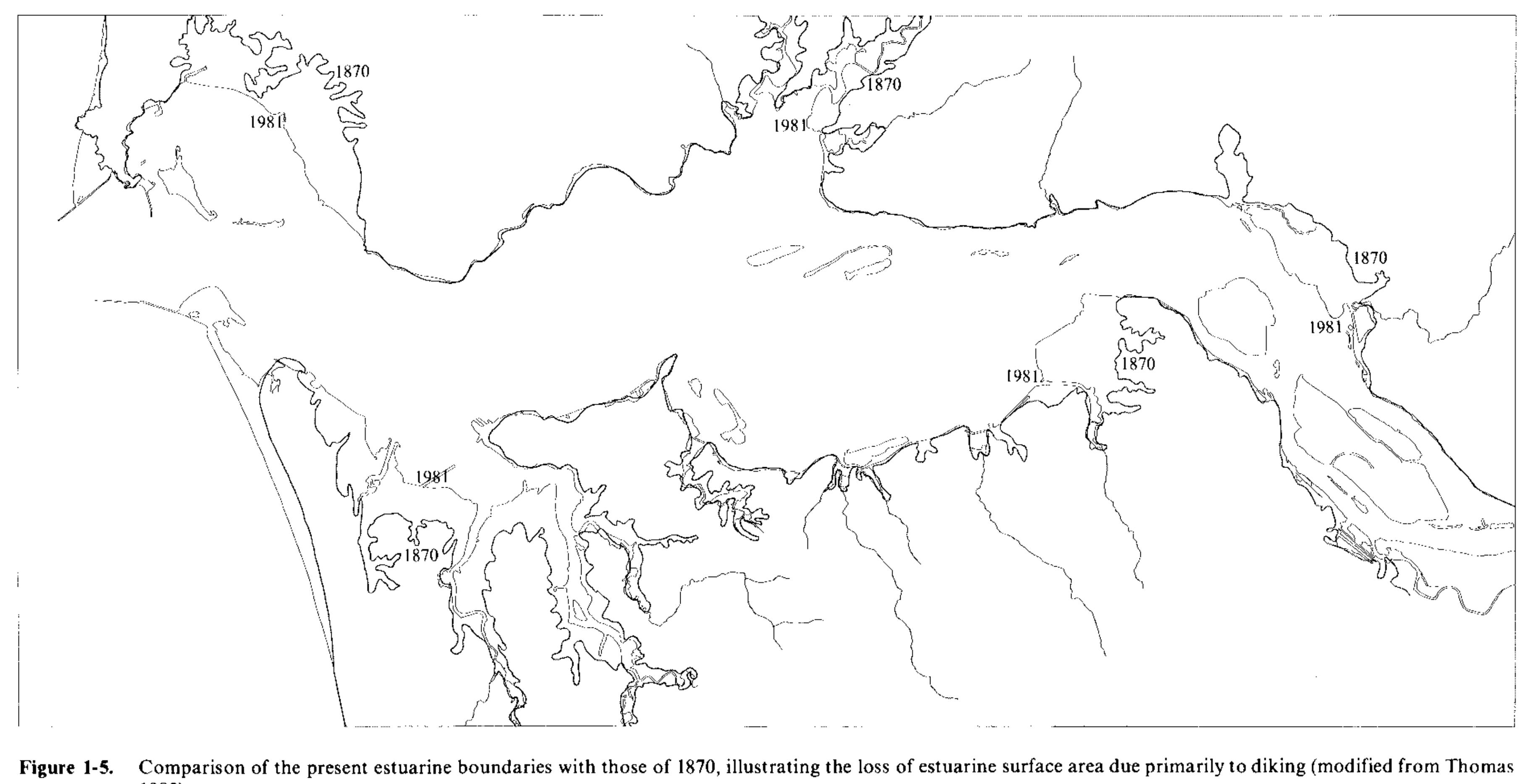


Figure 1-5. Comparison of the present estuarine boundaries with those of 1870, illustrating the loss of estuarine surface area due primarily to diking (modified from Thomas 1983).

Pile dikes are used in the estuary to confine and stabilize the navigation channel. Pile dikes are built of a double vertical row of timber piles bolted together by a horizontal spreader beam to give them stability. The piles are driven into the river bottom. They are usually perpendicular to the shoreline and reach toward the channel. They narrow the channel width, causing currents to run faster and scour the channel bottom until a depth is reached that compensates for the lost breadth. The first pile dikes were constructed in the 1890's. Most were built between 1914 and 1935, by which time a 35-foot-deep channel from the estuary mouth to Portland was completed.

The jetties and pile dikes have been effective in replacing the naturally shifting complex of river channels with a single stable channel. As a result, dredging on a major scale has not been necessary. Dredging efforts have been concentrated on obtaining new project depths, channel realignments, and maintenance dredging on a limited number of sandbars. The disposal of dredged material has caused greater changes in the estuary's surface area than dredging itself. As noted above, 12 percent of the loss in the estuary's area can be attributed to fills, many of which were for the sole purpose of disposing of dredged sediments. Rice, Lois, and Mott Islands and Miller Sands (Plate 2) are among the largest of many dredge-spoil islands in the estuary.

The extensive changes in the bathymetry and circulation of the estuary that have occurred over the past century have resulted from natural processes, human activity, and the response of physical estuarine processes to human activity. It is not possible to discriminate precisely among the effects of these three factors, but the response of physical estuarine processes to human activity has clearly been substantial. CREDDP investigators estimate that, excluding the entrance region (to about RM-6), the estuary accumulated 315 million cubic meters of sediment between 1868 and 1958 (an average of 3.5 million cubic meters per year), while the entrance region lost 247 million cubic meters. Most of the sediment lost from the entrance region is believed to have moved farther into the estuary (accounting for half the increase upriver from RM-6), ending up mostly in Baker Bay, Trestle Bay, and Desdemona Sands. The rest of the sediment lost from the entrance region was deposited at Clatsop and Peacock Spits, or moved to areas along the coast, particularly the Washington coast and Willapa Bay (Plate 1, Map b). These massive movements of sediment were in response to the jetties. The other half of the sediment increase upriver from RM-6 resulted from sediments introduced by the river. Newly constructed pile dikes upriver from the estuary may have induced movement of coarse bottom sediments downriver, producing temporary sources of sediment to the estuary that would account for much of the riverine contribution.

At the rate of 3.5 million cubic meters per year of sediment accumulation, the estuary would be completely filled with sediments in only 800 years, a small fraction of the estimated age of the Columbia River Estuary. It is therefore clear that the recent rate of net sediment deposition is abnormally high. The immediate result of the factors that have accelerated deposition is that the estuary has fewer and deeper channels than in 1868 and broader, shallower expanses of sandbars and tidal flats.

These changes have affected circulation and salinity patterns in the estuary. Dikes, fills, and accumulated sediments leave less space for water; CREDDP investigators estimate that the average volume of water entering the estuary on flood tide has been reduced 10 to 15 percent. Because more tidal flow was conveyed in channels of smaller cross-section, the velocities of tidal currents were probably greater in 1868 than today. And because tidal currents are primarily responsible for the transport of saline water into the Columbia River Estuary, saline water probably intruded farther up the estuary in 1868 than it does today.

The construction of many dams upriver from the estuary has also affected its circulation and salinity patterns. The first dam on the Columbia was completed in 1933, inaugurating an era of riverflow control, power production, and diversion of water for irrigation. Today the riverflow is less variable than it was before dam construction, extreme highs and lows are less extreme (Figure 1-1), and the average flow is lower. As a result of dam construction upriver and bathymetric changes in the estuary, the average flushing time is now longer, although still very short relative to most estuaries. The increase in flushing time is due to the reduced volume of water exchanged over the tidal cycle and the reduced average riverflow. This, plus the concentration of currents into a few deep channels and the accompanying reduction of currents elsewhere, has resulted in a faster accumulation of fine, muddy sediments in the bays and backwaters of the estuary as these environments have become relatively more tranquil.

Human influences on the biological characteristics of the estuary are more difficult to determine than these physical changes. One change in animal life has been dramatic: the vast decline in the numbers of salmonid fish, including salmon and steelhead trout, that pass through the estuary.

Salmonids have a complex life cycle. They are anadromous, meaning that they spend most of their lives in the ocean but spawn in fresh water. Individuals of most species return to spawn in the same creeks and streams where they were hatched, which requires a journey of nearly 2,000 kilometers for some. Salmonid spawning grounds were formerly spread throughout the Columbia River drainage basin.

The Columbia was among the most productive river systems in the world for salmonid fish. Astoria and other communities around the estuary were salmon boom towns between 1870 and 1920. For the river system as a whole, the total annual catch of salmon and steelhead trout frequently exceeded 40 million pounds. With each decade after 1920, however, the average catch dropped significantly. By the 1960's the average was down to about seven million pounds per year.

There were several causes of the decline, but two principal causes stand out. One was overfishing, suggested as a problem as early as the 1880's. Both Oregon and Washington had established fish commissions by 1890, primarily to regulate the salmon fishery. The second factor involved in the decline was the construction of dams. The first of these was Rock Island, completed in 1933 near the confluence of the Wenatchee and Columbia Rivers in Central Washington. Bonneville Dam was constructed in 1938 and Grand Coulee in 1941. Today there are over 50 major dams on the Columbia and its tributaries. Many were built with little or no consideration of the conditions required by salmonids to reach their upriver spawning grounds. Rock Island Dam cut off the entire watershed above it when it was constructed. Addition or improvement of facilities to assist the passage of fish across the dams has proven to be difficult, but efforts are continuing.

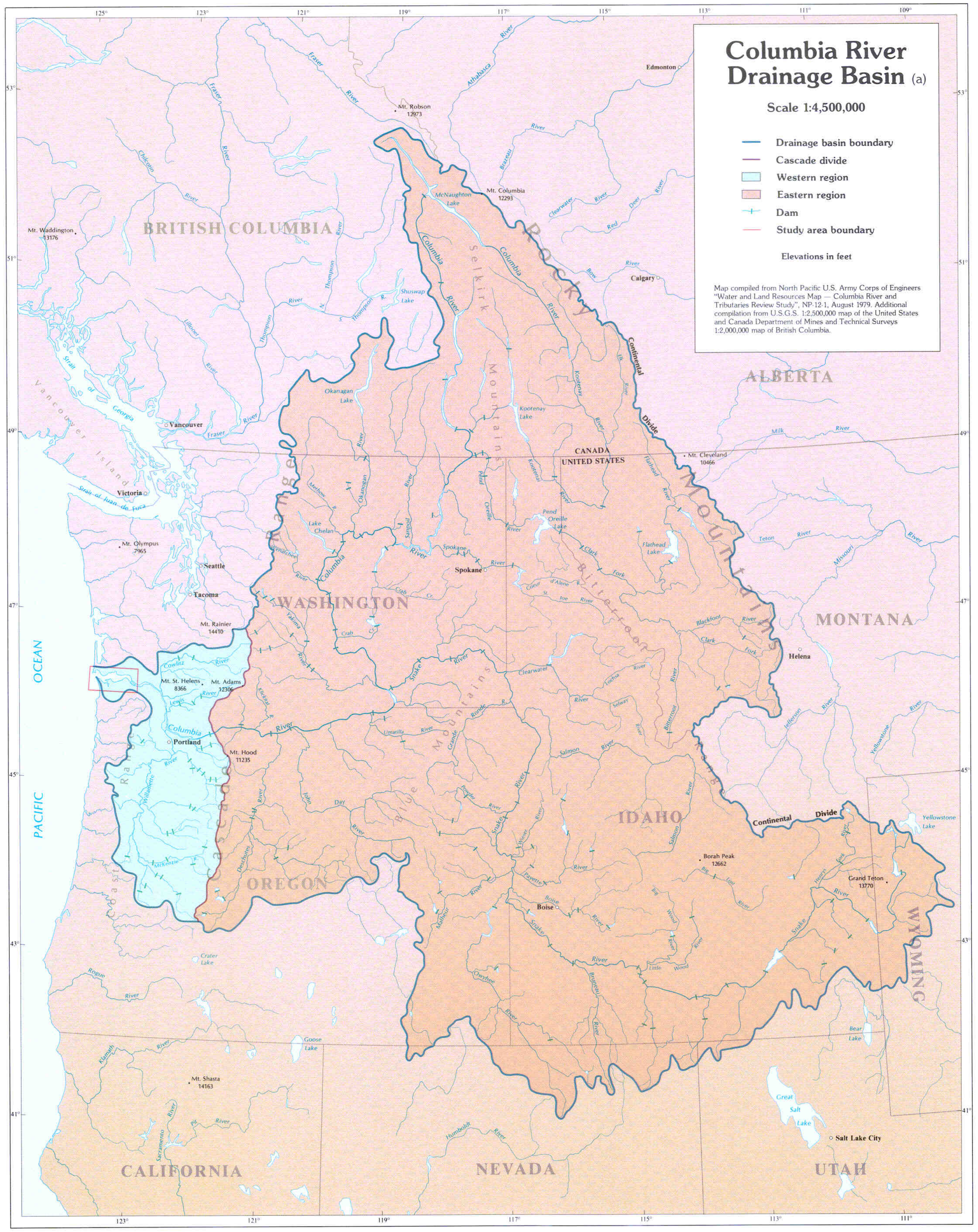
Commercial salmon fishing in the Columbia River Estuary continues today on a much-reduced scale. As the salmon catch has continued to decline in the 1980's, sturgeon has become the most valuable of commercially-caught species in the estuary in terms of total catch. Dungeness crab are caught commercially in the downriver portion of the estuary, but the majority of landings are from the ocean. Crayfish, eulachon, and American shad are also harvested commercially in the estuary.

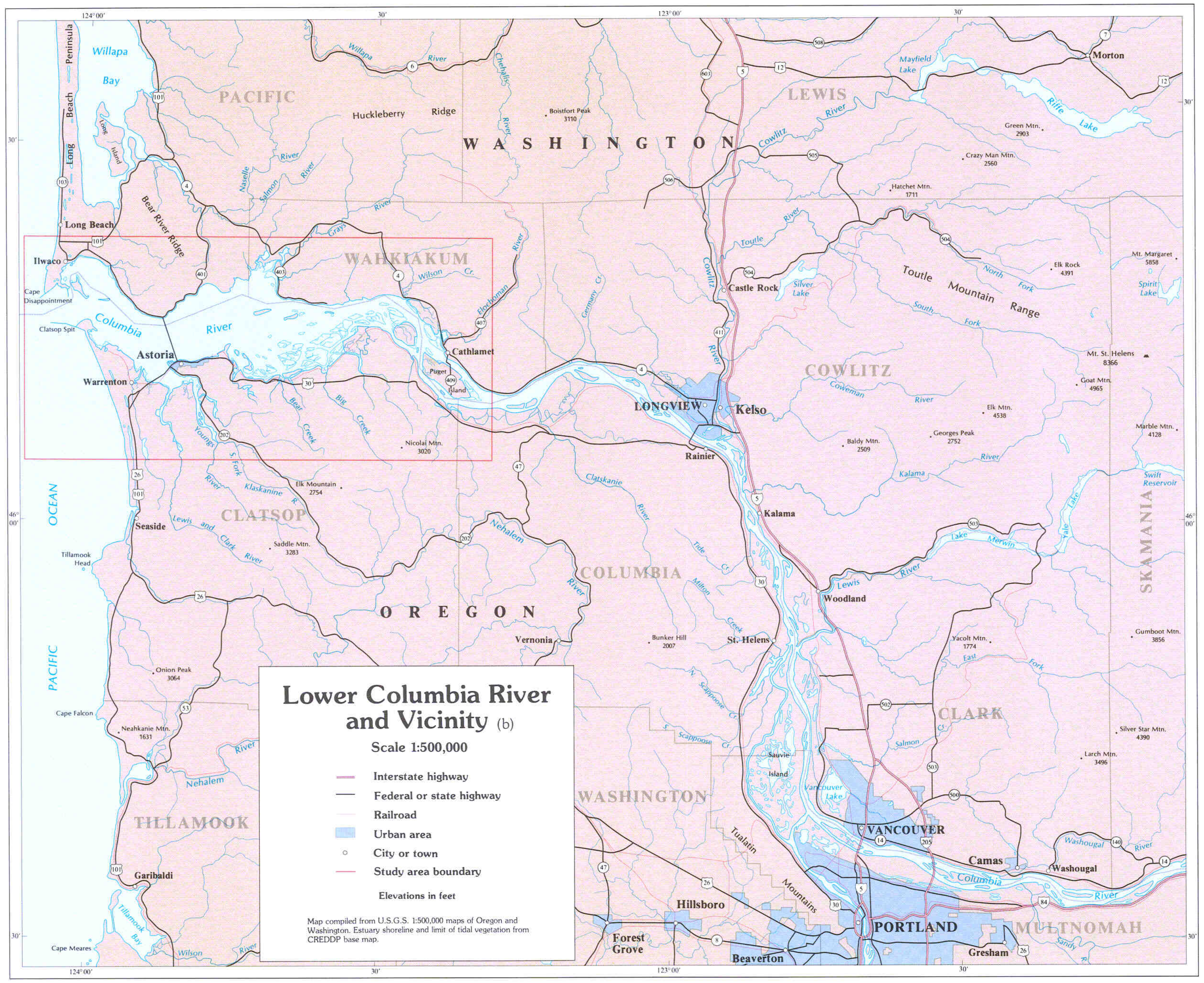
The estuary supports a recreational fishery for primarily the same species as are caught commercially. In addition, perch, flounder, tomcod, rockfish, lingcod, and sea-run cutthroat trout are caught recreationally. The estuary provides moorage at more than ten public and private mooring basins for over 2,000 oceangoing small boats, most of which are used for commercial and recreational fishing in the ocean.

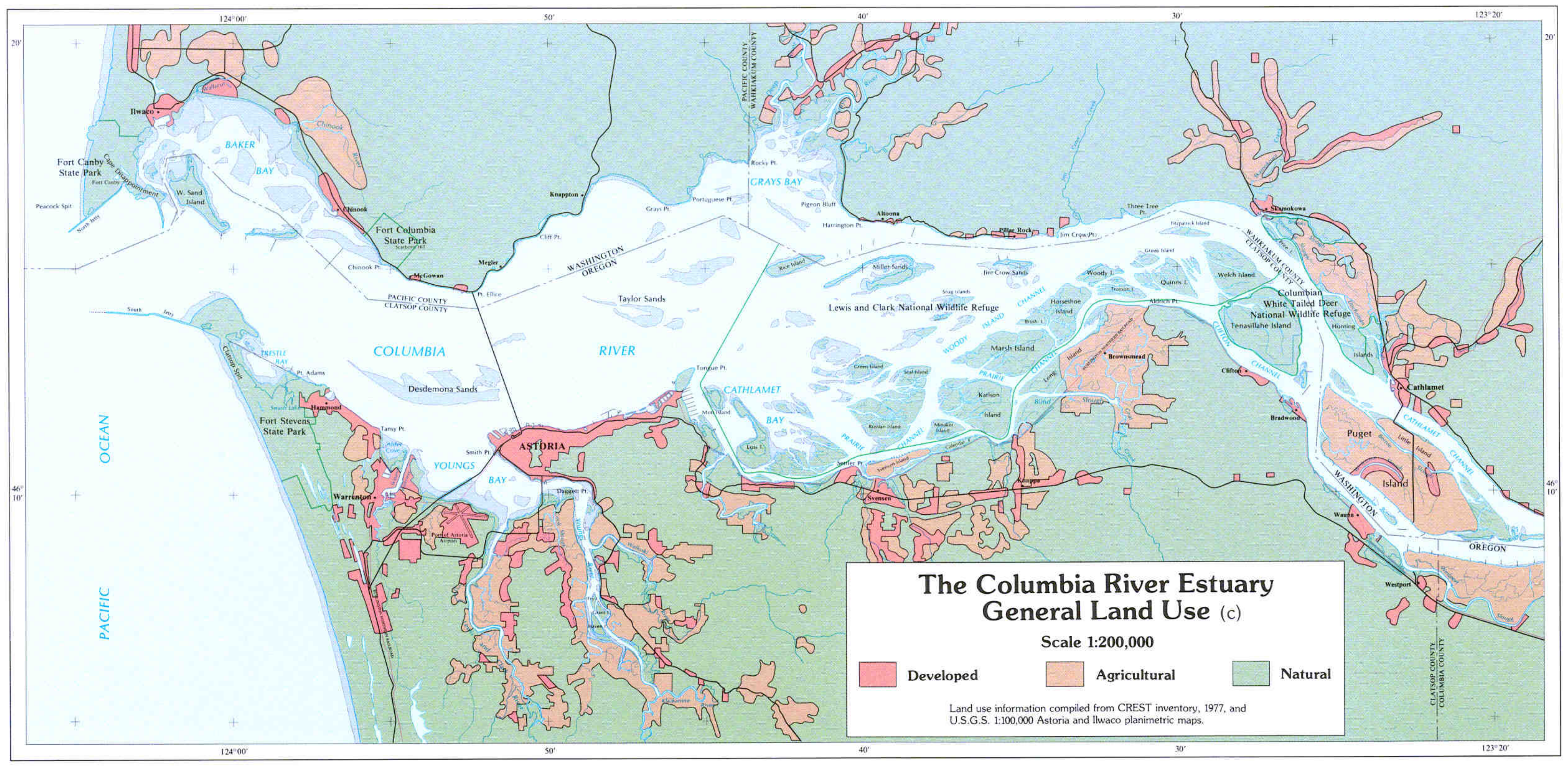
In addition to fishing, the other primary human use of the estuary is shipping. In 1983 about 2,000 oceangoing cargo ships entered the estuary, the great majority bound for the upriver ports of Portland, Oregon, and Longview, Washington. About 30 million tons of commodities are shipped annually on the lower Columbia River. The major imports are petroleum products, aluminum and iron ores, chemicals, and finished goods, and the major exports are wheat, logs, and woodchips. The only destination point with adequate moorage for oceangoing cargo ships in the estuary itself is the Port of Astoria, with piers at the west end of Astoria that can accommodate nine vessels. Seventy-nine ships called at the Port of Astoria in 1983. Log exports account for virtually all the activity.

Many of the sloughs in the easern portions of the estuary and the lower reaches of most of the tributary rivers serve as log storage sites. Logs are rafted and secured to pilings. Most of the logs exported through the Port of Astoria are stored at such sites and then towed to the Port docks for loading on oceangoing vessels. Log sorting yards and wood processing plants also use in-water storage sites.

Two large tracts in the estuary are protected as wildlife refuges. The Lewis and Clark National Wildlife Refuge and the Columbian White-tailed Deer National Wildlife Refuge (Plate 1, Map c) were both established in 1972. The former covers about 140 square kilometers, almost all of it estuarine, and the latter covers about 20 square kilometers, of which about one third is part of the estuary. The two refuges include a substantial portion of the remaining tidal swamps and marshes in the estuary, which are very important for much of its wildlife (see Chapter 6). The refuges are managed by the Fish and Wildlife Service of the United States Department of the Interior.


Columbia River
Drainage Basin (a)
Scale 1:4,500,000
Drainage basin boundary
Cascade divide
Western region
Eastern region
Dam
Study area boundary
Elevations in feet
Map compiled from North Pacific U.S. Army Corps of Engineers "Water and Land Resources Map — Columbia River and Tributaries Review Study", NP-12-1, August 1979. Additional compilation from U.S.G.S. 1:2,500,000 map of the United States and Canada Department of Mines and Technical Surveys 1:2,000,000 map of British Columbia.
BRITISH COLUMBIA
ALBERTA
WASHINGTON
MONTANA
IDAHO
OREGON
WYOMING
CALIFORNIA
NEVADA
UTAH
PACIFIC
OCEAN
CANADA
UNITED STATES
Seattle
Portland
Spokane
Boise
Helena
Calgary
Edmonton
Vancouver
Victoria
Salt Lake City


Lower Columbia River
and Vicinity (b)
Scale 1:500,000
Interstate highway
Federal or state highway
Railroad
Urban area
City or town
Study area boundary
Elevations in feet
Map compiled from U.S.G.S. 1:500,000 maps of Oregon and Washington. Estuary shoreline and limit of tidal vegetation from CREDDP base map.
WASHINGTON
OREGON
PACIFIC
WAHKIAKUM
LEWIS
COWLITZ
CLATSOP
COLUMBIA
TILLAMOOK
WASHINGTON
CLARK
MULTNOMAH
SKAMANIA
Astoria
Warrenton
Ilwaco
Long Beach
Cathlamet
LONGVIEW
Kelso
Rainier
Kalama
Seaside
St. Helens
VANCOUVER
PORTLAND
Hillsboro
Beaverton
Gresham
Camas
Washougal


The Columbia River Estuary
General Land Use (c)
Scale 1:200,000
Developed
Agricultural
Natural
Land use information compiled from CREST inventory, 1977, and U.S.G.S. 1:100,000 Astoria and Ilwaco planimetric maps.
COLUMBIA
RIVER
OCEAN
PACIFIC
ASTORIA
BAKER BAY
CATHLAMET BAY
YOUNGS BAY
Lewis and Clark National Wildlife Refuge

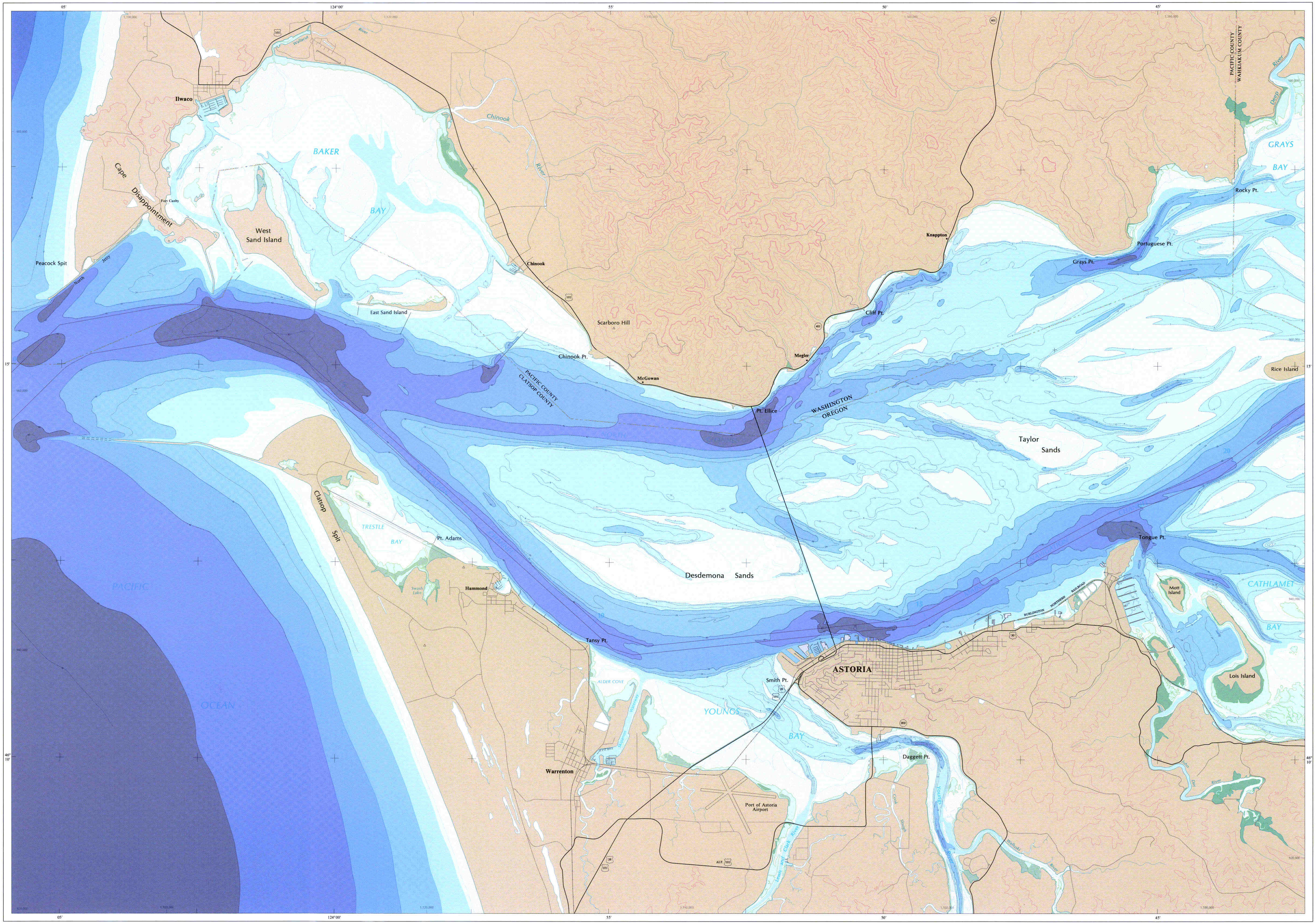
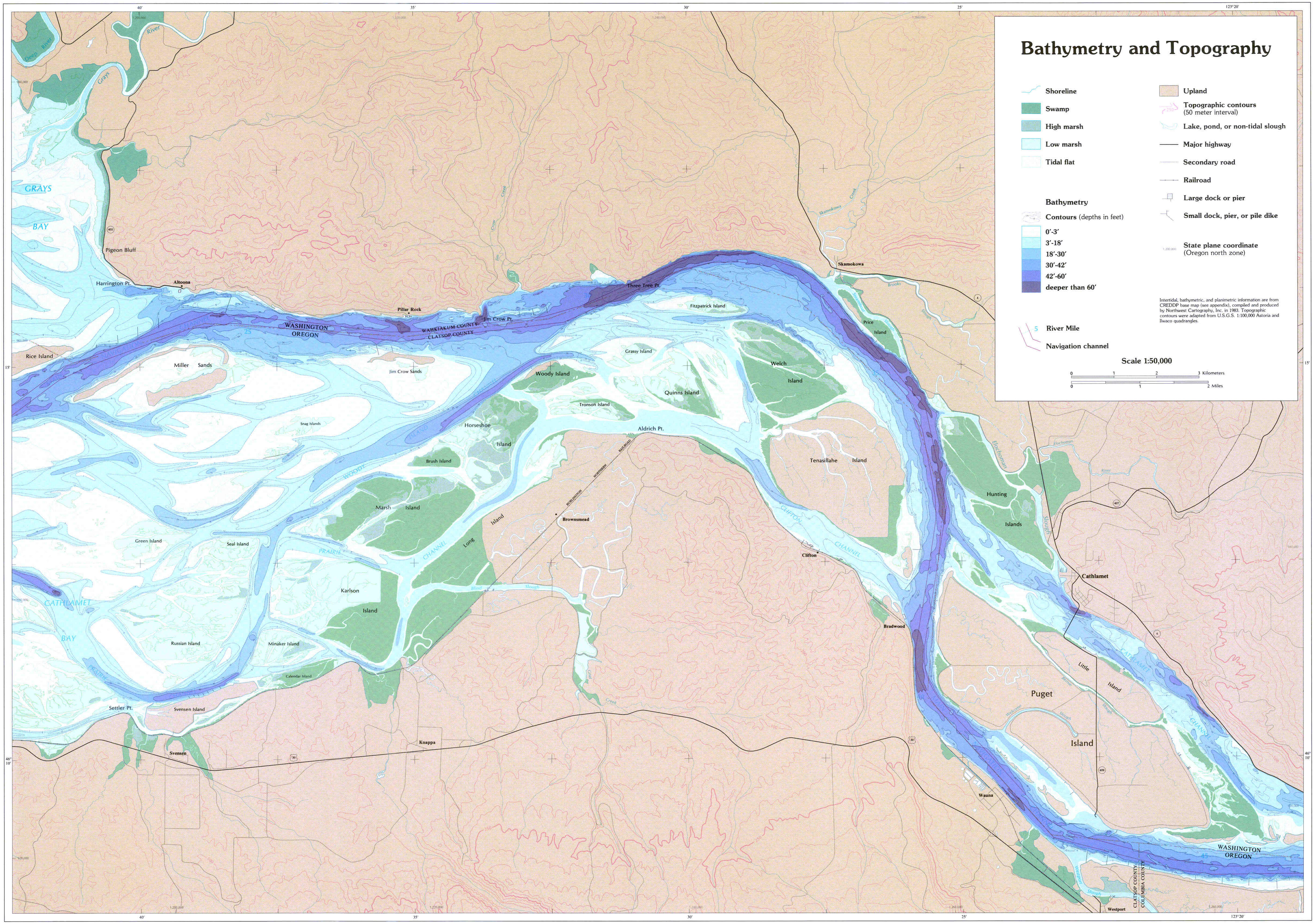


Plate 2 Bathymetry and Topography


Bathymetry and Topography
Shoreline
Swamp
High marsh
Low marsh
Tidal flat
Bathymetry
Contours (depths in feet)
0'-3'
3'-18'
18'-30'
30'-42'
42'-60'
deeper than 60'
River Mile
Navigation channel
Upland
Topographic contours (50 meter interval)
Lake, pond, or non-tidal slough
Major highway
Secondary road
Railroad
Large dock or pier
Small dock, pier, or pile dike
State plane coordinate (Oregon north zone)
Intertidal, bathymetric, and planimetric information are from CREDDP base map (see appendix), compiled and produced by Northwest Cartography, Inc. in 1983. Topographic contours were adapted from U.S.G.S. 1:100,000 Astoria and Ilwaco quadrangles.
Scale 1:50,000
0 1 2 3 Kilometers
0 1 2 Miles
GRAYS BAY
Grays River
Deep River
Pigeon Bluff
Harrington Pt.
Altoona
Pillar Rock
WASHINGTON
OREGON
WAHKIAKUM COUNTY
CLATSOP COUNTY
Jim Crow Pt.
Three Tree Pt.
Fitzpatrick Island
Skamokawa
Price Island
Rice Island
Miller Sands
Jim Crow Sands
Grassy Island
Woody Island
Welch Island
Quinns Island
Tronson Island
Aldrich Pt.
Snag Islands
Horseshoe Island
Brush Island
Tenasillahe Island
Hunting Islands
Marsh Island
Long Island
Brownsmead
Green Island
Seal Island
PRAIRIE CHANNEL
CLIFTON CHANNEL
Clifton
Cathlamet
CATHLAMET BAY
Karlson Island
Bradwood
Russian Island
Minaker Island
Calendar Island
Little Island
Puget Island
Settler Pt.
Svensen Island
Svensen
Knappa
Wauna
WASHINGTON
OREGON
CLATSOP COUNTY
COLUMBIA COUNTY
Westport

Chapter 2.

PHYSICAL CHARACTERISTICS

The principal physical characteristics of the Columbia River Estuary include riverflow, tidal heights and currents, water properties (such as salinity, temperature and nutrients), sediment structure, and sediment transport. Water currents, tides, and salinity influence the movement of water, or circulation, in the estuary. These are the subjects of the first section in this chapter. The sediment structure and transport are influenced by water circulation and are the subjects of the second section in this chapter.

Currents and water properties are described in terms of both their horizontal distribution in the estuary and their vertical distribution within the water column. The horizontal distribution is the arrangement of the characteristics across different regions of the estuary. The vertical distribution is their arrangement in relation to depth. Often, vertical distribution is described in terms of layers of water, each with different physical characteristics. For example, under certain tidal and riverflow conditions, the currents can flow upstream in the bottom water layer and downstream in the surface water layer (Figure 2-1). Also, the salinity is usually higher in the bottom water layer than in the surface layer.

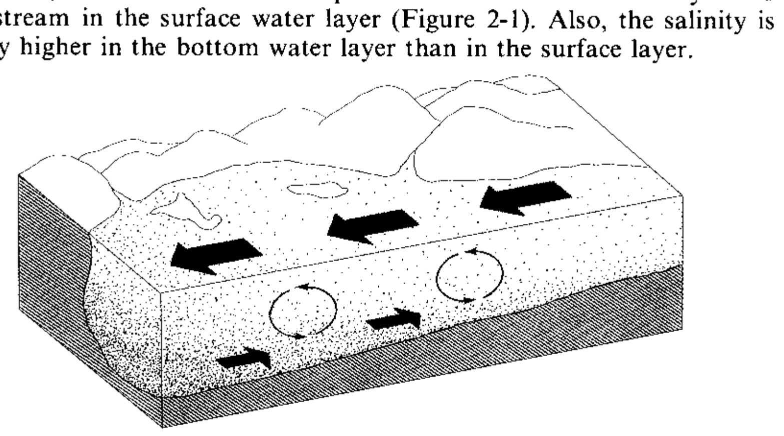


Figure 2-1. Schematic representation of two-layered circulation in the Columbia River Estuary. The large gray arrows represent downstream-flowing surface water and the smaller black arrows represent upstream-flowing bottom water. Curved black arrows represent mixing.

The estuary's sediment structure is described in terms of the morphology, or shape, of the estuary floor and the horizontal distribution of sediment types. Sediment types are classified primarily by grain size. The process of sediment transport (the movement of sediment along the bottom and in the water) determines the sediment structure.

The physical characteristics influence one another in a complex manner. For example, tides and riverflow affect currents, currents affect salinity distribution and sediment transport, salinity distribution affects currents, and sediment transport affects sediment distribution. This chapter describes these interrelationships and how they influence the physical structure of the estuary.

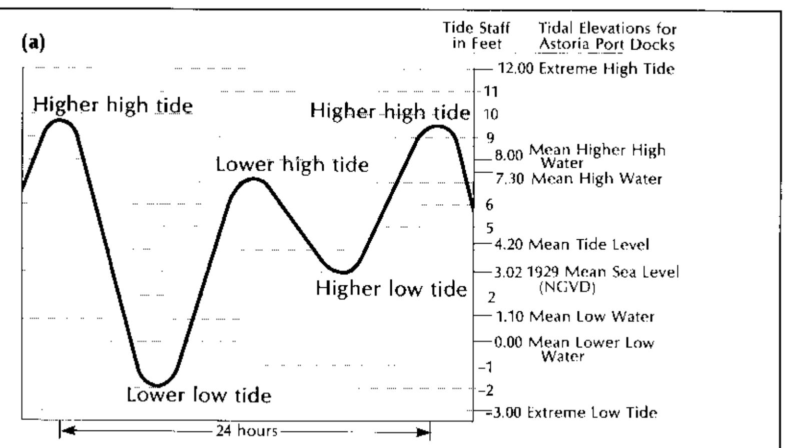
Aside from the basic interest in describing the physical structure of the estuary, physical characteristics are studied for other reasons. Physical characteristics such as salinity, currents, and sediment type influence the biological attributes of the estuary. This chapter, therefore, also serves as background information for understanding the subsequent biological chapters.

The tides are generated by the gravitational effects of the sun and the moon on the waters of the world ocean and by their motions relative to the earth and to each other. A graph of the tides in the Columbia River Estuary on a typical day indicates that there are two complete tidal cycles with different tidal ranges during each 24.8-hour tidal day (Figure 2-2). Important tidal datums (reference elevations derived from averaging high water measurements or low water measurements) are also shown in Figure 2-2. Mean lower low water (MLLW), normally defined as the zero datum, is the zero tide level between the river mouth and approximately Harrington Point, Washington, and Settler Point, Oregon (RM-23). Other tidal datums are expressed in relation to MLLW. Upriver from Harrington and Settler Points another datum, Columbia River Datum (CRD), is used as the zero datum. CRD is defined by U.S. Army Corps of Engineers as the average of lower low waters during the low riverflow period in 1911. CRD is used in upriver areas because water surface levels are increasingly affected by river discharge and decreasingly by tides as one proceeds upriver.

The average range of the tides varies during the 28-day lunar month. Tides with a large tidal range are called spring tides while those with a small tidal range are called neap tides (Figure 2-3). One spring-neap cycle lasts about two weeks (one-half lunar month). Since the strength of tidal currents is associated with the tidal range, the estuary's circulation and salinity distribution vary greatly between spring and neap tides.

The tidal range is equivalent to the difference in elevation of the peak of the tidal wave and the trough. As the tidal wave progresses up the estuary, it is distorted by bottom friction and the irregularities of the channels. The mean tidal range first increases upriver to Astoria (RM-15) and then decreases (Figure 2-7). The initial increase in tidal range in the lower estuary is the result of the funnel-like shape of the channel system: the cross-sectional area of the channels decreases sharply upriver from Hammond (RM-8), causing an increase in tidal range. Above Astoria the loss of tidal energy to friction is so large that the tidal range decreases upriver despite the decreasing channel cross-section. Changes in riverflow also have a strong effect on the tidal properties. Under high riverflow conditions, the tidal range is much reduced and the tidal wave moves upriver much more slowly.

(a)



(b)

Extreme High Tide (EHT) — The highest projected tide that can occur. It is the sum of the highest predicted tide and the highest recorded storm surge.

Mean Higher High Water (MHHW) — The average height of the higher of the two daily high tides observed over a specific time interval.

Mean High Water (MHW) — The average of all observed high tides. The average is of both the higher high and the lower high tides recorded each day over a specific time period.

Mean Tide Level (MTL) — The average of MHW and MLW at a given station.

Mean Sea Level (MSL) — A datum based upon observations taken over a number of years at various tide stations along the west coast of the United States and Canada.

Mean Low Water (MLW) — The average of all observed low tides. The average is of both the lower low and the higher low tides recorded each day over a specific time period.

Mean Lower Low Water (MLLW) — The average height of the lower of the two daily low tides observed over a specific time interval.

Extreme Low Tide (ELT) — The lowest estimated tide that can occur.

(c)

	OREGON			WASHINGTON	
Tidal Elevation	Fort Stevens	Youngs Bay	Tongue Point	Fort Canby	Harrington Point
MHHW	8.30	8.60	8.20	7.80	7.70
MHW	7.60	7.90	7.60	7.10	7.00
MLW	1.20	1.20	1.10	1.10	0.90
MLLW	0	0	0	0	0
NGVD	3.51	3.60	3.05	3.12	2.56

Figure 2-2. Tidal characteristics of the Columbia River Estuary: (a) graph of tidal heights over a 24-hour period, showing elevations of tidal datums in feet at the Astoria Port Docks (RM-13); (b) definitions of tidal datums; and (c) elevations of tidal datums in feet at five additional locations in the Columbia River Estuary (modified from Oregon Division of State Lands 1983; Oregon State University 1975).

Circulation and Salinity

The patterns of water circulation and salinity distribution in the Columbia River Estuary result mainly from the interaction of tides and riverflow. The Columbia River Estuary has a greater range between high and low tides and receives a larger river discharge than most other estuaries in the United States, resulting in very rapid and turbulent currents. Tidal currents move saline ocean water into the mouth of the estuary while the strong riverflow carries fresh water through the estuary from the upriver end, limiting the extent to which salt water can move upstream.

Circulation and salinity are the major physical factors controlling the sedimentological and biological characteristics of the estuary. Water currents erode, transport, and deposit sediments and thus determine the composition of sediments at different localities in the estuary. Similarly, circulation patterns influence the distribution of small organisms suspended in the water column. The salinity distribution also affects the distribution of estuarine organisms. Each species living in the estuary is adapted to exist under a specific range of salinity conditions. The populations of each species occur in areas where salinities are within their adapted ranges.

This section discusses circulation and salinity together because each has a strong influence on the other. Circulatory processes control salinity distribution through the movement of ocean water in and out of the estuary and the mixing of ocean water and river water. Mixing causes the dilution of ocean water with fresh water to produce brackish water. Salt water is moved into the estuary mainly through a mixing process driven by tidal currents. The turbulence and mixing associated with the tidal flow causes an upstream exchange of salt from high salinity water to low salinity water. As a result, salt moves farther upriver than any of the ocean water does.

The salinity distribution also affects circulation, mainly because of differences in the density of salt and fresh water. Salt water is denser and therefore heavier than fresh water. When ocean water and river water meet (irrespective of tides or riverflow), ocean water exerts more pressure on river water than river water exerts on ocean water. The force resulting from this imbalance, called a pressure gradient force, tends to push ocean water into the estuary and upstream along the bottom. The salinity differences between the two water types thus tend to result in upstream currents along the bottom.

Factors Affecting Circulation and Salinity

The circulation and salinity distributions in estuaries are determined by many physical fators, including river discharge, tides, winds, mixing, bottom topography, ocean salinity, ocean currents, and estuarine currents resulting from the pressure gradient force. The relative importance of each factor and the ways in which the factors interact determine the circulation and salinity distribution patterns in each estuary. The primary factors controlling circulation in the Columbia River Estuary are riverflow, tides, and currents resulting from the pressure gradient force. Salinity distribution is, in turn, determined by the circulation patterns and the mixing process driven by tidal currents.

River discharge is a major contributor to the downstream currents of the estuary. The portion of total downstream flow attributed to river discharge is greatest in the upriver reaches of the estuary and gradually decreases toward the estuary mouth as tidal currents become increasingly important. River discharge in the Columbia River Estuary varies about fivefold from low riverflow to high riverflow periods (see Chapter 1). This variation is one factor accounting for seasonal variations in the estuary's circulation and salinity distribution patterns.

Tides are another important factor affecting circulation and salinity in the estuary. The rise and fall of the tides is the result of a wave (the tidal wave) passing the point of observation. What is observed as the tide rising is in fact the tidal wave entering the estuary. As the peak of the wave begins to enter the estuary, the water level becomes high enough to overcome the downstream river currents. This creates flood currents. After the peak of the wave passes through the estuary, the water level becomes lower and the resulting ebb currents combine with the river currents to produce a strong downstream flow. The tidal range, or the difference between high and low tides, determines the strength of the tidal currents (Figure 2-2). The tidal range also determines the distance traveled by water masses over a tidal cycle, called the tidal excursion. Greater tidal ranges move water upriver and downriver greater distances and produce larger tidal excursions. The tidal range varies during the 28-day lunar month; tides with a large range are called spring tides while those with a narrow range are called neap tides (Figure 2-3). The variation in tidal range is another factor accounting for variability in circulation and salinity distribution patterns.

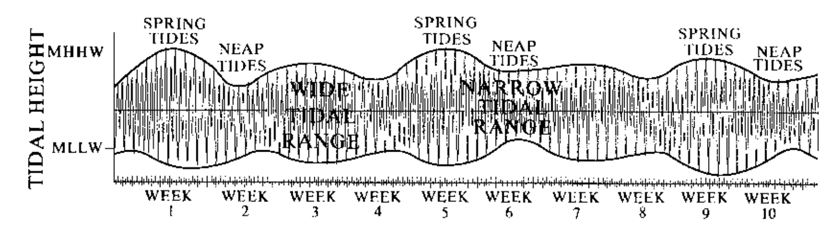


Figure 2-3. Recording tide gauge data showing spring and neap tide ranges (modified from Jay 1984).

A third factor affecting circulation, currents resulting from the pressure gradient force, is important within the area of salt water intrusion (mainly downriver from Tongue Point). The pressure gradient force tends to create upstream bottom currents in this region. The vertical salinity distribution in this region is sometimes characterized by an abrupt change from low salinities in the surface water layer to high salinities in the bottom water layer. During these periods, the water column is said to be stratified. The relative importance of the pressure gradient force in determining circulation is related to the degree of this salinity stratification. Under highly stratified conditions, the upstream bottom currents resulting from the pressure gradient force are relatively strong. When mixing between the surface and bottom waters reduces the stratification, these upstream currents become relatively weak.

The currents resulting from the three factors discussed above are all influenced by friction. As water flows over the bottom, the energy level of the flowing water is reduced by friction. The result is weaker currents near the bottom than near the surface. Also, friction creates turbulence. This turbulence enhances the mixing of fresh and salt water, weakening the currents resulting from the pressure gradient force. Because the Columbia River Estuary has a relatively shallow basin, friction against the bottom has a relatively large effect on circulation patterns.

Figure 2-4 shows an example of how the surface and bottom currents are affected by the balance among currents resulting from river discharge, tides, and the pressure gradient force. This figure shows average currents in the main navigation channel downriver from Tongue Point during moderate to low riverflows and tidal ranges. (Circulatory patterns during high riverflows or strong tides are very different.) Ebb currents are strong at the surface because they are a combination of downstream-flowing river and tidal currents and are weak at the bottom because they are reduced by friction and opposed by the pressure gradient force (Figure 2-4a). Flood surface currents are not as strong as ebb surface currents because they are a result of upstream tidal flow opposing downstream riverflow. The bottom currents during flood tide are, however, stronger than those during ebb tide because the upstream flood flow is increased by the pressure gradient force (Figure 2-4b). The mean currents (Figure 2-4c) are determined by taking the difference between the total flood and total ebb currents. The mean current direction is downstream on the surface and upstream on the bottom (Figure 2-4c).

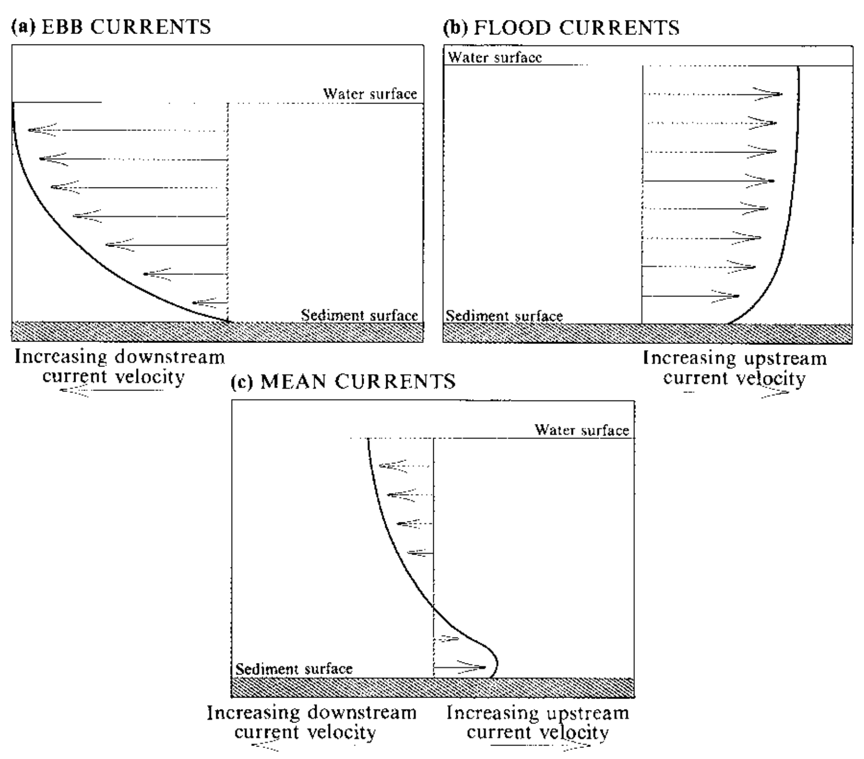


Figure 2-4. Profile of current velocities in the main navigation channel downriver from Tongue Point during conditions of moderate to low riverflow and tidal ranges: (a) ebb currents are downstream at all depths and are stronger near the water surface than bottom; (b) flood currents are upstream and are nearly equal in strength at all depths; (c) mean currents are downstream near the surface and upstream near the bottom (modified from Simenstad et al. 1984).

Derivation, Uses, and Limitations of the Figures and Maps (Figure 2-5 and Plates 3 through 5)

CREDDP investigators used two approaches to study the estuary's circulation and salinity. The first involved measuring the tides, currents, and salinity in the estuary. The second method was to develop computer models which, through a series of mathematical formulas, could recreate and display the circulation patterns of the Columbia River Estuary under various tidal and riverflow conditions. These models allowed investigators to characterize the estuary's circulation under combinations of tidal and riverflow conditions not encountered during field studies.

Three sets of maps and figures were developed from the results of both study approaches to depict circulation and salinity distribution patterns in the estuary. The first set consists of maps of water transport in the estuary's channels (Figure 2-5). The other two sets depict salinity distribution: first as sections of the main navigation channel (Plate 3, Figure a), and secondly as a set of salinity distribution maps (Plate 3, Map b and Plates 4 and 5).

Water Transport Maps (Figure 2-5)

The water transport maps show water flow during a low riverflow (discharge of 4,000 cubic meters per second), neap tide period. The phrase water transport describes the volume of water that flows past a point over a given time period. The units of water transport used on the maps are cubic meters per second (m^3/s). These maps were derived from a computer model of Columbia River Estuary circulation and salinity and are useful for showing the patterns of water flow among the various channels of the estuary. They do not, however, show water flow in shallow water areas, nor do they distinguish between surface water and bottom water flows.

Salinity Sections (Plate 3, Figure a)

The salinity sections on Plate 3 depict the vertical and horizontal salinity distributions in the main navigation channel. They represent a vertical slice through the channel running lengthwise from the mouth of the estuary to RM-30. CREDDP investigators compiled the sections using salinity measurements taken at various depths along the channel. Salinity distributions are shown for minimum, maximum, and mean salinity intrusions under each of three sets of physical conditions: neap tides during low riverflow, with a river discharge of 3,400 to 4,250 m^3/s, or 120,000 to 150,000 cubic feet per second (cfs); spring tides during low riverflow; and spring tides during high riverflow, with a river discharge of 15,100 to 16,300 m^3/s (535,000 to 575,000 cfs). Minimum salinity intrusions occur during ebb tides while maximum intrusions occur during flood tides. Salinity distribution during neap tides and high riverflow is not shown because it is very similar to the distribution during spring tides and high riverflow.

The sections are useful for illustrating changes in the estuary's salinity structure under different riverflow and tidal conditions. The sections on Plate 3 are examples of the average salinity structure under different physical conditions and do not represent all possible types of vertical salinity distributions in the estuary. Abrupt changes in salinity at particular depths are not shown on the sections because the contours represent data that were averaged over several tidal cycles. Highly stratified conditions are represented on the sections by the more horizontal contours.

Salinity Distribution Maps (Plate 3, Map b and Plates 4 and 5)

The salinity distribution maps were derived from salinity measurements obtained at various depths throughout the estuary. The maps show the salinity both at the surface and at a depth of nine meters. Like the sections, they show the salinity distributions during minimum, maximum, and mean salinity instrusions. The minimum intrusions occur during outgoing spring tides and the maximums occur during incoming neap tides. The maps are arranged to compare the salinity distribution during periods of high riverflow, with a discharge of 8,800 m^3/s (310,000 cfs), and low riverflow, with a discharge of 4,400 m^3/s (155,000 cfs). A high riverflow minimum salinity intrusion map is not included because under such conditions (ebbing spring tide) the salinity is zero at all depths upriver from RM-2.

The maps were derived from salinity measurements taken mainly in the north and main navigation channels. Salinity distribution in shallow water and in minor channels is poorly known; therefore, the maps are less accurate in shallow areas. The salinity distribution varies greatly over different combinations of tidal and riverflow conditions. Much of this variation should fall within the minimum and maximum salinity intrusions shown on the maps. However, during unusually high or low riverflows, salinity may intrude less than the minimums shown or more than the maximums.

Interpretation of the Figures and Maps (Figure 2-5 and Plates 3 through 5)

Water Transport Maps (Figure 2-5)

Figure 2-5 shows typical water flow patterns in the estuary's channels. The flood, ebb, and mean flows are strongest in the north channel from the river mouth up to the Astoria-Megler bridge (RM-14). Just upriver from the bridge, channels convey the water flow between the north and main navigation channels. Upriver from these channels, most of the flow is conveyed by the main navigation channel. These flows result from a combination of tidal currents and river currents. CREDDP investigators found that most of the flows resulting from tidal currents move up and down the estuary primarily in the north channel, whereas flows resulting from river currents primarily follow the main navigation channel. Downriver from Tongue Point the water flows are stronger in the north channel than in the main navigation channel because tidal currents are stronger than river currents in that region of the estuary.

River currents move water downstream along the main navigation channel in part because channel training structures such as pile dikes have been constructed to create this effect (see Chapter 1). Pile dikes direct riverflow from the south side of Puget Island to the north side of Tenasillahe Island at RM-38, away from Woody Island Channel at RM-30, and diagonally across the estuary from Altoona at RM-24 toward Tongue Point. Downriver from Tongue Point the flows resulting from river currents naturally follow the south side of the estuary to the mouth.

Salinity Sections (Plate 3, Figure a)

While the water transport maps demonstrate the major circulation patterns in the estuary, the salinity sections aid in examining details of the vertical distribution of currents in the region of salt water intrusion. The vertical distributions of currents and of salinity vary widely under different tidal and riverflow conditions and have a large influence on each other. Currents occurring at the surface can differ markedly in speed and direction from those occurring near the bottom, particularly in the area downriver from Tongue Point (Figure 2-4). These currents are not indicated on the salinity sections but are discussed in some detail below because of their relationship with salinity stratification and because, together with the processes affecting stratification, they are the principal factor determining the salinity intrusions shown on the sections.

During low riverflows, the neap and spring tide salinity and circulation patterns differ markedly from each other. During neap tides, there is more stratification (represented on the sections by the more horizontal contours) because there is less tidal energy for mixing than during spring tides. The mean currents near the surface reflect a balance between downstream riverflow and reversing tidal currents. The result is net downstream currents near the surface. The bottom currents result from a balance between downstream riverflow, reversing tidal currents, and upstream currents resulting from the pressure gradient force. Because of the strong stratification during low riverflow neap tides, the upstream bottom currents resulting from the pressure gradient force are relatively strong while the downstream riverflow stays near the surface and has relatively little effect on bottom currents. The result is net upstream currents along the bottom. Flood tides bring saline water relatively far into the estuary (maximum salinity intrusion) and ebb tides do not force saline water very far downriver (minimum salinity intrusion).

With the same low riverflow but during spring rather than neap tides, the elevated tidal energy increases vertical mixing and reduces salinity stratification (represented on the sections by the more vertical contours), so that the bottom water is no longer separated from the surface water. Upstream bottom currents resulting from the pressure gradient force are therefore not as pronounced as during neap tides, and downstream riverflows have a greater influence near the bottom. The upriver range of salinity near the bottom on flood tides (maximum salinity intrusion) is therefore not as great during low riverflow spring tides as during neap tides, and saline water is forced farther downriver on ebb tides (minimum salinity intrusion).

Changes in salinity structure over the spring-neap cycle are much less pronounced during high riverflow periods. Riverflow is strong and tidal mixing is not great enough to mix the fresh and salt water thoroughly. As a result, the water column is moderately to strongly stratified at all times during high riverflows. Plate 3, Figure a shows high riverflow salinity intrusions during a spring tide. Because of the greater downstream riverflows, salt water intrudes a shorter distance into the estuary than during low riverflows. During strong ebb tides (minimum salinity intrusion) the entire estuary becomes freshwater. Saline water moves in and out of the estuary with the tides as a wedge of salt water during high riverflow conditions.

Salinity Distribution Maps (Plate 3, Map b and Plates 4 and 5)

The set of salinity distribution maps illustrates the effect of riverflow on salinity distribution. No minimum (outgoing spring tide) salinity intrusion map is shown for high riverflow periods because under such conditions the estuary becomes almost entirely freshwater. During low riverflows, the minimum intrusion of saline surface water is to RM-7 while at nine meters depth, saline water intrudes to about RM-11 in the main navigation channel and to RM-13 in the north channel (Plate 3, Map b). During high riverflows, the maximum (incoming neap tide) salinity intrusion is to about RM-15 on the surface and to RM-20 at nine meters depth (Plate 4, Map a). The low riverflow maximum salinity intrusion is much greater, reaching RM-23 on the surface and RM-28 at nine meters depth (Plate 4, Map b). The mean salinity maps (Plate 5) show salinity distribution averaged over spring ebb tides and neap flood tides (minimum and maximum salinity intrusions respectively). These isolate the effects on salinity distribution of high riverflow (Plate 5, Map a) and low riverflow (Plate 5, Map b).

CREDDP investigators found that the upstream exchange of salt caused by the turbulence associated with tidal currents is more important in bringing saline water into the estuary than upstream bottom currents resulting from the pressure gradient force. Salt water enters the estuary primarily above mid-depth in the north channel and leaves the estuary, along with the riverflow, near the surface of the main navigation channel. Salt water crosses the estuary from the north channel to the main navigation channel in small channels upriver from the Astoria-Megler bridge (Figure 2-5a). The mean surface salinity maps during both high and low riverflow demonstrate the effects of this salinity transport pattern (Plate 5). Surface salinity intrudes farther in the north channel than in the main navigation channel because the bulk of saline water enters the estuary through the north channel.

Discussion

The differences in salinity structure during different tidal and riverflow conditions in the Columbia River Estuary reflect the effects of currents on stratification and mixing. Generally, when river currents are strong compared with tidal currents, the water column becomes stratified. Conversely, when tidal currents are strong compared with river currents, the water column becomes mixed. During high riverflow periods, when river currents are strong compared with either spring or neap tidal currents, the water column is stratified during all tidal conditions. During low riverflows, the difference in strength between river currents and the weaker neap tidal currents also allows for water column stratification. During the stronger spring tides, however, the water column becomes more mixed (less stratified).

The greatest upriver range of salinity intrusion is just above RM-30 in the bottom waters and occurs during low riverflows and neap tides when the water column is highly stratified. These conditions persist only a few days during the period of the weakest tides. The CREDDP computer model

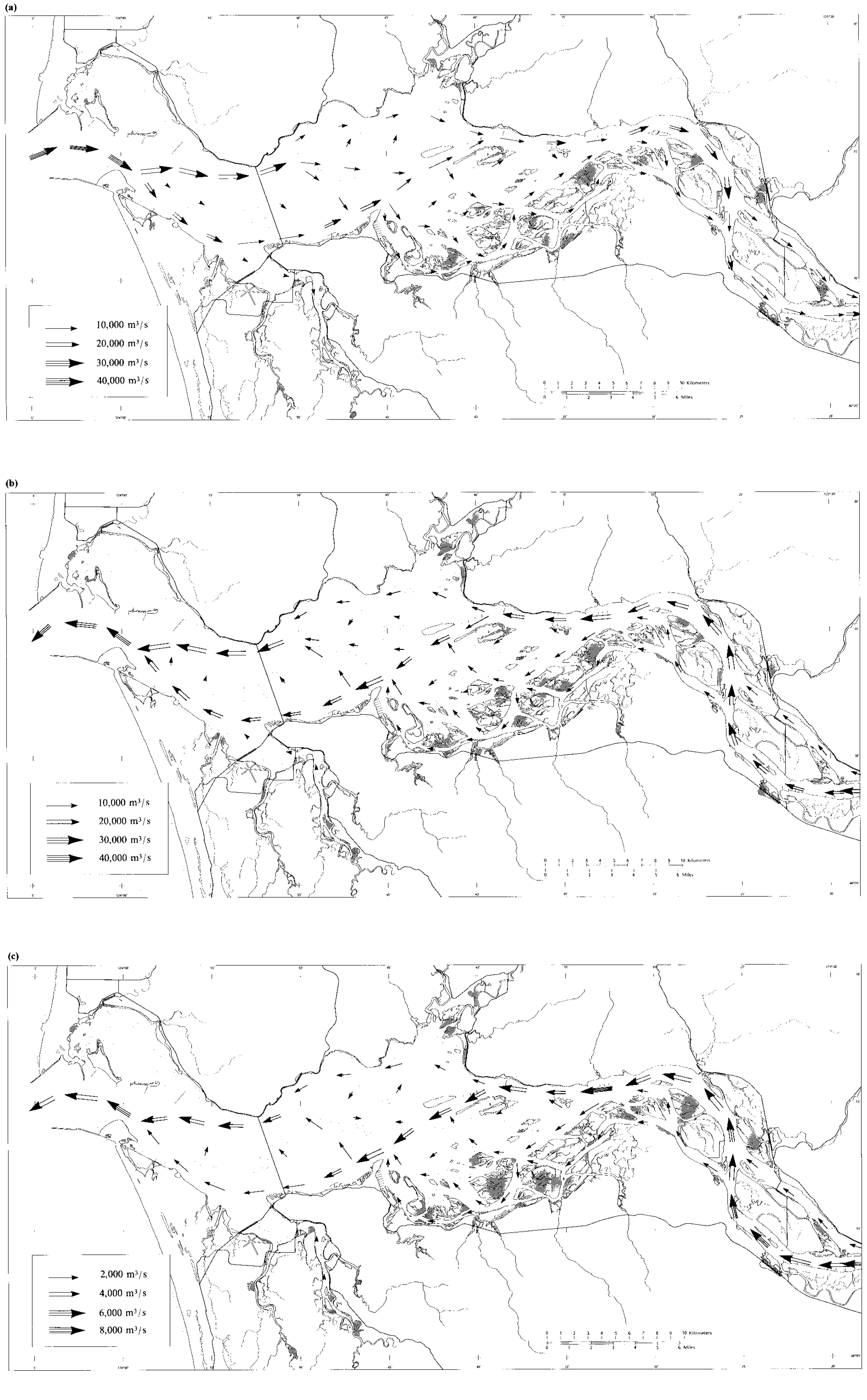


Figure 2-5. Water transport patterns under low river discharge (140,000 cfs or 4,000 m^3/s) and neap tide conditions: (a) flood tide, (b) ebb tide, and (c) mean water transports (Hamilton 1984).

predicts that a radical decrease in river discharge (cutting the river discharge to half the present low riverflow season discharge) would eliminate the possibility of highly stratified conditions altogether because the weaker currents associated with such low river discharge would be insufficient to create stratification during even the weakest neap tides. The maximum salinity intrusion would then occur on spring tides because of the larger tidal excursion. The computer model for this extreme low discharge condition predicts that the 1 part per thousand salinity contour would reach approximately to the western end of Puget Island at RM-37.5 (Figure 2-6). Salinities of 5 to 10 parts per thousand would occur in the interior of Cathlamet Bay both at the bottom and at the surface. This is very different from the situation portrayed on Plate 3, Figure a. Because of the high degree of stratification under present low riverflow neap tides, salinity intrusion occurs only in deeper channels. Surface salinities in Cathlamet Bay remain below 1 part per thousand despite salinity intrusion into the deeper channels of the bay.

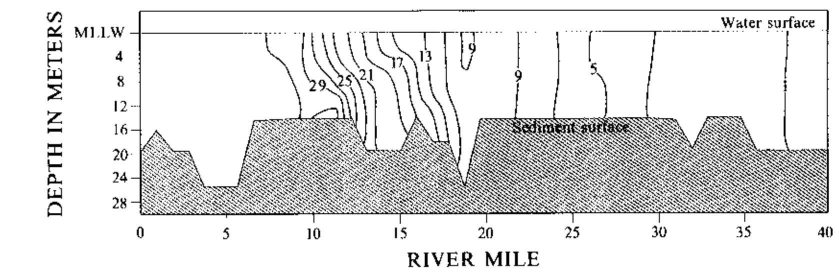


Figure 2-6. Salinity section in the main navigation channel of the Columbia River Estuary, showing maximum salinity intrusion in parts per thousand for an extreme low river discharge (70,000 cfs or 2,000 m^3/s) spring tide. The river discharge represented is about one-half the present low riverflow season discharge of the Columbia River. This salinity distribution section was produced using a computer model (Hamilton 1984).

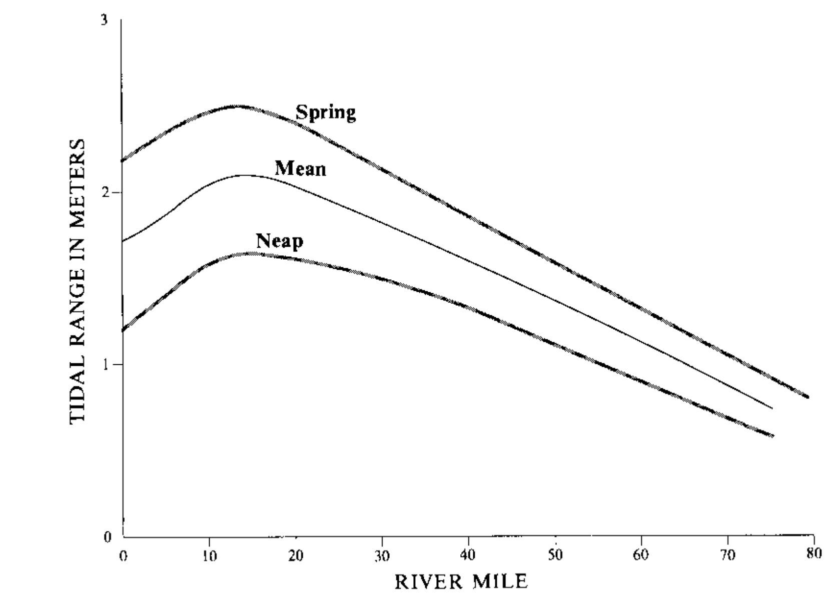


Figure 2-7. Spring, neap, and mean tidal ranges for the Columbia River to RM-80 (from Jay 1984).

Sediments

The sediments of the Columbia River Estuary are the organic and inorganic substances that have been deposited on bedrock to form the estuary floor. At any given time there are also sediments suspended in the water column. Many of the physical features of the estuary are composed of sediments that have been transported and shaped by water currents, waves, and wind. Most of the influences that have determined the appearance and character of the estuary are still acting to change the shape of islands, relocate channels, and create or remove tidal flats.

Sediments have a large influence on the biological characteristics of the estuary. The stability of the bottom and the grain size of sediments are important to benthic and epibenthic communities (see "Benthic Primary Producers", "Benthic Infauna", and "Epibenthic Organisms"). The erosion and deposition of sediments around the estuary's shoreline and islands are important in creating or destroying habitats for vegetation and mammals in the estuary (see "Tidal Marshes and Swamps", "Marine Mammals", and "Aquatic and Terrestrial Mammals"). Also, the concentration of suspended sediments in the water affects turbidity, which is important in determining phytoplankton productivity (see "Phytoplankton").

Sediment movement also has a direct influence on human activities. The federal government and local ports spend millions of dollars annually for dredging to maintain deep water shipping access into and through the estuary.

CREDDP investigators concentrated sediment research on two objectives. The first objective was to describe the processes that act to transport sediment in the Columbia River Estuary. These processes create a mosaic of sedimentary environments characterized by distinct landforms, sediment grain sizes, and elevations. The second objective of sediment research was to describe the distribution of these sedimentary environments.

Factors Affecting Sediment Transport and Distribution

Sediment transport is the movement of sediments in the water column and along the bottom. Sediment transport in the water column is called suspended transport while sediment transport along the bottom is called bedload transport (Figure 2-8). The estuary has high rates of suspended sediment transport but the high average river discharge tends to flush these suspended sediments out to sea. Bedload transport is a more important factor in the long-term erosion and deposition of sediments in the estuary.

In general, the movement of sediments in the estuary is controlled by currents. In comparison with many other estuaries, the currents of the Columbia River Estuary are stronger and more variable and produce a more complex distribution of sediments. Also, the characteristics of currents within the estuary fluctuate on daily, weekly, seasonal, and annual time scales, resulting in similar fluctuations in sediment transport.

The two-layered circulation system that occurs in estuaries complicates the sediment patterns (see "Circulation and Salinity"). While the net current flow is downstream, a weaker current moves upstream along the bottom of the estuary (Figure 2-1). When it is weakly developed, this system acts to buffer the bottom against the strong downstream-flowing ebb currents. When it is strongly developed, the net upstream flow in the deep channels may actually serve to transport bedload sediment upstream in the portion of the estuary between Hammond and Tongue Point. The largest effect is on the suspended sediments. This circulation pattern will often produce a turbidity maximum in the estuary (Figure 2-9), further increasing the amount of suspended sediment.

Sediment distribution around the estuary is described in terms of types of bottom sediments. The most common characteristics used to classify sediment types are the percentage of each of several different grain-size classes within a sediment sample, called the grain-size distribution, and mineralogy, the minerals making up the sediments. Grain-size distribution (Table 2-1) can help determine and predict sediment stability, the processes that produced the sediment distribution under examination, and the types of bottom organisms that may be present on the sediment. The organic content of sediments (detritus and small plants and animals) is also used to describe sediment type. The Columbia River Estuary's sediments have an organic content ranging from less than 1 percent in most of the main stem of the estuary to about 3 to 15 percent in the quiet peripheral bays. This is unusually low compared with many other estuaries, due principally to the characteristically rapid currents of the estuary.

Among the factors affecting the sizes and amount of sediments delivered to the estuary is the source area. The main source of sediments to the estuary is the Columbia River drainage basin. Although sediments from clay-size to gravel-size can be found in the Columbia River, most of the sediments transported to the estuary fall in the narrow range of fine to coarse sand (Table 2-1). No precise estimates of sediment transport (suspended plus bedload) into the estuary have ever been made; however, at a site upriver near Portland, Oregon, researchers have estimated that the Columbia River transports about 13,000,000 tons of sediments annually. Depending on river discharge, this can vary from 5,000,000 to 41,000,000 tons per year. Most of these sediments probably reach the estuary. It is unknown what proportion of these sediments remain in the estuary or continue into the ocean. It appears that much of the coarser (sand-size) material is trapped in the estuary while much of the finer material escapes.

Sediments are also supplied to the estuary from the adjacent ocean floor. The Columbia River has deposited so much sediment along the nearby coast and in the ocean, however, that these marine sediments have a very similar mineralogical composition. Thus, it is difficult to distinguish between sediments derived from the river and sediments of marine origin on the basis of mineralogy.

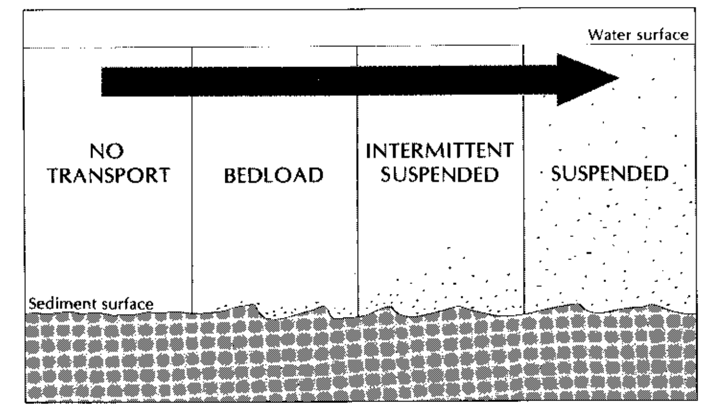


Figure 2-8. Schematic representation of the relationship between currents and sediment transport.

Sediment transport is controlled by the strength of the currents along the estuary bottom. As the current increases, grains of sediment begin to roll, slide, and bounce along the bottom. The strength of the currents determines how far, how fast, and what types of sediments are transported. When the current strength is low relative to the size of the sediments on the bottom, sediment transport rates are low and sediment movement is confined to a thin layer along the bottom. This is classified as bedload sediment transport. Sediments transported in bedload can produce bedform sand waves resembling sand dunes. At higher current speeds, bedload transport rates increase while other grains leave the bottom and become suspended in the turbulent current flow of the water column. Sediment movement in the water column is called suspended sediment transport. Because it is more difficult for currents to move larger grains, suspended sediment transport generally moves fine grains and bedload sediment transport moves coarse grains. The type of sediment transport active at any time is determined by the strength of the current and the size of the sediment grains available at that site.

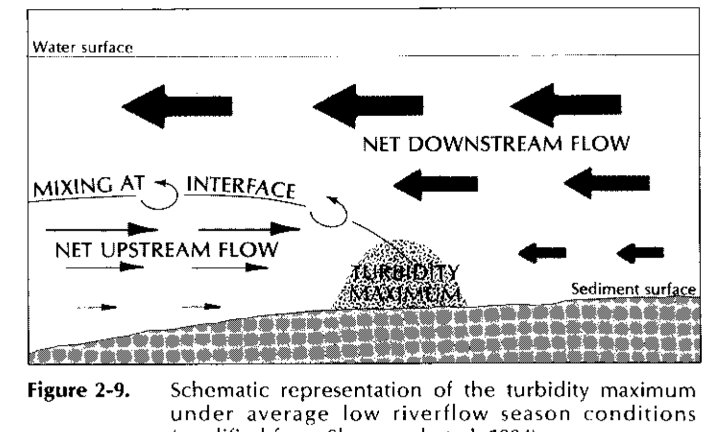


Figure 2-9. Schematic representation of the turbidity maximum under average low riverflow season conditions (modified from Sherwood et al. 1984).

The turbidity maximum is a phenomenon involving high concentrations of suspended sediments that occurs near the upriver limit of the net upstream bottom flow. The turbidity maximum is caused, at least partially, by a trapping mechanism created by the currents in the estuary. Its occurrence results from interactions among riverflow, tides, and the pressure gradient force discussed in "Circulation and Salinity". Under conditions of moderate to low river discharge and average to neap tidal ranges, there is a net upstream flow of bottom water in the region downriver from Tongue Point (RM-18). Material suspended in the lower portion of the downstream-flowing river water is stopped as it encounters the upstream-flowing salt water. Material in the upper layer may gradually sink into the lower layer. If this occurs downriver from the turbidity maximum, the material will settle into the upstream-flowing bottom layer and be carried upriver toward the turbidity maximum. The location of the turbidity maximum shifts with the tidal and riverflow seasons. Its average position is at about Tansy Point (RM-10) except during the low riverflow season when it shifts upriver to about RM-15. The increased tidal energy during spring tides (see "Circulation and Salinity") causes fine material to be eroded from the bottom over portions of the estuary; some of this material is trapped in the turbidity maximum, causing much higher suspended sediment concentrations. When current activity is reduced, some of these suspended sediments are deposited in the deeper portions of the turbidity maximum zone.

Description		Phi Units	Metric Units (millimeters)
BOULDER			
		−8	256
COBBLE	Large		
		−7	128
	Small		
		−6	64
GRAVEL	Very Coarse		
		−5	32
	Coarse		
		−4	16
	Medium		
		−3	8
	Fine		
		−2	4
	Very Fine		
		−1	2
SAND	Very Coarse		
		0	1
	Coarse		
		+1	0.500
	Medium		
		+2	0.250
	Fine		
		+3	0.125
	Very Fine		
		+4	0.062
SILT	Coarse		
		+5	0.031
	Medium		
		+6	0.016
	Fine		
		+7	0.008
	Very Fine		
		+8	0.004
CLAY	Coarse		
		+9	0.002
	Medium		
		+10	0.001
	Fine		
		+11	0.0005
	Very Fine		
		+12	0.00024

Table 2-1. Sediment grain-size classes (modified from Shepard 1963).

Grain size is one of the most important characteristics to distinguish among sediment types. The grain-size distribution is defined as the relative amount, as a percentage, of sediments in each of several different grain-size classes within a given sediment sample. Sedimentologists generally determine grain-size classes using a classification system called the phi scale which is correlated with common names such as gravel, sand, and silt. The most important aspect is that the larger the phi number, the smaller the grain size. The finest clays have sizes around 11 or 12 phi, sands around 0 and 1, and the very large cobbles and boulders are −7 or −8. The common names of classes are precise; for example, fine sand is composed of sand grains ranging from 2 to 3 phi.

A number of tests can be used to describe grain-size distribution and to determine coarser and finer sediments. Among these are the percentage of silt plus clay. High percentages of silt and clay can indicate quiet areas where sediments tend to settle, while low percentages are indicative of stronger currents. The coarsest one-percentile, the size of the largest one percent of the grains, is another measure that can be used as a gauge of the coarsest sediments.

The degree of sorting is used to help interpret the processes causing sediment distribution. Sediment samples in which many size classes are represented are called poorly-sorted. Well-sorted sediments represent few size classes. Generally, good sorting indicates either that one consistent process (for example, steady currents) is acting on the sediments or that the source of sediments consists of only a few size classes. Poor sorting indicates that variable processes (for example, variable currents) are acting on the sediments or that the source of sediments is variable. Well-sorted sediments can have coarser sediments predominating if currents are a significant factor or if the area sampled is nearer the source region. Finer sediments will predominate if the source region is more distant or if currents are weaker.

Derivation, Uses, and Limitations of the Maps (Plates 6 through 9)

The maps on Plates 6 through 9 are based on information gathered during the CREDDP studies and earlier studies supported by the U.S. Army Corps of Engineers. The maps have been grouped into three categories: distribution of sediment types (sediment distribution), bedforms (sediment transport), and sedimentary environments (based on both sediment distribution and transport).

The maps showing sediment distribution (Plates 6 and 7) are based on more than two thousand samples. Data from these samples were interpreted for regions of the estuary based on both water depth and general circulation patterns. The sediment classes and measurement units on the maps are based on Table 2-1. Rock outcrops and gravel bed locations were determined with side-scan sonar (see below). Plate 6 and Plate 7, Map a show sediment distribution variations among the three riverflow seasons (see Chapter 1) and are based on samples collected over the course of several weeks during each of the riverflow seasons. Plate 7, Map b displays the silt plus clay distribution and emphasizes the areas where silt plus clay were present only on a seasonal basis.

To produce the bedform maps (Plate 8 and Plate 9, Map a), the bottom of the estuary was studied with an acoustic-imaging technique called side-scan sonar. The acoustic images received are the result of the topography and reflectivity of the bottom (Figure 2-10).

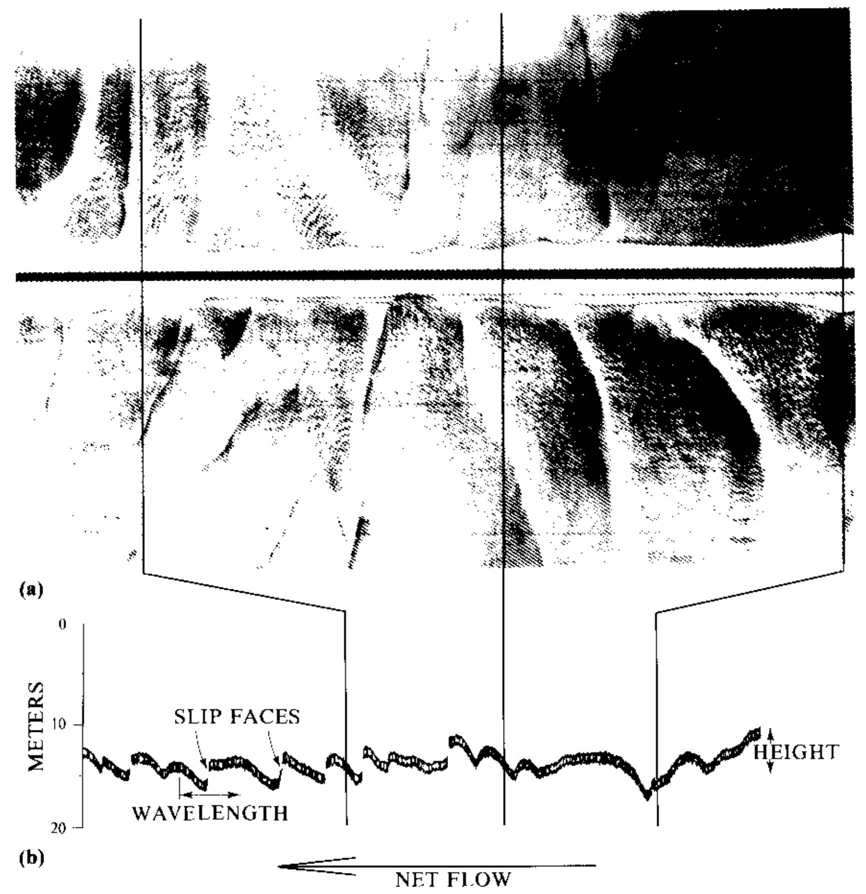


Figure 2-10. Large downriver-oriented bedforms in the main navigation channel near Rice Island (RM-22): (a) side-scan sonar image showing bedforms from above; (b) vertical profile (side view) of bedforms (from an echo sounder) showing bedform wavelength of about 100 meters and height of about 3 meters. Bedforms are oriented downriver, with the net water flow (Sherwood et al. 1984).

The final map (Plate 9, Map b) shows the sedimentary environments in the estuary. These environments were identified using a variety of sources: the sediment distribution maps shown on Plates 6 and 7, the CREDDP bathymetry maps (*Bathymetric Atlas of the Columbia River Estuary*; see Preface), aerial photos, side-scan sonar records, National Oceanic and Atmospheric Administration charts, United States Geological Survey maps, and CREDDP historical habitat maps (*Changes in Columbia River Estuary Habitat Types over the Past Century*; see Preface).

Although the number of samples used for the sediment distribution maps was very large, there remains some uncertainty in the extrapolations. In areas where sediment type is likely to vary over short distances (for instance, near shore, especially when tidal marsh or swamp vegetation alternates with small tidal channels, or in areas with rock outcrops or large sandwaves) the maps are not sufficiently detailed to accurately portray the changes in sediment composition. They do, however, display trends and patterns on an estuary-wide scale that are important in understanding the sedimentology of the estuary. The locations of bedrock or gravel on the bottom were obtained from side-scan sonar records. These records probably underrepresent the actual percentage of rock to be found along some of the sides of the steep channels.

The bedform maps were developed to display the distribution of bedload sediment transport patterns. These maps contain many generalizations. They can predict bedform type location and bedform sediment transport some of the time but they are not sufficient for estimating sediment transport rates.

The sedimentary environment map is based largely on the judgment of the investigators and does not represent the only possible classification scheme for estuarine sediment types. It does, however, combine information from many sources into a generalized view of the estuary's sediment patterns.

Interpretation of the Maps (Plates 6 through 9)

Sediment Distribution (Plate 6 and Plate 7, Map a)

These seasonal maps show the overall pattern of sediment distribution in the Columbia River Estuary. Most of the estuary is covered in either fine or medium sand. The offshore regions, including the outer tidal delta (outer sandbar), and most of the portions of the estuary downriver from RM-6 except for the channel are characterized by fine sand (Table 2-1). Fine sand is also found on most of the large tidal sandflats in the estuary, especially on Sand Island, Desdemona Sands, and Taylor Sands, and the unvegetated tidal flats of Cathlamet Bay. Medium sand predominates in most of the remaining channel areas. This range of sizes, from fine sand to medium sand, falls within the narrow range of source sediments transported into the estuary from the Columbia River.

Coarse sand is generally found along the main navigation channel in the upriver portions of the estuary. This pattern is indicative of the strong currents in that channel region. The coarsest sands were obtained from the deep bathymetric depressions found near some of the bedrock headlands and the dikes and jetties where strong currents scour out deep holes and leave only the coarsest sediments behind. During CREDDP investigations, only a few samples containing any gravel-sized material were recovered, and these were located in the immediate vicinity of rock headlands or their talus (rock debris) slopes.

Only a small fraction of the finer river material (very fine sand, silt, and clay) is retained in the estuary. These sediments are found in the peripheral bays, including Baker Bay, Trestle Bay, Youngs Bay, Cathlamet Bay, and the basin to the east of Tongue Point (MARAD Basin). This is due to the weak currents in these bays. Fine sediments are also found in both small and large channels in samples from some seasons. These channel silts typically exist as thin (two to five centimeter) layers that were deposited over fine to medium well-sorted sands. (Sorting is discussed under Table 2-1).

These fine layers are probably short-lived and are closely related to the behavior of the turbidity maximum (Figure 2-9). The bottom waters in the turbidity maximum contain high concentrations of suspended sediments. When the turbidity maximum is well developed and tidal current activity is reduced, fine sediments (silt and clay) are deposited in a layer. Although evidence is inconclusive, this phenomenon seems to be related to the spring-neap tidal cycle in the Columbia River Estuary (see "Circulation and Salinity"). During neap tides the turbidity maximum is well developed and fine sediment deposition occurs; resuspension results from the stronger currents of the spring tides.

Comparison of the three seasonal maps reveals that the distribution of the coarse to medium sand in which finer sediments predominate varies considerably with season. In the high riverflow season (April through June) a tongue of this sediment type extends downriver along the main navigation channel to approximately Astoria. It then extends to the north channel along broad diagonal channels between Taylor Sands and Desdemona Sands (Plate 6, Map a). In the low riverflow season (July through October), this sediment type is observed in the main navigation channel westward to Tongue Point. Downriver from Tongue Point, however, the distribution becomes patchy along the diagonal channels connecting the main navigation channel and the north channel (Plate 6, Map b). In the fluctuating riverflow season (November through March), the upriver pattern is again similar and continuous nearly to Astoria (RM-13), where it ends without crossing the diagonal channels (Plate 7, Map a). This pattern probably reflects seasonal changes in water transport. During the high and fluctuating riverflow seasons, the coarse sediment moves farther downriver than during the low riverflow season. The tongue of sediment extending diagonally between the large tidal sandflats may indicate an important area of water transport between the north and main navigation channels (see "Circulation and Salinity").

Fine-grained sediments greater than 3 phi (Table 2-1) occur in various distributions in the three seasons. They are most common in the high riverflow season, when they dominate the grain-size distributions in Baker Bay, Youngs Bay, and Cathlamet Bay (Plate 6, Map a). These areas also have predominantly fine-grained sediments in the fluctuating riverflow season (Plate 7, Map a) but in the low riverflow season the extent of the areas with medium sand increases (Plate 6, Map b). This sediment pattern seems unusual since finer-grained sediments occur in areas of weaker currents and the river discharge in the high and fluctuating riverflow seasons is much stronger than in the low riverflow season. The peripheral bays, however, almost always have conditions favorable to the deposition of fine sediments (Figure 2-11). The greatest deposition would be expected to occur when riverflow is high since that is when the supply of fine sediment suspended in the water is greatest.

A distinctive type of sediment, described as rip-up clasts (also called sandy-silt clasts or mudballs), was recovered in numerous samples by CREDDP investigators. The clasts are usually slightly consolidated and disc-shaped with a mean size in the coarse silt range. They are found primarily downriver from Tongue Point, often associated with fine to medium sands. Most of those found upriver from Tongue Point are more highly compacted clays, some of which have root traces. The clasts in the lower estuary are usually associated with the two-layered deposits and the turbidity maximum. CREDDP investigators speculate that these clasts were originally deposited as a fine sediment layer and were subsequently torn up by strong currents (hence, rip-up clasts). The clasts found upriver from the turbidity maximum zone appear to be of different origin and may represent chunks of sediment that have been torn from the riverbanks or from marshes.

Silt Plus Clay Distribution (Plate 7, Map b)

The silt plus clay distribution map differentiates between those areas with greater than or less than 10 percent silt plus clay. An overlap exists where samples obtained from the same area in different seasons fall into different categories. These overlapping regions represent the areas in which seasonal accumulations of fine sediments occur. Silt and clay occur throughout the year only along the margins of the estuary, in the peripheral bays, and among the vegetated islands of the upriver portions of the study area. These areas contain silt and clay because they are sheltered from strong currents.

The limited distribution of silt and clay in the majority of the estuary reflects the strong currents characteristic of the Columbia River Estuary. At times, however, fine-grained sediments appear on some parts of the mid-estuary tidal sandflats (Desdemona Sands, Taylor Sands, and the flats in Cathlamet Bay). Silt and clay also appear on an intermittent basis in the main navigation channel and the north channel and in the smaller channels dissecting the tidal flats. When present in the large channels, fine-grained deposits are confined to the area downriver from Tongue Point; they appear mostly in the main navigational channel between RM-10 and RM-13 and in the north channel between the Chinook pile dike and Cliff Point. This pattern in the main channels is probably related to the activities of the turbidity maximum and the two-layered deposits described earlier.

Bedform Distribution (Plate 8 and Plate 9, Map a)

Much of the estuary bottom is covered with sedimentary bedforms such as ripples, dunes, or sandwaves (Figures 2-10 and 2-12). Virtually all of the channel portions of the estuary are occupied by either large or small bedforms and only a few areas appear to be featureless at the resolution of the side-scan sonar. Several major categories of bedforms were identified and are presented on Plate 8 and Plate 9, Map a. These include unidirectional downriver or upriver-oriented bedforms, and bedforms with reversing orientations.

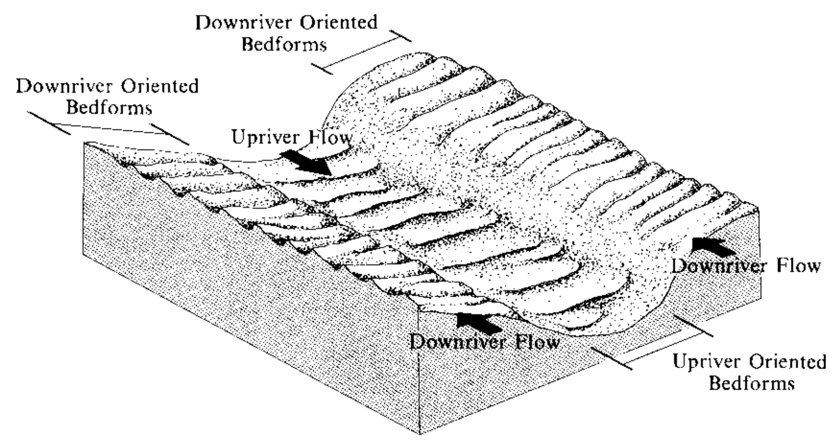


Figure 2-12. Schematic representation of bedforms in a portion of the main navigation channel between Hammond (RM-8) and the Astoria-Megler bridge (RM-14). Bedforms on the channel sides are oriented downriver while those on the channel bottom are oriented upriver (Sherwood et al. 1984).

The unidirectional, downriver-oriented bedforms predominate in the estuary channels upriver from Tongue Point. They are referred to as downriver-oriented because the steeper face (slip-face) of the bedform faces downriver, indicating downstream bedload transport. The orientation of the bedform therefore indicates the direction of net current movement (Figure 2-10). In the deeper channels, these bedforms have heights of up to 3 meters and wavelengths of more than 100 meters. Smaller bedforms are commonly superimposed on the larger bedforms. These also are oriented downriver. Very coarse sediments occupy the troughs of some of the large bedforms. The dominance of downriver-oriented bedforms in the upper estuary is a result of the strong, predominantly downstream currents in this region. This also indicates a prevailing downstream bedload sediment transport.

Generally smaller bedforms that reverse their orientation with the tides are present from the outer tidal delta upriver to Hammond in the main navigation channel and to the vicinity of the Chinook pike dike in the north channel. These areas are occupied by bedforms with wavelengths of approximately three to ten meters, and heights of up to one meter. Reversal of these bedforms over consecutive ebb and flood tides is documented in several instances and the bedforms are commonly oriented with the prevailing current direction. Reorientation coincident with the reversal of tides indicates that the tidal currents are the dominant factor influencing bedload transport in the lower estuary. Because the bedforms reverse, the direction of net bedload sediment movement in this area cannot be determined from the bedform information alone.

In the channels just east of the reversing bedforms described above, bedforms do not reverse orientation; instead, they display upriver-oriented steeper faces over the tidal cycle. The appearance of the bedforms varies with season and location. They range in height from less than 0.3 meter to 2 meters and in wavelength from 3 meters to 40 meters. The degree of asymmetry also varies. Some of the larger bedforms are nearly symmetric and rounded while others are highly asymmetric and have steeper faces. These bedforms suggest a net upstream bedload sediment transport. Smaller bedforms with upriver-oriented steeper faces occupy large portions of both the north and main navigational channels between Hammond and the Astoria-Megler bridge (RM-14). In much of this area, the channel sides and tidal flats are occupied by downriver-oriented bedforms. As a result, there is a reversal of bedform orientation with depth that reflects the estuarine circulation and remains consistent over the tidal cycle (Figure 2-12). At a point farther upriver, upstream sediment transport in deep water ends, converging with normal downriver transport. This is a region of sediment transport convergence and net sediment deposition and is located between Hammond and Astoria in the main navigational channel (Figure 2-11). Flavel Bar (RM-11 to RM-13), a sandbar requiring frequent dredging, is located in this region. This is also approximately the area where the turbidity maximum (Figure 2-9) usually occurs.

The distribution and orientation of bedforms is dynamic and varies seasonally (Plate 8 and Plate 9, Map a). The upriver extent of upriver-oriented bedforms varies in response to river discharge. During the low riverflow season, upriver-oriented bedforms extend nearly to Tongue Point in the main navigation channel and into both forks of the north channel south of Megler (Plate 8, Map b). During the fluctuating riverflow season, the limit of upriver-oriented bedforms in the main navigation and north channels is pushed downriver to just east of the Astoria-Megler bridge (Plate 9, Map a). During the high riverflow season, no upriver-oriented bedforms are found east of Tansy Point in the main navigation channel, while in the north channel the upriver limit of upriver-oriented bedforms is located downriver from the Astoria-Megler bridge (Plate 8, Map a).

Sedimentary Environments (Plate 9, Map b)

The sedimentary environment map summarizes all of the results of the CREDDP sedimentological study. The sedimentary environments are delineated according to the processes operating in each environment and not by any one particular physical characteristic such as sediment grain size.

The classification system and chief characteristics of the environments are summarized in Table 2-2. The most striking feature of the map is the complexity of the sedimentary environments. This emphasizes the dynamic nature of the Columbia River Estuary and the variability in the distribution of its physical properties.

Discussion

Water movement (currents and waves) strongly influences sediment characteristics and processes. Generally, protected bays have finer sediments and a higher percentage of silt and clay than the channels or tidal sandflats. Currents and the related turbidity maximum are apparently responsible for deposits of silt found in the main channels. The characteristics of bedforms emphasize the influence of at least three types of water flow in the estuary. In the portion of the estuary upriver from Tongue Point, the bedforms indicate that riverflow dominates the sediment transport. In the entrance region downriver from Hammond, where the bedforms reverse during a tidal period, the importance of tidal flows is evident. In the portion of the estuary between Tongue Point and Hammond, where upriver-oriented bedforms occur on the channel bottom and downriver-oriented bedforms are seen on the slopes and tidal sandflats, the influence of the two-layered circulation system is clearly important.

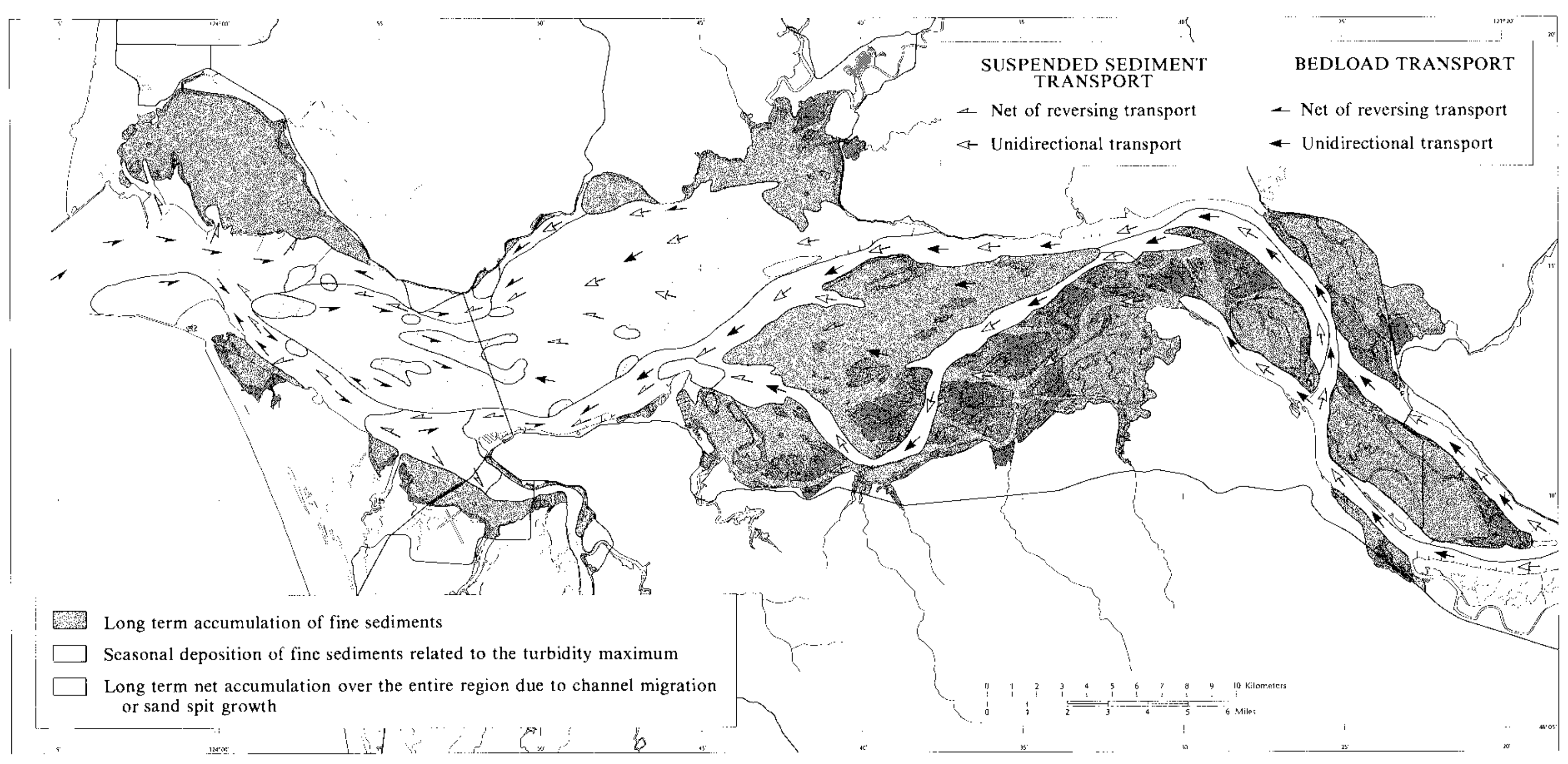


Figure 2-11. Patterns of sediment transport and deposition in the Columbia River Estuary (Sherwood et al. 1984).

Environment	Landform	Sediment Texture	Sorting	Depth below MLLW	Other Characteristics
I. Wave Transport Dominant					
Ocean Beaches and Nearshore	Beach face; berm top	Coarse sand	Well sorted	4 m	Accretion has increased since jetty construction.
II. Wave & Current Transport Combined (high energy)					
A. Exposed Intertidal Flats					
1. Marine (exposed to ocean waves)	Lower estuary beaches	Med.-coarse sand	Well sorted	1 m	Areas have shifted considerably in past 150 years.
2. Brackish or Fresh	Intertidal flats; point bars	Med.-coarse sand	Well sorted	1 m	Areas have shifted considerably in past 150 years.
B. Open Marine (exposed to ocean waves and continental shelf currents)	Outer tidal delta; offshore extension of channel; adjacent continental shelf	Fine sand	Well sorted	1-4 m	Delta has spread seaward since jetty construction; river and shelf circulation determine sediment transport.
III. Wave & Current Transport Combined (low energy)					
A. Protected Tidal Flats					
1. Unvegetated					
a. Marine	Sand and mud flats	Fine sand; silt	Variable	1 m	
b. Brackish or Fresh	Sand and mud flats	Variable	Variable	1 m	Morphology and grain size controlled by fluvial processes.
2. Vegetated					
a. Marine	High and low salt marsh	Fine sand; silt; clay	Poorly sorted	n/a	Low sediment transport rates
b. Brackish or Fresh	High marsh, low marsh & swamp	Variable	Poorly sorted	n/a	Low sediment transport rates
IV. Current Transport Dominant					
A. Tidal Flow Dominant (high energy)					
1. Tidal Shoals and Bars	Subtidal deposition; bedforms	Variable	Variable	1-10 m	High transport rates; reversing or upriver oriented bedforms
2. Small Tidal Channels	Subtidal deposition; bedforms	Med.-fine sand; silt	Variable	6 m	Drains bays and shoals; where isolated, finer sediments present
3. Tidal Channel	Subtidal deposition; bedforms	Med.-fine sand; silt	Variable	10 m	Major conduits for tidal flow; reversing bedforms; active bedload transport
B. Density-Driven Estuarine Circulation Dominant	Estuarine channel	Variable	Variable	10 m	Upriver-oriented bedforms
C. Fluvial Processes Dominant					
1. River Shoals and Bars	Point-bars	Variable	Variable	1-10 m	Downriver-oriented bedforms; high sediment transport rates
2. Shallow River Channels	Side Channels or Sloughs	Variable	Variable	1-6 m	May or may not be active channels
3. Deep River Channels	Large, downriver-oriented bedforms	Coarse-med. sand	Variable	10 m	Fluvial processes dominant; active erosion and deposition
D. Low Energy Depositional					
1. Protected Embayment	Peripheral bays	Fine sand; silt; clay	Poorly sorted	1-10 m	Minimal energy environment; fine sediment accumulation
V. Other Environments					
A. Beach Ridges and Dunes (formed after 1800)	Beaches, dunes	Fine sand	Variable	n/a	Sediments accreted after jetty construction.
B. Beach Ridges and Dunes (formed before 1800)		Fine sand	Variable	n/a	Sediments accreted prior to jetty construction.
C. Bedrock and Talus	Cliffs; headlands	n/a	n/a	n/a	Mostly volcanics and pyroclastics; minimal erosion
D. Lowlands (mostly river floodplain)	Fluvial sediments above MHW	Fine sand; silt, clay	Poorly sorted	n/a	Older floodplains included on map.
E. Emergent Fill	Dikes; filled land	Variable	Variable	Variable	Dredge or other artificial fill.
F. Submerged Fill		Variable	Variable	Variable	Rip-rap; dredge or other artificial fill.
G. Lakes; Ponds; Stagnant Sloughs	Fresh water; low energy	Silt; clay	Poorly sorted	Variable	Lakes are generally depositional.

n/a = not applicable

Table 2-2. Sedimentary environments of the Columbia River Estuary (see Plate 9, Map b) (from Sherwood et al. 1984).

Bedform characteristics can be used to predict deposition and erosion patterns. The most striking pattern described by CREDDP investigators is the apparent convergence of upstream and downstream bedload sediment transport in a zone in the main navigation and north channels between Hammond (RM-8) and Astoria (RM-18) (Figure 2-11), and the coincident occurrence of the turbidity maximum (Figure 2-9). In the Columbia, as in many other estuaries, this zone shifts upriver and downriver in response to changing tides and riverflow, although the range of this shift is probably much greater in the Columbia.

In addition to the convergence zone occuring in the main navigation and north channels, two other depositional patterns in the Columbia River Estuary are mapped in Figure 2-11. The first occurs in the comparatively quiet peripheral bays and embayments that have a long-term accumulation of fine sediment due to weak current conditions. A second pattern of sediment deposition occurs in areas with a long-term net accumulation of sediment due to channel migration or sandspit growth. These areas are located throughout the estuary and are almost wholly the result of man-made channel training structures or channel dredging activities.

Submerged sandbars, tidal sandflats, and islands are very characteristic features of the Columbia River Estuary and they also reflect sedimentary and water circulation processes. Desdemona Sands and Taylor Sands are products of the complex interactions of extremely variable tidal flows, riverflow, and windwaves. Tidal sandflats and submerged sandbars of similar form are unusual among the world's estuaries. The Cathlamet Bay islands, on the other hand, seem to display a more typical morphology (Figure 2-13). As a result of predominant downstream flow, the islands' upriver edges are steep and erosional, while the downriver edges slope gently and tend toward deposition.

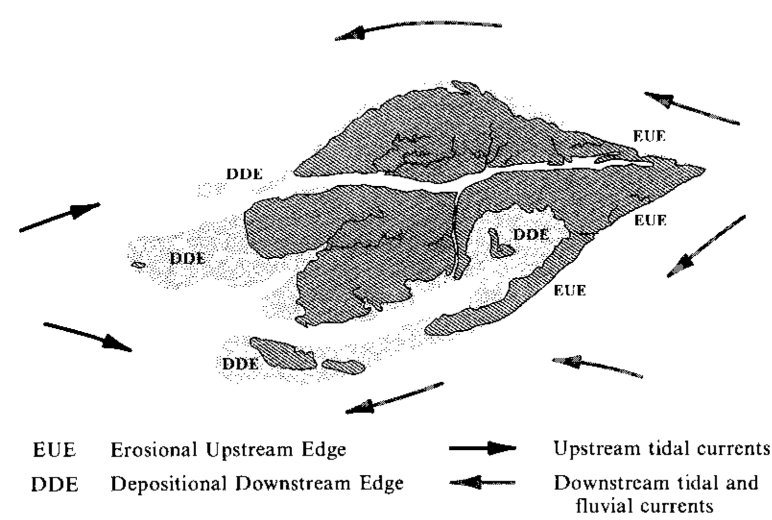
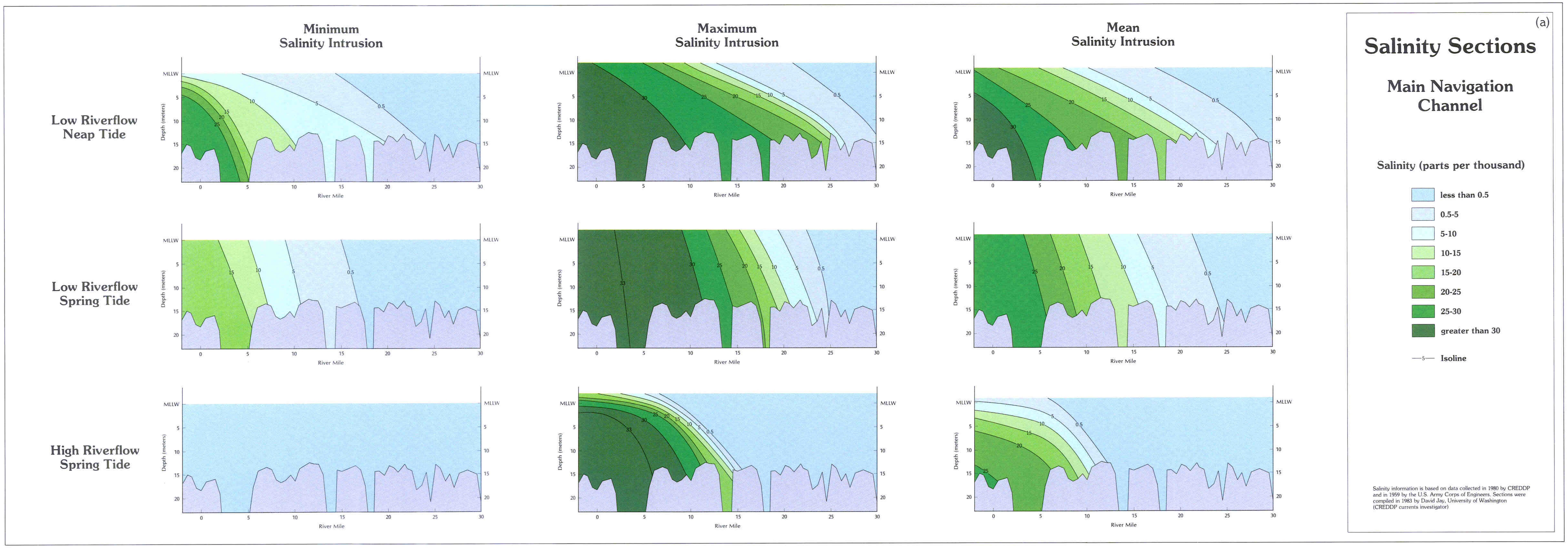
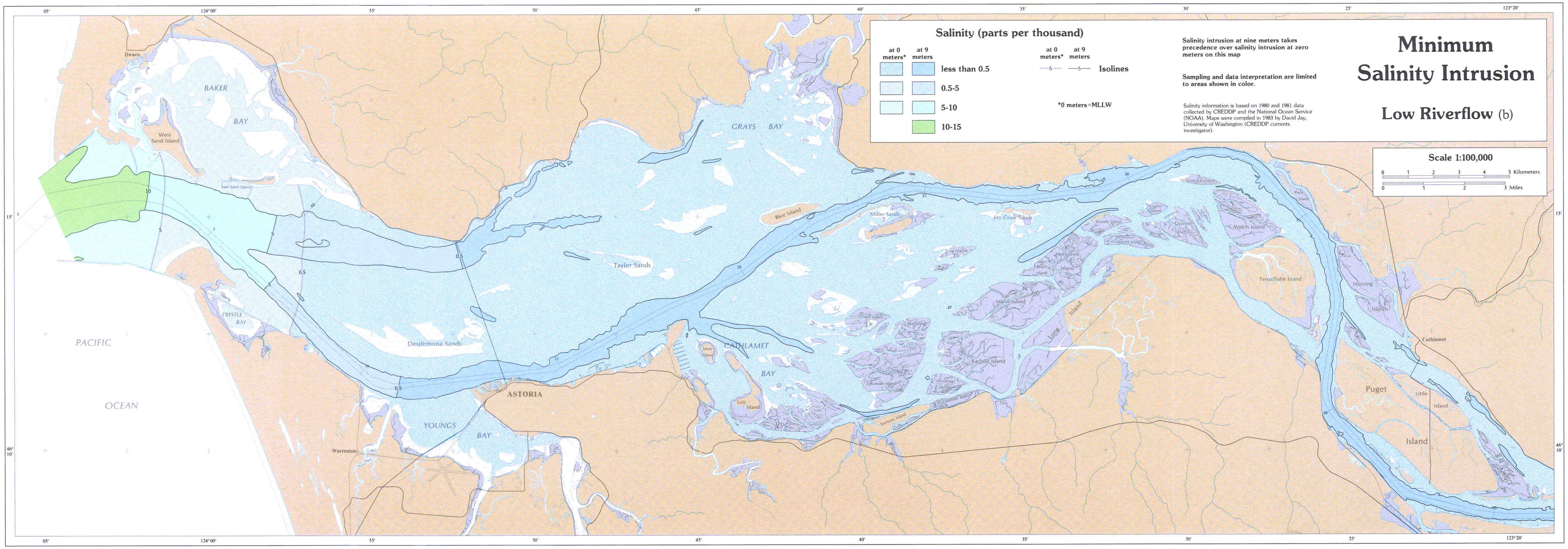


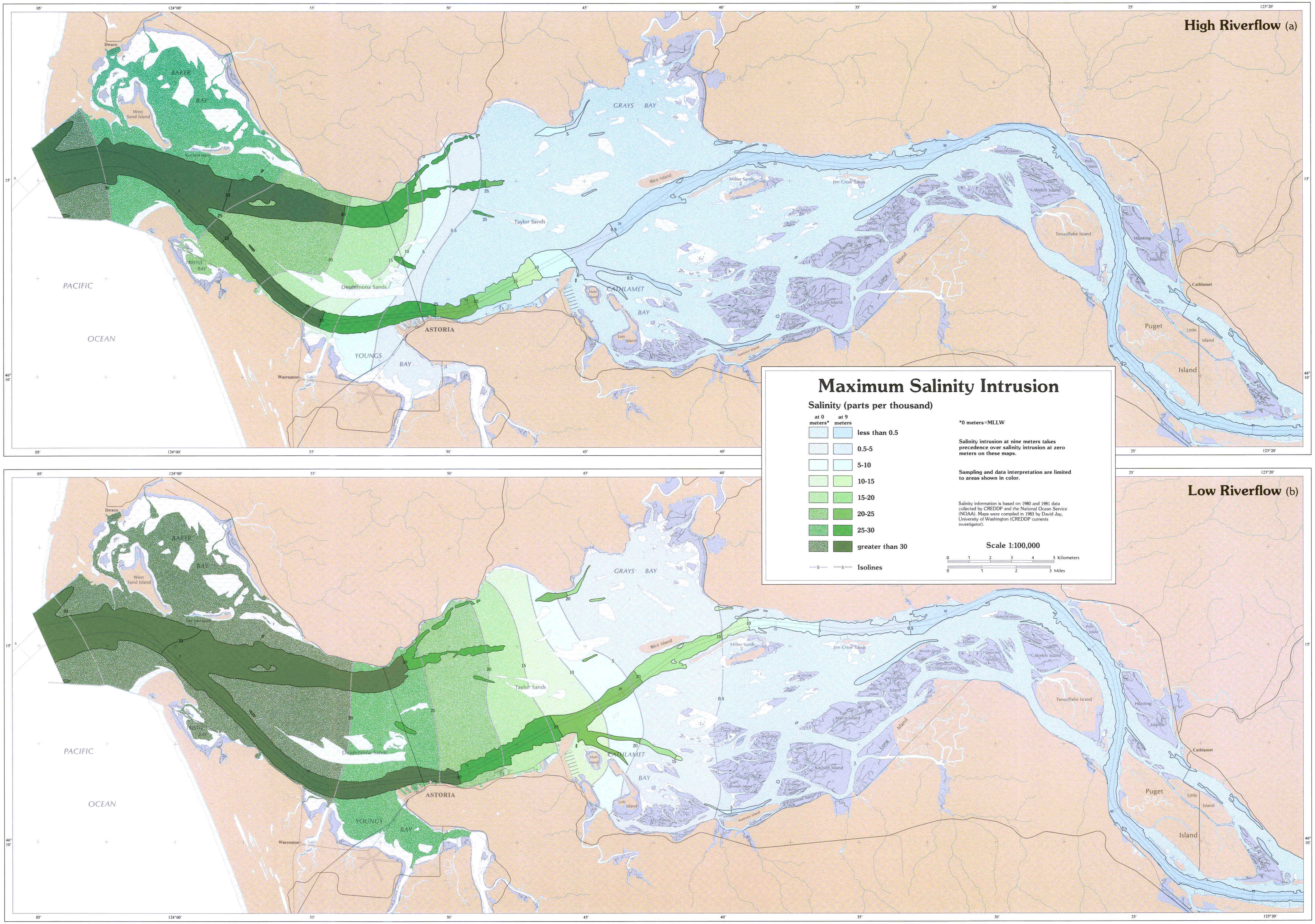
Figure 2-13. Patterns of sediment deposition and erosion on a vegetated island in Cathlamet Bay. The upriver portion (right of diagram) is subject to erosion while the downriver portion is subject to deposition (note tidal flats) (Sherwood et al. 1984).

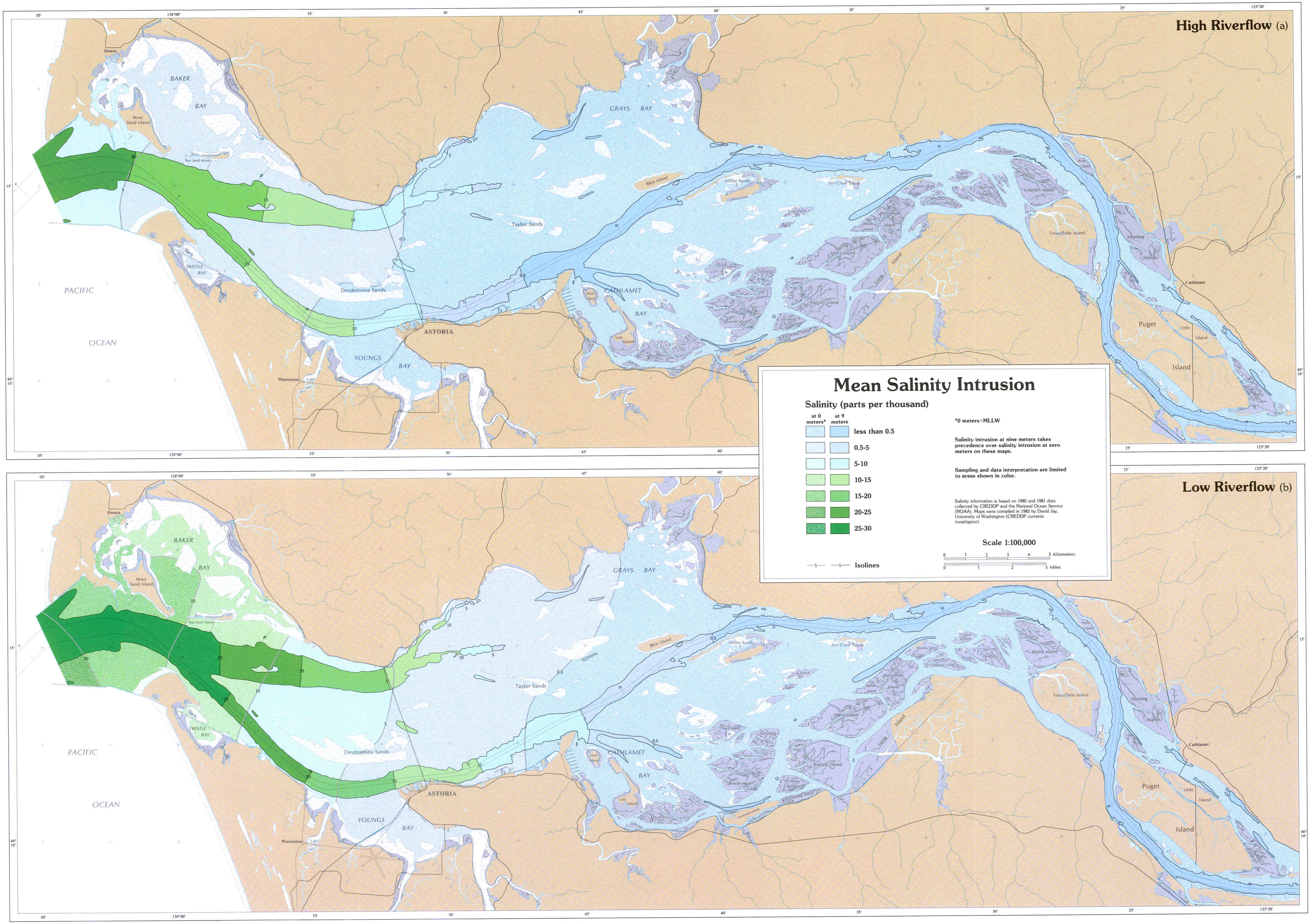
Sedimentary environments affect many of the biological characteristics of the estuary. Benthic infauna and epibenthic organisms (see those sections in Chapter 4) are closely tied to the sediments, so that their adaptations and feeding behavior are often explained in terms of sediment association. The stability of the sediments, or how easily the sediments are mixed, is a key factor in determining the productivity of benthic diatoms on the estuary's tidal flats (see "Benthic Primary Producers"). The morphological characteristics of the vegetated islands can determine the distribution of tidal marsh communities. Typically, an upriver edge of an island is higher than the downriver, and a community consisting of species adapted to infrequent tidal inundation is found along the upriver edge while one with species adapted to frequent tidal inundation is found on the downriver side (see "Tidal Marshes and Swamps").

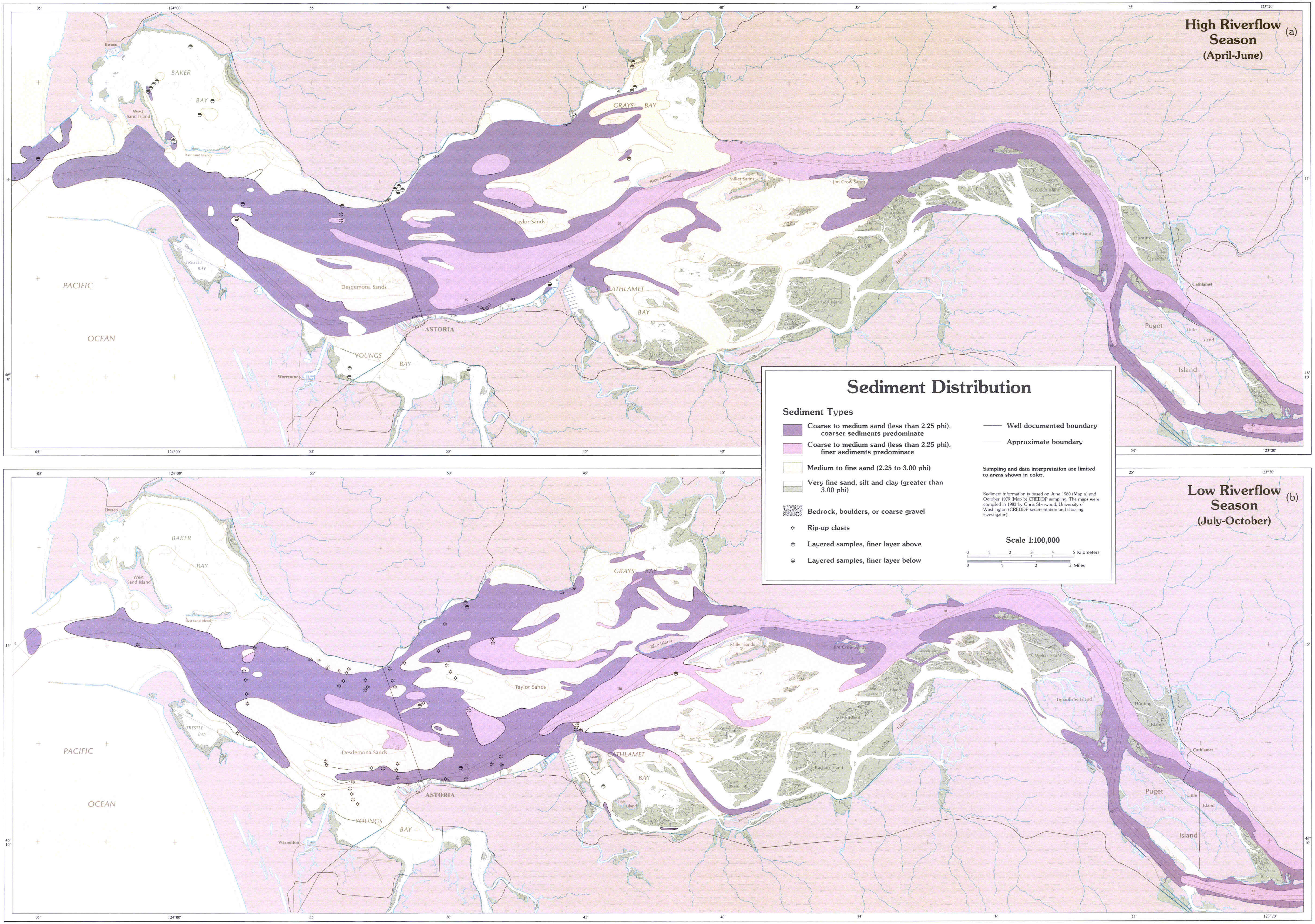
Biological effects can have an indirect effect on human activities. However, sediment type and transport have a direct effect on human use of the estuary. In areas of sediment transport convergence such as Flavel Bar, the U.S. Army Corps of Engineers has to conduct very frequent and expensive dredging operations to keep the main navigation channel open to shipping. Jetties, pile dikes, and other channel training structures have been placed in many locations in the estuary to prevent sediment deposition. While helping to solve the nearby navigation problems, these structures often cause sediment deposition elsewhere in the estuary.

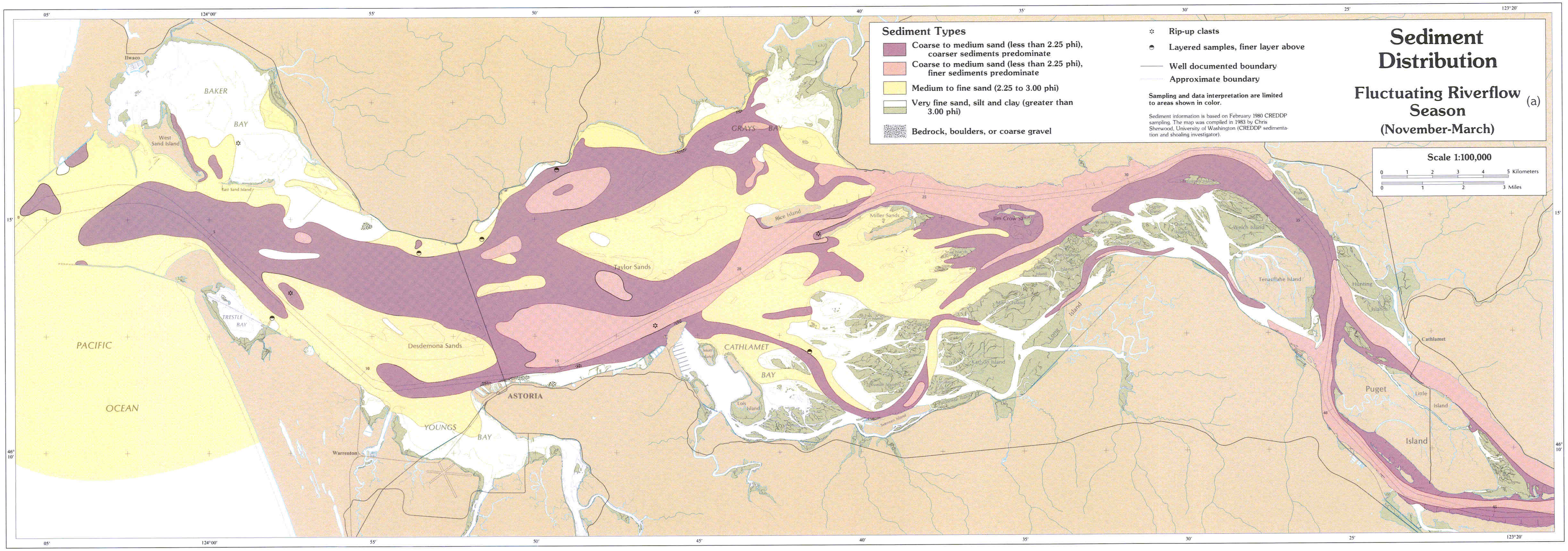

(a)
Salinity Sections
Main Navigation Channel
Minimum Salinity Intrusion
Maximum Salinity Intrusion
Mean Salinity Intrusion
Low Riverflow Neap Tide
Low Riverflow Spring Tide
High Riverflow Spring Tide
MLLW
Depth (meters)
River Mile
Salinity (parts per thousand)
less than 0.5
0.5-5
5-10
10-15
15-20
20-25
25-30
greater than 30
Isoline
Salinity information is based on data collected in 1980 by CREDDP and in 1959 by the U.S. Army Corps of Engineers. Sections were compiled in 1983 by David Jay, University of Washington (CREDDP currents investigator)

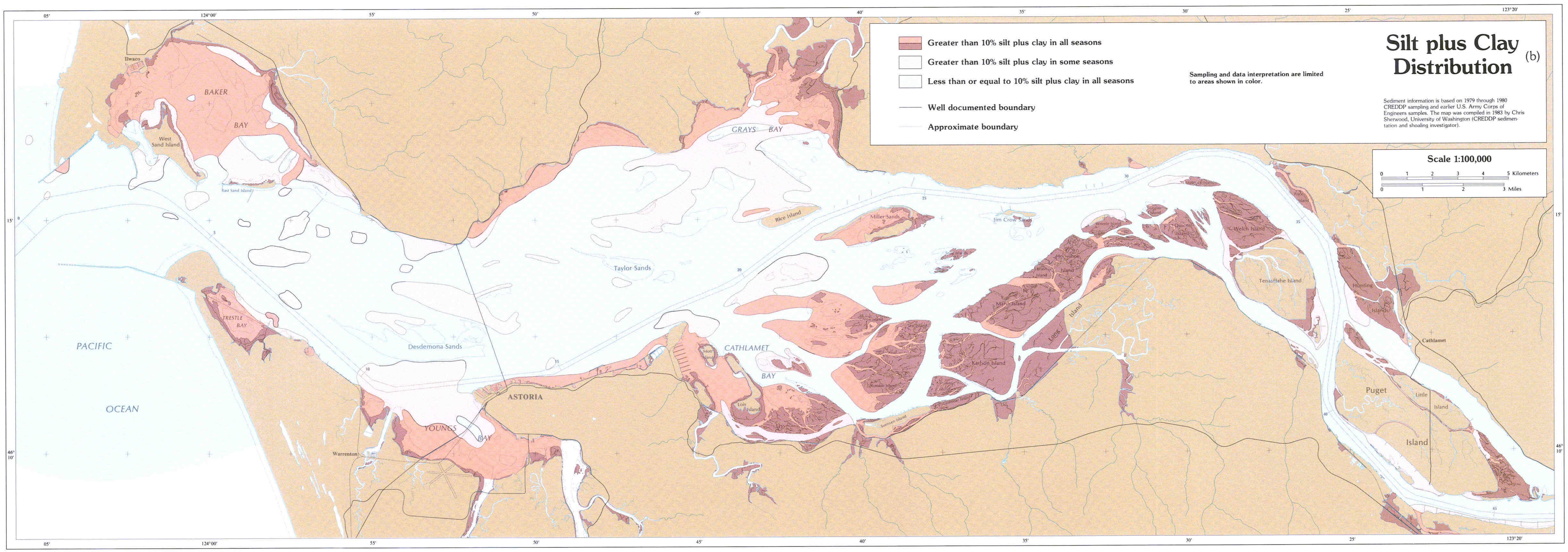

Minimum Salinity Intrusion
Low Riverflow (b)
Salinity (parts per thousand)
at 0 meters*
at 9 meters
less than 0.5
0.5-5
5-10
10-15
Isolines
*0 meters=MLLW
Salinity intrusion at nine meters takes precedence over salinity intrusion at zero meters on this map
Sampling and data interpretation are limited to areas shown in color.
Salinity information is based on 1980 and 1981 data collected by CREDDP and the National Ocean Service (NOAA). Maps were compiled in 1983 by David Jay, University of Washington (CREDDP currents investigator).
Scale 1:100,000
Kilometers
Miles
BAKER BAY
West Sand Island
GRAYS BAY
Rice Island
Taylor Sands
Desdemona Sands
PACIFIC OCEAN
ASTORIA
YOUNGS BAY
Warrenton
TRESTLE BAY
CATHLAMET BAY
Jim Crow Sands
Tenasillahe Island
Cathlamet
Puget Island
Long Island
Ilwaco

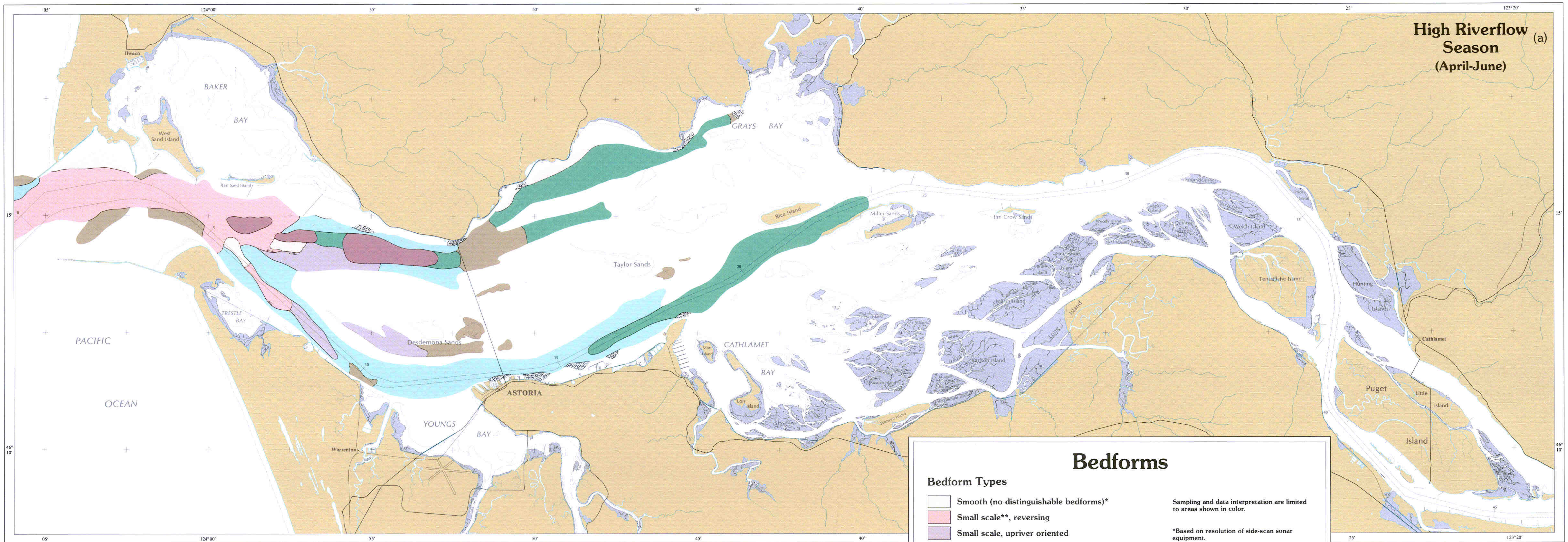

High Riverflow (a)
Low Riverflow (b)
Maximum Salinity Intrusion
Salinity (parts per thousand)
at 0 meters*
at 9 meters
less than 0.5
0.5-5
5-10
10-15
15-20
20-25
25-30
greater than 30
Isolines
*0 meters=MLLW
Salinity intrusion at nine meters takes precedence over salinity intrusion at zero meters on these maps.
Sampling and data interpretation are limited to areas shown in color.
Salinity information is based on 1980 and 1981 data collected by CREDDP and the National Ocean Service (NOAA). Maps were compiled in 1983 by David Jay, University of Washington (CREDDP currents investigator).
Scale 1:100,000
Kilometers
Miles
PACIFIC
OCEAN
BAKER
BAY
West Sand Island
Ilwaco
Warrenton
ASTORIA
YOUNGS
BAY
Desdemona Sands
Taylor Sands
GRAYS BAY
Rice Island
Miller Sands
Jim Crow Sands
CATHLAMET
BAY
Tenasillahe Island
Welch Island
Hunting Islands
Cathlamet
Puget
Island
Little Island
124°00'
123°20'


High Riverflow (a)
Low Riverflow (b)
Mean Salinity Intrusion
Salinity (parts per thousand)
at 0 meters*
at 9 meters
less than 0.5
0.5-5
5-10
10-15
15-20
20-25
25-30
Isolines
*0 meters=MLLW
Salinity intrusion at nine meters takes precedence over salinity intrusion at zero meters on these maps.
Sampling and data interpretation are limited to areas shown in color.
Salinity information is based on 1980 and 1981 data collected by CREDDP and the National Ocean Service (NOAA). Maps were compiled in 1983 by David Jay, University of Washington (CREDDP currents investigator).
Scale 1:100,000
5 Kilometers
3 Miles
PACIFIC
OCEAN
BAKER
BAY
Ilwaco
West Sand Island
GRAYS BAY
Taylor Sands
Desdemona Sands
ASTORIA
YOUNGS
BAY
Warrenton
TRESTLE BAY
CATHLAMET
BAY
Rice Island
Miller Sands
Jim Crow Sands
Welch Island
Tenasillahe Island
Hunting Islands
Cathlamet
Puget
Island
Little Island
Long Island
Karlson Island
Marsh Island
Lois Island


High Riverflow Season (a)
(April-June)
Low Riverflow Season (b)
(July-October)
Sediment Distribution
Sediment Types
Coarse to medium sand (less than 2.25 phi), coarser sediments predominate
Coarse to medium sand (less than 2.25 phi), finer sediments predominate
Medium to fine sand (2.25 to 3.00 phi)
Very fine sand, silt and clay (greater than 3.00 phi)
Bedrock, boulders, or coarse gravel
Rip-up clasts
Layered samples, finer layer above
Layered samples, finer layer below
Well documented boundary
Approximate boundary
Sampling and data interpretation are limited to areas shown in color.
Sediment information is based on June 1980 (Map a) and October 1979 (Map b) CREDDP sampling. The maps were compiled in 1983 by Chris Sherwood, University of Washington (CREDDP sedimentation and shoaling investigator).
Scale 1:100,000
0 1 2 3 4 5 Kilometers
0 1 2 3 Miles
PACIFIC
OCEAN
BAKER
BAY
West Sand Island
TRESTLE BAY
Desdemona Sands
Taylor Sands
ASTORIA
YOUNGS
BAY
Warrenton
GRAYS
BAY
Rice Island
Miller Sands
Jim Crow Sands
CATHLAMET
BAY
Welch Island
Tenasillahe Island
Hunting Islands
Puget
Island
Little Island
Cathlamet
Ilwaco


Sediment Distribution
Fluctuating Riverflow Season (a)
(November-March)
Sediment Types
Coarse to medium sand (less than 2.25 phi), coarser sediments predominate
Coarse to medium sand (less than 2.25 phi), finer sediments predominate
Medium to fine sand (2.25 to 3.00 phi)
Very fine sand, silt and clay (greater than 3.00 phi)
Bedrock, boulders, or coarse gravel
Rip-up clasts
Layered samples, finer layer above
Well documented boundary
Approximate boundary
Sampling and data interpretation are limited to areas shown in color.
Sediment information is based on February 1980 CREDDP sampling. The map was compiled in 1983 by Chris Sherwood, University of Washington (CREDDP sedimentation and shoaling investigator).
Scale 1:100,000
0 1 2 3 4 5 Kilometers
0 1 2 3 Miles
BAKER BAY
West Sand Island
East Sand Island
Ilwaco
GRAYS BAY
Rice Island
Miller Sands
Jim Crow Sand
Taylor Sands
Desdemona Sands
TRESTLE BAY
PACIFIC OCEAN
ASTORIA
YOUNGS BAY
Warrenton
CATHLAMET BAY
Lois Island
Karlson Island
Tenasillahe Island
Cathlamet
Puget Island
Little Island
124°00′
123°20′


Silt plus Clay Distribution (b)
Greater than 10% silt plus clay in all seasons
Greater than 10% silt plus clay in some seasons
Less than or equal to 10% silt plus clay in all seasons
Well documented boundary
Approximate boundary
Sampling and data interpretation are limited to areas shown in color.
Sediment information is based on 1979 through 1980 CREDDP sampling and earlier U.S. Army Corps of Engineers samples. The map was compiled in 1983 by Chris Sherwood, University of Washington (CREDDP sedimentation and shoaling investigator).
Scale 1:100,000
0 1 2 3 4 5 Kilometers
0 1 2 3 Miles
BAKER BAY
West Sand Island
East Sand Island
Ilwaco
GRAYS BAY
Rice Island
Miller Sands
Jim Crow Sand
Taylor Sands
Desdemona Sands
TRESTLE BAY
PACIFIC OCEAN
ASTORIA
YOUNGS BAY
Warrenton
CATHLAMET BAY
Lois Island
Karlson Island
Tenasillahe Island
Cathlamet
Puget Island
Little Island
124°00′
123°20′



Bedforms

Bedform Types

- Smooth (no distinguishable bedforms)*
- Small scale**, reversing
- Small scale, upriver oriented
- Small scale, downriver oriented
- Large scale**, upriver oriented or symmetrical
- Large scale, downriver oriented
- Patchy or indistinct bedforms
- Bedrock, boulders, or coarse gravel
- Scarp
- Well documented boundary
- Approximate boundary

Sampling and data interpretation are limited to areas shown in color.

***Based on resolution of side-scan sonar equipment.**

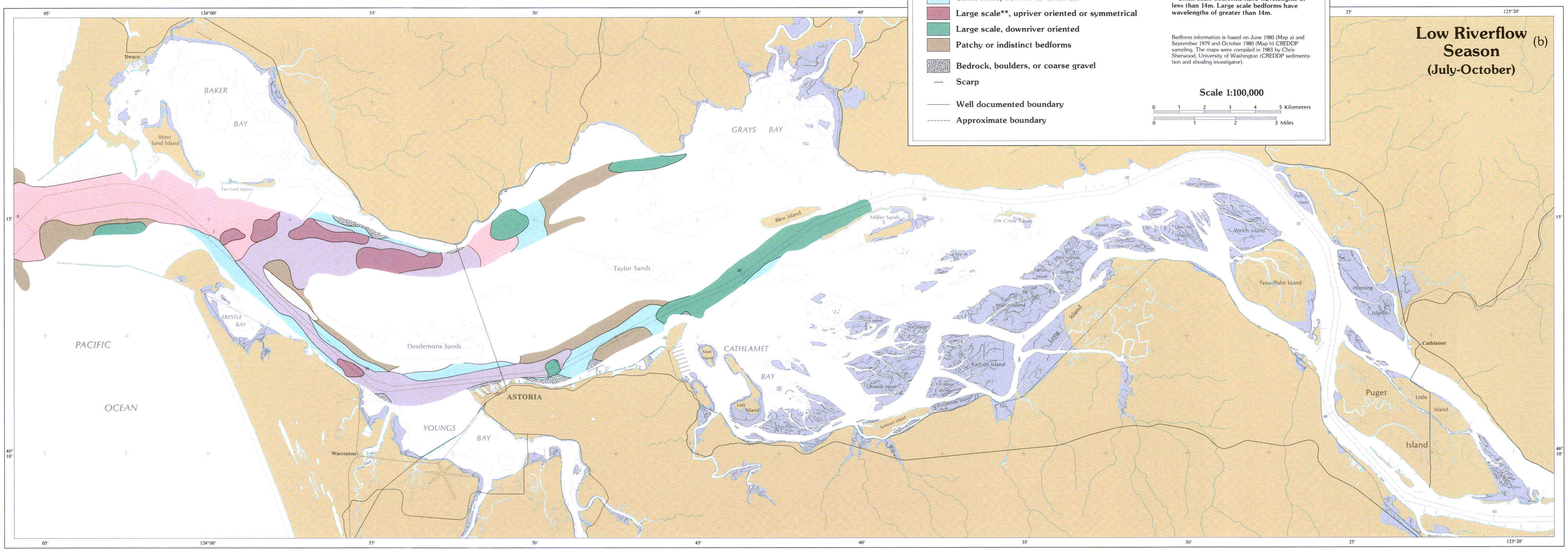
****Small scale bedforms have wavelengths of less than 14m. Large scale bedforms have wavelengths of greater than 14m.**

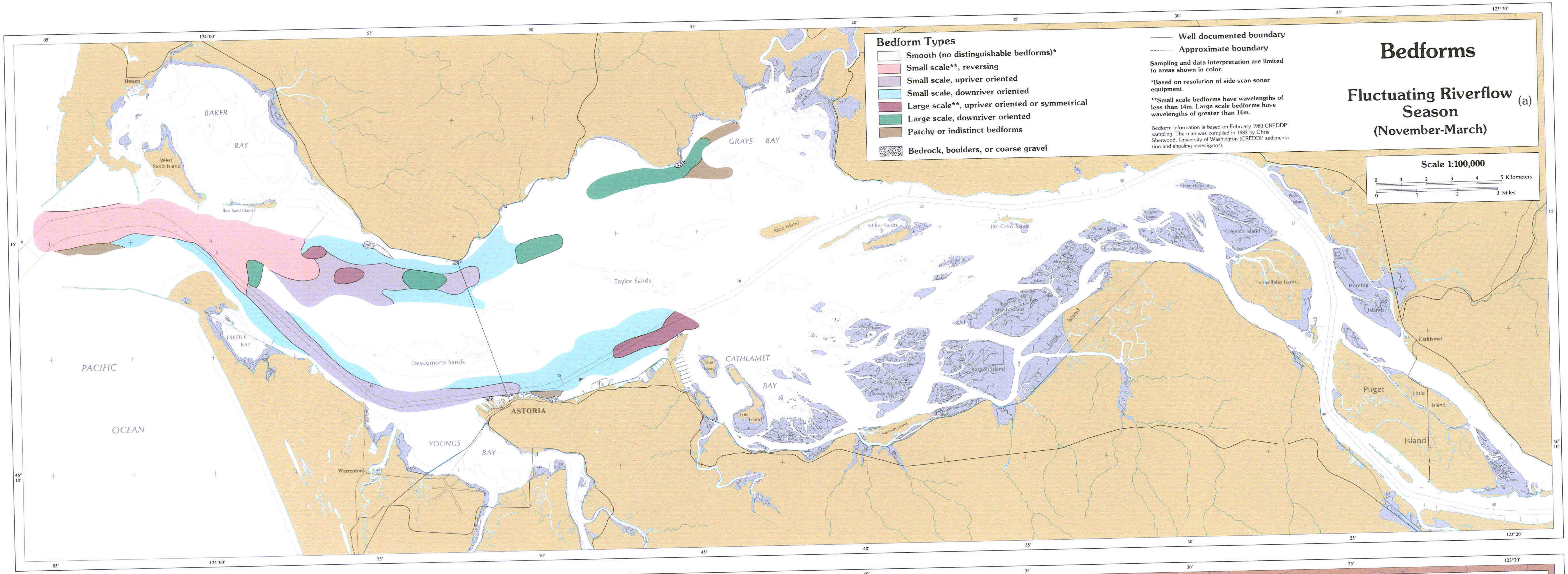
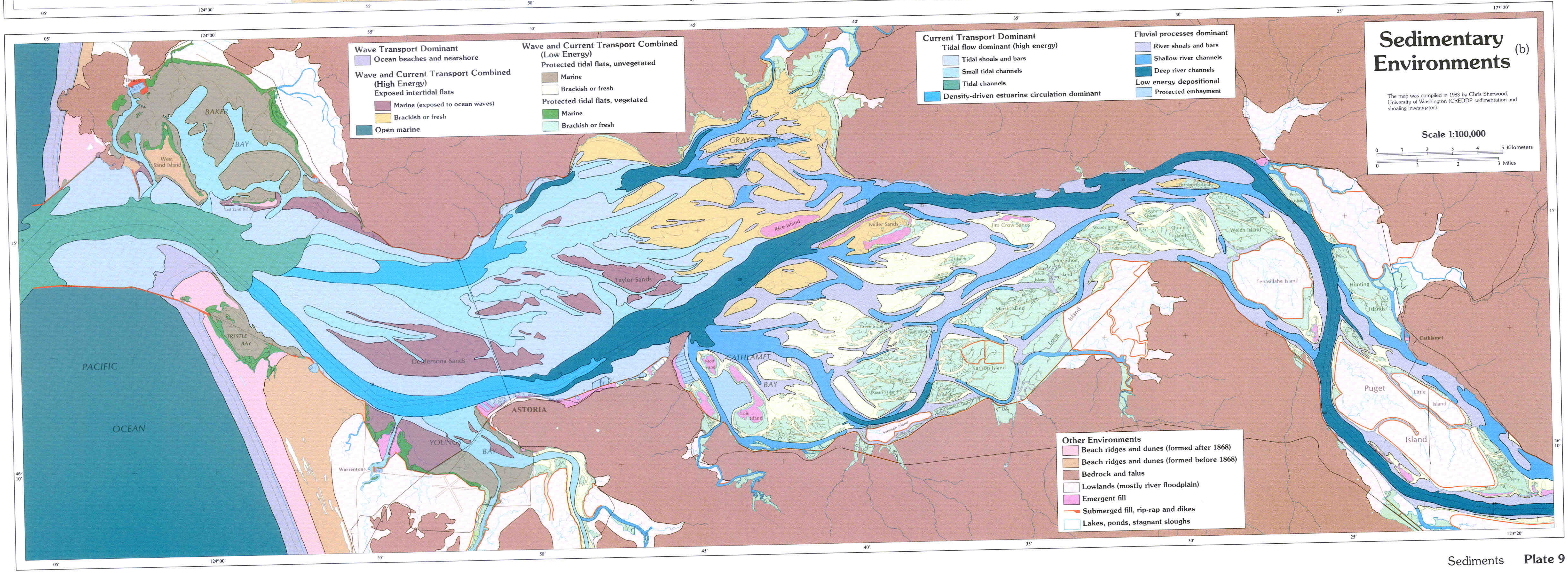
Bedform information is based on June 1980 (Map a) and September 1979 and October 1980 (Map b) CREDDP sampling. The maps were compiled in 1983 by Chris Sherwood, University of Washington (CREDDP sedimentation and shoaling investigator).

Scale 1:100,000

0 1 2 3 4 5 Kilometers

0 1 2 3 Miles




Bedforms
Fluctuating Riverflow Season (a)
(November-March)
Bedform Types
Smooth (no distinguishable bedforms)*
Small scale**, reversing
Small scale, upriver oriented
Small scale, downriver oriented
Large scale**, upriver oriented or symmetrical
Large scale, downriver oriented
Patchy or indistinct bedforms
Bedrock, boulders, or coarse gravel
Well documented boundary
Approximate boundary
Sampling and data interpretation are limited to areas shown in color.
*Based on resolution of side-scan sonar equipment.
**Small scale bedforms have wavelengths of less than 14m. Large scale bedforms have wavelengths of greater than 14m.
Bedform information is based on February 1980 CREDDP sampling. The map was compiled in 1983 by Chris Sherwood, University of Washington (CREDDP sedimentation and shoaling investigator).
Scale 1:100,000
Kilometers
Miles
BAKER
BAY
West Sand Island
GRAYS BAY
PACIFIC
OCEAN
TRESTLE BAY
Desdemona Sands
Taylor Sands
ASTORIA
YOUNGS
BAY
Warrenton
CATHLAMET
BAY
Rice Island
Miller Sands
Jim Crow Sands
Tenasillahe Island
Welch Island
Karlson Island
Puget
Island
Cathlamet

Sedimentary Environments (b)
The map was compiled in 1983 by Chris Sherwood, University of Washington (CREDDP sedimentation and shoaling investigator).
Scale 1:100,000
Kilometers
Miles
Wave Transport Dominant
Ocean beaches and nearshore
Wave and Current Transport Combined (High Energy)
Exposed intertidal flats
Marine (exposed to ocean waves)
Brackish or fresh
Open marine
Wave and Current Transport Combined (Low Energy)
Protected tidal flats, unvegetated
Marine
Brackish or fresh
Protected tidal flats, vegetated
Marine
Brackish or fresh
Current Transport Dominant
Tidal flow dominant (high energy)
Tidal shoals and bars
Small tidal channels
Tidal channels
Density-driven estuarine circulation dominant
Fluvial processes dominant
River shoals and bars
Shallow river channels
Deep river channels
Low energy depositional
Protected embayment
Other Environments
Beach ridges and dunes (formed after 1868)
Beach ridges and dunes (formed before 1868)
Bedrock and talus
Lowlands (mostly river floodplain)
Emergent fill
Submerged fill, rip-rap and dikes
Lakes, ponds, stagnant sloughs
BAKER
BAY
West Sand Island
GRAYS BAY
PACIFIC
OCEAN
TRESTLE BAY
Desdemona Sands
Taylor Sands
ASTORIA
YOUNGS
BAY
Warrenton
CATHLAMET
BAY
Rice Island
Miller Sands
Jim Crow Sands
Tenasillahe Island
Welch Island
Karlson Island
Puget
Island
Cathlamet

Chapter 3.

PRIMARY PRODUCERS

Because all living material originates with plants, they are called primary producers, and the process of plant growth is called primary production (see Chapter 1). Primary producers in the Columbia River Estuary can be grouped into three major types: single-celled plants that float at all depths in the water; single-celled plants that grow on the tidal flats; and grasses, sedges, trees, and other many-celled plants that inhabit the estuary's tidal marshes and swamps. These three types were the subject of separate CREDDP investigations and each is described separately in this chapter. Many-celled plants that live below the surface of the water such as eelgrass and seaweeds (large algae) are not common in the Columbia River Estuary and were not studied by CREDDP investigators. These submerged aquatic plants are considered to be typical flora for many estuaries, but conditions in the Columbia do not favor them.

The single-celled plants in the estuary are among the simplest and most primitive members of the plant world. Those that float in the water are called phytoplankton ("phyto" means plant; "plankton" refers to organisms that are suspended in the water and drift passively). In the Columbia River Estuary, most of the phytoplankton are diatoms, algae which have siliceous cell walls resembling glass. Diatoms also grow on the tidal flats of the estuary, where they are called benthic primary producers ("benthic" refers to the bottom of a body of water). Marsh and swamp plants are much more complex than diatoms, having roots, stems, and leaves. These plants inhabit the higher-elevation environments of the estuary, environments which are covered with tidal water for shorter periods than the tidal flats. The habitats of these three major plant types are shown in Figure 3-1.

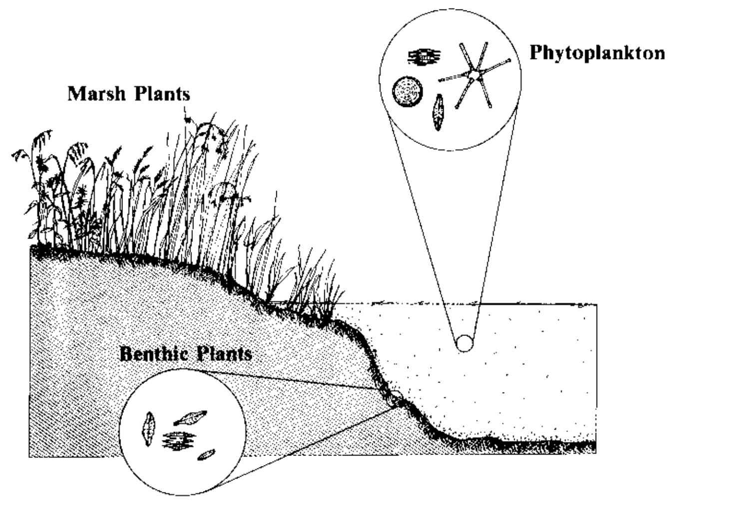


Figure 3-1. Habitats of three major plant types in the Columbia River Estuary.

Primary production occurs through the process of photosynthesis, which requires the green pigment chlorophyll. When light strikes a molecule of chlorophyll, a complex series of reactions occurs which produces organic compounds. These compounds are used by the plant to fuel its metabolic processes and to grow more plant tissue or create more plant cells. The raw material for these organic compounds comes largely from nutrients in the water and from carbon dioxide; oxygen is a byproduct of the process.

Estuarine researchers are interested in the amount of plant material (plant biomass) produced in the estuary because this material helps provide food for estuarine animals. Biomass may be expressed as the weight of fresh or dried plant material. Since all organic compounds are carbon-based, it is often useful to describe biomass in terms of amounts of carbon. This can be accomplished by multiplying the weight of the plant material by its known carbon content. For example, it is known that about 40 percent of marsh plant dry weight is carbon; thus, multiplying dry weight by 0.4 yields an estimate of the amount of carbon in the marsh plant material. The biomass present per specified unit of area is the standing crop, which is expressed as fresh or dried plant weight (or carbon weight) per unit of area (for example, per square meter).

While biomass and standing crop indicate the amount of plant material present at a specific time, productivity refers to the amount of plant material produced over a period of time, that is, the rate of primary production. It is expressed as fresh or dried plant weight or grams of carbon produced per unit of area per unit of time (for example, per square meter per hour or per square meter per year). The total amount of organic material produced by plants over a period of time is referred to as gross primary productivity. Some of this material, however, must be used by the plants for their own metabolic needs. When the metabolic requirements are subtracted from gross primary productivity, the result is net primary productivity. Net primary productivity is a more useful measure for some purposes because it expresses the rate of production of plant material available to consumers.

Several factors determine how much primary production can occur. First among these is the availability of light, which depends on cloud cover, length of day, angle of the sun, and (for underwater plants) the amount and turbidity of overlying water. The availability of raw materials and nutrients needed to support plant growth is also important; besides water and carbon dioxide, which are superabundant, the most importat of these raw materials often are the nutrients nitrogen, phosphorus, and silica. Sometimes trace elements such as iron, copper, zinc, cobalt, and others are important. A third set of influential factors consists of physical characteristics such as temperature and salinity.

Primary producers are consumed by animals either as living plants or in a dead or partially decomposed condtion. The dead and decaying remains of plants, as well as those of other types of organisms, are collectively referred to as detritus. Detritus provides food for many animals in the estuary, principally invertebrates, and is most often consumed after the decaying material has broken into very small particles. These detrital particles can drift in the water column along with the phytoplankton or settle on the bottom and become part of the bottom sediments.

Primary production occurring within the Columbia River Estuary varies among the three main types of plants. Depending on the region of the estuary, marsh plants produce from 237 to 702 grams of carbon per square meter per year ($gC/m^2/yr$), phytoplankton from 31 to 72 $gC/m^2/yr$, and benthic diatoms from 3 to 70 $gC/m^2/yr$ (Figure 3-2). By comparison agricultural lands around the world produce from 25 to 1,000 $gC/m^2/yr$.

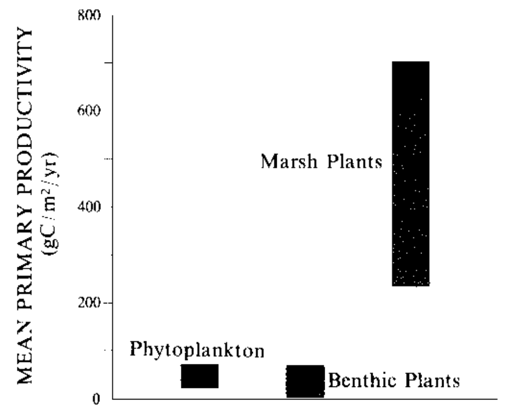


Figure 3-2. Ranges of annual net primary productivity for phytoplankton, benthic plants, and marsh plants of the Columbia River Estuary. The ranges shown here are for regional mean values, which were derived by grouping the data from the sampling sites according to the regions described in Chapter 7 (from Simenstad et al. 1984).

Although marsh plant productivity per square meter is higher than phytoplankton productivity, the total production of marshes is lower. This is because the area occupied by marshes is much smaller than the total open water area. The total primary production rate of the whole 41,200 hectares (101,750 acres) of the Columbia River estuarine ecosystem is about 30,000 metric tons (33,000 tons) of plant carbon per year. Of this, about 38 percent is produced by marsh plants, 57 percent by phytoplankton, and 5 percent by benthic diatoms.

The primary production occurring within the estuary combined with the imports of detritus and phytoplankton originating upriver make up the total primary carbon supply of the estuary. The 30,000 metric tons of carbon produced per year within the estuary is small compared with the tonnage imported from upriver. CREDDP investigators have estimated that the total carbon contribution from upriver amounts to 184,000 metric tons per year, or about 86 percent of the estuary's total annual carbon supply. The relative fractions of all the carbon sources to the estuary are shown in Figure 3-3. CREDDP investigators suggest that a large portion of this carbon is flushed from the estuary into the ocean. The remainder is either consumed within the estuary or is buried and decomposed within the sediments.

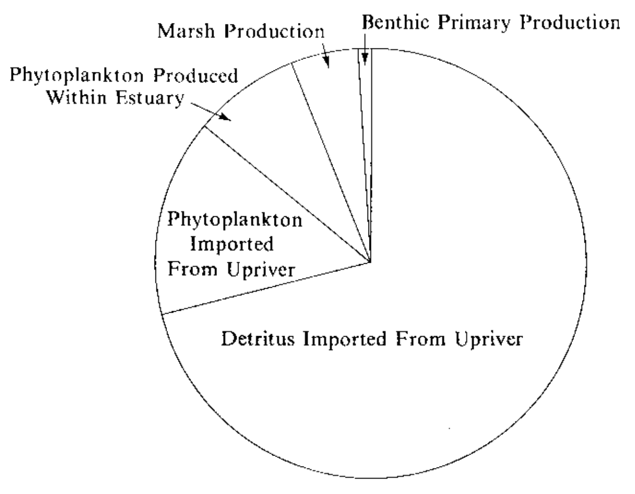


Figure 3-3. Sources of organic carbon in the Columbia River Estuary. Proportions of total carbon produced in the estuary, (white area), are based on estimates of the total annual net primary production of phytoplankton, marsh plants, and benthic primary producers. Proportions of total imported carbon, (gray area), are based on estimates of particulate detritus and phytoplankton introduced annually into the estuary from upriver (from Simenstad et al. 1984).

Phytoplankton

Phytoplankton are single-celled plants that float at all depths in the water. Their position is determined almost solely by the estuarine currents that carry them. The strong and turbulent downstream flows tend to move phytoplankton through the estuary and at the same time circulate them between the surface water and deep water. Those that remain in the surface water for relatively long periods receive enough sunlight to survive and reproduce; those that happen to be in the darker deep waters for long periods die and become part of the estuarine detritus. Both living phytoplankton and detritus of phytoplankton origin provide food for many of the estuary's invertebrates.

Most of the phytoplankton in the Columbia River Estuary are diatoms, some of which are shown in Figure 3-4. Although diatoms can grow as long as one millimeter, those in the Columbia River Estuary are generally less than thirty-three micrometers long (one thirtieth the diameter of the period at the end of this sentence). Diatoms reproduce by simple cell division and can divide as often as once a day when growing conditions are favorable.

The phytoplankton community of the Columbia River Estuary consists mainly of freshwater diatoms which originate upriver. On the average, only about one third of the estuary's phytoplankton are the products of cell divisions that have taken place in the estuary, while the remainder are produced upriver and brought into the estuary by the riverflow. Thus, the community in the estuary is principally an extension of the riverine community. There is also a small community of marine phytoplankton near the mouth of the estuary.

Factors Affecting Productivity

The most important factor determining the productivity of phytoplankton in the Columbia River Estuary is the availability of light. Season and cloud cover determine the amount of light reaching the water surface, while water clarity determines the amount of light penetrating below the surface. The water of the Columbia River Estuary, like that of many other estuaries, is very turbid and therefore severely limits light penetration. As a

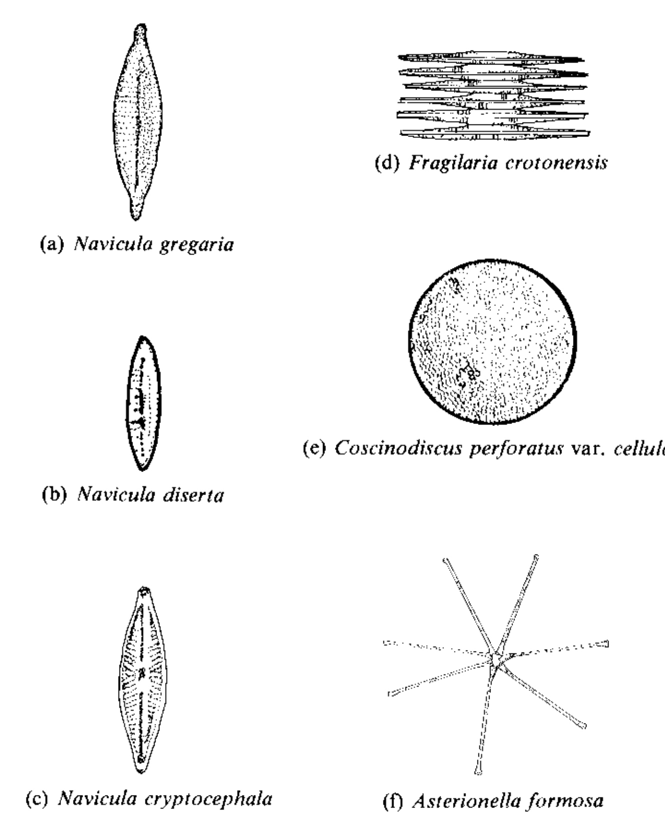


Figure 3-4. Selected Columbia River Estuary diatoms. Species (a) and (b) are benthic, (c) and (d) are planktonic, and (e) and (f) are both benthic and planktonic (McIntire 1983).

result, only the upper portion of the water column receives adequate light for phytoplankton photosynthesis. The depth of this productive layer in the Columbia River Estuary varies from about 1.5 to 4.5 meters depending on season and location. Moreover, the skies over the estuary are overcast or foggy a good deal of the time (see Table 1-1). CREDDP investigators concluded that phytoplankton production is limited by light in the Columbia River Estuary.

Nutrients are also important factors affecting the rate of primary production. In many estuaries, the nutrients needed to support primary production (such as nitrogen and phosphorus) are in short supply during some seasons. In the Columbia River Estuary, however, nutrients are generally in great abundance, but they are of little use to cells receiving insufficient light. Nitrogen may occasionally be in short supply in late spring and summer when rapid phytoplankton growth occurs.

The primary productivity in the water column often is closely related to the abundance of phytoplankton cells. The total productivity of a given area of the water column is usually higher if the area is occupied by high concentrations of cells. One factor affecting phytoplankton abundance is the extent of grazing, the consumption of phytoplankton cells by animals such as the zooplankton. In parts of the ocean and in some estuaries grazing causes drastic reductions in phytoplankton abundance. This is not a major factor in the Columbia River Estuary, however, where the zooplankton apparently consumes only about 1 percent of the phytoplankton produced within or passing through the estuary per day.

Derivation, Uses, and Limitations of the Map (Plate 10)

CREDDP investigators measured phytoplankton biomass, rates of production, and physical and chemical environmental factors approximately every other month over a 16-month period at up to 52 stations per cruise. They collected samples from several standard depths at stations in the main channels, bays, shallows, and side rivers. In order to map phytoplankton productivity, CREDDP investigators divided the estuary into zones (see Plate 10) and grouped the productivity data from the stations within each zone. The grouped data were then converted into annual net productivity figures for each of the zones.

The map of annual productivity is useful for showing estuary-wide patterns in phytoplankton productivity. The map does not, however, show the large variations in productivity which occur over short time periods such as the twice-daily tidal cycle, the day-night cycle, and the seasonal cycle. Also, variations from station to station, which can be larger than the estuary-wide differences, are not indicated on the map.

Interpretation of the Map (Plate 10)

Plate 10 shows a pattern of decreasing phytoplankton productivity from the upriver portion of the estuary to the estuary mouth. Apparently the freshwater species that dominate the phytoplankton are destroyed when the fresh riverflow that carries them begins to mix with marine water. As a result, rates of primary production are high in the freshwater portions of the estuary where phytoplankton are abundant, but decrease as the cells encounter saline water and die.

The location at which inflowing phytoplankton cells encounter saline water coincides approximately with that of the turbidity maximum (see "Sediments"). The location of the turbidity maximum in the estuary depends on tides and the volume of riverflow. Its average position is at about Tansy Point (RM-10) except during the low riverflow season when it shifts upriver to about RM-15. As a result, the extent to which freshwater phytoplankton move into the estuary before dying also depends on tidal and riverflow conditions. The heavy concentration of dead and dying cells at the turbidity maximum contributes to the richness of this zone as a feeding area for the zooplankton and for epibenthic and benthic infaunal organisms (Figure 3-5).

Phytoplankton productivity is relatively low in Grays Bay and Youngs Bay. This pattern differs from many other estuaries where quiet, shallow areas support extremely high primary productivity. Such estuaries have low flushing rates, allowing the phytoplankton to linger in the well-lit shallow waters and build up large populations. The Columbia River Estuary, on the other hand, has a high flushing rate and the phytoplankton are transported rapidly over the shallow areas.

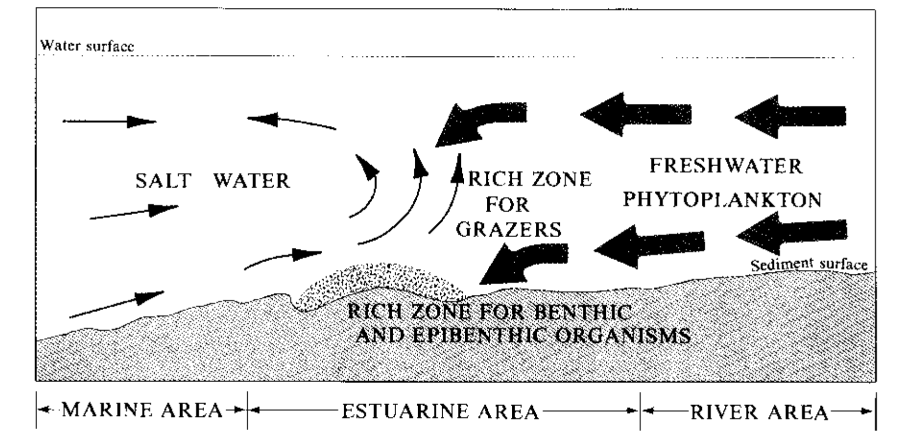


Figure 3-5. Schematic representation of freshwater phytoplankton encountering saline water. The concentration of dead and dying phytoplankton cells near the upriver limit of salinity intrusion (also the area of the turbidity maximum) creates a rich feeding zone for zooplankton, benthic infauna, and epibenthic organisms. The diagram represents the low riverflow season (modified from Frey et al. 1984).

The monthly distribution of net phytoplankton productivity is shown in Figure 3-6. The figure summarizes the effects of the two most important physical factors on phytoplankton productivity: salinity (as indicated by river mile) and light availability. Read from top to bottom, Figure 3-6 illustrates higher production rates in the freshwater upper estuary as compared with the saline lower estuary. Read from left to right, the figure illustrates the effects of light intensity on phytoplankton productivity. The highest productivity occurs during the summer months because that is when the length of the daylight period and light intensity are greatest. After the May 1980 Mt. St. Helens volcanic eruption, phytoplankton productivity decreased dramatically when volcanic ash increased the turbidity of the water in the estuary (see "Effects of the Mt. St. Helens Eruption" on this page).

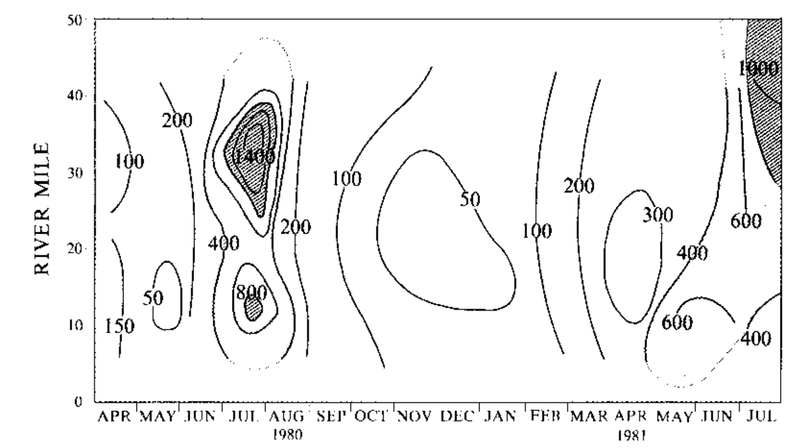


Figure 3-6. Phytoplankton productivity in the Columbia River Estuary as a function of location and sampling month. The contours represent net productivity in $mgC/m^2/day$ (Frey et al. 1984).

Discussion

The destruction of freshwater species as they encounter saline water is the principal reason why photoplankton productivity in the Columbia River Estuary is low compared to that of most other estuaries, such as Chesapeake Bay (Figure 3-7). This is related to the large volume of the Columbia's riverflow and the corresponding high flushing rates. The flushing time in the Columbia River Estuary is only one to five days. This contrasts with many other estuaries in which water may take weeks or months to reach the ocean. As a result, a productive brackishwater phytoplankton community develops in such estuaries in the region where fresh water makes a slow transition to marine water. In the Columbia, the transition occurs so rapidly that masses of freshwater cells are destroyed and a true brackishwater phytoplankton community is unable to develop.

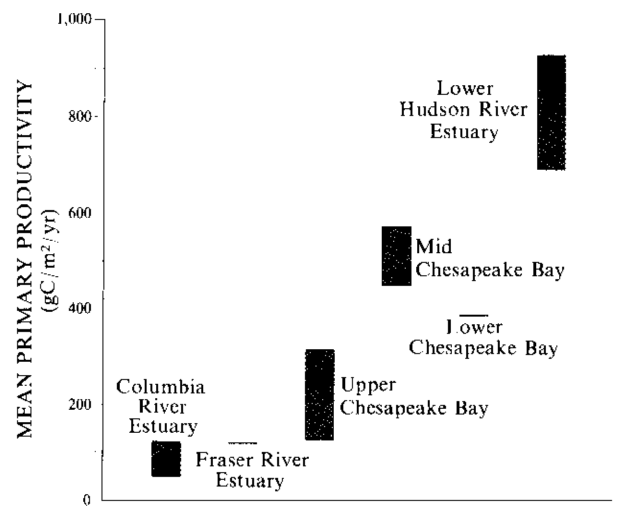


Figure 3-7. Mean primary productivity of phytoplankton in some North American estuaries. Values are expressed as single means or as ranges of means, depending on available data (modified from Simenstad et al. 1984).

The results of CREDDP research indicate that the phytoplankton production that occurs within the estuary is not among the most important factors in supporting its animal life. Although both living phytoplankton and detritus derived from phytoplankton are undoubtedly important components of the estuary's food supply, it is the upriver production of phytoplankton, rather than that which occurs in the estuary, that accounts for most of the phytoplankton in the estuary (Figure 3-3). Of the total carbon supply of the estuary, however, only about 23 percent is in the form of phytoplankton; most of the rest is in the form of detritus (Figure 3-3). This supports the conclusion that detritus is the most important food source to Columbia River Estuary consumers.

Benthic Primary Producers

Benthic primary producers include single-celled and filamentous algae and submerged aquatic flowering plants that grow on the sediments of tidal flats. Along with detritus from the water column and adjacent tidal marshes, these plants provide the food necessary to support epibenthic and benthic infaunal animals.

CREDDP investigators found that most of the primary production occurring on the tidal flats of the Columbia River Estuary is carried out by diatoms. Blue-green algae are also found frequently growing on the sediment in low elevation marshes in late summer but do not contribute much to primary production on a year-round basis. CREDDP investigators also found that many-celled algae and submerged flowering plants contribute little to benthic primary production in the estuary.

Planktonic diatoms have been described earlier in this chapter, and benthic species are similar in appearance (Figure 3-4). However, unlike the planktonic diatoms, most of which are generated upriver and move quickly through the estuary, most of the estuary's benthic diatoms are produced within the estuary and tend to remain there. There are exceptions; planktonic forms are found on the sediments and benthic forms in the water column from time to time.

Benthic diatoms in the estuary include freshwater species, brackishwater species, and species that tolerate a wide range of salinity. Salinity influences the species composition of benthic diatom communities, which vary from site to site according to the range of salinities at each site (Table 3-1). Although species composition varies according to salinity ranges, CREDDP investigators found that salinity does not influence the abundance and productivity of benthic diatoms in the estuary.

Many-celled algae exhibit a patchy distribution and are relatively rare in the estuary. *Enteromorpha intestinalis*, a green alga (Figure 3-8), was abundant in samples from low elevation marshes in April and May 1980 at sites in Youngs Bay and Baker Bay; it was also observed associated with individual shoots of the flowering plant *Zostera marina* (eelgrass) on a tidal flat in Baker Bay during CREDDP sampling. The marine alga *Fucus distichus edentatus* (rockweed) was found associated with low marsh sediments in Baker Bay.

Submerged flowering plants that are present in the estuary include *Zostera marina* (Figure 3-8) and several freshwater species. During CREDDP sampling, individual shoots of eelgrass were often conspicuous in Baker Bay between MLLW and two feet above MLLW. Apparently the habitat in this region is marginal for the growth and survival of *Z. marina*, as the plants do not develop dense beds similar to populations in other estuaries. This species also has a limited distribution in Trestle Bay. CREDDP investigators found other species of submerged flowering plants in fresh water at a site in Grays Bay.

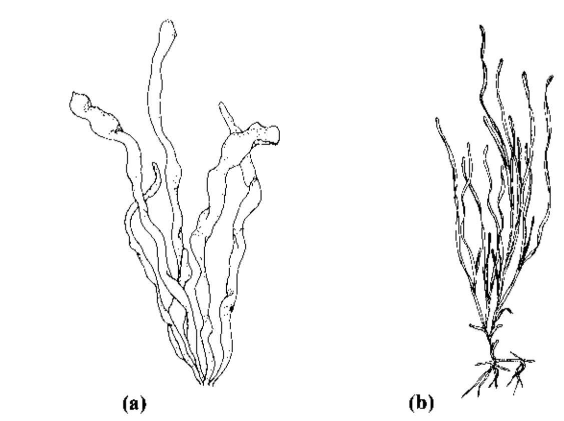


Figure 3-8. Selected benthic plants of the Columbia River Estuary: (a) *Enteromorpha intestinalis*, a many-celled green alga, and (b) *Zostera marina* (eelgrass), a flowering plant.

Factors Affecting Productivity

In order to survive, benthic plants must receive sufficient light energy and nutrients for photosynthesis and be relatively free from the disruption caused by sediment mixing and transport. For these reasons, the benthic vegetation of the Columbia River Estuary is generally confined to the intertidal regions from about MLLW to the upper limit of moist sediments in low elevation marshes. At depths below MLLW, light does not penetrate sufficiently into the water to maintain a large benthic plant standing crop. Even within the intertidal regions supporting benthic vegetation, light is insufficient for photosynthesis during high tides. Benthic diatoms in these intertidal regions of the estuary therefore receive adequate light for photosynthesis only during the low tides occurring during daylight hours. CREDDP investigators have estimated that this period lasts an average of 4.2 hours per day.

Effects of the Mt. St. Helens Eruption

Mt. St. Helens, a volcano 90 kilometers east of the estuary's eastern limit, erupted on May 18, 1980, and sent about 100 million cubic meters of ash and sand down the Toutle and Cowlitz Rivers toward the Columbia. The estuary became extremely turbid and the depth at which phytoplankton could receive sufficient light to photosynthesize was reduced to about half a meter. As a result, phytoplankton productivity decreased to 25 percent of its normal level. Phytoplankton biomass, however, was not reduced, supporting the hypothesis that most phytoplankton in the estuary are imported from upriver rather than produced within the estuary. Two months after the eruption, phytoplankton productivity had returned to normal.

Besides light, sediment stability is the most important factor affecting benthic diatom productivity in the estuary. Sediment stability refers to the amount of mixing or disruption of bottom sediments. Where sediments are unstable, benthic diatoms are mixed into the sediment and covered by sand grains so that they cannot photosynthesize. Productivity in these sediments is therefore low. Stable sediments, on the other hand, permit high benthic primary productivity. Generally, areas exposed to strong currents, such as Desdemona Sands, have unstable sediments while protected areas such as Youngs Bay have stable sediments.

Derivation, Uses, and Limitations of the Map (Plate 10)

CREDDP investigators used two sampling approaches to determine the distribution of benthic primary productivity. The first involved monthly sampling at five intensive study sites from April 1980 through April 1981. The concentration of chlorophyll *a*, the rate of primary production, sediment characteristics, salinity, and temperature were measured. The concentration of the plant pigment chlorophyll *a* provides a measure of plant biomass and is closely correlated with primary productivity. The other sampling approach involved a broad survey of 31 additional sites from May 1981 through August 1981. Chlorophyll *a* concentrations were measured at these sites and rates of primary production were estimated from an equation derived from work at the intensive study sites.

Plate 10 shows both hourly and yearly rates of gross benthic primary production. Hourly rates are averages for only those hours throughout a 12-month period when daylight and tidal conditions permit photosynthesis, and are expressed in milligrams of carbon per square meter per hour ($mgC/m^2/hr$). The annual values are derived from the hourly rates and are expressed in grams of carbon per square meter per year ($gC/m^2/yr$). Since the majority of benthic primary production occurs between MLLW and the lower limit of marshes, the values are shown for only the tidal flats. The range of values on each of the tidal flats was obtained from one of three possible sources: for flats adjacent to the intensive study sites, the mapped values were obtained directly from productivity measurements; for tidal flats adjacent to other survey sites, the productivity values were based on chlorophyll *a* measurements; and for flats with no sampling sites, the productivity values were based on measurements obtained from sites with similar sediment characteristics. Thus, the amount of data supporting the productivity values on each tidal flat depends on its proximity to sampling sites.

Plate 10 is useful for illustrating estuary-wide patterns in benthic primary productivity. Together with some of the maps of physical characteristics and with the interpretation below, it helps convey some of the relationships between benthic primary productivity and the factors that affect it.

Interpretation of the Map (Plate 10)

In the Columbia River Estuary, benthic primary production is highest in Baker, Youngs, and Trestle Bays and lowest on the exposed beaches of Clatsop Spit and the mid-estuary tidal sandflats. Grays and Cathlamet Bays show intermediate productivity levels. Values vary somewhat among individual tidal flats within each of these areas.

Many of the variations in benthic primary productivity among different areas of the estuary can be explained in terms of sediment stability. The peripheral bays such as Youngs, Trestle, and Baker Bays are not exposed to strong currents. Their sediments are therefore fine-grained (see "Sediments") and stable throughout most of the year and benthic primary productivity is high. Grays and Cathlamet Bays are subjected to greater currents and sediment mixing and have lower productivity values. The extremely low productivity on Clatsop Spit and the mid-estuary tidal sandflats (for example, Desdemona Sands) can be explained by their exposure to waves and strong currents. Sediments in both areas are coarse and very unstable (see "Sediments").

Patterns of annual benthic primary productivity reflect the average physical conditions at each site. These conditions, however, vary during the year, and so do rates of primary production. For example, CREDDP investigators found extreme variation on a sandy intertidal site on Quinns Island (Figure 3-9). Although the sediment grain-size distribution remained about the same throughout the study period, productivity was very low in June 1980 and high in September 1980. CREDDP investigators suggest that during the high riverflow season, the strong flows caused sediments to be very unstable, accounting for the low production rates. Production rates were higher in August and September because the river discharge had decreased and sediments had become more stable. The rates then went down again in winter as the river discharge again became higher and more disruptive of sediments and as light intensity reached its minimum.

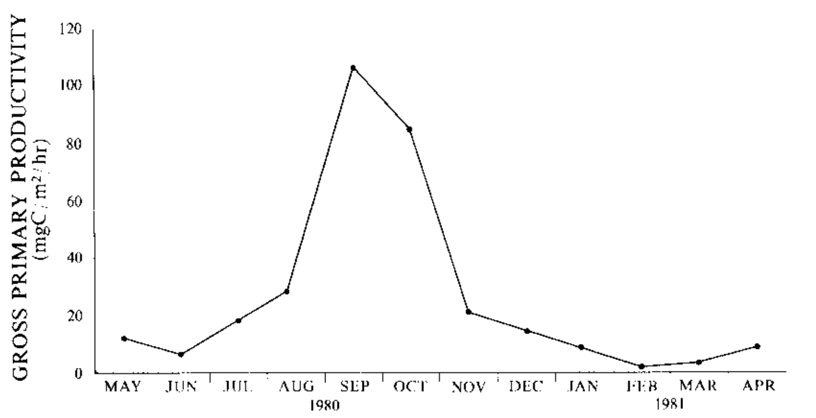


Figure 3-9. Gross benthic primary productivity by month for a sampling site on Quinns Island (McIntire and Amspoker 1984).

Discussion

Rates of benthic primary production on Columbia River Estuary tidal flats are similar to those of other estuarine benthic diatom communities. These production rates are, however, much lower than those on tidal flats occupied by dense beds of submerged flowering plants or many-celled algae. For example, eelgrass beds on tidal flats in Netarts Bay, Oregon, are about 20 times more productive than the benthic diatom communities of the Columbia River Estuary.

Area	Salinity Range of Dominant Benthic Species: Freshwater	Brackishwater	Tolerant of a Wide Range
Baker Bay		*Navicula diserta*	*Achnanthes hauckiana*
		Navicula salinicola	*Achnanthes lemmermanni*
Youngs Bay	*Fragilaria pinnata*	*Gyrosigma fasciola*	*Achnanthes hauckiana*
			Navicula cryptocephala
			Nitzschia hungarica
Grays Bay	*Achnanthes lanceolata*		*Achnanthes hauckiana*
	Navicula submuralis		*Navicula gregaria*
Cathlamet Bay	*Navicula submuralis*		*Navicula gregaria*
	Fragilaria pinnata		
	Achnanthes lanceolata		
	Amphora ovalis var. *pediculus*		
Upriver from Cathlamet Bay	*Achnanthes lanceolata*		*Achnanthes hauckiana*
	Amphora ovalis		*Navicula gregaria*
	Navicula capitata		

Table 3-1. Abundant benthic diatom species in various regions of the Columbia River Estuary (from McIntire and Amspoker 1984).

CREDDP investigators identified the different species of benthic diatoms that they found in five widely-separated regions in the estuary. Some of the species they found are known to grow in freshwater areas, some are brackishwater species, and some can tolerate a wide range of salinities. Investigators found a different mix of diatom species at each site. The species composition at a site results from the long-term variations in salinity at that site, and may therefore provide a useful supplement to the information derived from isolated salinity measurements taken at specific times.

The dominance of brackishwater species and species tolerant of a wide salinity range at the sampling site in Baker Bay clearly indicates that the site is subjected to higher salinities than the sampling sites in Youngs Bay, Cathlamet Bay, Grays Bay, and other sites upriver from Tongue Point. Abundant diatom species at the Youngs Bay site include a freshwater species, a brackishwater species, and several species tolerant of a wide salinity range. This indicates that the site is exposed to intermittent periods of fresh water with enough influence from brackish water to generate a diatom flora with salt tolerant species.

Abundant benthic species in Grays Bay include two freshwater species and two species tolerant of a wide salinity range. The occurrence of freshwater species is evidence of the lack of saltwater influence in the bay. Freshwater species are also dominant in the diatom flora of Cathlamet Bay, suggesting the strong riverine influence. The diatom flora at the sites upriver from Cathlamet Bay clearly indicate that this region of the estuary is exposed to freshwater conditions. Abundant species include several freshwater species and a few species tolerant of a wide salinity range.

Total net benthic primary production in the Columbia River Estuary amounts to approximately 1,500 metric tons of carbon per year. This is only about 1 percent of the total carbon supply of the estuary (Figure 3-3). However, the importance of benthic primary production in the estuary may be greater than this percentage suggests. Many benthic animals (especially deposit-feeders; see "Benthic Infauna") occupy tidal flats rich in benthic diatoms; therefore, these diatoms are more available to them than other estuarine food sources.

Tidal Marshes and Swamps

Between the estuary's open water and the surrounding uplands lie the tidal wetlands. Tidal wetlands are those areas with elevations from about one meter below MLLW (Extreme Low Tide) to about 3.7 meters above MLLW (Extreme High Tide) or to the limits of tidally-influenced vegetation if such vegetation extends into elevations above Extreme High Tide. In the Columbia River Estuary, most tidal wetlands can be characterized as either sandflats, mudflats, marshes, or swamps. The tidal sandflats and mudflats are at the lowest wetland elevations. Their vegetation consists of benthic diatoms and some submerged flowering plants (see "Benthic Primary Producers"). Tidal marshes and swamps are found in higher elevation wetlands, usually one meter or more above MLLW. Tidal marsh plants in the estuary include many species of grasses, reeds, and broad-leaved plants that are adapted to survive periodic inundation and exposure by the tides. Tidal swamps are at the highest wetland elevations and receive less frequent tidal inundation. Their vegetation is dominated by shrubs and trees (Figure 3-10).

(a)

(b)

Figure 3-10. Examples of a Columbia River Estuary (a) tidal marsh (CREST photo) and (b) tidal swamp (photo by William Barnett).

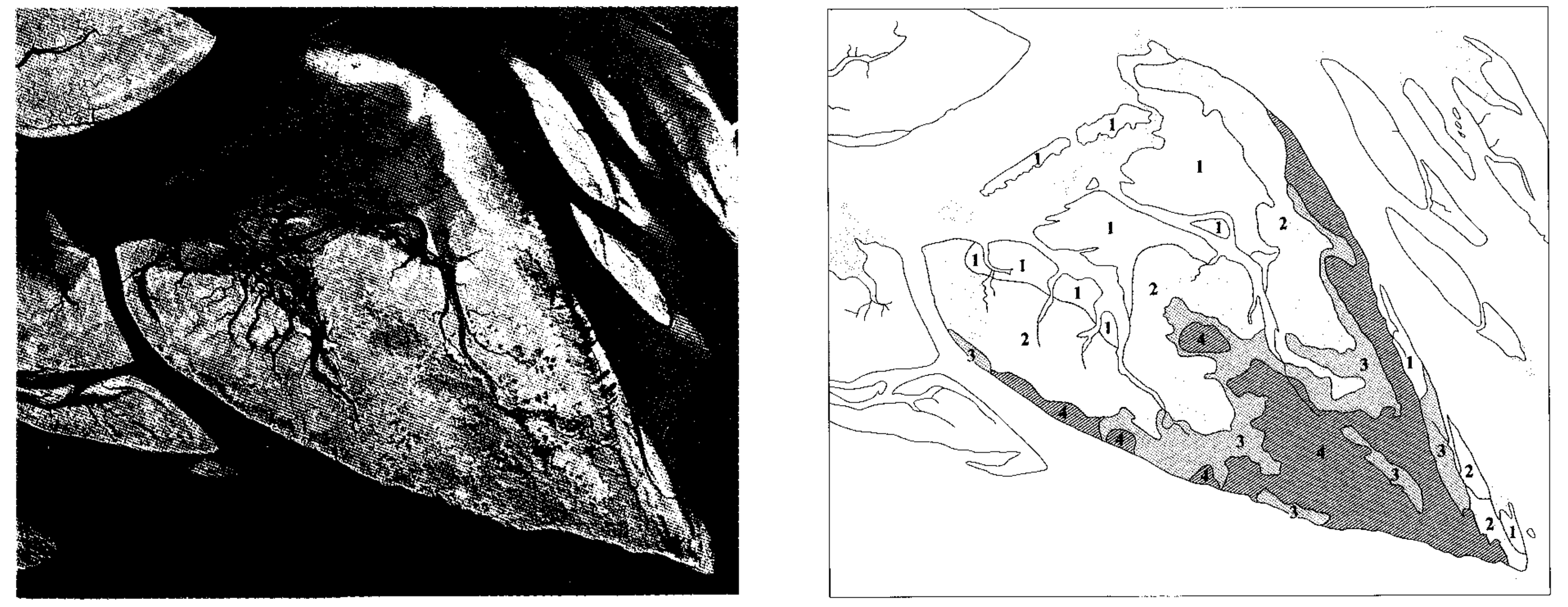
A characteristic of tidal marshes and swamps that is important to many animal species is the network of drainage channels, called tidal channels, which develops due to the constant rising and falling of the tide. Quinns Island, illustrated in Figure 3-11, provides a good example of a tidal channel network. Tidal channels may originate within wetlands or may have both an upriver and a downriver end.

The estuary's tidal marshes and swamps and their associated tidal channels provide habitat for a large variety of animals. Many invertebrate species live within the sediments. Finfish use tidal channels and marshes for nursery and feeding areas. Small aquatic mammals such as muskrat, nutria, and beaver live in the marshes and swamps and use tidal channels as transportation corridors. Some larger mammals, including the endangered Columbian white-tailed deer, and a multitude of bird species also depend on these habitats.

The extent of tidal marshes and swamps has been greatly decreased as a result of human activities. In the Columbia River Estuary, the surface area of tidal marshes and swamps has been reduced by 65 percent over the past century. The main cause for the loss has been diking to create agricultural land (see Chapter 1).

Factors Affecting Distribution and Productivity

The pattern of tidal marsh and swamp plant growth during the year is a reflection of the cycle of seasons. Seasonal changes in the tidal marshes are particularly striking. In the late summer, at the height of the growing season, the tidal marshes consist of dense vegetation that is often a meter or more in height. By winter, however, they appear as bare flats with only a stubble of dead plant stems remaining. A portion of the season's growth of marsh sedges, grasses, and herbs is contributed as detritus to the aquatic ecosystem of the estuary.



1. LOW MARSH	2. LOW MARSH	3. HIGH MARSH	4. SCRUB-SHRUB COMMUNITY
Scirpus validus	*Carex lyngbyei*	*Impatiens capensis*	*Salix sitchensis*
Juncus oxymeris	*Equisetum fluviatile*	*Lotus corniculatus*	*Salix lasiandra*
Eleocharis palustris	*Juncus oxymeris*	*Carex lyngbyei*	*Cornus stolonifera*
Carex lyngbyei	*Deschampsia caespitosa*	*Myosotis laxa*	*Spiraea douglasii*
Scirpus fluviatilis	*Sium suave*	*Carex obnupta*	*Physocarpus capitatus*
	Boltonia asteroides	*Leersia oryzoides*	*Pyrus fusca*
		Potentilla pacifica	*Picea sitchensis*
		Lysichitum americanum	*Lysichitum americanum*
		Equisetum fluviatile	*Rosa pisocarpa*

Figure 3-11. Aerial photo and map of Quinns Island showing vegetation communities (photo courtesy of the U.S. Army Corps of Engineers, Portland District). Abundant species in each community are listed in the accompanying table (modified from Thomas 1983).

The distribution of marsh and swamp plant species, and of characteristic communities of species, is affected primarily by salinity and elevation. Since the range of salinity tolerated by plants differs among species, the tidal marsh and swamp communities differ from the saline lower estuary to the freshwater upper estuary. Tidal marshes and swamps of the Columbia River Estuary are classified into two types based on salinity; brackishwater and freshwater. Saltmarshes (marshes inhabited by plant species which tolerate very high salinities) do not exist in the Columbia River Estuary. Apparently, salinity levels in the estuary are never high enough for these marsh types to develop. Elevation is important because the lower the elevation, the more often the marsh is inundated by the tides. Plants adapted to live under conditions of frequent inundation grow at the lower elevations. Plant species which can tolerate only occasional inundation are found at higher elevations.

Derivation, Uses, and Limitations of the Map (Plate 10)

Plate 10 shows the estuary's tidal marsh and swamp communities and tidal marsh standing crop and productivity. Primary production of the estuary's tidal swamps was not measured. The estuary-wide distribution of the communities is mapped while standing crop and production are shown only at the specific sites where they were measured.

CREDDP investigators defined the vegetation communities in terms of species composition and mapped them using aerial photographs of the estuary. The investigators grouped the communities into low marsh, high marsh, and swamp. The marsh communities were further grouped into freshwater (upriver from Tongue Point) and brackishwater (downriver from Tongue Point). Low marsh, high marsh, and swamp are defined in terms of plant species. The criterion for distinguishing swamps from marshes is the presence of woody vegetation (shrubs or trees). Those marshes inhabited by species more tolerant of tidal inundation are low marshes while those inhabited by species less adapted for inundation are high marshes.

The tidal marsh and swamp communities shown on the map are not separated from one another by distinct boundaries. Instead, the change is gradual, with an area of transition existing between communities. This applies not only to the change from one wetland community to another but also to the change from wetland to upland. The boundary lines on the map lie within these transitional areas and are not intended to represent absolute demarcations between communities. Generally, the transition from flats to low marsh occurs around one meter above MLLW, the transition from low marsh to high marsh or swamp occurs somewhere between 2.0 and 2.6 meters above MLLW, and the transition from high marsh or swamp to upland occurs somewhere between 2.4 and 3.7 or more meters above MLLW. The elevation ranges of high marsh and of swamp are almost identical.

CREDDP investigators measured tidal marsh standing crop and species composition at 22 sites shown on Plate 10. The measurements were taken throughout the marsh growing season in 1980 (April, May, June, July, and October) and at the peak of the growing season in 1981 (early August). The investigators separated the standing crop measurements into four categories: aboveground live material (stems and leaves), aboveground attached dead material (dead leaves still attached to the plants), decaying plant litter (loose dead material on the ground), and belowground live plant material (roots and underground stems). All of these measurements are expressed in grams of dry weight per square meter (gDW/m^2). Plate 10 presents aboveground total standing crop measurements for July 1980 and August 1981. These total standing crop values include both live and attached dead plant material. Late July 1980 and early August 1981 values, collected at the peak of the growing season, were selected for display because they typify the peak standing crop values for the tidal marshes.

The primary productivity estimates were derived from the standing crop measurements. The procedure for this derivation involves comparing standing crop measurements sequentially through the growing season. For this reason, primary productivity estimates were developed only for 1980, when a series of measurements was available. Plate 10 shows net annual aboveground tidal marsh plant productivity estimates for each study site in 1980. All values represent grams of dry weight per square meter per year ($gDW/m^2/yr$).

The standing crop measurements and productivity estimates are useful for drawing comparisons with the estuary's other primary producers. Because the variability among sites and between sampling years was so wide, patterns of production in relation to physical factors are not obvious. However, CREDDP investigators concluded that aboveground marsh productivity increases both upriver from the estuary mouth and from lower to higher marsh elevations. These patterns most likely reflect the importance of salinity and the duration of tidal inundation, respectively. Nevertheless, because of wide variations in measurements within each site and among sites of the same marsh type, it was not possible to rank marsh types according to productivity.

Interpretation of the Map (Plate 10)

Distribution of Tidal Marshes and Swamps

CREDDP investigators classified the estuary's tidal marshes and swamps into six major types: brackishwater low marsh, brackishwater high marsh, freshwater low marsh, freshwater high marsh, brackishwater scrub-shrub swamp, and freshwater scrub-shrub/forested swamp (Tables 3-2 and 3-3). As can be seen on Plate 10, brackishwater low marshes fringe much of the shoreline of Baker, Trestle, and Youngs Bays. Brackishwater high marsh is best developed in Trestle Bay and brackishwater scrub-shrub swamp in Youngs Bay. Freshwater vegetation communities extend upriver from Tongue Point (RM-18). Freshwater low marshes are widespread throughout the islands of Cathlamet Bay, fringe much of Grays Bay, and occur on the downriver portions of Tronson, Quinns, Grassy, and Fitzpatrick Islands, near Aldrich Point (RM-30). Freshwater high marshes are present along the eastern shores of Grays Bay and are more broadly developed across portions of Marsh, Horseshoe, and Welch Islands. Shrub and tree-dominated freshwater swamps are best developed in Cathlamet Bay (Karlson, Marsh, and Long Islands) and farther upriver at Welch (RM-34) and Hunting (RM-37) Islands.

Area	Low Marsh	High Marsh	Swamp	Total
Brackishwater Locations				
Baker Bay	219	21	19	259
Trestle Bay	66	58	2	126
Youngs Bay	285	135	50	470
Other	3	1	1	5
Freshwater Locations				
Cathlamet Bay	1,832	279	1,762	3,873
Grays Bay	276	31	268	575
Upriver from Cathlamet Bay	174	115	334	623
Estuary-Wide Totals	**2,855**	**640**	**2,436**	**5,931**

Table 3-2. Area in hectares of tidal marshes and swamps in the Columbia River Estuary (planimetered data, CREDDP staff 1983).

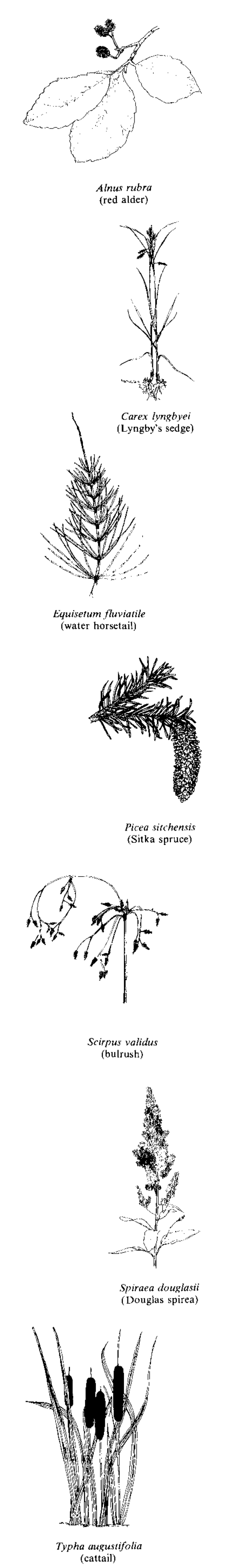


Figure 3-13. Selected plants of Columbia River Estuary tidal marshes and swamps.

The species occurring in Columbia River Estuary marshes change as one moves upriver and from low to high elevations. This is a reflection of the species' different tolerances of saline water and tidal inundation, respectively. Table 3-3 shows the species composition of tidal marsh sites expressed as percent cover. Percent cover refers to the relative area occupied by each plant species within a sampling site. One species, *Carex lyngbyei* (Figure 3-13), occurred at nearly all of the sampling stations. This species and several others are the principal members of the tidal marsh and swamp communities described below.

Brackishwater Low Marshes

These marshes are characterized by simple plant communities in which only one or two species cover the largest area of the marsh. *Scirpus americanus*, *Carex lyngbyei*, and *Agrostis alba* are generally the most abundant species, each reaching prominence at successively higher elevations across the low marshes. *Triglochin maritimum* (seaside arrow-grass), a common saltmarsh species, is another characteristic plant, although never found in great abundance. *Carex lyngbyei* stands at Baker Bay are unusual in that clumps of the marine brown alga *Fucus distichus edentatus* commonly occur attached to the sediments among the *Carex* plants. Another locally distinctive feature among the brackishwater low marshes is the occurrence of dense stands of *Typha angustifolia* (Figure 3-13) at site 10 in outer Youngs Bay.

Site 11 in Youngs Bay has the richest low marsh flora (15 species) and includes a number of species more commonly associated with the freshwater marshes farther upriver. These include *Alisma plantago-aquatica* (water plantain), *Eleocharis palustris*, *Equisetum* sp. (horsetail), *Oenanthe sarmentosa*, *Scirpus microcarpus* (small-fruited bulrush), and *Typha latifolia*.

Brackishwater High Marshes

Three of these marshes were sampled, all in Trestle Bay. Their vegetation is more complex than that of the brackishwater low marshes, with increasing numbers of species appearing at higher elevations. *Carex lyngbyei* and *Agrostis alba* remain important but several additional species, scarce or absent from the low marshes, also contribute significantly to both percent cover and biomass. These include *Potentilla pacifica*, *Lathyrus palustris*, *Juncus balticus*, and *Aster* sp. (probably *A. subspicatus*). Other species occasionally present include *Carex obnupta* (slough sedge), *Festuca arundinacea* (reed fescue), *Oenanthe sarmentosa*, *Rumex crispus*, (curly-leaved dock) and *Vicia gigantea* (giant vetch).

Freshwater Low Marshes

East of Tongue Point, freshwater tidal marshes replace the brackishwater marshes of the downriver portion of the estuary. The freshwater marsh vegetation is more variable than the brackishwater marsh; it also contains greater numbers of species. Freshwater low marshes, for example, have 13 to 26 species per site, compared with only 4 to 15 species per site in brackishwater low marshes.

Several species in the freshwater tidal marshes are widely distributed marsh plants and are commonly found at both low and high marsh study sites. *Carex lyngbyei*, already noted as a brackishwater marsh dominant, remains the most widespread and abundant of all species encountered at freshwater sites. *Aster* spp., *Deschampsia caespitosa*, and *Alisma plantago-aquatica*, all found at lower estuary brackishwater marshes, increase substantially in abundance within the freshwater marshes. Four additional species, not represented in the downriver portions of the estuary, also commonly occur at both low and high freshwater marshes: *Elodea canadensis*, *Mimulus guttatus* (common monkey-flower), *Sagittaria latifolia*, and *Sium suave*. Less common but widely dispersed species occasionally occurring among both low and high freshwater marshes include *Callitriche* sp. (water starwort), *Isoetes echinospora* (quillwort), *Myosotis laxa* (smaller forget-me-not), and *Phalaris arundinacea* (reed canary-grass).

In addition to the widespread species noted above, a second major species group contains plants commonly present or abundant in freshwater low marshes. This group includes several species also recorded from brackishwater marshes, *Lilaeopsis occidentalis*, *Scirpus validus* (Figure 3-13), and *Juncus balticus*. Species not found in the lower estuary, *Eleocharis palustris*, *Juncus oxymeris*, and *Polygonum hydropiperoides* (mild water pepper), are also included. Two additional common species, *Littorella* sp. (plantain) and *Ranunculus* sp. (buttercup), are apparently restricted to freshwater low marshes.

Freshwater High Marshes

The freshwater high marshes sampled are also more variable and have greater numbers of species than their brackishwater counterparts (14 to 28 species per site, compared with only 5 to 10 species at brackishwater sites).

In addition to the broadly distributed group of freshwater marsh plants already noted above, *Agrostis alba*, *Lotus corniculatus*, and *Potentilla pacifica*, while sometimes found at low marsh sites, are more characteristic and abundant at freshwater high marsh localities. Both *A. alba* and *P. pacifica* are less abundant in the upriver portions of the estuary, however, than among downriver brackishwater marshes.

Several species are noted only at freshwater high marsh study sites. For example, *Caltha asarifolia*, *Equisetum fluviatile* (swamp horsetail), *Festuca arundinacea*, *Habenaria dilatata* (boreal bog orchid), *Rumex crispus*, and *Oenanthe sarmentosa* are present, although each rarely contributes more than a few percent to the total cover. Other species, while less frequently encountered, contribute more significantly to high marsh plant cover when they do occur: *Mentha* sp., 25 percent cover at Grays Bay (site 15); *Lysichitum americanum*, 17 percent cover at Tronson Island (site 20); and *Typha latifolia*, 52 percent cover at Puget Island (site 22).

Brackishwater Scrub-Shrub Swamp

These communities occur in mosaic patterns mixed with brackishwater high marsh. The most abundant woody shrub species include *Salix hookeriana* (coast willow), *Lonicera involucrata* (black twinberry), *Rubus spectabilis* (salmonberry), *Picea sitchensis* (Sitka spruce) (Figure 3-13), and occasionally *Alnus rubra* (red alder) (Figure 3-13). The understory vegetation includes most of the same species previously noted from the brackishwater high marshes.

Freshwater Scrub-Shrub Swamp

This extensive swamp type is dominated by *Salix sitchensis* (Sitka willow). *Salix lasiandra* (red willow), *Cornus stolonifera* (red osier dogwood), and *Spiraea douglasii* (Douglas spirea) (Figure 3-13) are also important woody shrub species. *Lysichitum americanum* commonly occurs in the understory vegetation.

Freshwater Forested Swamp

This swamp type occurs in a mosaic pattern with the freshwater scrub-shrub swamps described above. While the same shrub species remain abundant, tall trees of *Picea sitchensis* (Sitka spruce) are dominant. Well developed areas have a hummock-hollow topography, with many upland forest species occurring on the hummocks and wetland species in the hollows.

	Brackishwater Low Marsh								Brackishwater High Marsh			Freshwater Low Marsh						Freshwater High Marsh				
SAMPLING SITES:	1	2	3	4	6	7	10	11	5	8	9	12	14	16	17	19	21	13	15	18	20	22
SPECIES:																						
Fucus distichus (rockweed)	18																					
Scirpus americanus (bulrush)	*	77	33									*						*				
Agrostis alba (creeping bentgrass)	†			6	†	80		4	38	39	27								3	*		
Scirpus validus (bulrush)	5						1	1					19			19		†				†
Carex lyngbyei (Lyngby's sedge)	77	23	63	91	100	16	82	87	14	51	2	21	35	74	12	67	85	58	30	82	43	†
Aster sp.			†						5		7	9		†		*	3	7	3	*		33
Potentilla pacifica (Pacific silverweed)				†		2	†		33	2	41			†					6		5	
Lilaeopsis occidentalis				2	†		†	*				4		7	1		1			*	2	
Lathyrus palustris (wild pea)									6	9	15											
Juncus balticus (Baltic rush)						1			5	†	8	32						†				
Deschampsia caespitosa (tufted hairgrass)					†	1						11	13			4	3	7	6	2	8	
Oenanthe sarmentosa (wild parsley)								6		†								†	3	2		
Typha angustifolia (cattail)							17							1								11
Eleocharis palustris (common spikerush)								†				4	†	12	52	8	1	†	†		2	
Elodea canadensis (waterweed)												13	8		9			20				
Sium suave (water parsnip)												4		*	†	†	3	9		5	*	
Juncus oxymeris (rush)												2	8	3	16	1	5	*		1	5	†
Lotus corniculatus (lotus)														†				†	6			
Caltha asarifolia (yellow marshmarigold)																		*	8		2	
Sagittaria latifolia (wappato)													17		4	*				2		*
Mentha sp. (mint)																			25			
Lysichitum americanum (skunk cabbage)																			†		27	†
Typha latifolia (narrow-leaved cattail)																						52

*Present in samples but mean cover is less than 0.5 percent.
†Present nearby but absent from samples.

Table 3-3. Mean percent cover of the principal plant species at Columbia River Estuary tidal marsh sampling sites (July 1980). For sampling sites, see Figure 3-14 (Macdonald and Winfield 1984).

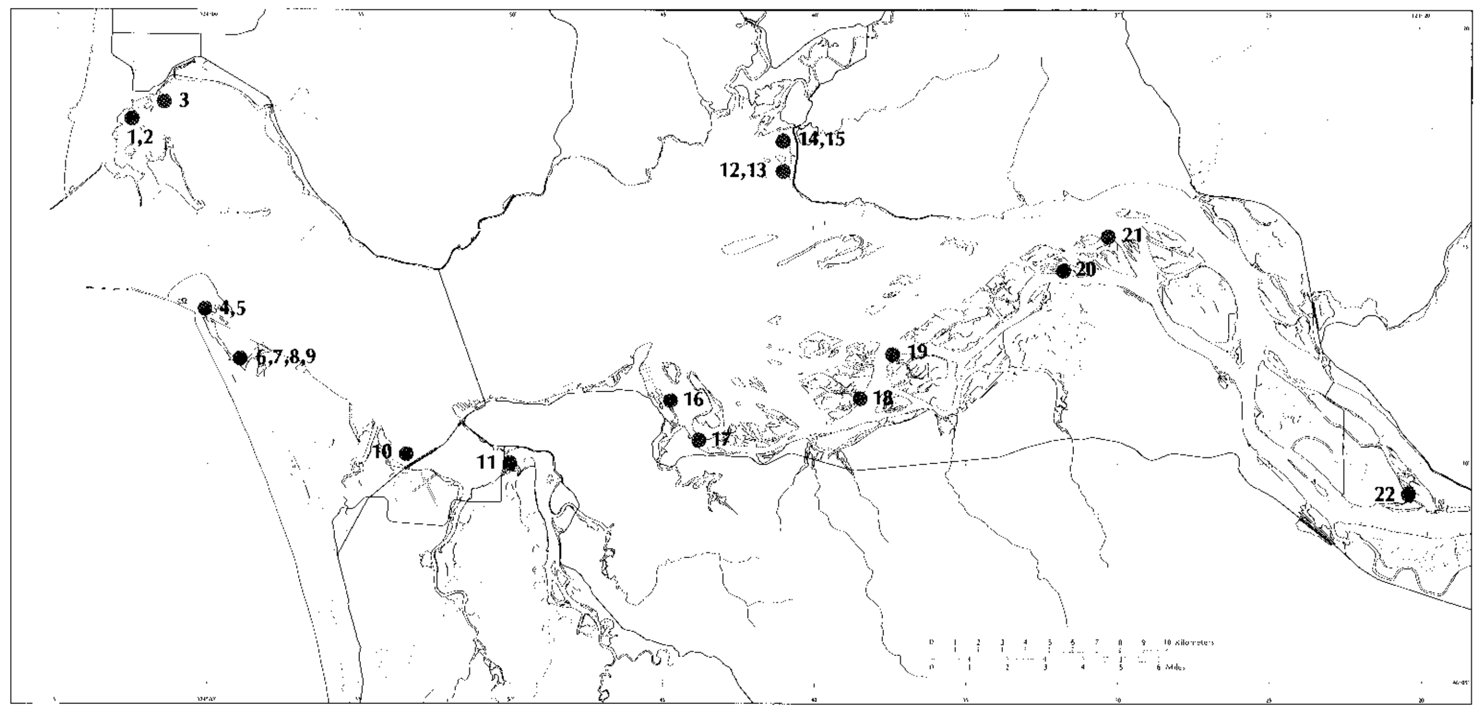


Figure 3-14. Sampling sites used for the study of Columbia River Estuary tidal marshes (Macdonald and Winfield 1984).

Tidal marsh and swamp growth takes on different patterns in different regions of the estuary. Downriver from Tongue Point the marshes generally fringe the shorelines in narrow bands, with the lowest elevation communities adjacent to the water and progressively higher elevation communities toward the uplands. Tidal swamps in these areas are not very widespread. The lowest elevation marsh communities are typically patchy and represent the new colonizers of the adjacent tidal mudflat. These fringing marshes are, for the most part, of fairly recent origin (less than 100 years old) and take their present form because of human alterations to the estuary. In Youngs Bay, many of the marshes front dikes that were built to transform older marshes and swamps into agricultural land. Once the dikes were built, only a narrow fringing intertidal area was left to be colonized by marsh plants. The Trestle Bay marshes formed after the construction of the South Jetty. The jetty altered currents, resulting in sediment deposition on Clatsop Spit (see Chapter 1) and the creation of Trestle Bay. Similarly, many of the fringing Baker Bay marshes formed after the entrance jetties were built and the bay's shore became sheltered from ocean waves. Widespread tidal marshes and swamps formerly present on the floodplain adjacent to Baker Bay have been diked and converted to agricultural land.

Most of the marshes and swamps upriver from Tongue Point appear to have formed prior to human alterations on the estuary. Some of the islands of eastern Cathlamet Bay and farther upriver (for example, Horseshoe, Woody, Tronson, Quinns, and Welch Islands) show a pattern of marsh distribution that is different from the downriver patterns. The upriver sides of these islands have the highest elevation communities and the downriver sides of the lowest (Figure 3-11). The slope from high upriver edge to low downriver edge is related to sedimentation patterns (see "Sediments"). The downriver edge is the site where the sediments are deposited. These are colonized by marsh plants which form patchy low marsh communities. The upriver edges of these islands, which are most subject to erosion, are steep and relatively high. These are inhabited by species characteristic of high marshes and swamps.

Distribution of Tidal Marsh Standing Crop

Plate 10 and Table 3-4 show the wide variation in tidal marsh standing crop measurements among the sampling stations. Because of this variation, no clear conclusions can be drawn regarding the rank order of marsh types from high standing crop to low standing crop. Also, the patterns of standing crop distribution in relation to salinity and elevation are difficult to discern.

Marsh Type	Mean*	Range*
Brackishwater		
Low Marsh		
July 1980	1001	83-3609
August 1981	997	265-3822
High Marsh		
July 1980	830	492-1259
August 1981	1169	341-1815
Freshwater		
Low Marsh		
July 1980	600	102-2009
August 1981	513	98-1167
High Marsh		
July 1980	980	202-3656
August 1981	1042	330-5158
All Marshes Combined		
July 1980	**864**	**83-3656**
August 1981	**892**	**98-5158**

*Values are expressed in gDW/m^2 of live tissue plus attached dead plant material of current year's growth.

Table 3-4. Aboveground tidal marsh plant standing crop in the Columbia River Estuary, July 1980 and August 1981 (Macdonald and Winfield 1984).

The monthly changes in tidal marsh standing crop during the growing season, however, are evident in the data. Figure 3-12 shows monthly average values for aboveground live and belowground live standing crop. Average aboveground live standing crop on the marshes throughout the estuary was 112 grams of dry weight per square meter (gDW/m^2) in April, the lowest value recorded for any month sampled. It climbed rapidly through the end of June (735 gDW/m^2), and held steady through August. By mid-October, however, estuary-wide marsh standing crop had declined substantially again (257 gDW/m^2).

Belowground live standing crop measurements emphasize two important aspects of the estuary's tidal marshes. First, the belowground live standing crop is always substantially higher than the aboveground live plant standing crop. Second, seasonal patterns of belowground standing crop are the opposite of aboveground standing crop trends. Belowground standing crop was highest in April (20 times greater than aboveground), lowest at the end of June (less than double aboveground values), and up again in July and October (Figure 3-12).

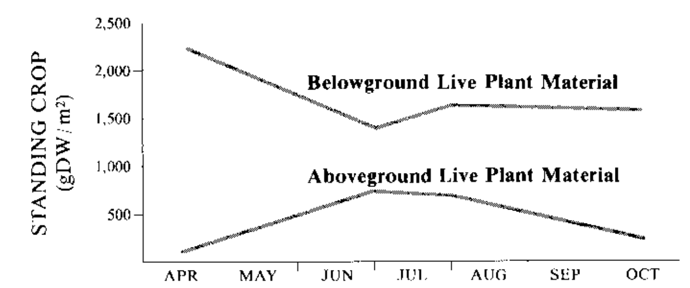


Figure 3-12. Monthly changes in mean standing crop of aboveground live and belowground live tidal marsh plant material. Data are averaged over all Columbia River Estuary tidal marsh sampling sites in 1980 (modified from Macdonald and Winfield 1984).

The reciprocal relationship between changes in aboveground and belowground standing crop shows that late in the growing season some species, such as *Carex lyngbyei*, transfer biomass and nutrients from aboveground shoots to overwintering root systems. Subsequently this stored material supports and accelerates the spring burst of growth typical of many marsh plants in cooler climates.

Distribution of Tidal Marsh Primary Productivity

Net annual aboveground productivity estimates for each sampling site are shown on Plate 10. Table 3-5 summarizes the estimates for each of the four tidal marsh types. As with standing crop, the ranges of values obtained for each category are large, and no conclusions regarding differences between marsh types could be made. The mean tidal marsh productivity value (based on data from all 22 study sites) was 964 $gDW/m^2/yr$. This value is probably representative of all tidal marshes in the Columbia River Estuary.

Marsh Type	Mean*	Range*
Brackishwater		
Low Marsh	1136	475-2528
High Marsh	944	803-1175
Freshwater		
Low Marsh	636	364-912
High Marsh	1095	768-1502
All Marshes Combined	**964**	**364-2528**

*Values are expressed in $gDW/m^2/yr$.

Table 3-5. Estimated net aboveground tidal marsh plant productivity in the Columbia River Estuary, 1980 (Macdonald and Winfield 1984).

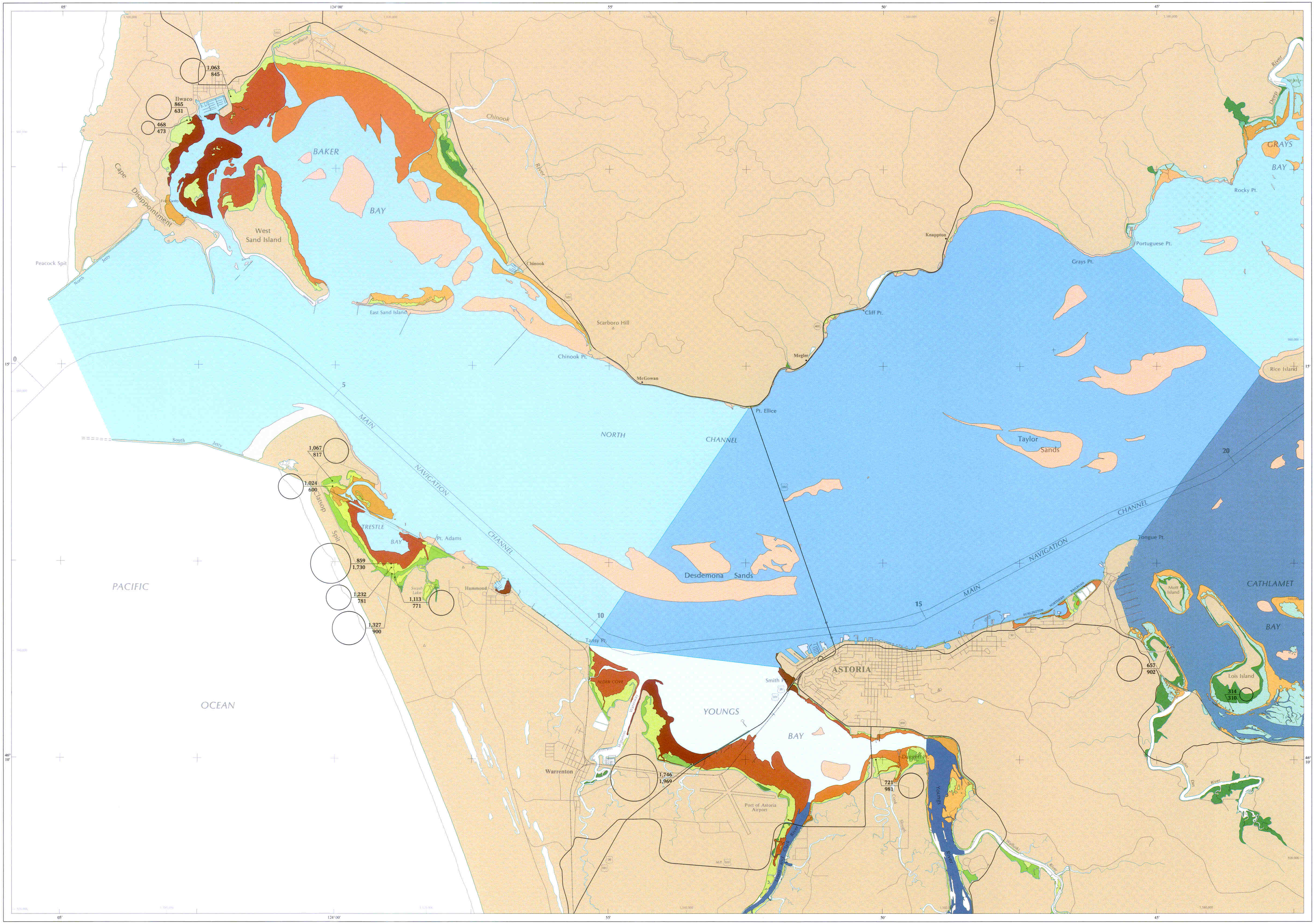
Discussion

The Columbia River Estuary supports extensive brackishwater and freshwater tidal marshes. The brackishwater marsh communities are very similar to those in other estuaries of the region. Although small freshwater marshes also exist in other nearby estuaries, the occurrence of extensive freshwater tidal marsh communities is uncommon on the west coast of North America. Extensive freshwater tidal marshes can develop only in estuaries with a large tidally-influenced area and a strong and constant riverflow which keeps much of this area fresh. Estuaries on the west coast that fit these criteria include the Fraser River Estuary, British Columbia, Canada; the Columbia River Estuary; and San Francisco Bay, California. Each has extensive freshwater tidal marshes and although the marshes of the Fraser River and Columbia River Estuaries are somewhat similar, many of the species present in the Columbia have not been reported in the Fraser. Because of their large extent and unusual flora, the freshwater tidal marshes of the Columbia River Estuary can be considered unique among the region's tidal marshes.

Although the flora is unusual, marsh plants of the Columbia River Estuary, like those of most estuaries, are very productive. Of the primary producers in the estuary, marsh plants are the most productive on a per square meter basis (Figure 3-2). However, they account for only 38 percent of the carbon produced within the estuary because they occupy a relatively limited area. When compared to all carbon sources to the estuary (including phytoplankton and detritus imported from upriver), marshes account for only about 5 percent (Figure 3-3).

Animals consume marsh plant material either directly or as detritus. The direct consumers, including mammals, birds, and insects, eat the live plants. The detritivores, mainly aquatic invertebrates, consume decaying plant material that has been removed from the marsh surface by tidal action. This removal of plant material is referred to as detritus export.

A portion of the detritus export occurs during the growing season when dead plant material breaks off the plants, decays, and is washed from the marshes. As noted above, a large portion of the aboveground plant material produced during the year is transferred to the belowground root material before the growing season ends. The remainder, which has been estimated at 50 percent of the annual production, comprises the dead vegetation seen on the marshes in late fall. Most of this detritus is exported during winter and early spring when high riverflows sweep the dead plant shoots and leaves from the marshes.


BAKER
BAY
West
Sand Island
Cape
Disappointment
Ilwaco
Peacock Spit
North Jetty
East Sand Island
Chinook
Chinook Pt.
Scarboro Hill
McGowan
Knappton
Cliff Pt.
Megler
Pt. Ellice
Grays Pt.
Portuguese Pt.
Rocky Pt.
GRAYS
BAY
Rice Island
NORTH
CHANNEL
MAIN
NAVIGATION
CHANNEL
Taylor
Sands
Desdemona
Sands
South Jetty
Clatsop
Spit
TRESTLE
BAY
Pt. Adams
Hammond
Swash Lake
PACIFIC
OCEAN
Tansy Pt.
ALDER COVE
YOUNGS
BAY
Smith Pt.
ASTORIA
Warrenton
Port of Astoria Airport
Tongue Pt.
Mott Island
Lois Island
CATHLAMET
BAY
1,063
845
865
631
468
473
1,067
817
1,024
600
859
1,730
1,232
781
1,113
771
1,327
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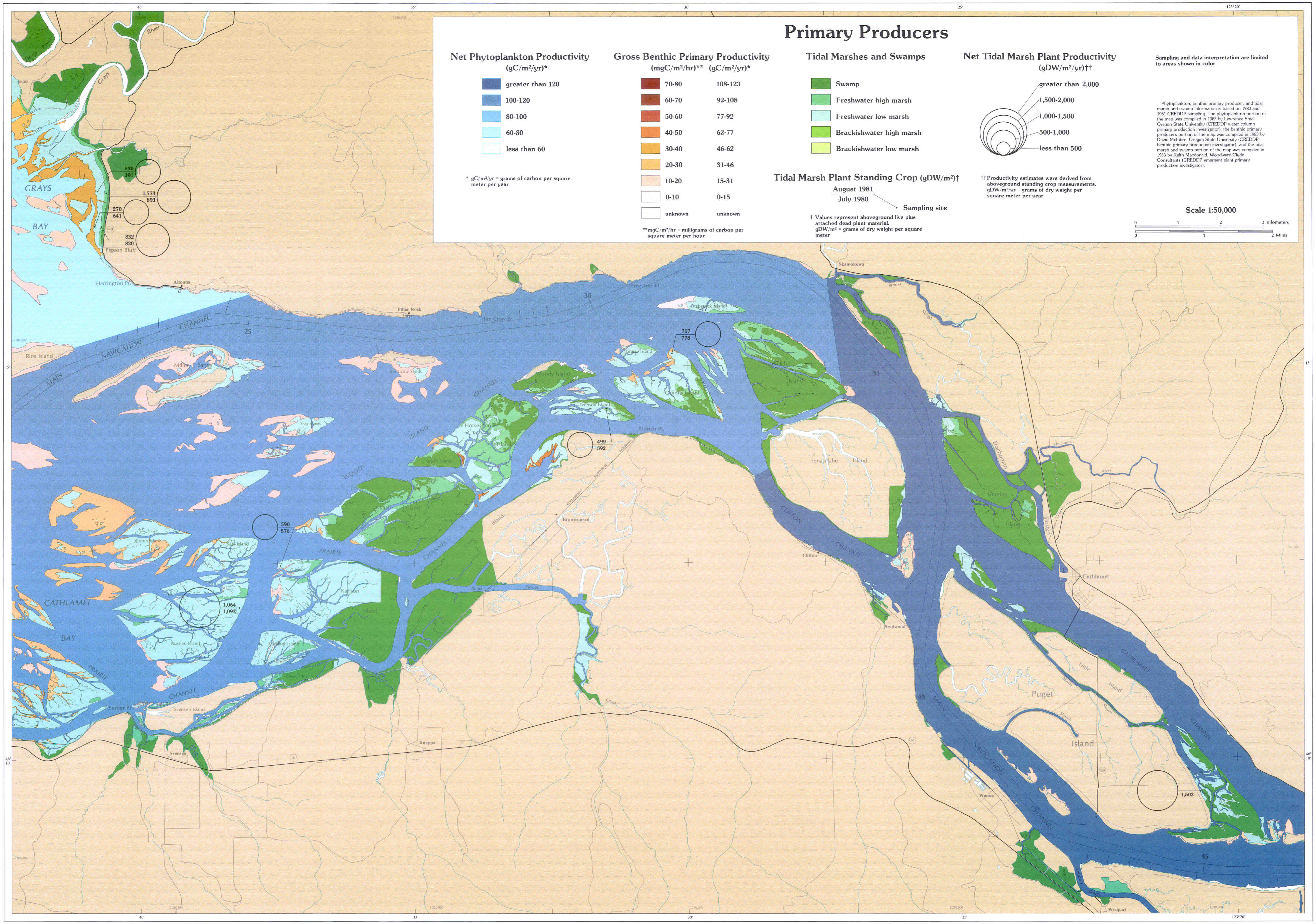
1,969
721
981
657
902
314
310


Primary Producers
Net Phytoplankton Productivity (gC/m²/yr)*
greater than 120
100-120
80-100
60-80
less than 60
* gC/m²/yr = grams of carbon per square meter per year
Gross Benthic Primary Productivity (mgC/m²/hr)** (gC/m²/yr)*
70-80 108-123
60-70 92-108
50-60 77-92
40-50 62-77
30-40 46-62
20-30 31-46
10-20 15-31
0-10 0-15
unknown unknown
**mgC/m²/hr = milligrams of carbon per square meter per hour
Tidal Marshes and Swamps
Swamp
Freshwater high marsh
Freshwater low marsh
Brackishwater high marsh
Brackishwater low marsh
Tidal Marsh Plant Standing Crop (gDW/m²)†
August 1981
July 1980
Sampling site
† Values represent aboveground live plus attached dead plant material.
gDW/m² = grams of dry weight per square meter
Net Tidal Marsh Plant Productivity (gDW/m²/yr)††
greater than 2,000
1,500-2,000
1,000-1,500
500-1,000
less than 500
†† Productivity estimates were derived from aboveground standing crop measurements.
gDW/m²/yr = grams of dry weight per square meter per year
Sampling and data interpretation are limited to areas shown in color.
Phytoplankton, benthic primary producer, and tidal marsh and swamp information is based on 1980 and 1981 CREDDP sampling. The phytoplankton portion of the map was compiled in 1983 by Lawrence Small, Oregon State University (CREDDP water column primary production investigator); the benthic primary producers portion of the map was compiled in 1983 by David McIntire, Oregon State University (CREDDP benthic primary production investigator); and the tidal marsh and swamp portion of the map was compiled in 1983 by Keith Macdonald, Woodward-Clyde Consultants (CREDDP emergent plant primary production investigator).
Scale 1:50,000
0 1 2 3 Kilometers
0 1 2 Miles
GRAYS
BAY
CATHLAMET
BAY
Skamokowa
Puget
Island
Cathlamet
Tenasillahe Island
Westport
Wauna
Clifton
Brownsmead
Svensen
Knappa
MAIN NAVIGATION CHANNEL
CLIFTON CHANNEL
CATHLAMET CHANNEL
PRAIRIE CHANNEL
WOODY ISLAND CHANNEL
530
391
1,773
893
270
641
832
820
717
778
499
592
590
576
1,064
1,093
1,502

Chapter 4.

INVERTEBRATES

Animal life can be separated into vertebrate and invertebrate groups. Vertebrates are animals with backbones; invertebrates do not have backbones. Of the known species of animals, about 96 percent are invertebrates. The principal invertebrates in the Columbia River Estuary can be classified as shown in Figure 4-1. The crustaceans comprise the largest number of invertebrates in the estuary; the most important of these are amphipods and copepods. Bivalves, polychaetes, and oligochaetes are also important members of the estuarine ecosystem.

Many factors affect the distribution of invertebrate species in the Columbia River Estuary. The most important is salinity. The range of salinity (lowest to highest) to which it is exposed is usually more important in determining a species' distribution than is the average salinity. An organism cannot survive in a location whose salinity range exceeds its tolerances for even short periods of time. The difference between minimum and maximum salinities in most regions of the Columbia River Estuary is very wide (see "Circulation and Salinity"); thus organisms with narrow tolerances tend to be excluded.

Invertebrates consume detrital particles and living single-celled plants such as phytoplankton and benthic diatoms, all of which are too small to be eaten by most vertebrates. Some invertebrates are carnivores, preying on smaller invertebrates. The detritivores and herbivores are important to the food web because they convert detritus and microscopic plants into food for larger animals. Without the invertebrates much of the primary production and all of the particulate detritus in the estuary would be useless to vertebrates.

Three teams of CREDDP investigators studied the estuary's invertebrates, focusing on the distribution of species, their abundance and productivity (see "Measures of Invertebrate Abundance and Productivity" on this page), and the role of physical factors. The research was divided according to habitats. One team sampled the water column at all depths, collecting the invertebrates of the water column known as the zooplankton. Another team sampled the sediments, collecting the invertebrates known as the benthic infauna. Because the epibenthic zone at the surface of the sediments is also distinctive, a third team concentrated on this habitat (Figure 4-2). The boundaries between these habitats are not rigid, and some species are found in more than one habitat.

Zooplankton

The community of small invertebrates that live in the water column is called the zooplankton. This community is considered to be planktonic because individual members, called zooplankters, are not strong enough swimmers to move against the currents of the estuary. Some are able to move up and down in the water column, however. The zooplankton is the major food for several species of fish, including longfin smelt, American shad, and Pacific herring. The zooplankton of the Columbia River Estuary consists almost entirely of three kinds of crustaceans: copepods, cladocerans, and mysids (Figure 4-1). Other less abundant members of the zooplankton include rotifers, benthic infauna larvae, and fish larvae.

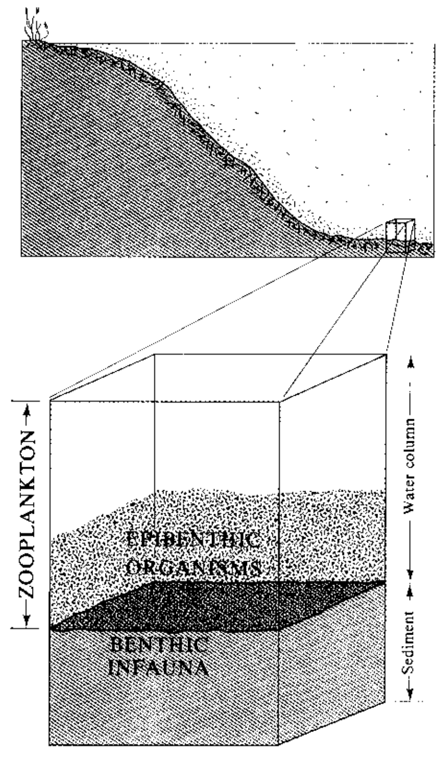


Figure 4-2. Schematic representation of three invertebrate habitats.

Members of the zooplankton can be herbivores, detritivores, and/or carnivores. Generally, the cladocerans and some copepods such as *Eurytemora affinis* feed on both phytoplankton and detritus. The mysids and other copepods, such as *Cyclops vernalis* and *Oithona similis*, are more versatile, able to consume phytoplankton, detritus, and smaller zooplankters. Most zooplankters consume phytoplankton and detritus by creating currents with their appendages and sweeping food particles into their mouths, a mechanism known as filter-feeding.

Factors Affecting Distribution and Abundance

Salinity, circulation, temperature, and reproductive cycles are the chief factors affecting the distribution and abundance of the Columbia River Estuary zooplankton. Availability of food and consumption by predators also may be important, but little is known about these factors.

The distribution of zooplankton species and assemblages (groups of species that occur together) is closely related to salinity. In the Columbia River Estuary, assemblages fall into three categories: freshwater, estuarine (brackishwater), and marine. The freshwater assemblage consists of zooplankters swept into the estuary from upriver. Most are intolerant of even very low salinity and die when they reach brackish water. The estuarine assemblage lives within the brackishwater reach is usually most abundant in the brackish bottom waters near the upriver limits of saline water. The marine assemblage consists of species common in coastal waters and tends to be associated with the more saline bottom water.

Because they are planktonic, zooplankton species tend to be associated with discrete water masses of the appropriate salinity and to move with those water masses. As a result, circulation affects zooplankton distribution. The locations of the three assemblages in the estuary depend mainly on riverflow volume. When high river discharges push the saline waters of the estuary downriver, the three assemblages shift downriver as well. Tidal fluctuations affect the distribution of the three assemblages, moving them up and down the estuary during flood and ebb tides. Certain combinations of riverflow and tidal conditions affect the distribution of the marine and estuarine assemblages: during low riverflow neap tide conditions, bottom saline water moves upriver (see "Circulation and Salinity"), resulting in an upriver transport of the zooplankton associated with it.

Temperature and periods of reproduction affect zooplankton abundance. For species adapted to warm water, summer water temperatures bring high growth rates and high reproductive rates. Cold water species are more abundant during winter. Zooplankton species usually produce several generations a year, and can produce a new generation in less than a month when conditions are favorable.

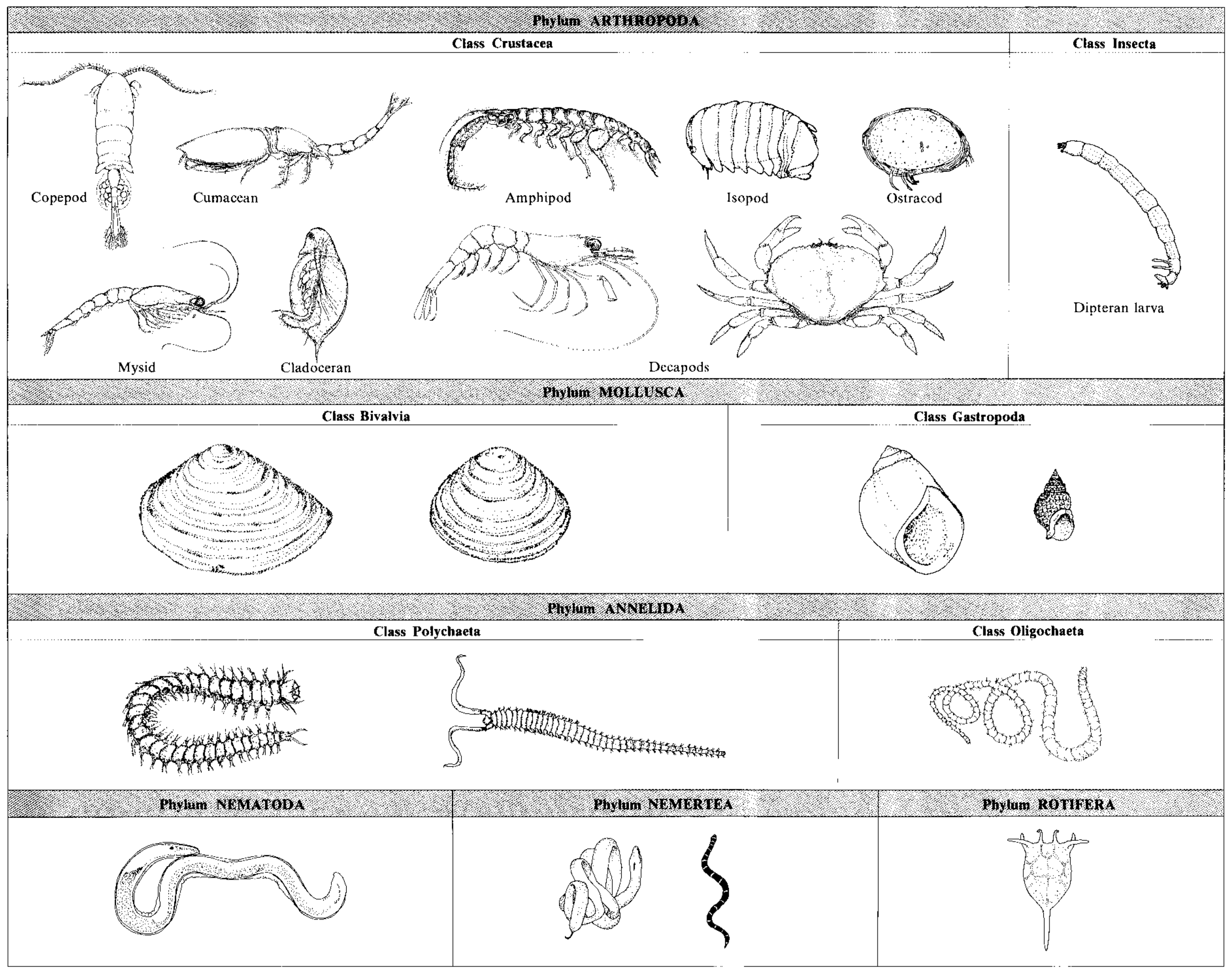


Figure 4-1. Classification of selected invertebrates representing the principal Columbia River Estuary invertebrate phyla.

Derivation, Uses, and Limitations of the Maps (Plates 11 and 12)

CREDDP investigators sampled the zooplankton approximately every two weeks during the spring, summer, and fall of 1980. The zooplankton study area encompassed ten stations in the navigation channel from RM-5 to RM-23. Plates 11 and 12 show the locations of the stations, which were chosen to cover the spectrum of zooplankton assemblages from marine through freshwater. Investigators sampled the water column at each station during flood tides. They also measured salinity in the surface water and at a depth of ten meters.

Plates 11 and 12 show 16 maps of density and distribution. There are two maps for each of eight key species, one presenting the results from a high riverflow spring tide date in spring, and the other showing the results from a low riverflow neap tide date in late summer. The eight species were selected to represent the three zooplankton assemblages (marine, estuarine, and freshwater), while also including representatives from each of the major crustacean groups. The two extremes in the estuary's physical conditions were chosen to show the effects of currents and salinity on zooplankton distribution.

The maps demonstrate the relationships between zooplankton distribution and physical factors. Marine and estuarine species are found primarily in the bottom waters and their distributions are closely correlated with deep water salinity. The distribution of freshwater species relates more to surface salinity.

Because the maps show zooplankton distribution and abundance for only two dates, a limited period is represented. Zooplankton abundance varies widely over short periods. For example, CREDDP investigators found a *Eurytemora affinis* density of over 150,000 animals per square meter of water surface (animals/m²) at one site on April 29, 1980; two weeks later this site had fewer than 200 animals/m². Such variation is not shown on the maps. Nor are the effects of reproductive cycles shown. All the maps represent conditions of above-average intrusion of salt water since sampling was done during flood tides. As a result, the distributions of marine and brackishwater zooplankton are farther upstream than average. The maps do not show differences in zooplankton abundance at different depths, since the entire water column was sampled uniformly.

Interpretation of the Maps (Plates 11 and 12)

Marine Assemblage (Plate 11, Maps a through f)

The marine zooplankton assemblage of the Columbia River Estuary is represented on Plate 11 by *Acartia clausi* (Maps a and b), *Oithona similis* (Maps c and d), and *Archeomysis grebnitzkii* (Maps e and f).

Acartia clausi (Figure 4-3) is a marine copepod which tolerates brackish salinities down to about 15 parts per thousand (ppt). During CREDDP sampling, its maximum density was about 5,000 animals/m². Under high riverflow conditions (Plate 11, Map a), its population extends from the mouth to about RM-11, while during low riverflow (Plate 11, Map b) its upriver limit is at about RM-19. These upriver limits correspond to deep water salinities of about 15 to 25 ppt. The high densities of *A. clausi* during the low riverflow date result in part from neap tide bottom currents transporting these marine copepods into the estuary. In addition, the late summer warmer waters allow for faster growth and reproduction.

Oithona similis (Figure 4-4) is a marine copepod whose population is located in the downriver portions of the estuary during both high and low riverflow seasons (Plate 11, Maps c and d). This species enters the estuary with the flood tide. During both high and low riverflow its population extends upriver to a deep water salinity level of about 20 to 25 ppt (Plate 11, Maps c and d).

The mysid *Archeomysis grebnitzkii* (Figure 4-5) is a marine species but can tolerate very low salinities. Its population extends upriver nearly to fresh water under both high and low riverflow conditions (Plate 11, Maps e and f).

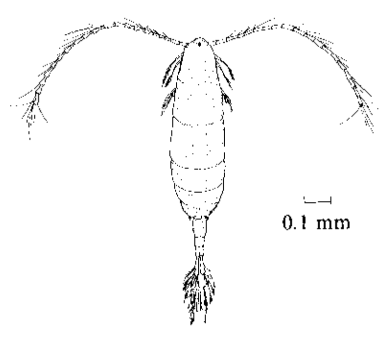


Figure 4-3. *Acartia clausi.*

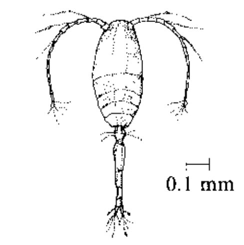


Figure 4-4. *Oithona similis.*

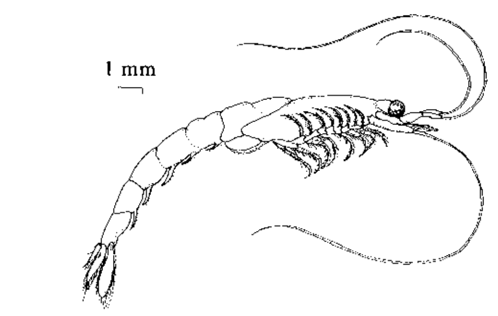


Figure 4-5. *Archeomysis grebnitzkii.*

Estuarine Assemblage (Plate 11, Maps g and h and Plate 12, Maps a and b)

The estuarine zooplankton assemblage is represented by *Eurytemora affinis* (Plate 11, Maps g and h) and *Neomysis mercedis* (Plate 12, Maps a and b). *Eurytemora affinis* (Figure 4-6) is a copepod found in salinities ranging from near 0 to about 15 ppt. Its Columbia River Estuary population is greatest in spring and early summer when densities average around 25,000 to 75,000 animals/m² and occasionally exceed 250,000 animals/m². *E. affinis* is one of the most important foods in the estuary for plankton-feeding fish.

Under high riverflow conditions (Plate 11, Map g), most of the *E. affinis* population is between RM-9 and RM-15, with highest densities in a narrow zone in the upriver portion of this range. Deep water salinities in this high-density zone range from near 0 to 15 ppt. Plate 11, Map h shows an upriver shift in distribution under low riverflow neap tide conditions. Most of the population is between RM-17 and the upriver limit of sampling (RM-23), corresponding to a salinity range of 10 to 12 ppt. In both cases the organisms are associated with the upriver limit of saline water, which shifts upriver under low riverflow conditions.

Neomysis mercedis (Figure 4-7) is a mysid which is adapted to low salinities and tolerates fresh water. Most of its population occurs at the extreme upriver limit of saline water. This species' peak high riverflow density is at RM-15 (Plate 12, Map a) while its peak low riverflow density is at RM-21 (Plate 12, Map b). Under both high and low riverflow conditions *N. mercedis* probably extends upriver beyond the zooplankton study area. The bulk of the population shown on the two maps occupies areas in which the bottom water salinity is either zero or low (up to 10 ppt).

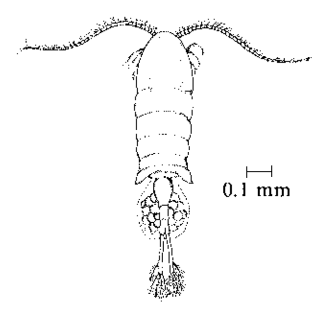


Figure 4-6. *Eurytemora affinis.*

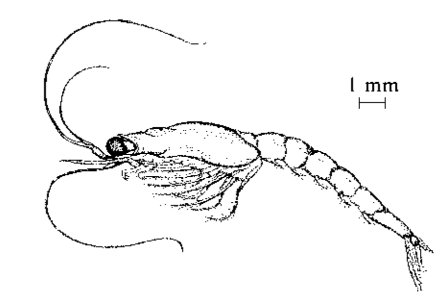


Figure 4-7. *Neomysis mercedis.*

Freshwater Assemblage (Plate 12, Maps c through h)

The freshwater zooplankton assemblage of the Columbia River Estuary is represented on Plate 12 by *Cyclops vernalis* (Maps c and d), *Daphnia pulex* (Maps e and f), and *Bosmina longirostris* (Maps g and h). These are riverine species which are transported by riverflow into the estuary. The *C. vernalis* population extends downriver to between RM-7 and RM-11 under both high and low riverflow conditions (Plate 12, Maps c and d).

Daphnia pulex (Figure 4-8) and *Bosmina longirostris* are freshwater cladocerans and are important prey for several species of fish. Both species extend downriver to between RM-7 and RM-11 (Plate 12, Maps e and through h). CREDDP and other investigators have found that the densities of both species are high in summer, decline in fall, remain low during winter, and rise again in early spring. This is probably related to reproductive seasons, water temperatures, and factors upriver from the estuary.

Measures of Invertebrate Abundance and Productivity

The abundance of animals may be measured as density or standing crop. Density is the number of individuals of a species per unit of area. Standing crop is the collective weight of those individuals per unit of area. Standing crop may be expressed as wet weight or dry (dehydrated) weight, or converted to grams of carbon. The weight of all the invertebrate species of a given habitat may be combined in a standing crop value.

Whereas standing crop represents the total weight of animals at a given time, productivity represents the total amount of standing crop generated over a period of time. Productivity is usually expressed as grams of animal weight per square meter of habitat per year (g/m²/yr). It is a better indicator of the total amount of food available to predators than is standing crop. Consider an example in which the standing crop on January 1 was 10 g/m²; during that year growth and reproduction added an additional 20 g/m², while predation removed 20 g/m². The standing crop the following January 1 would still be 10 g/m² but the productivity during that year would be 20 g/m²/yr. Therefore, much more food was available to predators than indicated by standing crop measurements alone.

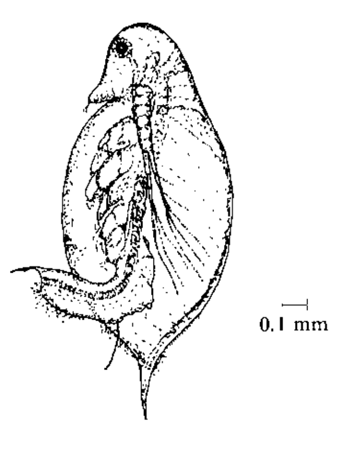


Figure 4-8. *Daphnia pulex.*

Discussion

The distributions of the three zooplankton assemblages shown in Plates 11 and 12 are different for the two riverflow conditions. Under high riverflow conditions, the marine assemblage (Plate 11, Maps a, c, and e) does not extend far into the estuary. The estuarine group is confined to a narrow band near the upriver limit of saline bottom water intrusion (Plate 11, Map g and Plate 12, Map a). This occurs because the salinity of the bottom water decreases abruptly over a relatively short distance as it encounters a strong riverflow. Under low riverflow conditions, the marine and estuarine assemblages shift upriver (Plate 11, Maps b, d, f, and h and Plate 12, Map b). The saline bottom water extends farther upriver and as a result the estuarine assemblage occupies a much broader band.

The estuarine zooplankton assemblage, which is the most productive, has a complex relationship with the physical processes of the estuary. The estuarine assemblage tends to be associated with the bottom waters of the estuary, whose direction of flow is upstream under most conditions. As a result, these zooplankters are moved upstream as well. This allows the zooplankters of the estuarine assemblage to become concentrated at the upriver limit of salinity intrusion. This mechanism prevents them from being flushed out of the estuary and allows them to develop a sizable population. The upriver limit of salinity intrusion is associated with the turbidity maximum and is a site where dead and dying phytoplankton and detritus from upriver accumulate, providing abundant food for the estuarine zooplankton.

Benthic Infauna

The benthic infauna is the community of invertebrates that live within the bottom sediments. Since some animals exist either below the sediment surface or crawling over it, the distinction between the benthic infauna and epibenthic organisms is not rigid. The smallest infaunal animals are microscopic, but CREDDP investigators focused on those longer than half a millimeter, called the macrofauna (Figure 4-9). Most of the macrofauna in the Columbia River Estuary are bivalves, amphipods, or polychaetes (Figure 4-1). Unlike many other estuaries, the Columbia River Estuary does not support commercially exploitable populations of macrofaunal species such as oysters and edible clams. Macrofaunal species are important because, along with the smaller benthic organisms, they form the principal link between detritus and fish, birds, and mammals.

Factors Affecting Distribution

The distribution of the benthic infauna is governed by many physical, chemical, and biological factors. In the Columbia River Estuary, CREDDP investigators concluded that salinity and sediment type are the major factors that influence distribution. Dissolved oxygen content in the sediments, water temperature, predation, and competition among species influence the distribution of species in other estuaries; these factors, although not studied by CREDDP, probably influence distribution in the Columbia River Estuary as well.

Salinity is the most important factor affecting the distribution of the benthic infauna. Species are adapted to tolerate marine, brackishwater, or freshwater conditions. Within a salinity zone, sediment type strongly influences the distribution of species. Fine sediments and their entrapped organics support high densities of deposit-feeders, while coarse sand sediments favor filter-feeders. (For an explanation of deposit-feeding and filter-feeding, see "Life History Patterns of the Benthic Infauna" on this page.) The type of dwelling of a species also affects its association with sediment types. For example, a species requiring fine sand grains to incorporate into its burrow lining could not exist in a coarse sand or fine silt environment.

Derivation, Uses, and Limitations of the Maps (Plate 13)

The CREDDP benthic infauna investigators designed their sampling to account for the major benthic environments. They defined three general salinity zones in the estuary and five or six sediment regions within each zone. The salinity zones were the marine-dominated lower estuary, the brackishwater middle estuary, and the freshwater upper estuary (Figure 4-10). The investigators delineated sediment regions according to depth and degree of exposure to strong currents, as follows: main channels, minor channels, marsh channels, protected flats, exposed flats, and slopes (between main channels and flats). Generally, the main channels and slopes have the coarsest sediments while the protected flats and marsh channels have finer sediments and a higher organic content. The other regions have intermediate sediment textures.

Approximately ten sites within each environment were sampled during September 1981. For each species, CREDDP investigators determined the standing crop in each sample, then calculated standing crop averages representing all samples in each environment. Plate 13 shows the boundaries separating different environments; the standing crop values within the boundaries are the averages obtained from the September 1981 samples. These standing crop values are expressed as milligrams of ash-free dry weight per square meter (mgAFDW/m^2). Ash-free dry weight differs from dry weight in that the weight of hard, undigestible tissue (for example, exoskeleton or shells) is subtracted from the total dry weight to obtain the weight of soft tissues only.

Conditions are not constant within the benthic environments shown on Plate 13. Infauna population size and community structure can change seasonally and from year to year. Since the maps represent one date, they do not show these variations. Benthic infauna standing crop does not change abruptly at the boundaries of the infaunal environments shown in Plate 13; there is a gradual transition in standing crop levels between any two adjacent environments.

Interpretation of the Maps (Plate 13)

Total Benthic Infauna (Plate 13, Map a)

Plate 13, Map a shows standing crop for all macrofaunal organisms collected during the CREDDP survey. Standing crop is highest on protected flats (fine sediments) and decreases toward deeper and more exposed areas (coarse sediments). Protected areas support a large standing crop of deposit-feeders because of the abundance of detritus and the stability of the sediments, while channel bottoms support a lower standing crop because the sediments are unstable.

Plate 13, Map a also shows that total standing crop is generally lower in the middle estuary than in the marine or freshwater zones. These differences are probably related to the salinity tolerances and relative sizes and abundances of the species involved. The fresh and brackishwater amphipod *Corophium salmonis* (Plate 13, Map b) is very abundant and is a major contributor to standing crop in some areas. Clams tend to dominate the total infauna standing crop wherever they are abundant because they are so large. The presence of *Macoma balthica* (Plate 13, Map c), a marine and brackishwater deposit-feeding clam, explains the high standing crop observed on lower estuary protected flats (for example, Baker Bay) and the overall higher standing crop in the lower than middle estuary. The presence of the freshwater clam *Corbicula manilensis* (Plate 13, Map d) along with abundant *C. salmonis* explains the high standing crop in the upper estuary. Most of the middle estuary flats (for example, Desdemona Sands) are unprotected and have coarse sediments, making them relatively inhospitable to *M. balthica* and *C. salmonis* (both deposit-feeders). While the sediments in such areas might support the filter-feeder *C. manilensis,* the salinity range is too wide. Large standing crops of deposit-feeders *(C. salmonis* and *M. balthica)* do exist in the middle estuary wherever there are protected fine-sediment flats, as in Youngs Bay. Seasonal population fluctuations are probably also a factor in explaining these distributions.

Corophium salmonis (Plate 13, Map b)

Corophium salmonis (Figure 4-11) is a fresh and brackishwater surface deposit-feeder found from Baker Bay upriver at least as far as Portland. It occurs in muddy sand, where it builds a U-shaped tube. *C. salmonis* is eaten by many fish species. Downstream-migrating juvenile salmon consume it almost exclusively because *C. salmonis* is so abundant during the period when salmon migrate downstream. Plate 13, Map b reflects the salinity and sediment requirements of *C. salmonis.* The amphipod is abundant in such low salinity areas as Youngs Bay, Cathlamet Bay, and Grays Bay. *C. salmonis* is more abundant in the muddy-sand habitats of the bays than in the coarse-sand habitats of the channels.

CREDDP investigators conducted year-round studies of *C. salmonis* at Desdemona Sands and Grays Bay. Spring generation juveniles were produced in May and grew throughout the summer, producing the fall generation in July and August. Fall juveniles overwintered, producing a new generation the next spring. The Desdemona Sands population (Figure 4-12) disappeared in September and reappeared in April as adults and subadults. The population increased dramatically during early summer, reaching peak densities in August, and then declined rapidly. Densities at Desdemona Sands ranged from zero to about 95,000 animals/m^2. At Grays Bay (Figure 4-13), density increased steadily from August into the winter, peaking in February. Density then declined steadily to its lowest point in July. The fall and winter population increases were caused by immigration of adults and subadults. Densities at Grays Bay ranged from 5,000 to 30,000 animals/m^2.

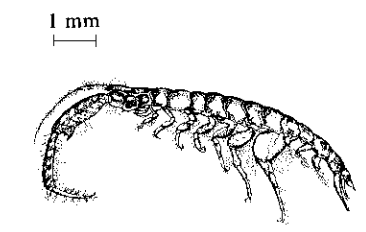


Figure 4-11. *Corophium salmonis.*

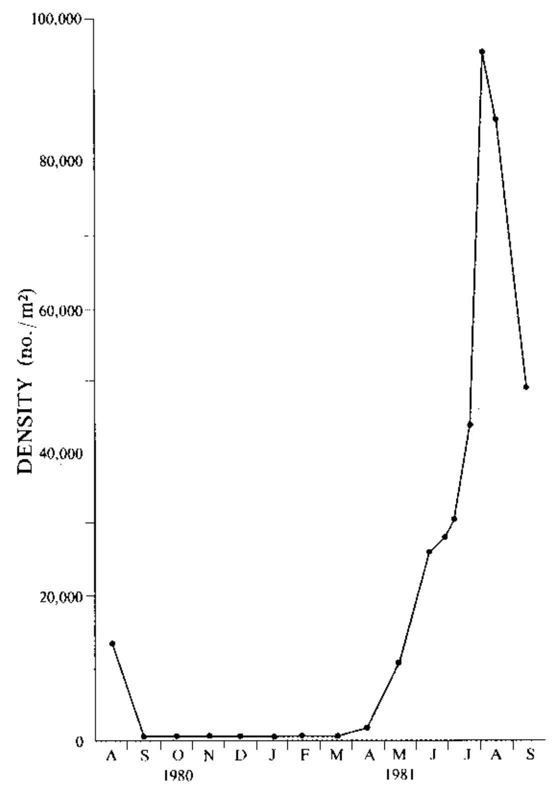


Figure 4-12. Density of *Corophium salmonis* at a sampling site on Desdemona Sands, August 1980 to September 1981 (Holton et al. 1984).

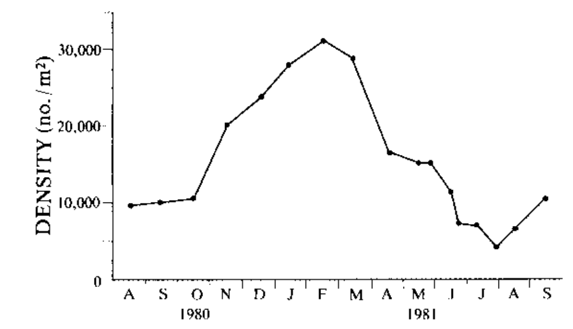


Figure 4-13. Density of *Corophium salmonis* at a sampling site in Grays Bay, August 1980 to September 1981 (Holton et al. 1984).

Total annual *C. salmonis* production was 8.2 grams of ash-free dry weight per square meter per year (gAFDW/m^2/yr) in Grays Bay and 13.1 gAFDW/m^2/yr on Desdemona Sands. *C. salmonis* contributed about 90 percent of the Grays Bay infaunal production and 96 percent of the Desdemona Sands production. In some freshwater areas of the estuary *C. salmonis* does not dominate the standing crop because of the presence of *Corbicula manilensis. C. salmonis* dominates the annual production in these areas, however, and is an important food resource in the estuary.

Macoma balthica (Plate 13, Map c)

Macoma balthica (Figure 4-14) is a small marine and brackishwater clam. It is a surface deposit-feeder found in muddy and muddy sand sediments. Birds feed on the large individuals in the tidal flats, and *M. balthica* has been found to be an important food item for starry flounder, sculpin, and Dungeness crab.

The distribution of *M. balthica* shown on the map reflects its adaptations to marine and brackishwater conditions and muddy sand sediments. It is particularly abundant in Baker Bay and outer Youngs Bay. *M. balthica* tends to dominate the infaunal standing crop in the lower estuary.

M. balthica shows small density fluctuations during the year (Figure 4-15). The population densities rarely exceed 5,000 animals/m^2. In Baker Bay, the annual production of *M. balthica* was estimated to be 13.6 gAFDW/m^2/yr, accounting for about 75 percent of the total annual benthic infaunal production at that site.

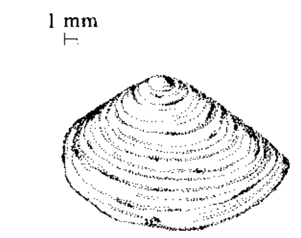


Figure 4-14. *Macoma balthica.*

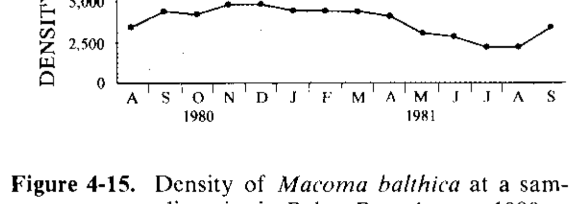


Figure 4-15. Density of *Macoma balthica* at a sampling site in Baker Bay, August 1980 to September 1981 (Holton et al. 1984).

Corbicula manilensis (Plate 13, Map d)

Corbicula manilensis (Figure 4-16) is a small riverine clam adapted to fresh water but able to tolerate very low salinity. It is a filter-feeder, more frequently found in sandy than muddy sediments. Although many clam species burrow into the sediments, *C. manilensis* is always found on or near the sediment surface.

The distribution of *C. manilensis* reflects its adaptation to freshwater or low salinity habitats. Along with *Corophium salmonis, C. manilensis* tends to dominate the infaunal standing crop in the freshwater region. The species is more abundant in deeper water habitats, probably because coarser, more sandy sediments tend to occur in deeper water. The density of *C. manilensis* in Grays Bay ranges from about 100 to 1,000 animals/m^2 (Figure 4-17). Although the density is rather low compared with other infaunal species, the relatively large size of this clam accounts for its importance in the total infauna standing crop. *C. manilensis* is abundant in many parts of the Columbia River but in the estuary it is on the edge of its distribution. The estuarine population is composed mostly of juveniles.

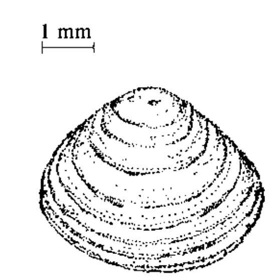


Figure 4-16. *Corbicula manilensis.*

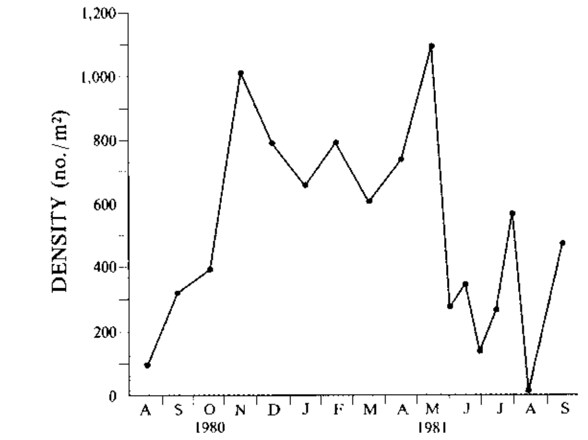
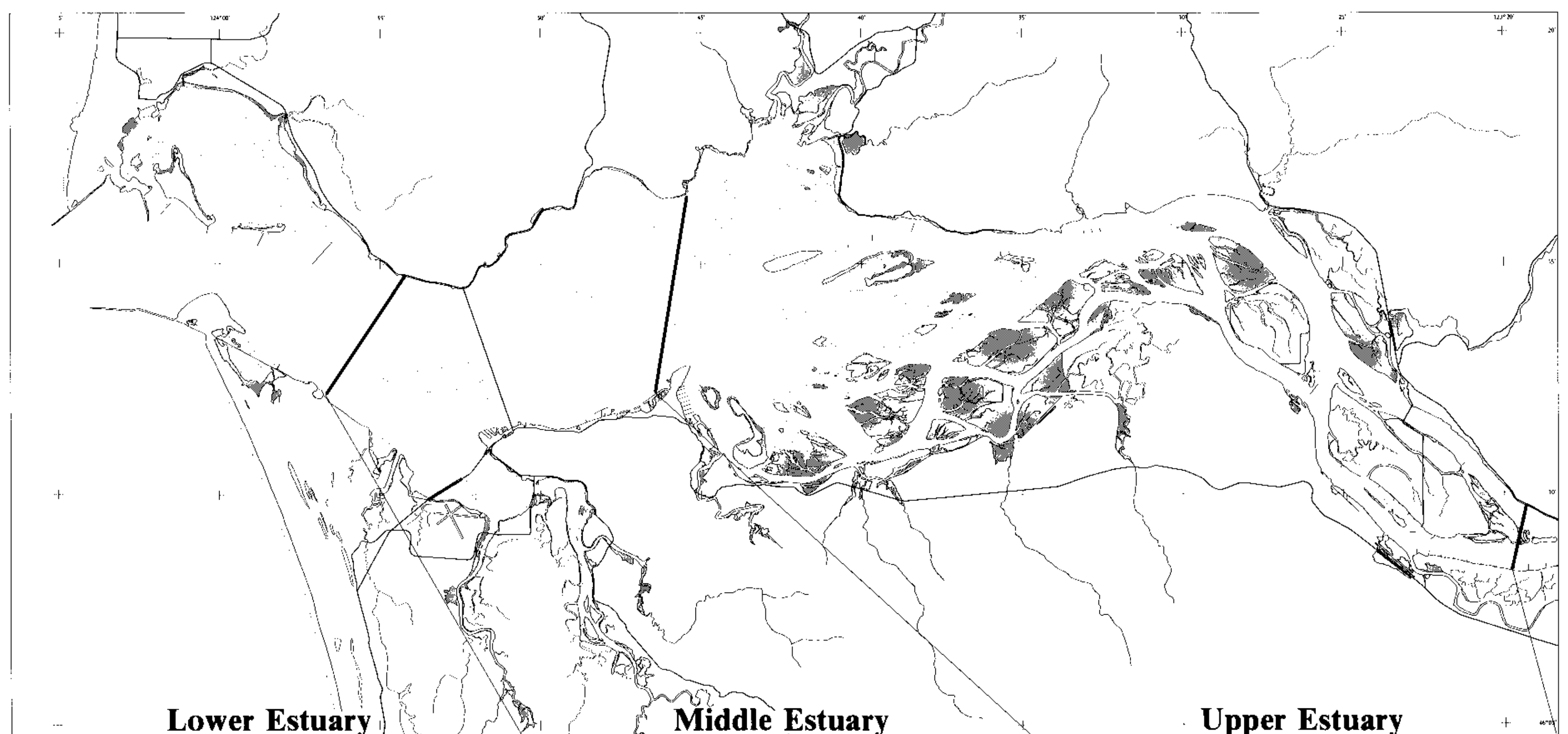


Figure 4-17. Density of *Corbicula manilensis* at a sampling site in Grays Bay, August 1980 to September 1981 (Holton et al. 1984).

Pseudopolydora kempi (Plate 13, Map e)

Pseudopolydora kempi (Figure 4-18) is a tube-dwelling, surface deposit-feeding polychaete adapted to brackishwater and muddy sand habitats. The map shows that *P. kempi* populations are largest in the shallow protected areas in the lower estuary, mainly Baker Bay. This distribution probably reflects the species' lack of tolerance for low salinity water and its adaptation to muddy sand sediments.

CREDDP investigators found that, in Baker Bay, the density of *P. kempi* was high in August when young are released (as many as 10,000 animals/m^2), declining to fewer than 1,000 animals/m^2 the following summer (Figure 4-19). A detailed study of productivity at a site in Baker Bay indicated a rate of 1.12 gAFDW/m^2/yr, a value more than three times its average standing crop at the study site of 0.33 gAFDW/m^2. *P. kempi* production accounted for 6 percent of the annual production of the entire benthic infauna at the Baker Bay site.



Lower Estuary	Middle Estuary	Upper Estuary
	Fine Sediments	
(e.g. Baker Bay) *Macoma balthica* *Pseudopolydora kempi* turbellarians* *Hobsonia florida* *Neanthes limnicola* oligochaetes	**(e.g. Youngs Bay)** turbellarians* *Hobsonia florida* *Neanthes limnicola* oligochaetes *Corophium salmonis* *Fluminicola virens*****	**(e.g. Cathlamet Bay)** oligochaetes *Corophium salmonis* *Fluminicola virens* *Corbicula manilensis* insect larvae (families Chironomidae and Heleidae)
	Coarse Sediments	
(e.g. channels) polychaetes (family Spionidae) *Paraphoxus milleri***** nemerteans	**(e.g. sandbars)** *Paraphoxus milleri* nemerteans *Eohaustorius estuaris****** *Eogammarus confervicolus* oligochaetes *Neanthes limnicola* *Corophium salmonis*	**(e.g. channels)** *Corophium salmonis* insect larvae (families Chironomidae and Heleidae) *Corbicula manilensis* (mostly juveniles)

*flatworms **a gastropod ***an amphipod

Figure 4-10. Generalized distribution and composition of major benthic infaunal assemblages found in the Columbia River Estuary (from Holton et al. 1984).

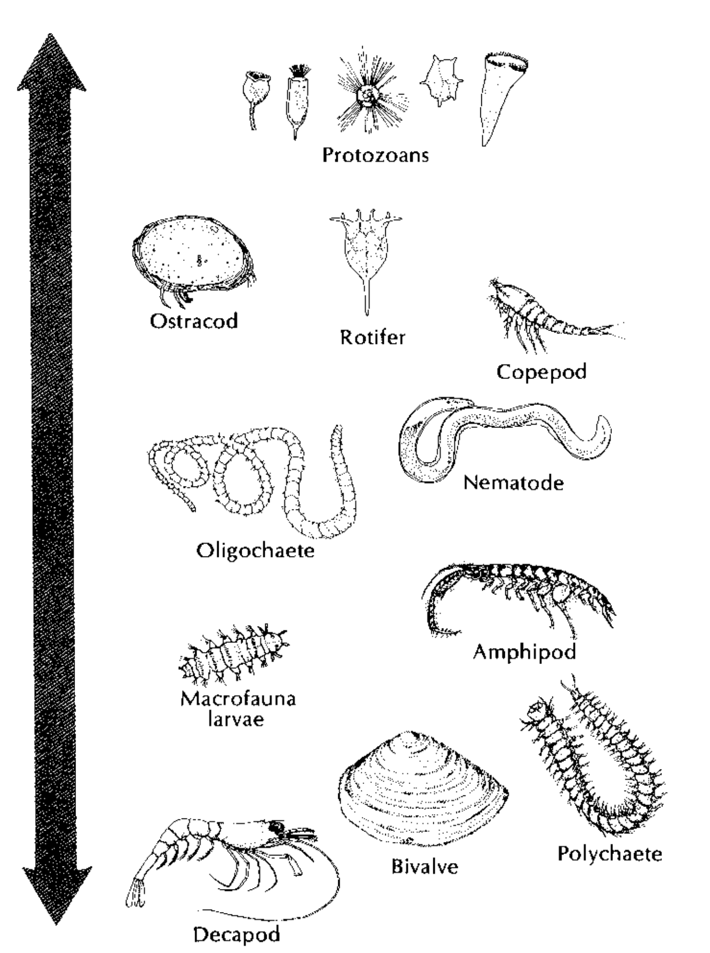


Figure 4-9. Size classification of benthic invertebrate types. Selected Columbia River Estuary invertebrates are shown.

Although most knowledge of the benthic invertebrates in the estuary is limited to the macrofauna, the smaller invertebrates also play a vital role in the ecosystem. These organisms are generally classified as microfaunal (less than 0.063 millimeters) and meiofaunal (0.063 to 0.5 millimeters). The microfauna consists mainly of protozoans (single-celled animals), which, along with bacteria and fungi, are the initial colonizers and decomposers of detritus. The meiofauna consists of small invertebrates such as copepods and nematodes, which consume detritus. The micro- and meiofauna, along with the macrofauna, are the major links between detritus and fish in the Columbia River Estuary.

Life History Patterns of the Benthic Infauna

A major distinction within the infauna involves food-gathering and consumption patterns. Some species ingest the sediment directly, obtaining their nutrition from the detritus and microscopic living matter within the sediments. Others position themselves near the sediment surface and periodically reach out to sweep in suspended plant material from the surface (for example, *Corophium salmonis,* Figure 4-11). Still others use siphons to vacuum the adjacent surface, drawing in currents of water and extracting portions of the suspended food matter (for example, *Macoma balthica,* Figure 4-14). All of these consumption patterns are called deposit-feeding and rely primarily on detritus. Deposit-feeding is the most common feeding mode of the Columbia River Estuary infauna.

Another method of consumption is called filter-feeding. Filter-feeding species use siphons (for example, *Corbicula manilensis,* Figure 4-16) or tentacles (some polychaetes) to reach up into the overlying water and filter out its suspended small animals and plants. Other filter-feeders pump water through their burrows and extract the suspended material. Filter-feeders primarily consume live food such as phytoplankton rather than detritus.

A third feeding type is predation. Some macrofaunal species actively consume other invertebrates. Often, predatory invertebrates are capable of consuming detritus as well.

Consumption patterns are generally related to the type of sediment in which a species is found. Since deposit-feeders get much of their nutrition from detritus, they tend to be found in fine muddy sediments rich in organic material. Filter-feeding is often associated with sandy environments where deposit-feeders interfere less with filter-feeding species.

Some primarily deposit-feeding species such as *Corophium salmonis* construct tubular dwellings of fine sand cemented with secreted mucus. The animal periodically moves up the tube to sweep in the adjacent deposits, then withdraws again. Many other deposit-feeders are highly mobile, burrowing through and ingesting the sediment at the same time. Filter-feeders generally live in tubes or deep within the sediment, reaching the surface with siphons. Predators, because they must actively seek out prey, are generally mobile.

Another distinction within the infauna is concerned with the degree of opportunism exhibited by species. This refers to a species' ability to take advantage of changing environmental conditions. The Columbia River Estuary is a relatively unstable environment; riverflow is much greater than in most estuaries, currents are strong, salinity zones move many miles up and downriver on tidal and seasonal cycles, and the sediments shift actively. These circumstances favor opportunistic species. Generally, opportunistic species are characterized by high reproductive potential, rapid growth, and early maturity. Also, each of these species has a mechanism for broad dispersal at some point in its life cycle. Many infaunal species have a planktonic larval stage, that is, they release their young or larvae into the water column where currents disperse them over wide areas. Among some other species (for example, *Corophium salmonis*), juveniles and/or adults periodically swim up into the water column and are dispersed, often in response to a change in salinity. As a result of these life history patterns, sudden population increases and decreases in any given location are common among many infaunal species in the Columbia River Estuary.

Benthic infaunal species collected during CREDDP sampling and pertinent information concerning their life history patterns are listed in Figure 4-25.

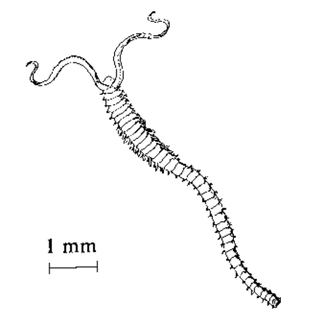


Figure 4-18. *Pseudopolydora kempi* (Rudy 1984).

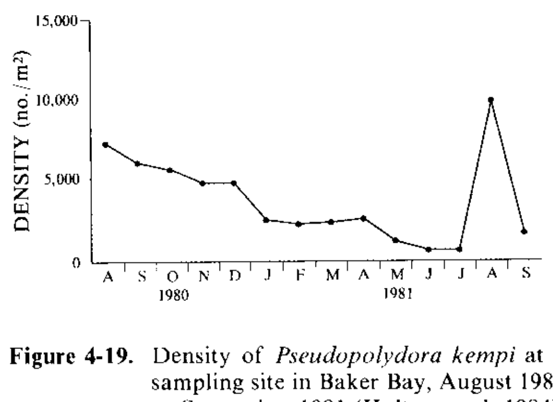


Figure 4-19. Density of *Pseudopolydora kempi* at a sampling site in Baker Bay, August 1980 to September 1981 (Holton et al. 1984).

Hobsonia florida (Plate 13, Map f)

Hobsonia florida (Figure 4-20) is a polychaete adapted to brackishwater and muddy sand habitats. Like *P. kempi*, *H. florida* is a tube-dwelling surface deposit-feeder.

The distribution of *H. florida* is similar to that of *P. kempi*. *H. florida* has a large population in Youngs Bay, however, because it has a greater tolerance for the low salinity conditions of this region.

CREDDP investigators found that in Baker Bay the density of *H. florida* fluctuated from about 2,000 animals/m² in winter and spring to a peak of over 30,000 animals/m² during the summer reproductive period (Figure 4-21). These figures may vary a great deal from year to year. The annual production of *H. florida* in Baker Bay amounted to 1.37 gAFDW/m²/yr, over five times its average standing crop (0.265 gAFDW/m²) at that site. *H. florida* accounted for 7.5 percent of the total annual production at the Baker Bay site during the CREDDP infauna study.

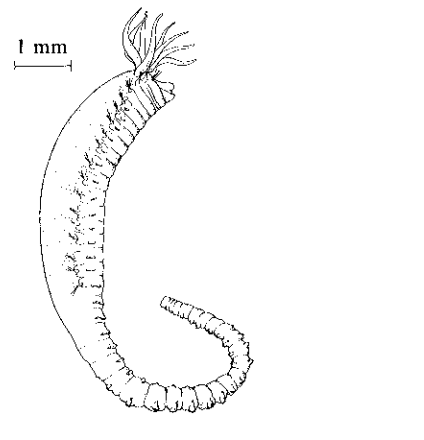


Figure 4-20. *Hobsonia florida* (Rudy 1984).

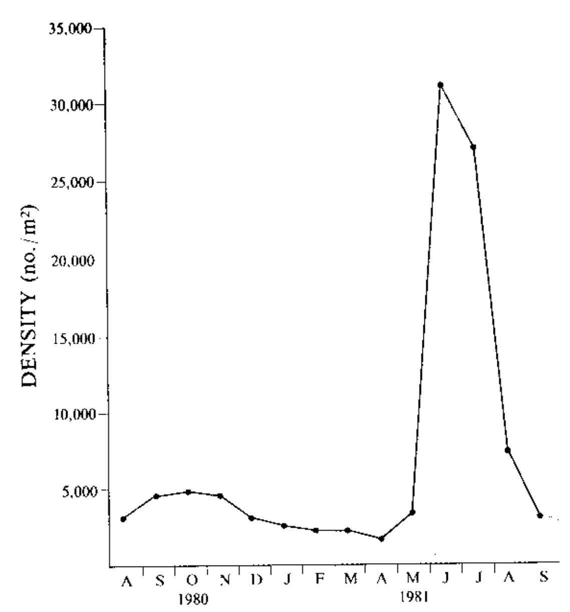


Figure 4-21. Density of *Hobsonia florida* at a sampling site in Baker Bay, August 1980 to September 1981 (Holton et al. 1984).

Neanthes limnicola (Plate 13, Map g)

Neanthes limnicola (Figure 4-22) is larger than the other abundant polychaetes in the estuary. It is a surface deposit-feeder but probably supplements its diet by consuming other infaunal organisms. *N. limnicola* is adapted to muddy sand sediments but is also found in sandy areas. Although a brackishwater species, *N. limnicola* tolerates fresh water. The map demonstrates this polychaete's tolerance for a wide range of salinity conditions. *N. limnicola* prefers the same regions as *H. florida* (Baker and Youngs Bay) but is also abundant on the middle estuary flats.

The density of *N. limnicola* is typically lower than that of the other polychaetes (Figure 4-23). Its standing crop is higher, however, because *N. limnicola* individuals are eight to twelve times heavier than the previously discussed polychaetes. CREDDP investigators estimated that Baker Bay populations produced 0.37 gAFDW/m²/yr, 2 percent of the total annual infauna production at that site.

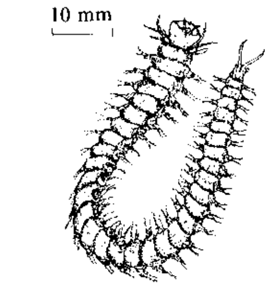


Figure 4-22. *Neanthes limnicola.*

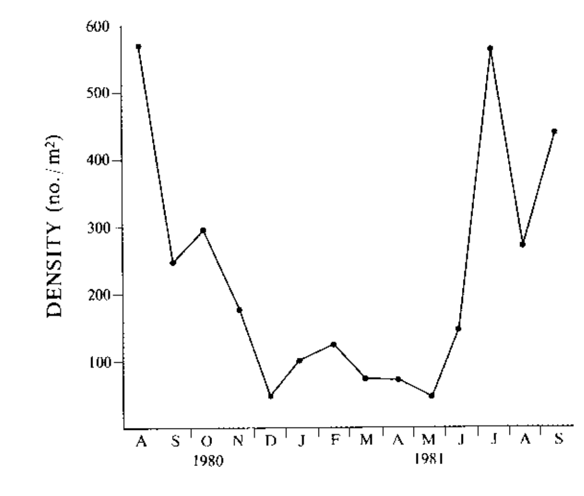


Figure 4-23. Density of *Neanthes limnicola* at a sampling site in Baker Bay, August 1980 to September 1981 (Holton et al. 1984).

Eogammarus confervicolus (Plate 13, Map h)

Eogammarus confervicolus (Figure 4-24) is a brackishwater amphipod with a wide salinity tolerance. This omnivorous species crawls on the sediment surface and can be found on both sandy and muddy sediments.

The abundance of *E. confervicolus* in the middle and lower estuary reflects its adaptation to brackish water. It is more abundant in the sandy sediments of the middle estuary flats than in the fine sand and mud of the peripheral bays. Seasonal fluctuations and production of *E. confervicolus* were not studied in the Columbia River Estuary.

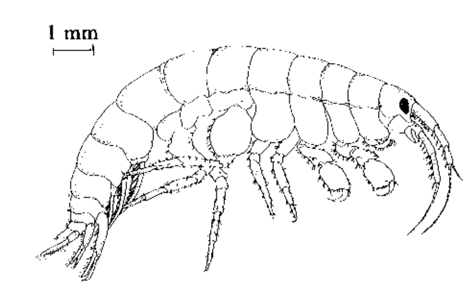


Figure 4-24. *Eogammarus confervicolus.*

Discussion

CREDDP investigators defined six infaunal assemblages, each with up to seven major species or groups of species. There are three fine sediment assemblages (lower, middle, and upper estuary) and three coarse sediment assemblages (lower, middle, and upper estuary) (Figure 4-10). These assemblages, based on a single survey, might be different under other sampling conditions.

Figure 4-10 shows the major species found in fine sediment assemblages of the lower estuary (exemplified by Baker Bay), middle estuary (Youngs Bay), and upper estuary (Cathlamet Bay). The Youngs Bay assemblage is similar to that of Baker Bay except that the marine species less tolerant of fresh water, *M. balthica* and *P. kempi*, are not abundant in Youngs Bay, while species intolerant of marine conditions (*C. salmonis* and *Fluminicola virens*, a gastropod) are abundant in Youngs Bay. Some species are common to both Youngs Bay and Cathlamet Bay; the riverine forms occur only in Cathlamet Bay, while the brackishwater forms do not occur there.

There is a diversity of polychaete species in the coarse sediment assemblages of the lower estuary, but polychaetes become less important in the middle estuary, where the amphipod *Eohaustorius estuarius* is important. *C. salmonis* is found in middle and upper estuary coarse sediment assemblages, as well as fine sediment assemblages. Some areas of current-swept sandy sediments in the middle and upper estuary contain low densities of any macrofaunal species.

CREDDP research suggests three generalizations about the Columbia River Estuary benthic infauna. First, a few opportunistic species that are able to tolerate a wide range of salinities appear to dominate standing crop and production rates throughout the estuary. This is because the estuary's strong currents, active sediments and high tidal and seasonal variability in salinity provide an unstable habitat for the benthic infauna. Second, the shallow protected peripheral bays, with their fine sediments supporting the many species of deposit-feeders, support a relatively productive infaunal community wherever they occur in the estuary. Third, of all the species described in this section and mapped on Plate 13, *Corophium salmonis* appears to play the largest role in the food web. Its high standing crop and broad distribution are evident in Map b. It is very productive and is important to predators (see "Fish").

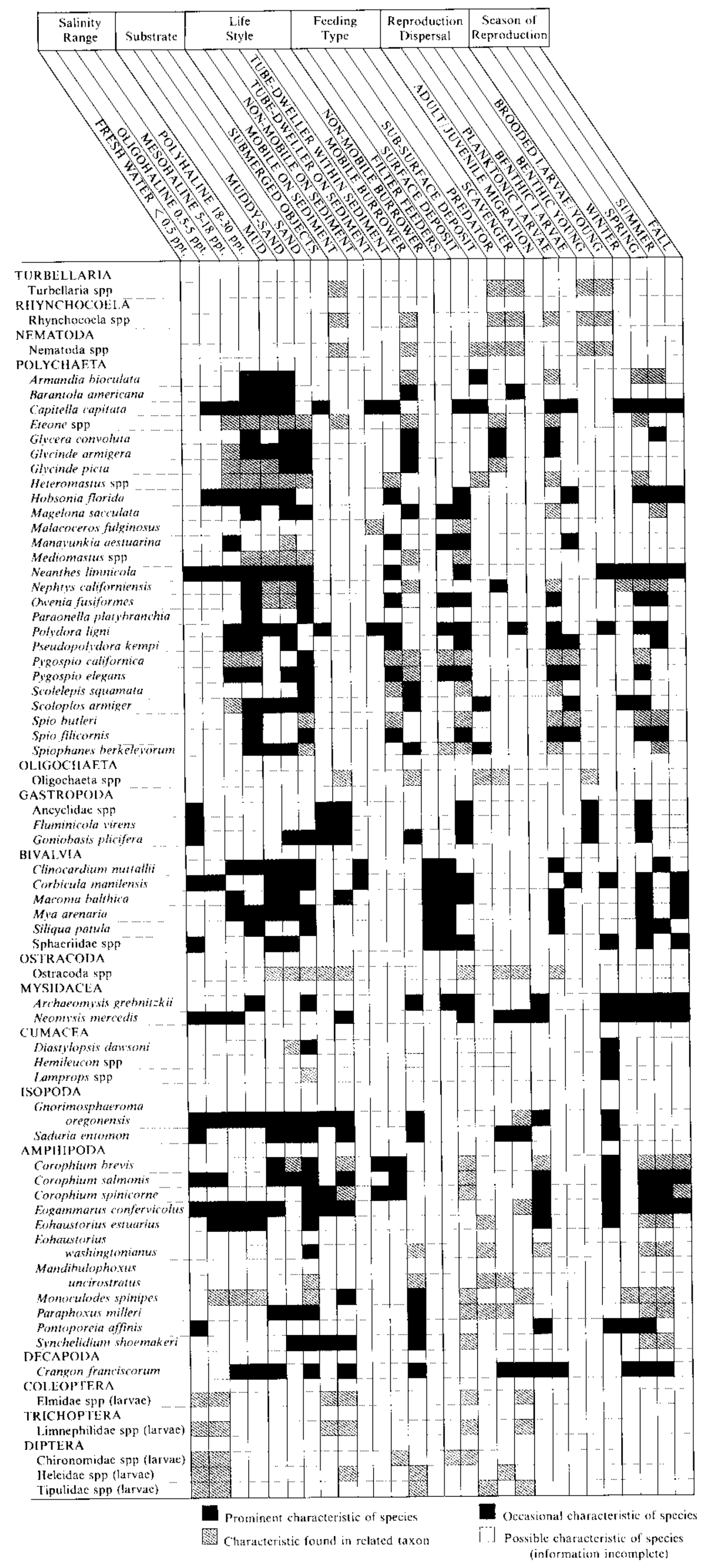


Figure 4-25. Characteristics of the invertebrate species and groups collected in the CREDDP benthic infauna distributional study (Holton et al. 1984).

Epibenthic Organisms

Epibenthic organisms are the invertebrates that live on or just above the surface of the bottom sediments. The habitat of epibenthic organisms includes the top centimeter of sediments and one meter of the overlying water. Because this habitat includes the layer of water above the sediment, some species (for example, *Eurytemora affinis* and *Neomysis mercedis*) can be classified as both planktonic and epibenthic. Epibenthic organisms in the Columbia River Estuary are important as food for fish, birds, and marine mammals. In addition, a recreational and commercial fishery exists for two epibenthic species, crayfish and Dungeness crab.

There are two categories of epibenthic organisms, epibenthic zooplankton and mobile macroinvertebrates. The epibenthic zooplankton consists of small organisms that live on or near the sediment surface. Copepods are the most numerous members of the epibenthic zooplankton. The two most numerous copepod species in the Columbia River Estuary are *Eurytemora affinis* and *Scottolana canadensis* (Figure 4-26). These two species are estuarine, remaining in the estuary throughout their life cycles. About half the estuary's epibenthic zooplankton, however, consists of freshwater forms that have washed down from the upriver areas where they originated. These include copepods, cladocerans, and a similar but unrelated group called rotifers (Figure 4-26). Epibenthic zooplankters tend to be most abundant in shallow areas, where they wash in and out on the tide or burrow into the sediment during low tide.

The second category of epibenthic organisms, mobile macroinvertebrates, consists of large invertebrates such as crabs and shrimp that crawl along the sediments. Three species of mobile macroinvertebrates, all crustaceans, were sampled by CREDDP investigators: the sand shrimp, *Crangon franciscorum;* the mysid or "opossum" shrimp, *Neomysis mercedis;* and the Dungeness crab, *Cancer magister* (Figure 4-27). The smallest of these, the mysid shrimp, grows to be about 15 to 30 times larger than the largest copepods in the estuary. Unlike epibenthic zooplankters, these macroinvertebrates are sometimes most common in the deeper, channel bottom habitats. A fourth mobile macroinvertebrate species, the crayfish *(Pacifastacus leniusculus)*, inhabits tidal channels in marsh and swamp habitat and was not sampled. This species is, however, important as a food resource to some birds and mammals (see "Birds" and "Aquatic and Terrestrial Mammals").

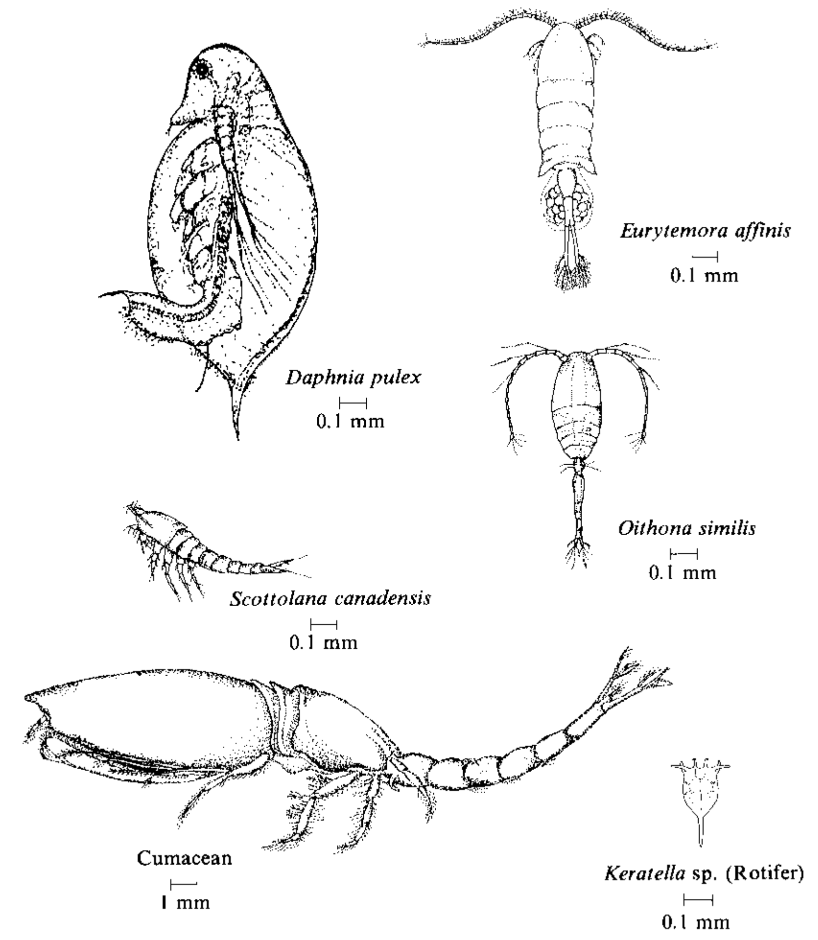


Figure 4-26. Selected epibenthic zooplankton species of the Columbia River Estuary.

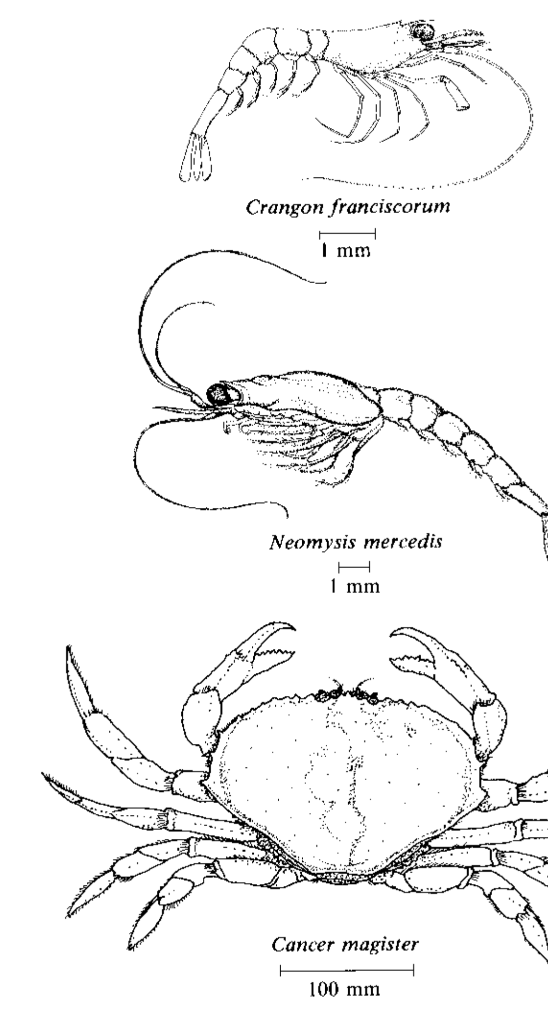


Figure 4-27. Principal mobile macroinvertebrate species of the Columbia River Estuary.

Factors Affecting Distribution

In the Columbia River Estuary, the greatest concentrations of epibenthic organisms are found in the area of the turbidity maximum (see "Sediments"). Suspended sediments, freshwater phytoplankton killed by saline water, zooplankters, and detritus are trapped in the turbidity maximum region. The position of the turbidity maximum depends largely on riverflow season; during the low riverflow season it is found upriver from its position during the high and fluctuating riverflow seasons. Peak epibenthic organism densities shift with the turbidity maximum.

The correlation of high epibenthic organism densities with the turbidity maximum is related to circulation and to the availability of food. Circulation creates the turbidity maximum, resulting in the trapping of epibenthic zooplankters. This mechanism allows the zooplankters to remain in the estuary long enough to develop an estuarine population, rather than being flushed out of the estuary.

The availability of food for epibenthic organisms is enhanced by the turbidity maximum. CREDDP investigators found that the high densities of epibenthic zooplankters coincided with increased concentrations of detritus and phytoplankton in the turbidity maximum, creating an abundant food supply for them. These zooplankters in turn are the primary prey of the mobile macroinvertebrates, principally *Neomysis mercedis* and *Crangon franciscorum*. Peak population densities of the mobile macroinvertebrates tend to occur in the turbidity maximum region during the low riverflow season, associated with high epibenthic zooplankton density. The mobile macroinvertebrates move actively to associate themselves with the turbidity maximum at this time. This may be a response to the high concentrations of epibenthic zooplankters, and may also be associated with changes in salinity.

Conclusive statements cannot be made regarding the role of the turbidity maximum and related biological factors in determining epibenthic organism density and distribution because CREDDP data are not adequate to distinguish the influences of the turbidity maximum from those of salinity intrusion.

Derivation, Uses, and Limitations of the Maps (Plate 14)

CREDDP investigators sampled epibenthic organisms at several sites located on the channel bottom, shallow slope, and tidal flat habitat types of the major estuarine regions. The sites indicated on Plate 14 were sampled at monthly or quarterly intervals. Abundance and distribution of organisms were mapped for three river discharge seasons: fluctuating riverflow season, high riverflow season, and low riverflow season (see Chapter 1 for a further explanation of river discharge seasons).

The maps were produced for the most part using data from only one site in each habitat type of each estuarine region. Therefore, variability in types of species and their density and standing crop within each habitat type is not accounted for. The maps show seasonal changes in abundance but, because epibenthic populations fluctuate both on a shorter time scale than seasons (daily, weekly, or monthly) and on a longer time scale (year-to-year), the maps cannot be used to predict the full array of possible population changes. However, the maps give an excellent picture of average population changes at the sampling sites during the year and an approximation of species abundance in various regions and habitat types.

Interpretation of the Maps (Plate 14)

The two maps on Plate 14 illustrate different river discharge seasons. Each map differentiates the epibenthic zooplankton from mobile macroinvertebrates. The following two interpretive subsections deal with these groups separately.

Epibenthic Zooplankton Density and Standing Crop

Plate 14 shows that epibenthic zooplankton density and standing crop are generally highest in the central estuary. There is a considerable seasonal shift in peak standing crop from the area between about RM-6 and the Astoria-Megler bridge during the high and fluctuating riverflow seasons (Plate 14, Map a) to the area between Tongue Point and Rice Island during the low riverflow season (Plate 14, Map b). This shift can be correlated with a similar shift in the estuary's turbidity maximum, as discussed previously.

Throughout the estuary, epibenthic zooplankton density and standing crop tend to be higher on the tidal flats than in the channels. This is probably related principally to current speed. Since tidal flats tend to have weaker currents than channels, they have more stable sediments and a higher settling rate of detritus onto the sediments.

Note that although epibenthic zooplankters are much smaller than mobile macroinvertebrates, their average standing crop exceeds that of macroinvertebrates in many locations in the estuary. That is because they are much more numerous than macroinvertebrates.

Epibenthic zooplankton species with similar habitat requirements can be grouped into assemblages. Two distinct assemblages occur in the estuary during high and fluctuating riverflow seasons: an upper estuary freshwater assemblage and a lower estuary brackishwater (estuarine) assemblage. The freshwater assemblage, found upriver from Tongue Point, is dominated by freshwater copepods and cladocerans. The estuarine assemblage, found downriver from Tongue Point, is dominated by brackishwater copepods, such as *Eurytemora affinis* and *Scottolana canadensis*, and the brackishwater mysid *Neomysis mercedis*. During the low riverflow season the situation is very different. Freshwater species are more evenly distributed throughout the estuary. Many of the freshwater and estuarine species that previously occurred in two distinct regions are associated in a single region between Youngs Bay and Jim Crow Sands.

Mobile Macroinvertebrate Density and Standing Crop

Three species, *Crangon franciscorum*, *Cancer magister*, and *Neomysis mercedis* (Figure 4-27), account for virtually all of the mobile macroinvertebrate density and standing crop shown on Plate 14. The distribution of *N. mercedis* is discussed in the "Zooplankton" section.

C. franciscorum is a true shrimp whose life cycle in the estuary is not well understood. CREDDP investigators found adults from Youngs Bay downriver to the mouth during winter and early spring but by May they were gone. Juveniles appeared in April, concentrated in the turbidity maximum region. They moved upriver during the low riverflow period. There were indications in August of a second influx of juveniles. As riverflow increased later in the fall, *C. franciscorum* populations moved back downriver.

Dungeness crab *(Cancer magister)* is a marine species that is much more abundant in the ocean than in the estuary. The lower estuary, however, is a nursery area for juveniles. Spawning takes place offshore and juveniles migrate into the saline areas of the estuary. During extreme low riverflow periods juveniles may be found as far upriver as Astoria. Adult crabs are rarely found in the estuary, and only in the deep channels downriver from Hammond and Chinook Point, where salinity is highest.

Total mobile macroinvertebrate density is dominated by *C. franciscorum* and tends to be highest in the central region of the estuary. The shift upriver accompanying the low riverflow season is probably due to a combination of the upriver shift of salinity intrusion and the turbidity maximum and associated shifts in the concentration of epibenthic zooplankters, the principal prey of *C. franciscorum*. Among habitat types, highest year-round densities of mobile macroinvertebrates (chiefly *C. franciscorum*) are found on tidal flats, but during the low riverflow season the peak density occurs in the channel near Rice Island. This suggests that strong currents in the channels limit the occurrence of *C. franciscorum* in that habitat during high and fluctuating riverflow seasons.

Patterns in seasonal distribution of mobile macroinvertebrate standing crop resemble those of density except for the influence of Dungeness crab, whose large size makes it important to standing crop values in spite of its low density. The elevated standing crop levels in the channels near the mouth of the estuary during high and fluctuating riverflow seasons and in the deeper, more saline reaches of the adjacent central estuary during the low riverflow season reflect the presence of Dungeness crab juveniles.

Discussion

Epibenthic organisms, like all the invertebrates discussed in this chapter, are crucially important to the fish, birds, and mammals that use the estuary because they convert phytoplankton and detritus into a form that can be eaten by vertebrates. An estuarine food web showing relationships among diatoms, detritus, and some invertebrates, fish, and mammals is shown in Figure 4-28. Epibenthic zooplankters in the Columbia River Estuary are primarily detritivores (see "Life History Patterns of Epibenthic Organisms" on this page). In turn, they provide a food supply for mobile macroinvertebrates and many fish species, including juvenile salmonids (see "Fish"). The annual production of the epibenthic zooplankton can be very high; epibenthic zooplankters can produce up to ten times their average standing crop annually. This is because of their high reproductive potential and fast growth rate.

Mobile macroinvertebrates consume small invertebrates (epibenthic zooplankters and benthic infaunal organisms), detritus, and living plant material. They, in turn, are consumed by fish, birds, marine mammals and, in the case of crayfish and Dungeness crab, human beings.

The interaction of physical and biological factors causes epibenthic zooplankters and mobile macroinvertebrates to be concentrated in the region of the turbidity maximum during much of the year, particularly the low riverflow season. Harbor seals and many species of fish that depend on mobile macroinvertebrates for food (Figure 4-28) concentrate in the same area during the low riverflow season.

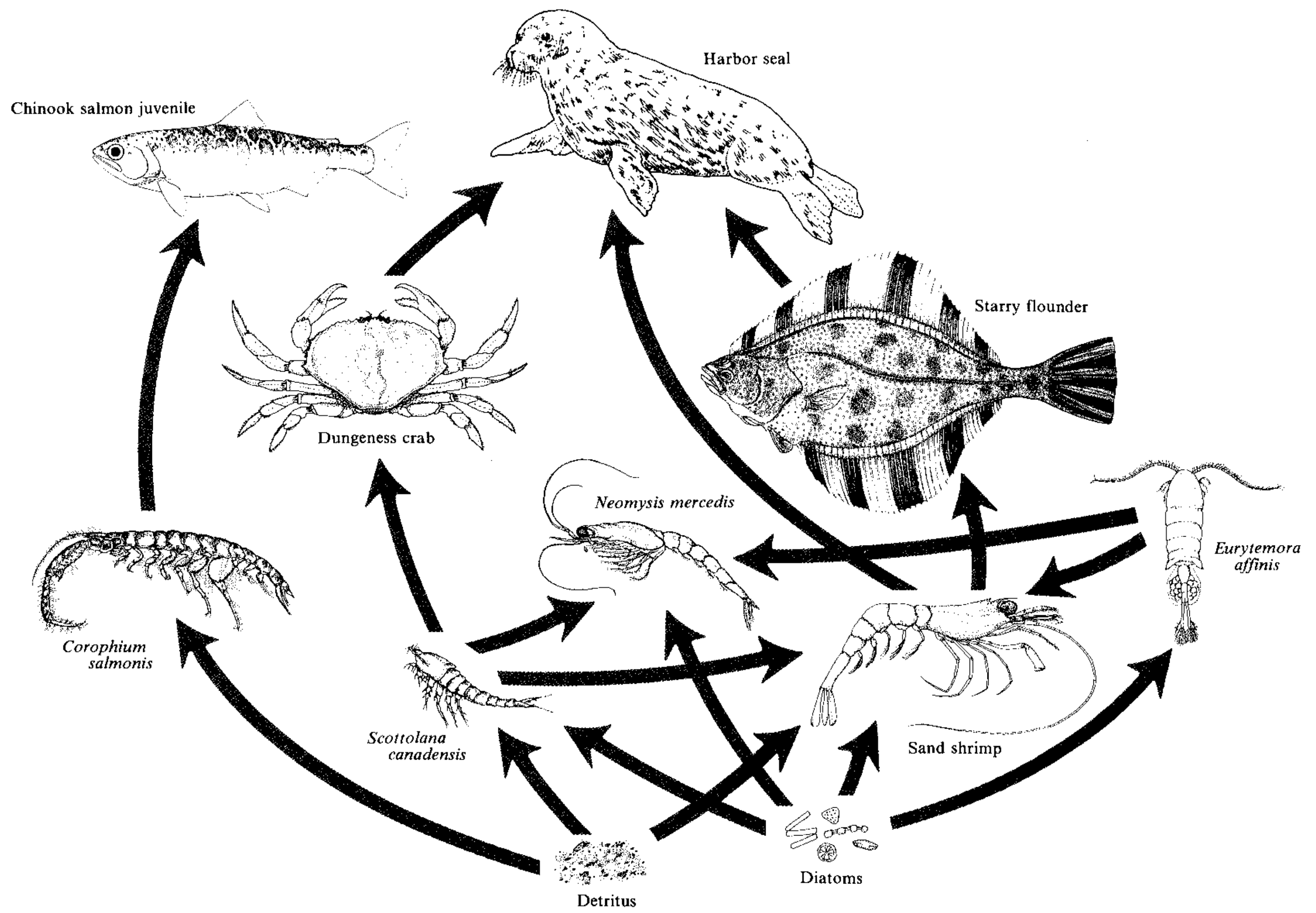


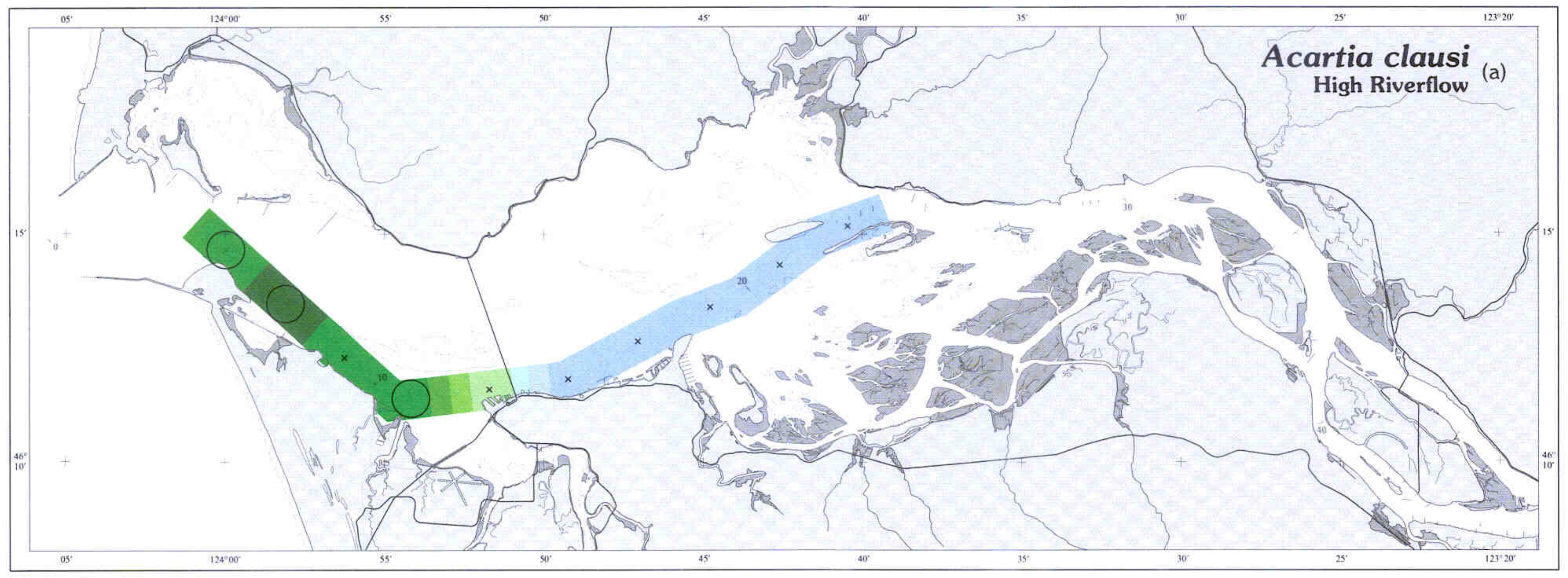
Figure 4-28. Part of the Columbia River Estuary food web, showing relationships among diatoms, detritus, and selected invertebrates, fish, and mammals. Arrows indicate "is consumed by" (modified from Simenstad 1984).

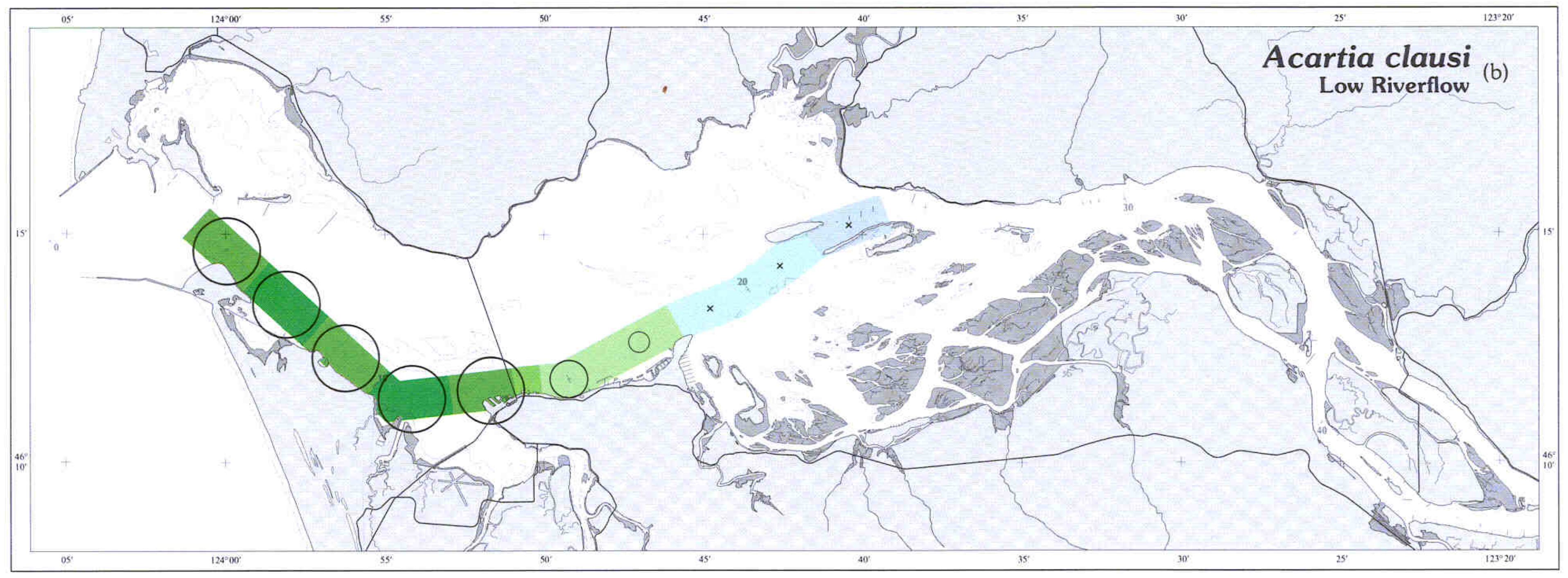
Life History Patterns of Epibenthic Organisms

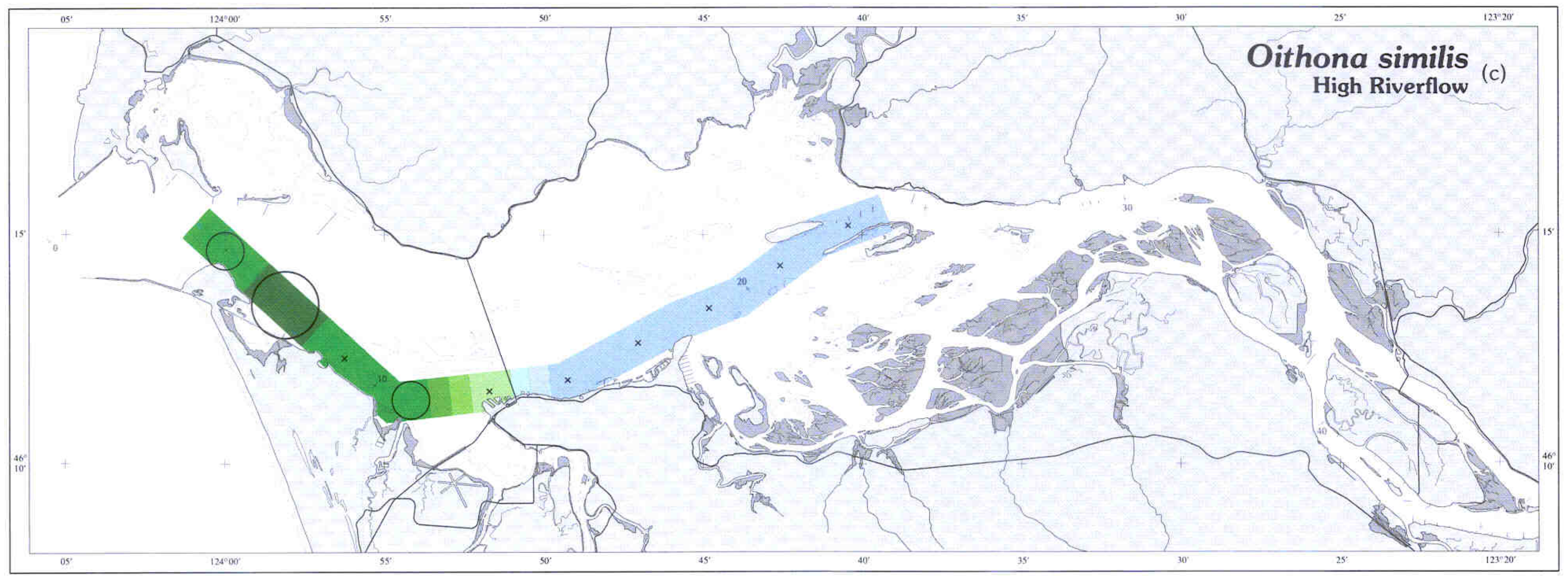
Epibenthic zooplankters feed on detritus, phytoplankton, and benthic diatoms. Principal feeding methods include filter-feeding, direct feeding (picking up food with their mouthparts), and feeding by scraping sand grains. The filter-feeders create currents with their appendages to sweep water-borne particles into their mouths. Their primary foods are phytoplankton and detritus. Direct feeders pick up or catch and consume detritus particles, phytoplankton, and probably benthic diatoms. The scrapers grasp individual grains of sand or particles of detritus and scrape the organic material from the surface. Some species display more than one feeding mode.

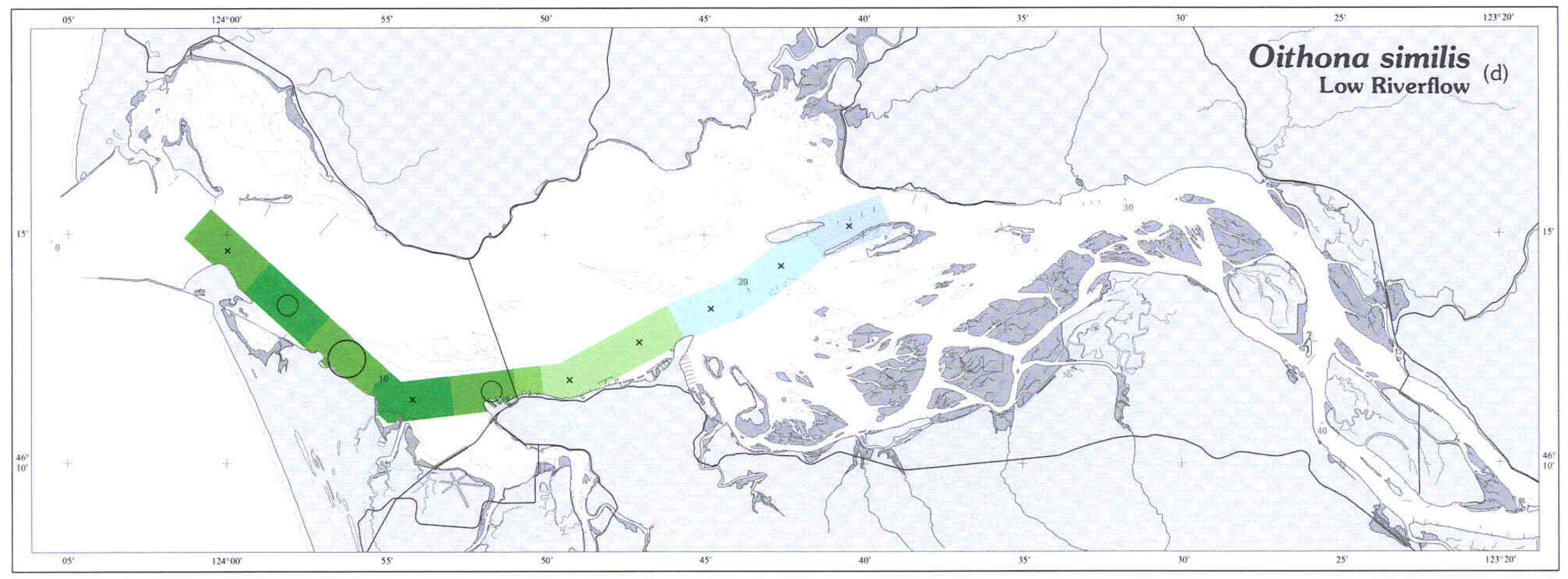
Detritus appears to be the most important food to epibenthic zooplankters in the Columbia River Estuary. Although the feeding methods vary, epibenthic zooplankters generally serve the same ecological role: processing detritus and converting it into forms (specifically, their own bodies) available to higher feeding levels. The mobile macroinvertebrates are omnivorous, consuming small benthic infaunal organisms, epibenthic zooplankters, phytoplankton, and detrital material.

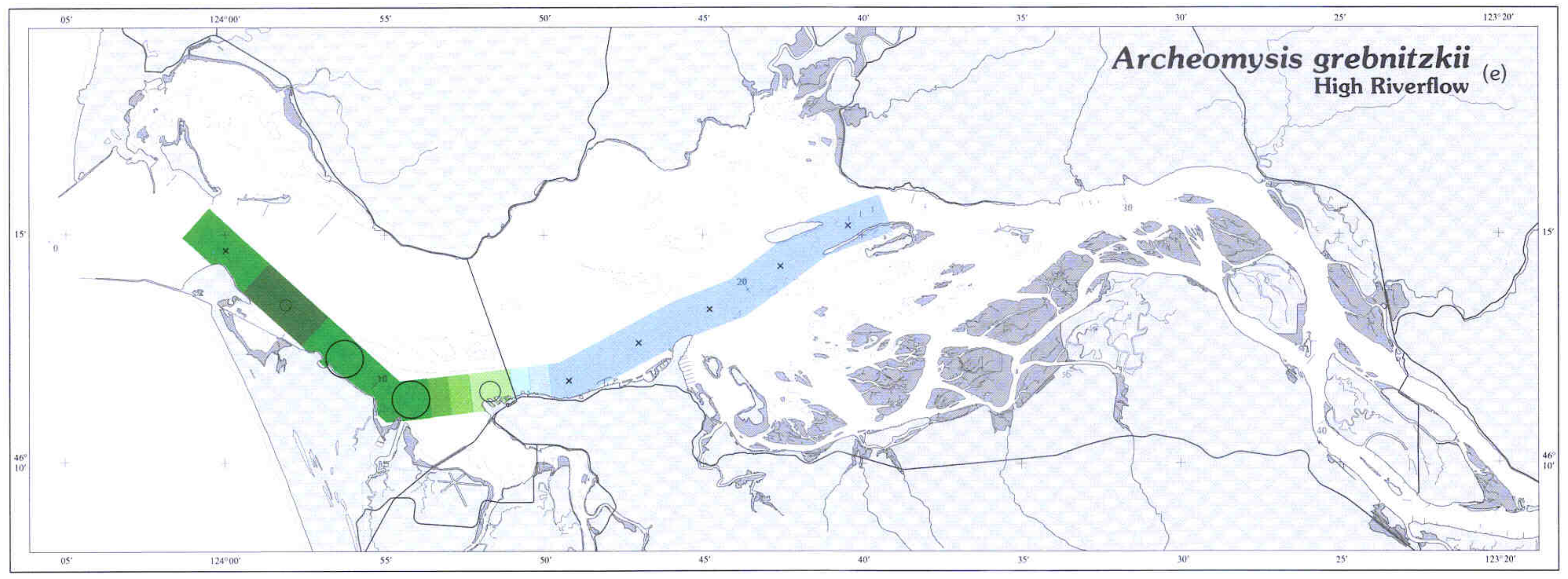
There are several reproduction and development modes among epibenthic organisms. The eggs may be brooded or released directly into the water column or sediments. The young of most forms pass through a series of planktonic larval stages before becoming adults. Some species, such as crabs, spend only a part of their life cycle in the estuary.

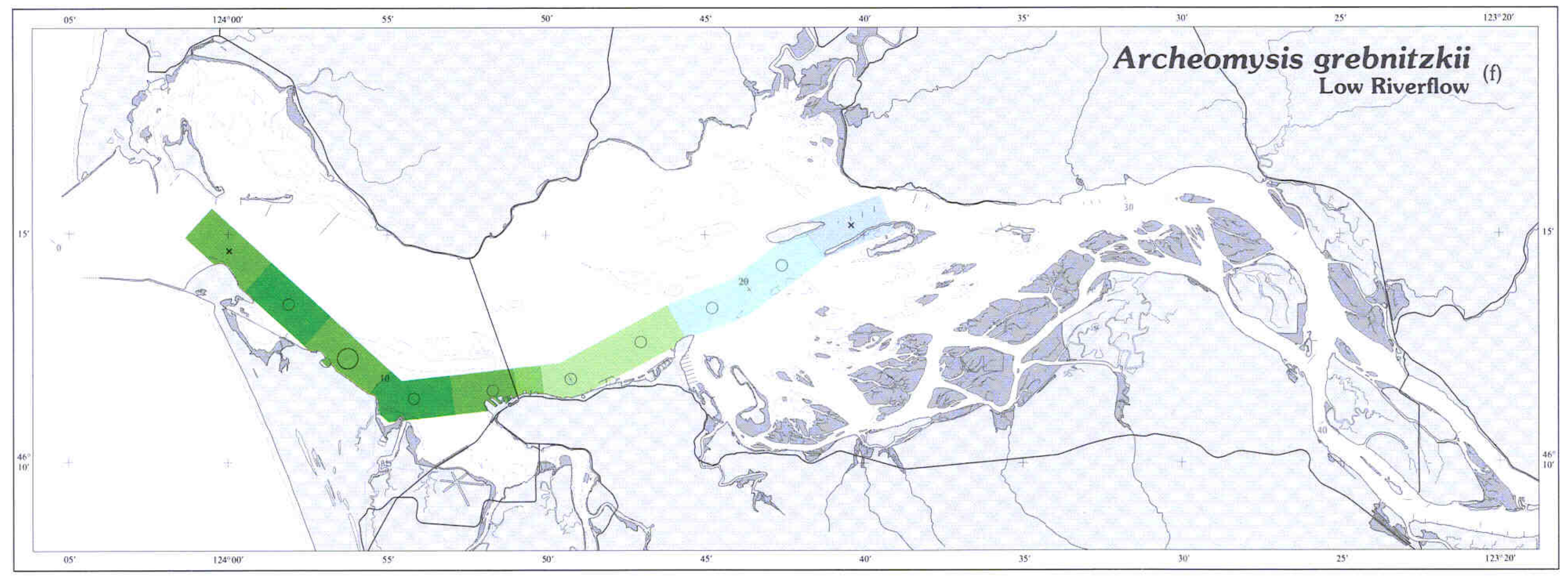


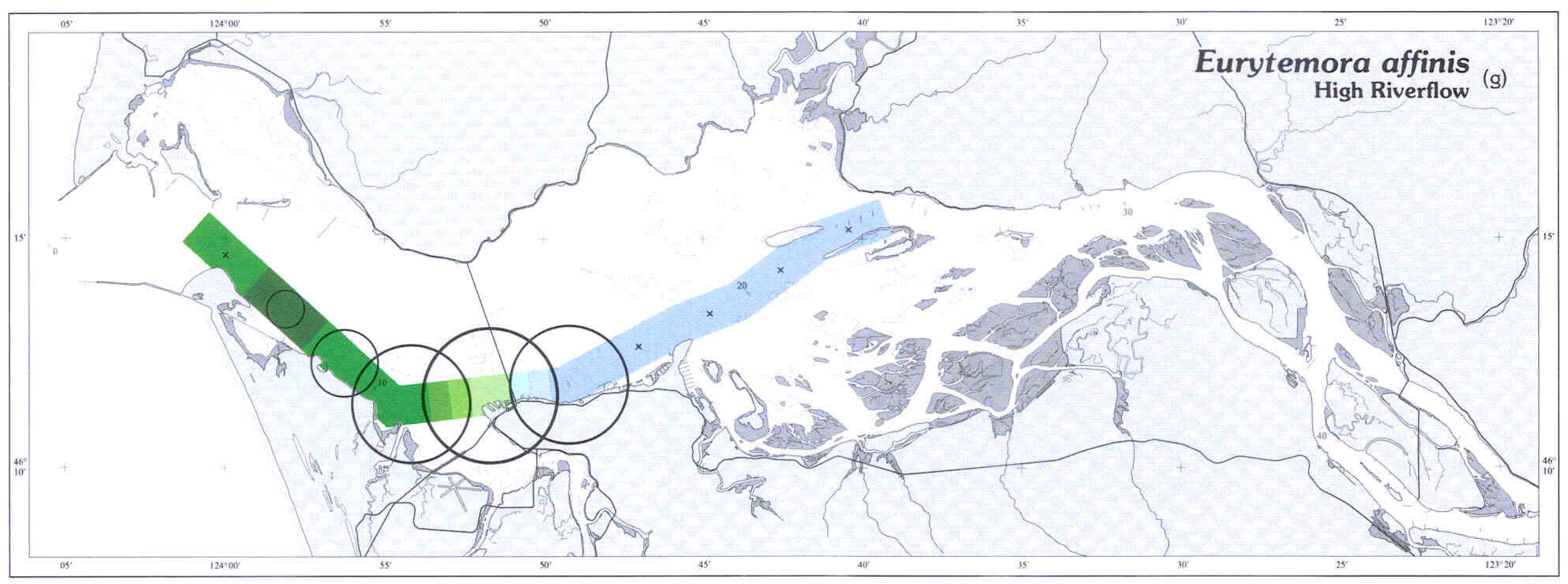


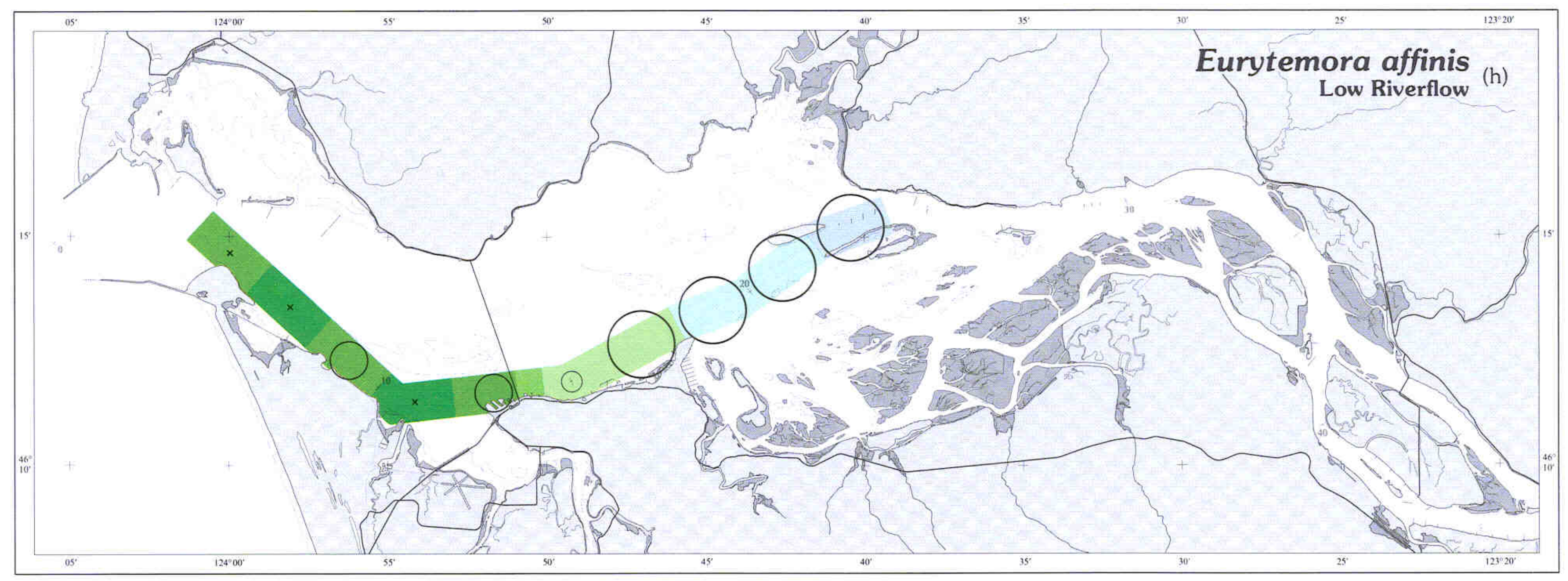












Zooplankton

Density (animals/m²)

- more than 100,000
- 10,000-100,000
- 1,000-10,000
- 100-1,000
- 10-100
- less than 10
- × zero

Sampling sites are located at centers of density symbols.

Deep Water Salinity* (parts per thousand)

- Fresh water
- 1-5
- 5-10
- 10-15
- 15-20
- 20-25
- 25-30
- greater than 30

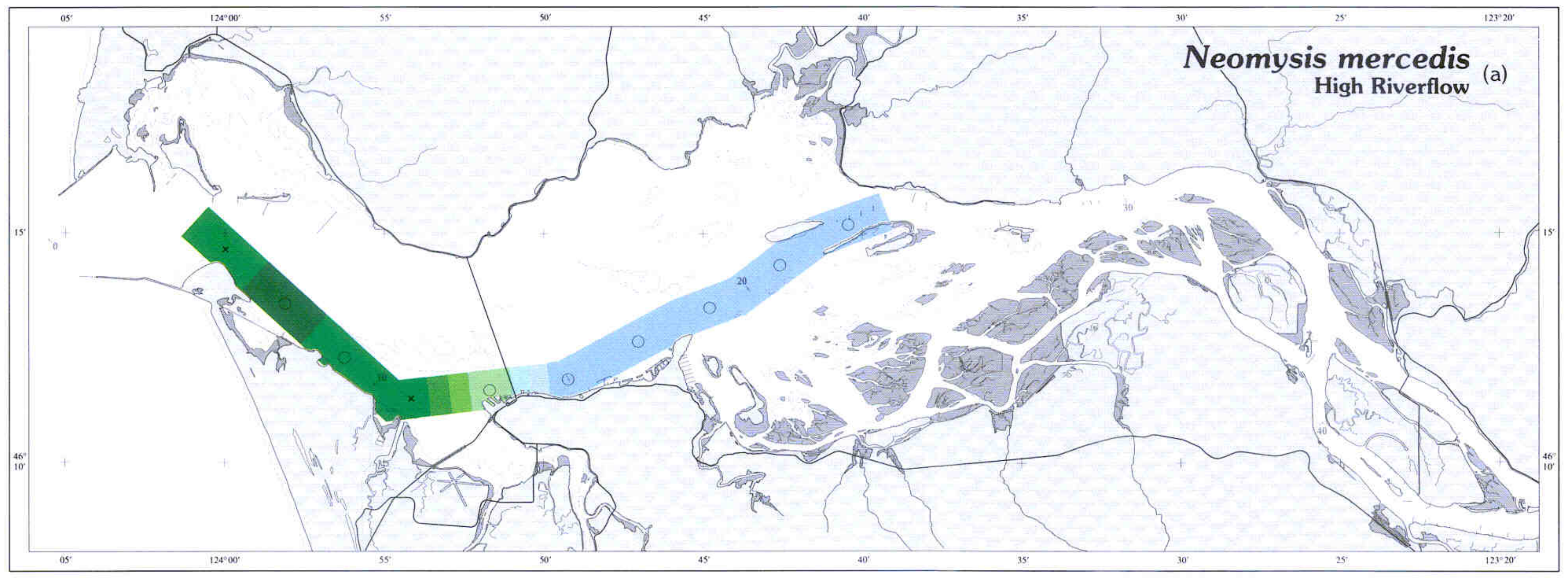
*Salinity was measured at a depth of ten meters.

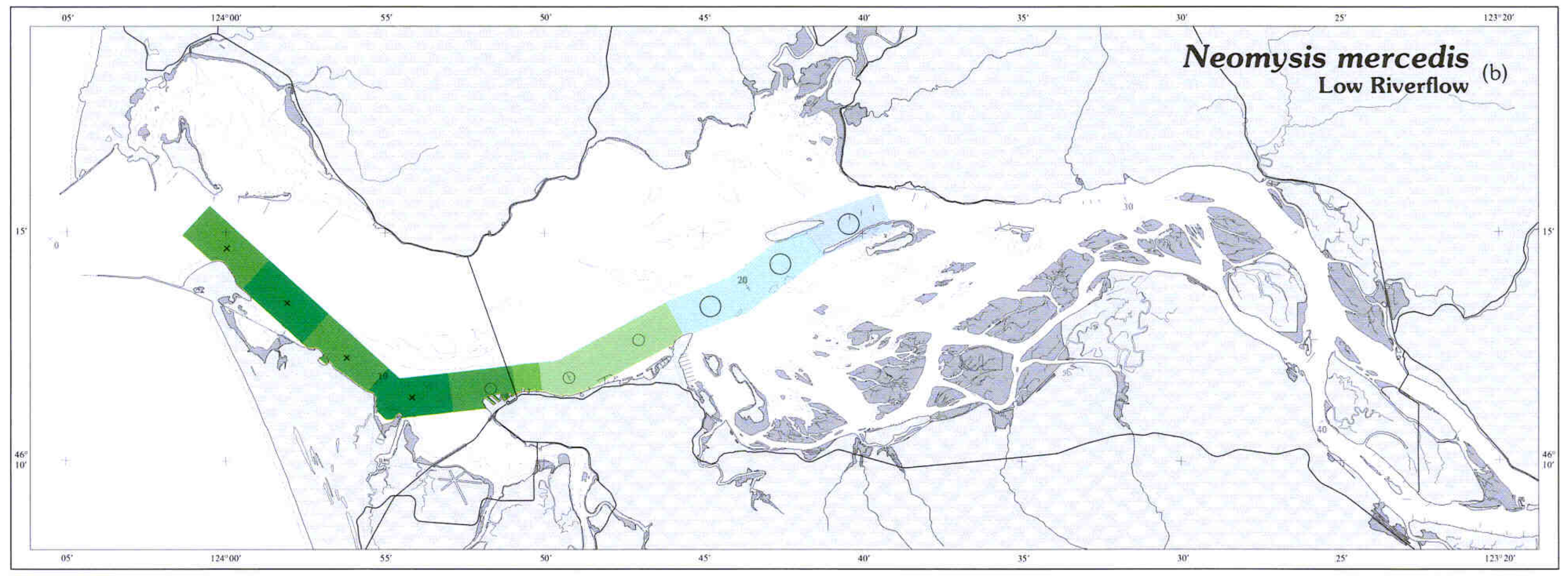
Zooplankton information is based on 1980 CREDDP sampling. The two sampling dates chosen to represent high riverflow and low riverflow were 13 May 1980 and 19 August 1980, respectively. The maps were compiled in 1984 by T. Saunders English, University of Washington (CREDDP zooplankton and larval fish investigator).

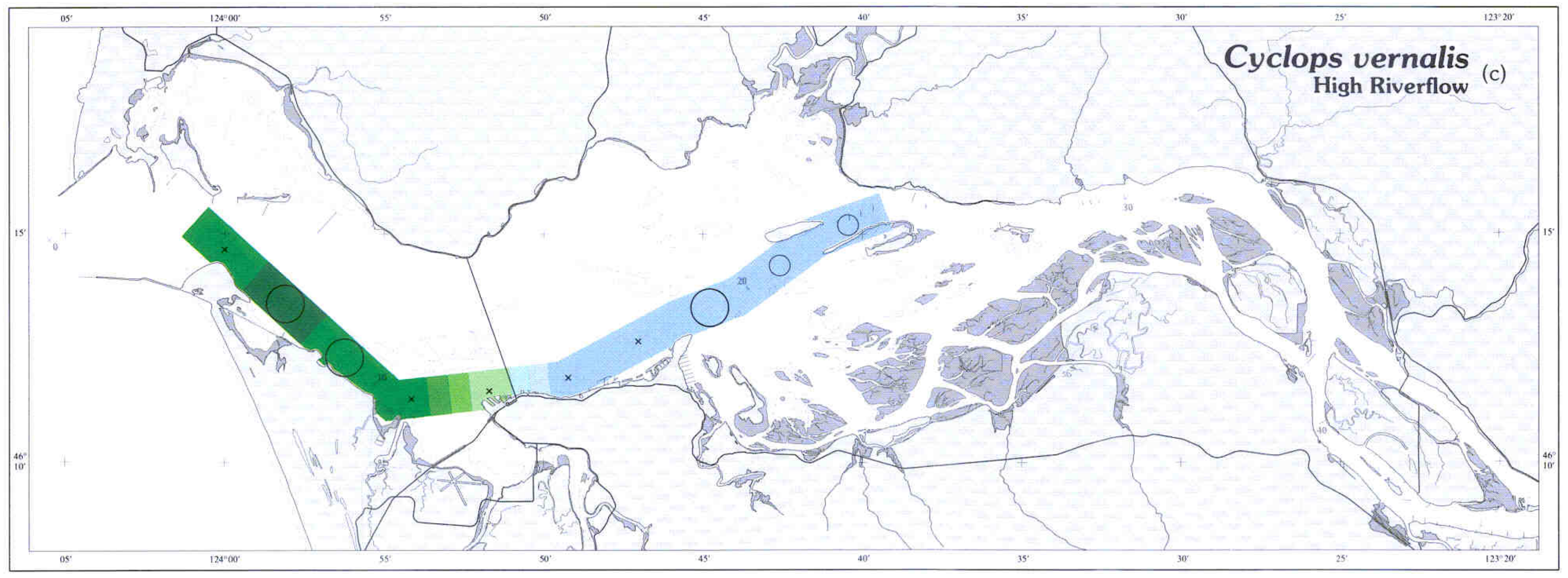
Scale 1:250,000

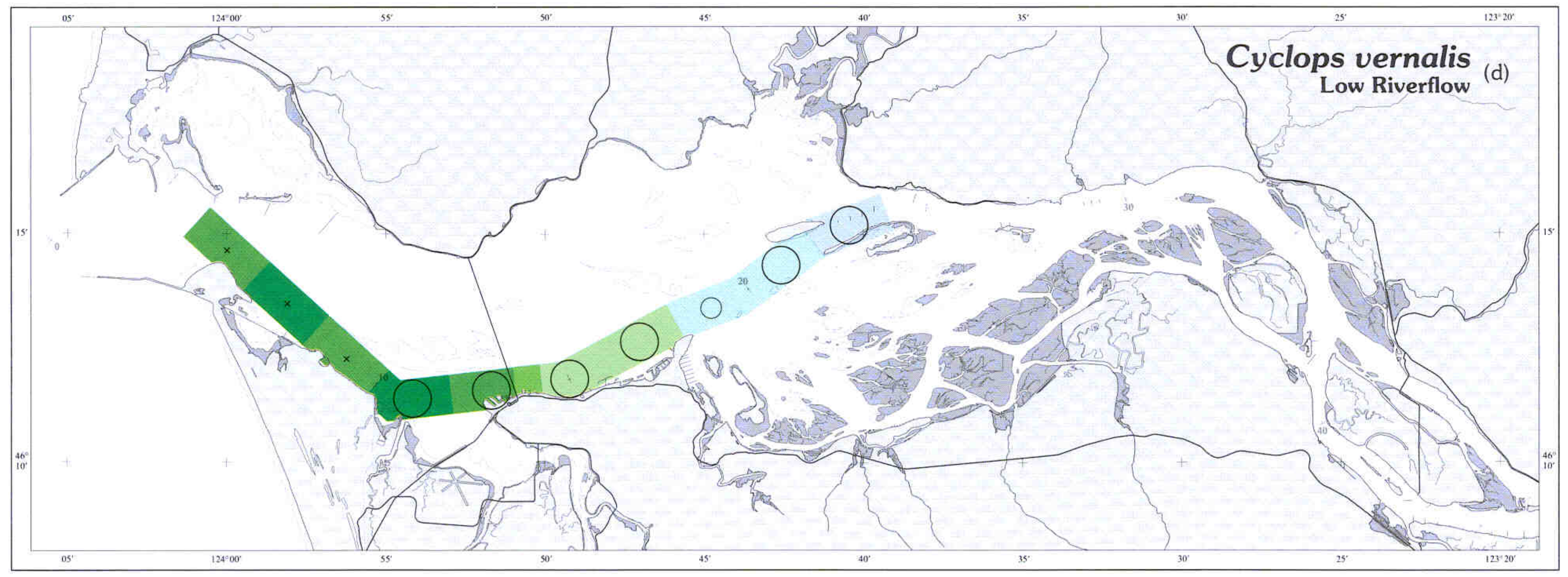
0 2 4 6 8 10 Kilometers

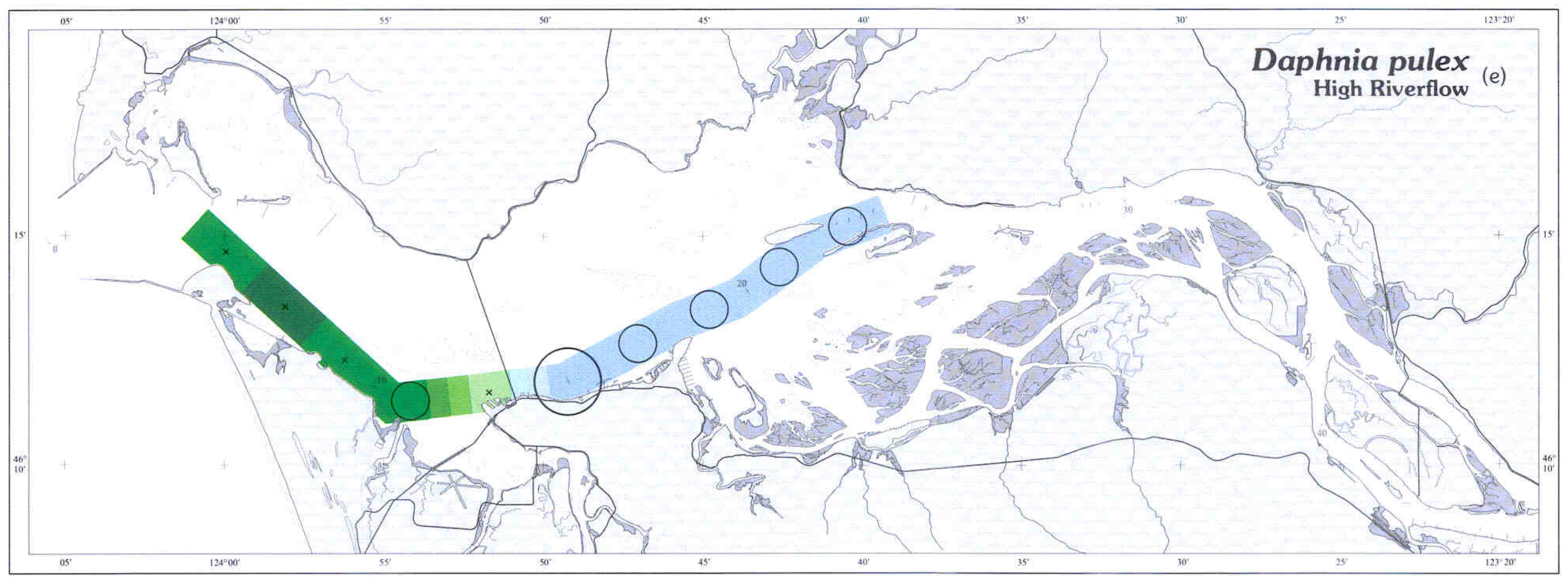
0 1 2 3 4 5 6 Miles

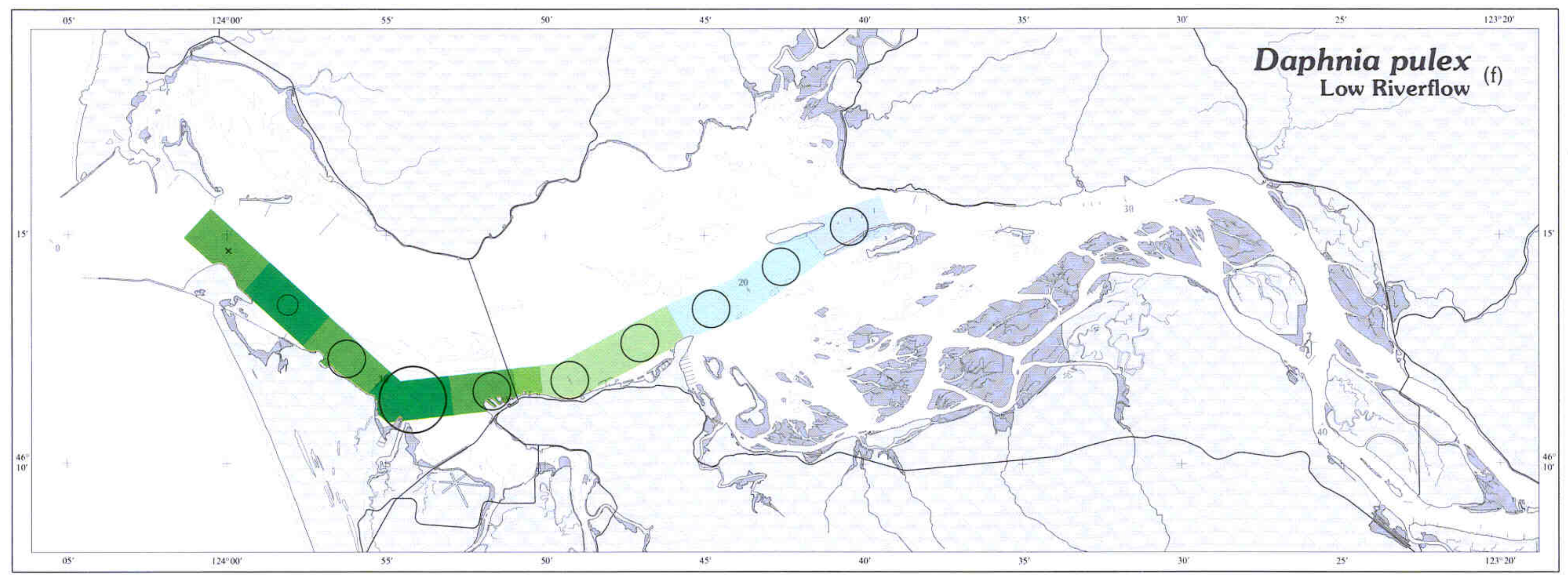


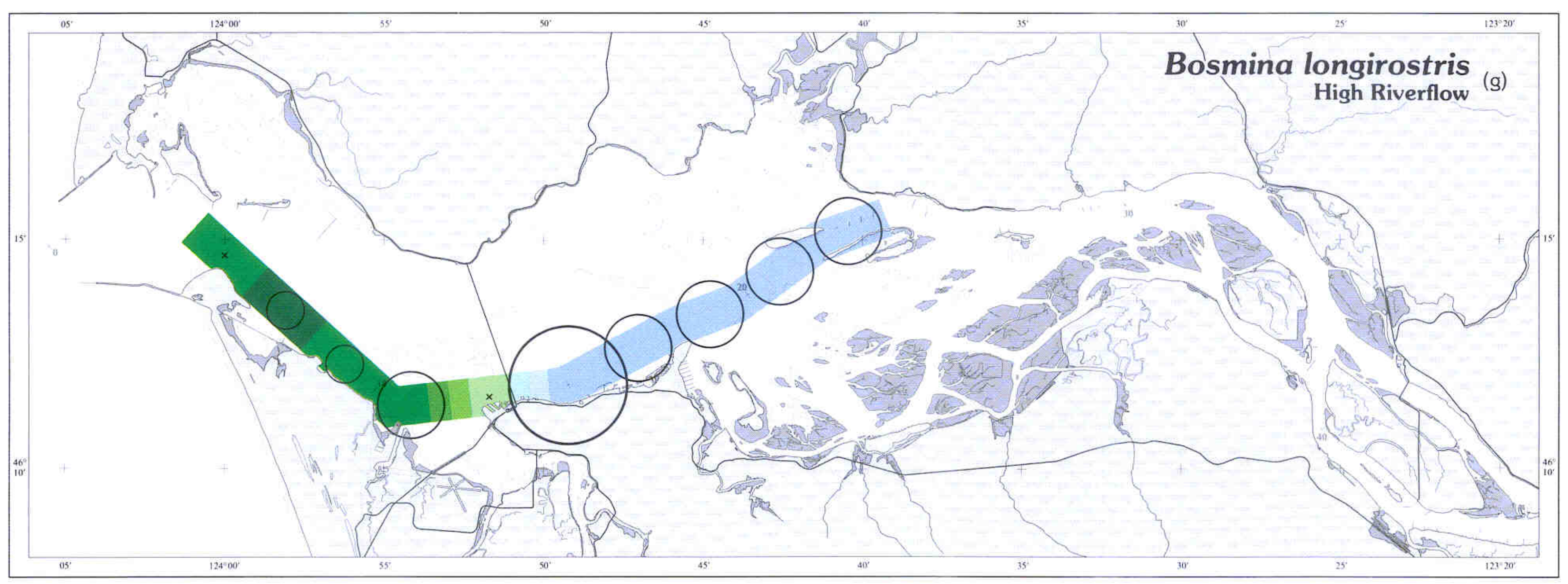


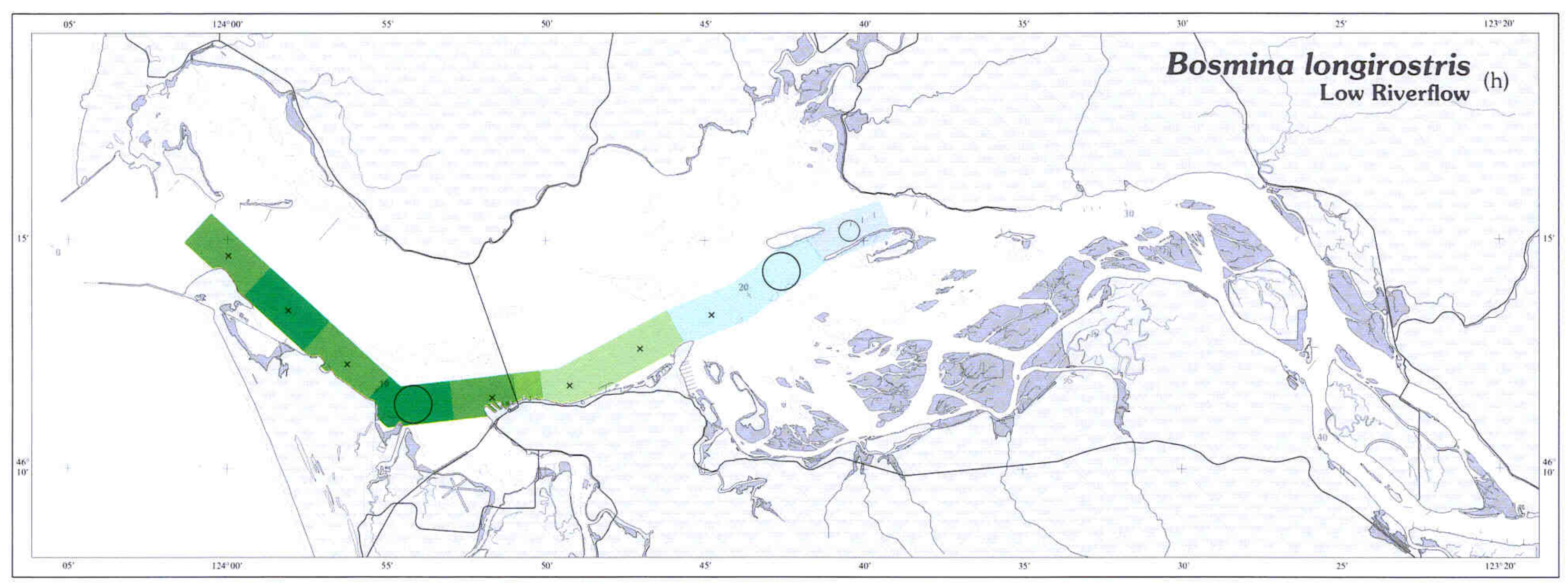












Zooplankton

Density (animals/m²)

- 10,000-100,000
- 1,000-10,000
- 100-1,000
- 10-100
- less than 10
- × zero

Sampling sites are located at centers of density symbols.

Deep Water Salinity* (parts per thousand)

- Fresh water
- 1-5
- 5-10
- 10-15
- 15-20
- 20-25
- 25-30
- greater than 30

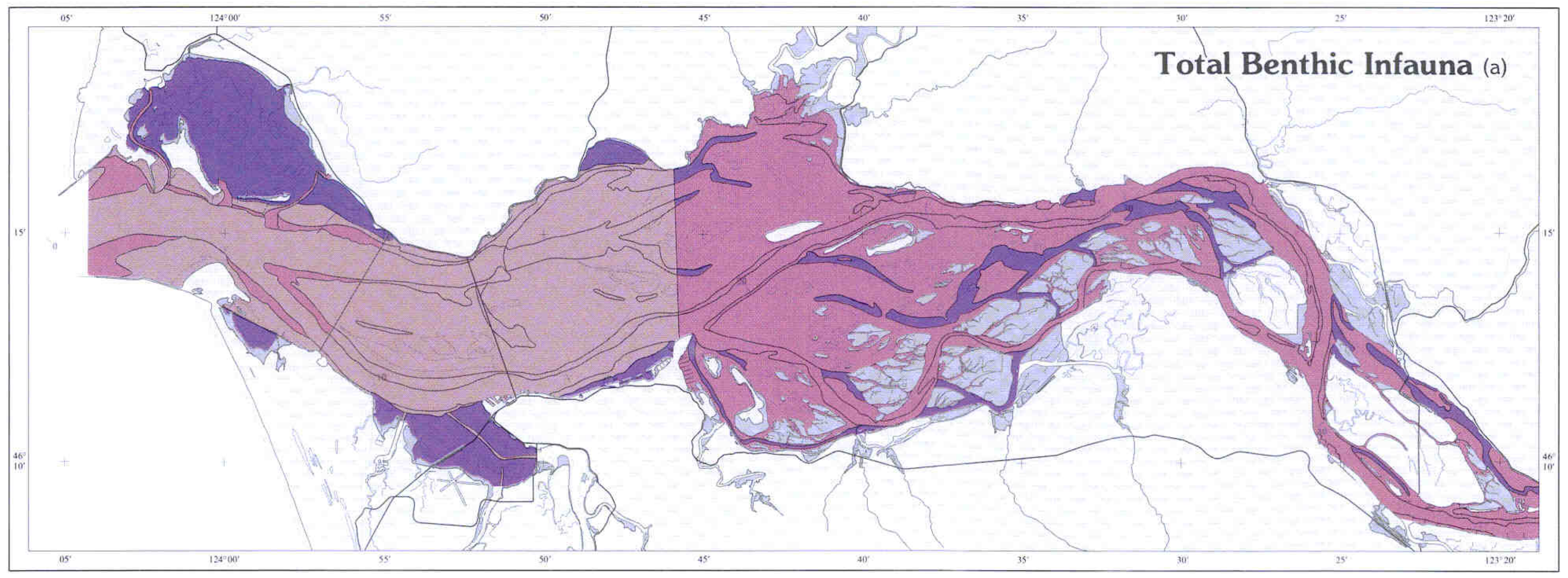
*Salinity was measured at a depth of ten meters.

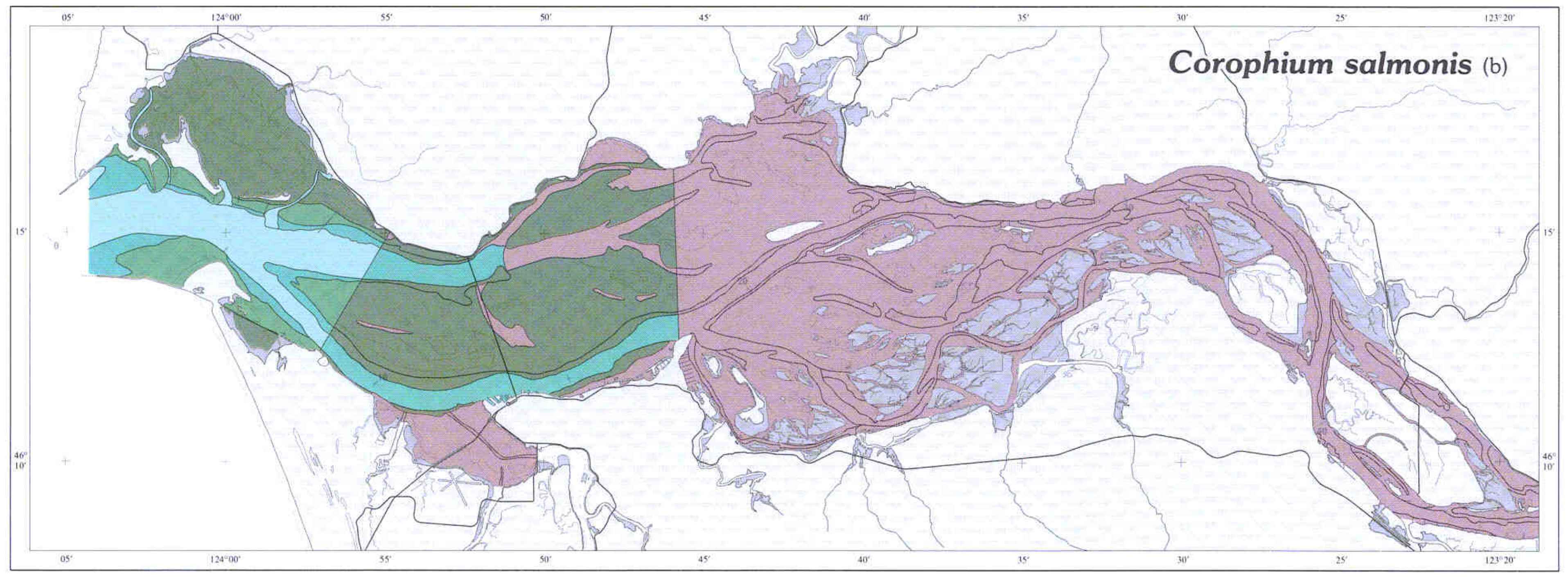
Zooplankton information is based on 1980 CREDDP sampling. The two sampling dates chosen to represent high riverflow and low riverflow were 13 May 1980 and 19 August 1980, respectively. The maps were compiled in 1984 by T. Saunders English, University of Washington (CREDDP zooplankton and larval fish investigator).

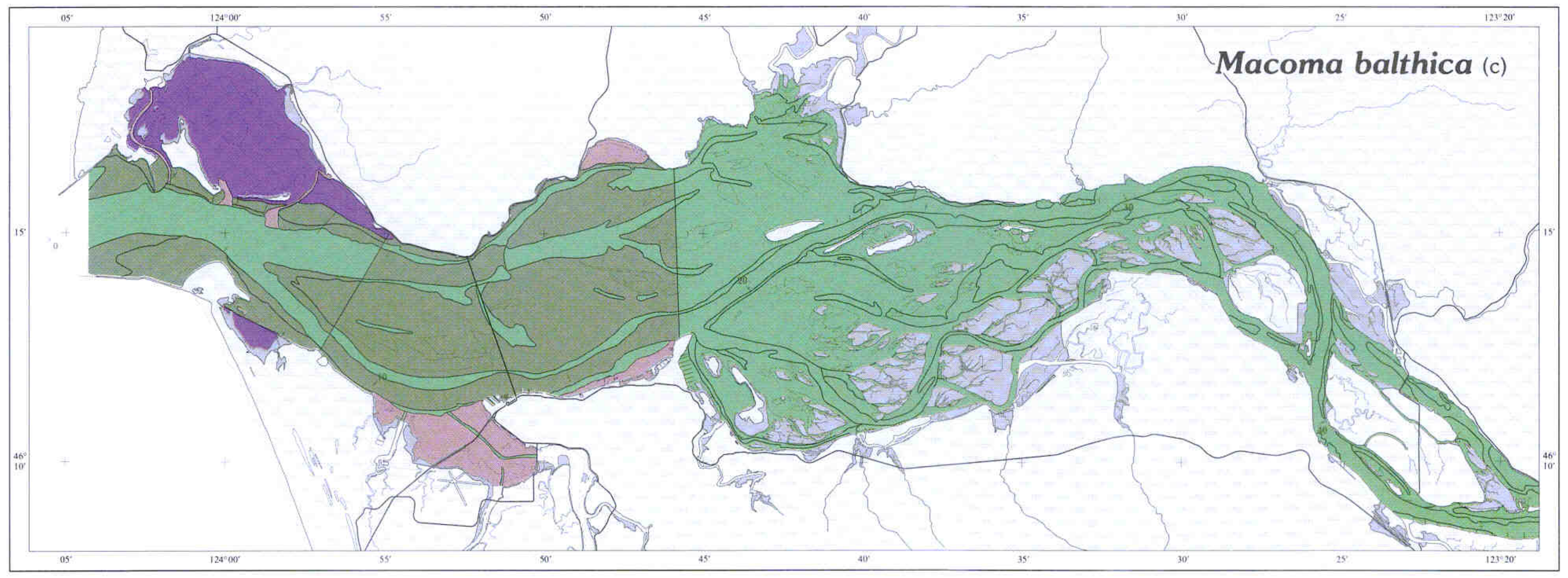
Scale 1:250,000

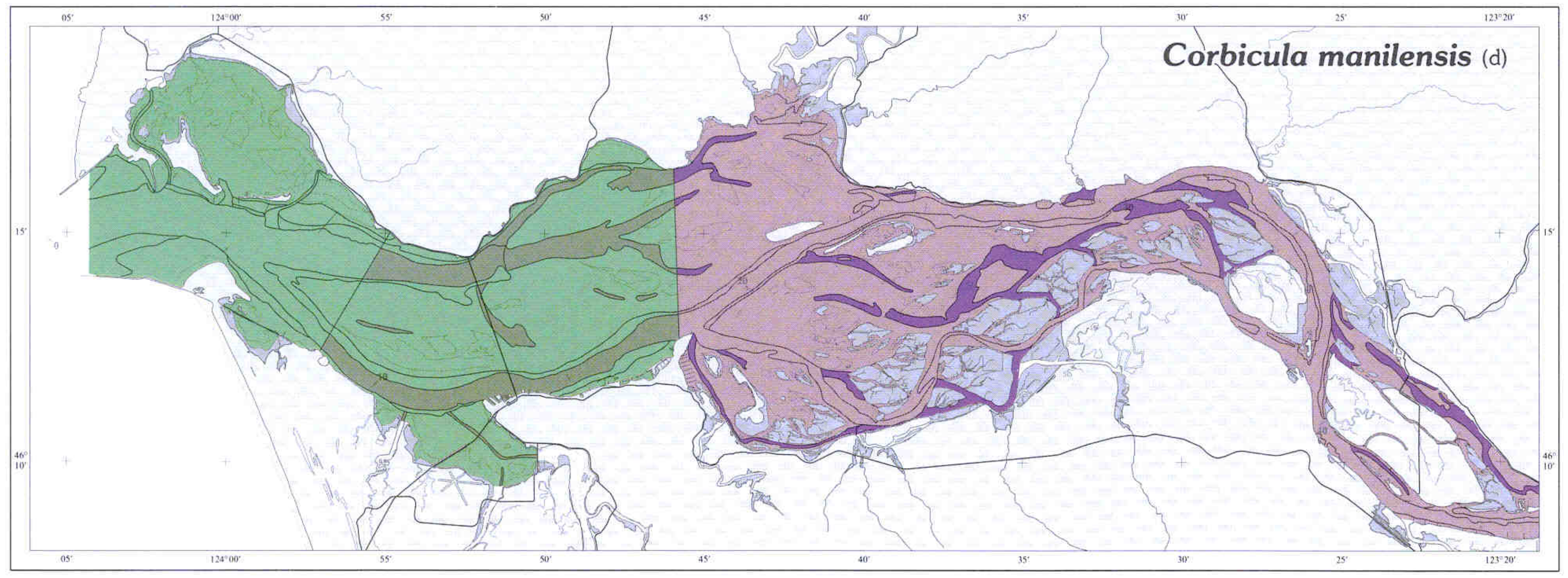
0 2 4 6 8 10 Kilometers

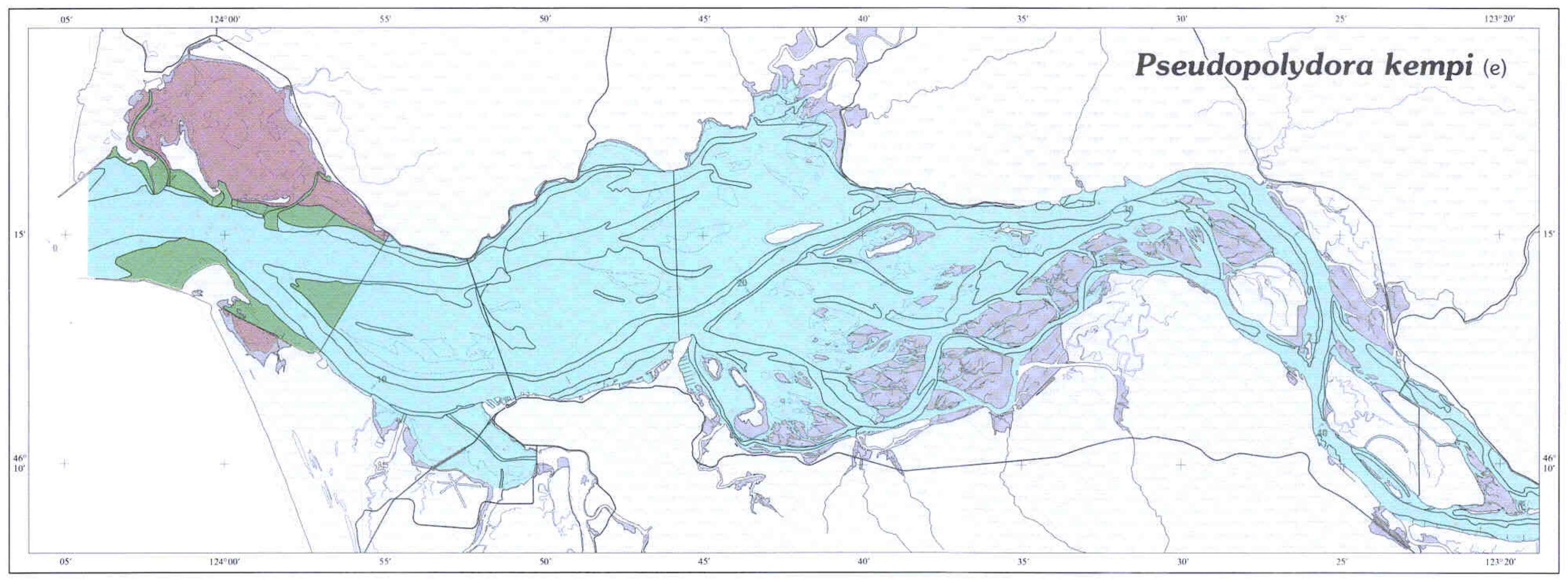
0 1 2 3 4 5 6 Miles

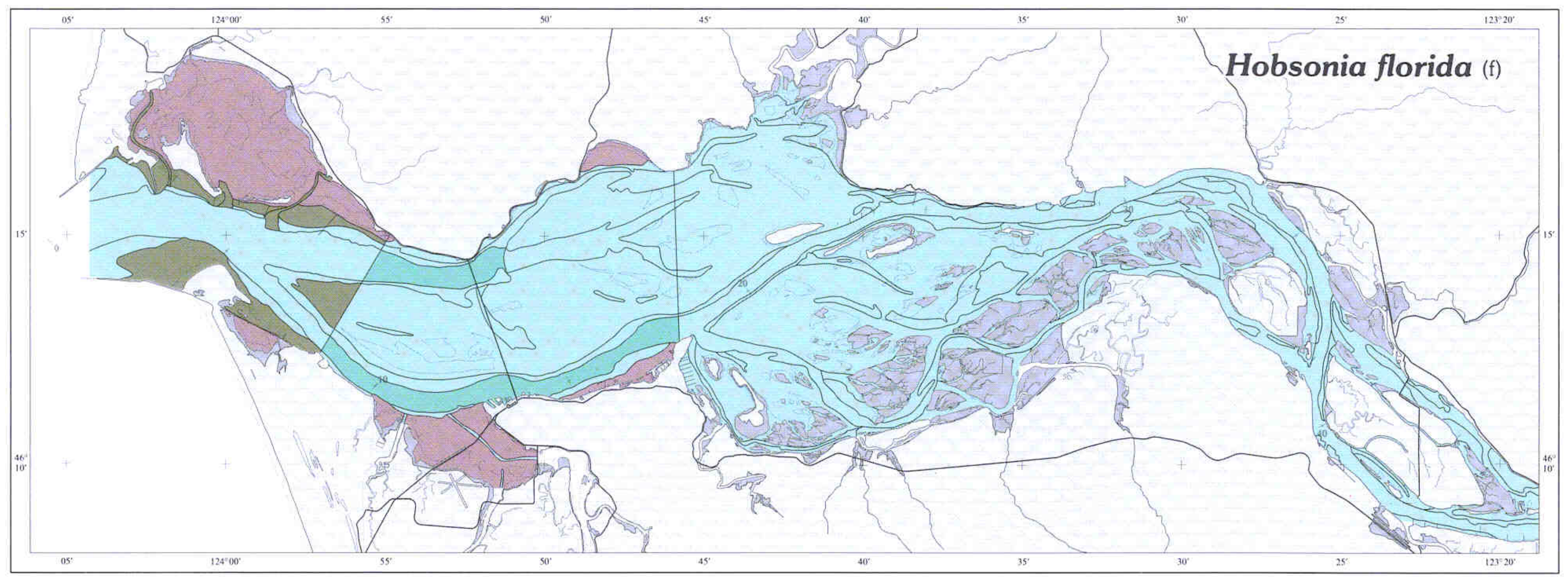


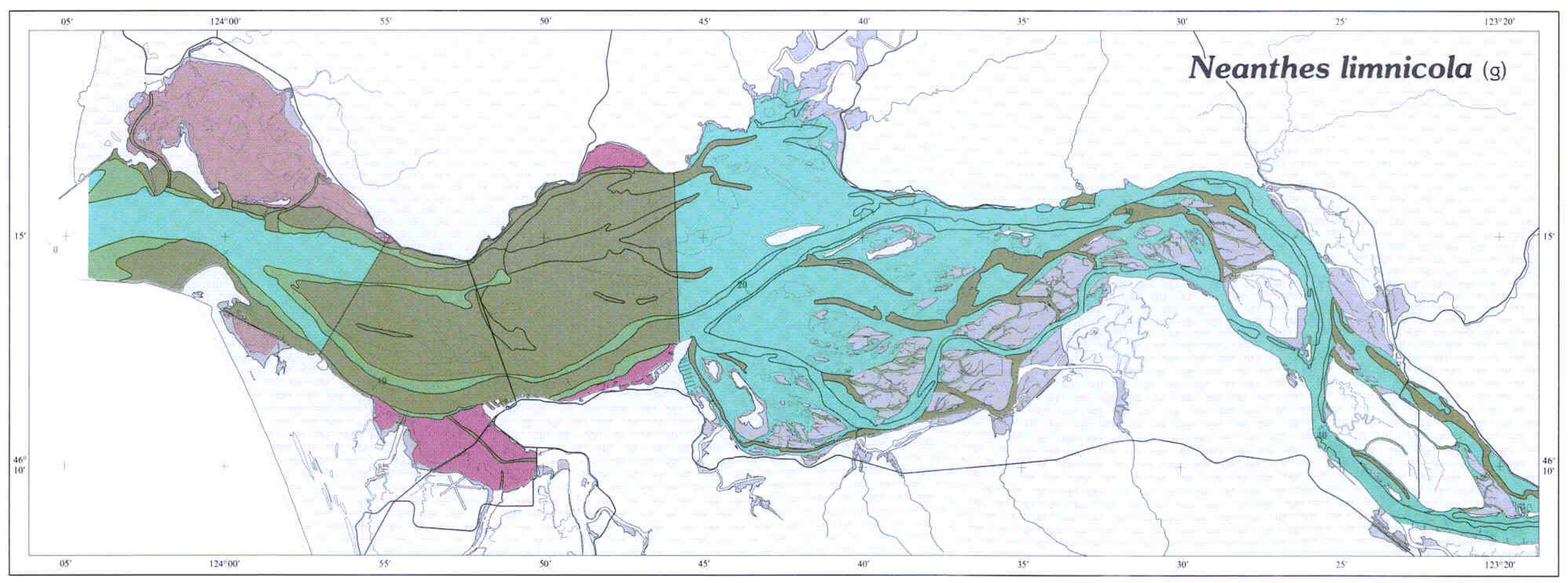


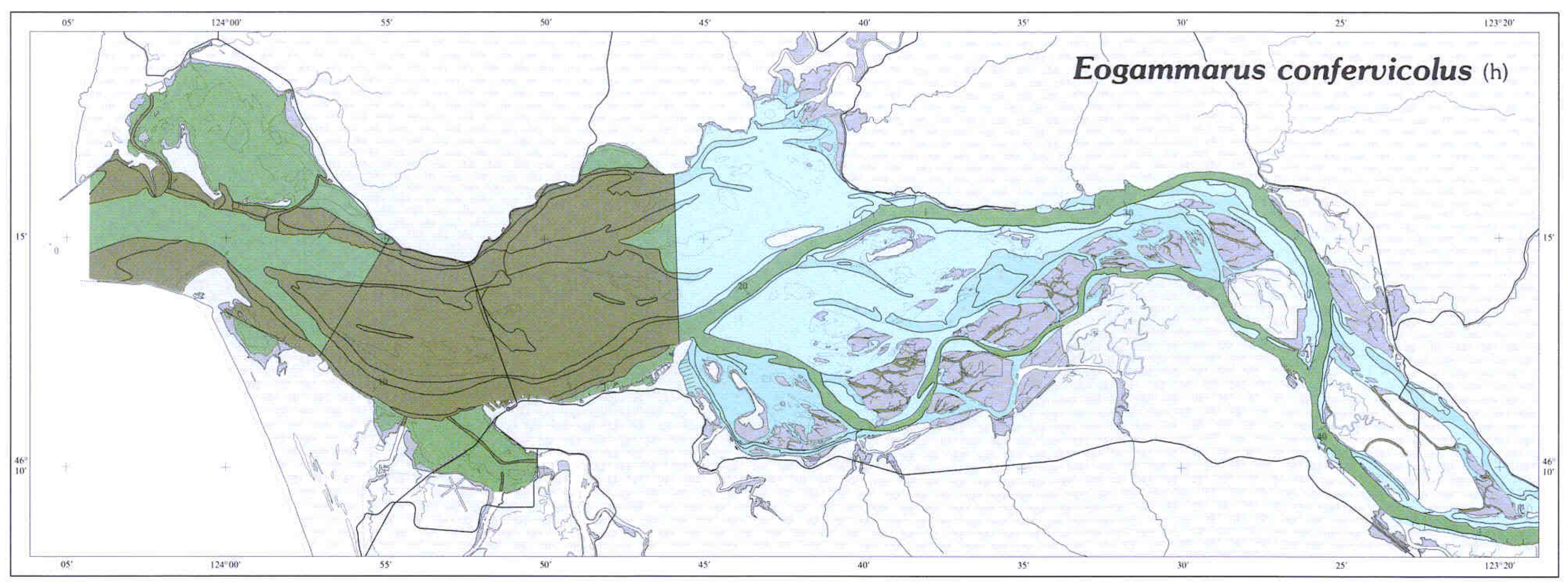












Benthic Infauna

Standing crop (mg AFDW/m²)*

- **2,000-20,000**
- **200-2,000**
- **20-200**
- **2-20**
- **0.2-2** (maps b,e,g,h)
  less than 2 (maps c,d)
- **0.02-0.2** (maps b,f)
  less than 0.2 (map g)
- **0.002-0.02** (map h)
  less than 0.02 (maps b,e,f)
- **less than 0.002**

Black lines within colored areas represent salinity and sedimentary regions, as defined by CREDDP benthic infauna investigators.

Sampling and data interpretation are limited to areas shown in color.

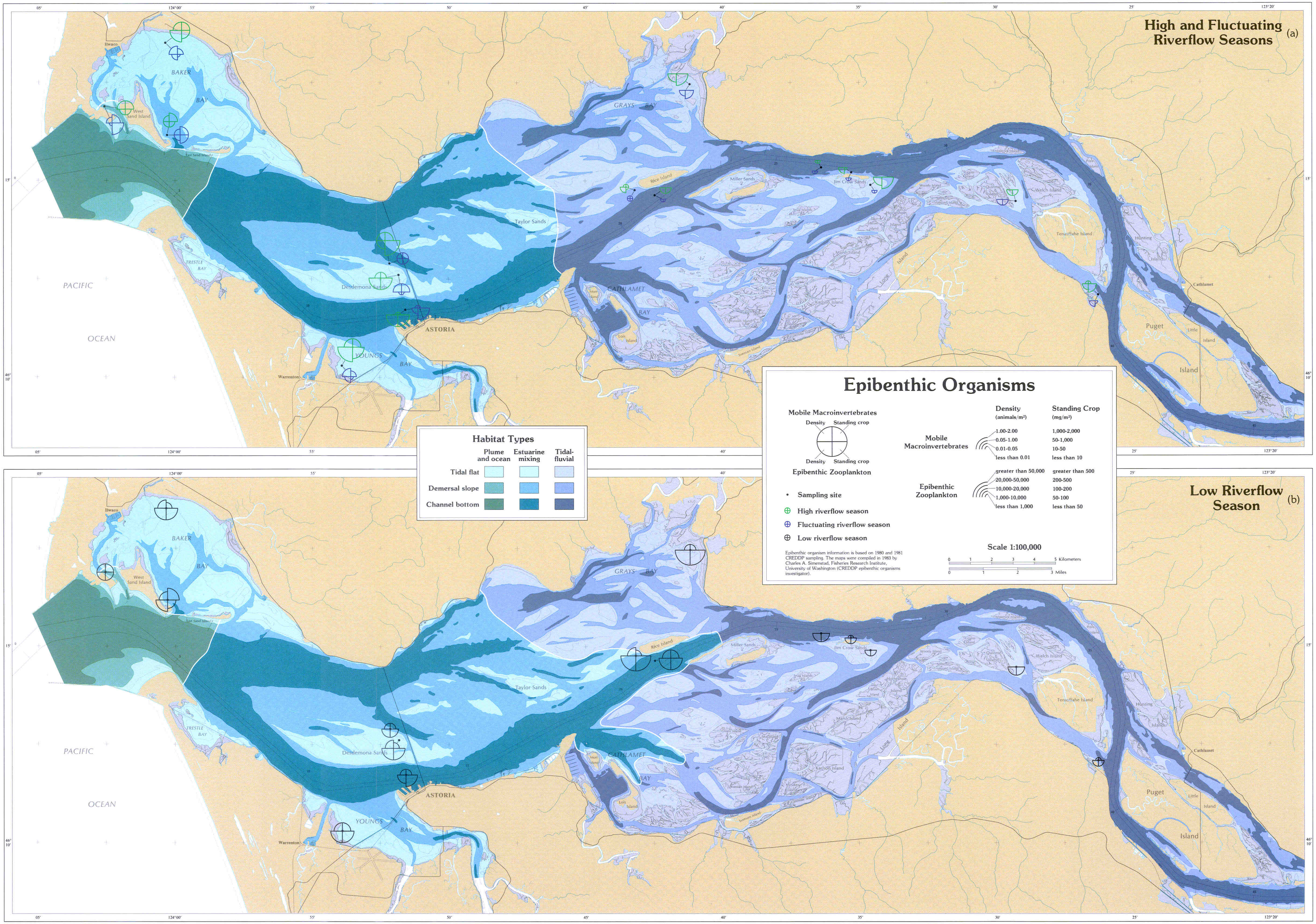
***mg AFDW/m² = milligrams ash-free dry weight per square meter**

Benthic infauna information is based on September 1981 CREDDP sampling. Maps were compiled in 1983 by Robert Holton and Duane Higley, Oregon State University (CREDDP benthic infauna investigators).

Scale 1:250,000

0 2 4 6 8 10 Kilometers

0 1 2 3 4 5 6 Miles


High and Fluctuating Riverflow Seasons (a)
Low Riverflow Season (b)
PACIFIC
OCEAN
BAKER
BAY
West Sand Island
TRESTLE BAY
Taylor Sands
Desdemona Sands
ASTORIA
YOUNGS
BAY
Warrenton
Ilwaco
GRAYS
BAY
Rice Island
Miller Sands
Jim Crow Sands
Welch Island
Tenasillahe Island
CATHLAMET
BAY
Cathlamet
Puget
Island
Habitat Types
Plume and ocean
Estuarine mixing
Tidal-fluvial
Tidal flat
Demersal slope
Channel bottom
Epibenthic Organisms
Mobile Macroinvertebrates
Density
Standing crop
Density
Standing crop
Epibenthic Zooplankton
Density (animals/m²)
Standing Crop (mg/m²)
Mobile Macroinvertebrates
1.00-2.00
0.05-1.00
0.01-0.05
less than 0.01
1,000-2,000
50-1,000
10-50
less than 10
Epibenthic Zooplankton
greater than 50,000
20,000-50,000
10,000-20,000
1,000-10,000
less than 1,000
greater than 500
200-500
100-200
50-100
less than 50
Sampling site
High riverflow season
Fluctuating riverflow season
Low riverflow season
Epibenthic organism information is based on 1980 and 1981 CREDDP sampling. The maps were compiled in 1983 by Charles A. Simenstad, Fisheries Research Institute, University of Washington (CREDDP epibenthic organisms investigator).
Scale 1:100,000
0 1 2 3 4 5 Kilometers
0 1 2 3 Miles

Chapter 5.

FISH

Of all the plants and animals of the Columbia River Estuary, fish have the greatest commercial and recreational value. Chinook and coho salmon and sturgeon are the principal species caught by commercial fishermen. American shad, Pacific herring, and eulachon also contribute to the commercial harvest. The principal fish caught by recreational fishermen include some of the above species as well as steelhead trout, sea-run cutthroat trout, perch, flounder, tomcod, rockfish, and lingcod.

Many of the important commercial and recreational fish, along with many other fish species, depend on the estuary during all or some part of their life cycles. Although a species may spend relatively little time in the estuary, that time may occur during a critical period in its life cycle. The large populations of estuarine invertebrates (benthic infauna, epibenthic organisms, and zooplankton) provide food for many fish species. The largest populations of fish occur in the central estuary between RM-8 and RM-18 and in the bays, where invertebrates are most abundant. Estuarine habitats, especially the shallow bays, are important as nursery areas. In addition, the estuary provides spawning habitat for some species (Pacific herring and shiner perch, for example).

Except for anadromous species (see below), the fish species of the Columbia River Estuary are classified as either marine or freshwater. Marine species, such as Pacific herring and northern anchovy, spend much of their life in the ocean, but use the estuary during parts of their life cycles. Marine species prefer higher salinities, but many are able to tolerate brackish water. Freshwater fish species, such as peamouth and largescale sucker, move into the estuary from the river. They prefer freshwater areas of the estuary but some can tolerate brackish water. Many species inhabiting the Columbia River Estuary are able to tolerate a wide range of salinities.

Marine and freshwater fish species characteristically occur in distinct types of estuarine habitats. The types of fish habitats are classified as intertidal, demersal, and pelagic. The intertidal habitats include the area from Extreme Low Tide to Extreme High Tide. During low tide, intertidal fish species also utilize shallow subtidal areas adjacent to the intertidal habitats. Demersal habitats, areas on the bottom or near the bottom, are occupied by flatfish and flounder. Pelagic habitats are open water areas. Although most species occupy one habitat in preference to the others, all species can be found in any of the three habitats.

Besides marine and freshwater fish, a third type of species, anadromous fish, utilizes the estuary. Typically, anadromous fish migrate as adults from the ocean to fresh water to spawn. After hatching, young anadromous fish remain in fresh water for different lengths of time, depending upon the species and race. Eventually the juveniles migrate to the ocean. Many slacken their speed when they reach the estuary, pausing to feed and to adjust gradually to the salt water. Once they reach the ocean, they remain there until adulthood. In time these adult fish migrate back to fresh water to spawn and the cycle begins again. Common anadromous species in the estuary include chinook and coho salmon and American shad. Anadromous fish are found in demersal, pelagic, and intertidal areas. Many of the anadromous individuals are able to tolerate wide salinity ranges; consequently, they can be found throughout the estuary at certain times of the year.

Columbia River Estuary Fish Feeding Groups

Fish that occur in similar regions and habitats of the Columbia River Estuary frequently eat similar prey. Figure 5-1 groups fish species in the estuary according to their food preferences, as determined by CREDDP investigators' analysis of fish stomach contents. The species composition and major prey items of these groups fluctuate during the year. The most consistently consumed prey species in the estuary are small crustaceans. For example, all pelagic feeding groups eat primarily calanoid* or other types of copepods found in the water column. During the low and fluctuating riverflow seasons (July through March) a separate pelagic feeding group also eats freshwater cladocerans of the genus *Daphnia* as well as copepods.

One demersal feeding group consumes amphipods, primarily *Corophium* spp. Starry flounder and staghorn sculpin are among species found in this group during all seasons. Fish that consume *Corophium* spp. are distributed throughout the estuary but are especially abundant in the middle to upper estuary and in protected habitats of Baker Bay and Youngs Bay.

A second demersal feeding group is abundant in the middle to lower estuary during each season. Species consistently in this group are Pacific tomcod, English sole, and snake prickleback. The members of this group consume calanoid copepods and amphipods (*Eogammarus* spp.) during the fluctuating riverflow season, mysid shrimp (*Archeomysis grebnitzkii*) during the high riverflow season, and a variety of other invertebrates during the low riverflow season.

Salmonids comprise a separate feeding group that eat *Corophium* spp. and insects at the water's surface in winter and spring. In summer juvenile chinook salmon shift to a diet of *Daphnia* spp., insects, and occasionally small fish. Salmonids frequently feed on insects at the water's surface and on amphipods near the estuary bottom or in the water column.

The distribution of feeding groups in the estuary reflects the distribution of prey species. In general, many fish, particularly demersal species, feed heavily in protected bays and in the broad transition zone between RM-8 and RM-18. This reflects the high production of epibenthic organisms in the estuarine zone and the high densities of benthic infauna and epibenthic organisms in protected bay habitats. The pelagic feeders are also abundant in the zone between RM-8 and RM-18, an area with high concentrations of the zooplankter *Eurytemora affinis* (a calanoid copepod).

*Copepods in the estuary are divided into three main groups: calanoids (for example, *Eurytemora affinis*), cyclopoids (for example, *Cyclops vernalis*), and harpacticoids (for example, *Scottolana canadensis*). Generally, calanoids and cyclopoids live in the water column while harpacticoids live in the sediments. All three can be found in the epibenthic zone.

Factors Affecting Distribution

As with many other organisms living in the estuary, salinity is the most important factor affecting fish distribution. Because the Columbia River Estuary is less saline than other nearby estuaries, the fish community consists of fewer exclusively marine species and more species that can tolerate only fresh water than these other estuaries. Many of the marine species, however, are able to tolerate a wide range of salinity. Since fish are very mobile, they are able to relocate rapidly in response to changes in salinity. Many swim back and forth with the tides as saline water moves in and out of the estuary.

The depth, vegetation, and sediment characteristics of habitats also affect fish distribution. Of the intertidal species, some occupy the tidal mudflats and sandflats while others prefer the tidal marshes and associated tidal channels. The demersal and pelagic species are found in deeper water areas. Smaller individuals of some demersal species tend to avoid areas with strong currents. The distribution of intertidal and demersal fish is sometimes correlated with sediment type. Sediment type, however, probably reflects other factors which affect fish distribution more directly. For example, demersal species such as starry flounder and English sole are most abundant in fine sediment environments, areas which both are protected from currents and have large numbers of benthic invertebrate prey.

The distribution and abundance of prey is another principal factor influencing fish distribution. Using data on fish stomach contents, CREDDP investigators classified fish species into feeding groups based on the type of prey consumed (see "Columbia River Estuary Fish Feeding Groups" on this page). Generally, pelagic species feed on water column organisms such as zooplankters while demersal and intertidal species consume epibenthic and benthic infaunal organisms. The area of greatest fish abundance in the estuary (between RM-8 and RM-18 and in the bays) coincides with high epibenthic organism and zooplankton abundance in the middle estuary tidal flats and channels (see "Epibenthic Organisms" and "Zooplankton") and high benthic infauna and epibenthic organism abundance in the adjacent peripheral bays (see "Benthic Infauna" and "Epibenthic Organisms"). The species composition and principal prey of feeding groups vary from one riverflow season to another. In addition, fish often change feeding groups as they mature. Changes in the distribution of a species at different stages of its life cycle may reflect changes in the type of prey it consumes.

For anadromous species, migration behavior is a principal factor affecting abundance and distribution in the estuary. These species are most abundant and most widely distributed during migration periods. Many of them are nearly absent from the estuary during the periods between migrations. Often, species follow specific migration paths; some species prefer to migrate in channels while others stay in shallow areas.

Derivation, Uses, and Limitations of the Maps (Plates 15 through 20)

CREDDP investigators took samples of the estuary's fish at monthly intervals from February 1980 through July 1981. They used three types of fishing gear for sampling: a beach seine for intertidal fish, a bottom trawl for demersal fish, and a purse seine for pelagic fish. Because each gear type samples a different volume of water, the investigators could not map the total catch data directly. To develop consistent relative abundance ranges, the investigators converted the catch data to reflect density (number of fish per hectare). The relative abundance categories shown on Plate 15 through 20 are: high, which corresponds to estimated densities of greater than 100 fish per hectare; medium, which corresponds to estimated densities of between 11 and 100 fish per hectare; and low, which corresponds to estimated densities of between 1 and 10 fish per hectare. Areas where a fish species' estimated density was below 1 fish per hectare are not shown on the maps.

CREDDP investigators mapped ten abundant fish species. Some of these were subdivided into age classes: less than one year old, one to two years old, and two years and older. Many fish species pass through a larval stage before being classified in the first age class. These larval fish were sampled by CREDDP zooplankton investigators but are discussed in this chapter.

The maps were produced for the ten species and their age classes for four seasons. The seasons represented are spring (April through June), summer (July through September), fall (October through December), and winter (January through March). The age classes are defined in terms of the calendar year rather than a fish's exact age. As of January 1, individuals produced during the previous year are classified as one year old.

The maps are useful for showing the distribution of abundant fish species in the estuary. Together with the invertebrate maps (Plates 11 through 14) and the maps of physical characteristics (Plates 3 through 9), the fish maps help identify important areas of the estuary for fish. Also, because the age classes of many of the fish species are mapped separately, the fish maps are useful for showing changes in distribution during fish species' life cycles.

There are, however, several important limitations to the accuracy of the maps. Each gear type samples individual species with a different degree of efficiency. Species that are able to avoid the nets or that live in areas not sampled by the gear are underrepresented in the sampling. Also, since the proportion of a given species' population sampled by each gear type is unknown, absolute density could not be estimated. Adult chinook and coho salmon were not captured frequently enough to be mapped. Also, although American shad two years and older are mapped (Plate 19, Maps e through h), their relative abundance was too low for their distribution to be portrayed as accurately as that of the other fish species. Fish are very mobile and their distributions go through changes that are more rapid than those shown on the seasonal maps. For example, fish populations move back and forth with the tides to stay at a physiologically adapted salinity level.

Interpretation of the Maps (Plates 15 through 20)

Pacific Herring (Plate 15, Maps a through d)

The Pacific herring (Figure 5-2) is a marine pelagic species common in the Columbia River Estuary in spring, summer, and fall. CREDDP investigators divided herring into two age classes: less than one year old, and one year and older. The estuary functions as a nursery and feeding area for herring, which migrate from the ocean into the estuary during the spring to feed and spawn. Some of the sexually mature individuals spawn in the estuary from April to July, with peak spawning in June and July. Small numbers of herring larvae and herring less than one year old appear in the estuary in spring, and as the year progressses the abundance of young herring increases. During the CREDDP study period, the herring less than one year old grew from a mean length of 68 millimeters in June to 102 millimeters in November. From April through October herring are classified in the pelagic feeding groups, eating mainly calanoid and harpacticoid copepods from April through June and mainly copepods (both calanoid and cyclopoid) and *Daphnia* spp. from July through October (Figure 5-1). During the fluctuating riverflow season (November through March) herring abundance was too low for classification into any feeding group.

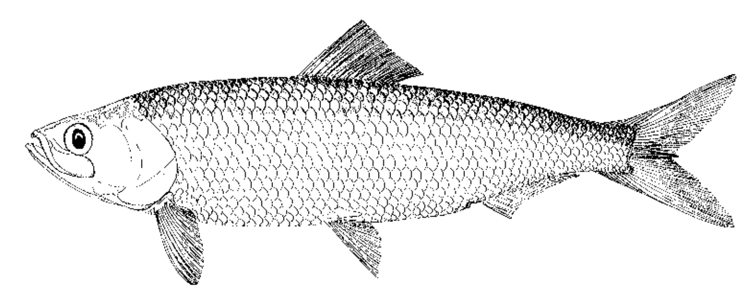


Figure 5-2. Pacific herring *(Clupea harengus pallasi)* (Snyder et al. 1984).

The distribution of Pacific herring less than one year old reflects the species' salinity tolerances, feeding behavior, and reproductive cycles. The relative abundance of these herring is low during the spring as young are produced (Plate 15, Map a). Their distribution is limited to the lower 14 miles of the estuary (from the ocean to the Astoria-Megler bridge). During the summer and fall there are dramatic increases in the distributions and abundances of these herring. The relative abundance of herring less than one year old is greatest during the summer, with high abundance in the lower and central estuary to Tongue Point (RM-18). This distribution reflects the species' tolerance for both marine and brackish water. These areas also contain large concentrations of copepods (see "Zooplankton" and "Epibenthic Organisms"), the major food for herring. The fall distribution pattern of herring less than one year old is similar to that of summer. The herring of this generation that were captured during winter were classified as one year and older. Since no new juveniles were found until the following spring, Plate 15, Map d shows no herring less than one year old present in the estuary during winter.

One year and older Pacific herring are most abundant in the estuary in spring when many adults move into the estuary from the ocean to feed and some to spawn. Their distributional range encompasses the marine and brackishwater areas of the estuary where planktonic and epibenthic copepods abound. The abundance of the older herring gradually decreases through summer, fall, and winter as the adults move back into the ocean.

Northern Anchovy (Plate 15, Maps e through h)

The northern anchovy (Figure 5-3) is a marine pelagic species that is commonly found both in the estuary and offshore in large schools during all seasons. The estuarine population is an extension of the larger coastal populations. The species spawns in the ocean, but all life cycle stages may be found in the estuary. The eggs and larvae are apparently swept into the estuary during flood tides. Anchovy are classified in the pelagic feeding groups, eating mainly copepods (Figure 5-1). Anchovy also consume phytoplankton.

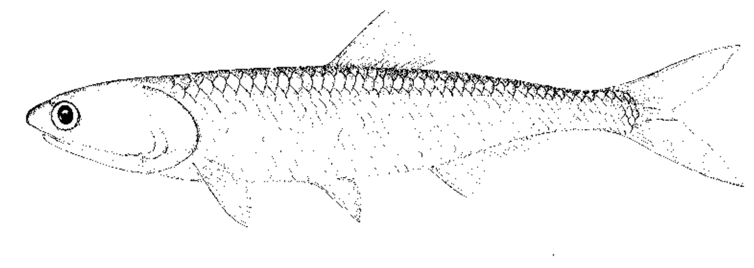


Figure 5-3. Northern anchovy *(Engraulis mordax)* (Snyder et al. 1984).

Northern anchovy less than one year old are not abundant in the estuary. During 1980 and 1981, they were found only during the fall months from the mouth of the estuary to about RM-18.

The distribution of anchovy one year and older reflects their preference for high salinities. During the low riverflow periods of summer and fall when salinity intrusion increases, anchovy are distributed farther upriver than during the high riverflow periods of winter and spring. The anchovy distribution also coincides with the distribution of large populations of copepods (see "Zooplankton" and "Epibenthic Organisms").

Pacific Staghorn Sculpin (Plate 16, Maps a through d)

The Pacific staghorn sculpin (Figure 5-4) is a marine demersal species that is able to tolerate fresh and brackish water. It is a year-round resident of the estuary. CREDDP investigators did not divide the species into separate age classes. Pacific staghorn sculpin are classified in a demersal feeding group, eating mainly *Corophium salmonis* year-round and, in addition, amphipods of the genus *Eogammarus* and some copepods from April through June (Figure 5-1). Staghorn sculpin also prey on the sand shrimp *Crangon franciscorum.*

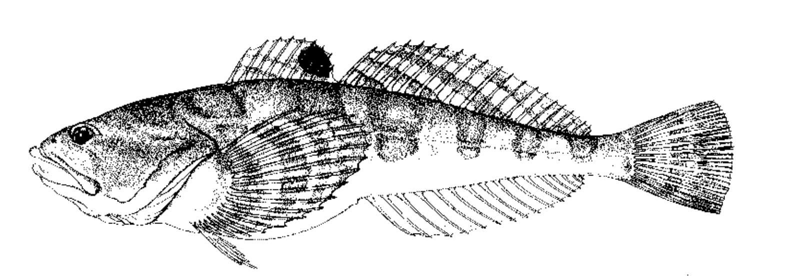
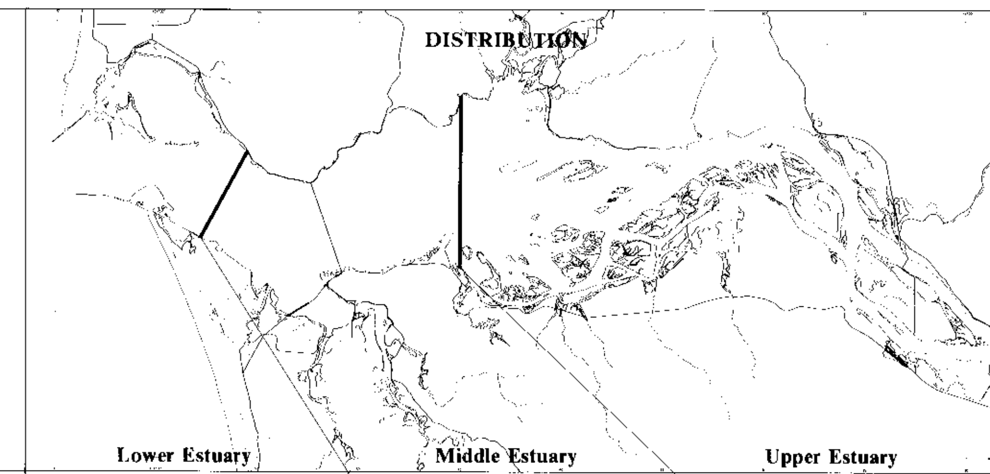


Figure 5-4. Pacific staghorn sculpin *(Leptocottus armatus)* (Snyder et al. 1984).



RIVERFLOW SEASON	FEEDING GROUP	FISH SPECIES*	PRINCIPAL PREY SPECIES**
Fluctuating Riverflow Season (November-March)	Pelagic 1	American shad (1) longfin smelt (1) threespine stickleback	Calanoid Copepods *Corophium salmonis*
	Pelagic 2	American shad (2) surf smelt whitebait smelt northern anchovy	Calanoid Copepods *Daphnia* spp.
	Demersal 1	Pacific staghorn sculpin starry flounder (1) starry flounder (2) prickly sculpin	*Corophium salmonis*
	Demersal 2	Pacific tomcod snake prickleback English sole (1) sand sole butter sole	Calanoid Copepods *Eogammarus confervicolus*
	Epibenthic and Water Surface	chinook salmon (0)	Insects *Corophium salmonis*
High Riverflow Season (April-June)	Pelagic 1	Pacific sand lance Pacific herring (0) Pacific herring (1) longfin smelt (1) surf smelt whitebait smelt northern anchovy chum salmon	Calanoid Copepods Harpacticoid Copepods
	Pelagic 2	American shad (1) American shad (2) sockeye salmon	Calanoid Copepods
	Demersal 1	Pacific staghorn sculpin starry flounder (1) starry flounder (2) shiner perch (1) English sole (0) prickly sculpin peamouth	Copepods *Corophium* spp. *Eogammarus* sp.
	Demersal 2	Pacific tomcod snake prickleback butter sole English sole (1) speckled sanddab shiner perch (0)	*Archeomysis grebnitzkii*
	Epibenthic and Water Surface	chinook salmon (0) chinook salmon (1) coho salmon steelhead trout threespine stickleback cutthroat trout	Insects *Corophium* spp.
Low Riverflow Season (July-October)	Pelagic 1	longfin smelt (1) northern anchovy (1) whitebait smelt	Calanoid Copepods Harpacticoid Copepods
	Pelagic 2	Pacific herring (0) Pacific herring (1) American shad (0) American shad (1) American shad (2) surf smelt longfin smelt (0) threespine stickleback shiner perch (1)	Copepods *Daphnia* spp.
	Demersal 1	starry flounder (0) starry flounder (1) starry flounder (2) Pacific staghorn sculpin shiner perch (0) prickly sculpin white sturgeon peamouth largescale sucker	*Corophium salmonis*
	Demersal 2	English sole (0) English sole (1) sand sole Pacific tomcod snake prickleback	Copepods and Other Invertebrates
	Epibenthic and Water Surface	chinook salmon (0) cutthroat trout	*Daphnia* spp. Insects Fish

*Age classes for all species except starry flounder, American shad, chinook and coho salmon are: (0), less than one year old; and (1), one year and older. For starry flounder, American shad, chinook and coho salmon the age classes are: (0), less than one year old; (1), one to two years old; and (2), two years and older.

**Principal prey species named represent the most important prey taxa common to the species in each feeding group.

Figure 5-1. Feeding groups in the Columbia River Estuary, showing generalized distribution of the fish species and principal prey during the three riverflow seasons (modified from Bottom et al. 1984).

The Pacific staghorn sculpin is able to live in the entire range of salinities in the estuary and in both the intertidal and deeper demersal habitats. With little variation, staghorn sculpin are distributed from the mouth of the estuary to Woody Island (RM-29) throughout the year. The numbers of staghorn sculpin vary somewhat from season to season but their relative abundance generally follows a consistent pattern year-round. Typically, their relative abundance is medium or high from about RM-5 to near Rice Island (RM-22), with lower abundance downriver from RM-5 and upriver from Rice Island. Staghorn sculpin have medium or high abundances in parts of Youngs, Grays, and Baker Bays.

English Sole (Plate 16, Maps e through h)

The English sole (Figure 5-5) is a marine demersal species that prefers high salinities and is found in the estuary only in the downriver portions. English sole do not utilize the estuary throughout their entire life cycle; the estuarine population consists mainly of juveniles (sexually immature individuals). CREDDP investigators divided the English sole population in the estuary into those less than one year old and those one year and older, but most of those in the older age class are still juveniles. Young English sole enter the estuary from the ocean and utilize the estuary as a feeding and nursery area. During the CREDDP study their mean length increased from 44 millimeters in February to 117 millimeters in December. Both age classes are classified in demersal feeding groups, eating mainly copepods, amphipods (*Corophium* spp. and *Eogammarus* spp.), and the mysid *Archeomysis grebnitzkii* (Figure 5-1). Other prey important to English sole include *Macoma balthica*, polychaetes, and oligochaetes.

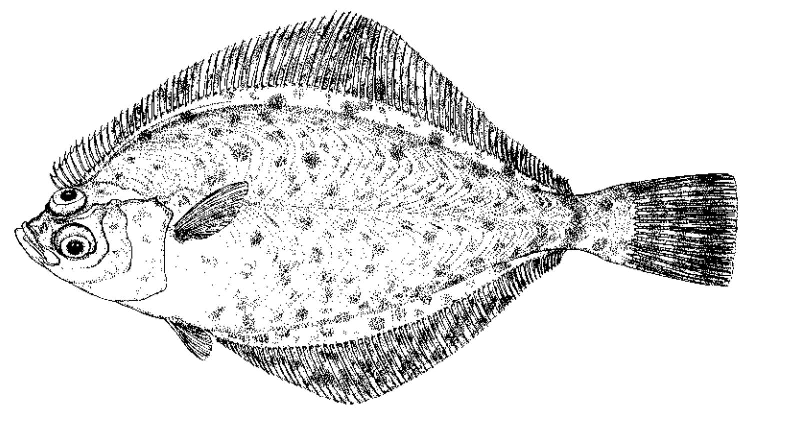


Figure 5-5. English sole *(Parophrys vetulus)* (Snyder et al. 1984).

The distribution of English sole less than one year old reflects their preference for high to moderate salinities. During the spring the relative abundance of this age class is low except in Baker Bay; maximum upriver distribution is to Astoria (RM-15). Summer and fall are the seasons of greatest abundance in the estuary for English sole less than one year old, particularly in localized areas such as Ilwaco and Chinook Channels. Their distribution extends farther upriver in summer and fall, probably because saline water intrudes farther upriver during those seasons. In winter both the relative abundance of these fish and the extent of their distribution decrease.

English sole one year and older are less abundant in the estuary than the younger fish. Their distribution in the lower estuary downriver from the Astoria-Megler bridge during all seasons reflects their preference for high salinities.

Starry Flounder (Plate 17)

The starry flounder (Figure 5-6) is a marine demersal species able to tolerate a wide range of salinities. Generally, the younger flounder prefer lower salinities and the older flounder prefer higher salinities. CREDDP investigators separated starry flounder into three age classes; those less than one year old and those from one to two years old are shown on Plate 17, Maps a through d and those over two years old are shown on Plate 17, Maps e through h. Adult starry flounder spawn in the ocean and the juveniles enter the estuary at a young age. During CREDDP sampling starry flounder less than one year old grew from a mean length of 70 millimeters in August to 81 millimeters in December. Those from one to two years old increased from 89 millimeters in February to 127 millimeters in December. Starry flounder are classified in a demersal feeding group, eating mainly *Corophium salmonis*, some other amphipod species, and copepods (Figure 5-1).

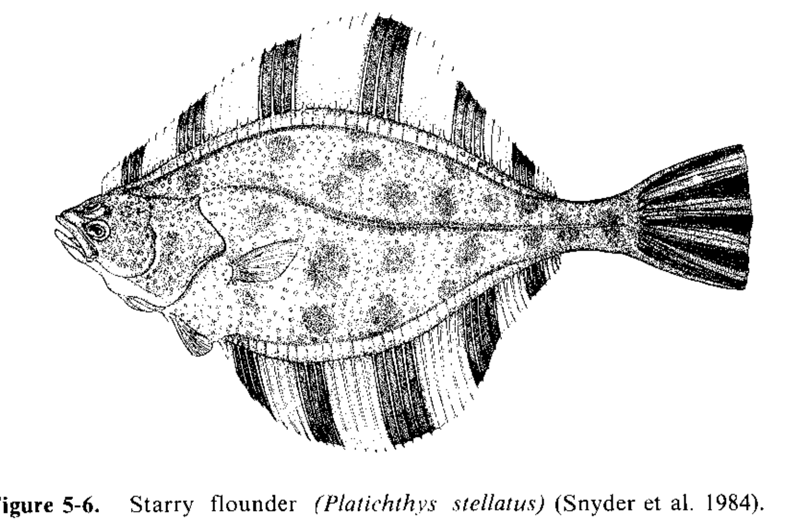


Figure 5-6. Starry flounder *(Platichthys stellatus)* (Snyder et al. 1984).

Starry flounder less than one year old are less abundant in the estuary than the other age classes. Although they are distributed throughout much of the estuary, they are more concentrated in the freshwater or low salinity areas. In the spring the relative abundance of these starry flounder is generally low and their distribution is restricted to part of Youngs Bay and an area between Tongue Point and Woody Island (RM-29). During the summer and fall their distribution extends throughout the estuary. Their abundance remains generally low except in areas of low current velocity such as Grays Bay, Youngs Bay, Baker Bay, Cathlamet Bay, and intertidal habitats. These are areas that have concentrations of amphipods such as *Corophium salmonis*, starry flounder's principal prey. The starry flounder of this generation that were captured during the winter were classified as one to two years old, and no new juveniles appeared until the following spring.

Starry flounder between one and two years old are the most abundant of this species' age classes. They are distributed throughout the estuary during all seasons of the year. Their abundance in different areas of the estuary fluctuates seasonally, but the changes do not follow any general pattern. In all seasons, densities are consistently medium or high in Ilwaco and Chinook Channels, Youngs Bay, Grays Bay, and some intertidal areas. One to two year old starry flounder are more abundant in the deep waters of the navigational channel than starry flounder less than one year old.

Starry flounder more than two years old are less widespread than those between one and two years. They are found more frequently in the higher salinity portions of the estuary. These older starry flounder are distributed throughout the estuary in winter and spring but in summer and fall the upriver limits of their distribution are about RM-38 and RM-29, respectively. Their relative abundance is low in much of the estuary during all seasons except winter, when their abundance is medium from RM-7 to RM-25. Medium or high relative abundances occur in localized areas of the estuary during all seasons. Like the other age classes, these starry flounder are most concentrated in bays and intertidal areas that have large concentrations of benthic prey such as *Corophium salmonis*.

Longfin Smelt (Plate 18, Maps a through d)

The longfin smelt (Figure 5-7) is an anadromous species that spawns in the estuary. Longfin smelt are found in pelagic, demersal, and intertidal areas and can tolerate a wide range of salinities. They spawn from November through March, with peak spawning in January and February. Smelt larvae are abundant in the estuary from January through May, reaching densities as high as 300 larvae per square meter. By summer, the new generation of smelt becomes large enough to be caught with the CREDDP fish sampling gear. During CREDDP sampling, longfin smelt less than one year old grew from a mean length of 51 millimeters in July to 75 millimeters in December. Longfin smelt are classified in pelagic feeding groups, eating mainly calanoid and harpacticoid copepods and cladocerans of the genus *Daphnia* (Figure 5-1). Longfin smelt also eat *Corophium salmonis* and *Neomysis mercedis* in the estuary.

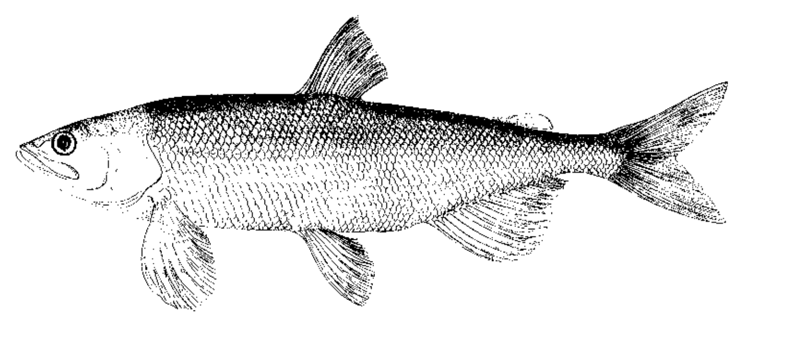


Figure 5-7. Longfin smelt *(Spirinchus thaleichthys)* (Snyder et al. 1984).

Longfin smelt less than one year old are not found in the estuary during winter and spring because at this time they are in the larval stage and are too small to be caught with the fish sampling gear. Longfin smelt less than one year old are abundant in the estuary in summer and fall. In the summer they are present from the ocean to RM-23 and in the fall to RM-27. Abundance in both summer and fall is generally medium from the mouth to above RM-20, with localized high abundance such as in Youngs Bay during the fall.

Older longfin smelt (one year and older) are widely distributed in the estuary during all seasons, particularly during fall and winter. In the spring and summer the older longfin smelt are present from the mouth of the estuary to RM-27. During the fall and winter they are distributed from the mouth to RM-38. In the spring older longfin smelt are highly abundant from RM-7 to RM-19. During the summer the area of high abundance expands, extending from RM-3 to RM-20. In the fall and winter abundance is at least medium in much of the estuary. Abundance from RM-21 to RM-30 increases to medium levels during these seasons.

Shiner Perch (Plate 18, Maps e through h)

The shiner perch (Figure 5-8) is a marine species that is able to tolerate brackish water. Shiner perch are unusual fish in that they bear their young live. They are found in demersal, pelagic, and intertidal areas and prefer areas with weak currents. Adult shiner perch begin migrating into the estuary from the ocean in April. They bear their young in the estuary in June and July and migrate back into the ocean in late fall. CREDDP investigators divided shiner perch into two age classes, less than one year old and one year old and older. Shiner perch are classified in both demersal and pelagic feeding groups (Figure 5-1). They eat mainly *Corophium* spp., copepods, and *Daphnia* spp.

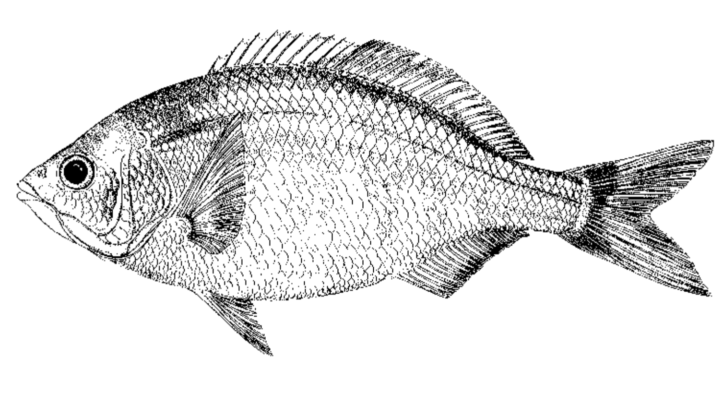


Figure 5-8. Shiner perch *(Cymatogaster aggregata)* (Snyder et al. 1984).

Shiner perch less than one year old were not found in the estuary during winter and spring but were distributed from the mouth of the estuary to RM-23 in the summer and from the mouth to RM-20 during the fall. The relative abundance of these shiner perch in the summer and fall was low in much of the estuary, with localized medium or high abundance in areas with weak currents such as Baker and Youngs Bays.

Shiner perch one year and older are distributed from the mouth of the estuary to Tongue Point in the spring. Relative abundance is low at this time except in Youngs Bay and adjacent areas and parts of Baker Bay. In the summer upriver distribution of shiner perch increases to RM-20 and abundance rises to medium or high levels in areas of the estuary extending from Baker Bay to Knappton. During the fall the upriver distribution increases slightly but abundance drops sharply as adults begin to move back into the ocean. In the winter the distribution of older shiner perch is considerably reduced from fall, extending upriver only a little farther than the Astoria-Megler bridge on the north side of the estuary. Most of the adult shiner perch have moved into the ocean by winter.

American Shad (Plate 19)

The American shad (Figure 5-9) is an anadromous species found throughout the estuary in pelagic, demersal, and intertidal areas. American shad were introduced from the east coast to the west coast of the United States in the late 1800's. CREDDP investigators divided American shad into three age classes. Those less than one year old and those from one to two years old (juveniles) are shown on Plate 19, Maps a through d; those two years and older (both juveniles and adults) are shown on Plate 19, Maps e through h. American shad spawn primarily upriver from the estuary; their main spawning range extends to the mid-Columbia and the Snake River systems. Peak upstream migration through the estuary is in June and July for adults, and peak downstream migration of juveniles is in November and December. Juveniles grow substantially while using the estuary as a nursery area. For example, during CREDDP sampling shad from one to two years old grew from a mean length of 119 millimeters in February to 235 millimeters in September. American shad are classified in pelagic feeding groups, eating mainly calanoid copepods, *Daphnia* spp., and *Corophium salmonis* (Figure 5-1). They also eat *Neomysis mercedis* in the estuary.

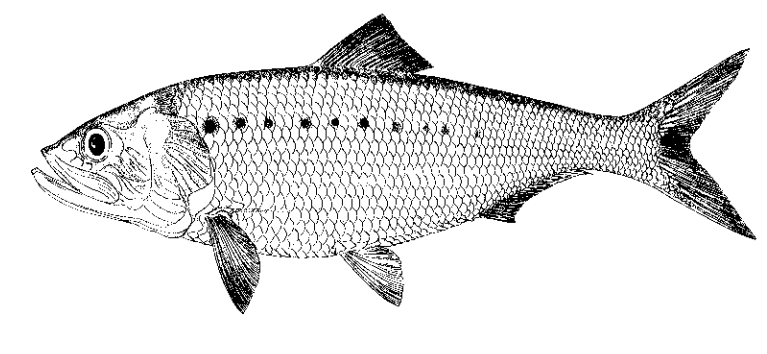


Figure 5-9. American shad *(Alosa sapidissima)* (Snyder et al. 1984).

The seasonal distribution of American shad less than one year old mainly reflects the migration behavior of juveniles. Virtually none of these shad are present in the estuary in winter or spring. Their abundance is low in summer as the first downstream migrants begin to appear in the estuary. These American shad are distributed from Youngs Bay to the upriver limit of the estuary study area at this time. In the fall both distribution and abundance increase as the bulk of the migrants appear in the estuary. During the fall they are present throughout the estuary, with medium abundance from RM-5 to RM-16 and high abundance upriver from RM-16.

American shad one to two years old are distributed throughout the entire estuary in the spring, although abundance is low except for localized areas and one large area extending from RM-6 to RM-21 where relative abundance is medium. In the summer the extent of their distribution decreases slightly but the area of medium abundance increases. In fall, both abundance and distribution decrease as these fish begin to move into the ocean. The medium abundance of this age class shown for winter represents the same generation as the less than one year old age class on the fall map.

The relative abundance of American shad two years and older is generally low. They are distributed throughout the estuary during spring and summer. Few shad of this age class are found in the estuary in fall and winter.

Chinook Salmon (Plate 20, Maps a through d)

The chinook salmon (Figures 5-10 and 5-11) is an anadromous species that spawns in streams throughout the Columbia River drainage basin and also is propagated in many hatcheries along the Columbia and its tributaries. CREDDP investigators classified chinook salmon into two age classes, both juveniles: those less than one year old and those from one to two years old. Adult chinook salmon were not sampled efficiently by CREDDP sampling gear and are not shown on the maps. Several races (distinct populations within the total group of individuals that use the Columbia River system) migrate through the estuary at different times. The major races, spring chinook, summer chinook, and fall chinook, are named for the upstream migration timing of the adults. Most of the downstream-migrating juvenile fall chinook are less than one year old. These fish remain in the estuary longer than other juvenile salmonids and prefer both pelagic and intertidal areas. Most of the spring and summer juvenile chinook in the estuary are from one to two years old. These fish generally migrate through the estuary rapidly and prefer pelagic areas. CREDDP investigators classified juvenile chinook salmon into a feeding group known as epibenthic and water surface feeders (Figure 5-1). They eat mainly *Corophium salmonis*, *C. spinicorne*, insects at the water surface, *Daphnia* spp., and small fish. They also eat *Neomysis mercedis* and *Crangon franciscorum* (see "Importance of the Estuary to Salmonid Production" on this page).

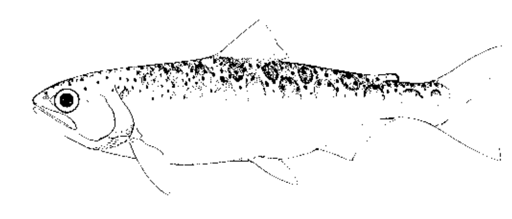


Figure 5-10. Juvenile chinook salmon *(Oncorhynchus tshawytscha)* (Snyder et al. 1984).

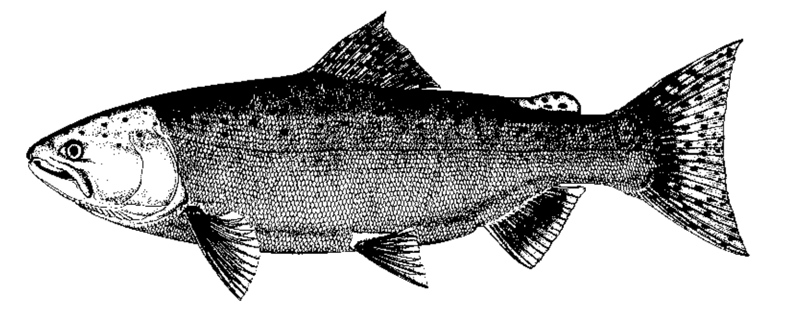


Figure 5-11. Adult chinook salmon *(Oncorhynchus tshawytscha)* (Pittard 1983).

The distribution of chinook salmon less than one year old reflects their migration behavior and their use of intertidal areas. In the spring these salmon are distributed throughout the entire estuary. Abundances are medium to high from Astoria (RM-15) upriver. They are also highly abundant in intertidal areas downriver from Astoria such as in Youngs Bay, near Hammond, near Clatsop Spit, and in Baker Bay. The distribution of chinook salmon less than one year old in summer is the same as in spring. Their relative abundance, however, increases as more juveniles move into the estuary. Summer abundance is medium through most of the estuary, with localized areas of high abundance. During the fall these salmon are less widely distributed and their relative abundance decreases sharply as juveniles move into the ocean. In the winter the distribution of this age class is restricted to small areas of the estuary, primarily intertidal areas. These intertidal areas have high concentrations of *Corophium salmonis*.

Chinook salmon from one to two years old are distributed throughout the estuary during the spring, with an area of medium abundance extending upriver from RM-18. Abundance in the remainder of the estuary is low except for a localized area of medium abundance from RM-5 to RM-8. Most of these fish have moved into the ocean by summer. A small number of one to two year old chinook salmon migrate through or reside in the estuary in fall and winter.

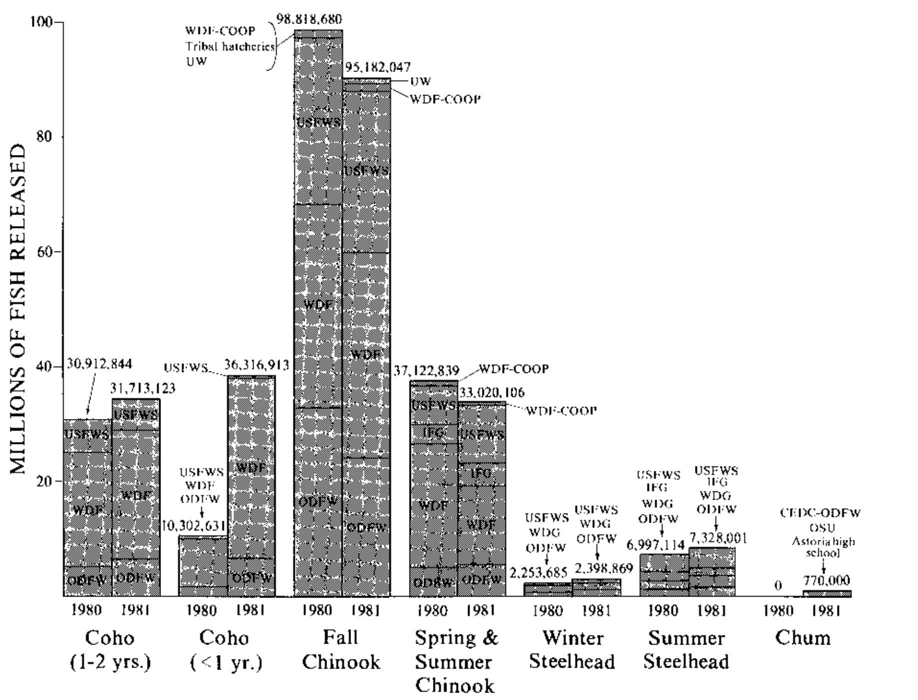


Figure 5-12 Number of hatchery salmonids released into the Columbia River system in 1980 and 1981. USFWS = United States Fish and Wildlife Service; ODFW = Oregon Department of Fish and Wildlife; CEDC = Clatsop Economic Development Committee; WDF = Washington Department of Fisheries; WDF-COOP = Washington Department of Fisheries Cooperatives; WDG = Washington Department of Game; UW = University of Washington; IFG = Idaho Department of Fish and Game (Bottom et al. 1984).

Coho Salmon (Plate 20, Maps e through h)

The coho salmon (Figures 5-13 and 5-14) is an anadromous species that spawns in the tributaries of the Columbia River and also is propagated in hatcheries. Adults migrate upstream through the estuary in late summer and fall. The juveniles migrate downstream in spring, mainly as one to two year olds. Juveniles tend to move through the estuary rapidly. They are classified in the epibenthic and water surface feeding groups, eating mainly *Corophium salmonis*, *C. spinicorne*, and insects at the water surface (Figure 5-1) during their passage through the estuary (see "Importance of the Estuary to Salmonid Production" on this page).

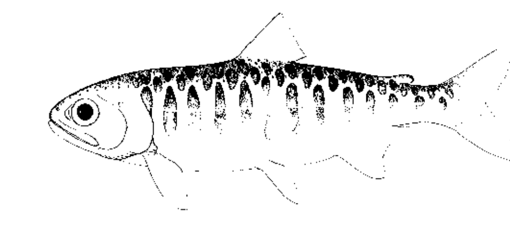


Figure 5-13. Juvenile coho salmon *(Oncorhynchus kisutch)* (Snyder et al. 1984).

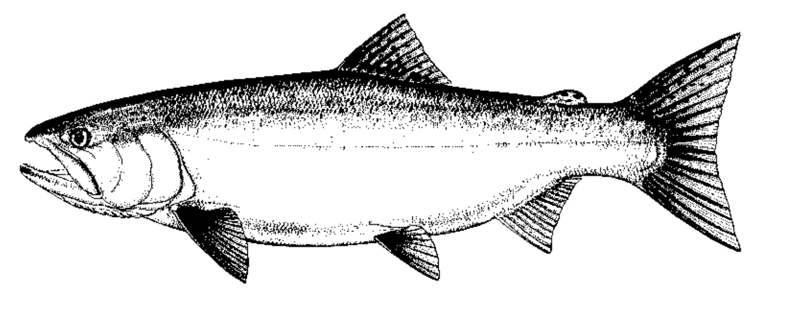


Figure 5-14. Adult coho salmon *(Oncorhynchus kisutch)* (Pittard 1983).

The seasonal distribution of coho salmon from one to two years old, the only age class abundant enough to map, reflects their migration behavior. In the spring, at the peak of their migration, juvenile coho salmon are moderately abundant almost everywhere in the estuary. During the summer abundances are low in all areas. No juvenile coho are found in the estuary in the fall, and few are found in the winter.

Species	% of salmonid catch	Months of largest catch* (peak month capitalized)
Chinook salmon less than one year old	68%	May, JUNE, July, August
Chinook salmon one to two years old	8%	April, MAY
Coho salmon	18%	MAY, June
Steelhead trout	5%	MAY
Chum salmon, sockeye salmon, cutthroat trout	1%	April, May, June

*Months when the average catch for that month was higher than the average monthly catch of that species over the entire 18-month CREDDP sampling period.

Table 5-1. Species composition and months of largest catch of juvenile salmonids caught in the Columbia River Estuary during 1980 and 1981 CREDDP sampling (from Bottom et al. 1984).

Importance of the Estuary to Salmonid Production

During the spring juvenile salmonids (salmonids include salmon and trout species) comprised about 33 percent of all fish sampled by CREDDP investigators in the Columbia River Estuary. Table 5-1 provides a good indication of the abundance of different juvenile salmonid groups in the estuary relative to each other, and of their periods of abundance. Juvenile salmonids constituted a much smaller portion of CREDDP samples during other seasons (6 percent in summer, 1 percent in fall, and 2 percent in winter).

Juveniles of most salmonid species move quickly through the estuary. These fish are most often collected in deep channel areas, which they use as a migration route to the ocean. Of all salmonids, chinook salmon less than one year old move most slowly through the estuary and were the most abundant species during the 1980-81 CREDDP fish survey. Chinook salmon of this age class released from hatcheries in April and May were caught in the estuary every month through October, indicating a long residence time compared with other salmonid species.

Estuarine migration rates and residence patterns reflect the rearing practices and release schedules of the 40 different hatcheries located in the Columbia River and its tributaries. In 1981, hatcheries produced 95 million fall chinook, 33 million spring and summer chinook, 68 million coho, 10 million steelhead, and 770 thousand chum salmon (Figure 5-12). Today, the number of salmon spawned in natural habitats of the Columbia River system is a small percentage of total hatchery production.

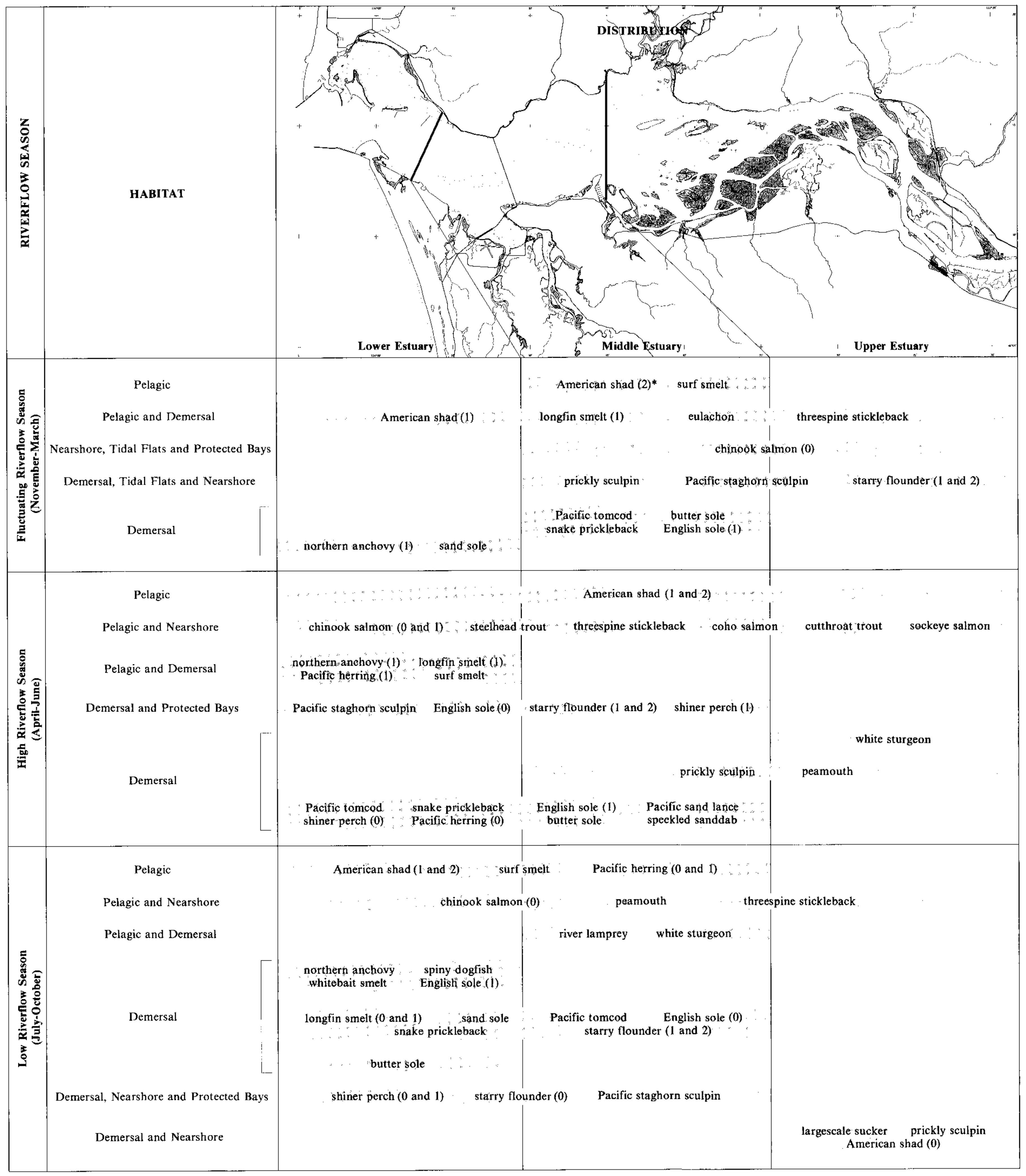
Researchers have suggested that the residence of young salmonids in the estuary is important for their survival in the ocean. Juvenile chinook salmon less than one year old benefit from the intertidal habitats where they can feed and grow in relative safety from predators. Food and shelter are important factors for these relatively slow moving salmon. Even salmonids that do not remain in the estuary for extended periods may benefit from the gradual adaptation to increasing salinity afforded by the estuarine environment. Water quality, flow, and channel habitat are the most important factors for these salmonids.

Discussion

CREDDP investigators classified the abundant fish of the Columbia River Estuary into several assemblages. Unlike feeding groups, which were classified based on an analysis of fish stomach contents, assemblages were determined on the basis of catch data: where, when, and in what numbers the fish were captured during CREDDP sampling. While no two fish species have precisely the same habitat requirements, it is possible to identify species that are associated with one another and that rely on similar regions and habitats of the Columbia River Estuary. The species in these assemblages and their distributions change seasonally as fish migrate into or out of the estuary and respond to changes in the estuarine environment. Among the most important factors affecting fish distribution in the Columbia River Estuary are the large changes in salinity levels that accompany seasonal changes in river discharge. For this reason, CREDDP investigators characterized fish assemblages for each of the three riverflow seasons of the Columbia River: fluctuating riverflow season (November through March), high riverflow season (April through June), and low riverflow season (July through October). Figure 5-15 illustrates the distribution of major fish assemblages during three months chosen to represent the three riverflow seasons: January, May, and August.

Each box in Figure 5-15 represents one fish assemblage. Some assemblages consist of just one principal species but most assemblages comprise several principal species. The range of each species may not extend throughout the entire assemblage range. The assemblages are defined in terms of their distribution between the mouth of the estuary and the upriver end of the study area, and in terms of the habitats where they are found. Five habitats are distinguished. These five habitats correspond to the three main fish habitats described at the beginning of this chapter (intertidal, demersal, and pelagic) except that the intertidal habitat is subdivided into three distinct types: tidal flats in the protected bays (protected bays), the tidal flats from Desdemona Sands to Jim Crow Sands (tidal flats), and sloping intertidal areas along the north and south shores other than the protected bays (nearshore). Some assemblages are found in a single habitat, others occupy combinations of two or three habitats.

As seasons progress through the year, the number of species in the estuary increases and the composition and distribution of fish assemblages becomes more complex (Figure 5-15). Some species and assemblages appear consistently throughout the year despite seasonal changes in river discharge and salinity. During the 1980-81 fish survey, American shad and surf smelt, for example, were always found in a pelagic assemblage abundant in the middle to lower estuary. Pacific tomcod, English sole, and snake prickleback were among demersal fishes in the middle to lower estuary much of the year. During the low riverflow season, shiner perch, Pacific staghorn sculpin, and starry founder were part of a demersal assemblage abundant in the lower and middle estuary and in protected habitats of Baker Bay and Youngs Bay. During the high riverflow season, juvenile salmonids migrating through the estuary comprised a distinct pelagic and nearshore assemblage found throughout the estuary. The greatest diversity of salmonids occurred during this period.

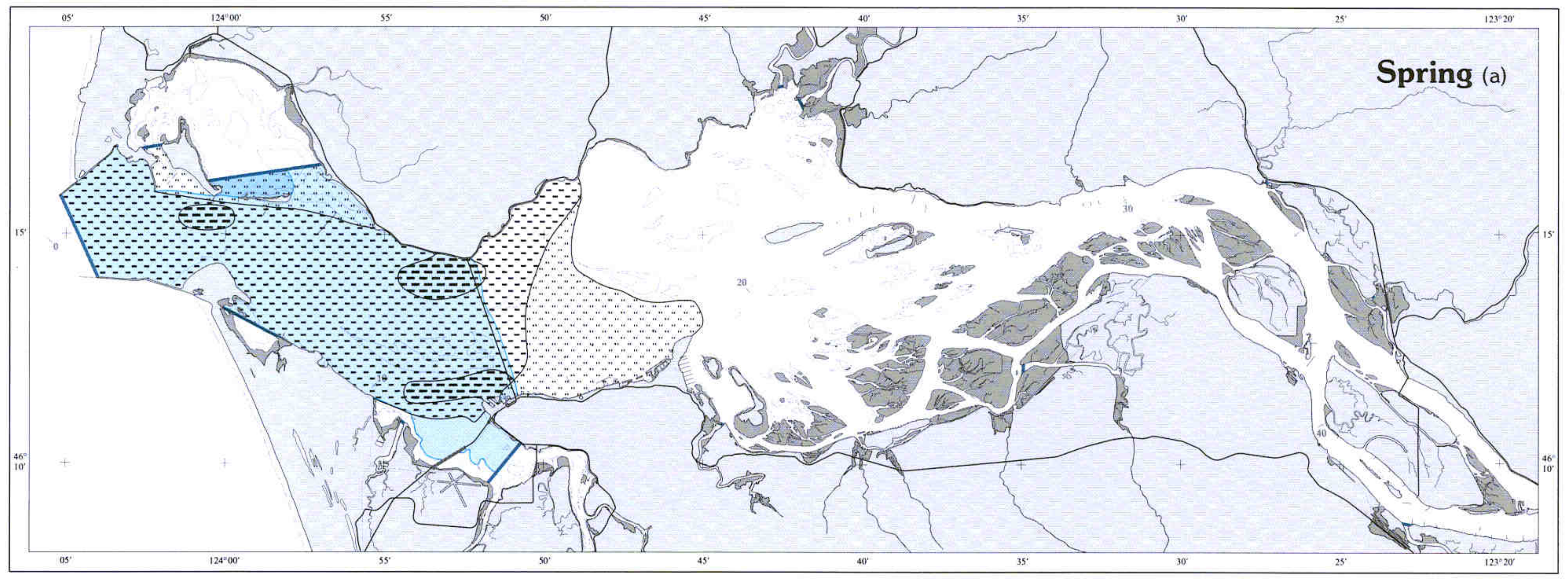


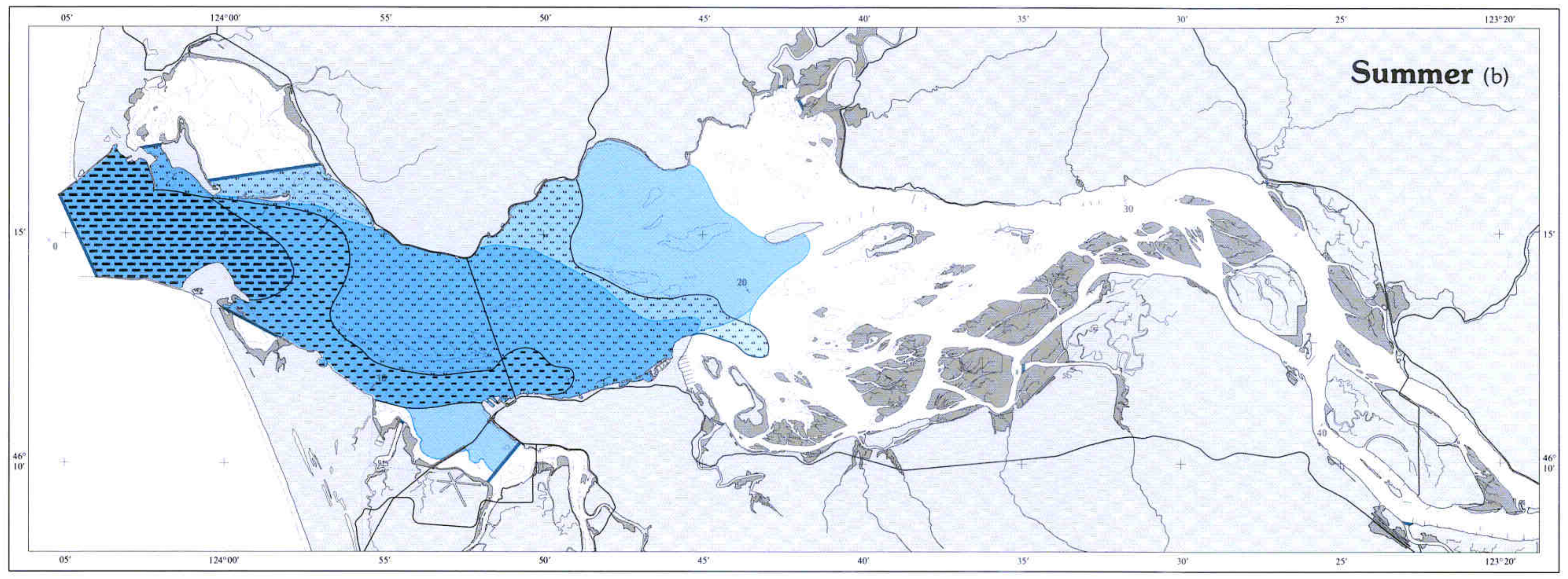
*Age classes for all species except starry flounder, American shad, chinook and coho salmon are: (0), less than one year old; and (1), one year and older. For starry flounder, American shad, chinook and coho salmon the age classes are: (0), less than one year old; (1), one to two years old; and (2), two years and older.

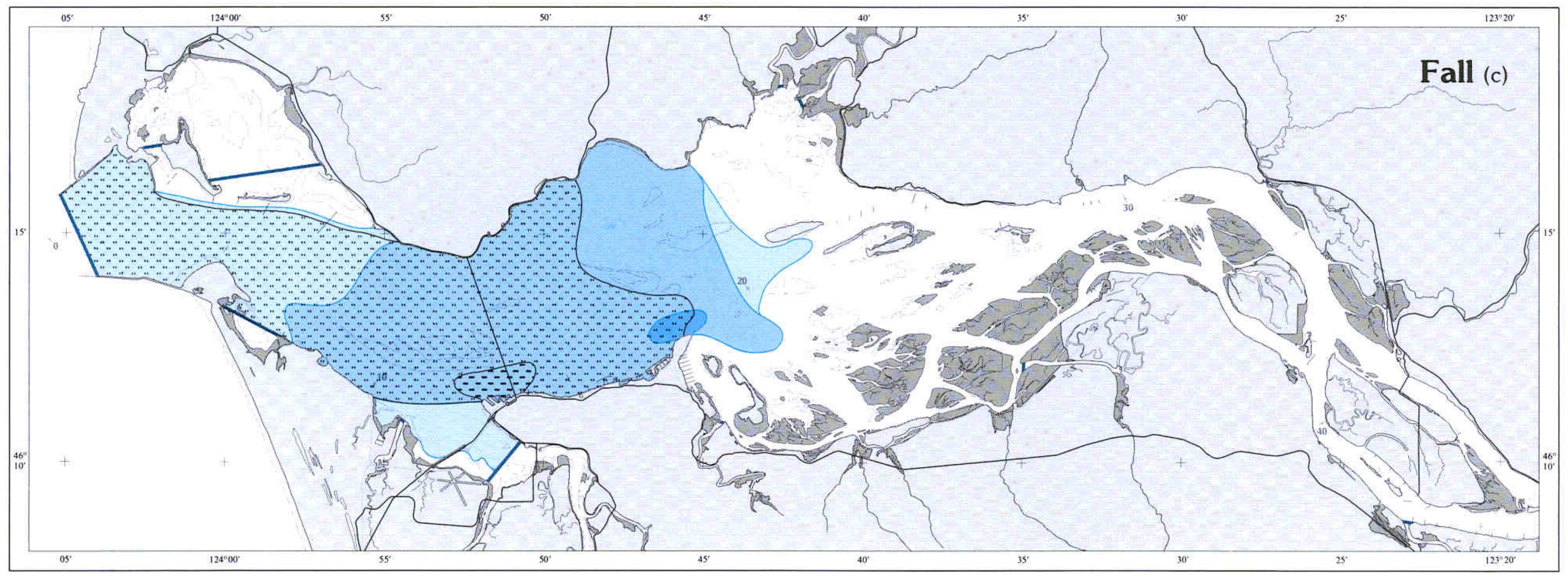
Figure 5-15. Generalized composition and distribution of major fish assemblages found in the Columbia River Estuary during the three riverflow seasons (Bottom et al. 1984).

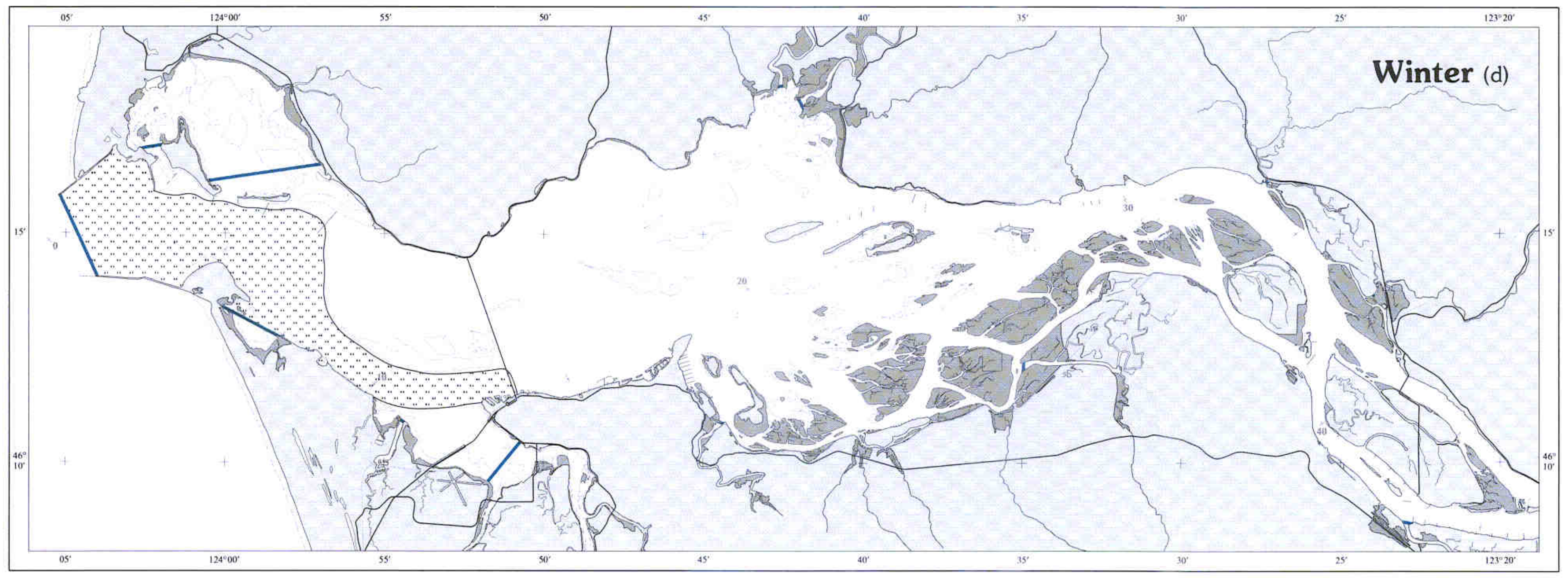
Pacific Herring

(Clupea harengus pallasi)









Relative abundance

Less than one year old

- high
- medium
- low

One year and older

- high
- medium
- low

— limits of data

Fish abundance information is based on 1980-1981 sampling supported by CREDDP and the National Marine Fisheries Service/ Northwest and Alaska Fisheries Center (NMFS-NWAFC). Maps were compiled in 1983 by George McCabe, NMFS-NWAFC (CREDDP fish investigator).

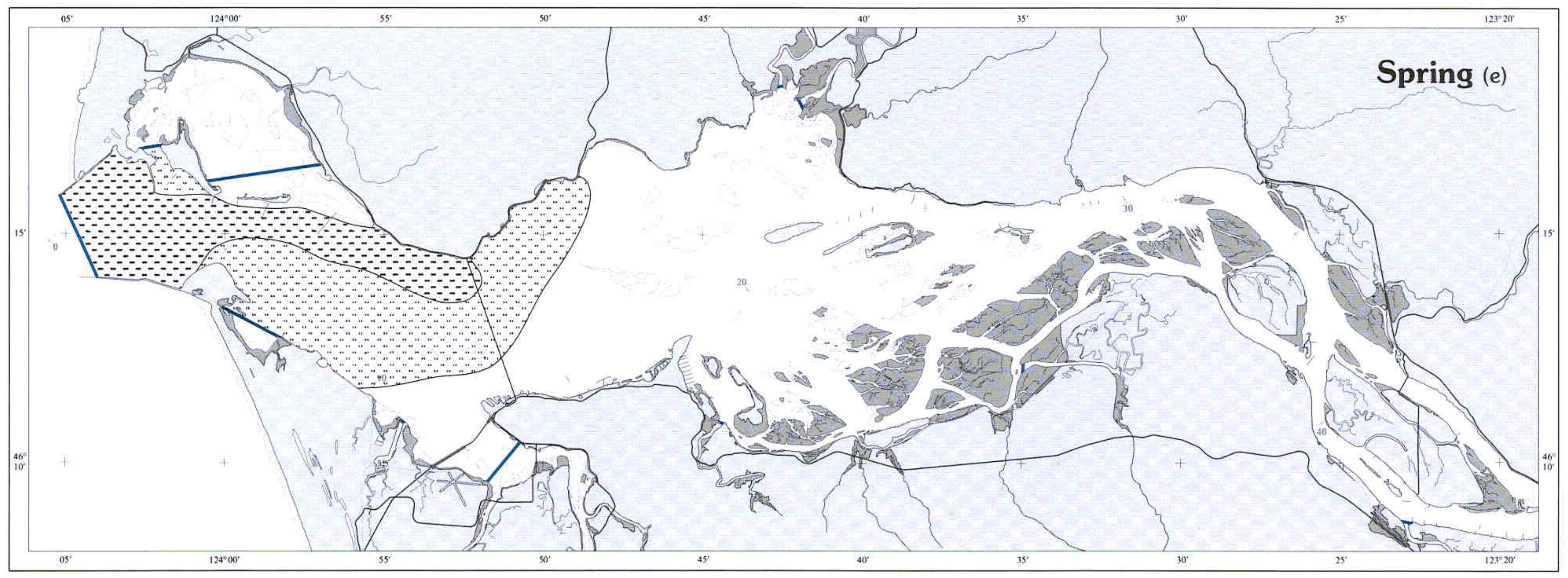
Scale 1:250,000

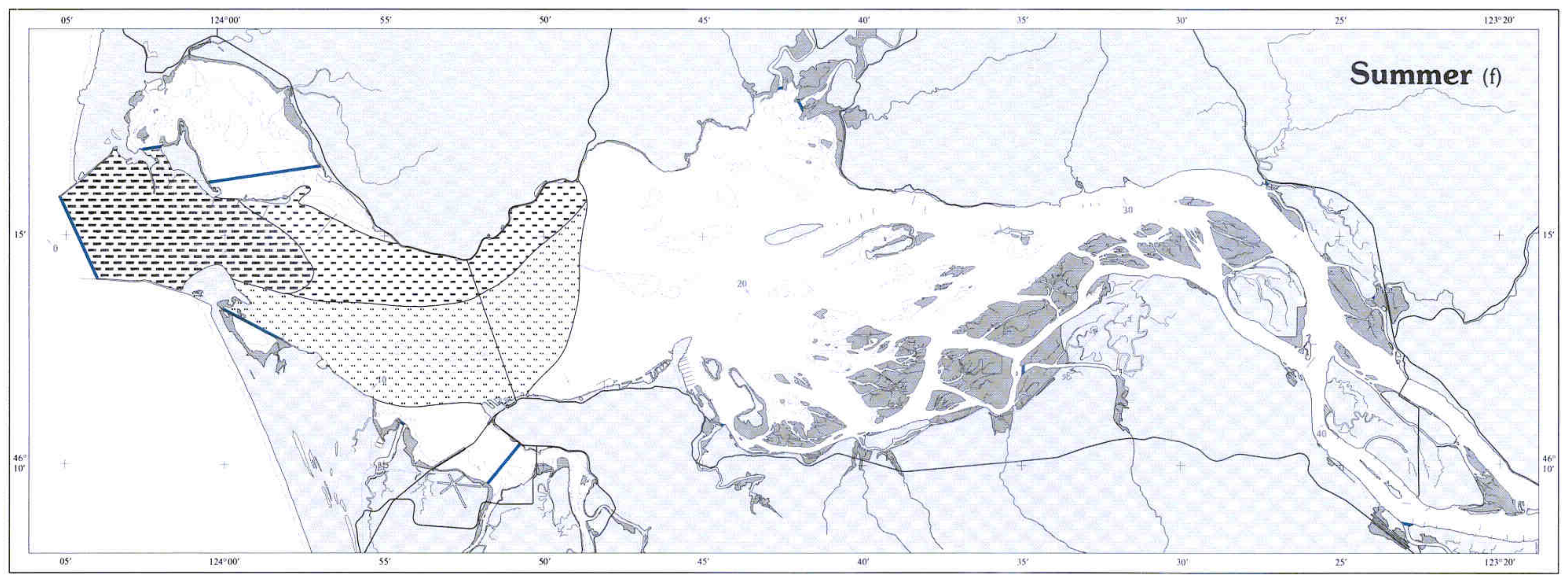
0 2 4 6 8 10 Kilometers

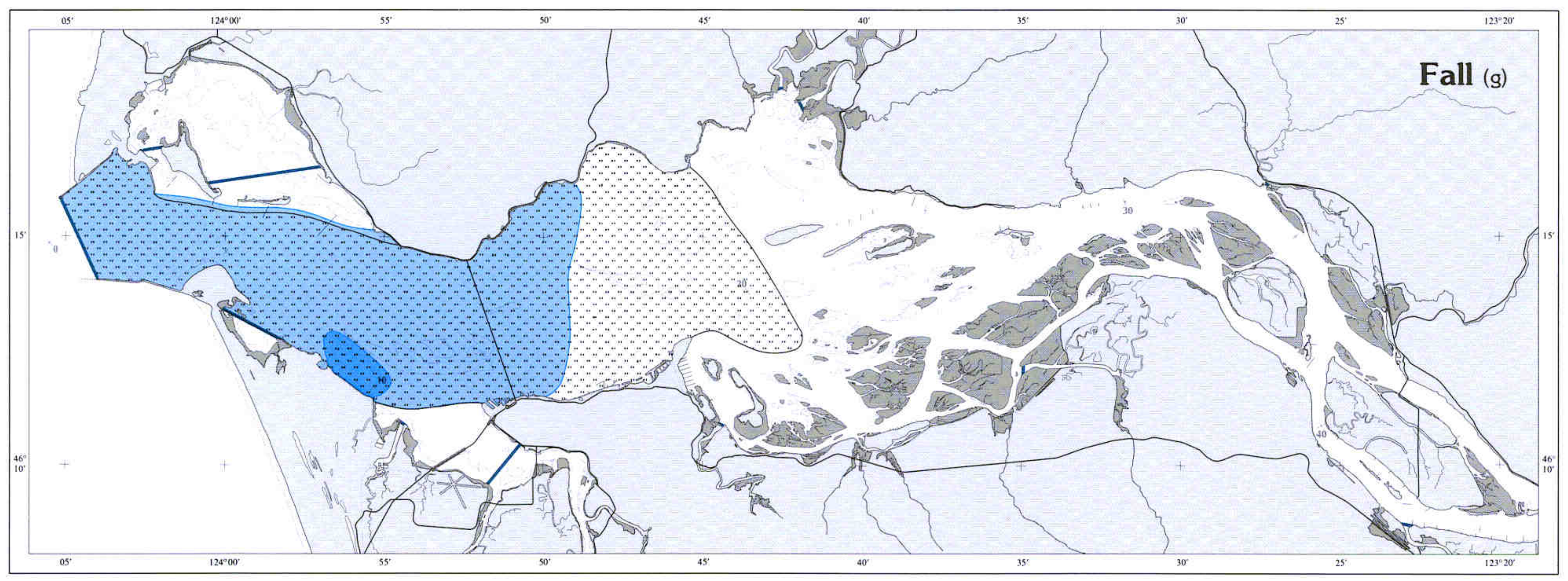
0 1 2 3 4 5 6 Miles

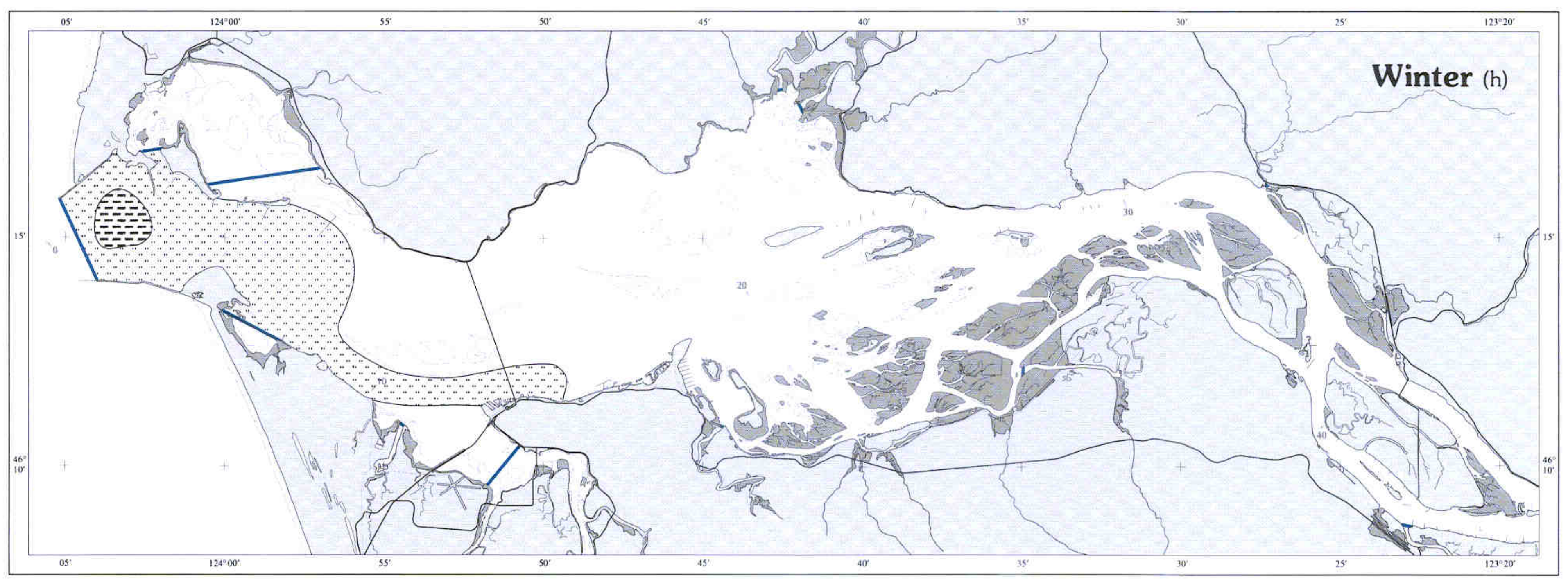
Northern Anchovy

(Engraulis mordax)









Relative abundance

Less than one year old

- high
- medium

One year and older

- high
- medium
- low

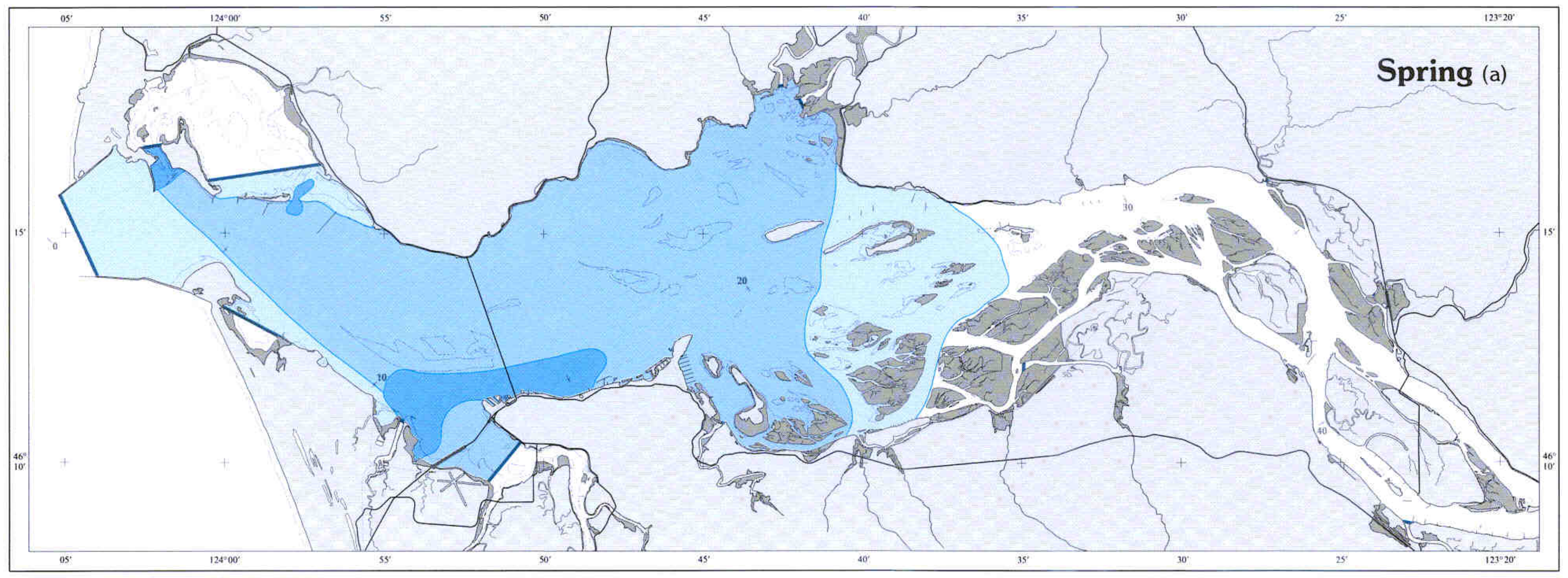
— limits of data

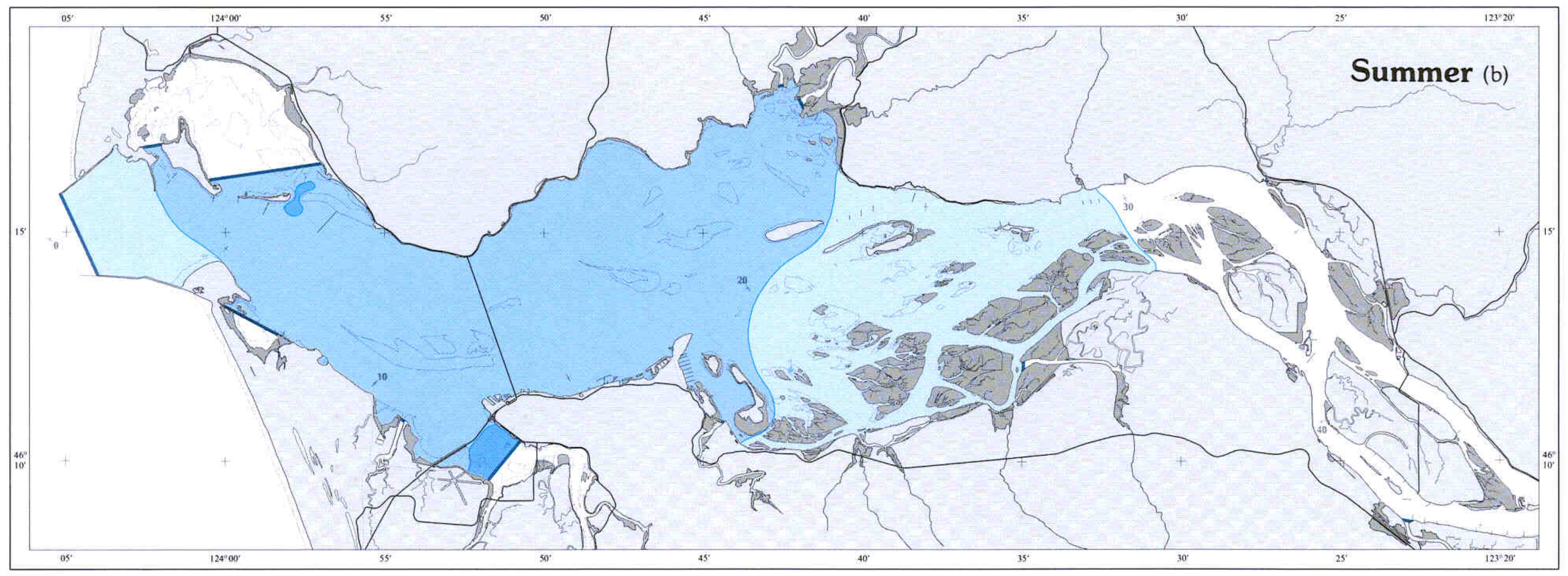
Fish abundance information is based on 1980-1981 sampling supported by CREDDP and the National Marine Fisheries Service/ Northwest and Alaska Fisheries Center (NMFS-NWAFC). Maps were compiled in 1983 by George McCabe, NMFS-NWAFC (CREDDP fish investigator).

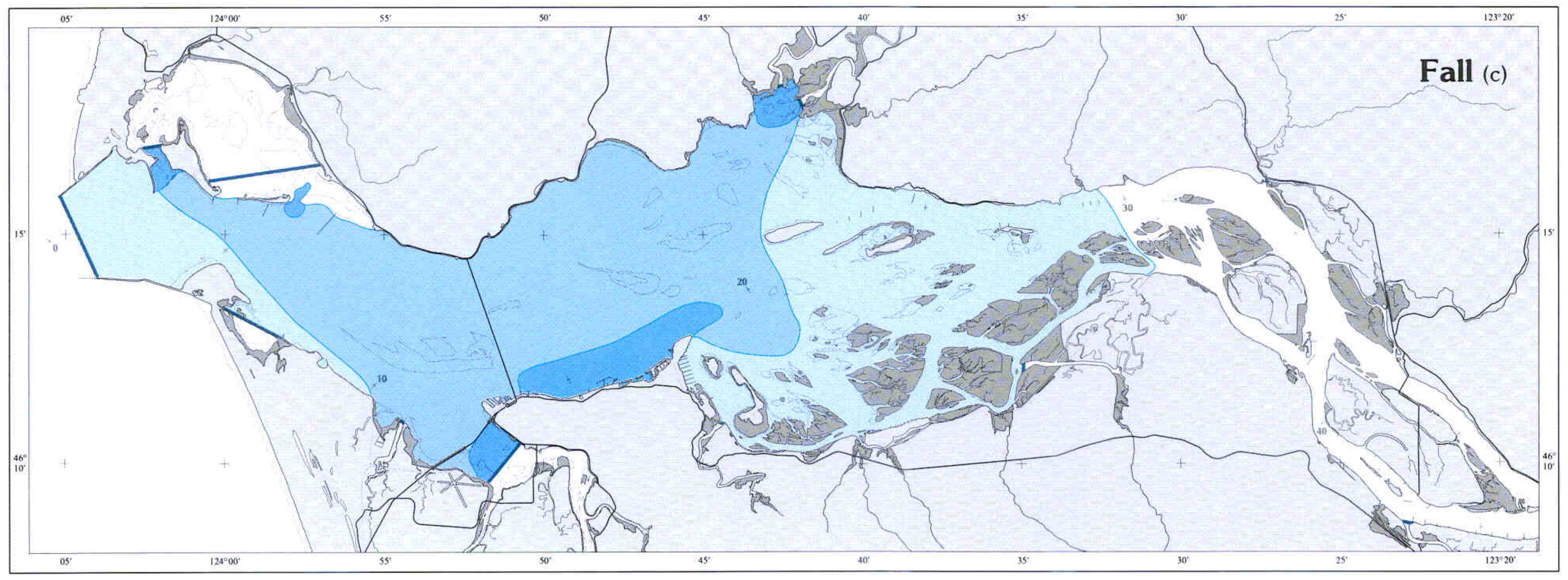
Scale 1:250,000

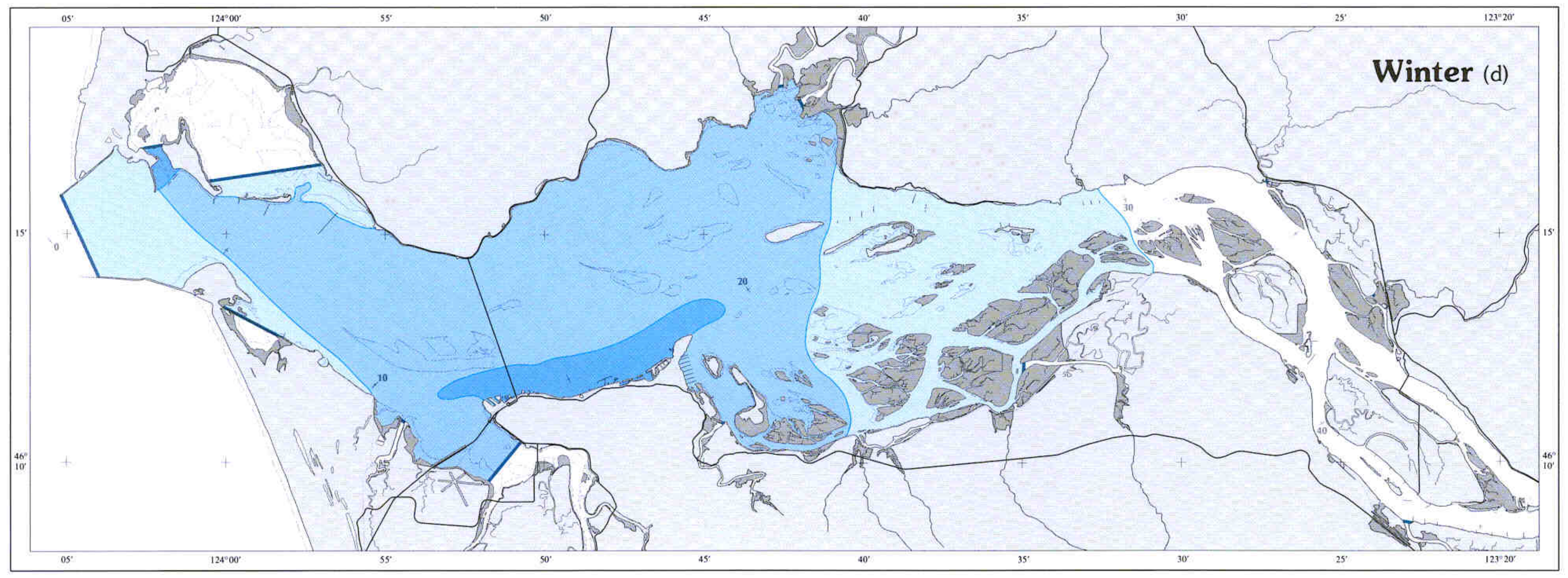
0 2 4 6 8 10 Kilometers

0 1 2 3 4 5 6 Miles









Pacific Staghorn Sculpin

(Leptocottus armatus)

Relative abundance

All ages combined

- high
- medium
- low

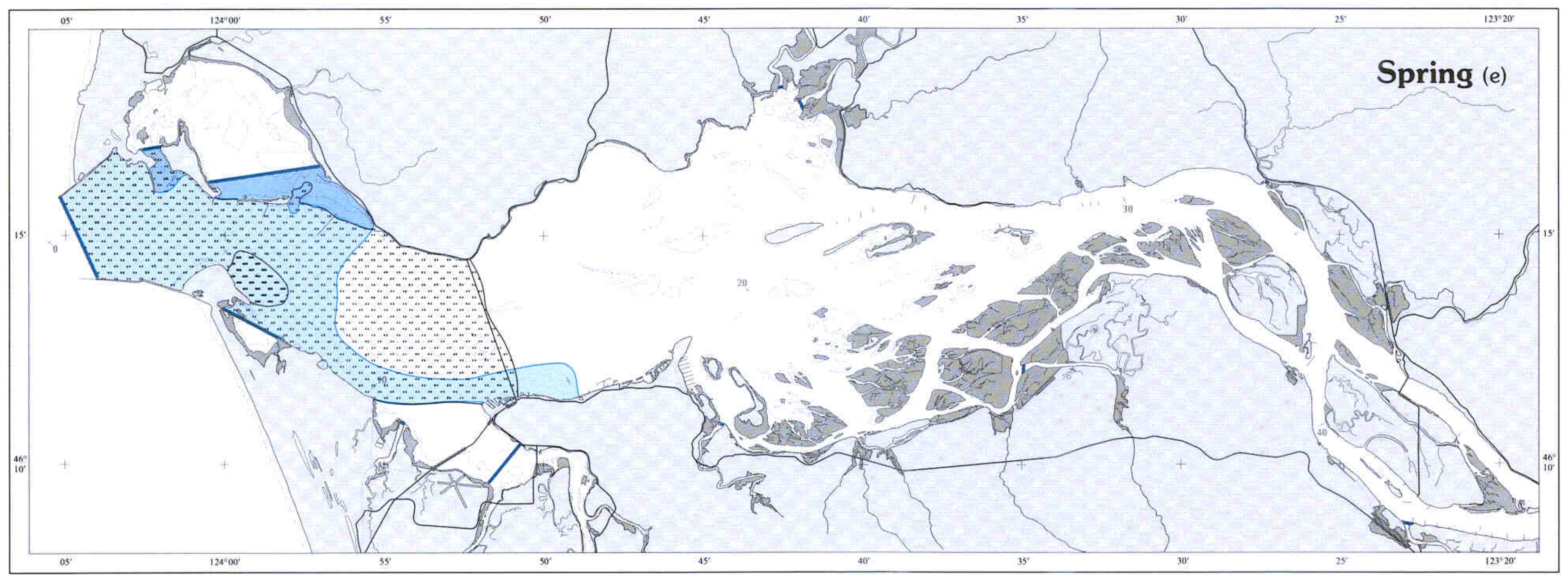
— limits of data

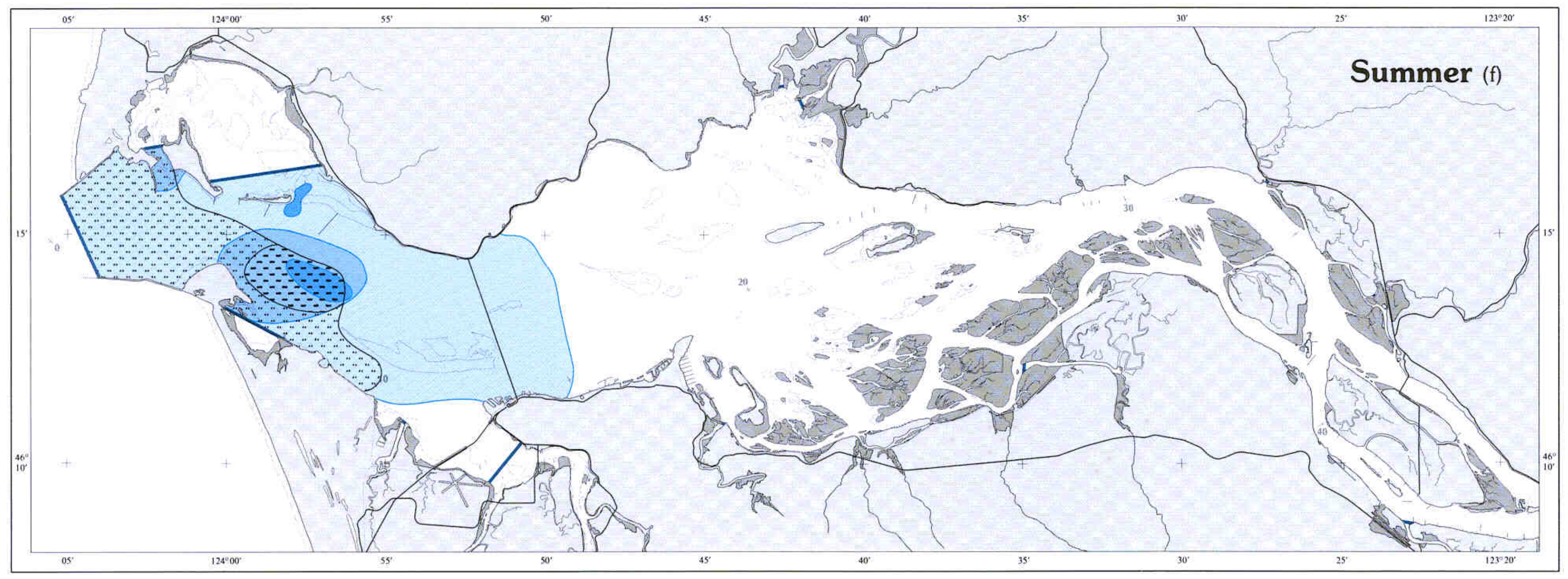
Fish abundance information is based on 1980-1981 sampling supported by CREDDP and the National Marine Fisheries Service/ Northwest and Alaska Fisheries Center (NMFS-NWAFC). Maps were compiled in 1983 by George McCabe, NMFS-NWAFC (CREDDP fish investigator).

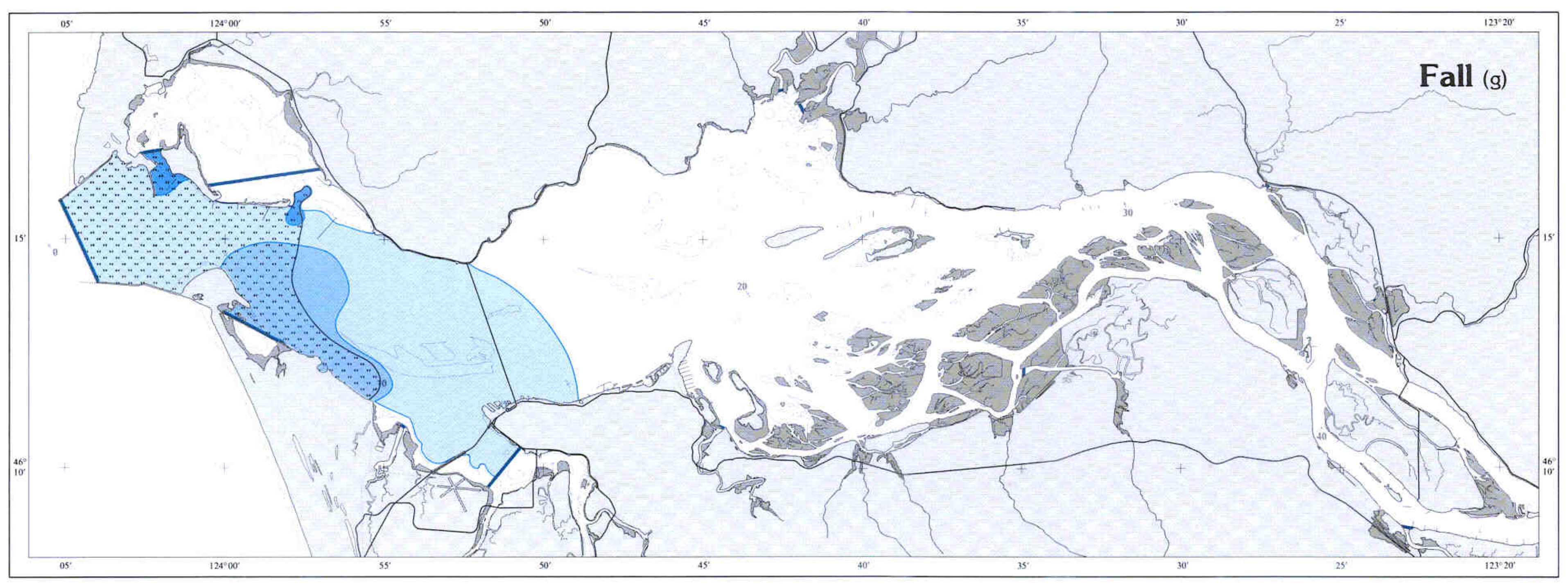
Scale 1:250,000

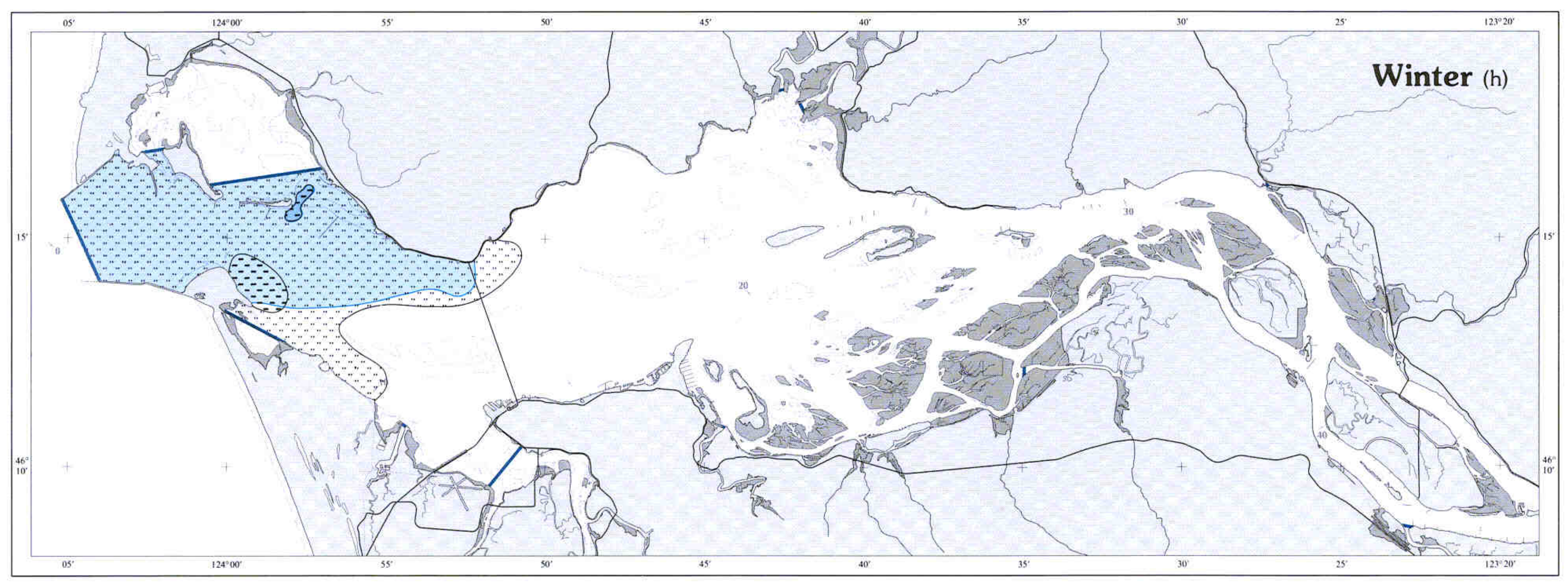
0 2 4 6 8 10 Kilometers

0 1 2 3 4 5 6 Miles









English Sole

(Parophrys vetulus)

Relative abundance

Less than one year old

- high
- medium
- low

One year and older

- medium
- low

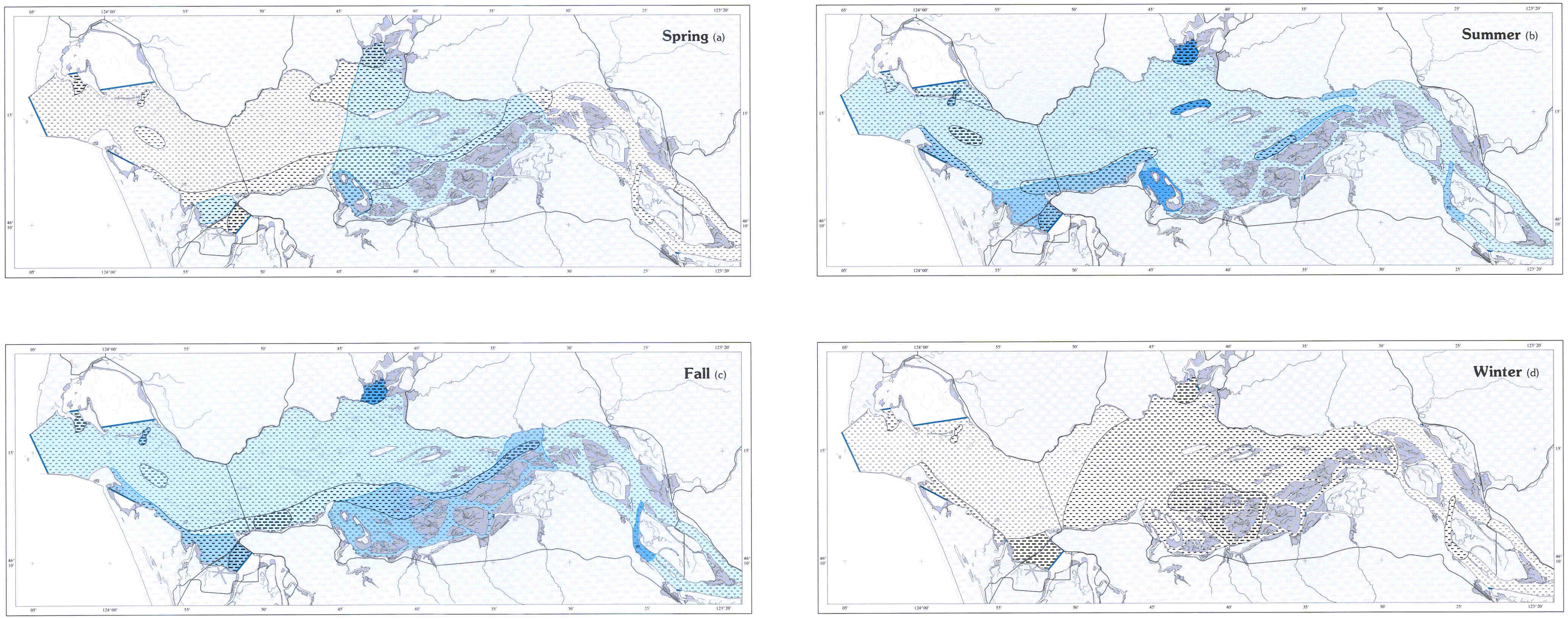
— limits of data

Fish abundance information is based on 1980-1981 sampling supported by CREDDP and the National Marine Fisheries Service/ Northwest and Alaska Fisheries Center (NMFS-NWAFC). Maps were compiled in 1983 by George McCabe, NMFS-NWAFC (CREDDP fish investigator).

Scale 1:250,000

0 2 4 6 8 10 Kilometers

0 1 2 3 4 5 6 Miles



Starry Flounder

(Platichthys stellatus)

Relative abundance

Less than one year old

- high
- medium
- low

One to two years old

- high
- medium
- low

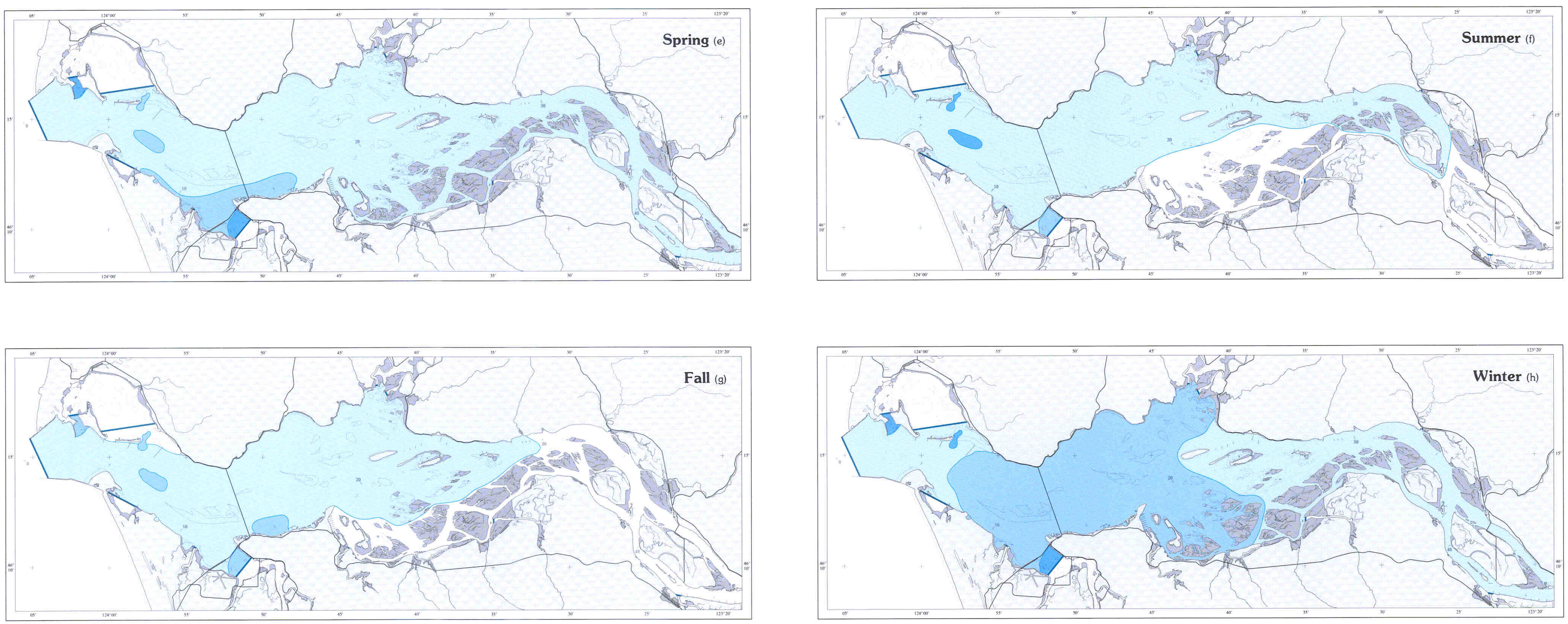
limits of data

Fish abundance information is based on 1980-1981 sampling supported by CREDDP and the National Marine Fisheries Service/Northwest and Alaska Fisheries Center (NMFS-NWAFC). Maps were compiled in 1983 by George McCabe, NMFS-NWAFC (CREDDP fish investigator).

Scale 1:250,000

0 2 4 6 8 10 Kilometers

0 1 2 3 4 5 6 Miles



Starry Flounder

(Platichthys stellatus)

Relative abundance

Two years and older

- high
- medium
- low

limits of data

Fish abundance information is based on 1980-1981 sampling supported by CREDDP and the National Marine Fisheries Service/Northwest and Alaska Fisheries Center (NMFS-NWAFC). Maps were compiled in 1983 by George McCabe, NMFS-NWAFC (CREDDP fish investigator).

Scale 1:250,000

0 2 4 6 8 10 Kilometers

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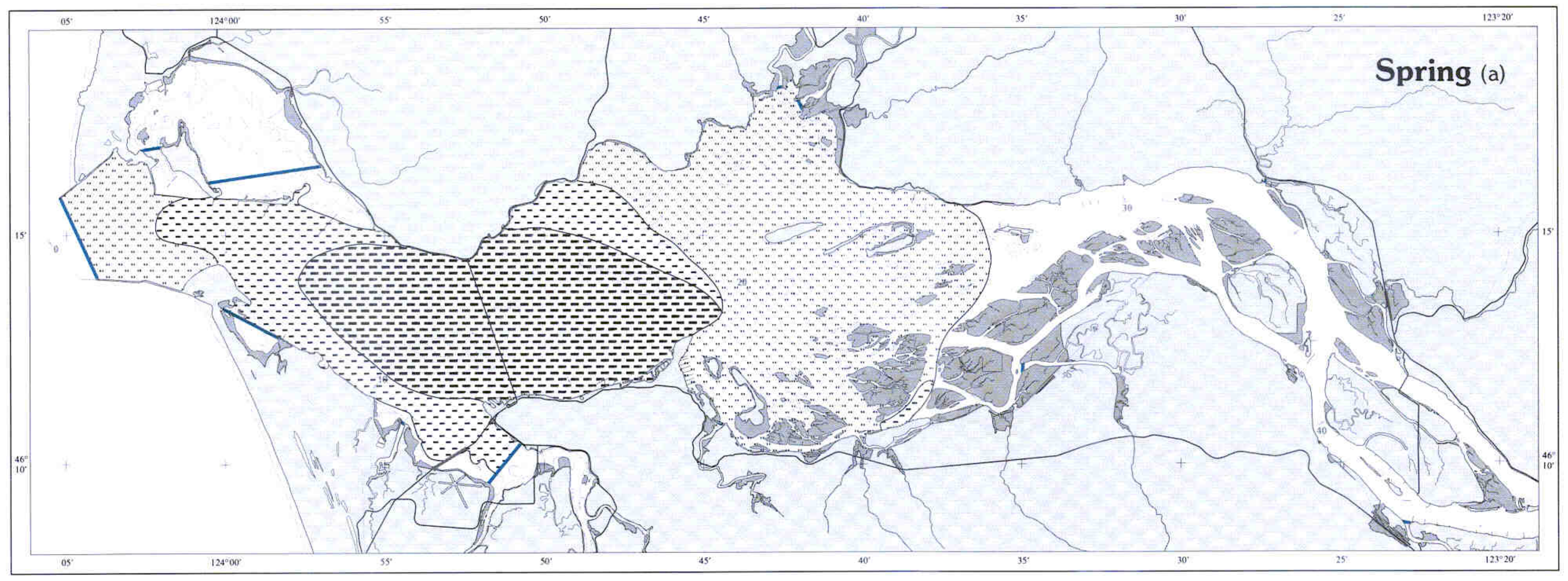
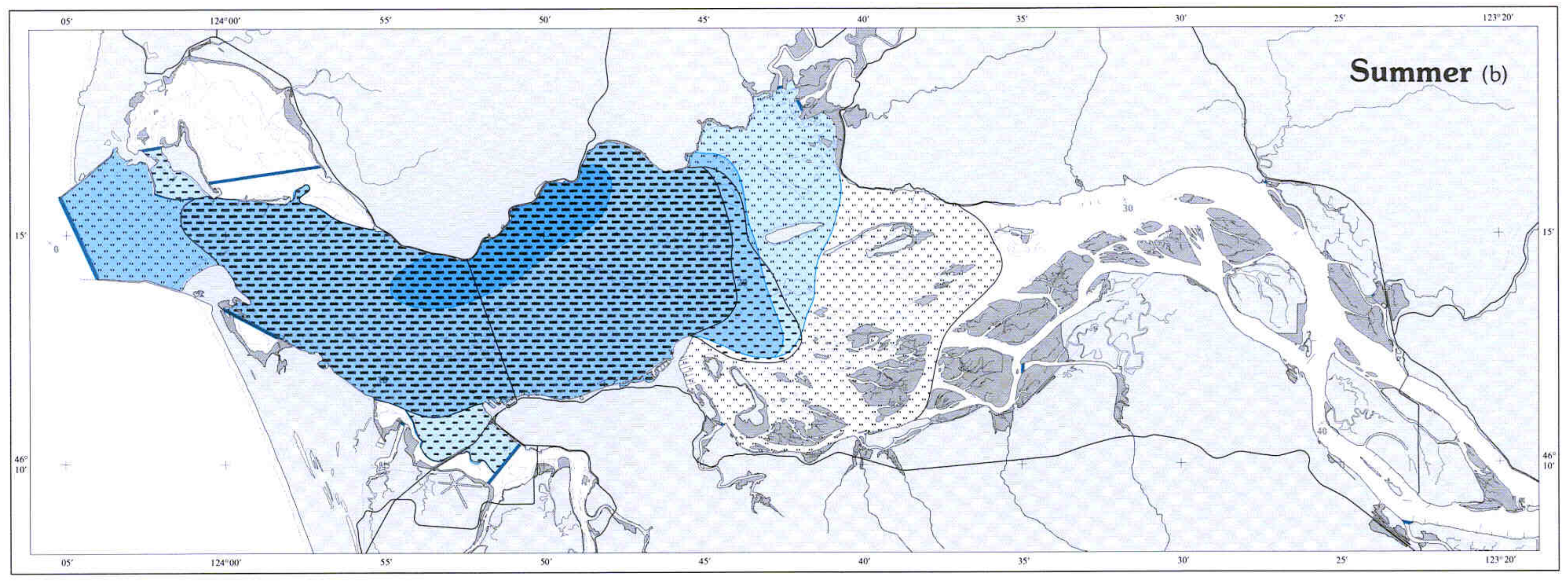
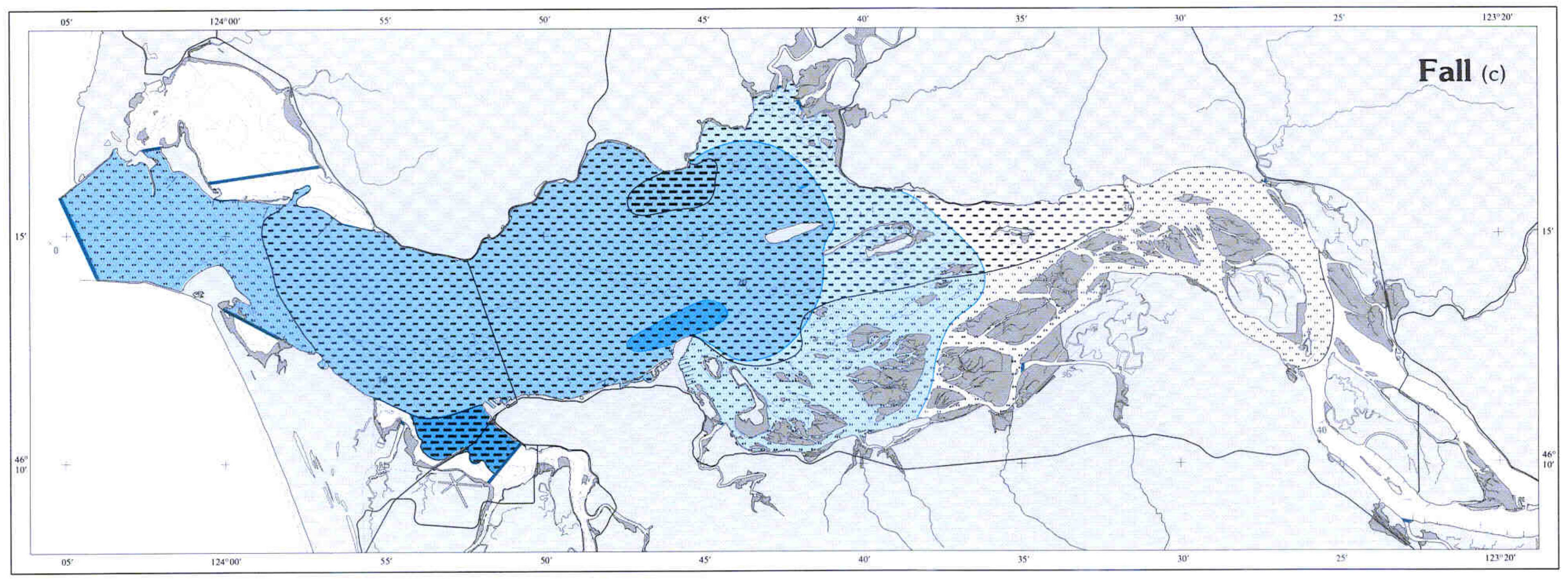
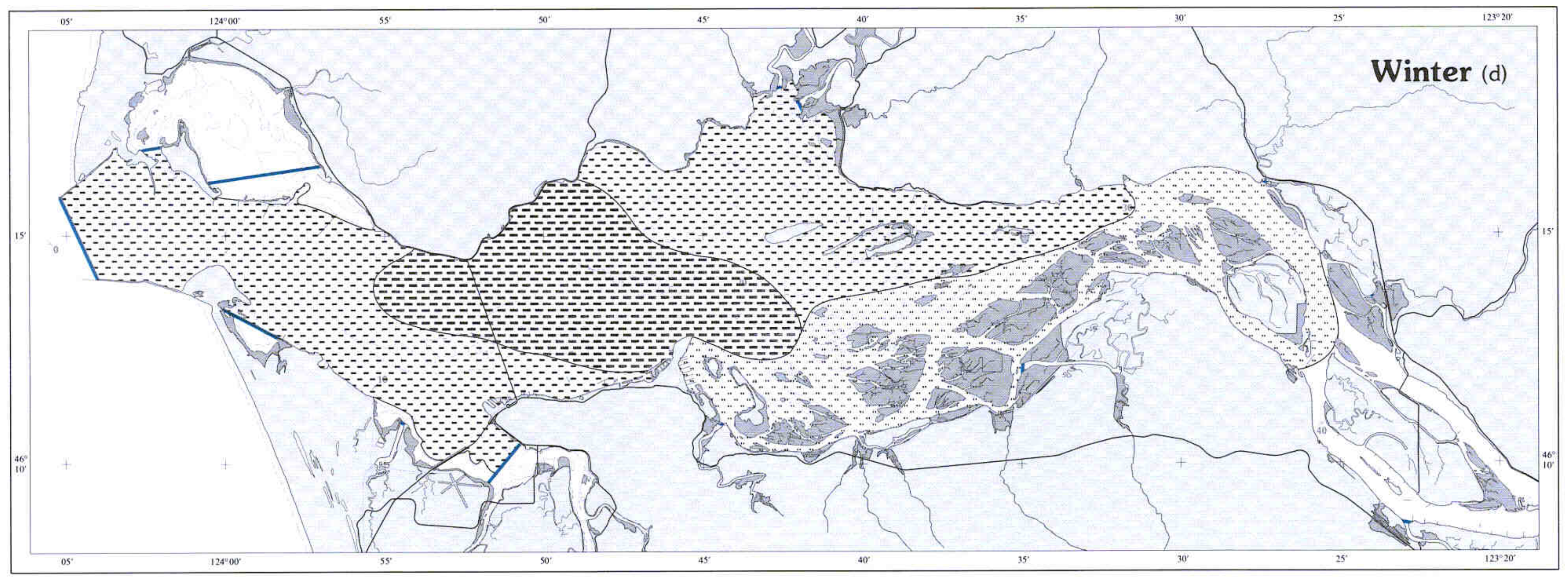








Longfin Smelt

(Spirinchus thaleichthys)

Relative abundance

Less than one year old

- high
- medium
- low

One year and older

- high
- medium
- low

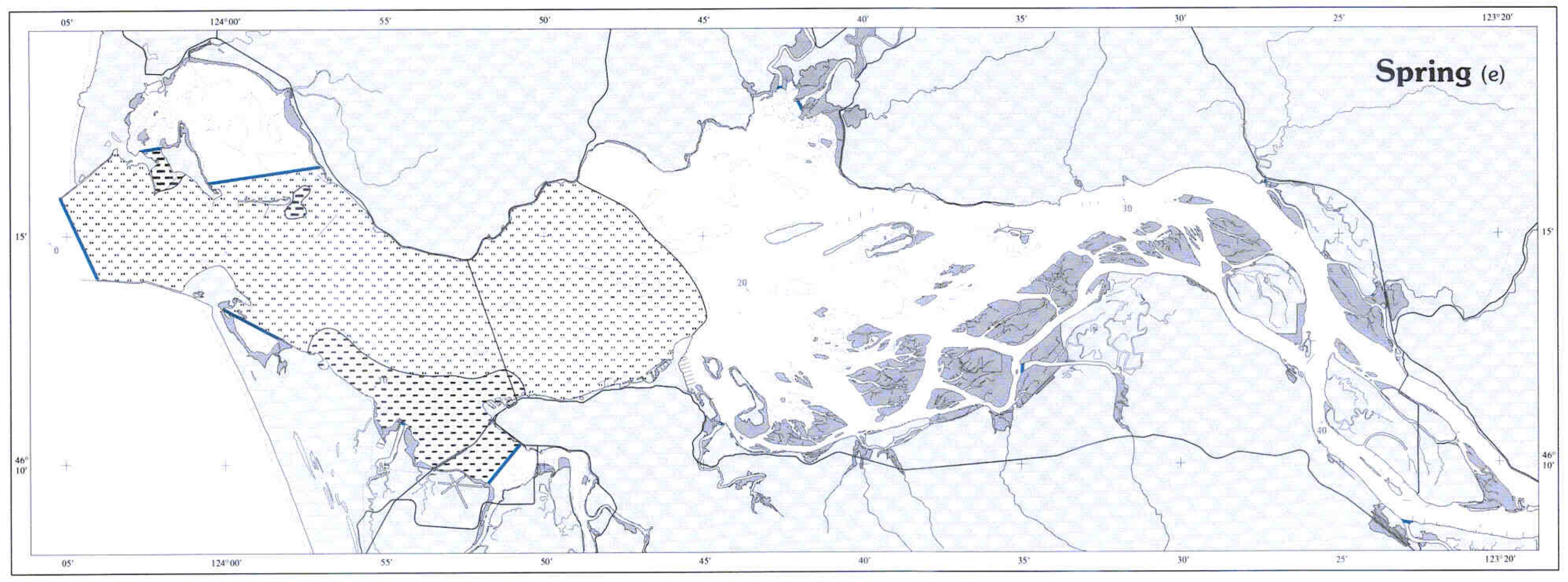
limits of data

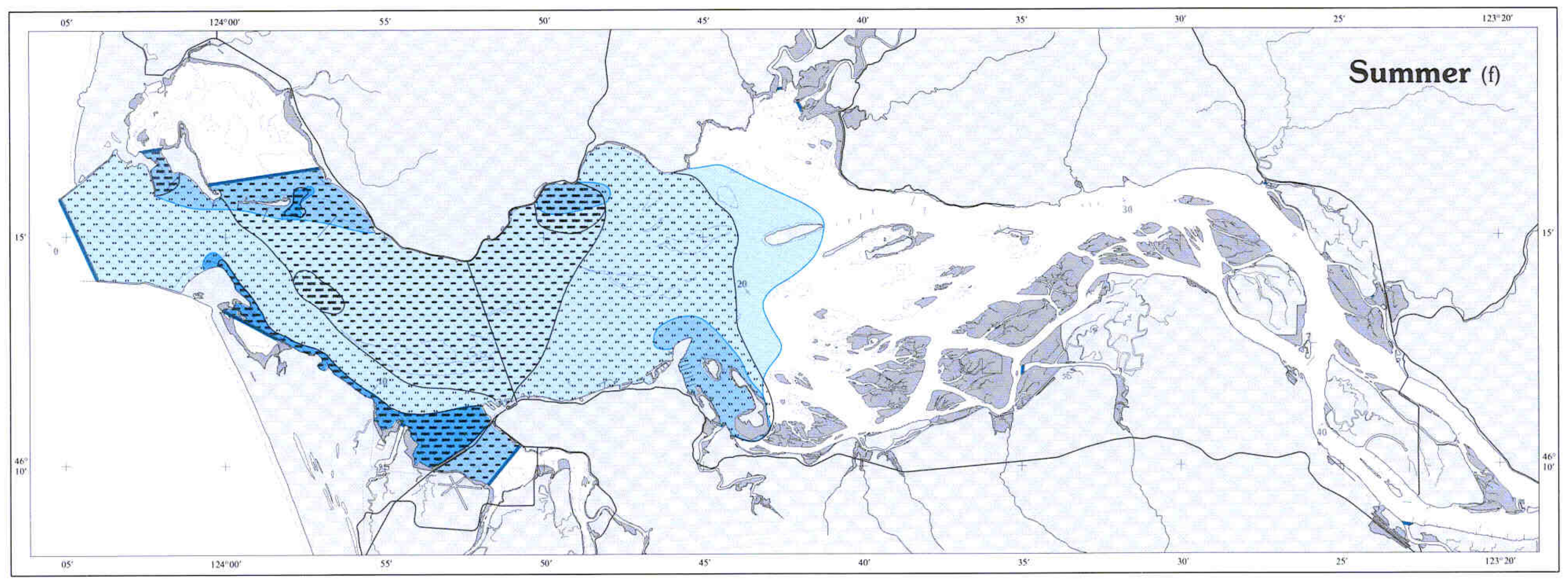
Fish abundance information is based on 1980-1981 sampling supported by CREDDP and the National Marine Fisheries Service/ Northwest and Alaska Fisheries Center (NMFS-NWAFC). Maps were compiled in 1983 by George McCabe, NMFS-NWAFC (CREDDP fish investigator).

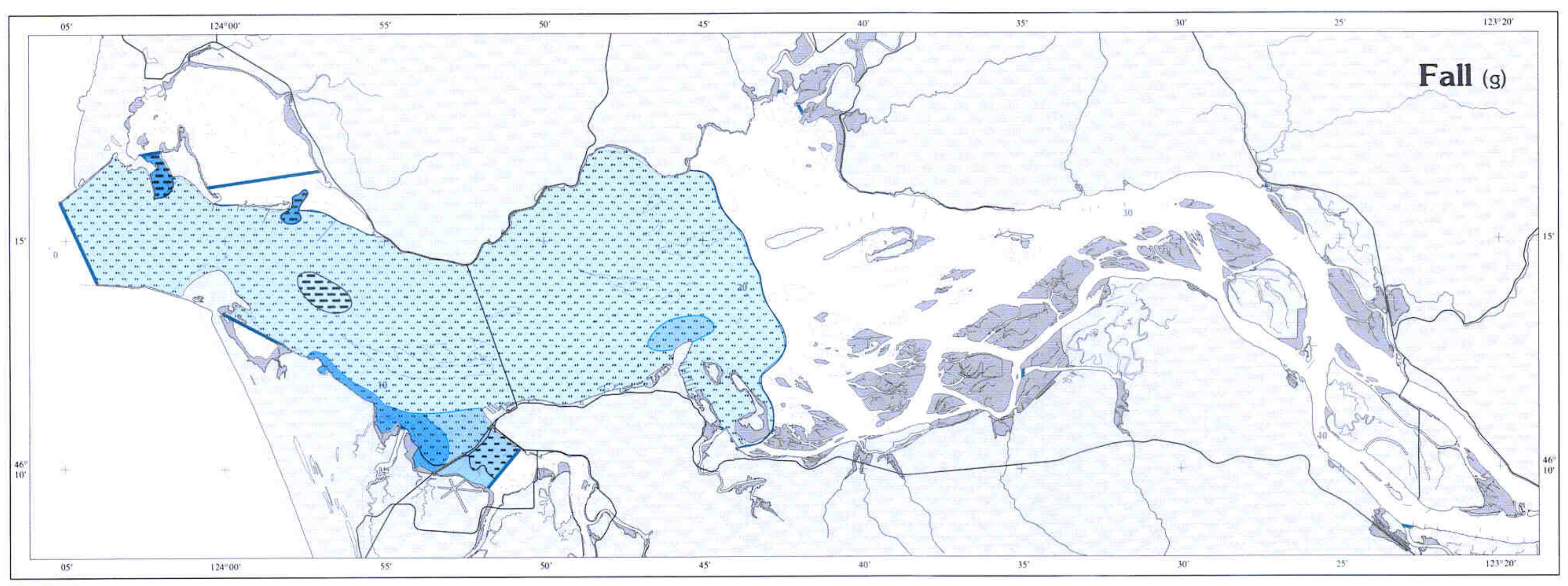
Scale 1:250,000

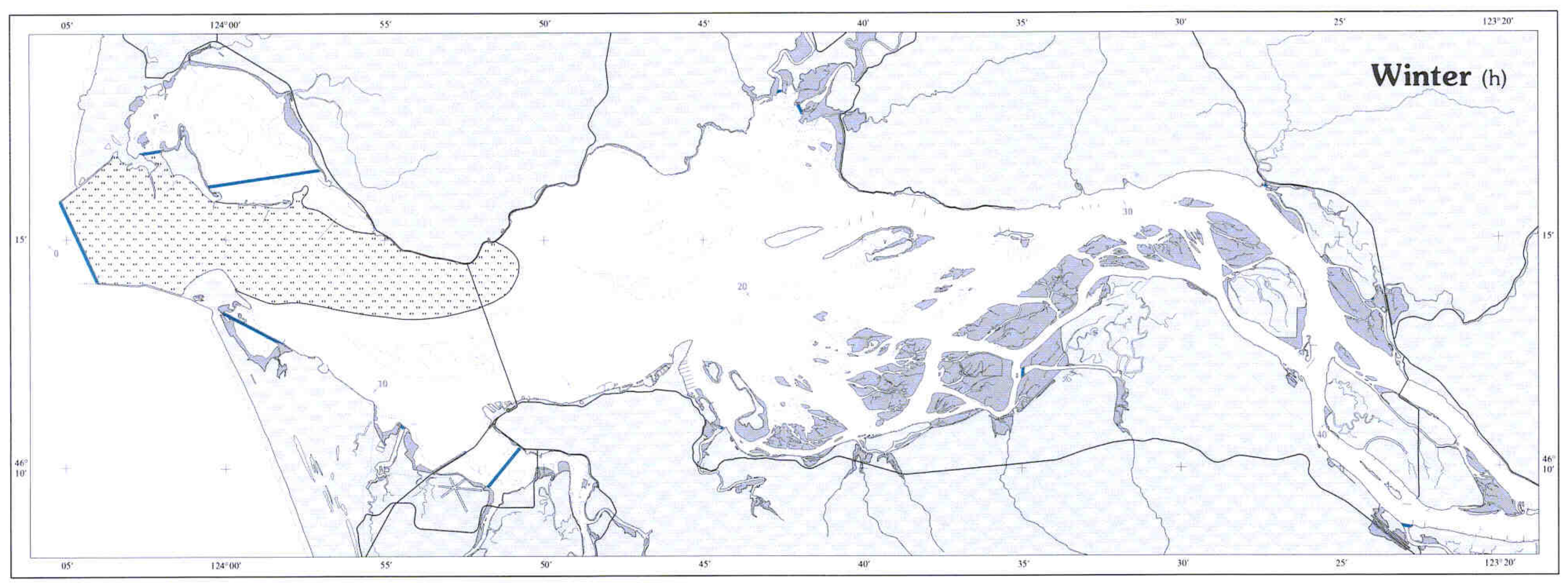
0 2 4 6 8 10 Kilometers

0 1 2 3 4 5 6 Miles









Shiner Perch

(Cymatogaster aggregata)

Relative abundance

Less than one year old

- high
- medium
- low

One year and older

- high
- medium
- low

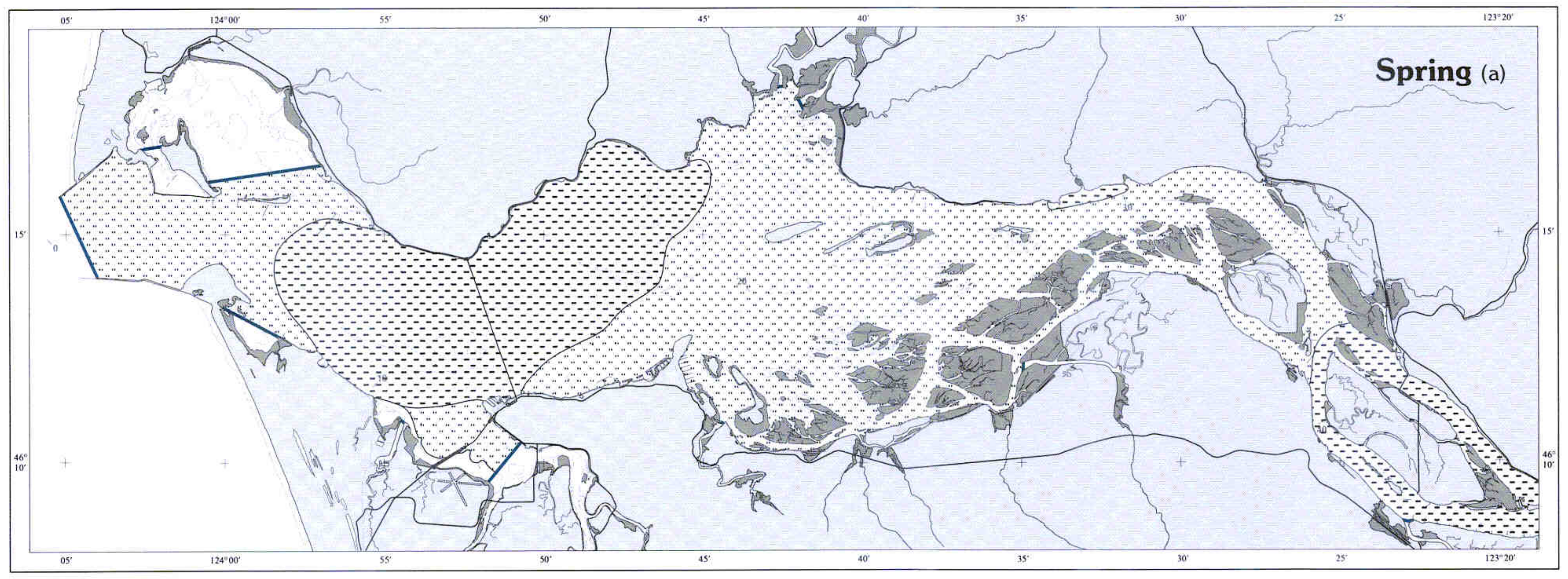
limits of data

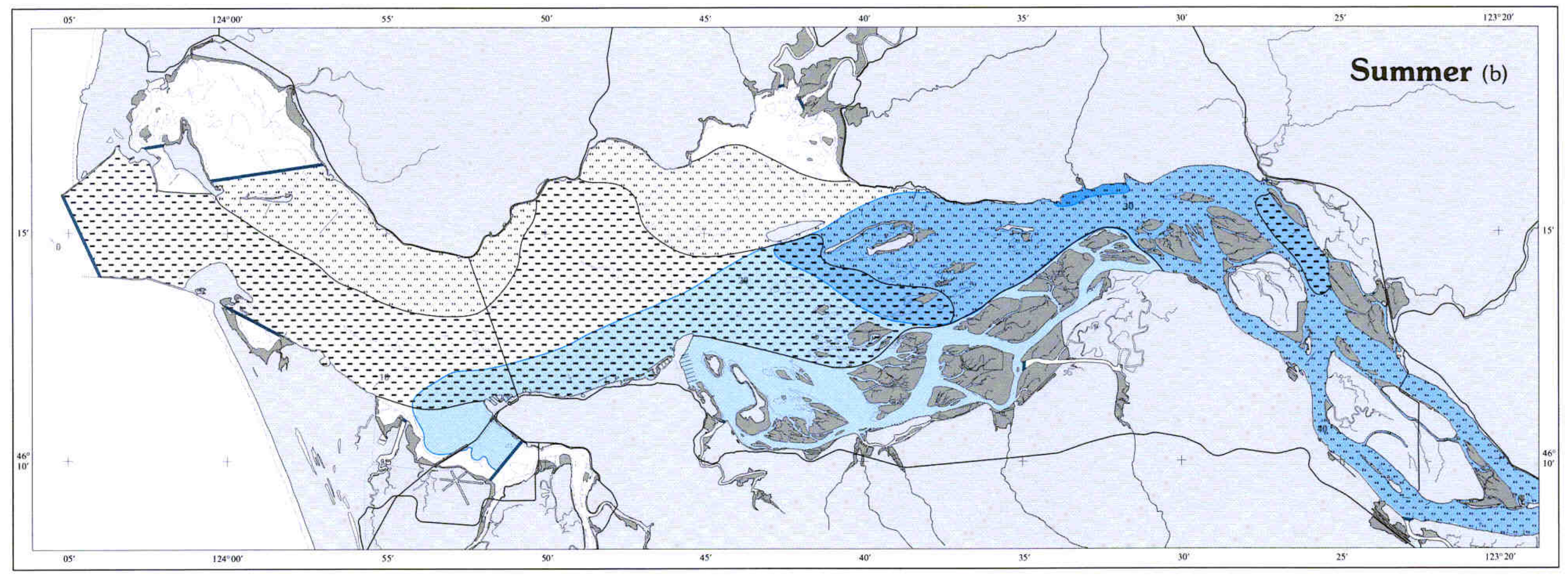
Fish abundance information is based on 1980-1981 sampling supported by CREDDP and the National Marine Fisheries Service/ Northwest and Alaska Fisheries Center (NMFS-NWAFC). Maps were compiled in 1983 by George McCabe, NMFS-NWAFC (CREDDP fish investigator).

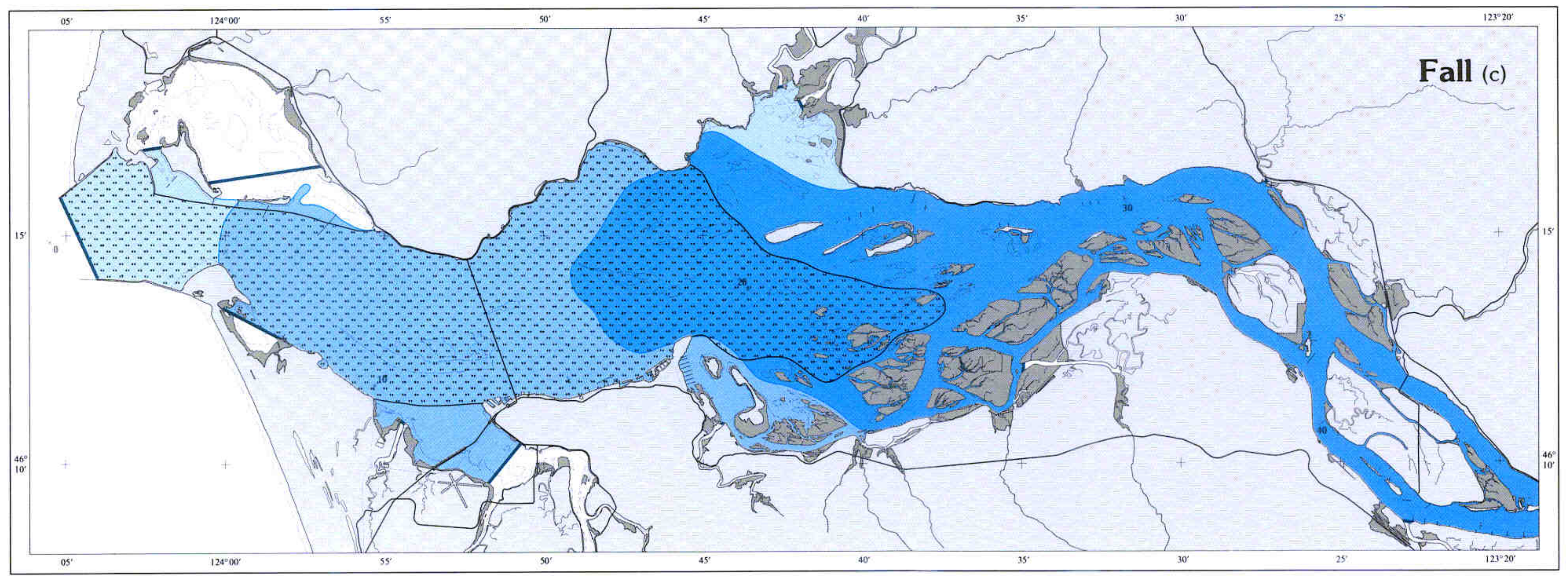
Scale 1:250,000

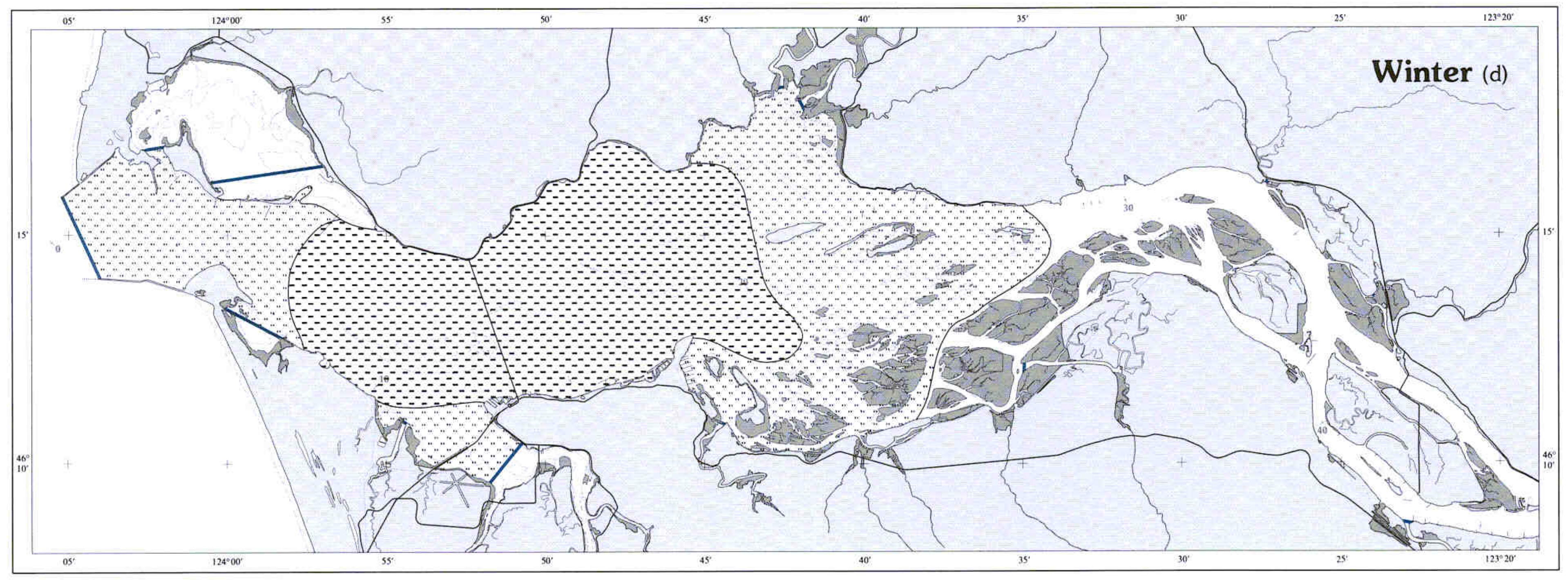
0 2 4 6 8 10 Kilometers

0 1 2 3 4 5 6 Miles









American Shad

(Alosa sapidissima)

Relative abundance

Less than one year old

- high
- medium
- low

One to two years old

- medium
- low

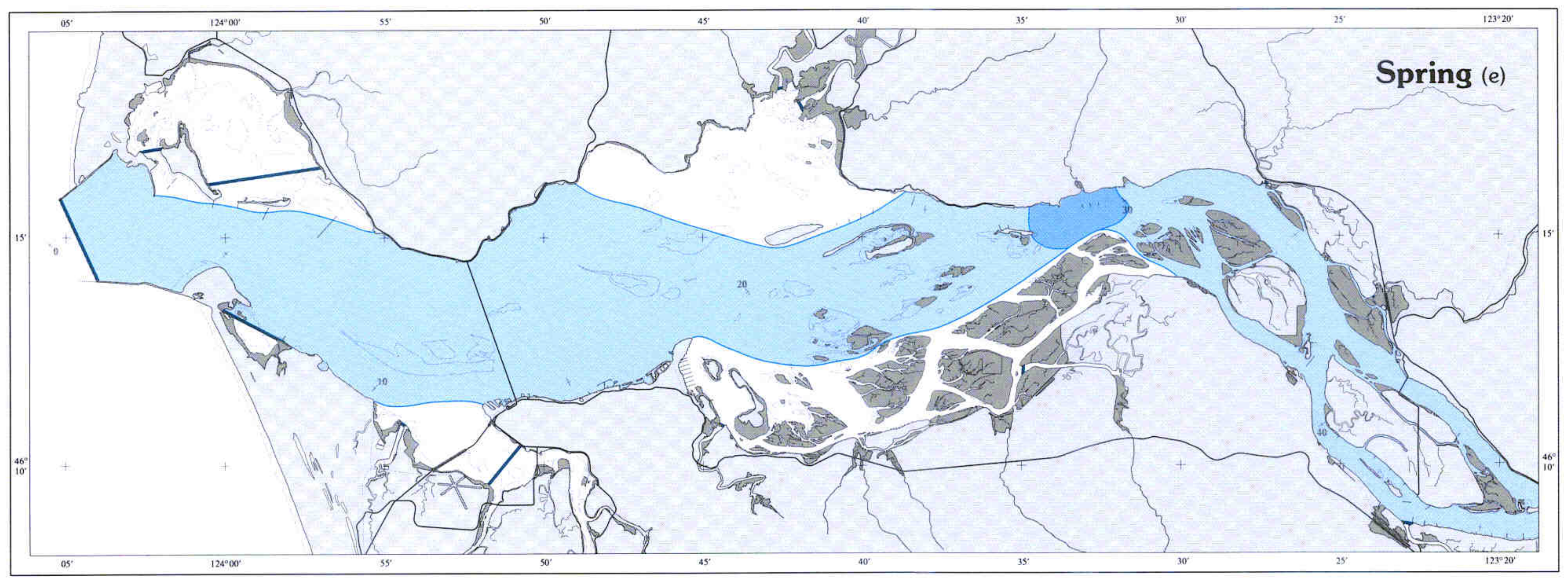
— limits of data

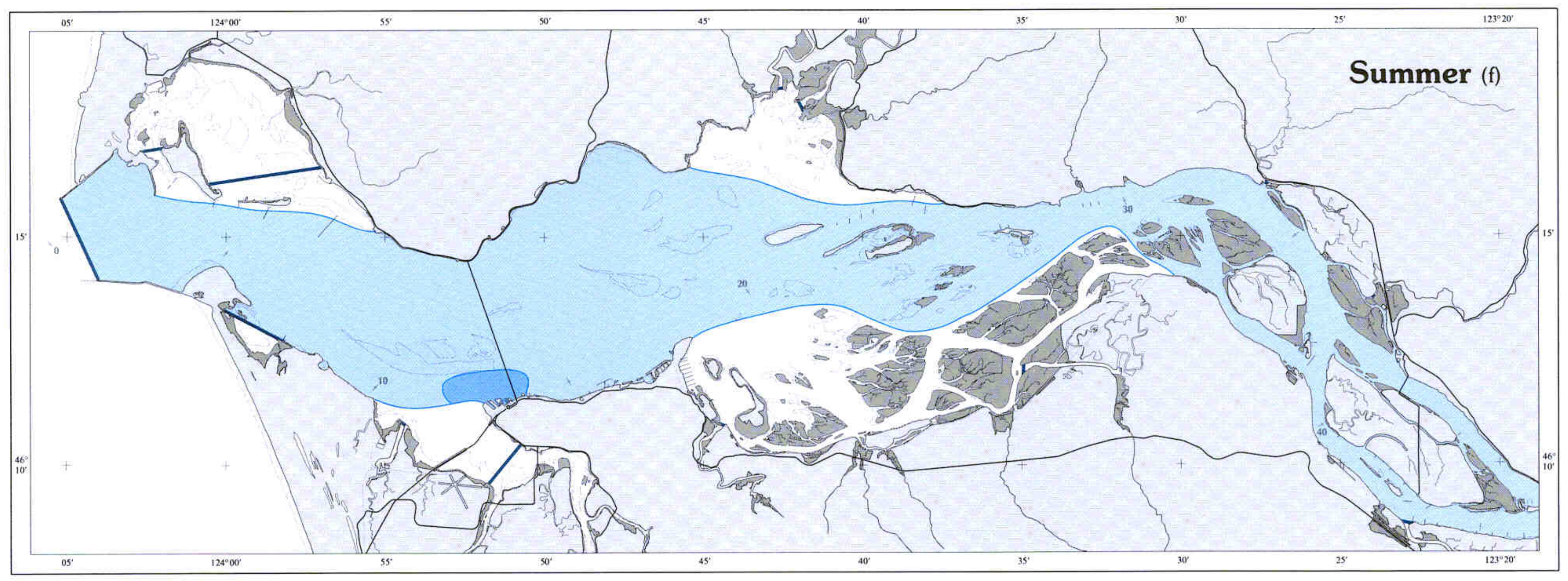
Fish abundance information is based on 1980-1981 sampling supported by CREDDP and the National Marine Fisheries Service/ Northwest and Alaska Fisheries Center (NMFS-NWAFC). Maps were compiled in 1983 by George McCabe, NMFS-NWAFC (CREDDP fish investigator).

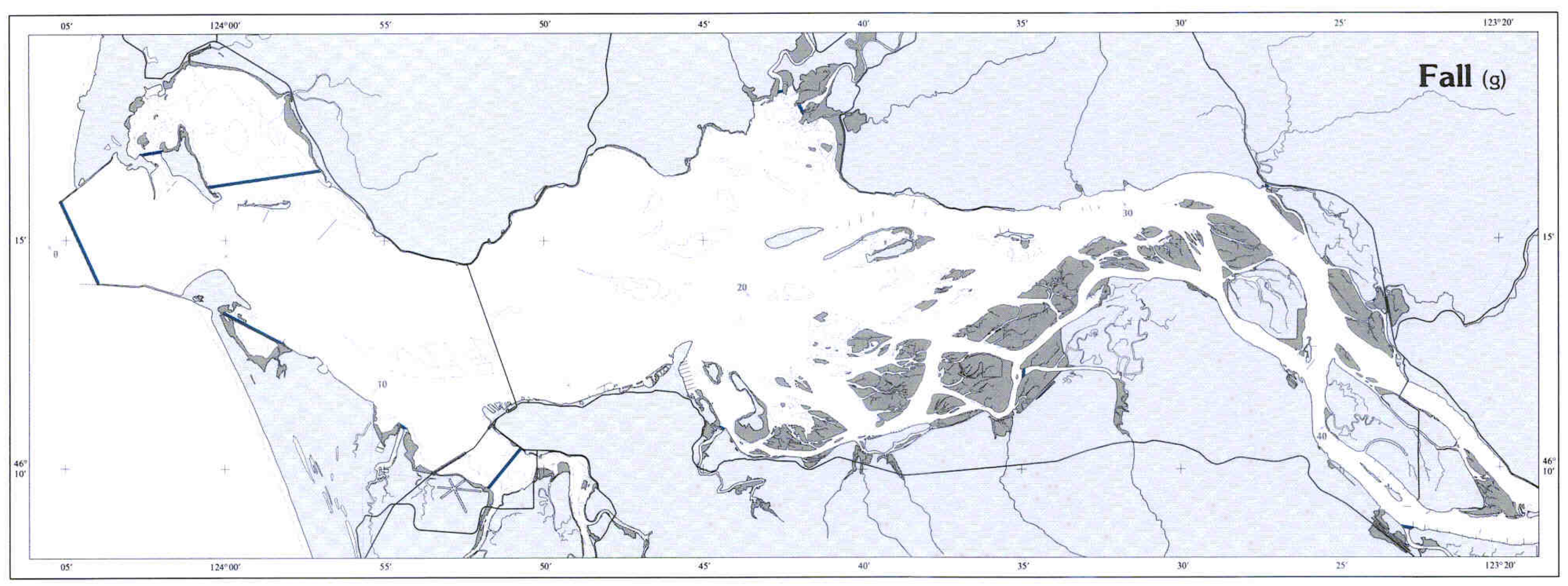
Scale 1:250,000

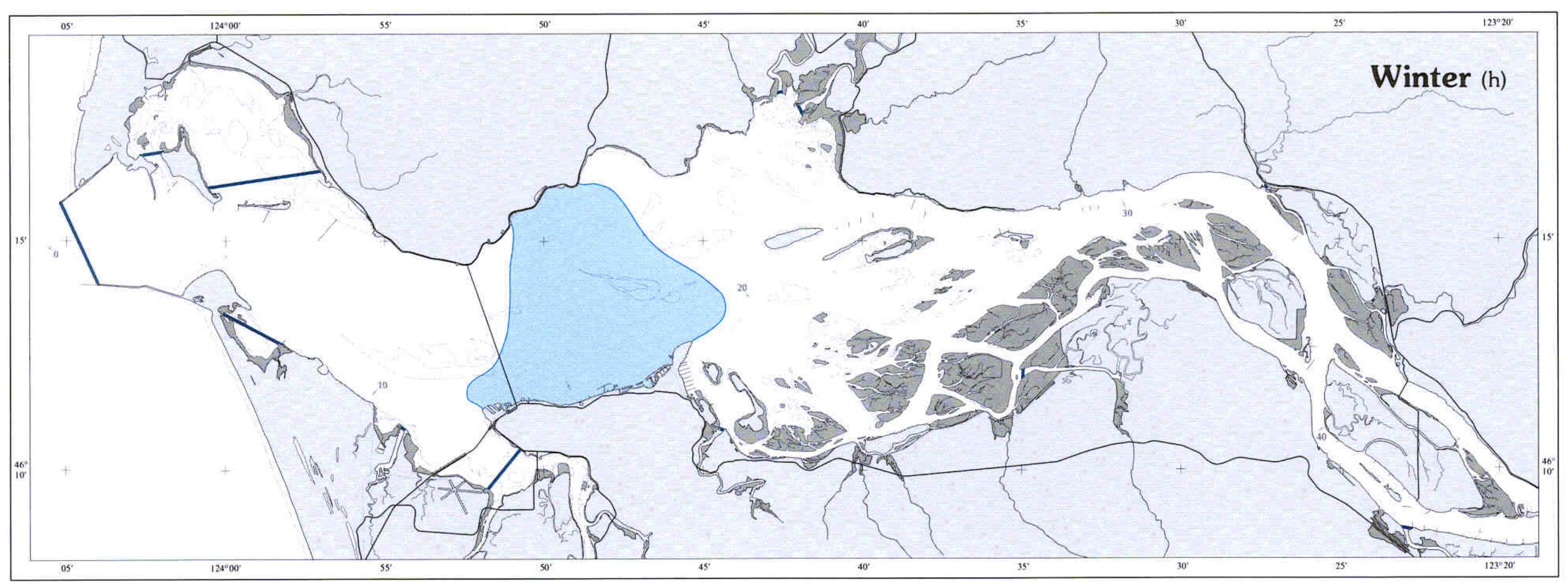
0 2 4 6 8 10 Kilometers

0 1 2 3 4 5 6 Miles









American Shad

(Alosa sapidissima)

Relative abundance

Two years and older

- medium
- low

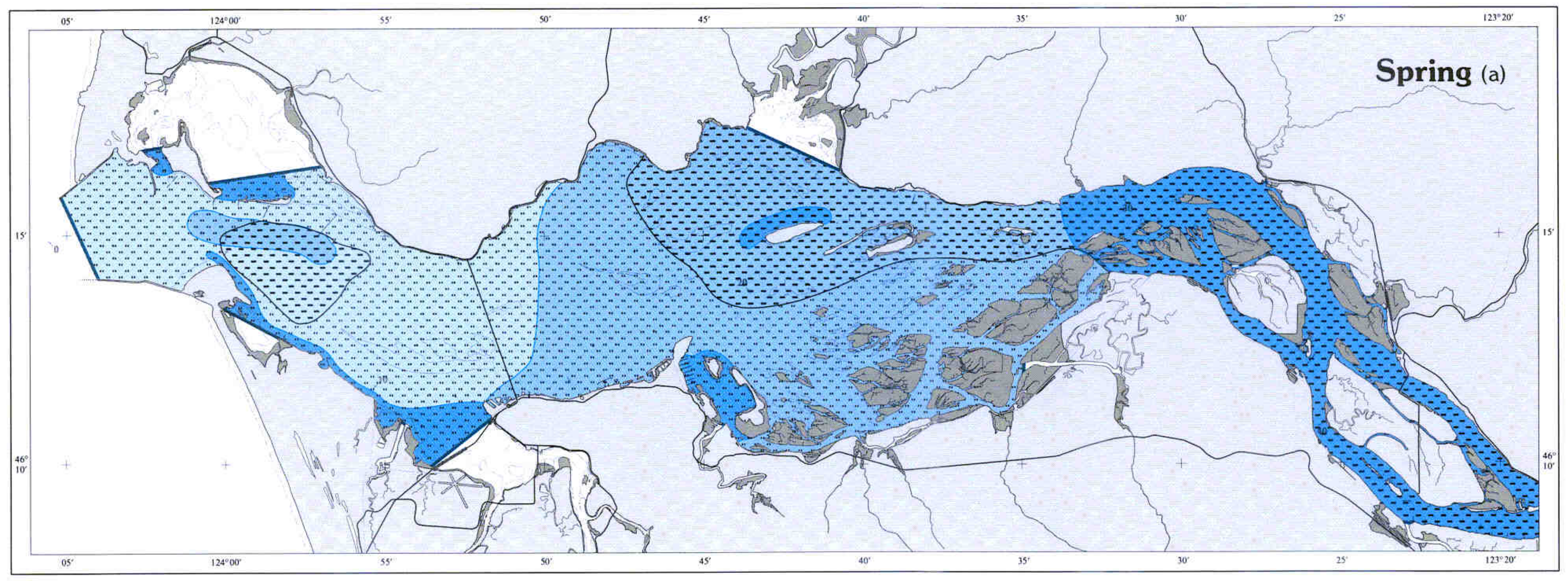
— limits of data

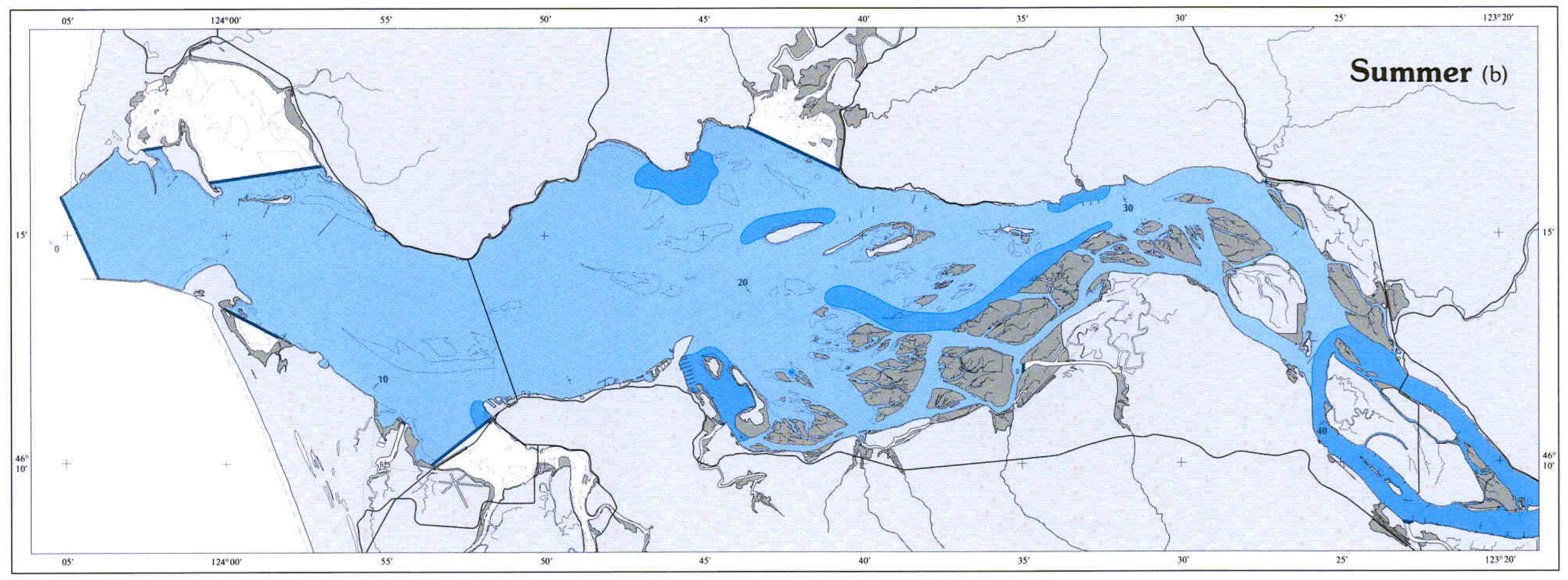
Fish abundance information is based on 1980-1981 sampling supported by CREDDP and the National Marine Fisheries Service/ Northwest and Alaska Fisheries Center (NMFS-NWAFC). Maps were compiled in 1983 by George McCabe, NMFS-NWAFC (CREDDP fish investigator).

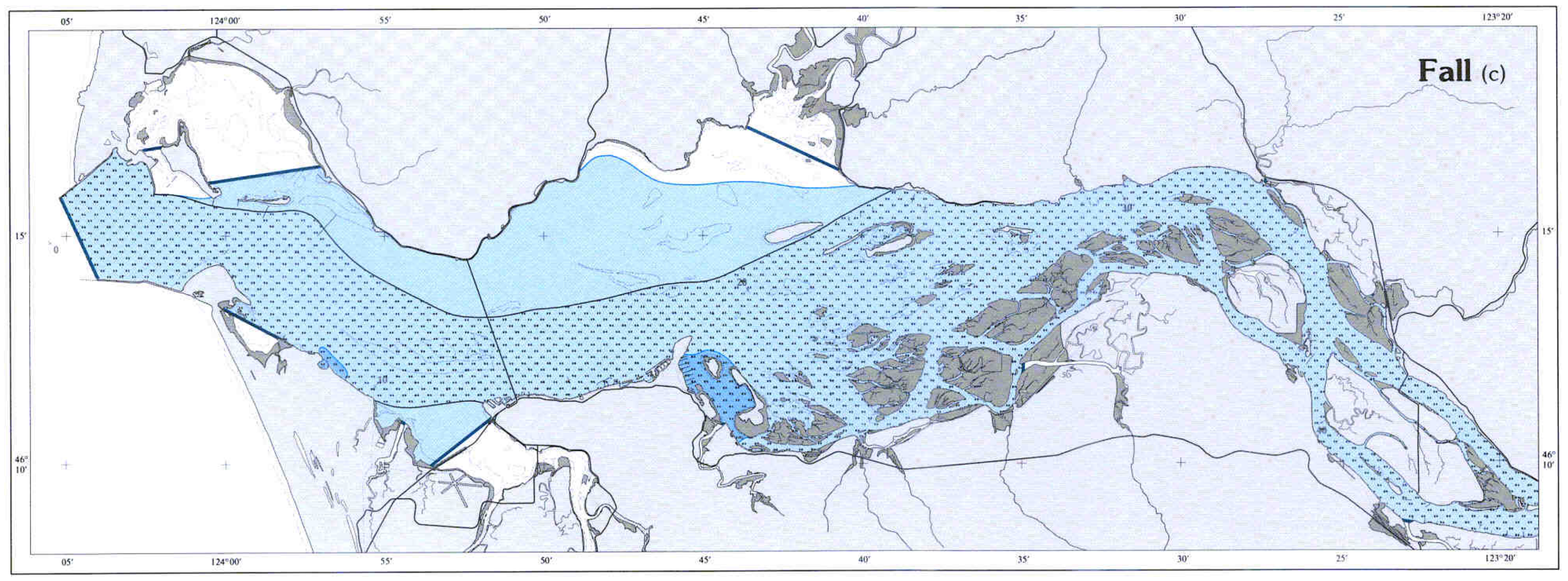
Scale 1:250,000

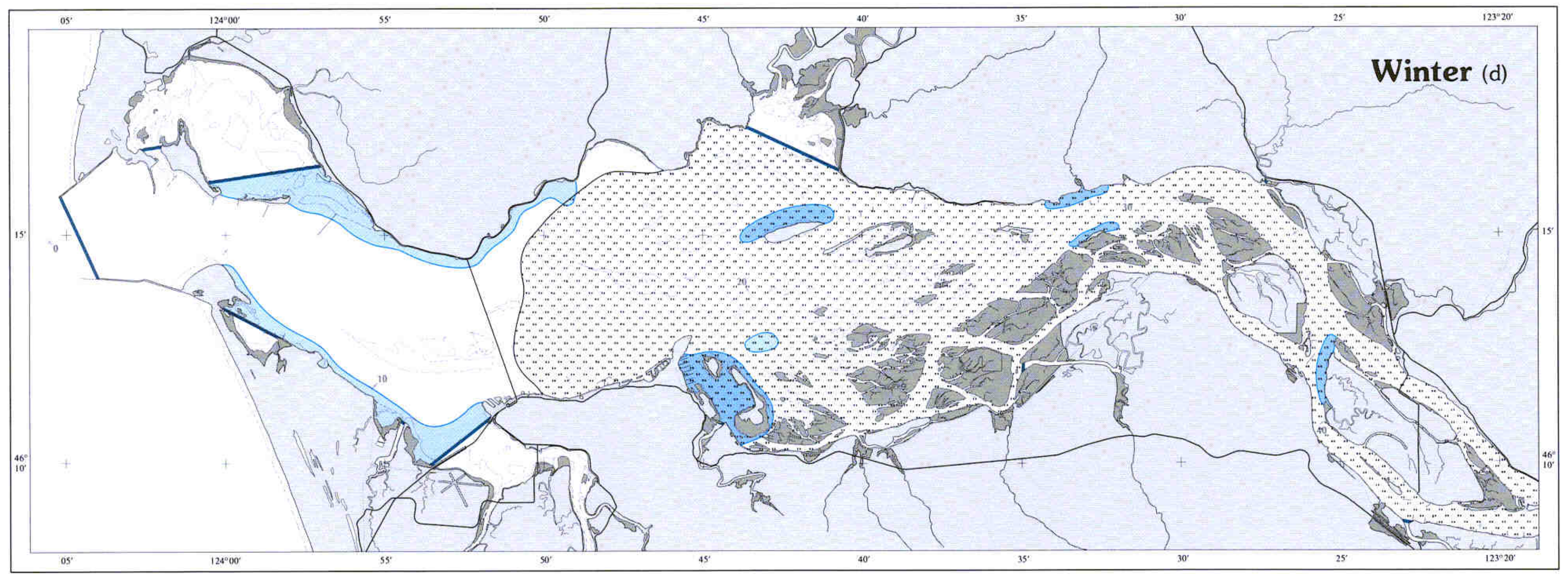
0 2 4 6 8 10 Kilometers

0 1 2 3 4 5 6 Miles









Chinook Salmon

(Oncorhynchus tshawytscha)

Relative abundance

Less than one year old

- high
- medium
- low

One to two years old

- medium
- low

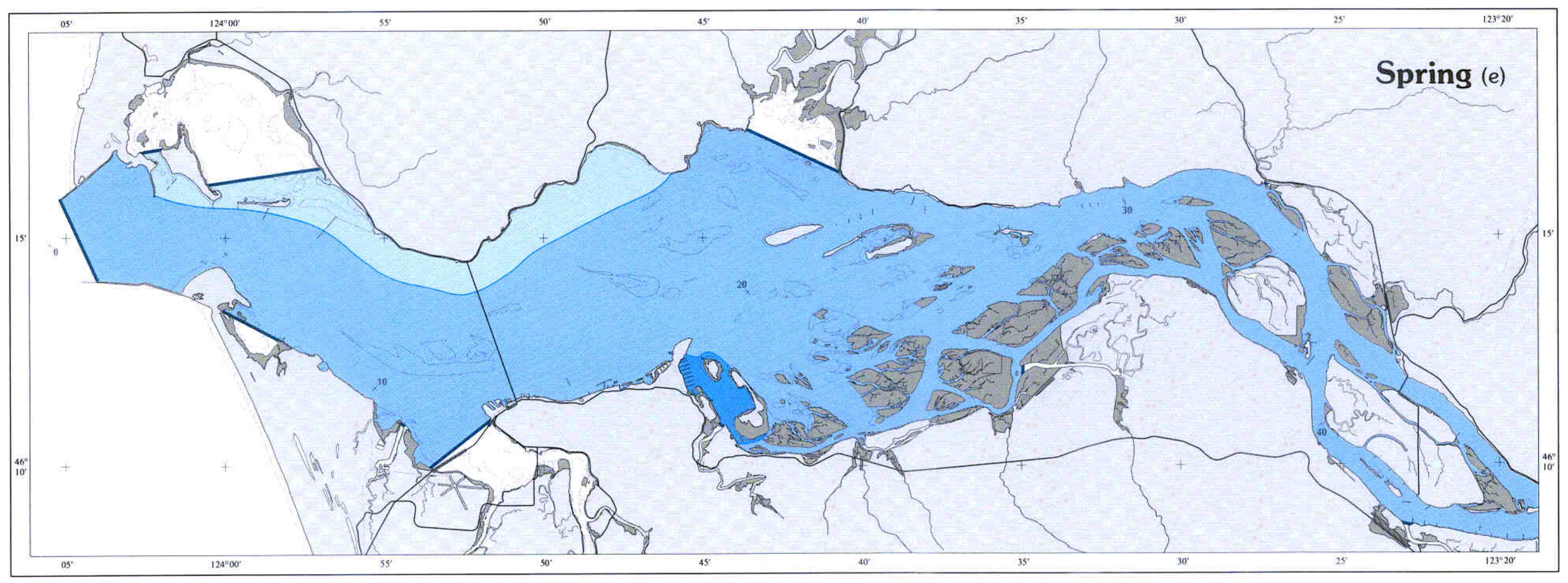
— limits of data

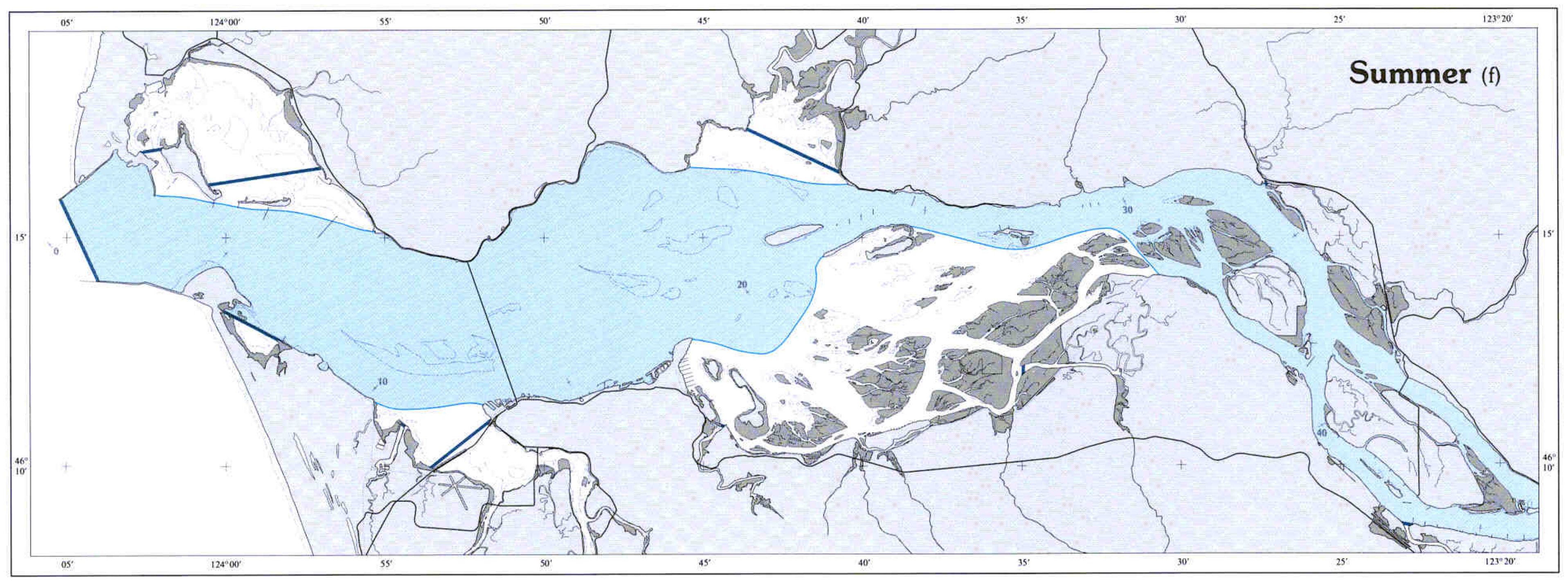
Fish abundance information is based on 1980-1981 sampling supported by CREDDP and the National Marine Fisheries Service/ Northwest and Alaska Fisheries Center (NMFS-NWAFC). Maps were compiled in 1983 by George McCabe, NMFS-NWAFC (CREDDP fish investigator).

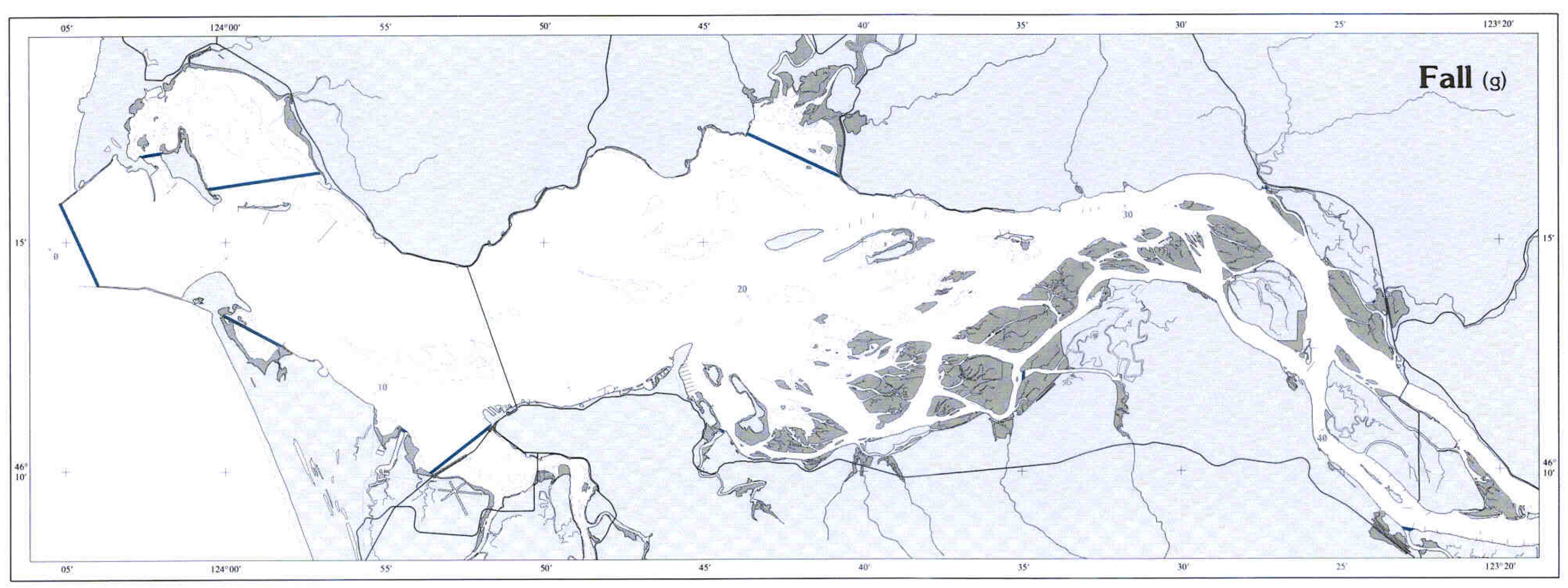
Scale 1:250,000

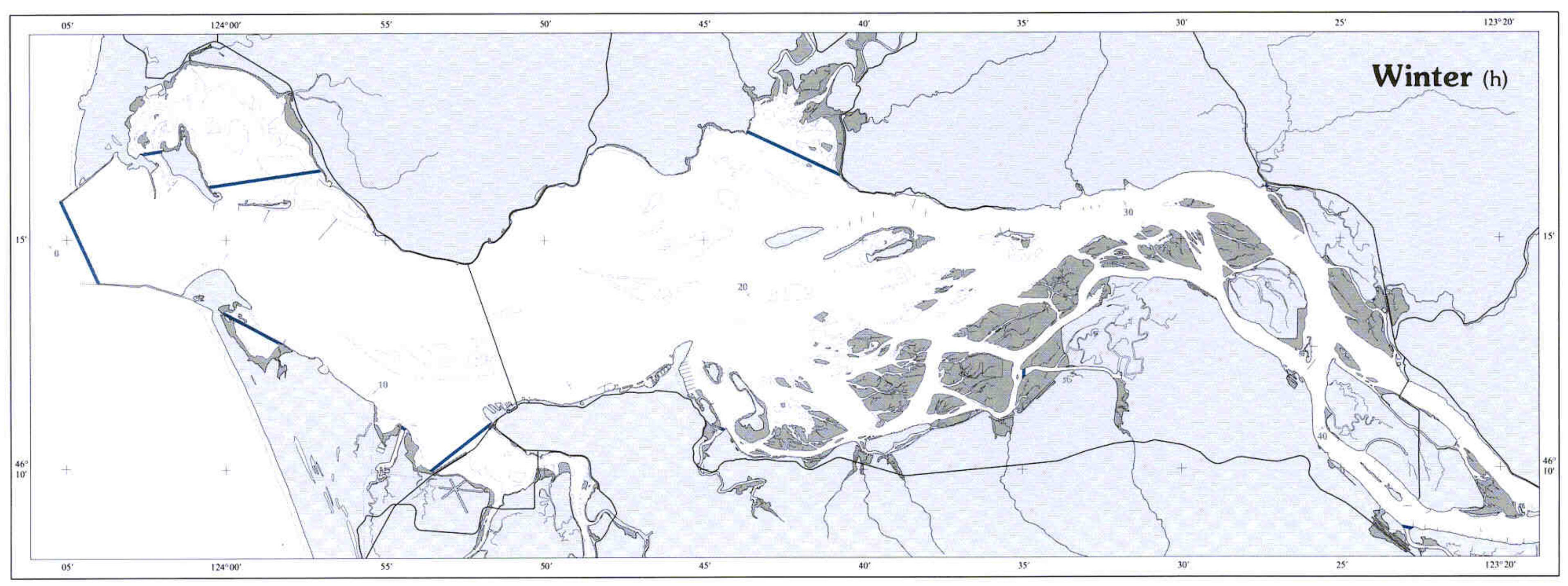
0 2 4 6 8 10 Kilometers

0 1 2 3 4 5 6 Miles









Coho Salmon

(Oncorhynchus kisutch)

Relative abundance

One to two years old

- high
- medium
- low

— limits of data

Fish abundance information is based on 1980-1981 sampling supported by CREDDP and the National Marine Fisheries Service/ Northwest and Alaska Fisheries Center (NMFS-NWAFC). Maps were compiled in 1983 by George McCabe, NMFS-NWAFC (CREDDP fish investigator).

Scale 1:250,000

0 2 4 6 8 10 Kilometers

0 1 2 3 4 5 6 Miles

Chapter 6.

BIRDS & MAMMALS

Birds

About 175 species of birds are known to occur in the Columbia River Estuary. Many of the species utilize the food and habitat provided by the estuary while others are more dependent on habitats adjacent to the estuary. The former group, those that utilize the estuary intensively, consists mainly of species dependent on fish, benthic invertebrates, or tidal marsh plants for their sustenance. CREDDP investigators concentrated their studies on ten key bird species representing this group of estuarine birds.

The key species fall into six general groups: shorebirds, gulls, waterfowl, diving birds, raptors, and wading birds. Shorebirds include dunlin, sanderlings, and western sandpipers. Because these three species are similar and tend to intermingle, they were studied as a group and are referred to collectively as peeps. Two species of gull, the glaucous-winged and western gull, were also studied as one group. These two species interbreed in the estuary. The key waterfowl include mallards, surf scoters, and common mergansers, while the key diving birds include western grebes, double-crested cormorants, and pelagic cormorants. Only one species of raptor, the bald eagle, was considered to be a key species. Although not particularly abundant, its status as a threatened species in the states of Oregon and Washington warranted its selection as a key species. The key wading bird species examined was the great blue heron.

Factors Affecting Distribution

Among the factors that have the greatest influence on the distribution and abundance of birds in the estuary are migration patterns, nesting patterns, availability of food, and availability of habitat. Unlike the estuarine organisms previously discussed, birds are generally not influenced directly by estuarine physical factors such as sediment type or salinity. Instead there is an indirect effect by which physical factors influence the distribution of prey and habitat, and these in turn affect bird distribution.

Dramatic changes in the abundance of birds and numbers of bird species occur seasonally in the estuary. These changes are principally related to patterns of bird migration. Greatest numbers of species and highest bird densities occur during spring and fall migrations when many birds stop for brief rests or for the entire winter. The fewest number of species and lowest densities occur in the estuary during the summer.

Nesting patterns also influence species distribution within the estuary. Nesting patterns can be divided into two categories: colonial nesting and solitary nesting. Colonial nesters congregate and nest in a well defined area during the nesting season. Many species return to the same site year after year and, in the case of great blue herons, successive generations may use the same site for over 100 years. Of the key species known to nest in the estuary, four are colonial nesters: gulls, double-crested cormorants, pelagic cormorants, and great blue herons. Solitary nesters include mallards, mergansers, and bald eagles. Although the solitary nesters do not form colonies, their nests still tend to be grouped in limited areas of preferred nesting habitat. During the nesting season, bird densities tend to be highest in areas of nesting colonies or concentrations of solitary nesters. Following the nesting season, adult birds and fledglings disperse to other areas of the estuary.

The location and availability of food influences the distribution of birds within the estuary. Peeps obtain food by either probing for benthic invertebrates in the sediments or picking organisms off the sediment surface. These birds tend to favor tidal mudflats rich in benthic invertebrates. The fish-eating divers such as cormorants and grebes pursue and capture their food, while fish-eating waders such as great blue herons stand motionless in shallow water and strike with their long beaks at passing prey. The divers prefer open water areas while the waders prefer shallow water and tidal mudflats. Dabbling ducks reach to the bottom in shallow water to consume plant material and associated invertebrates. Mallards, which fall into this class, tend to live in and around tidal marshes. Gulls and bald eagles can be classified as scavengers, consuming mostly dead and dying fish or whatever is available. Their distribution in the estuary is therefore difficult to characterize in terms of prey location because it is related to chance occurrences of refuse or carrion.

The availability of appropriate habitat is a fourth factor affecting species distribution and abundance. Appropriate habitat is defined mainly in terms of feeding and nesting patterns. In order to describe bird distribution, CREDDP investigators divided the estuary into several classes of habitats: open water, tidal mudflat, tidal marsh, shrub, and forest. The latter habitat corresponds roughly to tidal swamp as shown on Plate 10. Tidal marsh includes both high and low marsh while shrub represents the transition between high marsh and tidal swamp as shown on Plate 10 (Figure 6-11). Each bird species utilizes two or three of the habitat classes in preference to the others.

Derivation, Uses, and Limitations of the Maps (Plates 21 through 25)

Plates 21 through 25 show the seasonal abundance and nesting patterns of the ten key bird species and groups. The seasons represented are spring (March through May), summer (June through August), fall (September through November), and winter (December through February). The abundance information portrayed on the maps was collected in 1980 and 1981 using four methods. Three methods consisted of different survey techniques designed to measure densities. These survey data were converted to consistent numerical units (birds per square kilometer) for mapping peeps, gulls, mallards, surf scoters, common mergansers, western grebes, double-crested cormorants, and pelagic cormorants. The fourth method, incidental bird sightings, was used to measure the abundance of bald eagles and great blue herons. "Incidental bird sightings" is defined as the total number of birds sighted during a given sampling expedition. Incidental bird sightings show only relative abundance and cannot be expressed on a per-unit-area basis. Nest locations are mapped for gulls, double-crested cormorants, pelagic cormorants, bald eagles, and great blue herons.

The distributions shown on the maps are useful for determining important areas in the estuary for each species and seasonal patterns in bird use. Because birds are so mobile, all species can potentially be found anywhere in the estuary. Therefore, to emphasize patterns in bird distribution, the maps show only very high bird use areas. Regions where no bird use is mapped are regions where bird use is low.

The maps are not designed to be used for predicting bird abundance at specific locations. Because of the flocking tendency of many species, the count on any given survey may have been disproportionately high or low depending on the chance occurrence of a flock within the surveyor's range. Also, the density estimate for each species was based primarily on one or another of the three different survey techniques, depending on which technique was best suited to that species' behavior. Since each survey technique has a different set of biases, comparisons between different species' densities may be somewhat inaccurate. The incidental bird sighting data show only relative abundance within a species and should not be used with the density data to compare abundances between species. For all of these reasons, the bird density estimates are approximations and are not adequate for predicting actual species abundance. The location of high use areas for a given species can change dramatically from one year to the next. Since only one year's data were used for the maps, these potential changes are not accounted for on the maps.

Interpretation of the Maps (Plates 21 through 25)

Peeps (Plate 21, Maps a through d)

Peeps (Figure 6-1) are migratory birds that use tidal mudflat habitats and those tidal marsh habitats that contain extensive tidal mudflats and tidal channels. Peeps feed in these habitats during low tide and use nearby higher areas as resting sites during high tide. The diets of the three species of peeps are similar. Western sandpipers primarily consume aquatic insects, fly pupae, mollusks, polychaetes, and amphipods. Sandpipers feed by picking food items off the wetted surface of mud and sand, sometimes reaching beneath the surface of shallow water. Sanderlings consume a variety of insects, small mollusks, amphipods, polychaetes, and small fish. Sanderlings feed primarily by probing rapidly just below the surface of the sediments or by snatching prey off the surface. Dunlin feed by snatching objects from the surface or slowly and methodically probing beneath the surface. Dunlin consume a variety of crustaceans, insects, and polychaetes.

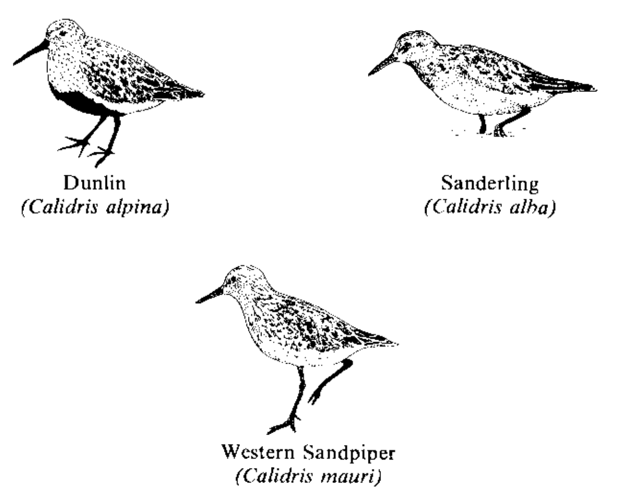


Figure 6-1. Key species of peeps in the Columbia River Estuary.

The distributional patterns and abundance of peeps in the estuary reflect their migration behavior and the occurrence of suitable prey. Highest concentrations of peeps occur during the spring and fall migration periods. Although numerous peeps winter in the estuary, their numbers are not as great as during migration periods. During the spring months, peep densities are highest in the vicinity of Quinns Island. Baker Bay and Youngs Bay tidal mudflats and tidal marshes on some Cathlamet Bay islands also receive moderate use in the spring (Plate 21, Map a). Summer densities are low and limited to nonbreeding birds or those leaving late for the northern breeding areas (Plate 21, Map b). Numbers begin to grow again in the fall, during which time Baker Bay and Youngs Bay receive the greatest use (Plate 21, Map c). Some shift in use is evident from fall to winter when peeps extensively use Grays Bay tidal mudflats and moderately use Baker Bay and Cathlamet Bay tidal marshes (Plate 21, Maps c and d). The areas receiving greatest peep use are all rich in benthic invertebrates such as amphipods, oligochaetes, and nematodes.

Gulls (Plate 21, Maps e through h)

Gulls (Figure 6-2) occur throughout the estuary during all seasons. Although their overall numbers are high, their density in any particular habitat is relatively low. They use open water, tidal mudflats, and tidal marshes for feeding. Loafing takes place on man-made structures as well as in open water and on tidal mudflats. Gulls are omnivorous, scavenging for refuse and dead or dying fish, clams, and worms, or feeding on schools of small fish close to the water surface.

Figure 6-2. Western and glaucous-winged gulls (*Larus occidentalis* and *L. glaucescens*) (photo by Jeffrey Mabee).

Concentrations of gulls are found at Youngs Bay, Grays Bay, and Cape Disappointment during different seasons. However, because gulls are scavengers and eat a wide variety of food, these seasonal distribution patterns probably reflect chance concentrations of prey and may not be repeated from year to year. There is a large gull nesting colony on East Sand Island; some nesting also occurs on Miller Sands and on rock jetties (Plate 21, Maps e through h). In June of 1980, the East Sand Island nesting colony contained over 1,300 nests. Of 85 nests examined by CREDDP investigators, 76 percent contained a combination of three young and/or eggs.

Mallards (Plate 22, Maps a through d)

Mallards (Figure 6-3) are large ducks that use the estuary as a migratory stopover area and also as a residence. This species occurs in the estuary during all seasons, primarily in open water, tidal mudflats, and the tidal marsh areas of protected bays. The open water and tidal mudflat areas are used for resting while the tidal marsh and some tidal mudflat areas are used for feeding. Mallards feed primarily on vegetative material, with invertebrates such as clams, snails, and aquatic insects comprising a much smaller portion of their diet.

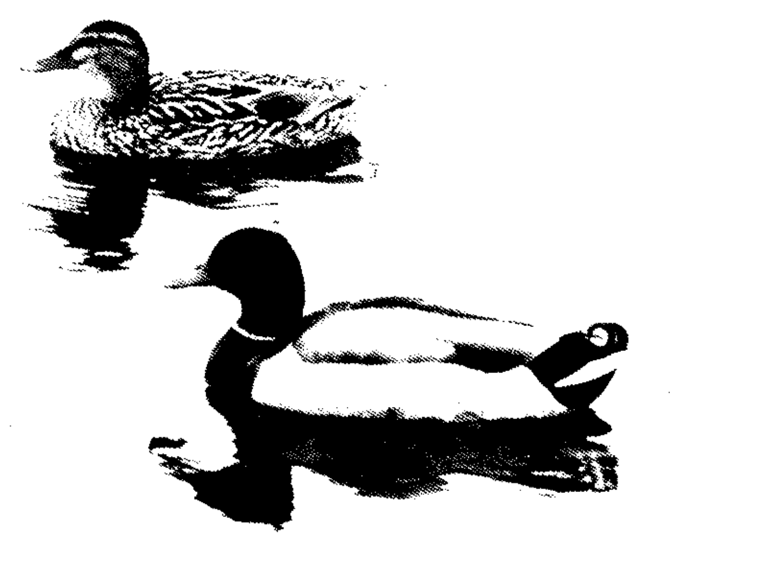


Figure 6-3. Mallard (*Anser platyrhynchos*) (National Audubon Society photo).

The migration behavior of mallards and their use of tidal marsh habitat are principal factors influencing their abundance and distribution in the estuary. During the spring, mallard populations are highest in Trestle and Cathlamet Bays (Plate 22, Map a). Summer populations are lower than populations during other times of the year because many of the birds migrate north to breed (Plate 22, Map b). Trestle, Grays, and Cathlamet Bays are heavily utilized during the fall (Plate 22, Map c). Grays Bay is also an important use area during the winter months (Plate 22, Map d). Mallard densities tend to decrease during the winter months when many of the birds migrate farther south.

Surf Scoters (Plate 22, Maps e through h)

Surf scoters (Figure 6-4) occupy open water habitats of the estuary. The species is essentially absent from the estuary during the summer since most breeding takes place in the Mackenzie River delta of the Northwest Territories, Canada. Surf scoters are diving ducks that feed mainly on animal matter, with mollusks constituting a majority of the animal foods. In the Columbia River Estuary, surf scoters most likely feed on clams.

The abundance and distribution of surf scoters is related both to their migration behavior and to the occurrence of suitable prey. During the spring months, surf scoters are most prevalent in the upriver portions of the estuary and near Cape Disappointment (Plate 22, Map e). Scoters are absent from the estuary during the summer (Plate 22, Map f) but during the fall and winter they tend to concentrate in the downriver portions of the estuary, with major concentrations in the vicinity of East Sand Island, Baker Bay, and Cape Disappointment (Plate 22, Maps g and h). The upriver portions of the estuary have high densities of the clam *Corbicula manilensis* while the downriver portions have high densities of *Macoma balthica* (see "Benthic Infauna").

Figure 6-4. Surf scoter (*Melanitta perspicillata*).

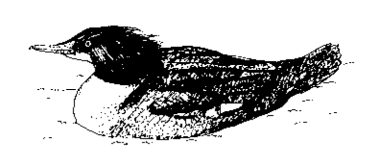


Figure 6-5. Common merganser (*Mergus merganser*).

Common Mergansers (Plate 23, Maps a through d)

The common merganser (Figure 6-5) is a resident of the estuary and is found in open water, tidal mudflat, and tidal marsh habitats. Open water is the most important habitat for this species. Common mergansers are diving ducks that feed almost exclusively on fish. They are opportunistic foragers, feeding on the most abundant prey available. Adult common mergansers occasionally consume fish as much as 30 centimeters long. Because mergansers reside in the estuary year-round, they feed on a wide variety of seasonally available fish such as Pacific herring, American shad, northern anchovy, smelt, salmon, stickleback, yellow perch, and steelhead trout.

Distributions of common mergansers in the estuary indicate a preference for the northern side of the estuary from Grays Point eastward, particularly in the vicinity of Grays Bay. The northern portion of the estuary from Grays Point to Jim Crow Point supports high densities of several fish species throughout the year. Common merganser density in Grays Bay is greatest in the summer due to the addition of newly-fledged juveniles (Plate 23, Map b). Mergansers are distributed more evenly in the upriver portion of the estuary during the winter (Plate 23, Map d).

Western Grebes (Plate 23, Maps e through h)

Western grebes (Figure 6-6) are long-necked waterbirds that occur in open water habitat seasonally throughout the estuary. Western grebes are predominantly fish-eaters along the Pacific Coast, although they are also known to consume insects. Studies of grebes conducted in Puget Sound, Washington, and Netarts Bay, Oregon, indicate that they eat mainly herring, surf perch, sculpins, starry flounder, and eulachon.

Figure 6-6. Western grebe (*Aechmophorus occidentalis*) (photo by Anne C. Geiger, Washington Dept. of Game).

Seasonal changes in the abundance of western grebes are accounted for by their migration behavior. During the spring, grebes congregate in large numbers in preparation for migration to northern breeding grounds (Plate 23, Map e). By summer they are gone (Plate 23, Map f). During the fall, density is low and grebes are concentrated west of Grays Bay (Plate 23, Map g), while in the winter Grays Bay is the location of greatest concentrations of grebes (Plate 23, Map h). Other wintering populations occur west of Grays Bay, in Cathlamet Bay, and in Youngs Bay. The occurrence of a large wintering population of western grebes in the vicinity of Grays Bay and the adjacent northern side of the estuary corresponds with high populations of forage fish such as longfin smelt, starry flounder, and Pacific herring.

Double-Crested Cormorants (Plate 24, Maps a through d)

Double-crested cormorants (Figure 6-7) are found in open water habitats and obtain food (primarily fish) by diving from the surface and swimming underwater to depths of 1.5 to 7.5 meters. Prey species probably include staghorn sculpin, threespine stickleback, seaperch, Pacific sand lance, Pacific herring, starry flounder, and crustaceans. Double-crested cormorants are often found in the vicinity of pilings and pile dikes where they perch to dry their feathers.

Double-crested cormorants occur in the estuary during all seasons, concentrating in the area around Cape Disappointment and Trestle Bay. Fish species occurring in high densities near Cape Disappointment include the Pacific staghorn sculpin (spring, fall, and winter), northern anchovy (summer and winter) and Pacific herring (summer). During the spring and summer, cormorant density increases at a large nesting colony in Trestle Bay (131 nests) and smaller sites on navigation channel markers east of Tongue Point (Plate 24, Maps a and b). High summer use occurs primarily between RM-20 and RM-30 (Plate 24, Map b). Concentrations shift west again in the fall as cormorants congregate in Trestle Bay and southeast of Baker Bay (Plate 24, Map c).

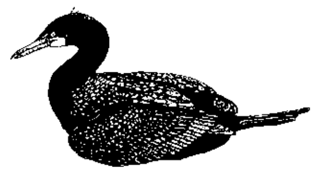


Figure 6-7. Double-crested cormorant (*Phalacrocorax penicillatus*).

Figure 6-8. Pelagic cormorant (*Phalacrocorax pelagicus*).

Pelagic Cormorants (Plate 24, Maps e through h)

Pelagic cormorants (Figure 6-8) have habitat requirements and feeding habits that are similar to those of double-crested cormorants. Both cormorant species are year-round residents of the estuary. Both prefer open water habitat, and both use man-made structures for wing drying.

Pelagic cormorants are less common and more restricted in range than double-crested cormorants, rarely occurring east of the Astoria-Megler bridge. A majority of sightings occurred at Cape Disappointment, where pelagic cormorants nest on the rocky cliffs. During a mid-summer nest survey, CREDDP investigators found approximately 100 nests; many young were present during late summer. An abundance of fish at the mouth to the estuary provides a food supply for the pelagic cormorant population there.

Bald Eagles (Plate 25, Maps a through d)

Bald eagles (Figure 6-9) occur in all seasons throughout the estuary and utilize open water, tidal mudflat, and tidal marsh habitats. Eagles nest in coniferous forests adjacent to the river. Bald eagles are opportunistic birds, feeding on the most available prey regardless of whether the prey type is fish, mammal, or bird. Although many studies have been conducted on the food habits of bald eagles, none is directly applicable to the estuary. Eagles in the estuary probably depend on a wide variety of seasonal foods such as salmon, American shad, waterfowl, and dead animals.

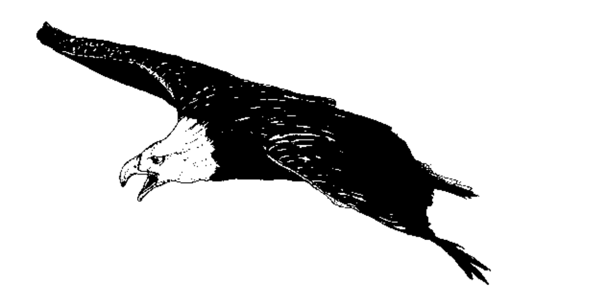


Figure 6-9. Bald eagle (*Haliaeetus leucocephalus*).

During the CREDDP study, bald eagles were sighted mainly near nesting sites, particularly in the vicinity of Grays and Cathlamet Bays. During the spring, Grays Bay, southern Cathlamet Bay, and Quinns Island were the areas of greatest use (Plate 25, Map a). Grays Bay was also important during summer and fall, while during the winter season southern Cathlamet Bay and Quinns Island were the most heavily used areas. Of the nesting sites shown on the bald eagle maps, only five were active during the 1980 breeding season. No young were produced at the nesting sites in 1980.

Great Blue Herons (Plate 25, Maps e through h)

Great blue herons (Figure 6-10) are large wading birds that are found throughout the estuary during all seasons. Herons feed in shallow open water, tidal mudflat, and tidal marsh areas and nest in shrub and forest areas adjacent to the estuary or on islands from Cathlamet Bay east to Puget Island. Because herons feed in both salt water and fresh water, a wide variety of fish is available to them in the estuary, including Pacific herring, salmon, surf smelt, longfin smelt, Pacific staghorn sculpin, starry flounder, northern anchovy, peamouth, and shiner perch.

Figure 6-10. Great blue heron (*Ardea herodias*) (CREST photo).

Great blue herons were most frequently observed during CREDDP investigations in Baker Bay and the northern part of Youngs Bay. These two portions of the estuary support large populations of potential prey items. Cathlamet Bay also receives moderate use during the summer, fall, and winter. The great blue heron maps identify four heron nesting colonies that were present in the estuary in 1980. Young were produced in all of these colonies during the 1980 breeding season.

Discussion

The major factors influencing bird distribution in the estuary vary from species to species. Generally, the overall abundance and seasonal distribution of year-round resident species are dependent on the availability of feeding and nesting habitat. Migratory bird abundance and distribution is also dependent on food availability but seasonal changes in abundance are mainly a result of migratory habits.

CREDDP investigators concluded that the Columbia River Estuary is an important area in the northwestern United States for the bird species described in this section. Open water areas, especially shallow areas of the Woody Island Channel, the zone from the Astoria-Megler bridge to Grays Point, and the area near Cape Disappointment, provide essential foraging habitat for the fish-eating birds. Of the fish-eaters, the mergansers and grebes tend to use the area upriver from Tongue Point while the cormorants use the area downriver from Tongue Point. Baker Bay tidal mudflats provide important foraging and resting areas for peeps. The rocky cliff at Cape Disappointment, channel markers west of Miller Sands, and man-made structures in Trestle Bay comprise the only known nesting sites for cormorants in the estuary. Approximately 95 percent of gull nesting in the estuary occurs on East Sand Island. The Columbia River Estuary and other Pacific coast estuaries are vital to birds migrating north or south along the coast. Migratory waterfowl that use the estuary as a temporary stop-off point include canvasbacks, scaups, ruddy ducks, pintails, widgeons, mallards, scoters, mergansers, and buffleheads.

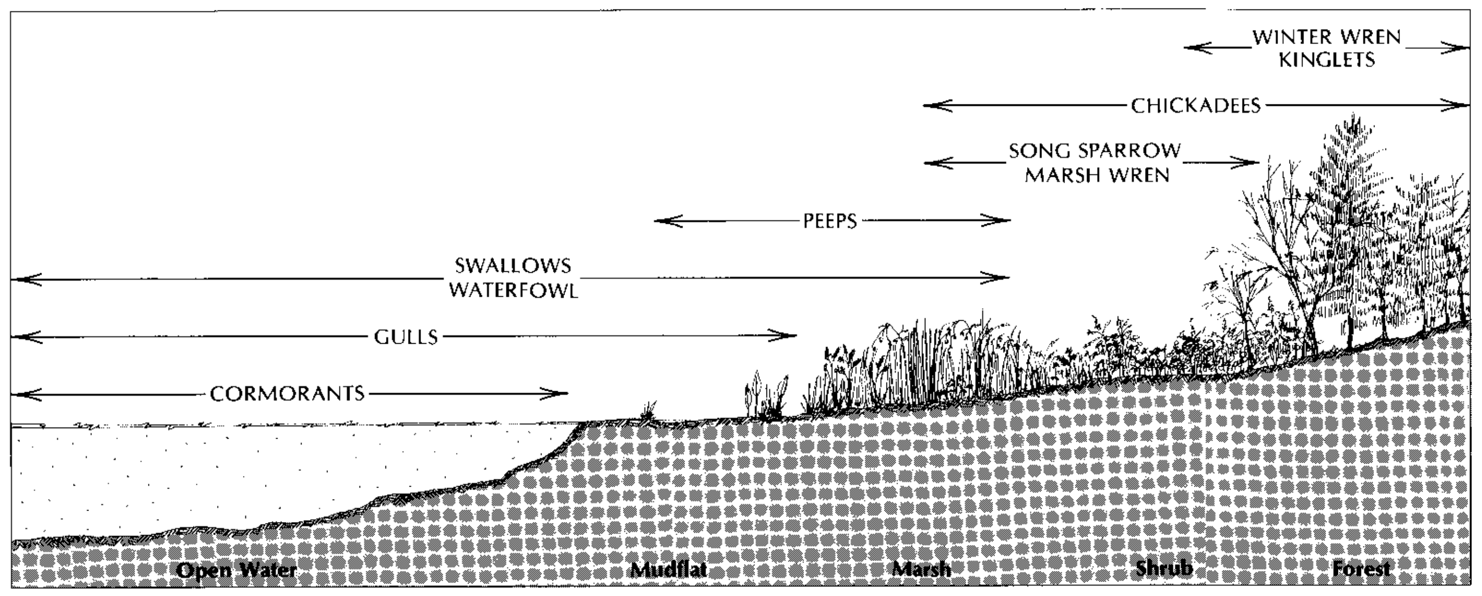


Figure 6-11. Principal ranges of common bird species and groups in Columbia River Estuary habitats (modified from Hazel et al. 1984).

The open water bird community consists of cormorants, gulls, and waterfowl such as scaups and scoters. The tidal mudflats are dominated by peeps, with swallows and gulls also present. Swallows, marsh wrens, peeps, and waterfowl are the dominant members of the tidal marsh community. Although containing fewer key species, the shrub habitats have a numerically abundant bird community dominated by black-capped chickadees, winter wrens, marsh wrens, ruby-crowned kinglets, common yellow throats, yellow-rumped warblers, and song sparrows. In the shrub and forested regions, black-capped chickadees, kinglets, and bushtits are numerically dominant.

When drawing comparisons between habitats and regions of the estuary, it is useful to examine the bird community as a whole. The bird community consists of the key species discussed in this section plus many other species that are abundant but not closely associated with the water. Figure 6-11 and 6-12 show the distribution among habitats and seasons of the most abundant species and groups in the bird community. The shrub and forest habitats support the highest density and largest number of species while tidal mudflats support the fewest species and open water and tidal marsh are intermediate. The occurrence of different types of habitat adjacent to the estuary also affects bird community composition. Riparian vegetation on the estuary's shores usually supports a diverse community of birds, with many of the species partially dependent on the estuary. Adjacent non-tidal wetlands are very important to waterfowl that use both tidal and non-tidal wetlands. Since the mix of habitats varies with location within the estuary, the bird community characteristics such as bird density and number of species present also differ from one region to the next (Figure 6-13). Overall, the Cathlamet Bay island area supports the greatest bird density and number of species, probably because of the diversity of habitats. Grays Bay, which also has many types of habitat, supports many bird species; however, bird densities are lower than in Cathlamet Bay. Baker and Youngs Bays support fewer species than upriver areas.

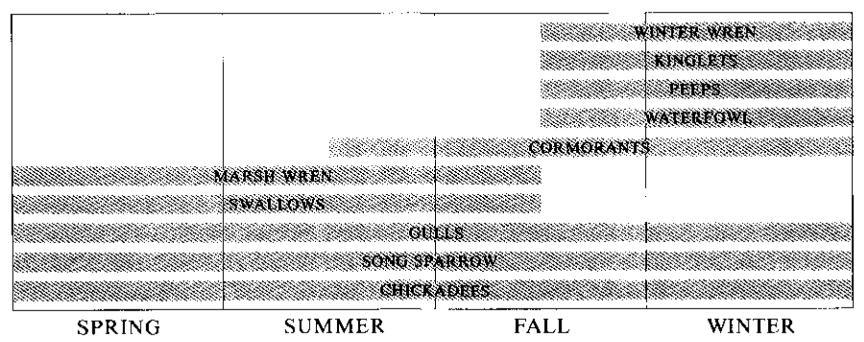


Figure 6-12. Seasonal occurrence of common bird species and groups in the Columbia River Estuary (modified from Hazel et al. 1984).

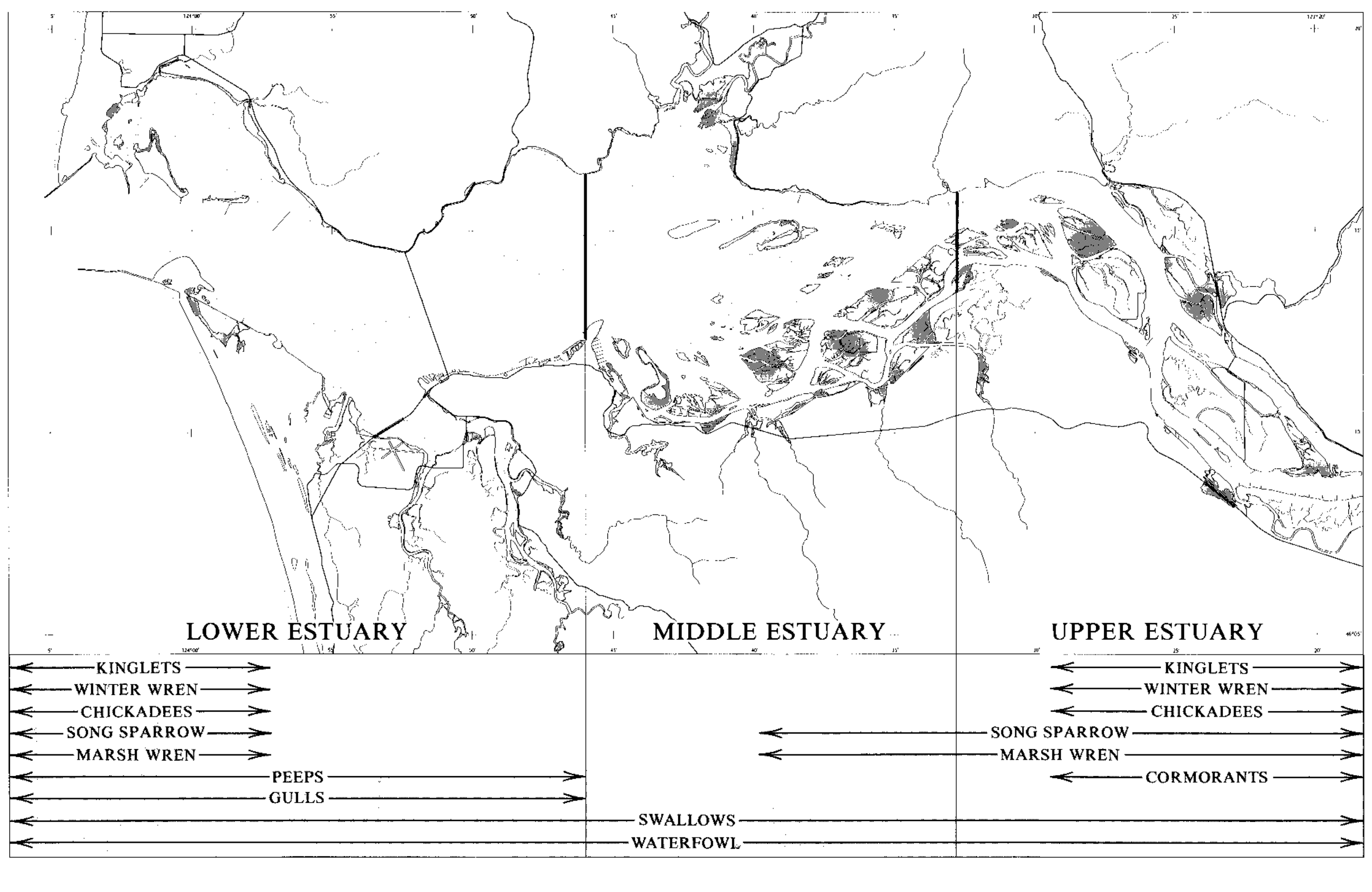


Figure 6-13. Principal ranges of common bird species and groups in general regions of the Columbia River Estuary (modified from Hazel et al. 1984).

Marine Mammals

There are two main groups of marine mammals in the North Pacific, cetaceans (whales, dolphins, and porpoises) and pinnipeds (seals, sea lions, and walruses). Like all mammals, both groups are warm-blooded, breathe air, bear their young live, and nurse their young. Only three marine mammal species, all pinnipeds, occur with any frequency in the Columbia River Estuary. Of the three pinniped species, only the Pacific harbor seal breeds in the estuary and can be considered a resident. Individual harbor seals, however, are not confined to the Columbia River Estuary but move freely around to other bays and estuaries on the Washington and Oregon coast. The other two species frequently encountered, the California sea lion and the northern sea lion, are migratory animals that use the estuary seasonally.

The three pinniped species are primarily fish-eaters, and they have an influence on the estuary's commercial fisheries that is related to their fish-eating behavior. Salmon caught in fishing nets are easy prey for seals, which remove or damage the netted fish. Seal-bite damage reduces the value of the total Columbia River Estuary salmon catch by an estimated 3 percent annually. Marine mammals are protected by the Marine Mammal Protection Act of 1972, which prohibits direct commercial exploitation of marine mammals while allowing commercial fishermen some options for protecting their catch and gear.

Factors Affecting Distribution

Migration patterns of marine mammals and the location of suitable prey and habitat are the principal factors affecting marine mammal abundance and distribution in the estuary. Marine mammal migrations along the Pacific coast and into and out of the Columbia River Estuary are mainly related to the mammals' annual breeding cycles. Sea lions generally migrate to the southern parts of their ranges for breeding and to the north for feeding. Abundance at the Columbia River mouth is influenced by groups of animals arriving, departing, or passing by. Their total migration distance can be over a thousand kilometers. A population of harbor seals migrates within the region of the Columbia River Estuary, at least as far as Tillamook Bay, Oregon, about 90 kilometers south of the Columbia, and Grays Harbor, Washington, about 70 kilometers north. Many members of this regional population move out of the Columbia River Estuary to adjacent bays and estuaries during the pupping season. Variations in prey abundance between the Columbia River Estuary and adjacent coastal areas are also a factor contributing to harbor seal migrations.

Whereas migrations determine marine mammal occurrence at the mouth of the estuary, the availability of prey influences their distribution within the estuary. Pinnipeds tend to congregate near abundant fish supplies and, in the case of harbor seals and California sea lions, populations actually follow fish runs through the estuary and on upriver, occasionally ranging all the way to Bonneville Dam (RM-145). Table 6-1 lists the prey species eaten most frequently by the three pinniped species.

The location of suitable habitat, defined mainly in terms of haulout sites, influences the distribution of pinnipeds within the estuary. Haulout sites are rocky areas, islands, or tidal flats occupied periodically as resting areas by large groups of pinnipeds (Figure 6-14). Haulout sites are usually low enough to be inundated at high tide but high enough to be above wave action during low tide. These sites are often adjacent to deep water channels and located near abundant food supplies.

Derivation, Uses, and Limitations of the Maps (Plate 26)

Plate 26 shows seasonal maps of marine mammal population counts on haulout sites and of incidental sightings in open water. CREDDP investigators conducted 71 aerial surveys from 1980 through 1982 to gather data for estimating pinniped abundance on haulouts. The data were grouped by calendar month regardless of year collected and months were combined for seasonal distributions: spring (March through May), summer (June through August), fall (September through November), and winter (December through February). Plate 26, Maps a through d depict the highest count obtained for a particular haulout location in surveys made during each season. Incidental marine mammal sightings were made by the CREDDP marine mammal investigators, other CREDDP researchers conducting field work in the estuary, and local citizens. These data were grouped by season and are shown on Plate 26, Maps e though h.

The maps are useful for showing pinniped population sizes and distribution within the estuary. Of the two groups of maps, the aerial count maps (Plates 26, Maps a through d) are the better indicators of pinniped population sizes. The counts represent minimum estimates because a portion of the population is under water during any given overflight and is therefore not counted at the time of the census. The aerial count maps also are good indicators of preferred haulout sites. The incidental sightings maps (Plate 26, Maps e through h) are useful for indicating general patterns of marine mammal distribution in relation to important foraging areas. The incidental sightings cannot, however, be converted to population estimates.

Interpretation of the Maps (Plate 26)

Each of the maps on Plate 26 displays information which distinguishes among several marine mammal species. Each section in the following discussion presents information on one of the marine mammal species and makes reference to the entire set of maps.

Pacific Harbor Seals

Adult Pacific harbor seals (Figure 6-15) are about 1.5 meters (5 feet) long and weigh an average of 75 kilograms (165 pounds). The Pacific harbor seals have a range from Baja California through the Aleutian Islands. Although they do not migrate throughout their range, some move as much as 550 kilometers (340 miles) up and down the coast. Harbor seals in the Columbia River Estuary are part of a regional population of 6,000 to 7,000 animals that are found from Tillamook Bay to Grays Harbor. The harbor seal population in the Columbia River Estuary fluctuates from about 500 in the summer to about 1,500 in the winter. Populations shift periodically from one area to another, declining in adjacent estuaries while building up in the Columbia.

Figure 6-15. Harbor seal *(Phoca vitulina)* (photo by Steven Jeffries, Washington Dept. of Game).

Harbor seals have several haulout sites throughout the estuary. These haulout sites invariably have immediate access to deep water channels, where the seals take refuge if disturbed. Harbor seal hauling behavior is timed with the tidal cycle. Animals begin to concentrate in the water at haulout locations about four hours before low tide. Once the tide is low enough, a few seals begin to haul out and the entire group follows quickly. They stay on the haulout until it is inundated by rising water two or three hours after low tide.

The prey species eaten most frequently by harbor seals in this area are all common within the estuary (Table 6-1). Nearly all seals feed heavily on eulachon, anchovy, and lamprey when these species are abundant. Sculpin, tomcod, sole, flounder, prickleback, and herring appear to be year-round staples. Sand shrimp (*Crangon* sp.) and Dungeness crab are eaten frequently by pups and nursing mothers while the pups learn to catch small schooling fishes and flatfish.

Harbor Seal	California Sea Lion	Northern Sea Lion
northern anchovy	eulachon	Pacific hake
eulachon	northern anchovy	rockfish
Pacific staghorn sculpin	lamprey spp.	eulachon
longfin smelt	Pacific herring	northern anchovy
lamprey spp.	Pacific tomcod	Pacific herring
Pacific tomcod	sand sole	Pacific staghorn sculpin
snake prickleback		Pacific lamprey

Table 6-1. Prey species eaten most frequently by pinnipeds in the Columbia River Estuary (from Jeffries et al. 1984).

Harbor seal abundance in the Columbia River Estuary is greatest from winter to mid-spring (Plate 26, Maps a and d and Figure 6-16). Haulout sites at Desdemona, Taylor, and Miller Sands and a site south of Three Tree Point are heavily used during these seasons. In addition, a group of 100 to 200 animals was sighted by CREDDP investigators on Wallace Island just east of the estuary study area limit. The incidental sightings maps show that seals in the water are also widespread in the upriver portions of the estuary during the winter (Plate 26, Map h). Greatest harbor seal abundance and farthest range upriver occur at the same time as the winter eulachon runs in the estuary. The Columbia River Estuary is the only source of this abundant fish in the area, making the estuary a favored foraging area for the regional harbor seal population. The distribution of seals on haulouts and in the water follows the main migration routes of eulachon.

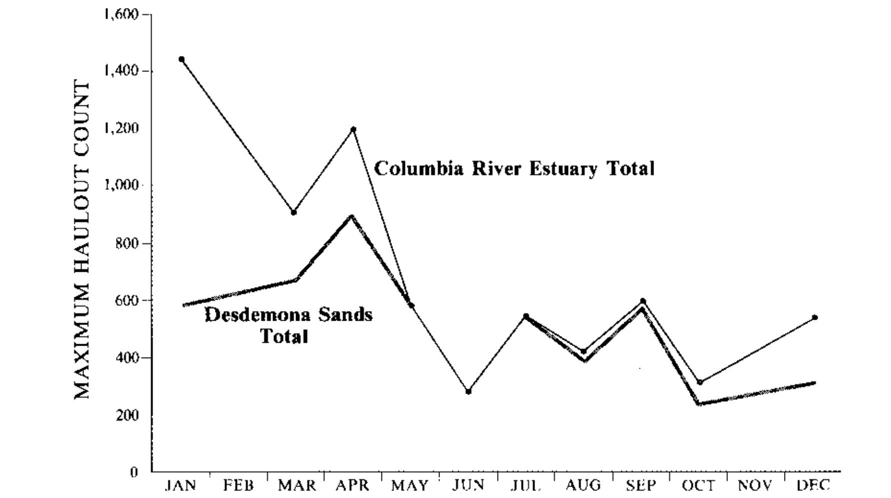


Figure 6-16. Haulout counts of harbor seals for Desdemona Sands and for the entire Columbia River Estuary. Each month's count is the maximum recorded for that month, regardless of year. Surveys were conducted from 1980 through 1983 (from Jeffries et al. 1984).

When the eulachon run ends, harbor seals abandon their upriver haulout sites. The number of seals declines in May, and for the rest of the year (summer and fall) Desdemona Sands is the only site where large groups continue to haul out (Plate 26, Maps b and c and Figure 6-16). Anchovy becomes a frequently eaten food during this period. This fish prefers high salinities and, as a result, is distributed mainly in the downriver portion of the estuary. Desdemona Sands provides the nearest haulout to these anchovy schools. The overall population decline in summer and fall (Figure 6-16) is caused by migration to preferred pupping grounds in Grays Harbor and Willapa and Tillamook Bays. During the CREDDP study period, fewer than ten pups (out of regional pup count of 1,000) were produced by the small seal population remaining in the estuary in summer and fall. Secluded haulouts near Green Island and Grays Bay were used for pupping (Plate 26, Maps a through c).

California Sea Lions

The California sea lion (Figure 6-17) is the familiar "trained seal" of circus fame. Males can weigh as much as 300 kilograms (660 pounds) while females reach about 100 kilograms (220 pounds). The breeding colonies of California sea lions are on islands and isolated beaches south of the Farallon Islands (off San Francisco, California), including both coasts of Baja California. The largest males form harems for breeding, which takes place from May to July. After breeding season, males start moving north to feeding grounds from northern California to British Columbia. The female migration is mainly to the south. Only male California sea lions have been observed in the Columbia River Estuary.

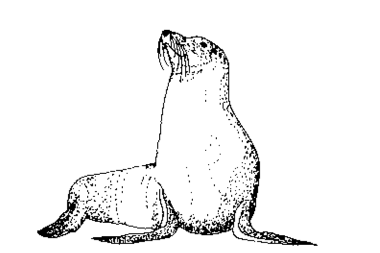


Figure 6-17. California sea lion *(Zalophus californianus).*

The first arrivals to the estuary appear in September. Numbers increase throughout the fall and winter, peaking in March. During the CREDDP study period, investigators estimated that the peak number of California sea lions using the estuary was between 200 and 225 (Figure 6-18). After April the population declines quickly and by June virtually all the animals have departed to join the females at the breeding grounds. While in the estuary,

Figure 6-14. Harbor seal haulouts (photos by Steven Jeffries, Washington Dept. of Game).

Hauling out is a behavior common to all pinnipeds. Although they can rest or sleep in the water, they regularly haul out on land for sleeping. Since they rely on metabolic energy and their insulating blubber for warmth in the water, hauling out may be essential for maintenance. Air is often warmer than the water, and air conducts body heat more slowly than water does. Therefore, hauling onto land may permit the deposition of body fat reserves rather than the conversion of fat to energy. Pinnipeds haul out more frequently and stay out of the water for longer periods when they are molting their fur. Maintaining high skin temperatures by basking is thought to aid the replacement of hair. They also haul out to give birth and to nurse their young. For all these reasons, haulout locations are considered critical habitat for pinnipeds.

California sea lions use the rocky tip of the South Jetty as a haulout site (Plate 26, Maps a through d). Unlike harbor seals, the hauling behavior of sea lions is related to time of day rather than stage of tide. The sea lions do most of their feeding in early morning and late afternoon and haul out in greatest numbers at midday.

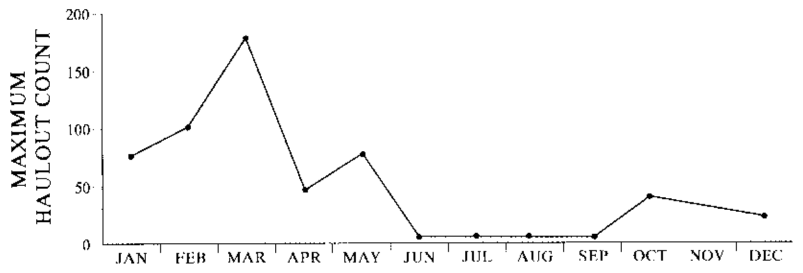


Figure 6-18. Seasonal abundance of California sea lions in the Columbia River Estuary. Each month's count is the maximum recorded for the South Jetty for that month, regardless of year. Surveys were conducted from 1980 through 1982 (Jeffries et al. 1984).

Although their only haulout is at the entrance to the estuary, California sea lions swim far up the Columbia River. During the winter they are numerous in the upriver portions of the estuary (Plate 26, Map h), are often seen near the mouth of the Cowlitz River, and have been sighted as far upriver as the Bonneville and Willamette Falls Dams. All major channels in the estuary are used as traveling routes, but the northern channels receive the most use (Plate 26, Maps e through h). Sea lions concentrate near Point Ellice at the northern end of the Astoria-Megler bridge and north of Tenasillahe and Puget Islands. This use of the river from January through March corresponds to the annual run of eulachon and two other anadromous species, lamprey and steelhead trout (Table 6-1). California sea lions consume eulachon more frequently than any other prey species in the estuary. Before and after the eulachon run, the relative absence of sea lions from the river corresponds to abundances of prey species in the ocean near the river mouth.

Northern Sea Lions

The northern sea lion (Figure 6-19) weighs about three times as much as the California sea lion. As the name implies, the range of the northern sea lion is farther north than that of the California sea lion, but there is considerable overlap. The northern sea lion's southern limit is off southern California, but the majority of the population is centered off Alaska. Breeding colonies are located along Vancouver Island and off the central Oregon coast as well as farther north and south. Northern sea lions breed in June and the males subsequently migrate north. Most of the northern sea lions using the Columbia River Estuary are females and young, with relatively few large males.

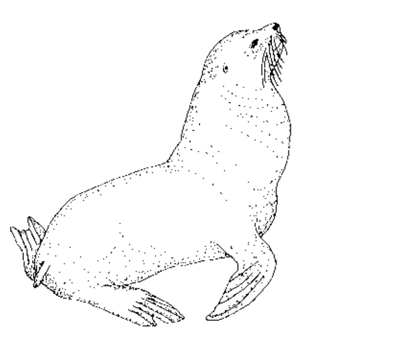


Figure 6-19. Northern sea lion *(Eumetopias jubatus).*

As with California sea lions, the tip of the South Jetty is the only haulout used by northern sea lions in the estuary (Plate 26, Maps a through d). Very few are present in summer and fall. Maximum density occurs around January, when an estimated 80 to 100 individuals were present during CREDDP investigations (Figure 6-20). The two sea lion species are found together on the South Jetty haulout.

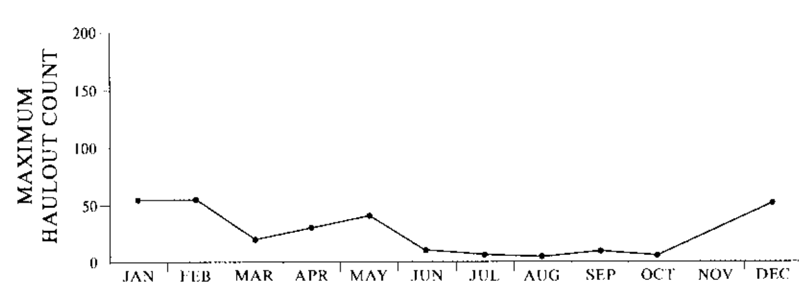


Figure 6-20. Seasonal abundance of northern sea lions in the Columbia River Estuary. Each month's count is the maximum recorded for the South Jetty for that month, regardless of year. Surveys were conducted from 1980 through 1982 (Jeffries et al. 1984).

Although eulachon and lamprey are part of their diet, northern sea lions consume marine fish species such as hake and rockfish more frequently (Table 6-1). Consequently they do not exhibit the major upriver movements of the foraging California sea lions (Plate 26, Maps e through h). However, CREDDP investigators did observe concentrations near Point Ellice in January (Plate 26, Map h). The northern sea lions were probably foraging on eulachon at this time.

Other Marine Mammals

Only two other marine mammal species were observed in the estuary, and both were considered accidental visitors. California gray whales were sighted between the jetties and, on flood tides, as far upriver as Chinook Point in March and April (Plate 26, Maps a and e). One northern elephant seal was reportedly sighted near Tongue Point (Plate 26, Map h), while another was found dead near County Line Park, Washington, at the eastern end of the CREDDP study area. Both species are migratory, ranging from Baja California to Alaska.

Discussion

The Columbia River Estuary plays an important role in supporting regional pinniped populations. At times, the estuary is used by 25 percent of the region's harbor seal population and a substantial percentage of the migrating California and northern sea lion populations. Although the estuary is not a major pupping area, it is vital in providing food and critical habitat for these pinnipeds.

The availability of an abundant food resource is the primary factor influencing the distributional patterns of the estuary's pinnipeds. Eulachon are consumed by large populations of pinnipeds in winter and seem to be the principal cause of the upriver movement of harbor seals and California sea lions. Anchovy and lamprey are important during the remainder of the year. These seasonally abundant fish resources support the largest numbers of pinnipeds, while year-round food sources such as sculpin, flounder, and sole take a secondary role.

Critical habitat for pinnipeds in the estuary includes both haulouts and foraging areas. Haulout sites are well defined, and the same site may be used consecutively for days, months, or years. Haulouts are located close to the pinnipeds' food resources and are essential for resting, molting, and pupping. Desdemona Sands is the most frequently used haulout site for harbor seals (Figure 6-16) and the South Jetty is the only known haulout for both species of sea lions. Unlike haulouts, foraging areas are not well defined but are determined by the distribution of abundant prey. During the CREDDP study period the Point Ellice area was an important feeding area for all three main pinniped species. The channel north of Tenasillahe and Puget Islands was used by concentrations of harbor seals and California sea lions. Harbor seals also used the areas between Rice Island and Miller Sands and between Woody Island and Jim Crow Sands.

Pinnipeds play a role in the human use of the estuary, mainly in interactions with the salmon fishery. Although seals may catch free-swimming salmonids, they feed on salmon species primarily when the fish are caught in fishermen's nets. CREDDP investigators reported that over 7,000 netted salmon per year were damaged by seals (and possibly by California sea lions) in 1980 and 1981, representing 5 percent of the total catch. During spring gillnet seasons pinniped predation on netted salmon is most frequent in the northern channels of the estuary between Desdemona and Taylor Sands. In fall the frequency of seal sightings around gillnet boats increases downriver, and predation spreads to upriver areas around Woody Island and Skamokawa. Overall, the major problem areas are the Point Ellice area, Cathlamet Channel to Fitzpatrick Island, between Rice Island and Miller Sands, and between Woody Island and Jim Crow Sands.

Aquatic and Terrestrial Mammals

The tidal swamps and marshes of the Columbia River Estuary provide food and habitat for a variety of mammal species. CREDDP investigators reported on the seven species they found to be the most frequent or otherwise significant users of the estuary. These include five species of furbearers (nutria, muskrat, beaver, river otter, and raccoon) and two species of deer (black-tailed deer and Columbian white-tailed deer). The Columbian white-tailed deer, although not numerous, was considered significant because it is listed as an endangered species. Of the furbearers, all but the raccoon are aquatic. The raccoon is a terrestrial (land) mammal but typically lives near the water's edge or in wetlands. Deer are also terrestrial mammals but use the estuary's tidal swamps for feeding and for refuge. Nutria, muskrat, beaver, and deer are herbivores, while river otter and raccoon eat mainly fish and crayfish.

Factors Affecting Distribution

The principal factor affecting the abundance and distribution of mammals in the estuary is the occurrence of appropriate habitat. While all the tidal swamps and marshes in the estuary provide protective cover for aquatic and terrestrial mammals, not all swamp and marsh areas are used to the same degree. The occurrence of mammals in these habitats is influenced mainly by two characteristics: elevation and tidal channels. The lower elevation tidal marshes are inundated by the tide most often and are occupied mainly by aquatic mammals. These marshes provide protection from terrestrial predators. Many of the low marsh islands of the estuary, especially in Cathlamet Bay, are located far from the mainland and contain little or no dry land during the two daily high tides. The terrestrial mammals (deer and raccoon) and the aquatic mammals preferring higher marshes (beaver and river otter) do not occur on these low marsh islands. Tidal channels (small sloughs or gullies that fill and drain wetlands over the tidal cycle, described in "Tidal Marshes and Swamps") are the focal point for furbearers' use of tidal marshes and swamps. These channels are feeding areas for river otter and provide transportation routes to and from feeding sites for the other aquatic furbearers. The banks of the tidal channels are also the primary locations for den building (denning). The extent of the tidal channel network within a particular marsh or swamp largely accounts for the degree of its use by furbearer populations in the estuary.

The types of food available in the mammals' habitat is another important factor affecting distribution. Of the herbivores, beaver and deer prefer the woody and shrubby plants of the estuary's swamps while muskrat and nutria consume mainly marsh plants. When the tidal marsh plants die back in the winter, some of these species eat the belowground roots and stems in these marshes. Otter and raccoon prefer fish, crustaceans, and clams and feed mainly in the tidal channels of swamps and higher elevations marshes.

Hunting and trapping rank among the major factors controlling mammals' population sizes in the estuary, especially in the case of muskrat, nutria, and raccoon. However, there is no evidence that these activities are threatening to the maintenance of any of the species' populations. In addition to hunting and trapping, predation by coyotes and birds also serves to control the population of these mammals.

Derivation, Uses, and Limitations of the Map (Plate 27)

To determine mammal use of the estuary, CREDDP investigators collected mammal feeding and denning information from a broad variety of the estuary's low marsh, high marsh, and swamp habitats. Three types of mammal use categories are distinguished on Plate 27: feeding, denning, and total use. Feeding and denning intensities are defined in terms of the proportion of a species' regional population using a given area for these purposes. High intensity feeding or denning indicates that more than 50 percent of a species' population in that general region of the estuary feeds or dens in the area indicated, medium represents from 20 to 50 percent, and low represents less than 20 percent. Since the total population sizes are not known, these figures represent relative intensity of feeding and denning and do not indicate actual numbers of animals present. Total use represents a combination of the denning and feeding information along with the CREDDP investigators' judgment of the value of the indicated area to the indicated mammal species. As with feeding and denning, total use values are relative to each other; however, they are not meant to represent specific percentages of population. High intensity of total use means that many individuals are spending a large portion of their time in the area indicated, while low use means that only a few individuals visit the area and then only infrequently.

The information on Plate 27 has several uses and limitations. Mammal use information can help in determining the relative importance of each vegetation type and of different areas to individual species. The information is also useful in interpreting important factors influencing the species' distributions. The most important limitation of the information is that use categories cannot be converted to density or population estimates. In addition, a comparison of two species' level of use of a given area does not indicate the relative numbers of the two species in that area. For example, high use by nutria (an abundant species) may mean that several thousand nutria occur in a given area, whereas high use by raccoon (a less numerous species) may indicate that only 50 raccoon occupy the same area. Also, mammal use is not spread evenly throughout each vegetation type; for example, tidal channels may have very high use while the remainder of the habitat has low use. In this case, the entire habitat is still classified as high use.

Interpretation of the Map (Plate 27)

Muskrat

Muskrat (Figure 6-21) are closely related to common mice and rats. They are about 50 centimeters long (including tail), twelve centimeters high at the shoulder, and weigh about one kilogram. Because they are small, muskrat are vulnerable to predatory birds and mammals. They rely on water for protection, feeding mainly during high tide and seldom swimming more than 60 meters from their dens. Muskrat require steep-sided tidal channels for constructing dens.

Plate 27 indicates that muskrat prefer the estuary's low marshes over high marshes and swamps. The lower elevation tidal marshes are not accessible to many of their predators. Since muskrat require steep-sided tidal channels, their use of any particular tidal marsh is related to the length and number of such channels. The Cathlamet Bay islands have well developed tidal channel systems and the highest muskrat use in the estuary. The principal low marsh vegetation community on these islands is dominated by Lyngby's sedge and horsetail, with water parsnip also present. These are all favored foods of muskrat (Table 6-2). Most of the low marshes in Trestle and Baker Bays are narrow fringing marshes along the shoreline with poorly developed tidal channel systems. As a result, muskrat use of these areas is relatively limited.

Figure 6-21. Muskrat *(Ondatra zibethicus).*

Figure 6-22. Nutria *(Myocastor coypus).*

Nutria

Nutria (Figure 6-22) are probably the most numerous mammals of the species discussed in this section. These aquatic rodents are native to South America and were introduced into the Gulf Coast, mid-Atlantic coast, and Pacific Northwest. Their average weight is over five kilograms and their average length, including tail, is about one meter. Because of their large size, they have few predators and their population has been expanding. Like muskrat, they build dens by burrowing into steep-sided tidal channel banks in marsh areas; however, they occasionally use log piles for dens. They regularly range 350 meters or more from their dens for feeding, using tidal channels for transportation routes.

Overall nutria use is highest in both low and high marshes. Feeding occurs mainly in low marshes while denning occurs in high marshes. Of the two principal food species consumed by nutria (Table 6-2), bulrush occurs in low marshes and sedges occur in both low and high marshes. This accounts for nutria's use of both tidal marsh types for feeding but with a preference for low marshes. Since nutria are relatively free from predators in the Columbia River Estuary, they can den in higher elevation marshes than muskrat. As with muskrat, the number of tidal channels determines denning use by nutria and, as a result, the Cathlamet Bay islands have the highest populations of nutria. Nutria use of Trestle Bay and Baker Bay fringing marshes is lower than in the upriver portions of the estuary since these marshes are narrow and lack well developed tidal channels.

Beaver

Beaver (Figure 6-23) are the largest rodents in North America. They average more than a meter in length and 15 kilograms in weight, and can weigh as much as 30 kilograms. In the Columbia River Estuary almost all beaver dens are tidal channel bank burrows rather than the more characteristic mound constructions.

Figure 6-23. Beaver *(Castor canadensis)* (CREST photo).

Beaver use of the estuary is almost entirely restricted to tidal swamp habitats. The most extensive tidal swamps are the Sitka spruce and Sitka willow swamps of the Cathlamet Bay islands, islands upriver from the bay, and Grays Bay. These swamps contain steep-sided tidal channels for beaver denning and abundant supplies of willow and cottonwood, beaver's most frequently eaten foods (Table 6-2). Downriver from Tongue Point, the estuarine swamps are small and poorly developed and beaver use is low.

River Otter

The river otter (Figure 6-24) is a close relative of the mink and weasel. Otter are one to one and a half meters long, about 25 centimeters high at the shoulder, and weigh between five and eleven kilograms. They are found on a majority of streams in the northwestern United States but, like most carnivorous mammals, are not particularly numerous in any area, including the Columbia River Estuary. Adjacent non-estuarine habitats are used more by these animals than estuarine habitats; therefore, CREDDP investigators assigned river otter only low or medium total use ratings on Plate 27.

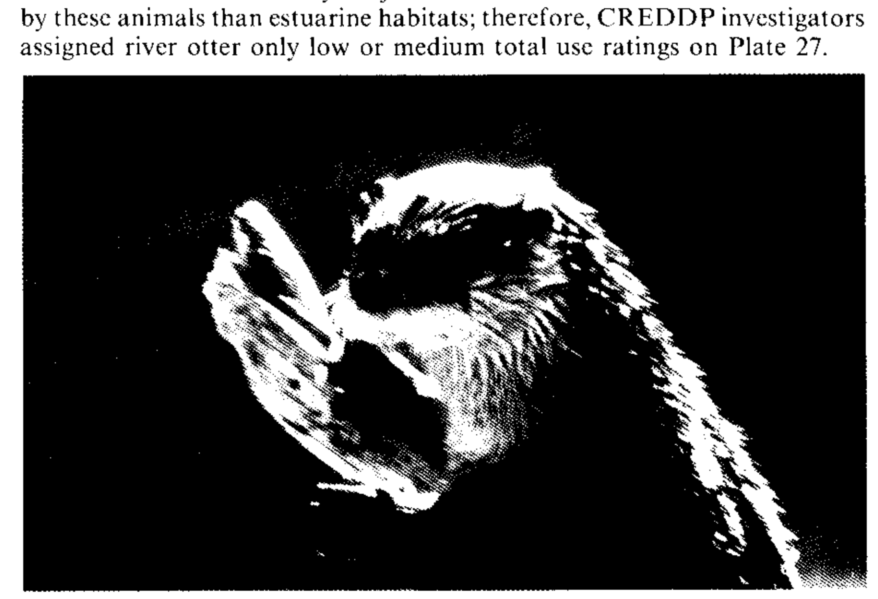


Figure 6-24. River otter *(Lutra canadensis)* (CREST photo).

Otter in the Columbia River Estuary are found mainly in swamps, where they feed in the tidal channels. Crayfish, carp, and sculpin are their most common foods (Table 6-2). The complex network of tidal channels and creeks in the swamps provide an excellent foraging area for otters. During low tide, the water in these channels tends to form shallow pools, concentrating fish in small areas and providing easily obtained food. Crayfish, another important food item, are also very numerous in these channels.

Raccoon

The raccoon (Figure 6-25) is a terrestrial carnivore measuring a little less than a meter in length and weighing about eight kilograms. Raccoon make use of tree nests and cavities for sleeping, resting, and raising young. In the Columbia River Estuary, crayfish are by far their most frequently eaten food throughout the year. Raccoon also eat birds, clams, and fruits seasonally (Table 6-2).

The greatest concentrations of raccoon are found in the tidal swamps and adjacent tidal marshes of the Cathlamet Bay islands. There are smaller populations of raccoon in Youngs, Baker, and Grays Bays and the tidal marshes adjacent to the forested shorelines of Oregon and Washington.

Muskrat	Nutria	Beaver	River Otter	Raccoon	Deer (both species)
water parsnip *(Sium suave)*	sedge *(Carex* sp.*)*	willow *(Salix* spp.*)*	crayfish *(Pacifastacus leniusculus)*	crayfish *(Pacifastacus leniusculus)*	blackberry *(Rubus* sp.*)*
horsetail *(Equisetum* sp.*)*	bulrush *(Scirpus* sp.*)*	cottonwood *(Populus* spp.*)*	sculpin *(Cottus* sp.*)*	clam *(Corbicula manilensis)*	horsetail *(Equisetum* sp.*)*
root material	tall fescue *(Festuca arundinacea)*	sedge *(Carex* sp.*)*	carp *(Cyprinus carpo)*	unidentified birds	Pacific ninebark *(Physocarpus capitatus)*
sedge *(Carex* sp.*)*	root material	red alder *(Alnus rubra)*	unidentified fish	Rosaceae fruit	western red cedar *(Thuja plicata)*
bulrush *(Scirpus* sp.*)*	wapato *(Sagittaria latifolia)*	creek alder *(Cornus stolonifera)*	starry flounder *(Platichthys stellatus)*	sculpin *(Cottus* sp.*)*	manna grass *(Glyceria* sp.*)*
tufted hairgrass *(Deschampsia caespitosa)*	tufted hairgrass *(Deschampsia caespitosa)*				
rush *(Juncus* sp.*)*	horsetail *(Equisetum* sp.*)*				

Table 6-2. Food items consumed most frequently by key aquatic and terrestrial mammals of the Columbia River Estuary (from Dunn et al. 1984).

Figure 6-25. Raccoon *(Procyon lotor)* (CREST photo).

Because raccoon make their dens in trees, all of their denning in the estuary occurs in the swamps. Their favored food in the Columbia River Estuary, crayfish, is also abundant in swamps. Raccoon also feed occasionally in tidal marshes where crayfish and other prey items occur.

Deer

Of the two species of deer studied by CREDDP investigators, the black-tailed deer is common while the Columbian white-tailed deer is rare. Black-tailed deer live along the Pacific coast from northern California to Alaska. Columbian white-tailed deer (Figure 6-26) were formerly found in lowland valleys from the Willamette and Umpqua Valleys in Oregon north to Puget Sound in Washington. Their distribution is now restricted to two small areas, a small section of the lower Columbia River that includes the eastern part of the estuary and an area near Roseburg, Oregon. Both species of deer are dependent on woody cover for protection and prefer habitats that provide both food and cover. Their most common food items in the estuary are blackberry, horsetail, Pacific ninebark, and Western red cedar (Table 6-2).

Figure 6-26. Columbian white-tailed deer *(Odocoileus virginianus leucurus)* (U.S. Fish and Wildlife Service photo).

Deer are more numerous in upland habitat than in the estuary and their use of the estuary is almost exclusively in swamp habitat (Plate 27). These tidal swamps provide both food and cover for the deer species. White-tailed deer particularly prefer the Sitka spruce swamps, which occur mainly on some of the Cathlamet Bay islands and on Welch, Puget, Hunting, Tenasillahe, and Price Islands upriver from Cathlamet Bay. The latter three islands, along with some adjacent Washington shoreland, are within the Columbian White-tailed Deer National Wildlife Refuge (Plate 1, Map c) and support the largest populations of this deer species.

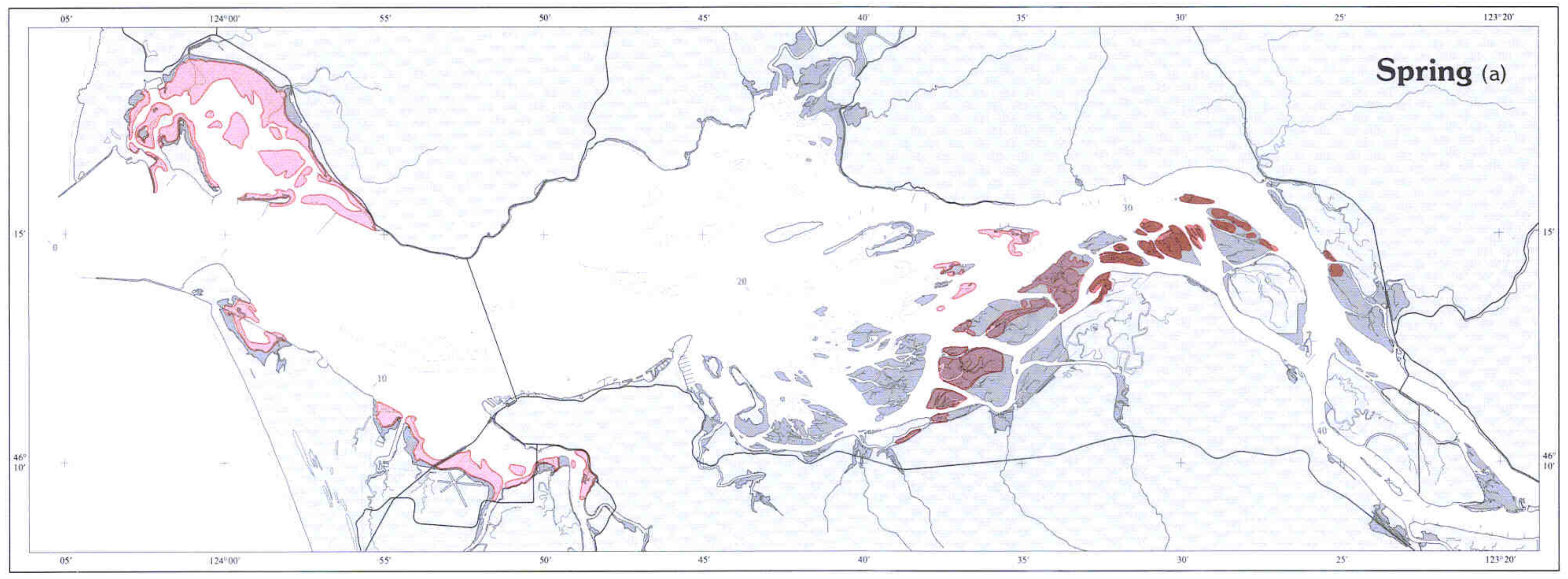
Discussion

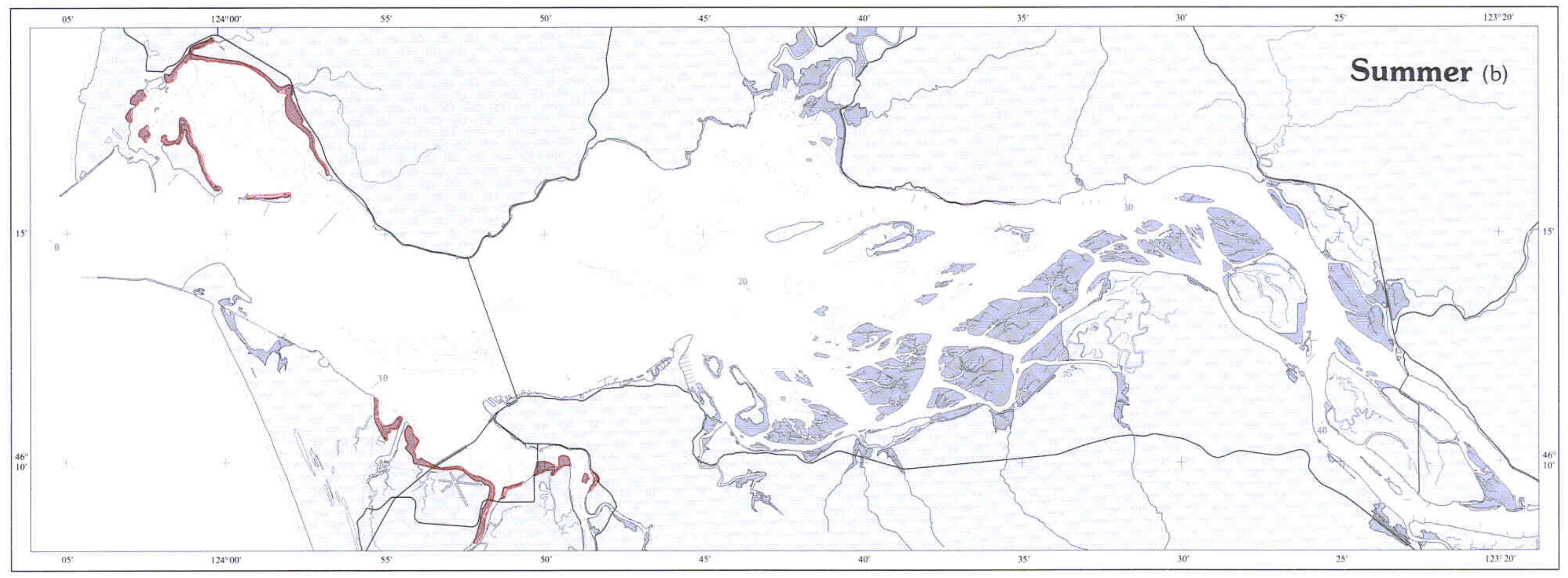
The differences in the ways mammal species use different types of vegetated tidal habitat reflect their individual food and shelter requirements. Muskrat, which are much more vulnerable to predators than nutria, need more shelter and are therefore restricted to the lower elevation marshes. The tidal swamp vegetation provides shelter and food for those species preferring woody vegetation, namely beaver and deer.

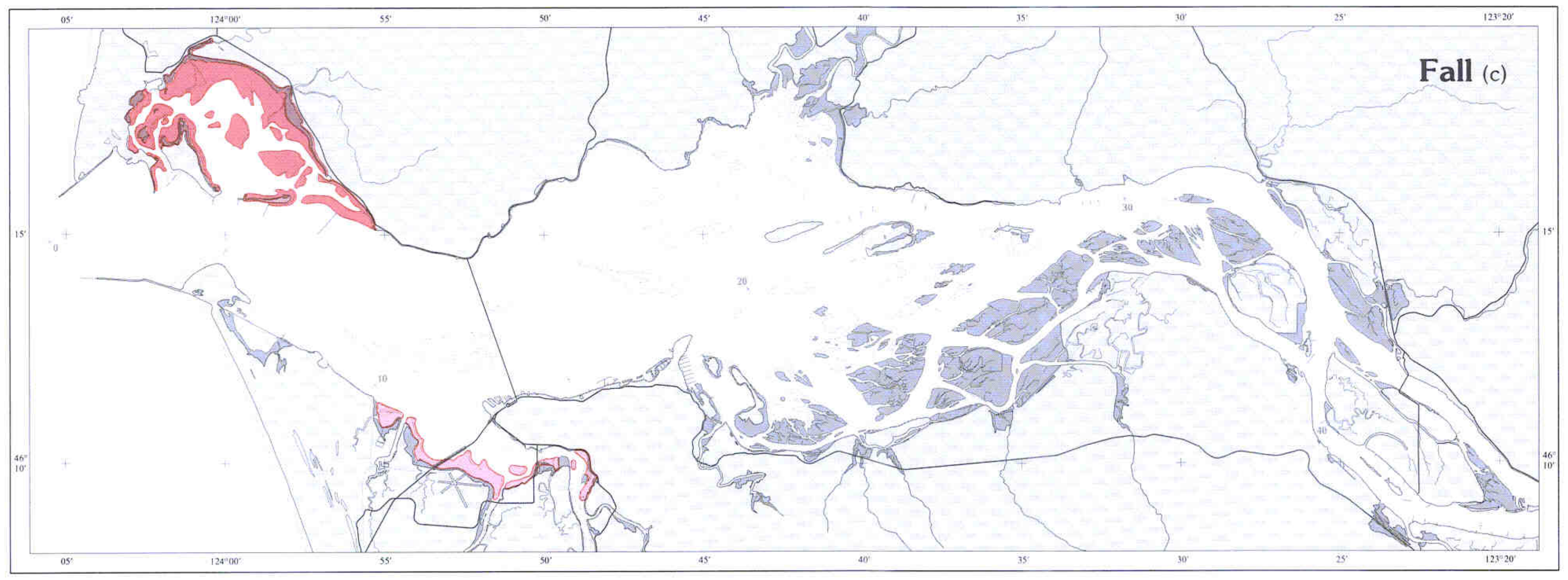
Well-developed tidal channels are important features of both marshes and swamps for many Columbia River Estuary mammals. Tidal channels, which occur in nearly all tidal marshes and swamps, provide denning sites, feeding sites, and transportation corridors for most of the key mammals of the estuary. Generally, areas with the most steep-sided channels and the largest network of channels receive the greatest mammal use. This is the case with the Cathlamet Bay islands. Estuarine marshes west of Tongue Point are generally smaller and have less developed tidal channel networks. Mammals are therefore not as abundant in these marshes as in Cathlamet Bay.

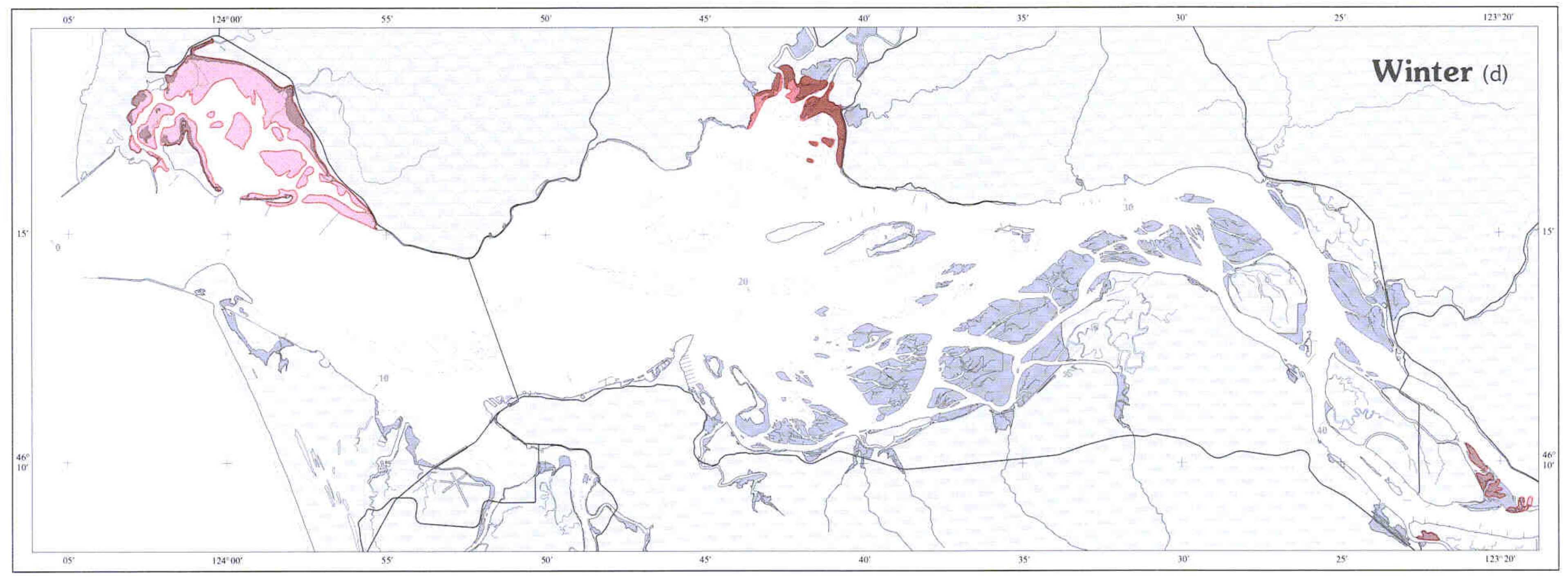
The main factor limiting the numbers of mammals in the estuary is the occurrence of appropriate habitat. Except for nutria, which are not native to the area, all the other species are thought to be much less numerous in the estuary today than they were 100 years ago, because the diking of tidal marshes and swamps has severely reduced their habitat (see "Human Activities and Their Effects" in Chapter 1). Tidal swamps and marshes together now cover only 35 percent of the surface area they formerly covered, and if recently formed fringing marshes with poorly developed tidal channels are excluded, the area of appropriate mammal habitat is only 27 percent of what it was 100 years ago. The most affected areas are west of Tongue Point, and the least affected area is Cathlamet Bay, much of which is now protected in the Lewis and Clark National Wildlife Refuge (Plate 1, Map c).

Peeps*









Density (birds/km²)

- more than 1,000
- 100-1,000

***Peeps include sanderling *(Calidris alba)*, western sandpiper *(Calidris mauri)*, and dunlin *(Calidris alpina)*.**

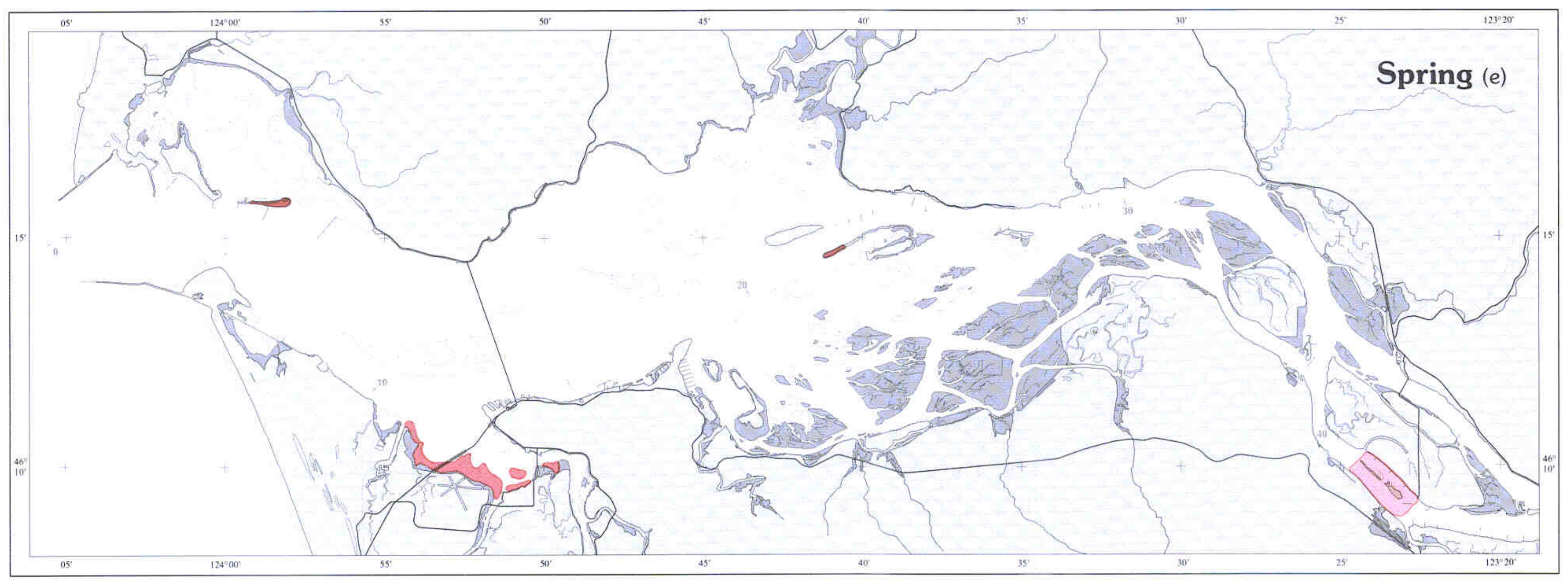
Bird density information is based on 1980-1981 CREDDP sampling. Maps were compiled in 1983 by Jones and Stokes Associates, Inc. (CREDDP avifauna investigators).

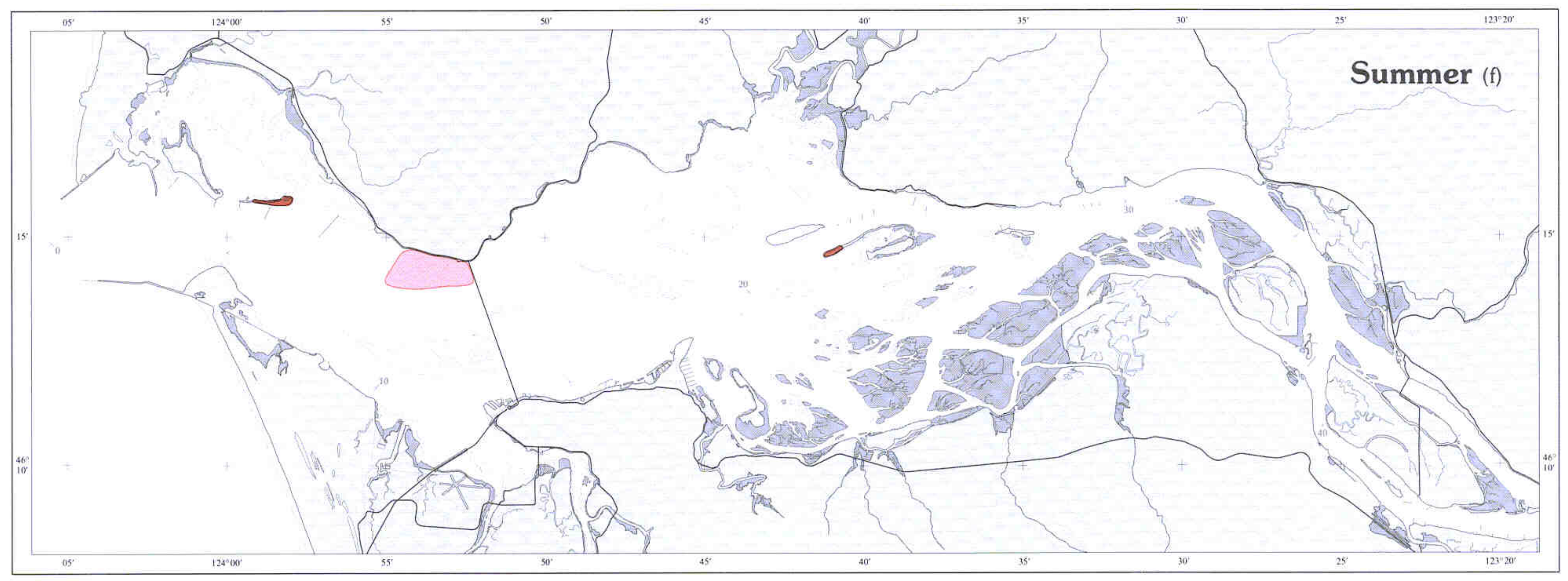
Scale 1:250,000

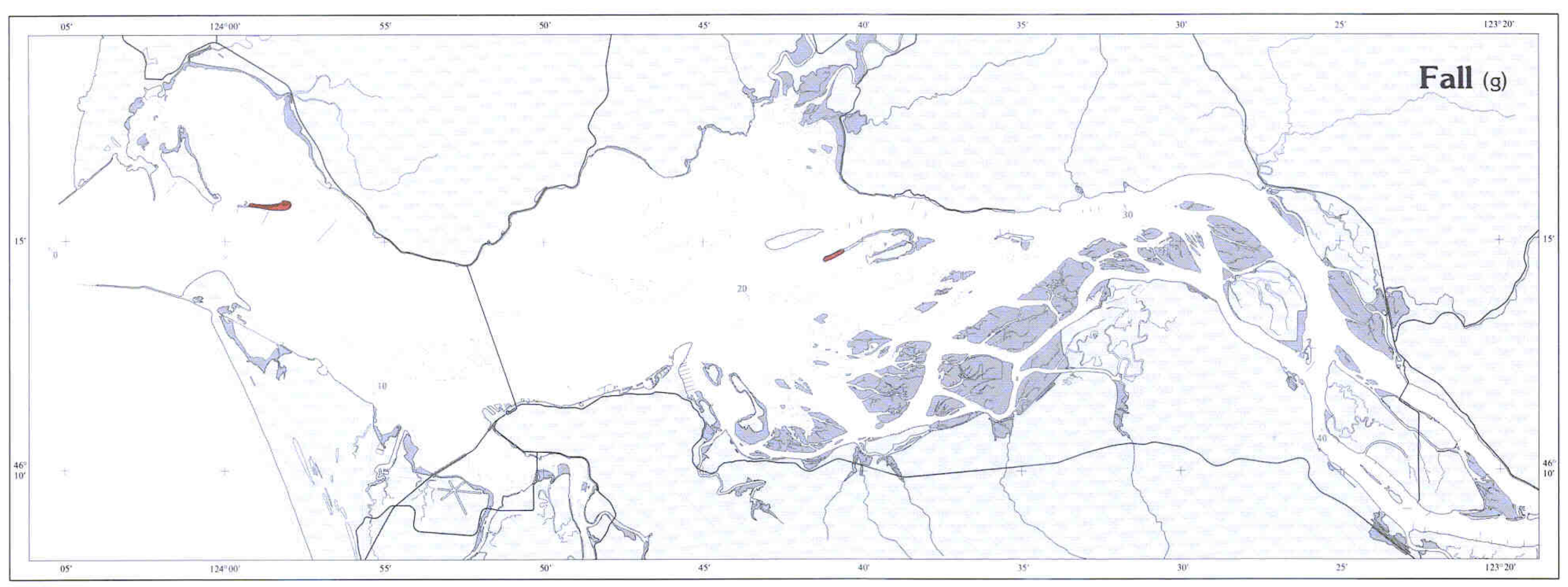
0 2 4 6 8 10 Kilometers

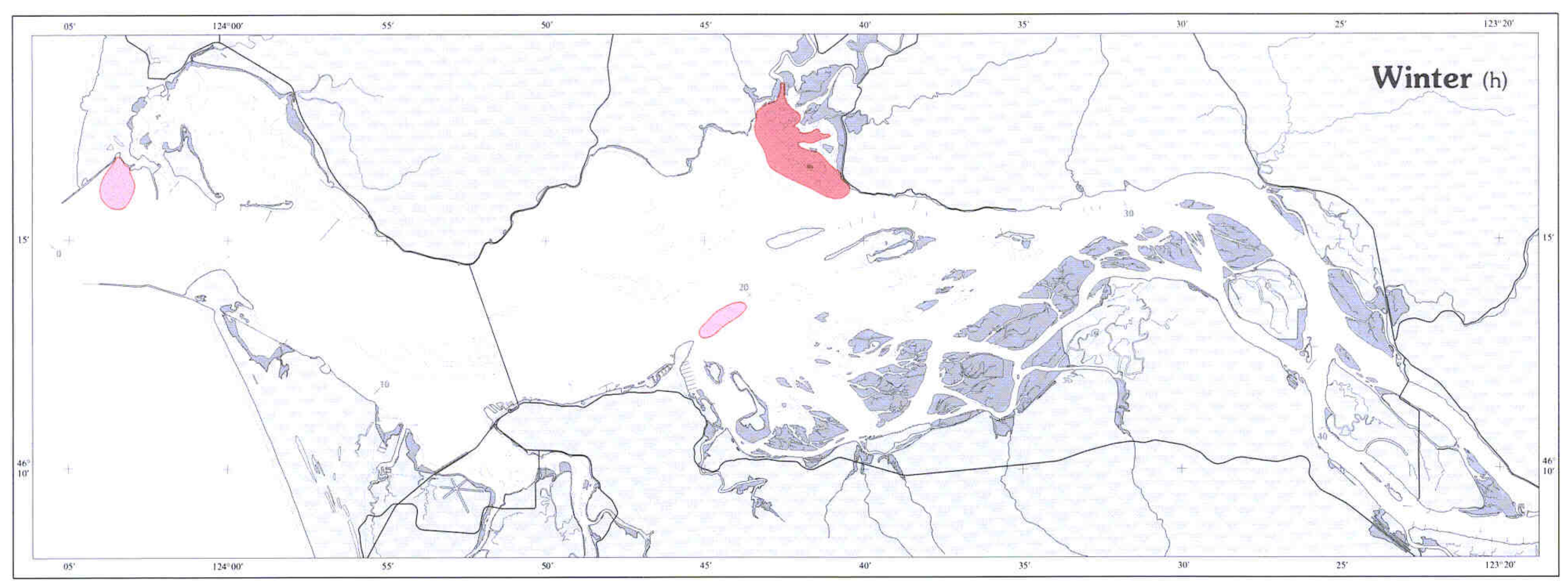
0 1 2 3 4 5 6 Miles

Hybrid Gulls*









Density (birds/km²)

- more than 20
- 10-20

Nesting

- Nesting colony

***Hybrid gulls include western gull *(Larus occidentalis)* and glaucous-winged gull *(Larus glaucescens)*.**

Bird density information is based on 1980-1981 CREDDP sampling. Maps were compiled in 1983 by Jones and Stokes Associates, Inc. (CREDDP avifauna investigators).

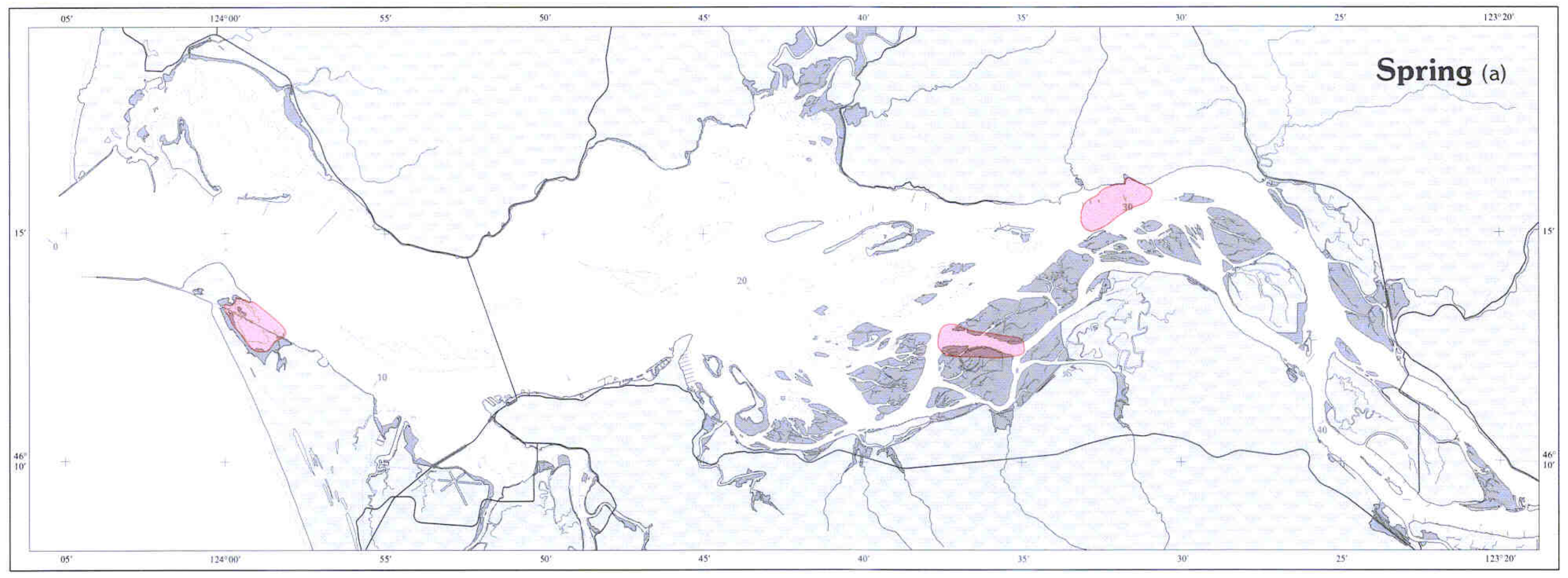
Scale 1:250,000

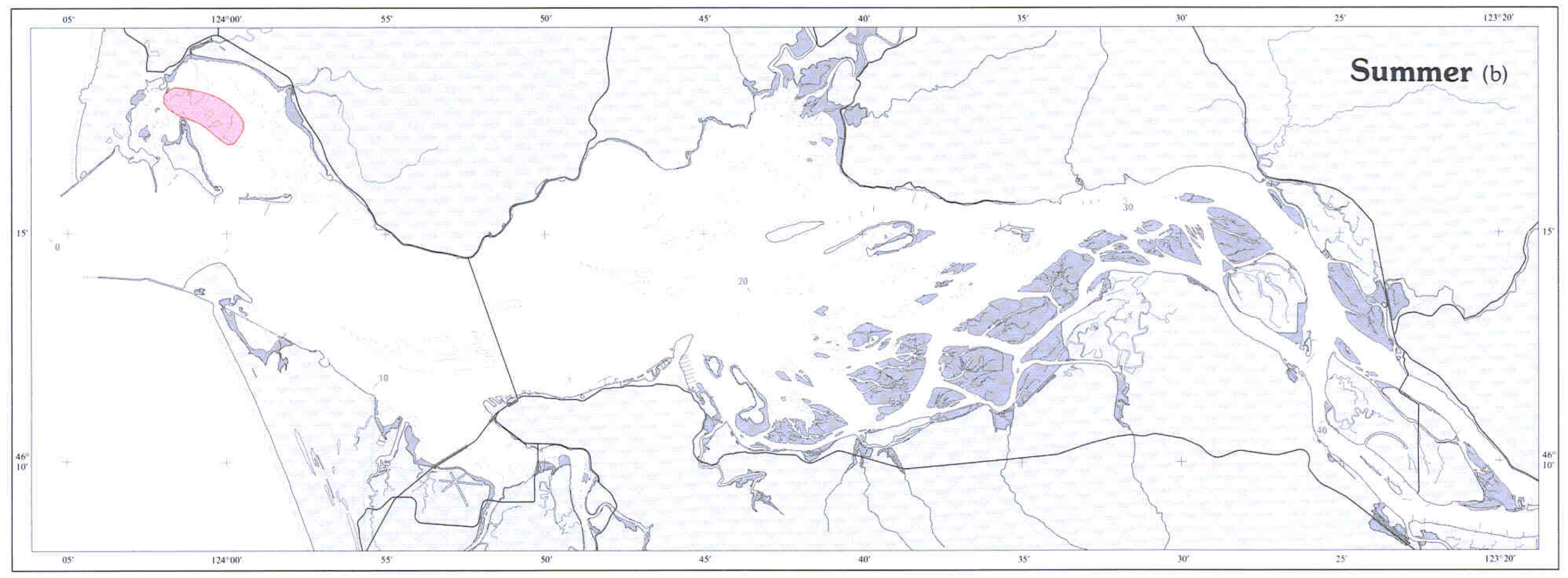
0 2 4 6 8 10 Kilometers

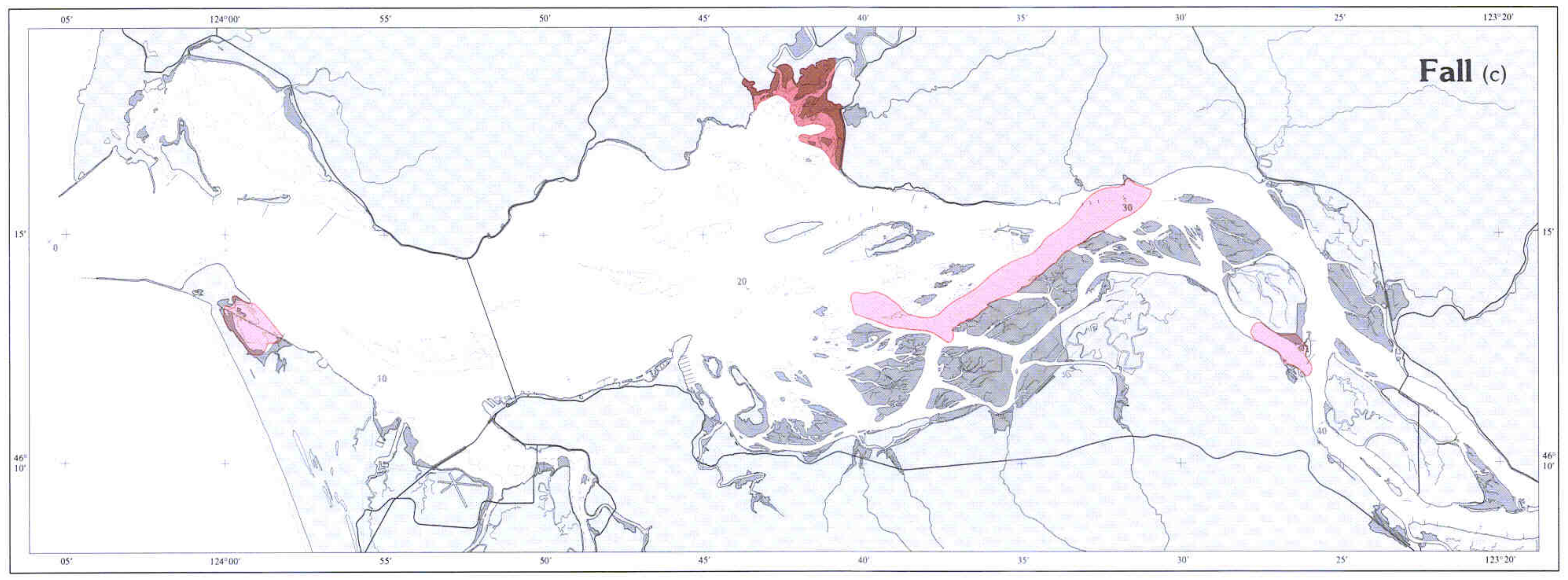
0 1 2 3 4 5 6 Miles

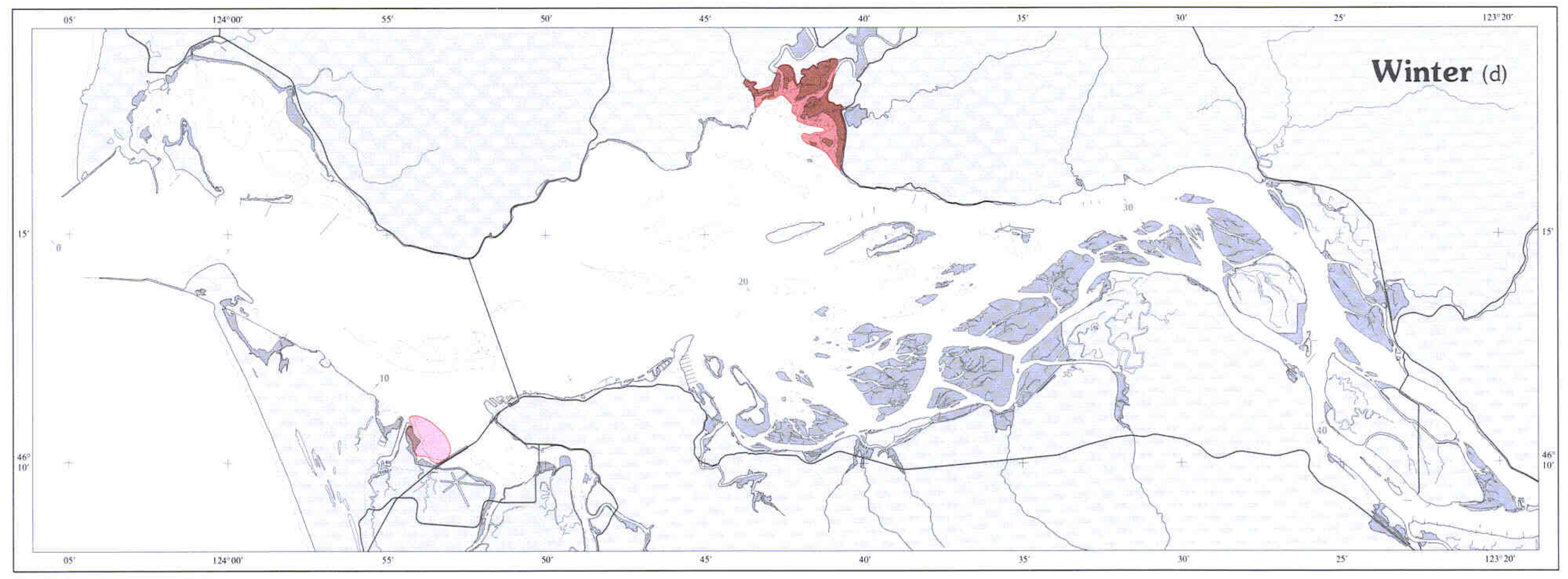
Mallard

(Anser platyrhynchos)









Density (birds/km²)

- more than 70
- 10-70

Bird density information is based on 1980-1981 CREDDP sampling. Maps were compiled in 1983 by Jones and Stokes Associates, Inc. (CREDDP avifauna investigators).

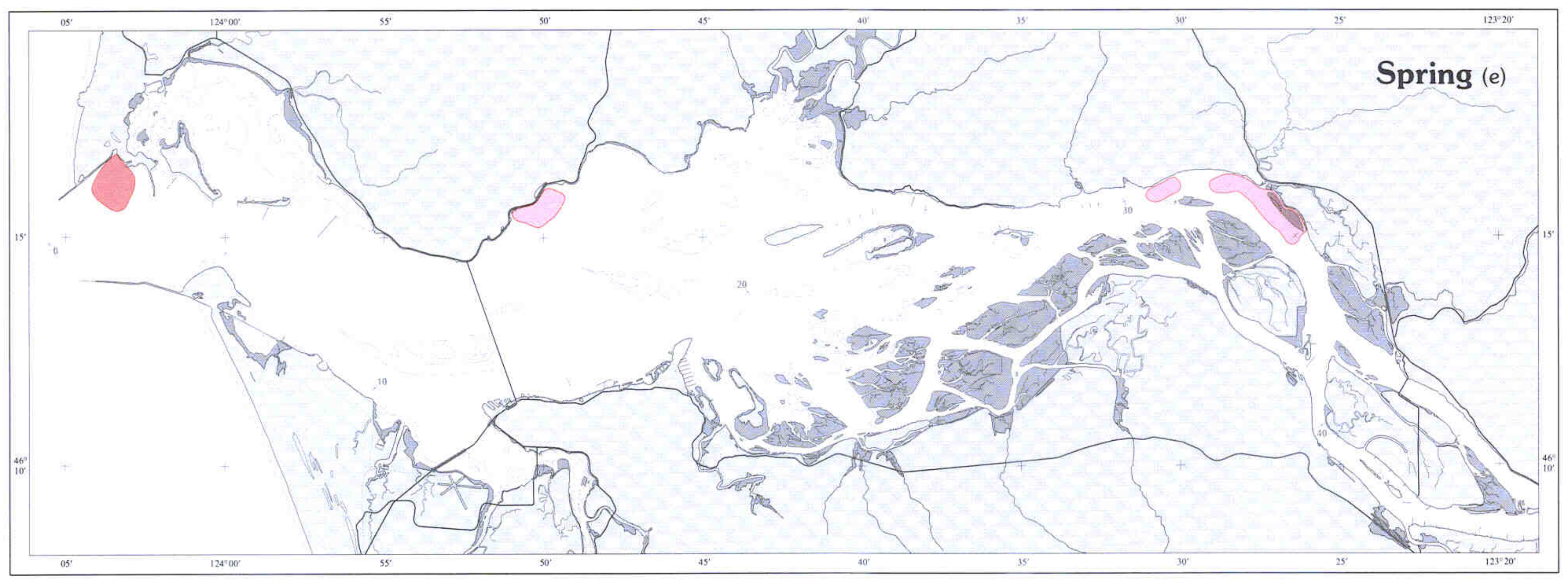
Scale 1:250,000

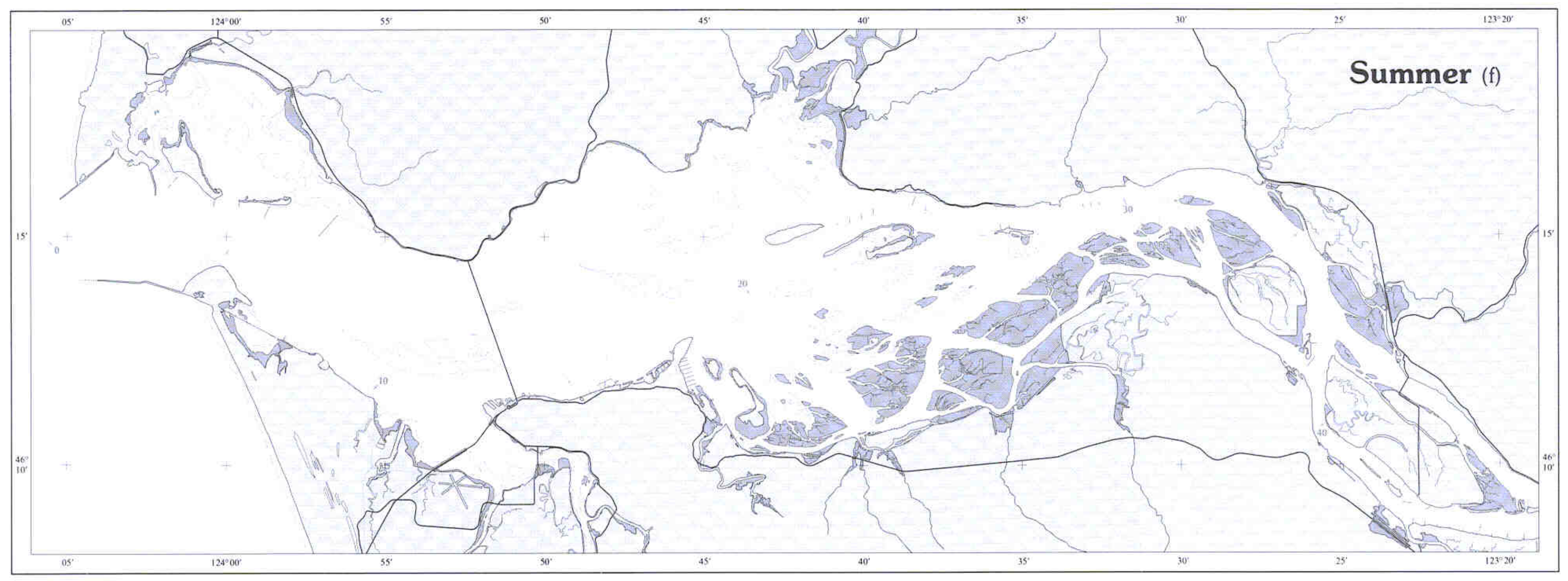
0 2 4 6 8 10 Kilometers

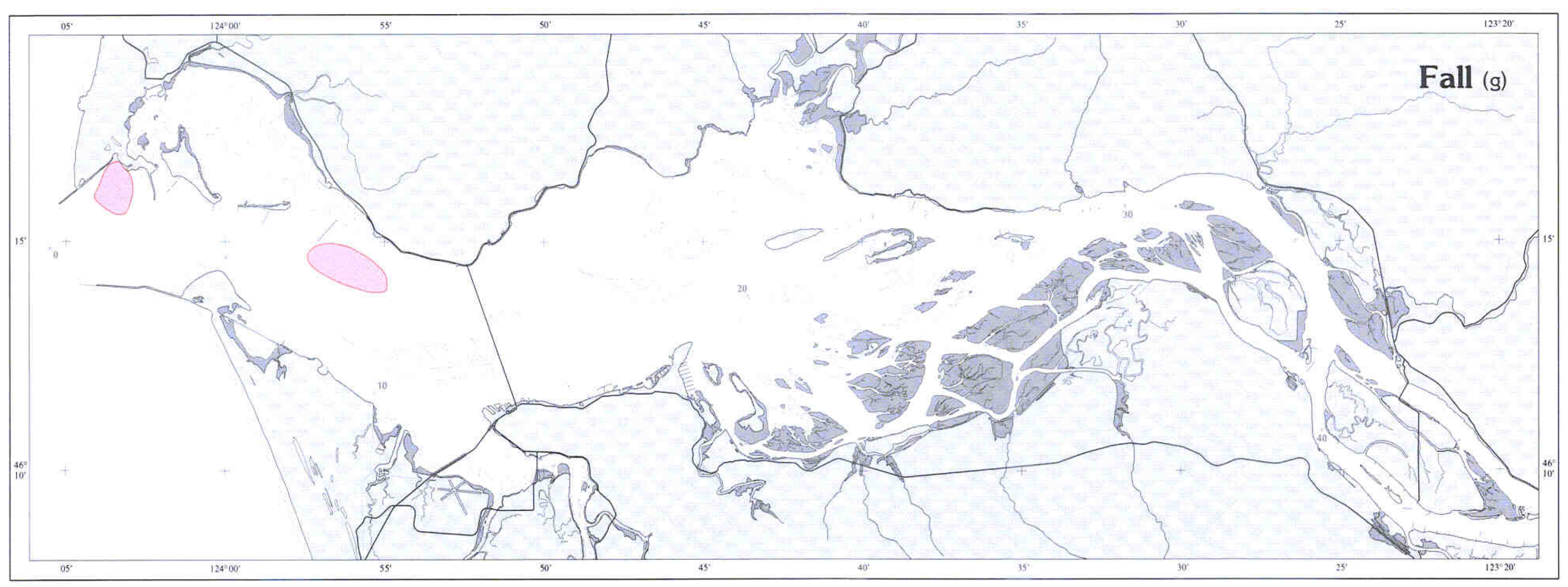
0 1 2 3 4 5 6 Miles

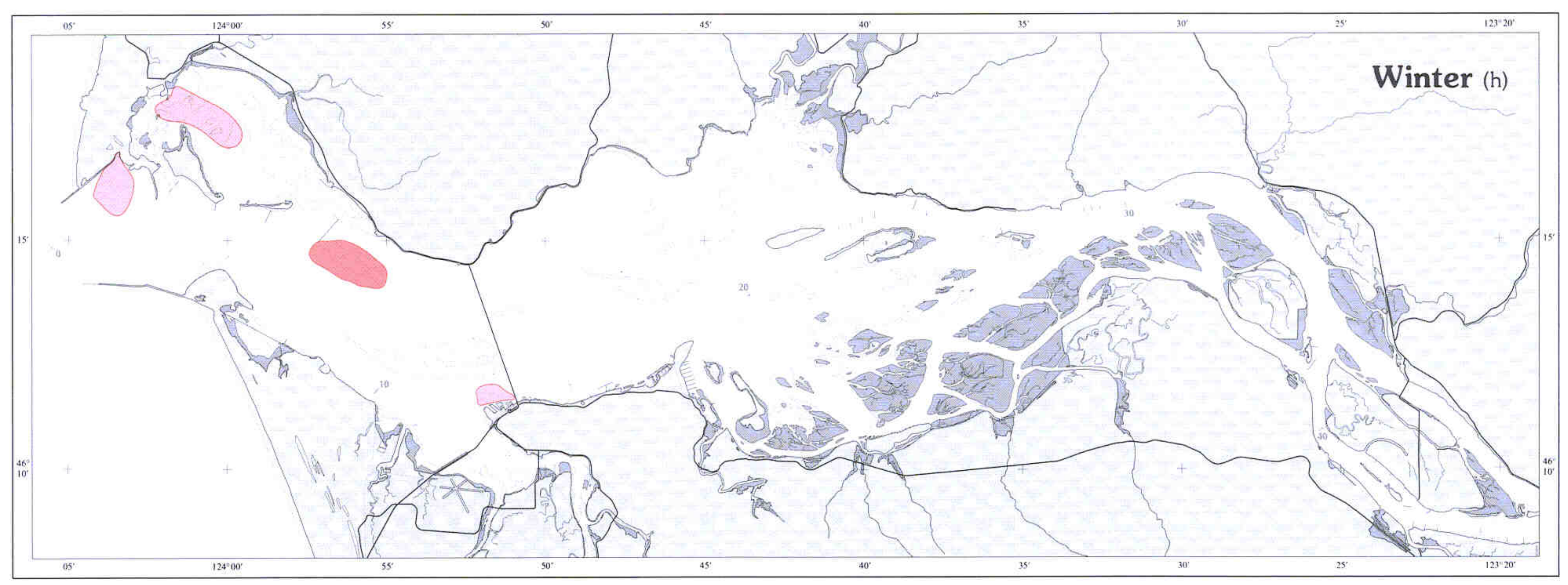
Surf Scoter

(Melanitta perspicillata)









Density (birds/km²)

- more than 70
- 10-70

Bird density information is based on 1980-1981 CREDDP sampling. Maps were compiled in 1983 by Jones and Stokes Associates, Inc. (CREDDP avifauna investigators).

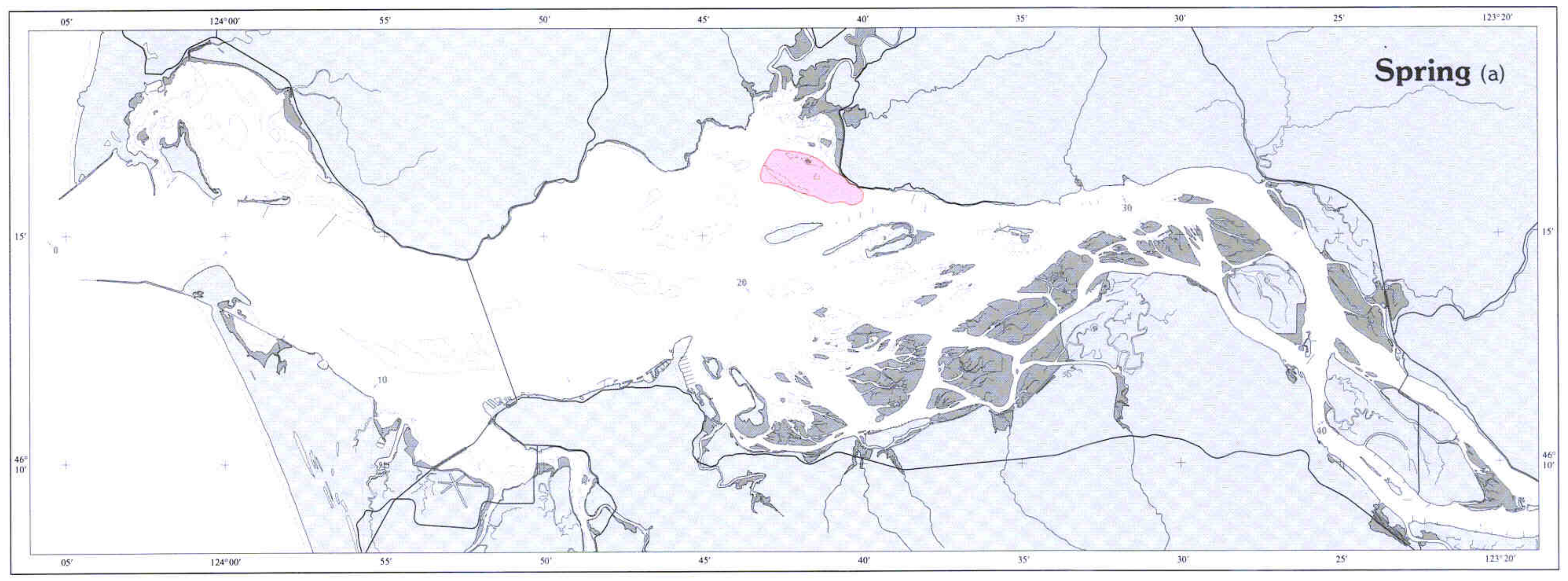
Scale 1:250,000

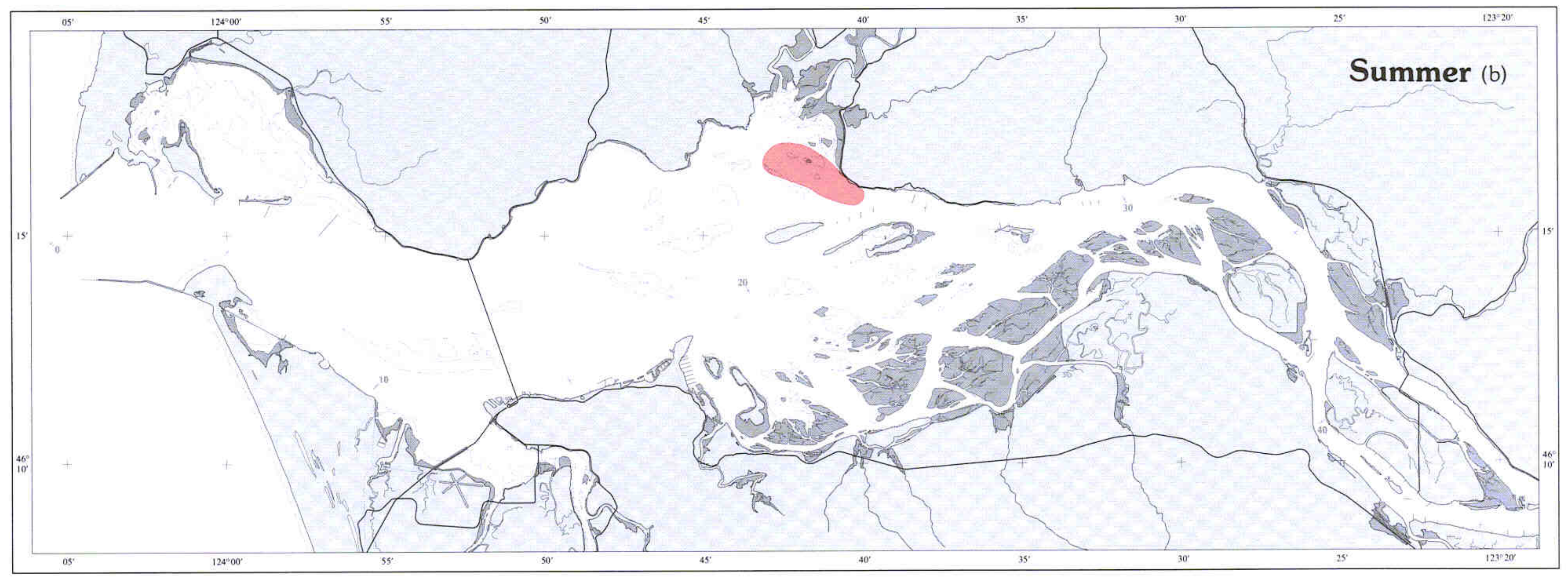
0 2 4 6 8 10 Kilometers

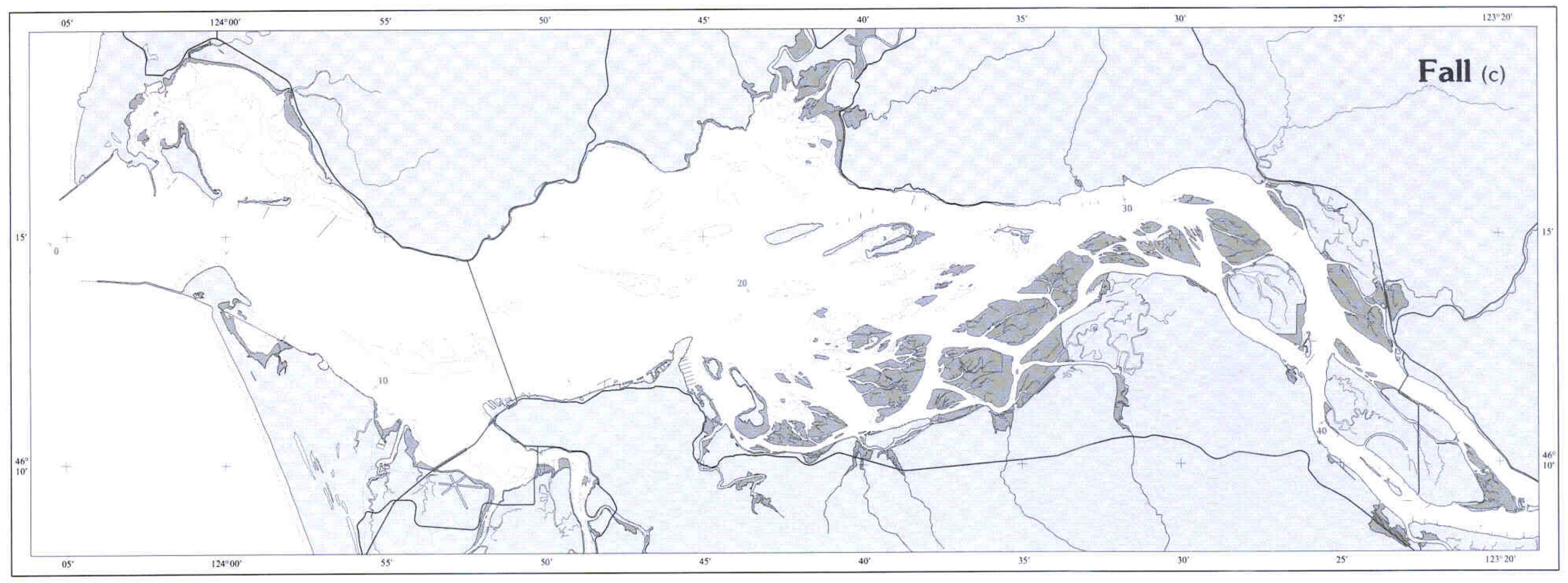
0 1 2 3 4 5 6 Miles

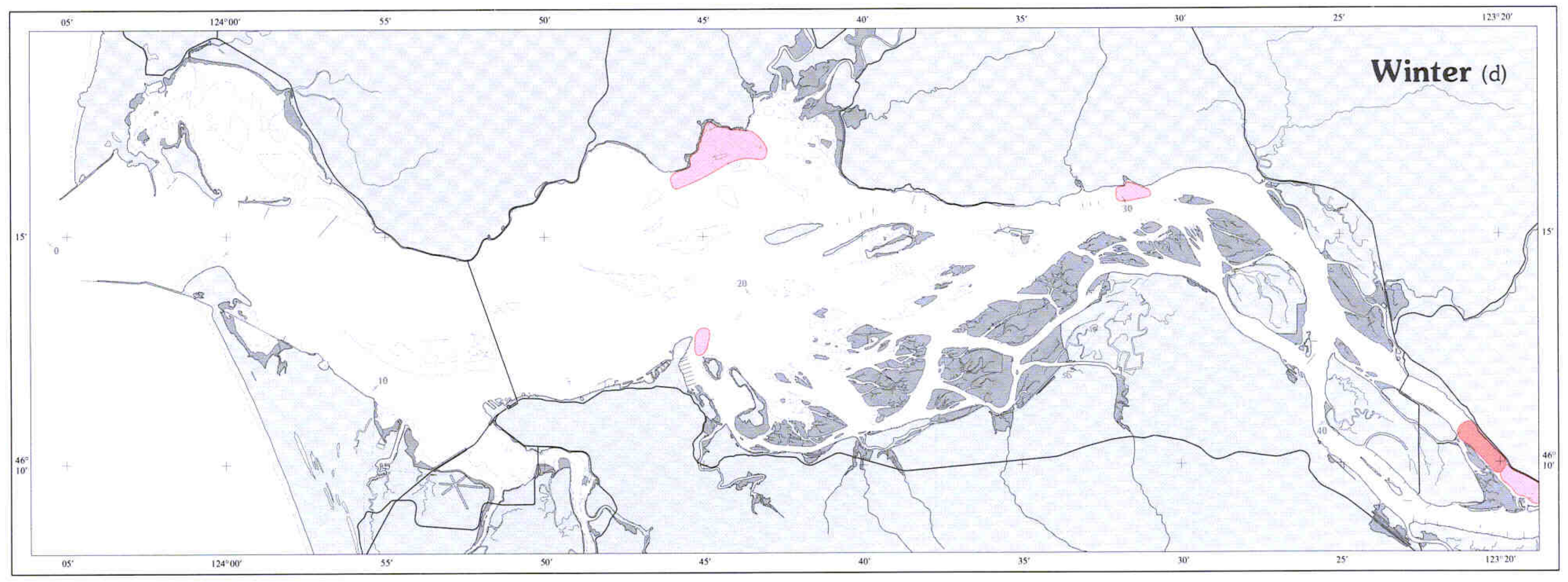
Common Merganser

(Mergus merganser)









Density (birds/km²)

- more than 40
- 10-40

Bird density information is based on 1980-1981 CREDDP sampling. Maps were compiled in 1983 by Jones and Stokes Associates, Inc. (CREDDP avifauna investigators).

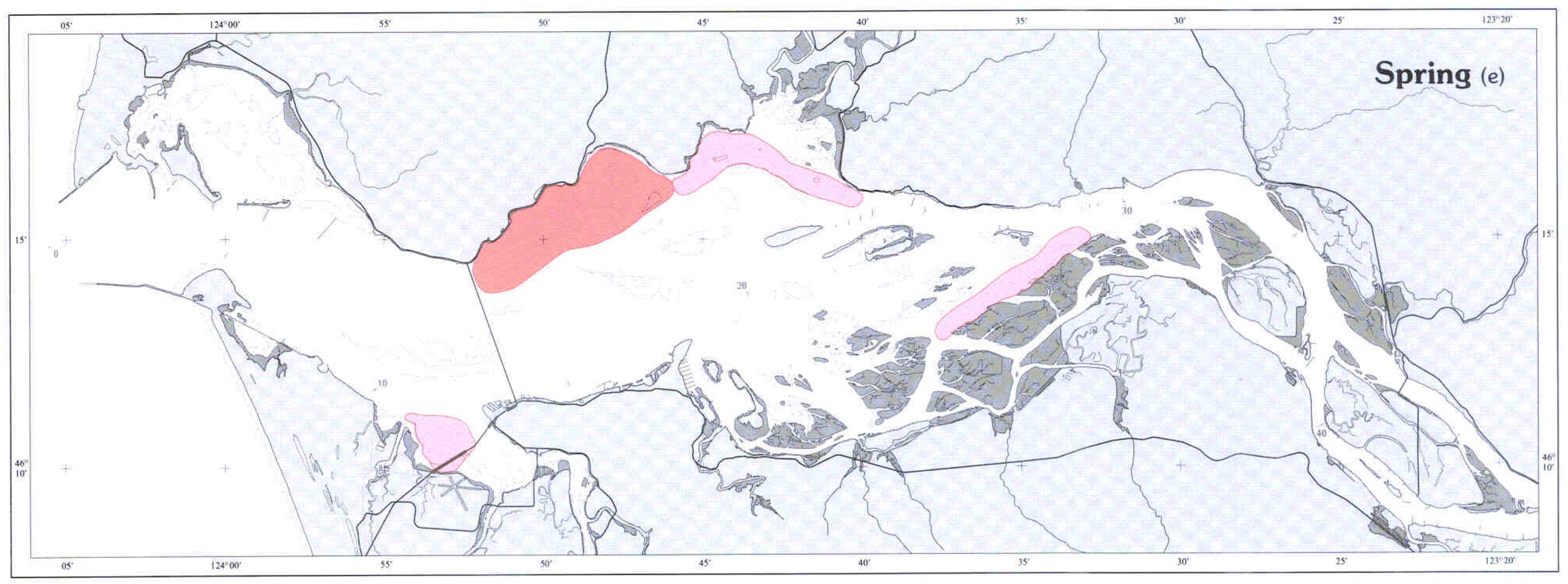
Scale 1:250,000

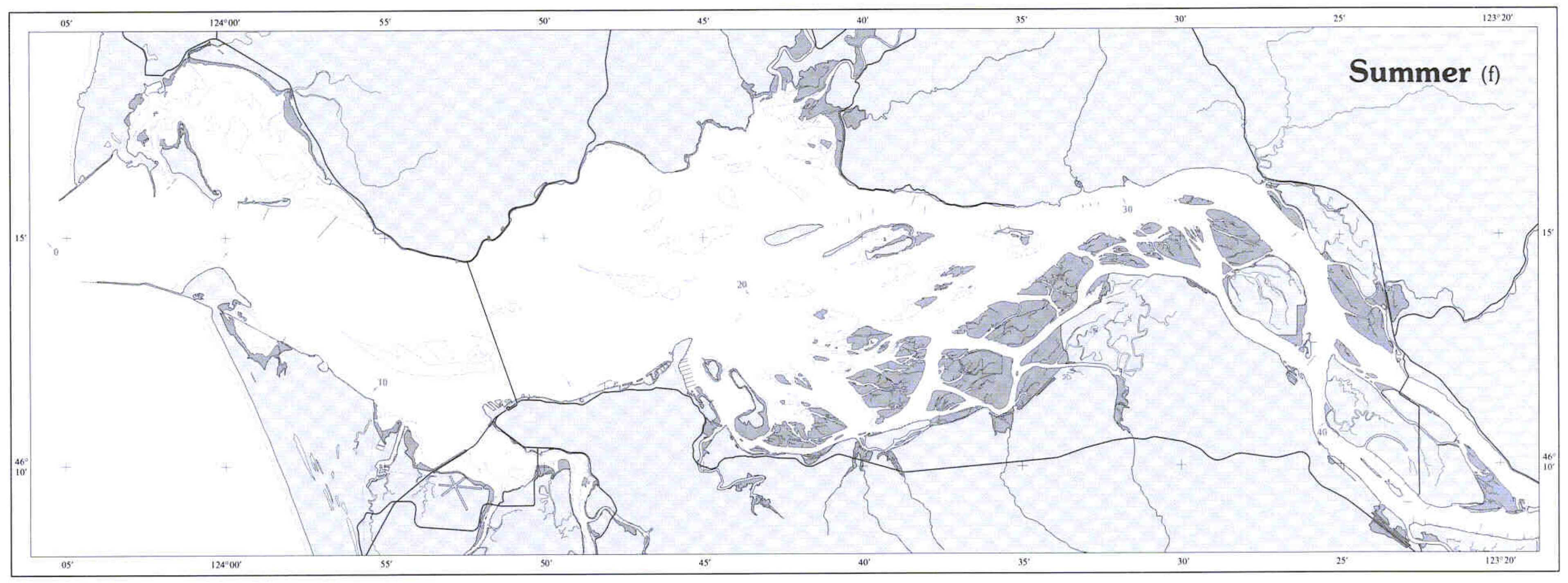
0 2 4 6 8 10 Kilometers

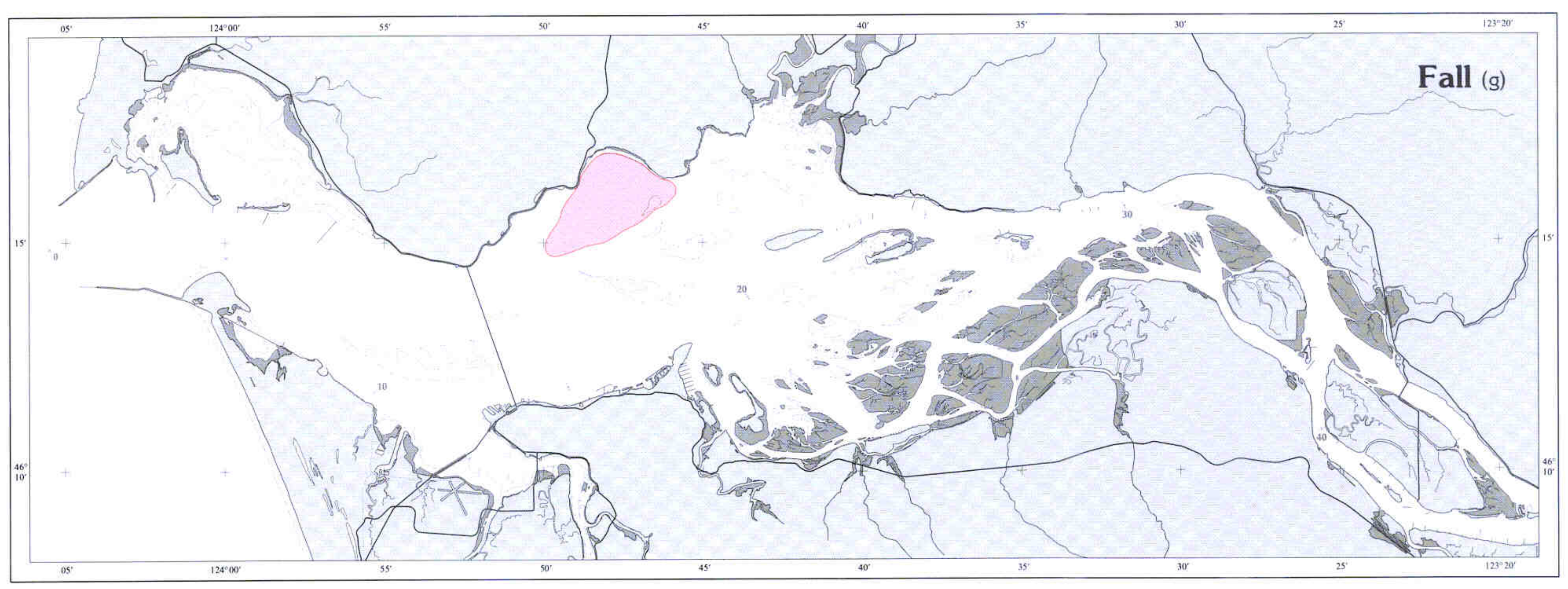
0 1 2 3 4 5 6 Miles

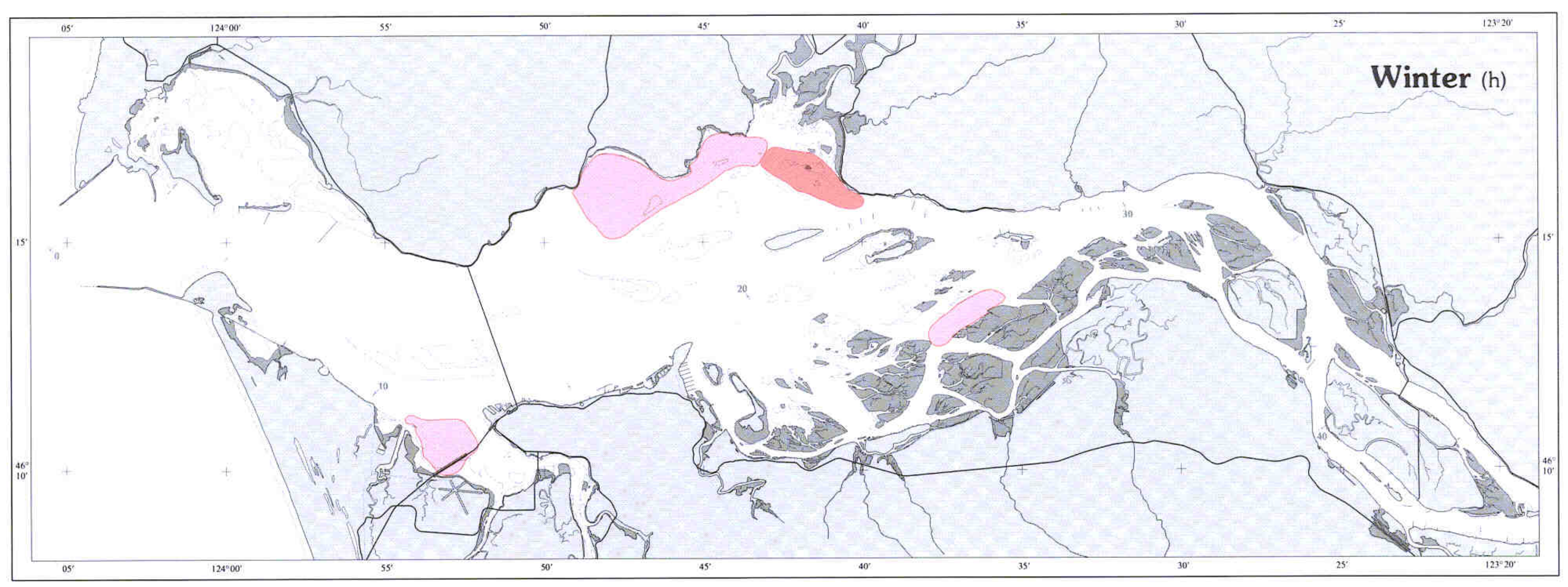
Western Grebe

(Aechmophorus occidentalis)









Density (birds/km²)

- more than 200
- 20-200

Bird density information is based on 1980-1981 CREDDP sampling. Maps were compiled in 1983 by Jones and Stokes Associates, Inc. (CREDDP avifauna investigators).

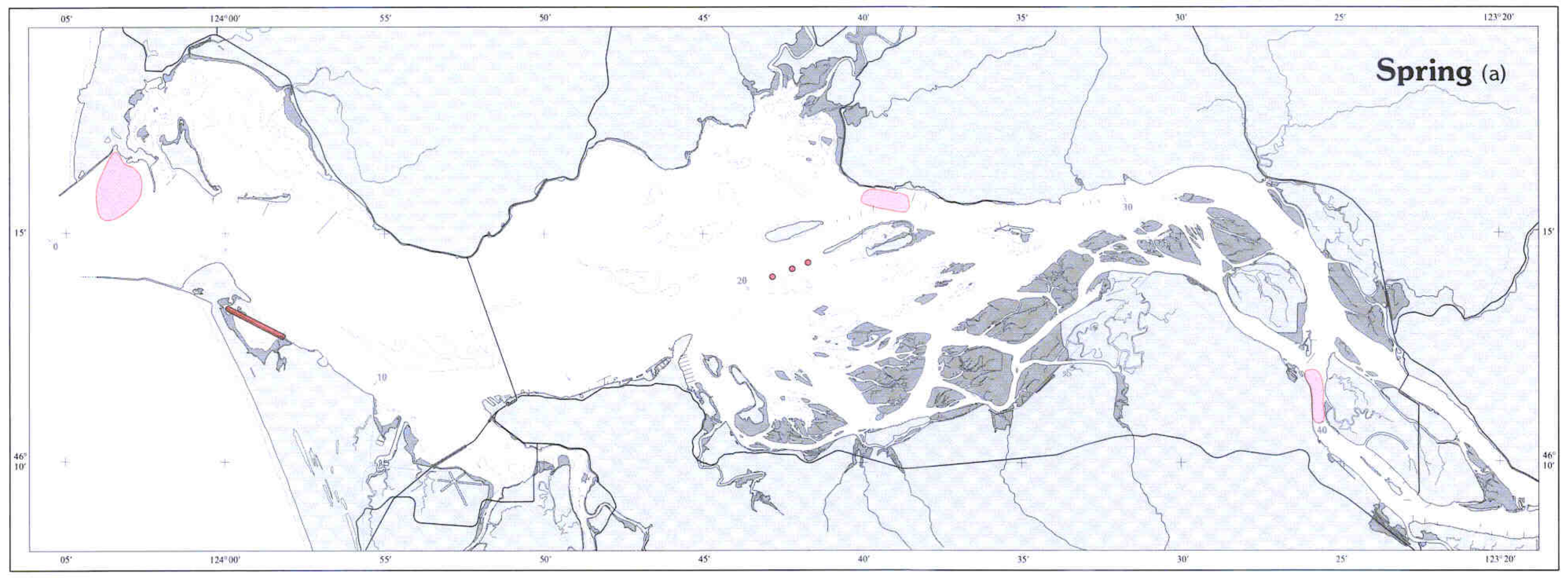
Scale 1:250,000

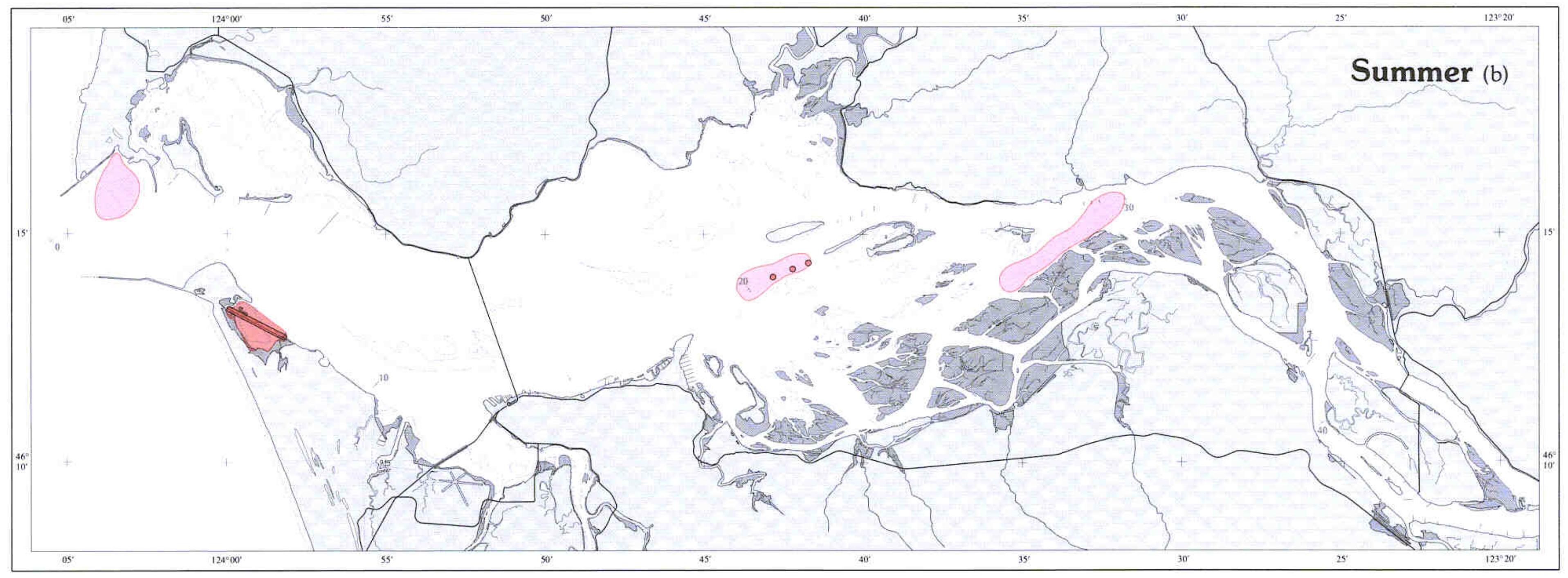
0 2 4 6 8 10 Kilometers

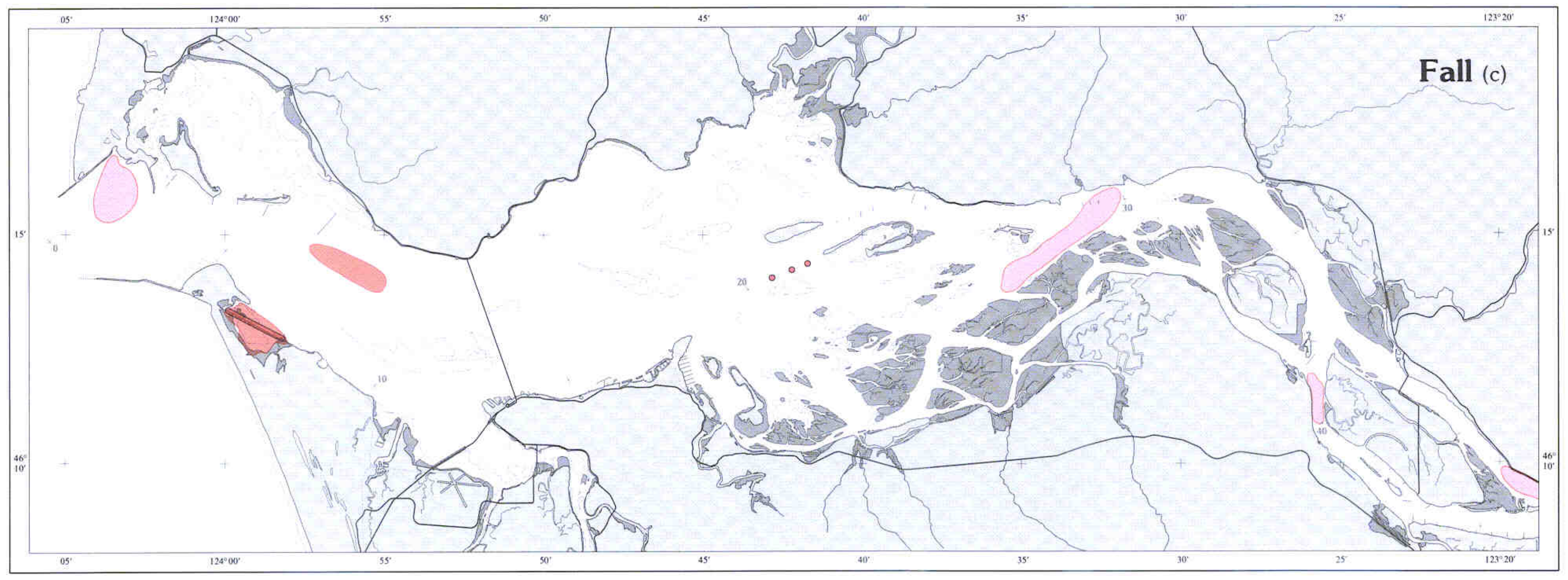
0 1 2 3 4 5 6 Miles

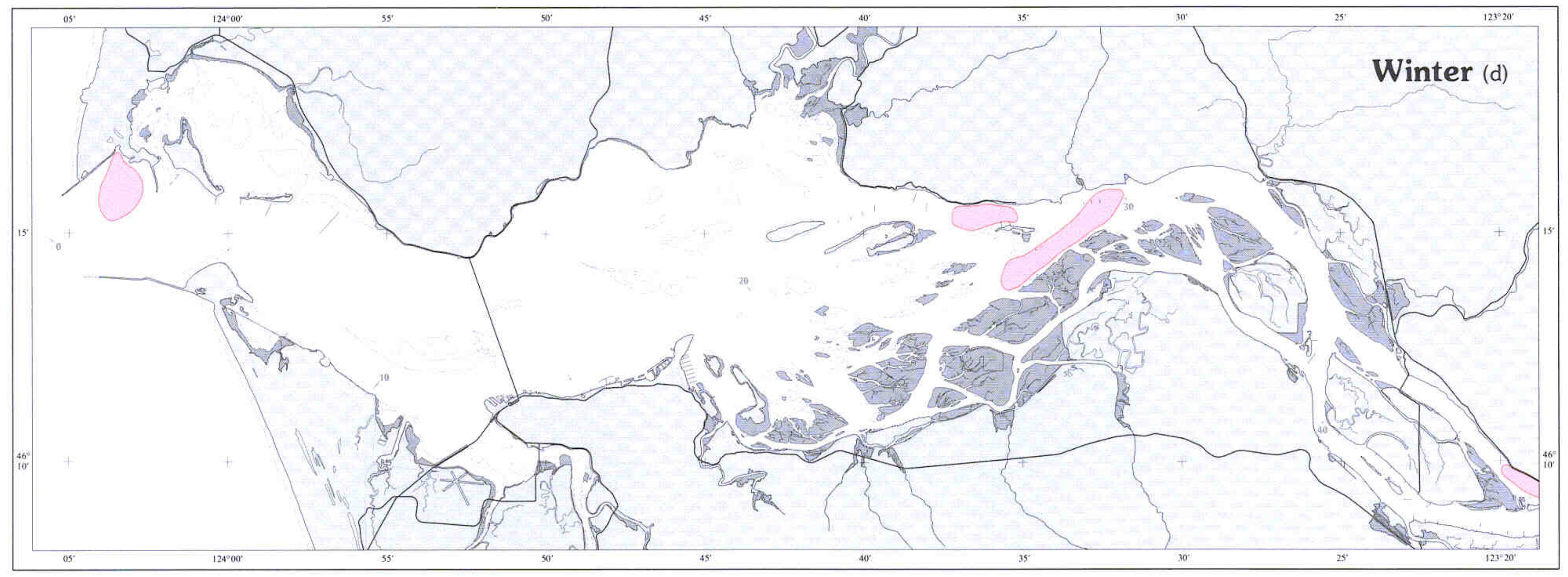
Double-Crested Cormorant

(Phalacrocorax auritus)









Density (birds/km²)

- more than 100
- 10-100

Nesting

- Nesting colony

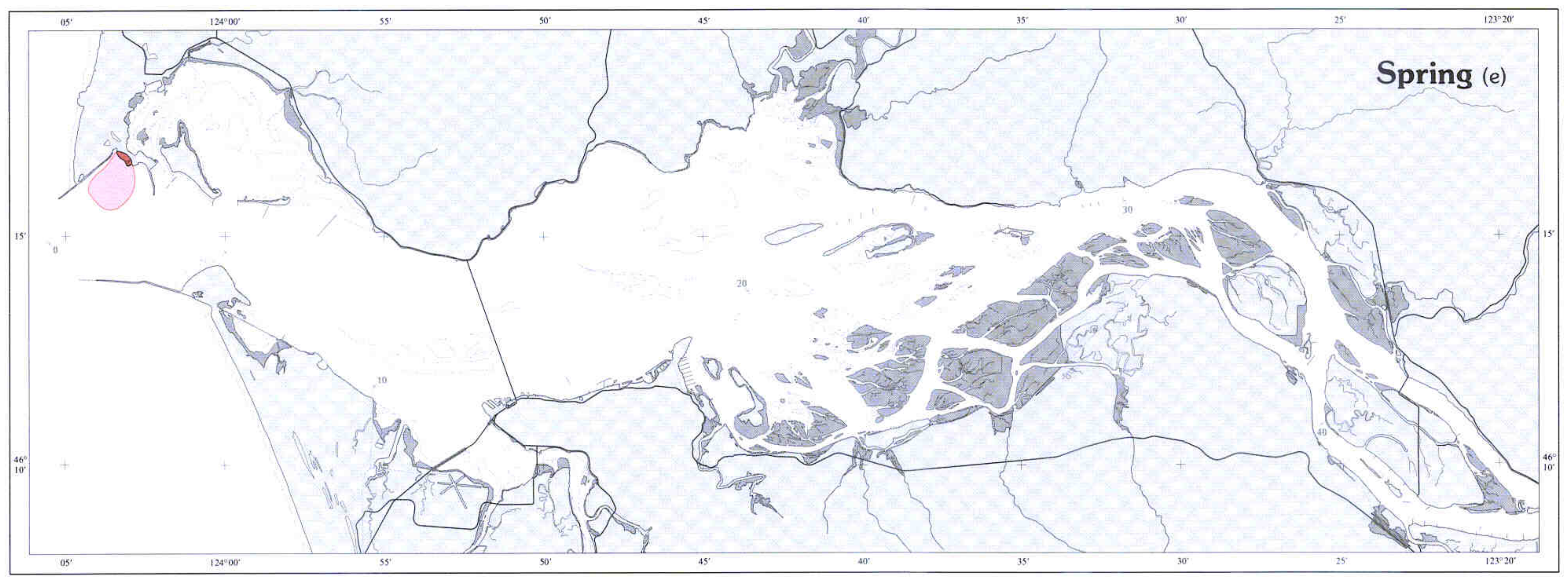
Bird density information is based on 1980-1981 CREDDP sampling. Maps were compiled in 1983 by Jones and Stokes Associates, Inc. (CREDDP avifauna investigators).

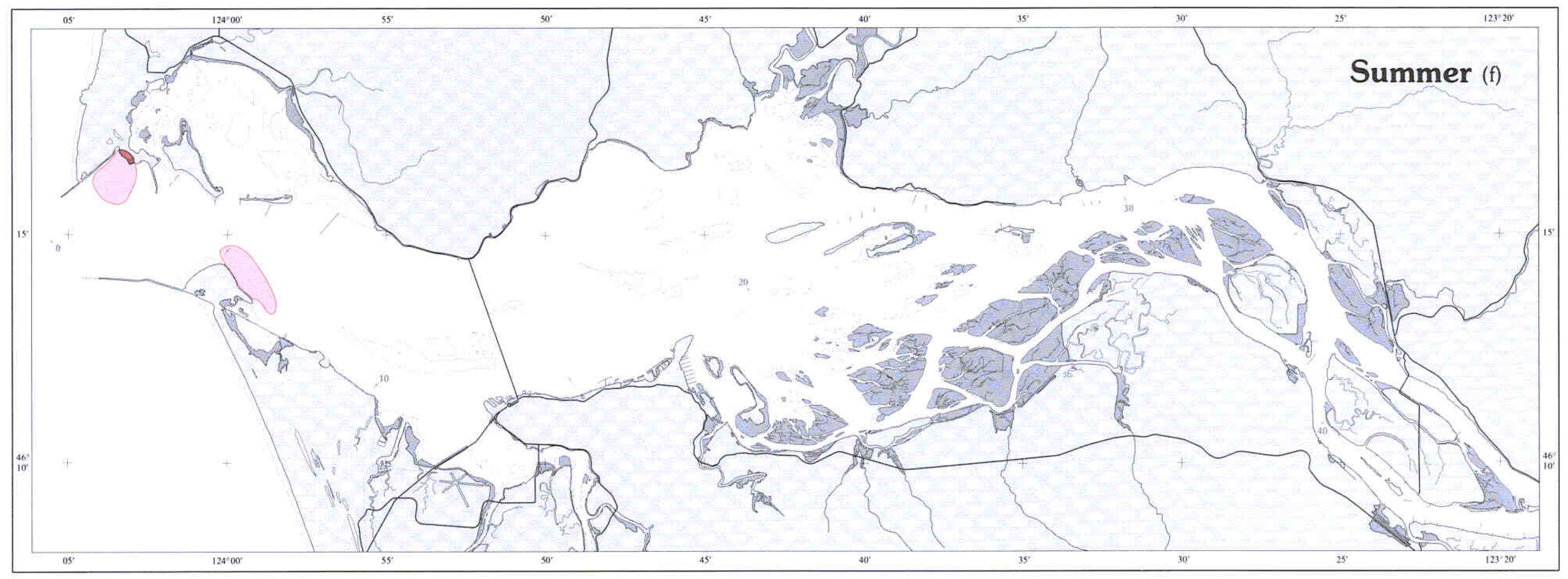
Scale 1:250,000

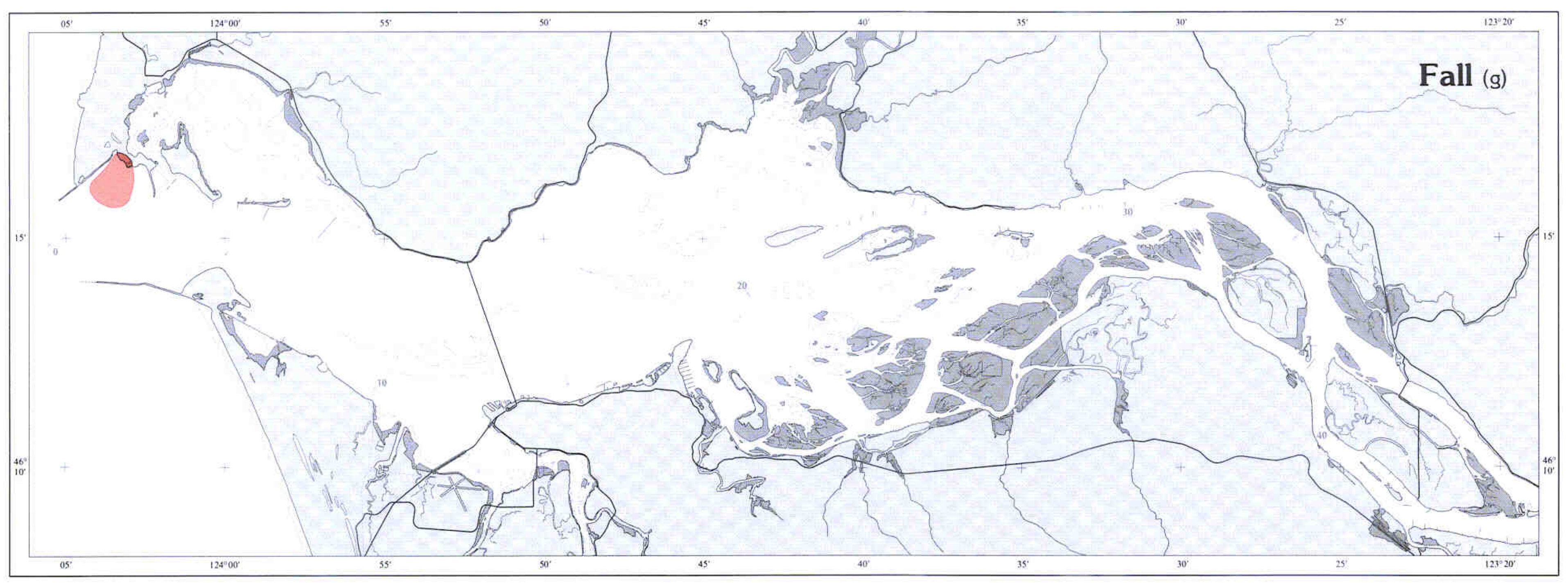
0 2 4 6 8 10 Kilometers
0 1 2 3 4 5 6 Miles

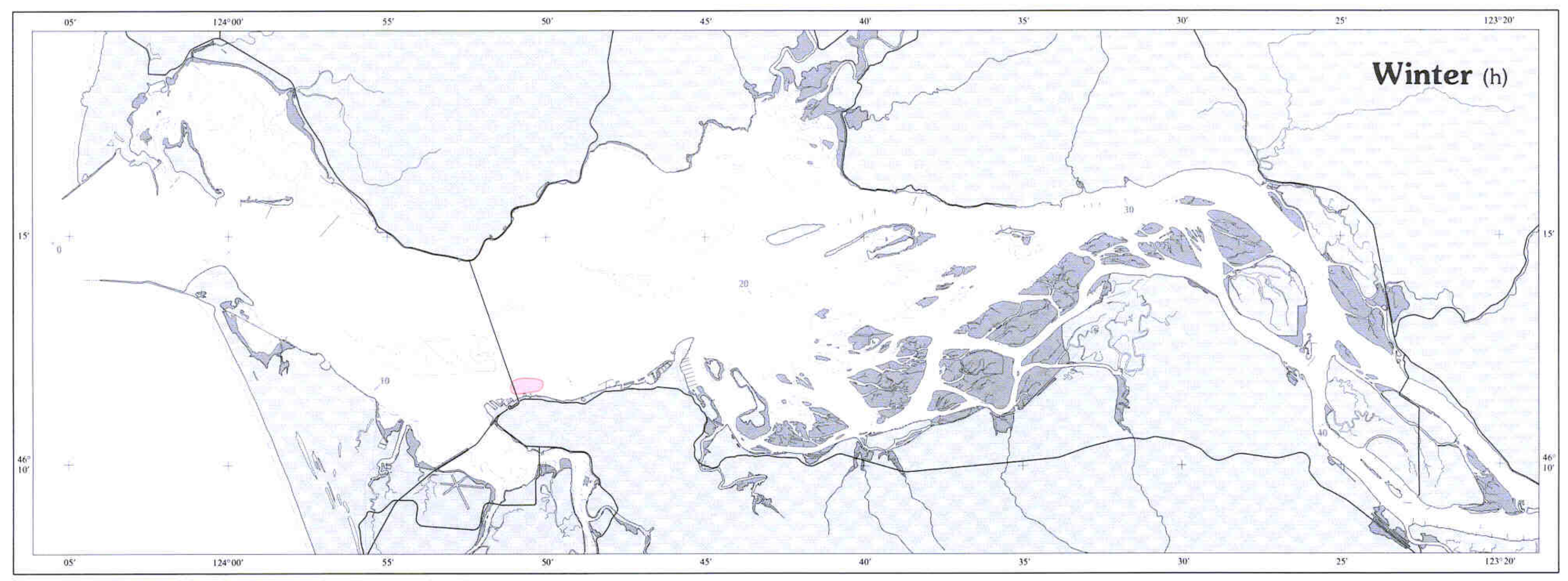
Pelagic Cormorant

(Phalacrocorax pelagicus)









Density (birds/km²)

- more than 70
- 20-70

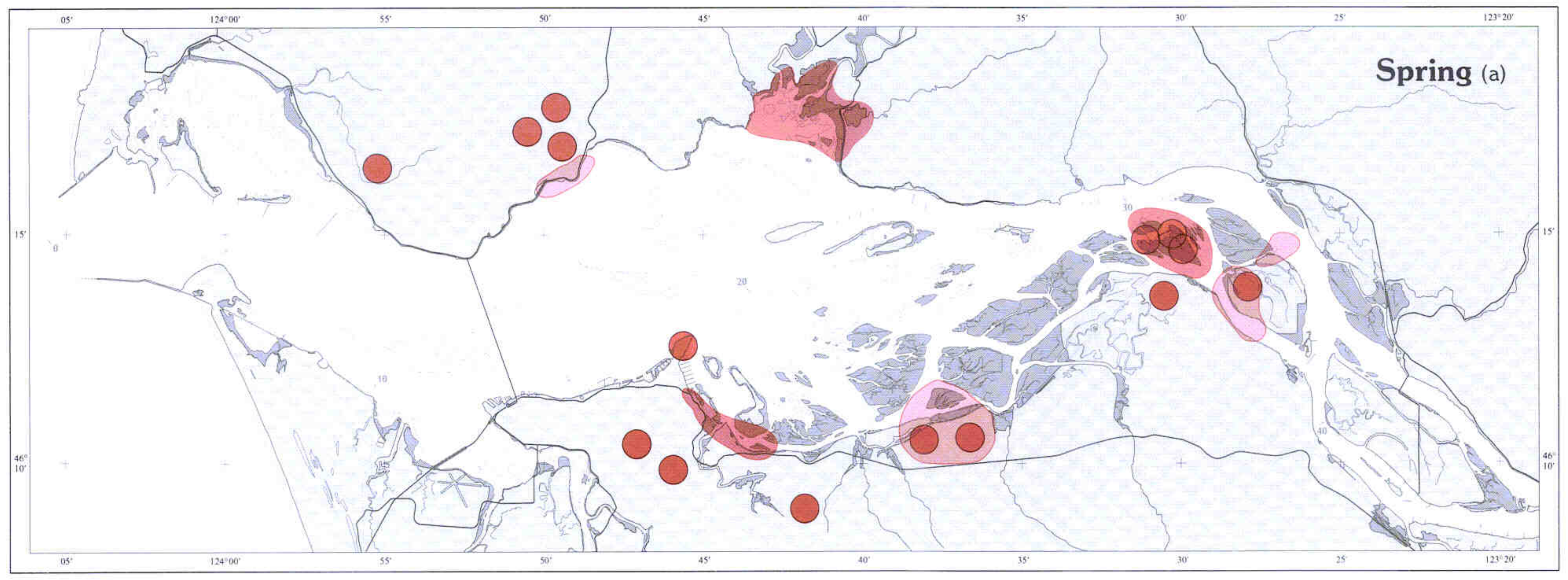
Nesting

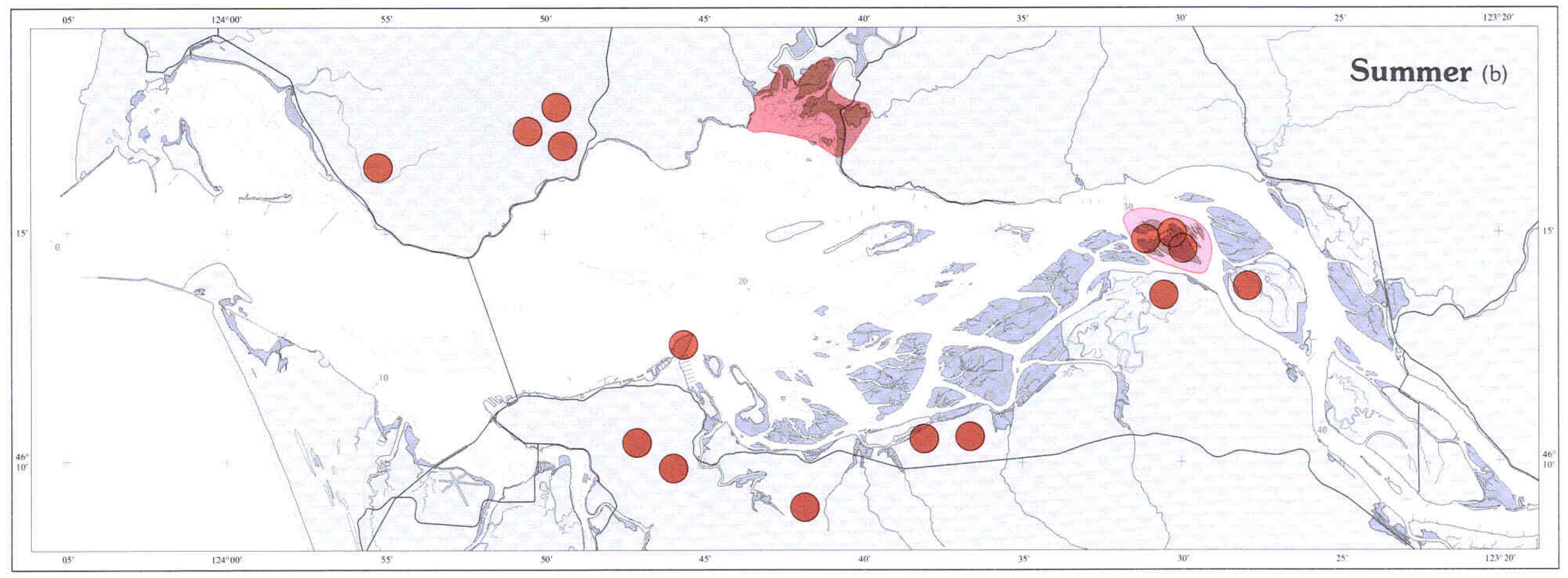
- Nesting colony

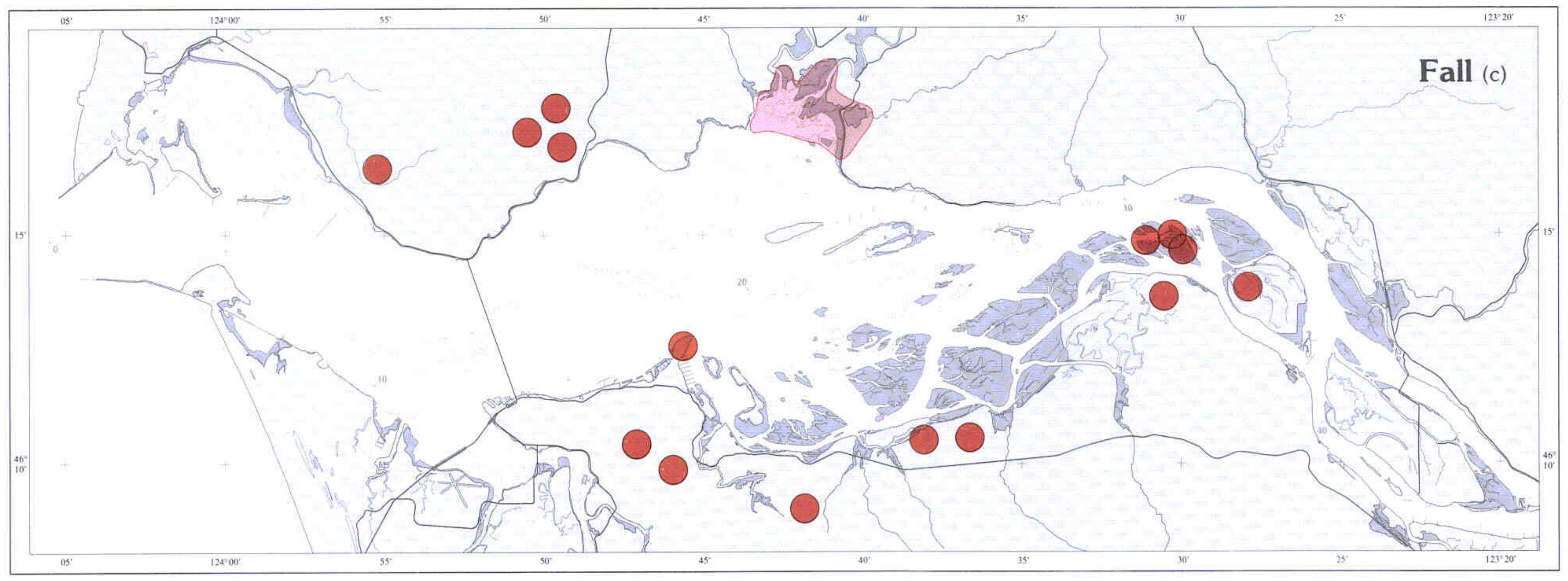
Bird density information is based on 1980-1981 CREDDP sampling. Maps were compiled in 1983 by Jones and Stokes Associates, Inc. (CREDDP avifauna investigators).

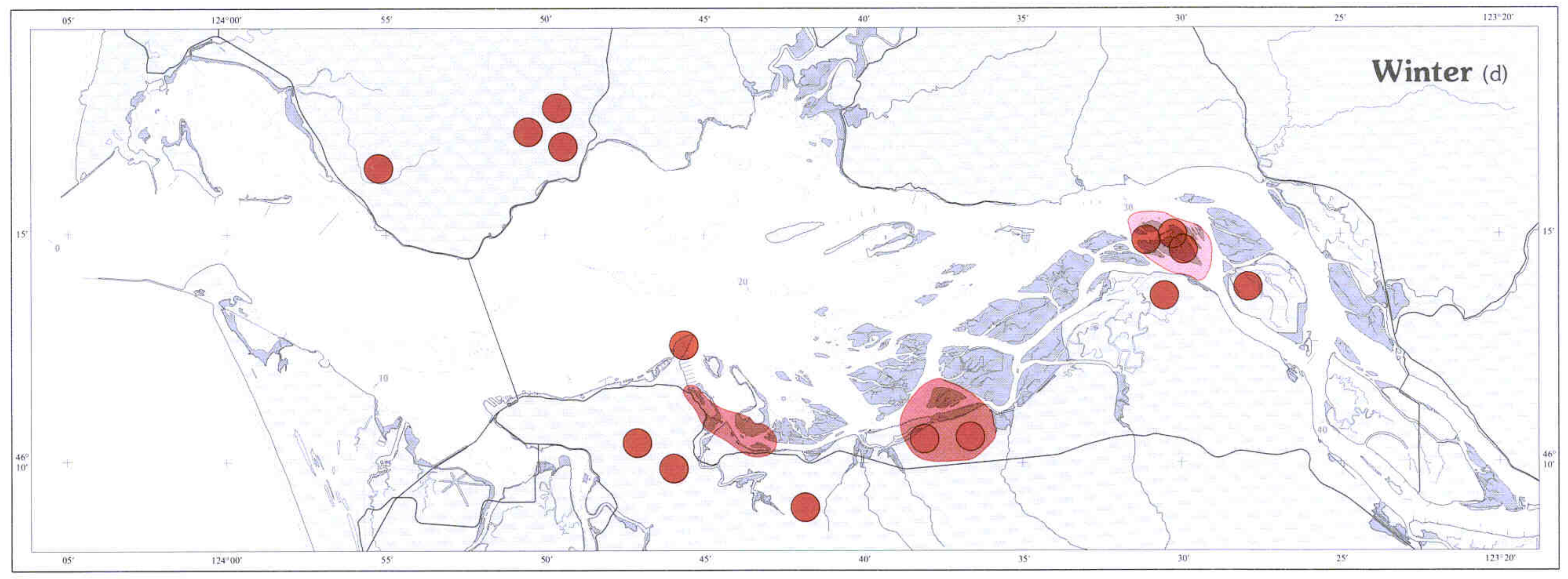
Scale 1:250,000

0 2 4 6 8 10 Kilometers
0 1 2 3 4 5 6 Miles









Bald Eagle

(Haliaeetus leucocephalus)

Incidental sightings*

more than 10

5-10

Nesting

Nesting site

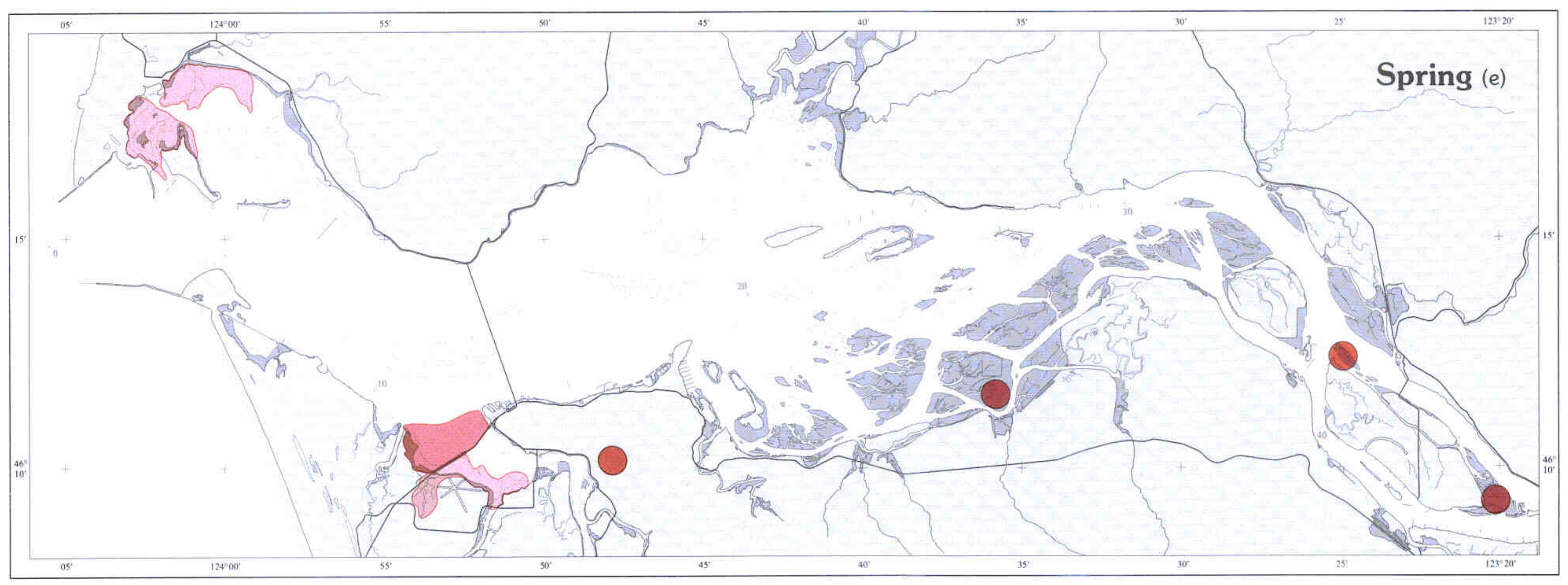
*Incidental sightings indicate relative intensity of use. Numbers represent total sightings for each season.

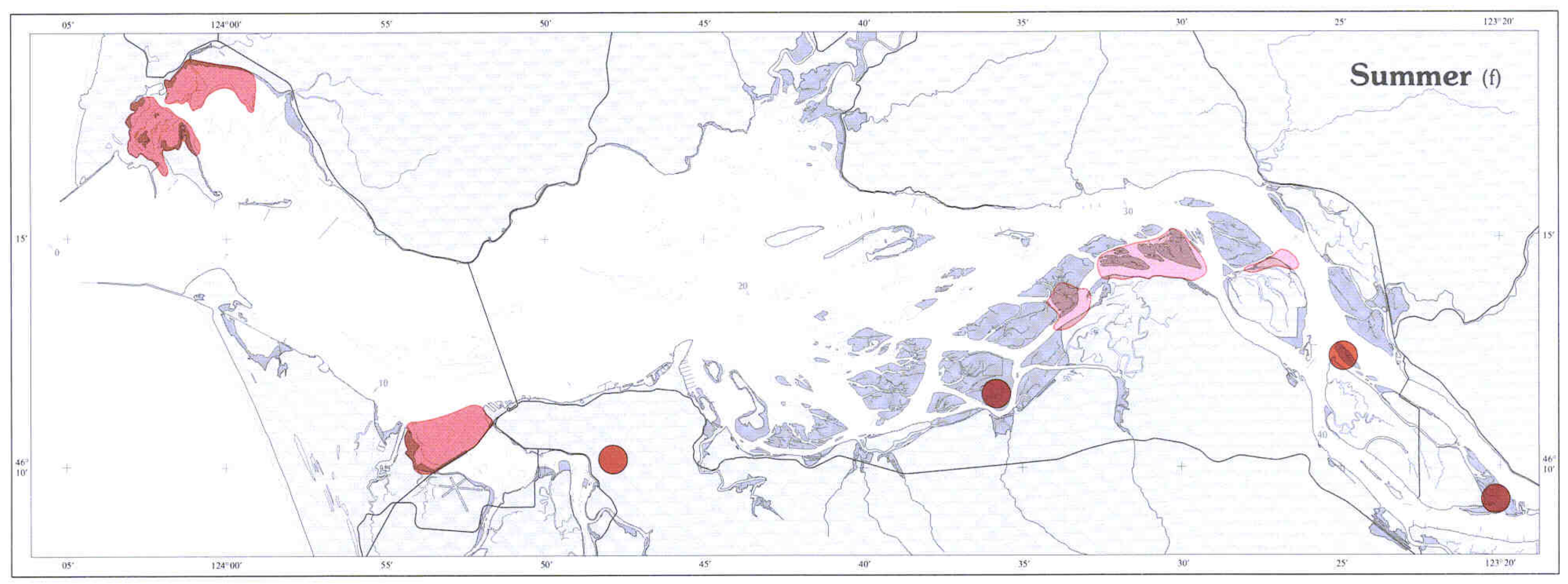
Incidental sightings information is based on 1980-1981 CREDDP sampling. Maps were compiled in 1983 by Jones and Stokes Associates, Inc. (CREDDP avifauna investigators).

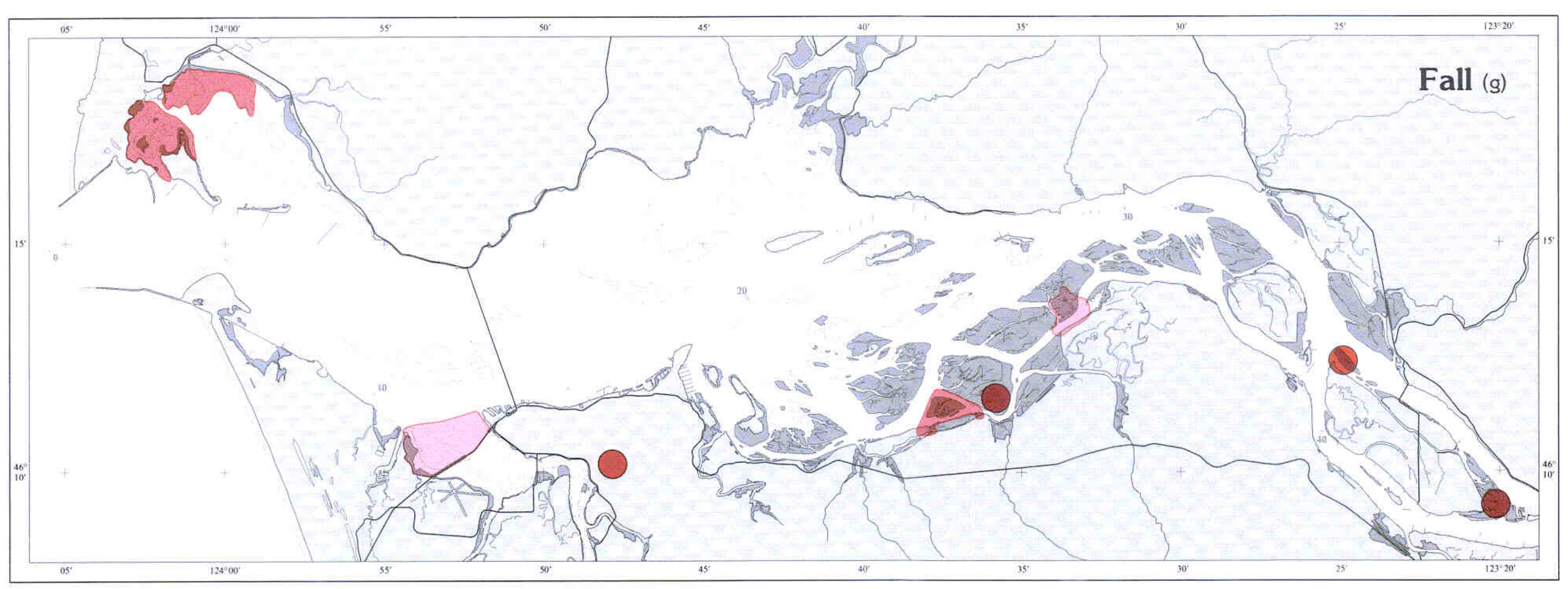
Scale 1:250,000

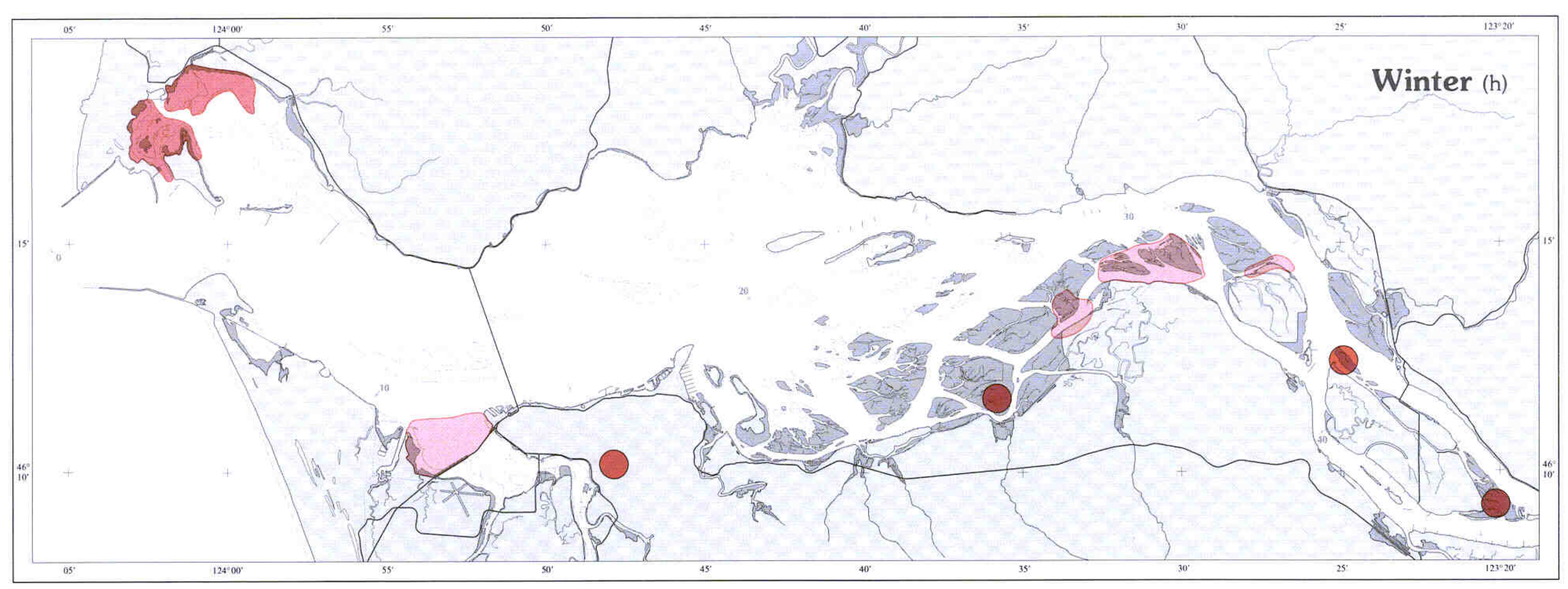
0 2 4 6 8 10 Kilometers

0 1 2 3 4 5 6 Miles









Great Blue Heron

(Ardea herodias)

Incidental sightings*

more than 20

10-20

Nesting

Nesting colony

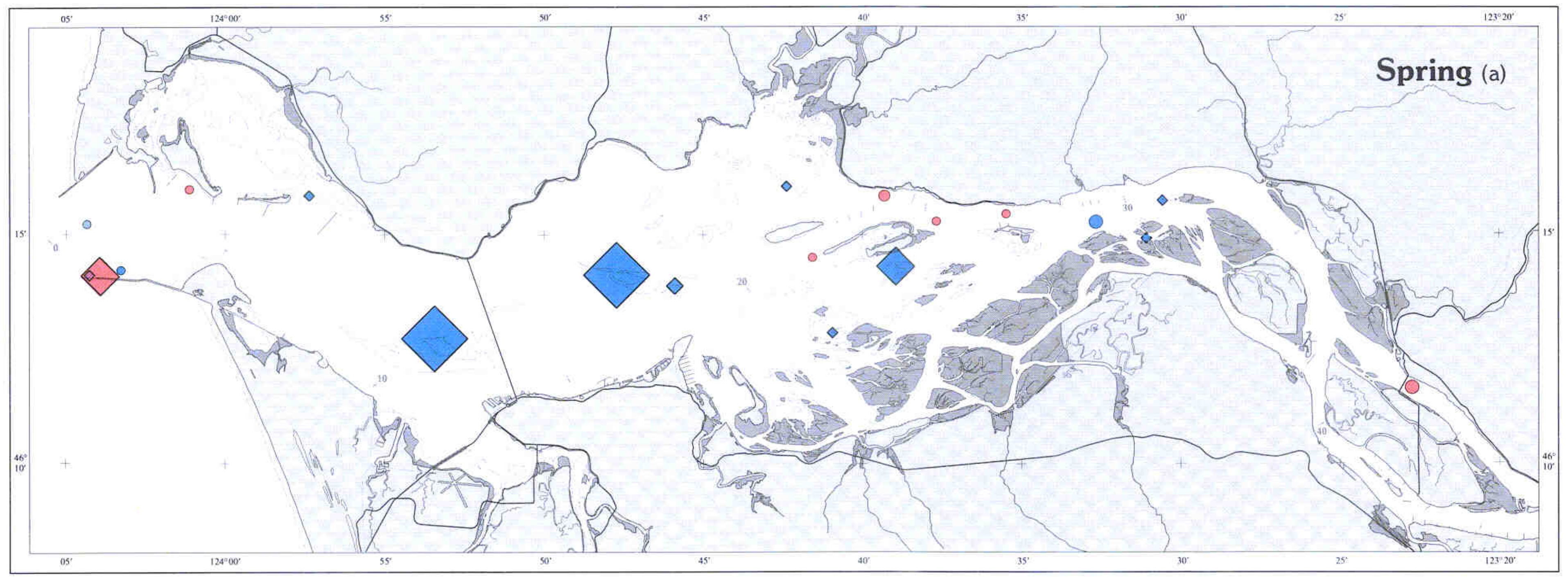
*Incidental sightings indicate relative intensity of use. Numbers represent total sightings for each season.

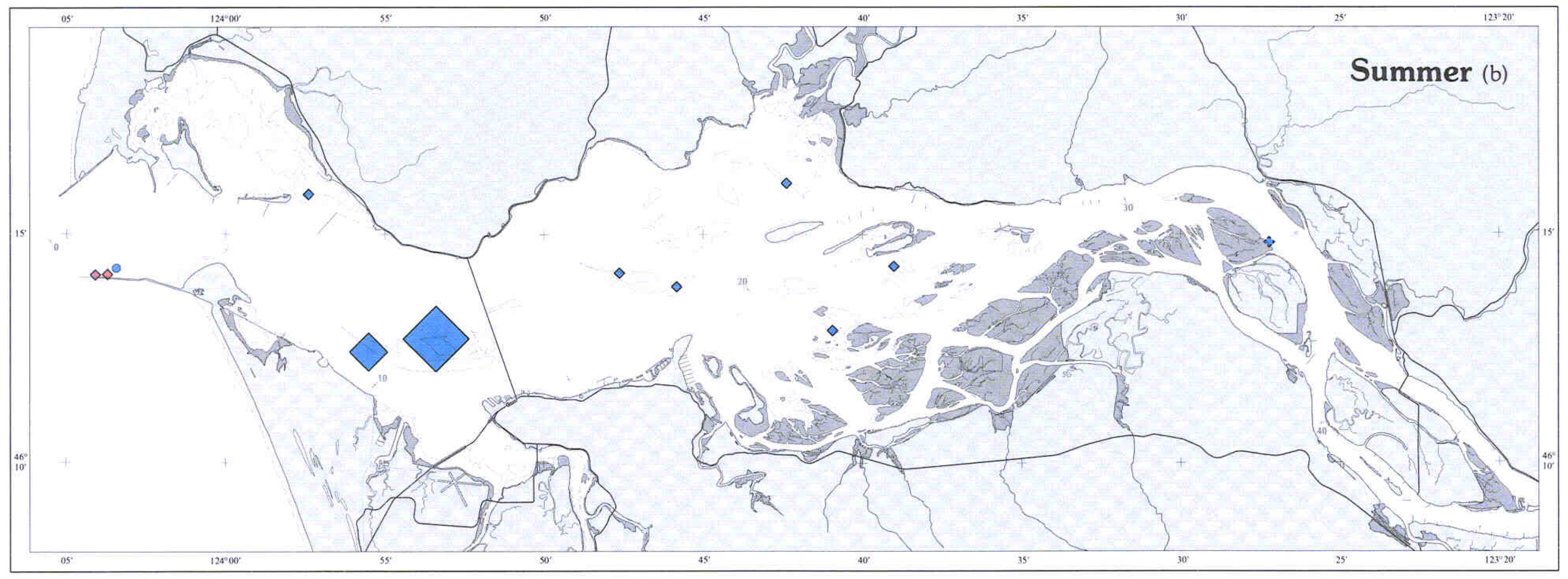
Incidental sightings information is based on 1980-1981 CREDDP sampling. Maps were compiled in 1983 by Jones and Stokes Associates, Inc. (CREDDP avifauna investigators).

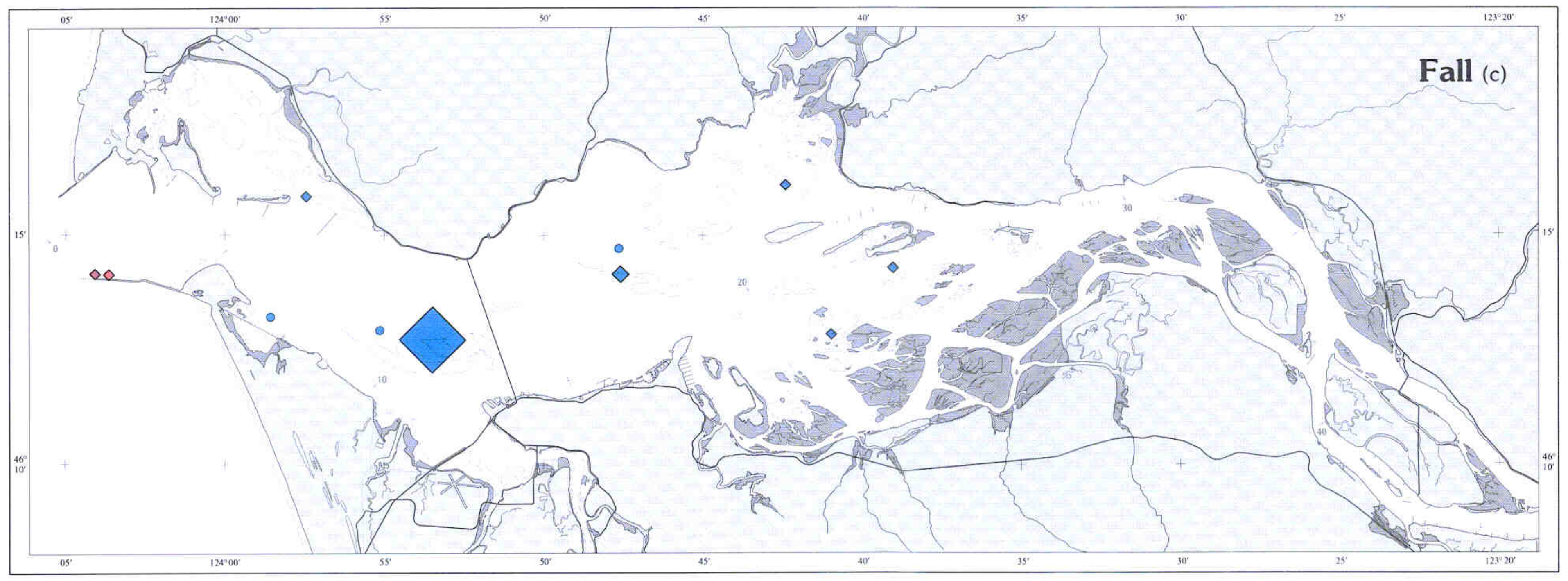
Scale 1:250,000

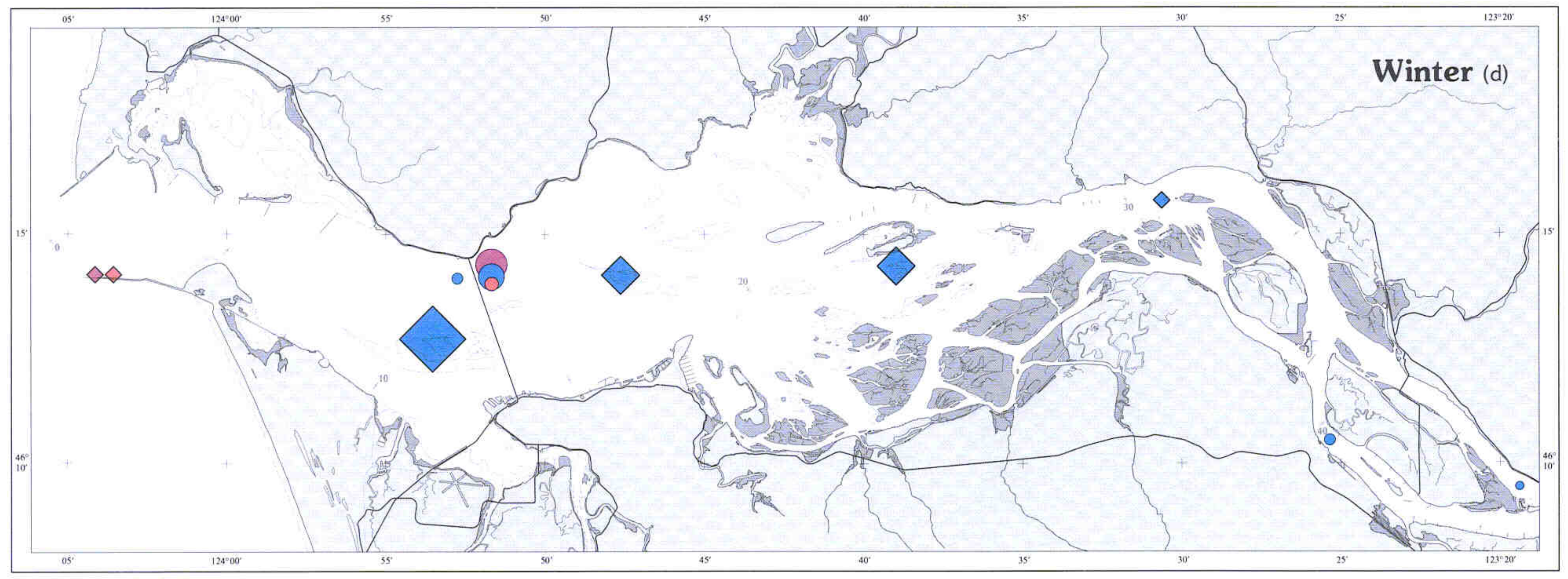
0 2 4 6 8 10 Kilometers

0 1 2 3 4 5 6 Miles









Aerial Counts of Marine Mammals

Haulout count*

- more than 500
- 101-500
- 50-100
- fewer than 50
- Alternate haulout

*Symbols represent highest count recorded for each season.

Sightings of individuals in water**

Symbol size is proportional to number of individuals sighted.

- 10
- 5
- 1

- **Harbor seals** *(Phoca vitulina)*
- **California sea lions** *(Zalophus californianus)*
- **Northern sea lions** *(Eumetopias jubatus)*
- **Gray whales** *(Eschrichtius robustus)*

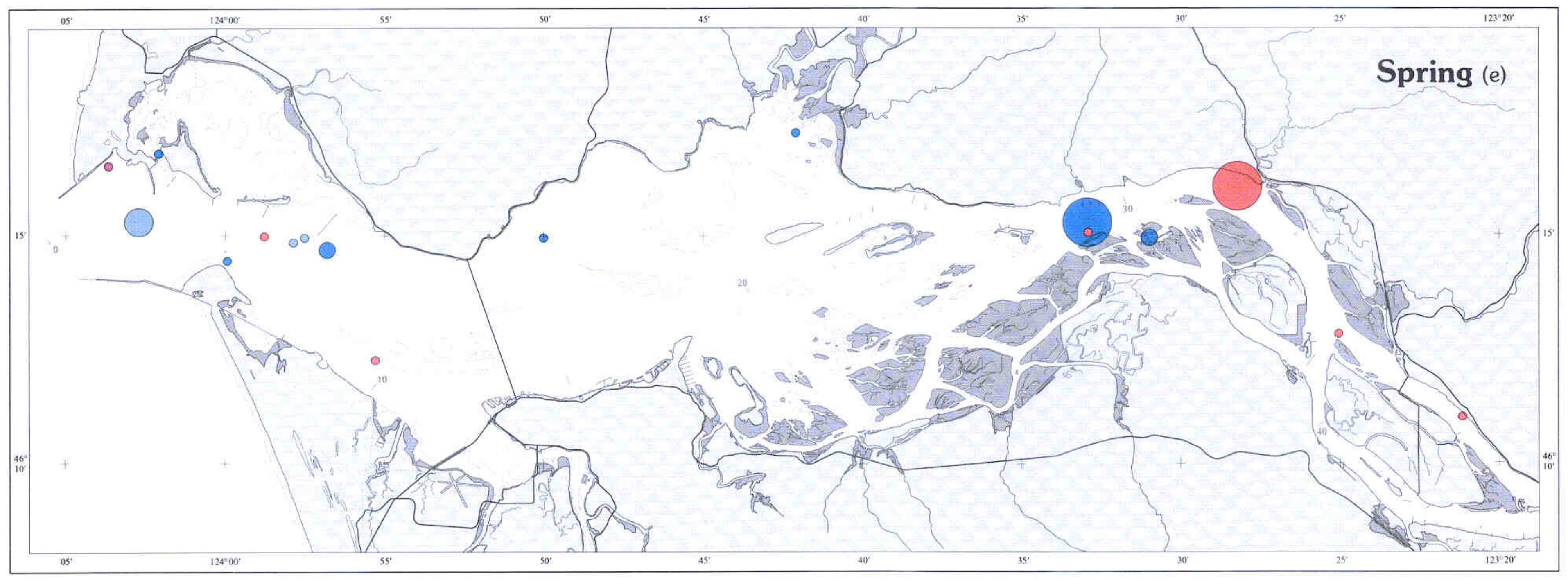
**Several surveys were recorded each season. All sightings from all of the surveys are represented.

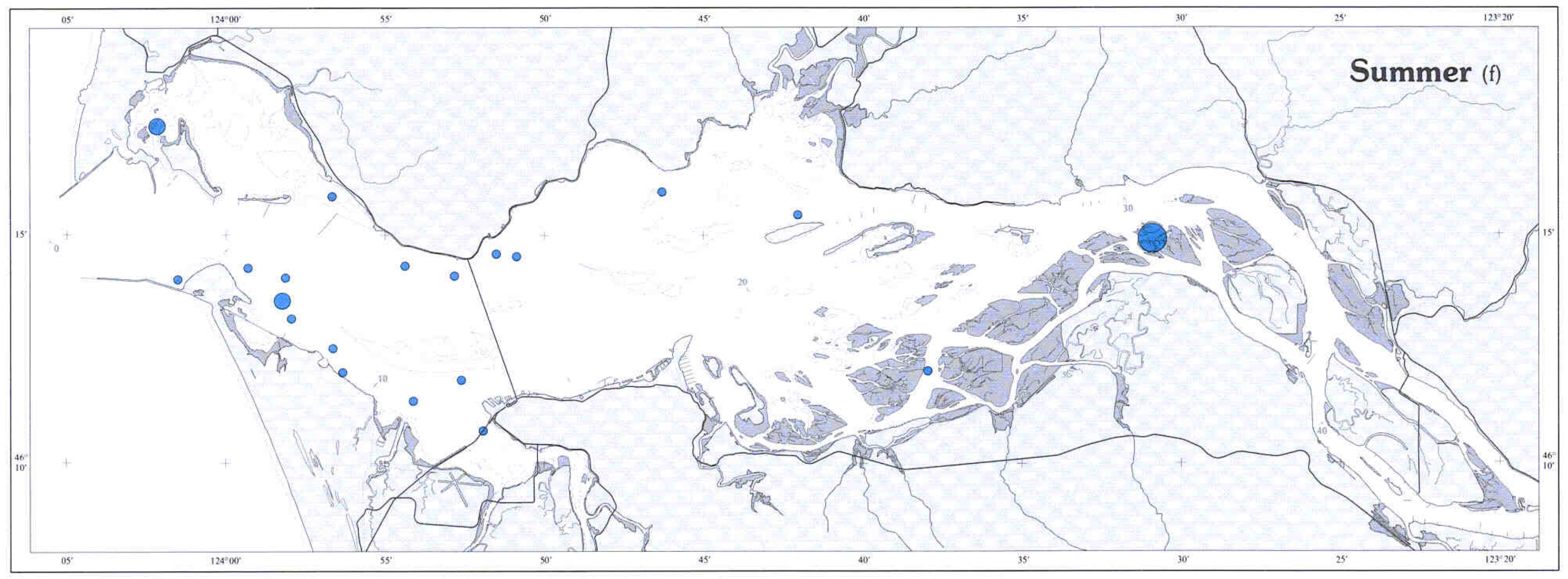
Marine Mammal information is based on 1980-1982 sampling supported by CREDDP, the National Marine Fisheries Service, the U.S. Marine Mammal Commission, and the Washington Department of Game. Maps were compiled in 1983 by Anne Geiger, Washington Department of Game (CREDDP marine mammals investigator).

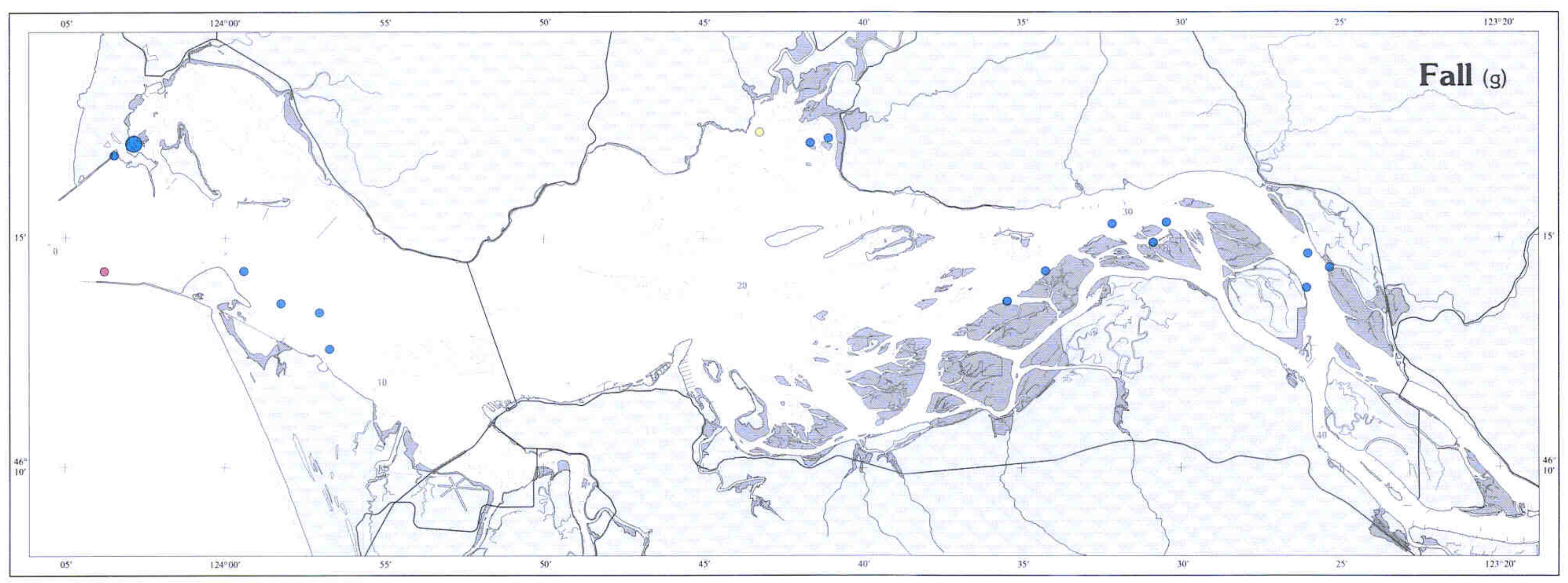
Scale 1:250,000

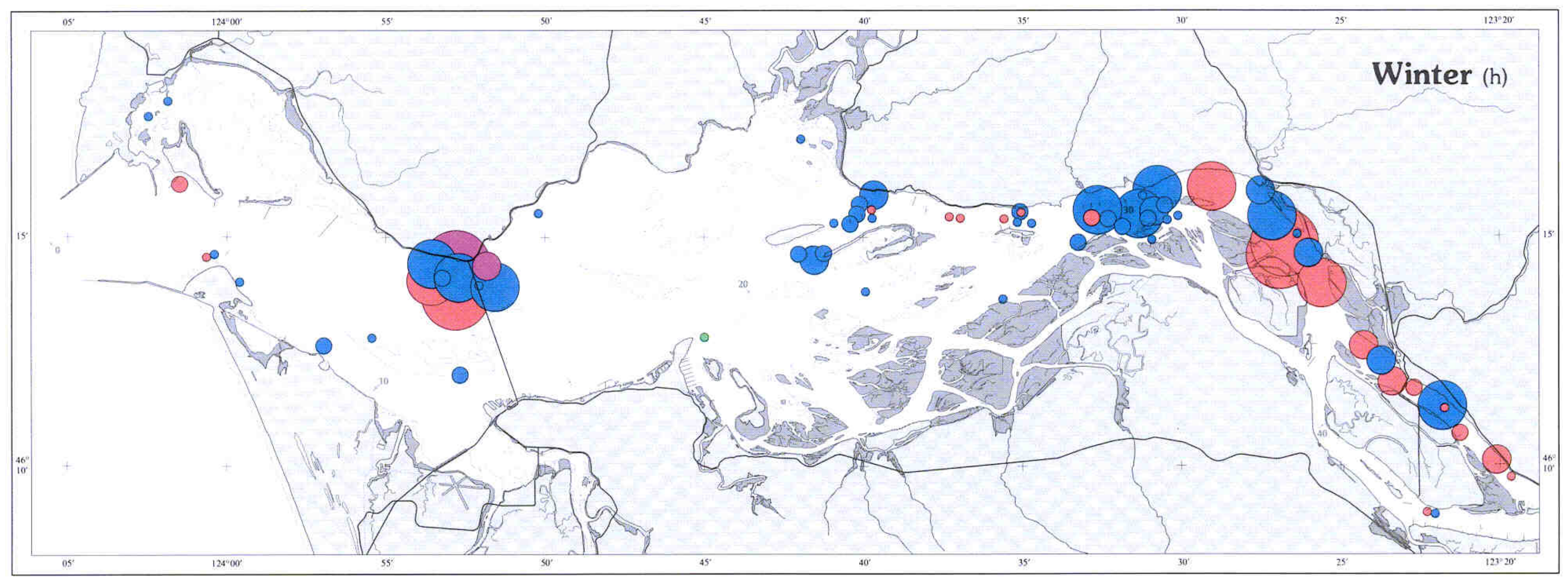
0 2 4 6 8 10 Kilometers

0 1 2 3 4 5 6 Miles









Marine Mammal Sightings*

- 16-30
- 8-15
- 4-7
- 2-3
- 1

- **Harbor seals** *(Phoca vitulina)*
- **California sea lions** *(Zalophus californianus)*
- **Northern sea lions** *(Eumetopias jubatus)*
- **Elephant seals** *(Mirounga angustirostris)*
- **Gray whales** *(Eschrichtius robustus)*
- **Unidentified sea lion species**

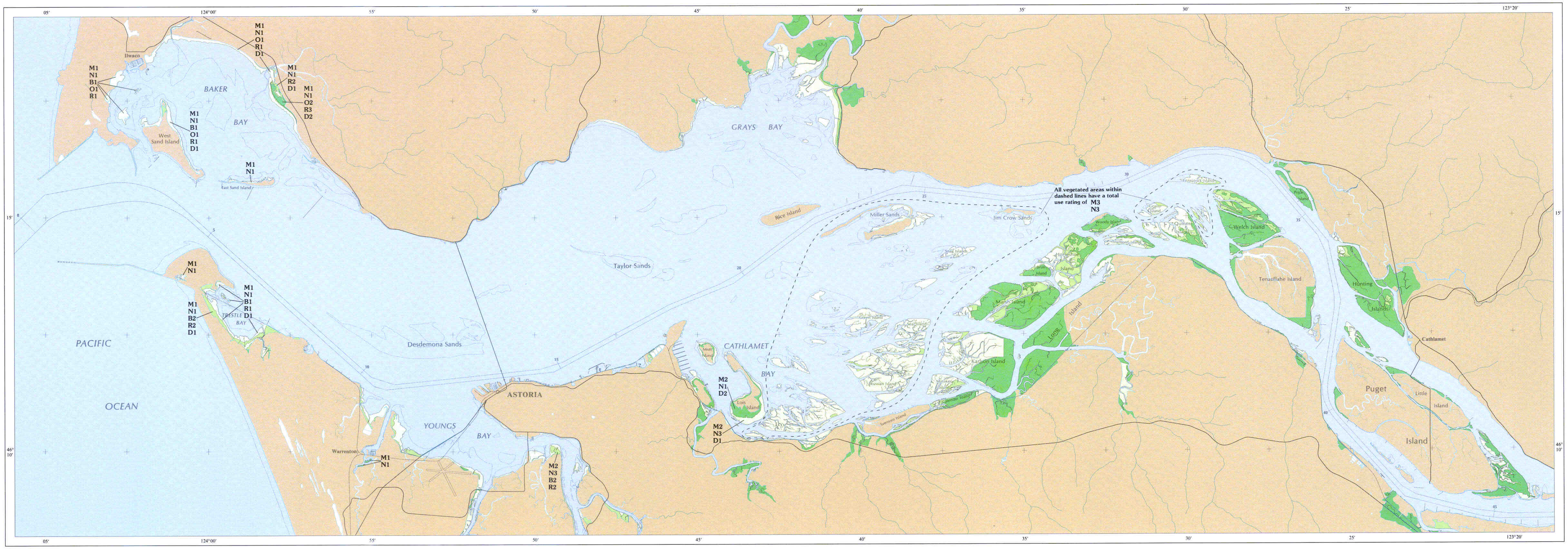
*Sightings were recorded from boats and from land. All sightings from all of the surveys are represented.

Marine Mammal information is based on reports from CREDDP marine mammals, avifauna, wildlife, and fish investigators (1980-1982), volunteers (1980-1982), and records kept by the National Marine Mammal Lab (NMFS) Platforms of Opportunity Program. Maps were compiled in 1983 by Anne Geiger, Washington Department of Game (CREDDP marine mammals investigator).

Scale 1:250,000

0 2 4 6 8 10 Kilometers

0 1 2 3 4 5 6 Miles



Aquatic and Terrestrial Mammals

Aquatic and terrestrial mammal information is based on 1980 and 1981 CREDDP sampling. The map was compiled in 1983 by James G. Fenton and Chris Merker, Washington Department of Game (CREDDP wildlife investigators).

Scale 1:100,000

0 1 2 3 4 5 Kilometers

0 1 2 3 Miles

Vegetation Types

- Swamp
- High marsh
- Low marsh

	Relative Feeding Intensity* high	medium	low	Relative Denning Intensity* high	medium	low	Total Use Rating** high	medium	low	Exceptions to Total Use Ratings† high	medium	low
Muskrat (*Ondatra zibethicus*)	Low marsh	High marsh, Swamp		Low marsh	High marsh, Swamp		Low marsh	High marsh, Swamp		M3	M2	M1
Nutria (*Myocastor coypus*)	Low marsh	High marsh	Swamp	Low marsh	High marsh	Swamp	Low marsh, High marsh		Swamp	N3	N2	N1
Beaver (*Castor canadensis*)	Swamp		High marsh, Low marsh	Swamp			Swamp	High marsh	Low marsh	B3	B2	B1
Otter (*Lutra canadensis*)	Swamp		Low marsh					Swamp	Low marsh	O3	O2	O1
Raccoon (*Procyon lotor*)	Swamp	High marsh	Low marsh	Swamp			Swamp	High marsh	Low marsh	R3	R2	R1
Deer (*Odocoileus virginianus leucurus*) (*Odocoileus hemionus columbianus*)	Swamp		High marsh, Low marsh	not applicable				Swamp	High marsh, Low marsh	D3	D2	D1

*Relative feeding and denning intensities:
high = more than 50% of the regional population uses the area.
medium = between 20% and 50% of the regional population uses the area.
low = less than 20% of the regional population uses the area.

**Total use ratings are estimates based on feeding and denning information. These values do not represent percentages of the regional populations.

†Exceptions listed on the map show all species present within the indicated area.

REGIONS AND HABITAT TYPES: A SYNTHESIS

Five CREDDP research team leaders and CREDDP staff collaborated to integrate the results of the program in order to evaluate the physical and biological characteristics of the estuary and the relationships among them. To carry out this task, it was necessary to divide the estuary into smaller units having fairly uniform physical and biological characteristics. Data from sampling stations within each unit could then be combined, making it possible to describe each area, compare the attributes of different areas, and infer relationships between their physical and biological characteristics. This chapter describes the system that these investigators used to divide the estuary and summarizes some of the information that resulted from their integration of CREDDP data.

The first criterion used to divide the estuary was salinity, the most biologically important factor. The estuary was divided into three zones based on salinity and related circulatory processes. Second, the estuary was divided into eight regions based on general physical characteristics such as distribution of sediments. The amount of exposure to energy of currents resulting from tides and riverflow was also considered. Finally, each region was subdivided into six habitat types based on elevation or vegetation.

Plate 28 shows how the estuary was divided into salinity zones, regions, and habitat types.

Salinity Zones

The three salinity zones were labeled plume and ocean, estuarine mixing, and tidal-fluvial.

Plume and Ocean

This zone has the highest proportion of ocean water and the highest salinities in the estuary. It is characterized by strong tidal currents and wave action. Suspended sediment concentrations are usually low; water in this zone is clearer than in areas of the estuary where turbid river water is more influential.

Estuarine Mixing

This zone is the major area in which salt water and fresh water meet and, to varying degrees, mix. Its circulation patterns result from complex interactions between tides and riverflow (see "Circulation and Salinity"). The eastern boundary of this zone is the upriver limit of saltwater intrusion, whose position during the low riverflow season (July through October) is farther upriver than its position during the high and fluctuating riverflow seasons. The estuarine mixing zone has high concentrations of suspended sediments; these are trapped in the turbidity maximum (see "Sediments"), which moves up and downriver within this zone depending on riverflow season.

Tidal-Fluvial

This is a freshwater zone, but it has tidal currents and variations in water height. Its downriver extent, the boundary shared with the estuarine mixing zone, depends on season. Turbidity varies depending on the concentration of suspended sediments in the river water entering the zone.

Regions

Characteristics of the eight regions shown on Plate 28 are described in the following paragraphs.

Entrance (Region 1)

This region corresponds to the plume and ocean salinity zone. It consists mostly of deep water areas, and its sediments are well-sorted medium-fine sand.

Baker Bay and Trestle Bay (Region 2)

These bays generally have lower energy levels than the main body of the estuary. Their sediments are finer and more poorly sorted than those of other parts of the estuary and include significant amounts of silt and clay. The construction of the entrance jetties has resulted in heavy sediment deposition.

Estuarine Channels (Region 3)

This region contains both the main navigation channel and the north channel. Its eastern reach is alternately in the estuarine mixing zone or in the tidal-fluvial zone, depending on riverflow season. The remainder of this region is always part of the estuarine mixing zone. Sediments are mostly medium-fine sand.

Youngs Bay (Region 4)

This region is usually subject to low energy levels except in channel areas. Like other embayments, its sediments are relatively fine and poorly sorted.

Mid-Estuary Shoals (Region 5)

This region consists of tidal flats and submerged sandbars separated by shallow channels. Most areas have moderate to high energy levels due to strong currents. Sediments are generally fine moderately-sorted sand and, historically, sediment deposition has been heavy. The eastern reach of this region is part of the tidal-fluvial salinity zone except during low riverflow season when the estuarine mixing zone expands eastward; the remainder is always part of the estuarine mixing zone.

Grays Bay (Region 6)

Sediments in this region range from medium sand to sandy silt, and deposition of sediments has been extensive. Grays Bay is subject to moderately energetic wave and current action because of its exposure to winds.

Cathlamet Bay (Region 7)

This is a large and diverse region with many islands composed of tidal flats, marshes, and swamps and with a complex network of channels. Sediment types vary accordingly. Fine sands and silts are found in tidal marshes and mudflats while medium-fine sand is found on the more exposed sandflats. The water in Cathlamet Bay is fresh except during low riverflow periods, when some salt water may enter along the bottom in the north channel and MARAD Basin. During low riverflow neap tide periods salinity may intrude along the bottom into the other channels south of Miller Sands. Salinity is probably always low or absent in shallow areas and only very rarely intrudes into the upriver half of the region.

Fluvial Region (Region 8)

This region includes the channels upriver of significant salinity intrusion and continues to the upriver limit of the CREDDP study area. Its sediments are among the coarsest in the estuary.

Habitat Types

Each region contains some or all of six habitat types, shown in profile in Figure 7-1. The habitat types are defined in the following paragraphs. Although metric units have been used in previous chapters, depths and elevations are given here in feet because the habitat-type classification system was developed using bathymetry maps showing depth contours in feet.

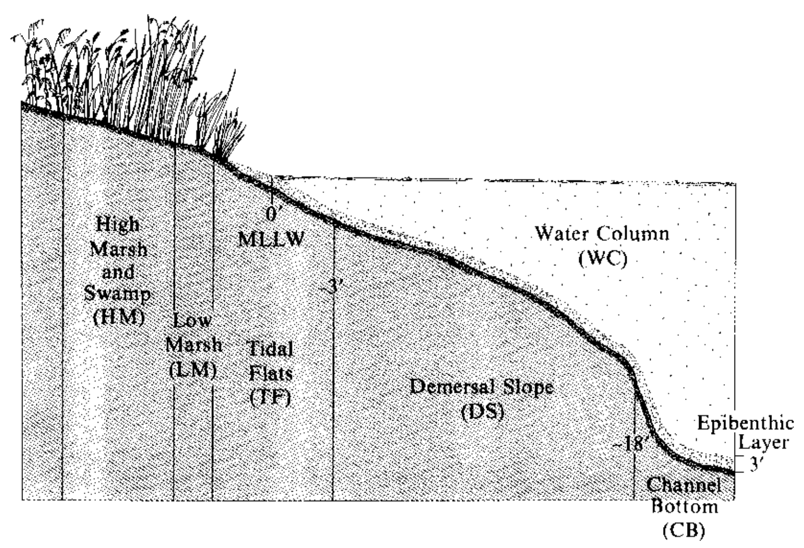


Figure 7-1. Illustration of the Columbia River Estuary habitat-type classification system (Simenstad et al. 1984).

Water Column

The water column habitat type extends from the surface of the water down to three feet above the sediment surface. By this definition, the epibenthic zone is excluded from the water column habitat type; the epibenthic zone is considered to be part of the habitat type that it overlies. For the purpose of measuring its surface area, the water column is defined as being bounded by the MLLW contour, covering the channel bottom and demersal slope habitat types and the part of the tidal flats habitat type below MLLW. Because of tidal fluctuation the water column is not actually restricted to the boundary described here.

High Marsh and Swamp

This habitat type is defined as those tidal wetlands having high marsh or swamp vegetation (see "Tidal Marshes and Swamps"). High marsh vegetation and swamp vegetation are defined in terms of the plant species present. The lower limit of these vegetation types is usually between 6.5 and 8.5 feet above MLLW and the upper limit is usually between 8.0 and 12.0 feet above MLLW. These areas receive only irregular tidal inundation.

Low Marsh

This habitat type is defined as those tidal wetlands having low marsh vegetation (see "Tidal Marshes and Swamps"). Low marsh vegetation is defined in terms of the plant species present. Elevations of the lower limits of low marshes have seldom been measured in the Columbia River Estuary. Three feet above MLLW is probably a typical elevation of the lower limit, and the range of this limit may be from 2.5 to 5.0 feet above MLLW. The upper limit of low marsh vegetation is usually between 6.5 and 8.5 feet above MLLW. These areas receive regular tidal inundation.

Tidal Flats

This habitat type covers the area from three feet below MLLW up to the lower limit of tidal marsh or swamp vegetation. In the few areas where there is no tidal vegetation, the upper limit of this habitat type is MHHW (about eight feet above MLLW).

Demersal Slope

This habitat type covers the area from 18 feet below MLLW to three feet below MLLW and includes the bottom sediments and the epibenthic zone. It is always submerged, the upper limit coinciding with the lowest possible water level (Extreme Low Tide).

Channel Bottom

The channel bottom habitat type includes the estuary bottom deeper than 18 feet below MLLW plus the associated epibenthic zone.

The surface area (in hectares) of these regions and habitat types are shown in Table 7-1. Some of the regions have been divided. For example, the areas of both Trestle Bay and Baker Bay (region 2) are shown, as well as the total area for the region. For the Estuarine Channels and Mid-Estuary Shoals regions (regions 3 and 5), the areas that are included in the estuarine mixing zone only when it expands during the low riverflow season are distinguished from the parts of these regions that are included in the estuarine mixing zone all year. Some of the habitat types have also been divided. For the high marsh and swamp habitat type, the areas of swamp and high marsh are each shown, as well as the total. For the tidal flats habitat type, the areas with elevations above MLLW are distinguished from those with elevations below MLLW. The area of the water column habitat type is the sum of the areas of channel bottom, demersal slope, and the portion of tidal flats below MLLW.

	WC	HM			LM	TF			DS	CB	
Region/Habitat Type	**Below MLLW**	**Swamp**	**High Marsh**	**Total**	**Low Marsh**	**Above MLLW**	**MLLW to -3'**	**Total**	**-3' to -18'**	**Below -18'**	**Total**
1. Entrance	3105					98	117	215	567	2420	3203
2. Trestle Bay	163	2	58	60	66	110	145	255	19		400
Baker Bay	1491	19	21	40	219	1226	784	2010	693	14	2975
Total	1654	21	79	100	285	1336	929	2265	712	14	3375
3. Estuarine Channels											
Estuarine Mixing Zone	5797	1	1	2	2	28	55	84	1007	4735	5829
Alternating Zones	1640	4		4	8	39	27	66	494	1119	1691
Total	7437	5	1	6	10	67	82	150	1501	5854	7521
4. Youngs Bay	1277	50	135	185	285	474	547	1020	680	51	2220
5. Mid-Estuary Shoals											
Estuarine Mixing Zone	4537				2	520	567	1087	3319	651	5058
Alternating Zones	557					24	182	206	326	49	581
Total	5094				2	544	749	1293	3645	700	5639
6. Grays Bay	3512	268	31	299	274	592	1386	1978	1820	305	4678
7. Cathlamet Bay	6036	1757	279	2036	1823	758	1944	2703	3197	895	10653
8. Fluvial Region	3203	334	115	449	174	66	269	334	958	1976	3893
Total Estuary	**31318**	**2435**	**640**	**3075**	**2853**	**3935**	**6023**	**9958**	**13080**	**12215**	**41182**

Table 7-1. Areas of habitat types within each region of the Columbia River Estuary (in hectares). Region 2 includes Baker Bay and Trestle Bay. Regions 3 and 5 include areas that are always in the estuarine mixing zone and areas that are in the estuarine mixing zone only during the low riverflow season. Habitat types are abbreviated as follows: WC = water column, HM = high marsh and swamp, LM = low marsh, TF = tidal flats, DS = demersal slope, CB = channel bottom (planimetered data, CREDDP staff 1983).

Productivity of Major Groups by Region and Habitat Type

One of the important attributes of a region and its habitat types is the productivity of the species associated with them. To evaluate this, the researchers who integrated the results of the CREDDP studies summarized the productivity of the regions and habitat types. Because the locational units and units of measurement described in this chapter may be different from those in previous chapters, the production values may not be comparable. Some habitat types and regions were represented by many sampling stations while others were not sampled at all for some organisms. As a result, some of the values in the summaries presented here are quite reliable, while others are based on fragmentary information.

Productivity for the eight regions and their habitat types is summarized in Table 7-2 in units of grams of carbon per square meter per year ($gC/m^2/yr$). The three major primary producers, phytoplankton, benthic plants, and marsh plants, are summarized. The consumers are divided into two groups based on feeding habits. Herbivores and detritivores include the herbivorous birds and mammals, deposit-feeding invertebrates, and filter-feeding invertebrates. Predators include the predatory invertebrates, fish, birds, and mammals.

Region	Phytoplankton	Benthic Plants	Marsh Plants	Herbivores/ Detritivores	Predators
Region 1					
WC	41.0			nd	0.06
TF		3.49		0.31	nd
CB				0.55	0.35
Region 2					
WC	41.5			nd	0.006
HM			331	0.14	nd
LM		41.8	372	0.12	0.002
TF		34.1		5.10	0.20
DS				2.90	0.80
Region 3					
WC	50.2			21.8	0.40
DS				1.32	0.08
CB				0.60	0.11
Region 4					
WC	31.8			nd	0.01
HM			331	0.14	nd
LM		69.5	702	0.12	0.008
TF		34.1		2.78	0.17
DS				2.85	0.05
Region 5					
WC	50.8			nd	nd
TF		13.0		0.70	0.24
DS				0.50	0.08
Region 6					
WC	39.2			nd	0.06
HM			422	0.15	0.001
LM		26.6	237	0.12	0.008
TF		12.7		2.53	0.08
DS				2.25	0.07
Region 7					
WC	61.9			nd	0.04
HM			372	0.15	0.00
LM		14.5	247	0.12	0.01
TF		13.4		1.01	0.30
DS				0.81	0.70
CB				0.07	0.01
Region 8					
WC	71.6			7.41	0.23
HM				0.15	0.001
LM		28.7		0.12	0.01
TF		13.8		1.72	0.18
DS				0.37	0.27
CB				0.26	0.82

nd - indicates that no data were available, no appropriate habitat was present, and/or production was incidental.

Table 7-2. Productivity of major estuarine plant and animal groups by region and habitat type, in $gC/m^2/yr$. Values for plant groups represent net primary productivity. Habitat types are abbreviated as follows: WC = water column, HM = high marsh and swamp, LM = low marsh, TF = tidal flats, DS = demersal slope, CB = channel bottom (from Simenstad et al. 1984).

To obtain the total annual production for a region and its habitat types, the productivity per square meter (Table 7-2) was multiplied by the area of the habitat type (Table 7-1). The results, expressed in metric tons of carbon per year, are shown in Table 7-3. These habitat-type production values are summed to provide regional and estuary-wide annual production totals for the three primary producer groups and two consumer groups. For the two consumer groups, the total estuarine production was further broken down by animal group as shown in Table 7-4. The subtotals for herbivores and detritivores and for predators shown in Table 7-4 (about 2,970 and 167 metric tons of carbon per year, respectively) are somewhat higher than those shown in Table 7-3 (about 2,300 and 132 metric tons of carbon per year, respectively). This is because CREDDP investigators estimated production for areas and animal groups that lacked data in order to develop Table 7-4.

Region	Phytoplankton	Benthic Plants	Marsh Plants	Herbivores/ Detritivores	Predators
Region 1					
WC	1290			0	2.05
TF		3.42*		0.67	0
CB				13.3	8.54
Total	1290	3.42		13.9	10.59
Region 2					
WC	964			0	0.10
HM			261**	0.14	0
LM		119	1060	0.35	0.01
TF		418*		115	4.61
DS				21.0	5.71
Total	964	537	1320	136	10.43
Region 3					
WC	3750			1620	30.0
DS				19.8	1.23
CB				35.2	6.50
Total	3750			1670	37.8
Region 4					
WC	481			0	0.15
HM			446**	0.26	0
LM		198	2000	0.35	0.02
TF		162*		28.4	1.75
DS				19.4	0.33
Total	481	360	2440	48.4	2.25
Region 5					
WC	2730			0	0
TF		70.8*		9.06	3.12
DS				18.3	3.14
Total	2730	70.8		27.4	6.26
Region 6					
WC	1610			0	1.93
HM			131**	0.46	0.003
LM		73.1	650	0.34	0.02
TF		75.0*		50.1	1.62
DS				41.0	1.18
Total	1610	148.1	781	91.9	4.75
Region 7					
WC	3970				2.66
HM			1040**	3.11	0.02
LM		265	4500	2.24	0.18
TF		102*		27.3	8.16
DS				25.9	22.2
CB				0.62	0.14
Total	3970	367	5540	59.2	33.4
Region 8					
WC	2320			237	7.46
HM			694**	0.69	0.004
LM		50.1	542	0.22	0.02
TF		9.03*		5.74	0.61
DS				3.56	2.55
CB				5.06	16.2
Total	2320	59.1	1236	252	26.8
Total Estuary	**17110**	**1545**	**11320**	**2300**	**132.2**

*Estimate for benthic plant production in the tidal flats habitat type is based on only the area above MLLW.

**Estimate for marsh plant production in the high marsh and swamp habitat type is based on only the high marsh area.

Table 7-3. Estimated total annual production of major estuarine plant and animal groups by region and habitat type, in metric tons of carbon per year. Habitat types are abbreviated as follows: WC = water column, HM = high marsh and swamp, LM = low marsh, TF = tidal flats, DS = demersal slopes, CB = channel bottom (from Simenstad et al. 1984).

Category	Metric Tons Carbon per Year
Herbivores and detritivores	
Filter-feeding infauna	34.0
Filter-feeding epibenthic zooplankton	32.4
Filter-feeding zooplankton	2510
Deposit-feeding epibenthic zooplankton	32.4
Deposit-feeding infauna	356
Herbivorous mammals	6.78
Herbivores birds	0.10
Total	2970
Predators	
Predatory infauna	62.1
Predatory mobile macroinvertebrates	22.0
Predatory zooplankton	5.48
Larval fish	44.4
Predatory fish	29.7
Predatory birds	3.96
Predatory mammals	0.03
Marine mammals	0.22
Total	167
Total	**3140**

Table 7-4. Estimated total estuary-wide annual carbon production of the two major estuarine animal groups, subdivided into major categories (Simenstad et al. 1984).

A final summary of production is shown in Figure 7-2. Production values for two of the three salinity zones, tidal-fluvial and estuarine mixing, are shown. These were obtained by summing the production values for the component regions. Production values for the plume and ocean zone are the same as the totals listed for region 1 in Table 7-3.

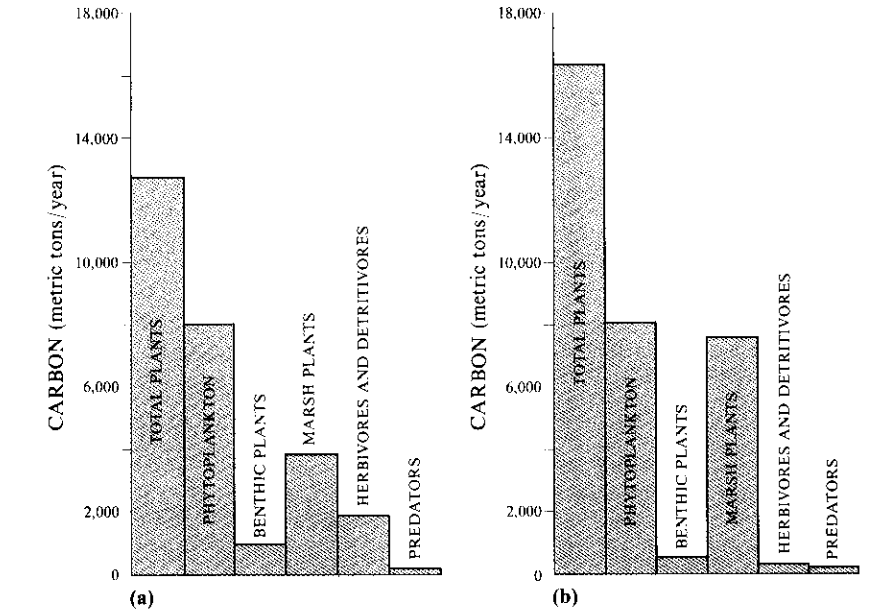


Figure 7-2. Annual carbon production of major estuarine plant and animal groups for two salinity zones: (a) estuarine mixing zone and (b) tidal-fluvial zone (from Simenstad et al. 1984).

Discussion

Although some of the production values are estimates based on fragmentary evidence, the summary of production presented here suggests some interesting conclusions about the Columbia River Estuary. Three major generalizations regarding the relative importance of plant groups, the relationship between production by plants, herbivores and detritivores, and predators, and the importance of filter-feeding zooplankters are discussed in the following paragraphs.

The major primary producers in the Columbia River Estuary are marsh plants and phytoplankton; benthic primary producers contribute much less to the estuary's overall carbon supply. On a per square meter basis, tidal marshes are more productive than phytoplankton (Table 7-2). Because phytoplankton occupy a much larger area of habitat, however, their total contribution to the carbon production of the estuary is greater. Regions of the estuary differ in the relative contribution of tidal marshes and phytoplankton (Table 7-3): in Baker and Trestle Bays, Youngs Bay, and Cathlamet Bay (regions 2, 4, and 7, respectively), tidal marsh production is higher than that of phytoplankton. This reflects the relatively high proportion of marsh area in these regions. When the salinity zones are considered (Figure 7-2), the contributions of marshes and phytoplankton are about equal in the tidal-fluvial zone (which includes regions 6, 7, and 8), while phytoplankton contribution is greater in the estuarine mixing zone (which includes regions 2, 3, 4, and 5).

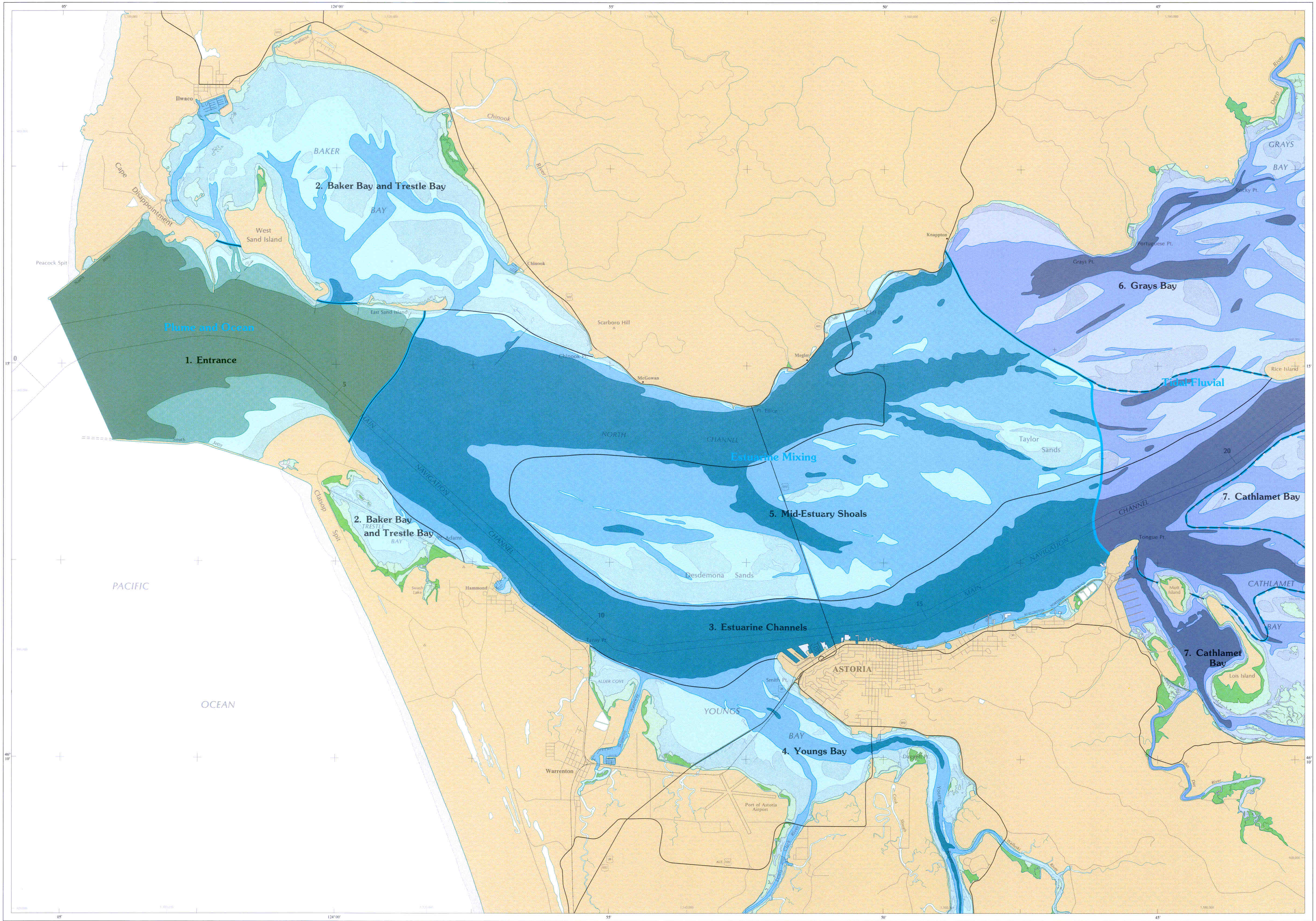
The total production for plants, herbivores and detritivores, and predators is about 30,000, 2,300, and 130 metric tons of carbon per year, respectively (Table 7-3). Primary production is more than ten times the production by herbivores and detritivores, which is more than ten times that of predators. This is not surprising; it is generally understood that about ten times as much production is required to support each succesive consumer level in an ecosystem. The amount of carbon entering the estuarine ecosystem is actually much higher than indicated here, because phytoplankton and detritus contributed from upriver of the estuary have not been considered. The production by plants within the estuary totals about 30,000 metric tons of carbon per year, while phytoplankton and detritus imported from upriver contribute about 184,000 metric tons of carbon per year to the estuary. Much carbon is exported to the ocean: CREDDP investigators estimate that about 175,000 metric tons of carbon per year are exported as detritus and phytoplankton. As a result, about 39,000 metric tons of carbon per year remain in the estuary. Not all of this remaining carbon is available to animals as food; some is deposited among the sediments of the estuary bottom and marshes as undigestible material. As a result, the amount of carbon that is available to herbivores and detritivores is less than 39,000 metric tons per year.

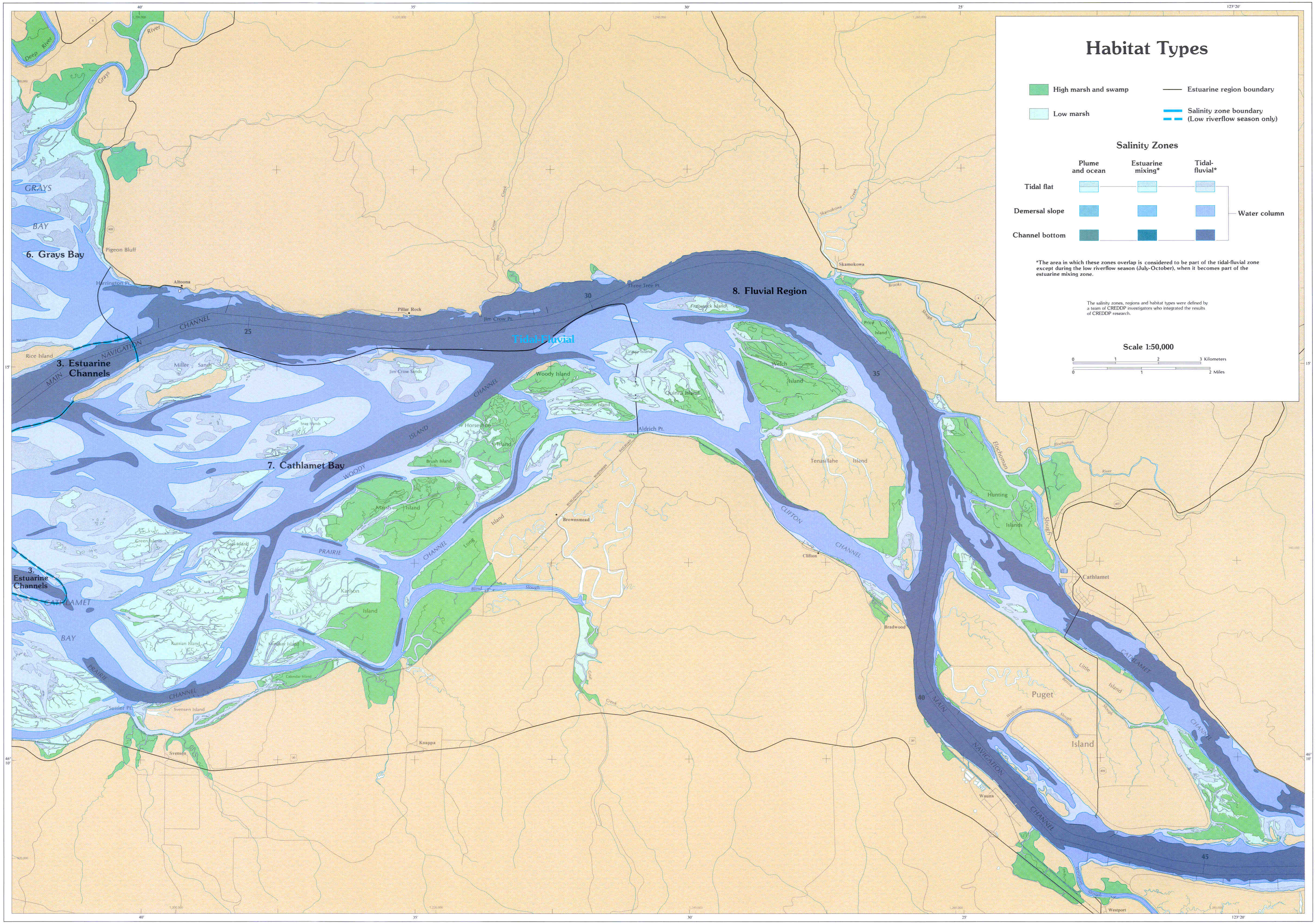
Animal production is greatest in the water column habitat type of region 3 (Estuarine Channels) (Table 7-3). This results from high rates of production by filter-feeding zooplankters. These organisms far outproduce any other animal group in the estuary (Table 7-4). Most of the zooplankton production values were taken in summer, so they have probably been overestimated here. Research in other estuaries suggests that annual production rates about half of those reported for the water column in region 3 (Table 7-2) are normal. If the production estimate for filter-feeding zooplankters in Table 7-4 were halved, this would still represent the major contribution to animal production.

Eurytemora affinis, which exists in both water column and epibenthic habitats, probably contributes the largest part of this production. It is commonly found in deep water channel habitats such as those in the Estuarine Channels region (region 3) and is associated with the turbidity maximum (see "Zooplankton"). The turbidity maximum concentrates the zooplankters, resulting in higher densities and production rates. Because phytoplankton and detritus are also concentrated, abundant food is available to the filter-feeding zooplankters. These factors support the high production of filter-feeding zooplankters such as *E. affinis*, resulting in their major contribution to animal production in the estuary.

The high productivity of estuarine zooplankters such as *E. affinis* is important to other members of the estuarine food web (see Figure 4-28). *E. affinis* is a major component of a food chain involving starry flounder and harbor seals, providing a link between diatoms and these vertebrate species. Another invertebrate, *Corophium salmonis*, is less productive, but it is a major estuarine food for the commercially important salmon (see Figure 4-28).

View downriver from Puget Island (U.S. Fish and Wildlife photo).


Plume and Ocean
1. Entrance
2. Baker Bay and Trestle Bay
3. Estuarine Channels
Estuarine Mixing
4. Youngs Bay
5. Mid-Estuary Shoals
Tidal Fluvial
6. Grays Bay
7. Cathlamet Bay
BAKER
BAY
TRESTLE
YOUNGS
GRAYS
CATHLAMET
PACIFIC
OCEAN
Ilwaco
Cape Disappointment
West Sand Island
Peacock Spit
East Sand Island
Chinook
Scarboro Hill
Chinook Pt.
McGowan
Megler
Knappton
Grays Pt.
Portuguese Pt.
Rocky Pt.
Rice Island
Pt. Ellice
NORTH
CHANNEL
MAIN NAVIGATION CHANNEL
Taylor Sands
Desdemona Sands
Tongue Pt.
Mott Island
Lois Island
ASTORIA
Smith Pt.
Warrenton
Hammond
Pt. Adams
Clatsop Spit
Port of Astoria Airport
Tansy Pt.
Alder Cove
Daggett Pt.


Habitat Types
High marsh and swamp
Low marsh
Estuarine region boundary
Salinity zone boundary
(Low riverflow season only)
Salinity Zones
Plume and ocean
Estuarine mixing*
Tidal-fluvial*
Tidal flat
Demersal slope
Channel bottom
Water column
*The area in which these zones overlap is considered to be part of the tidal-fluvial zone except during the low riverflow season (July-October), when it becomes part of the estuarine mixing zone.
The salinity zones, regions and habitat types were defined by a team of CREDDP investigators who integrated the results of CREDDP research.
Scale 1:50,000
3 Kilometers
2 Miles
6. Grays Bay
3. Estuarine Channels
7. Cathlamet Bay
8. Fluvial Region
Tidal-Fluvial
GRAYS
BAY
CATHLAMET
BAY
MAIN NAVIGATION CHANNEL
WOODY ISLAND CHANNEL
PRAIRIE CHANNEL
CLIFTON CHANNEL
CATHLAMET CHANNEL
Deep River
Grays River
Pigeon Bluff
Harrington Pt.
Altoona
Pillar Rock
Jim Crow Pt.
Three Tree Pt.
Rice Island
Miller Sands
Jim Crow Sands
Woody Island
Horseshoe Island
Brush Island
Marsh Island
Long Island
Karlson Island
Svensen Island
Svensen
Settler Pt.
Knappa
Brownsmead
Aldrich Pt.
Quinns Island
Welch Island
Tenasillahe Island
Clifton
Bradwood
Skamokawa
Price Island
Hunting Islands
Elochoman
Cathlamet
Puget Island
Little Island
Wauna
Westport
25
30
35
40
45

Glossary

accretion — the accumulation of sediments carried by flowing water; the build-up of land along a beach or shore by the deposition of sediments.
adaptation — structural, physiological, or behavioral characteristic which helps an organism fit its habitat and living requirements.
AFDW — ash-free dry weight; the dehydrated tissue weight after hard tissues, such as shells, have been removed.
alga (plural, algae) — simple plant form having no true roots, stems, or leaves. Algae range in size from microscopic single-celled plants to large seaweeds.
amphipod — invertebrate animal of the crustacean class. Amphipods are characterized by laterally flattened bodies and include sand fleas and related forms (see Figure 4-1).
anadromous — pertaining to fish which hatch in fresh water, migrate to ocean waters where they mature, and return to fresh water to spawn.

bathymetry — the measurement of depths of a body of water.
bedform — sediment bottom feature often resembling a sand ripple or a small sand dune (see Figures 2-10 and 2-12).
benthic — pertaining to the bottom of a body of water.
biomass — total weight of a group of organisms in a specified location.
brackish — pertaining to water with a salt content ranging between that of sea water and fresh water; brackishwater — of or in brackish water.

C — carbon.
carnivore — (a) a flesh-eating animal; (b) a mammal of the order Carnivora, which includes dogs, cats, bears, otters, raccoons, seals, and sea lions.
cfs — cubic feet per second; a measure of the rate of water flow.
chlorophyll — a green pigment essential to the process of photosynthesis, found primarily in plants. Chlorophyll *a* is a specific type of chlorophyll often used as an indicator of plant biomass.
cladoceran — invertebrate animal of the crustacean class. Cladocerans are often called water fleas (see Figure 4-1).
copepod — invertebrate animal of the crustacean class. Copepods are abundant members of the zooplankton (see Figure 4-1).
crustacean — a class of the arthropod phylum that includes, among others, crabs, water fleas, barnacles, and shrimp.

datum — see tidal datum.
demersal — pertaining to an organism, such as a fish, living close to or on the bottom of a body of water; pertaining to the habitat close to or on the bottom.
density — (a) the number of organisms per unit of area (for example, animals per square meter); (b) the weight of a substance, such as water, per unit of volume.
deposit-feeder — benthic animal that obtains food by ingesting organic material from the sediment surface (surface deposit-feeder) or by ingesting sediments, including organic material, as it burrows through the sediment (subsurface deposit-feeder).
deposition — see sediment deposition.
detritivore — an organism which consumes detritus.
detritus — particles of the decaying remains of dead plants and animals and associated microbes.
diatom — single-celled alga that has transparent cell walls composed of the hard mineral, silica (see Figure 3-4).
dike — a wall or berm built around a low-lying area to prevent tidal inundation and flooding. In the Columbia River Estuary, extensive dike systems have been erected as flood control structures, converting estuarine floodplain areas to land for agricultural and other human uses.
discharge — see river discharge.
dredging — deepening an aquatic area for navigational or other purposes by removing sediments and other material.
DW — dry weight; the weight of organic material that has been dehydrated.

ebb tide — period between high tide and the succeeding low tide; the outgoing tide.
ecology — the study of the relationships of living things to one another and to their environment.
ecosystem — the complex of a biological community and the physical environment functioning as an interacting system in a geographic area.
epibenthic — pertaining to the habitat that includes the sediment surface and the overlying one meter of water, or to the organisms that live in this habitat.
erosion — see sediment erosion.
estuarine — pertaining to an estuary or to the organisms living within an estuary, especially in predominantly brackishwater regions.
estuary — the region, usually in a river, where fresh river water mixes with saline ocean water.

filter-feeder — an animal that obtains food by filtering small particles of organic matter from water.
flats — see tidal flats
flood tide — period between low tide and the succeeding high tide; the incoming tide.
flushing time — the amount of time water takes to move through an estuary out to the ocean.
fluvial — pertaining to a river; of riverine origin; pertaining to the riverine, or freshwater, portion of an estuary.
food chain — a series of organisms depending upon one another for food; begins with plants and ends with carnivores.
food web — the combination of all of the food chains in a community (see Figure 4-28).

g — gram(s).
genus — a category of biological classification grouping one or more species which have fundamental characteristics in common. The first word in the scientific name of a species is the genus name. For example, the three species of peeps shown on Plate 21, Maps a through d are of the genus *Calidris*.
gillnet, gill net — a type of fishing gear that captures fish by entangling their gill covers in the meshes of the net; pertaining to the fishery that employs such gear.
grazing — the consumption of plants by animals, including the consumption of phytoplankton by zooplankton.

habitat — the specific environment in which an organism lives.
habitat type — the specific environment in which a community of organisms live; a grouping or classification of similar habitats.
haulout — a site where seals and sea lions congregate out of the water.
herbivore — a plant-eating animal.
hr — hour.

infauna — the group of organisms living within the sediments underlying a body of water.
inorganic — pertaining to matter of nonliving origin.
intertidal — the area exposed at low tides and inundated at high tides; defined as the area between Extreme Low Tide and Extreme High Tide.
intrusion — see salinity intrusion.
invertebrate — an animal that does not have a backbone.

larva (plural, larvae) — an immature form of an animal which is unlike the adult form and which requires fundamental changes before reaching the basic adult form.

m² — square meter.
m³ — cubic meter.
macrofauna — the group of benthic animals with lengths equal to or larger than 0.5 millimeter (see Figure 4-9).
macroinvertebrate — as used by CREDDP investigators, an epibenthic organism more than one millimeter long.
marsh — see tidal marsh.
meiofauna — the group of benthic animals between 0.063 and 0.5 millimeters long (see Figure 4-9).
mg — milligram.
MHHW — mean higher high water; a tidal datum defined as the average height of the higher of the two daily high tides at a given place measured over an 18.6 year period.
microfauna — the group of benthic animals less than 0.063 millimeters long (see Figure 4-9).
MLLW — mean lower low water; a tidal datum defined as the average height of the lower of the two daily low tides at a given place measured over an 18.6 year period.
mudflat — see tidal mudflat.
mysid — invertebrate animal of the crustacean class. Mysids are shrimp-like in appearance (see Figure 4-1).

neap tides — tides having ranges less than the mean tidal range.

oligochaete — segmented worm of the annelid phylum (see Figure 4-1).
omnivorous — pertaining to organisms that consume both animal and plant matter.
organic — pertaining to living matter or materials of living origin.

parts per thousand — a unit of measurement used in describing salinity. Water with a salinity of one part per thousand contains one unit of salt for every thousand units of water by weight.
pelagic — pertaining to the water column or to an organism living within the water column.
phi — a sediment grain-size measurement unit. Defined as the negative log₂ of the grain diameter in millimeters (see Table 2-1).
photosynthesis — the process by which plants utilize radiant energy from the sun to synthesize carbohydrates from carbon dioxide and water.
phylum — one of the principal divisions of the animal kingdom. The hierarchy of divisions used by scientists to classify the animal kingdom is: phylum, class, order, family, genus, species.
phytoplankton — microscopic plants suspended in the water column.
pinniped — a member of a suborder of mammals that includes seals, sea lions, and walruses.
planktonic — pertaining to organisms which drift passively or swim weakly in the water column.
polychaete — segmented marine or estuarine worm of the annelid phylum (see Figure 4-1).
ppt — parts per thousand.
pressure gradient force — a current-creating force caused by the pressure one body of water exerts on another. The pressure is a result of differences in the density or elevation of the two bodies of water.
primary producer — organism capable of synthesizing organic compounds using the sun's energy or chemical energy; refers to plants.
primary production — process by which plants produce organic material.
production — the amount of organic material generated by a plant or an animal.
productivity — the rate at which plants or animals generate organic material.

raptor — a bird of prey, for example, eagles, hawks, owls.
rip-up clast — consolidated sediment which has been torn loose from a previous deposit by current action.
river discharge — the volume of water flowing through a river per unit of time.
riverflow season — seasons defined by CREDDP representing three characteristic river discharge periods of the Columbia River during the year. The high riverflow season is from April through June; the low riverflow season is from July through October; and the fluctuating riverflow season is from November through March.
River Mile — mileage measurements along the main navigation channel of the Columbia River. River Mile Zero is at the river mouth.
RM — River Mile.

s — second.
saline — pertaining to waters containing dissolved salts.
salinity — saltiness, especially of water, usually measured in parts salt per thousand parts water.
salinity intrusion — the movement of saline ocean water into an estuary.
salmonid — fish species, such as salmon and trout, of the family Salmonidae.
sandbar — a subtidal ridge of accumulated sand.
sandflat — see tidal sandflat.
sandspit — a sandy point of land which projects from the shore into a body of water.
scarp — a steep rock face or steep slope.
sediment deposition — the adding of sediments to an area by some transporting agent, such as wind or flowing water.
sediment erosion — removal of sediment and other material by some transporting agent, such as wind or flowing water.
sediments — the organic and inorganic particulate materials, including gravel, sand, silt and clay, that cover the bottom of the estuary, including intertidal areas.
sediment transport — the movement of sediment by, for example, wind or flowing water.
shoal — a general term referring to a shallow area such as a sandbar.
shoaling — the deposition of sediment in an area.
slough — a narrow channel cutting through an intertidal area and receiving tidal flow.
sorting, sorted — an indicator of the number of grain-size classes represented in a sediment sample. Well-sorted sediments have fewer grain size classes.
sp. — species (singular); used to refer to one species in a genus when the actual species name is not known.
spit — see sandspit.
spp. — species (plural); used to refer to more than one species in a genus when the actual species names are not known.
spring tides — tides having ranges greater than the mean tidal range.
standing crop — the weight of a group of organisms per unit of area at a given time.
stratified, stratification — the layering of a substance. For example, water in many estuaries may have a saline bottom water layer and a fresh surface water layer.
subsurface deposit-feeder — see deposit-feeder.
subtidal — for CREDDP purposes, the area below Extreme Low Tide (approximately one meter below MLLW).
surface deposit-feeder — see deposit-feeder.
swamp — see tidal swamp.

tidal — pertaining to tides or an area periodically flooded and exposed by the tides.
tidal channel — a channel through which water drains and fills intertidal areas.
tidal datum — reference elevations derived from averaging tidal measurements (for example, the average of all lower low tide measurements for a given period at a given locality is mean lower low water).
tidal flat — a tidal sandflat or mudflat.
tidal marsh — an intertidal area covered with non-woody flowering plants.
tidal mudflat — an unvegetated intertidal area composed of fine sediments, such as silt.
tidal range — the difference between high tide and low tide.
tidal sandflat — an unvegetated intertidal area composed of coarse sediments, such as sand.
tidal swamp — an intertidal area covered with predominantly woody vegetation.
tides — the periodic rise and fall of sea level produced by the gravitational forces of the moon and sun acting upon the rotating earth.
tide, ebb — see ebb tide
tide, flood — see flood tide
tides, neap — see neap tides
tides, spring — see spring tides
turbidity — reduced water clarity resulting from the presence of suspended matter; the amount of particulate matter suspended in water.
turbidity maximum — an area in the water with very high concentrations of suspended matter. In many estuaries a turbidity maximum occurs near the upriver limit of net upstream bottom flow.

water column — (a) the water or its vertical extent; (b) the CREDDP habitat type extending from the water surface down to one meter above the sediment surface.
water transport — the volume of water that flows past a point over a given time period.

yr — year.

zooplankter — an individual member of the zooplankton.
zooplankton — the group of small (usually microscopic) passively suspended or weakly swimming animals in the water column.

Note: The definitions in this glossary are based on the context in which the terms are used in this atlas. These definitions may be more restrictive than those in common usage.

Weights and Measures

Length

micrometer (um) = 0.000001 meter (m)
millimeter (mm) = 0.0394 inch (in)
inch (in) = 25.40 millimeters (mm)
centimeter (cm) = 0.3937 inch (in)
inch (in) = 2.54 centimeters (cm)
meter (m) = 3.281 feet (ft)
foot (ft) = 0.3048 meter (m)
kilometer (km) = 3,281 feet (ft)
kilometer (km) = 0.6214 statute mile (mi)
statute mile (mi) = 1.609 kilometers (km)
statute mile (mi) = 0.869 nautical mile
kilometer (km) = 0.54 nautical mile
nautical mile = 1.852 kilometers (km)
nautical mile = 1.151 statute miles (mi)

Area

square meter (m^2) = 10.765 square feet (ft^2)
square foot (ft^2) = 0.0929 square meter (m^2)
acre (ac) = 4,047 square meters (m^2)
acre (ac) = 0.4047 hectare (ha)
acre (ac) = 0.00156 square mile (mi^2)
square mile (mi^2) = 640 acres (ac)
square kilometer (km^2) = 0.386 square mile (mi^2)
square mile (mi^2) = 2.59 square kilometers (km^2)
square mile (mi^2) = 259 hectares (ha)
square kilometer (km^2) = 247.1 acres (ac)
square kilometer (km^2) = 100 hectares (ha)
hectare (ha) = 10,000 square meters (m^2)
hectare (ha) = 2.471 acres (ac)

Volume

cubic meter (m^3) = 35.31 cubic feet (ft^3)
cubic feet (ft^3) = 0.0283 cubic meter (m^3)
cubic meter (m^3) = 264.2 gallons (gal)
cubic foot (ft^3) = 7.48 gallons (gal)
gallon (gal) = 0.003785 cubic meter (m^3)

Flow Rates

cubic meter per second (m^3/s) = 35.31 cubic feet per second (cfs)
cubic foot per second (cfs) = 0.0283 cubic meter per second (m^3/s)
cubic meter per second (m^3/s) = 15,852 gallons per minute (gpm)
cubic foot per second (cfs) = 448.8 gallons per minute (gpm)

Mass and Weight

milligram (mg) = 0.000035 ounce (oz)
gram (g) = 0.0353 ounce (oz)
kilogram (kg) = 2.205 pounds (lb)
pound (lb) = 0.454 kilogram (kg)
ton (t) = 907 kilograms (kg)
metric ton (MT) = 1,000 kilograms (kg)
metric ton (MT) = 2,205 pounds (lb)
metric ton (MT) = 1.1 tons

Temperature

degree Celsius = °C
degree Fahrenheit = °F
°C = (°F − 32) x 5/9
°F = (°C x 9/5) + 32

Appendix

The Base Map

In order to display Columbia River Estuary physical and biological characteristics as determined by CREDDP investigators, it was necessary to develop a new base map of the estuary. Existing maps either were outdated or incompletely portrayed intertidal areas such as tidal marshes and tidal flats. The new CREDDP base map shows the shoreline, tidal marshes and swamps, tidal flats, bathymetic contours, and principal cultural features of the Columbia River Estuary and its surroundings based on the most recent and accurate data available in 1982.

The principal source for compiling the base map was a set of aerial photos taken in 1981 by the U.S. Army Corps of Engineers at a scale of 1:48,000. These photos were taken during a low tide using false color infrared film, which is sensitive to differences in vegetation types and to the presence of water. After transfer to black and white film, a correction process (orthophotography) was applied to the aerial photos to remove distortion caused by camera tilt and by differences in elevation of ground features. These orthophotos were produced at a scale of 1:12,000 and two geographic reference grid systems were added: Oregon North Zone state plane coordinates, and latitude and longitude coordinates (1927 datum).

The features mapped using the orthophotos include the shoreline, tidal marshes and swamps, tidal flats, and cultural features. The shoreline is defined as the upper (shoreward) limit of tidal marsh or swamp vegetation. Where no vegetation is present, the shoreline is defined as MHHW. The mapping of the shoreline and the mapping of tidal marshes and swamps were therefore closely related processes.

Nineteen tidal vegetation communities in the Columbia River Estuary had been located and defined in 1980 (Thomas 1980) and had been mapped as overlays on a set of color aerial photos. These were classified for the CREDDP base map into three vegetation types (low marsh, high marsh, and swamp) and were transferred, with corrections, from the overlays to the 1:12,000 orthophoto base. The low marsh, high marsh, and swamp designations are defined in terms of the plant species present and do not follow a strict elevational gradation. The transition from low marsh to high marsh and swamp occurs between about 2.0 and 2.6 meters above MLLW*. The transition to upland vegetation occurs between about 2.4 and 3.7 meters above MLLW.

Where vegetation is present, the shoreline displayed on the base map is coincident with the transition from tidal to upland vegetation and varies with that transition from about 2.4 to 3.7 meters above MHHW. Where no vegetation is present, several sources were used to compile the shoreline at MHHW on the orthophoto base. MHHW is about 2.5 meters above MLLW at Tongue Point and varies slightly from this in other parts of the estuary.

The tidal flats were also compiled using the orthophotos. Tidal flats (also referred to as tidal sandflats and tidal mudflats) are intertidal areas lacking marsh vegetation. Since the tidal height during the aerial survey was approximately zero (MLLW), the water's edge on the photos was used to defined the low boundaries of the tidal flats. Because some sections of the water's edge are difficult to locate on the photos and because tidal elevation varies in different localities of the estuary, the lower boundary shown on the base map may actually range from about 0.3 meters below MLLW to 0.3 meters above MLLW. The upper boundary of the tidal flats is at the lower limit of tidal vegetation or, where no vegetation is present, at the shoreline (about MHHW).

Like the tidal flats, most of the cultural features on the map were compiled directly from the orthophotos. These consist principally of roads and towns but also include other distinctive landmarks such as lighthouses. Features located in the water, such as piers and pile dikes, were also mapped.

After all the information obtainable through the use of the 1:12,000 orthophotos had been compiled, the results were photographically reduced to a scale more suitable for mapping other information. Sounding data from bathymetric surveys conducted by the U.S. Army Corps of Engineers between 1980 and 1981 were used in conjunction with shoreline and tidal flat data from the orthophotos to generate the bathymetric contours (contours are expressed in feet below MLLW). Roads and railroads outside the area covered by the orthophotos, state and county lines, and the navigation channel were added using United States Geological Survey maps (1:24,000, 1:62,500, and 1:100,000 series) and 1:40,000 National Oceanic and Atmospheric Administration navigation charts.

*MLLW is about 0.9 meters below National Geodetic Vertical Datum (1929 general adjustment) at Tongue Point (see Figure 2-2).