CHANGES IN COLUMBIA RIVER ESTUARY HABITAT TYPES OVER THE PAST CENTURY

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COLUMBIA RIVER ESTUARY DATA DEVELOPMENT PROGRAM

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FOREWORD

Administrative Background

This study was undertaken to meet certain regulatory requirements of the State of Oregon. On the Oregon side of the Columbia River Estuary, Clatsop County and the cities of Astoria, Warrenton and Hammond are using the resources of the Columbia River Estuary Study Taskforce (CREST) to bring the estuary-related elements of their land and water use plans into compliance with Oregon Statewide Planning Goals and Guidelines. This is being accomplished through the incorporation of CREST's Columbia River Estuary Regional Management Plan (McColgin 1979) into the local plans.

Oregon Statewide Planning Goal 16, Estuarine Resources, adopted by the Land Conservation and Development Commission (LCDC) in December 1976, requires that "when dredge or fill activities are permitted in inter-tidal or tidal marsh areas, their effects shall be mitigated by creation or restoration of another area of similar biological potential.... Restoration is appropriate in areas where activities have adversely affected some aspect of the estuarine system...." Revised guidelines to accomplish mitigation, approved by LCDC in April 1980 and distributed in a "Mitigation/Restoration Information Paper," suggest that the following general steps be carried out in the planning process:

(1) identify estuary habitats, resources, functions and processes which have been diminished or lost in the past;
(2) identify estuary habitats, resources, functions and processes in areas identified for development requiring dredging or filling activities;
(3) identify the type and extent of adverse impacts to be mitigated when areas in (2) are developed;
(4) identify restoration, creation or enhancement actions or projects to offset past and anticipated adverse effects; and
(5) develop a coordinated program to carry out restoration, creation, or enhancement actions or projects.

Administrative History, Purpose and Funding of This Study

In its Final Draft Review for Compliance of the CREST Plan, produced in March 1981, LCDC found (page 86) that "the plan's factual base does not clearly document historic conditions or resources lost or diminished as a result of past alterations, activities, or catastrophic events or the causes for such losses." This study was undertaken by CREST in the fall of 1981 to address this finding and to carry out step (1) of the LCDC guidelines listed above. Funding was provided by a grant from the Oregon State Department of Energy with funds obtained from the National Oceanic and Atmospheric Administration (NOAA) and appropriated for the Coastal Energy Impact Program of the Coastal Zone Management Act of 1972. The grant funds a larger study of which this report is a part. That study, entitled "Estuarine Mitigation for Energy-Related Developments", addresses LCDC's remaining four steps listed above.

Funding for the final editing and publication of this report was provided by the Columbia River Estuary Data Development Program (CREDDP), a federally funded program administered under a cooperative agreement between CREST and NOAA. CREDDP is an applied research program with 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. Among CREDDP's objectives is to investigate causes of modern and historical bathymetric change. Moreover, program managers recognized a need to provide a broad historical perspective on the estuary as a context for the information that the program is developing. This is the first in a series of CREDDP products to be completed by June 1984 that will include technical reports, a resource atlas, a computerized data archive, a report integrating CREDDP information, and a user's guide to CREDDP information.

Acknowledgements

The project officer for this study was Michael DeLapa, CREST Director. CREDDP's Program Manager is John Damron. The other primary reviewers of the final draft were David Fox and Willa Nehlsen. Among several other reviewers whose comments were helpful at earlier stages in the preparation of this report were David Jay, Charles Simenstad and Ed Roy. Sally Metteer, cartographer of the two large insert maps, helped draft several of the figures. Thanks are also due to Elizabeth Rummell, the skillful and patient operator of CREDDP's word processor.

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scale 1:160,000 preceding page 1

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EXECUTIVE SUMMARY

This study compares information on the Columbia River Estuary from a time predating most human impacts with corresponding information derived from recent sources. Section 2, Methods and Materials, describes the selection and use of materials to achieve this comparison. Surveys conducted from 1868 to 1873 are the source of the historical materials selected. These materials permitted the mapping and measuring (in acres) of five estuarine "habitat types": deep water, medium depth water, shallows and flats, marshes, and swamps. Also, the areas removed from the estuarine system since the 1868-73 surveys were classified into five additional categories according to current use. Separate maps of seven subareas were constructed to permit a more detailed analysis of changes in acreage. Each subarea was mapped twice, one for the past, the other for the present.

Section 3, Results, presents the acreage data obtained and gives an account of the changes revealed by the maps. The data show an overall reduction in the estuary's area from 156,190 acres in 1870 to 119,220 acres in the present, a loss of 24 percent of the historical total. The greatest change, both in acres and as a percentage, is in the tidal swamp category, which shows a 77 percent loss. Swamps and marshes together lost 65 percent of their former area; deep and medium depth water acreages were reduced by 16 percent, while shallows and flats show a 10 percent increase in area. The distribution of these changes among the seven subareas is highly uneven.

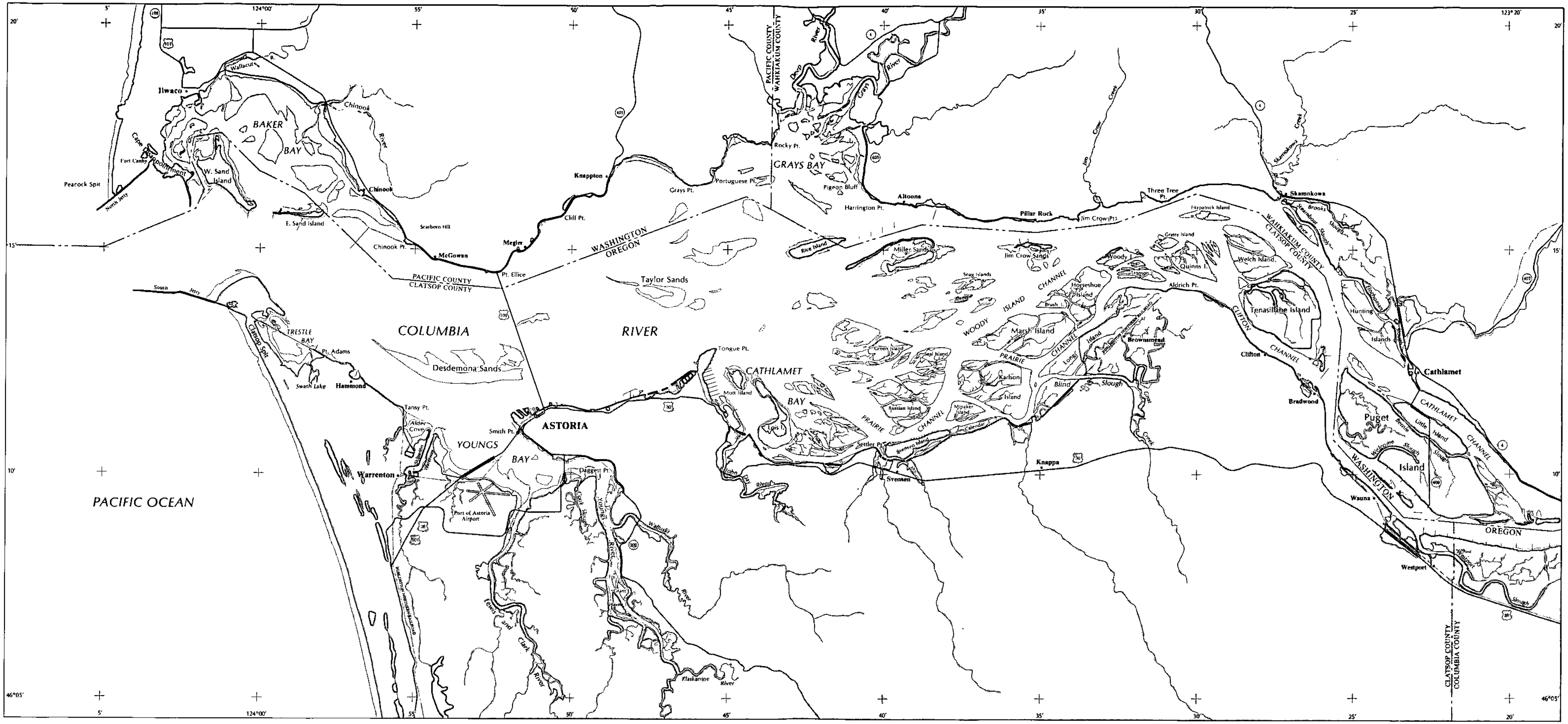
Sections 4 and 5, Discussion and Conclusions, interpret the results presented in Section 3 in the light of the author's background in estuarine ecology and personal knowledge of the estuary. The discussion addresses two questions: what factors have caused these changes, and what is the significance of the habitat types in terms of estuarine "values" (i.e., habitats, resources, functions, and processes)?

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

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

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

term, while diking and fills that create artificial uplands have resulted in a substantial loss of estuarine values.



Columbia River Estuary

Scale 1:160,000

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

0 1 2 3 4 5 6 Miles

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

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

1. INTRODUCTION

1.1 BACKGROUND

Estuaries, like many other natural systems, undergo gradual natural changes in topography, physical processes and the structure of floral and faunal communities. In estuaries these changes commonly occur over a time span of hundreds to thousands of years. Although rather short in a geologic sense, such a time span is long enough to make the system appear static to human observers. In many estuaries of the world human influence has accelerated these changes, resulting in systems that bear little resemblance to their natural, slowly-evolving state.

In the Columbia River Estuary such rapid changes have occurred over the past century. This study quantifies the mix of natural and human-induced changes in terms of surface area of distinct ecological regions or "habitat types", and discusses causes for these changes as well as the relationships between these changes and changes in ecosystem processes. The analyses in this paper also provide historical perspective to ecosystem or natural resource studies which endeavor to examine the estuary in detail during a single point in time.

1.2 APPROACH

Several methods are available for assessing historical ecosystem changes. In San Francisco Bay, Krone (1979) used historical bathymetric surveys to quantify changes due to shoaling and erosion, while Atwater et al. (1979) compared historical and modern maps augmented with an examination of underground fossil roots and stems to assess changes in tidal marshes.

No matter what the approach, any historical analysis requires the gathering of information on the estuary as it was in the past and the comparison of that information with recent data. As discussed in the Foreword, the administrative purpose of this study was to "identify (Columbia River) estuary habitats, resources, functions and processes which have been diminished or lost in the past." But when in the past? Clearly the intent of the instructions was that the primary focus should be on measuring the extent and effects of human impacts. Although human beings have inhabited the Columbia River Estuary region for thousands of years, their impacts were negligible until the arrival of large numbers of new settlers in the second half of the nineteenth century. Meanwhile, the estuary was constantly undergoing naturally-caused changes. These considerations made the mid-nineteenth century the optimum period for this study's historical data base.

At the same time, the quality of historical information would clearly be a limiting factor in this study. Generally, the detail and reliability of historical information would be inversely proportional to the time elapsed since it was originated. The phrase "estuary habitats, resources, functions and processes" would have to be more or less liberally interpreted depending on the quality of historical information that could be found. Thus the selection of an historical data base and the definition of a format for this study were interrelated processes.

Figure 1. The Cathlamet Bay Area as Mapped by Wilkes in 1841

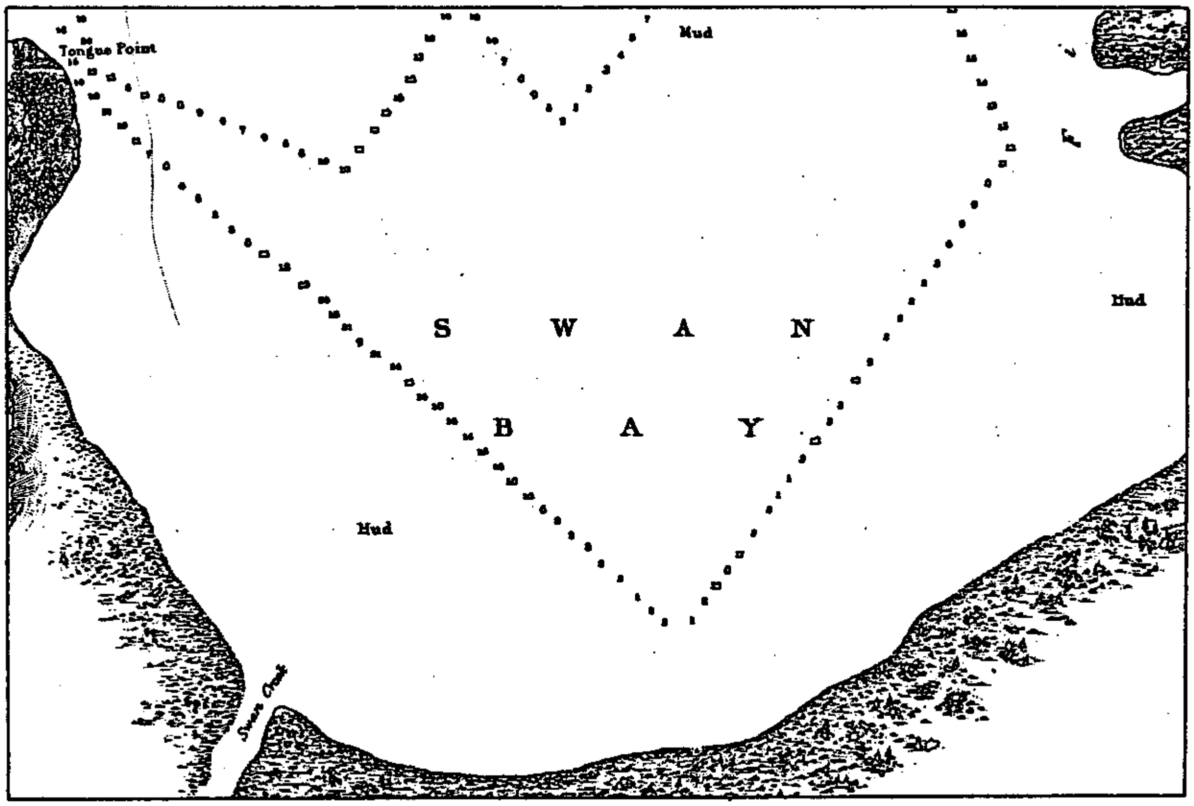
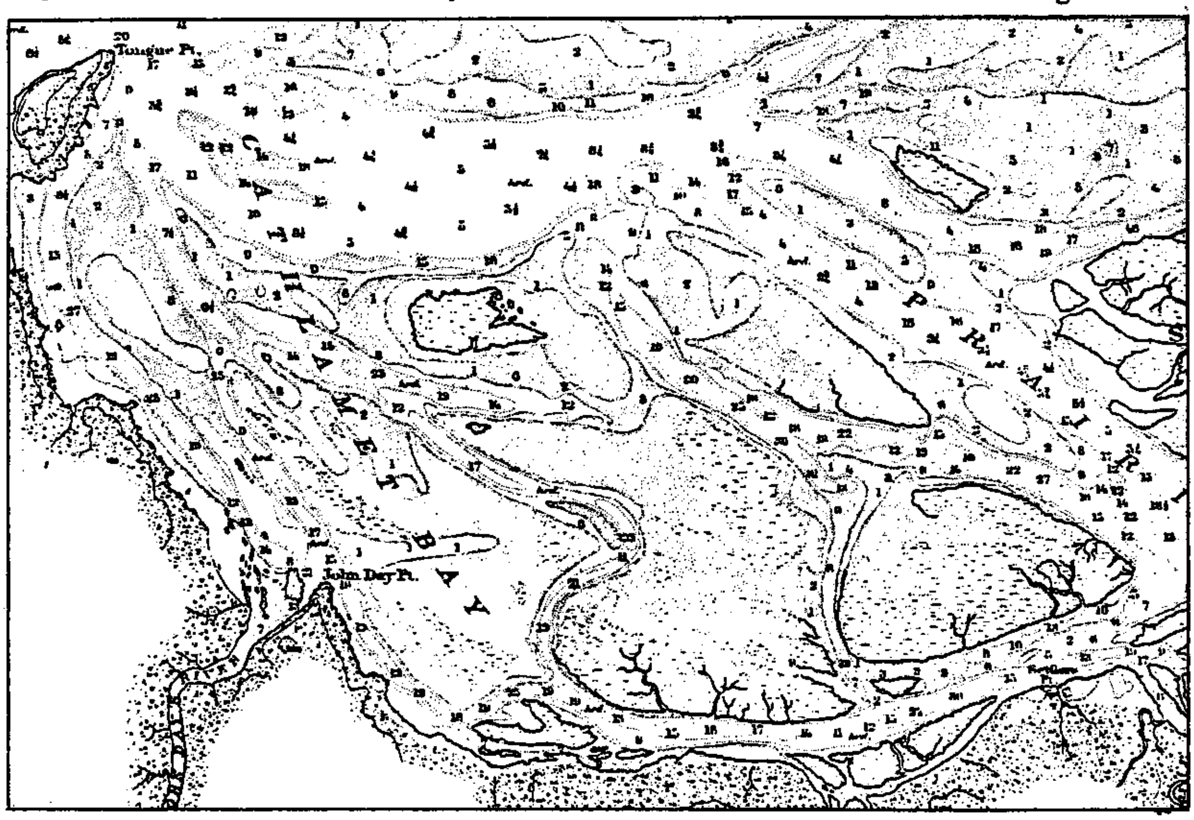


Figure 2. U.S. Coast Survey 1875 Chart from the Same Area as Figure 1



2. METHODS AND MATERIALS

2.1 HISTORICAL DATA BASE

2.1.1 Selection

Various kinds of historical documents were examined, such as old maps and navigation charts of the estuary, photographs dating from the late nineteenth and early twentieth centuries, and historical accounts of the estuary. These were found in the archives of a number of institutions, principally the CREST map collection and library, the Clatsop County Historical Museum, and the Columbia River Maritime Museum, all located in Astoria, Oregon; and the Oregon Historical Society map collection and library and the Army Corps of Engineers map collection, library, and photogrammetry department in Portland, Oregon.

After an examination of all these materials, charts issued by the U.S. Coast Survey* between 1870 and 1878 and drawn from 1868-1873 survey data were selected as the best available representation of the undeveloped estuary. The first sheet (1870) covered the River Mouth to east Astoria, the second sheet (1875) covered Tongue Point to Tenasillahe Island, and the third sheet (1878) covered Tenasillahe Island to Grimms Island.**

Earlier charts such as those produced by Wilkes in 1841 show extensive soundings in the subtidal area, but the graphic representation of the floodplain was judged to be unreliable for quantitative measurement (Figure 1). The soundings shown on the U.S. Coast Survey charts are more complete than those of Wilkes, and the floodplain and upland vegetation are depicted graphically with symbols that suggest great attention to detail (Figure 2). These were the first charts to include the whole floodplain.

2.1.2 Interpretation

No key could be found to the five symbols used on the charts. However, the symbols themselves and the manner in which they were used left little doubt as to their interpretation (Figure 3).

Soundings in deep water are shown without any symbols. Soundings to a depth of eighteen feet are shown by numerals (indicating feet below mean lower low water†) superimposed on symbol (1). The zero, six, and

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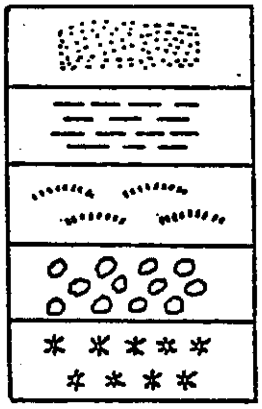
*The U.S. Coast Survey was later called the U.S. Coast and Geodetic Survey and is now the U.S. Geodetic Survey.

**The Locational Map preceding page 1 shows the locations of all places named in text. Grimms Island is omitted because it is east of the study area boundary.

† Mean lower low water (MLLW) is the average height of the lower of the two daily low tides over a specific time interval. Its elevation is by definition zero. Modern charts and tide charts use the same definition. It is not known what time interval was used by the U.S.

Figure 3. Interpretation of the Symbols Used in the Coast Survey Charts



1. Unvegetated flat and subtidal area to eighteen feet below mean lower low water
2. Vegetated wetlands, floodplain area
3. Grassland; emergent marsh if in floodplain
4. Deciduous trees and shrubs
5. Coniferous trees

twelve foot bathymetric contour lines are indicated by artful shadings of symbol (1), which extends above MLLW. Thus where soundings are absent symbol (1) was interpreted as unvegetated flats. Abbreviations such as "hrd" and "sft" occasionally appear superimposed on symbol (1) to indicate the nature of the sediment. Symbol (2) is shown extensively, always in combination with symbols (3), (4), and/or (5); it was therefore interpreted as an illustration of water, indicating the limits of tidal inundation. Symbols (3), (4) and (5) appear both with and without symbol (2) superimposed. Their meaning as pictorial representations seemed clear; thus symbol (3) in combination with symbol (2) would indicate emergent marsh, and symbols (4) and/or (5) in combination with symbol (2) would indicate forested and tall-shrub dominated swamps. These interpretations produced a portrait of the estuary that was recognizable and corresponded to the patterns one would expect to find.

2.1.3 Verification

Since the original field maps from which the charts were drafted are in the Oregon Historical Society collection in Portland together with reports from the survey teams, the content and quality of these were reviewed.

The work was carried out under the supervision of Cleveland Rockwell (topography) and Edward Cordell (hydrography). Rockwell and Cordell produced charts in the field at a scale of 1:10,000. From these field studies, the three Coast Survey charts were later drafted at a scale of 1:40,000. The reports from the survey teams indicate that their work on the lower Columbia River was carried out meticulously. The Annual Reports of the Superintendent of the U.S. Coast Survey for the years 1868-73 contain accounts based on these reports. Appendix A reproduces excerpts from these accounts.

Three methods were devised to test the accuracy of the information shown on the Coast Survey charts. Old photographs were compared with the vegetation shown on the charts, the current elevation of diked areas

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Coast Survey in 1868-73; the modern legal specification is 18.6 years.

shown on the charts as marsh was compared with that of adjacent diked areas shown as swamp, and the current configuration of drainage ditches in diked areas was compared with the tidal channel systems for the same areas shown on the charts. These tests are detailed in Appendix B. The conclusion was drawn that the charts are an accurate representation of the floodplain vegetation, at least for distinguishing emergent marshes from forested and tall-shrub dominated swamps. No method was found for checking the accuracy of the bathymetric data; the general observation that the survey was conducted with great attention to accuracy and detail led to the conlusion that the bathymetry could be accepted as reliable.

2.2 RECENT DATA BASE

The decision to select the U.S. Coast Survey charts as a source for historical data was based on their accuracy and detail in comparison with alternative sources; it was confirmed by the availability of recent data that closely matches, though in much greater detail, the kind of information that can be derived from the charts' symbols. The data referred to are the results of a wetlands vegetation mapping project conducted by the author (Thomas 1980) distinguishing fifteen tidal marsh and four tidal swamp vegetation communities. These results were supplemented for this study by information from 1977-78 color aerial photographs.

Bathymetric data for recent times were drawn from Northwest Cartography Inc. (1980) reproductions of the 1958 NOAA bathymetric survey. This was the most recent survey available, since at the time of the research for this study the Army Corps of Engineers 1980-81 bathymetric survey was incomplete.

2.3 STUDY FORMAT

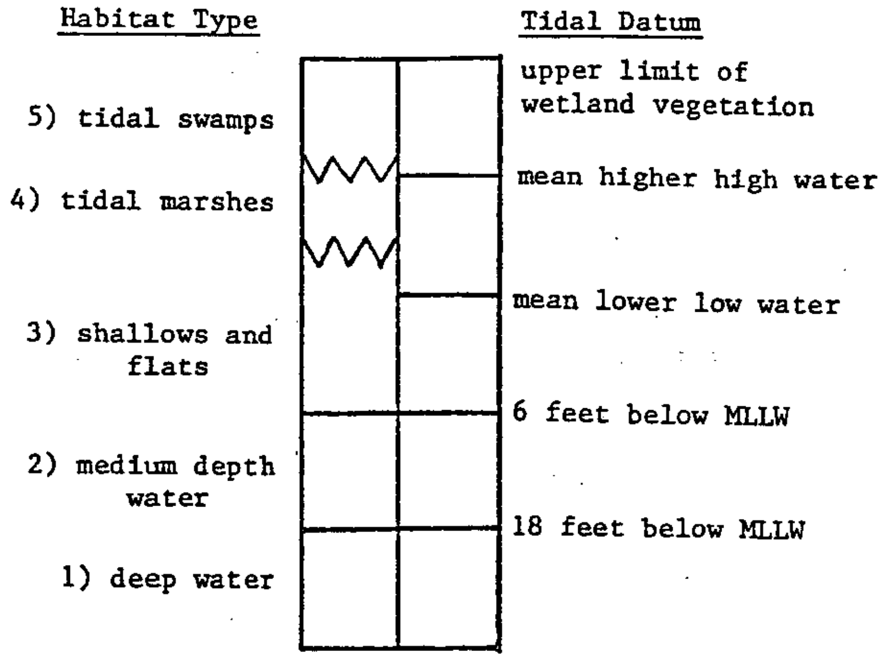
Part of the process of selecting materials for this study was to consider what kind of format they would permit. It was particularly desirable that the materials permit some degree of quantitative analysis of changes in the estuary. It became evident that this could be achieved with the U.S. Coast Survey charts by defining several categories of "habitat types", constructing maps to show the distribution of these habitat types, and measuring their acreages from the maps. It was decided that this was the best possible method of quantifying changes in "estuary habitats, resources, functions and processes".

2.3.1 Estuarine Habitat Types

No more than five estuarine habitat types could be delineated with precision. These are generally characterized by differing elevations. Two of the lines of demarcation, the eighteen foot and six foot bathymetric contour lines, are defined by elevation. The other boundaries are defined according to vegetation types, but these also tend to occur at distinct elevations (Figure 4).

The five estuarine habitat types were defined as follows:

Figure 4. Relative Elevations of the Five Estuarine Habitat Types



(1) Deep water: below the eighteen foot bathymetric contour.

(2) Medium depth water: from the eighteen foot up to the six foot bathymetric contour line. Types (1) and (2) are not markedly different from each other ecologically and can be combined when the results are discussed. The division was made because useful information on the shoaling process could be obtained in this way.

(3) Shallows and flats: from the six foot bathymetric contour line up to the edge of tidal marsh or swamp vegetation, or mean higher high water (MHHW) where vegetation is absent. These limits were selected for practical reasons since the MLLW contour was incompletely mapped and three feet below MLLW, which is the lower limit of wetlands defined by Cowardin et al. (1979), is seldom shown as a contour on charts, preventing the use of what is otherwise the preferred datum. Although various sediment properties such as grain size and organic content are critical factors in determining the community structure and abundance of organisms in shallows and flats, the abbreviations shown on the U.S. Coast Survey charts were insufficient to delineate sediment types.

(4) Tidal marshes: areas dominated by emergent vegetation and low shrubs; that is, areas shown with a combination of symbols (2) and (3) on the historical charts, and for recent times, areas defined as tidal marsh in Thomas (1980). Marshes are found from MLLW to slightly above MHHW, although they are rare at the lowest elevations.

(5) Tidal swamps: shrub and forest dominated wetlands, extending up to the line of non-aquatic vegetation (i.e., the line at which excess water ceases to be a factor controlling the composition of the vegetation). On the historical charts, areas shown with symbol (2) in

combination with symbols (4) and/or (5) were interpreted as tidal swamps. The information for recent times comes from Thomas (1980). These swamps may be of sufficiently high elevation that they are inundated only during spring tides, but they may also extend down below MHHW.

2.3.2 Non-Estuarine Habitat Types

In addition to these five estuarine habitat types, five categories of non-estuarine shoreland were defined in order to detail what happened to floodplain areas removed from the estuarine system. They are:

(6) Developed floodplain: all diked floodplain in use as agricultural land or converted to residential or other uses. Also included are small areas of fill for dikes, railroads, roads, residences, etc. on diked floodplain.

(7) Natural and filled uplands: areas where measurable (at scale 1:24,000) acreages have been filled, mostly through the disposal of dredge material. Within the diked floodplain, only the Port of Astoria Airport fill was included in this category; fills for roads and small industrial and residential sites were included in habitat type 6. The acreage covered by the dikes themselves was also included under habitat type 6, except for the massive dikes reinforced with dredge material on Puget Island, which were measured as a major fill. The "natural" uplands included in habitat type 7 are historical uplands which could not easily be excluded from the study area, such as isolated dunes in the Hammond/Warrenton floodplain, and upland areas which have formed through processes other than filling during the past hundred years, such as Clatsop Spit.

(8) Non-estuarine swamps: areas of diked floodplain which either were never cleared of woody plants, or else were cleared and reverted to swamp.

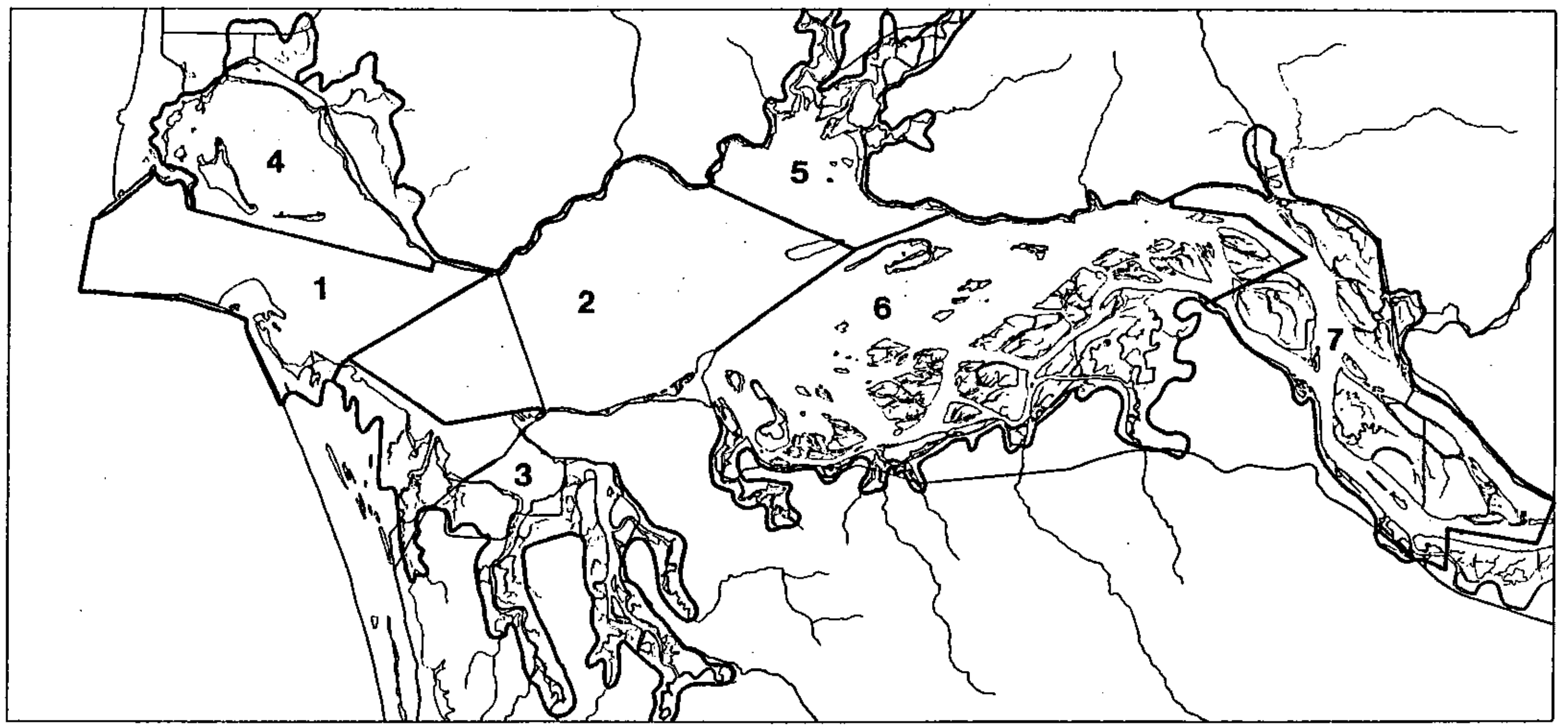
(9) Non-estuarine marshes: areas of diked floodplain which support emergent wetland vegetation. These are usually abandoned pastures dominated by common rush and slough sedge.

(10) Non-estuarine water: areas of former tidal sloughs which now form lakes and drainage channels and are separated from the estuary by dikes and tidegates. One small coastal lake shown on the 1870 chart is also included here.

2.4 PROCEDURES

In order that local effects of changes in estuarine habitat types might be better appreciated, the historical study area was divided into seven subareas (Figure 5): 1, the River Mouth; 2, the Mixing Zone; 3, Youngs Bay; 4, Baker Bay; 5, Grays Bay; 6, Cathlamet Bay; and 7, the Upper Estuary. An explanation of the boundaries of the historical study area and the seven subareas is provided in Appendix C. The boundaries were chosen to maximize the physical and biological distinctions among the subareas without creating undue mapping difficulties.

Figure 5. Study Area and Subarea Boundaries



(1) River Mouth
(2) Mixing Zone
(3) Youngs Bay
(4) Baker Bay
(5) Grays Bay
(6) Cathlamet Bay
(7) Upper Estuary

For each subarea, two work maps were drawn of an identical area at a scale of 1:24,000 showing the distribution in recent and in historical times of the habitat types described above.

The acreages of the various categories were measured by planimeter for each subarea. The results were tabulated and the changes were computed.

For each subarea, a report was written detailing the changes per habitat type as observed on the subarea's two work maps and as measured, together with an introductory description and discussion of the subarea as a whole. These subarea reports, which are included here as Appendix D, became the basis for the remainder of this report, and most of the information in them has been incorporated into the main body of this report. They are appended primarily for readers who wish to find collected in one place all the information contained in this report about any particular subarea(s). The general reader may be interested by the introductory descriptions without wishing to review the changes per habitat type, much of which is repetitive. Readers should be forewarned that these subarea reports are a liberal mixture of results, discussion and speculation.

Table 1. Past and Present Acreages of Each Habitat Type: Estuary Totals

Habitat type	1870 acreage	Present acreage	Change
(1) Deep water	35,140	32,580	- 2,560 (7.3%)
(2) Medium depth	34,210	25,720	- 8,490 (24.8%)
(3) Shallows/flats	40,640	44,770	+ 4,130 (10.2%)
(4) Tidal marshes	16,180	9,200	- 6,980 (43.1%)
(5) Tidal swamps	30,020	6,950	- 23,070 (76.8%)
(6) Developed floodplain		23,950	
(7) Uplands - natural & filled	1,930	7,590	
(8) Non-estuarine swamp		3,320	
(9) Non-estuarine marsh		3,130	
(10) Non-estuarine water	50	960	

1870 estuarine acreage	156,190	
Present estuarine acreage	119,220	(76.3%)
Estuarine acreage removed	36,970	(23.7%)
Non-estuarine wetlands added	7,360	

3. RESULTS

The results of the mapping and measuring project described in the previous section are contained in the two maps to be found in the inside front and back cover pockets of this report and in Tables 1 through 8. Each map is a composite of seven subarea work maps reduced to a scale of 1:62,500. Map 1 shows the estuary in 1870 (roughly); Map 2 is of the present (roughly). The maps delineate each of the five estuarine habitat types, but the five non-estuarine habitat types are handled as follows: habitat types 6 and 7 are grouped together and referred to as "upland", while habitat types 8, 9 and 10 are grouped together and referred to as "non-tidal wetlands". The fourteen original work maps are on file at the CREST office.

The acreage measurements and computations are presented in Tables 1 through 8. Table 1 shows the total estuary-wide acreages of each habitat type in 1870 and in the present together with the net changes in each estuarine habitat type. Tables 2 through 8 present the raw data as they were measured and computed per subarea. In the summations of each of these tables, "estuarine acreage" refers only to the first five (estuarine) habitat types; "non-estuarine wetlands" refers to habitat types 8 through 10, non-estuarine swamp, marsh and water. Figure 6 (on page 19, following Table 8) presents estuary-wide totals for each estuarine habitat type in graphic form.

According to these results, the total area of the estuary, from deep water up to the line of non-aquatic vegetation, is now only about three-quarters of what it was in 1870. Some 37,000 acres - almost 58 square miles - is no longer estuary. These areas have become diked floodplain (24,000 acres), uplands (6,000 acres), and non-estuarine wetlands (7,000 acres).

Change has not been limited to the removal of area from the estuary. The results indicate that many areas that remain part of the estuary have changed from one habitat type to another since 1870. Shallows and flats actually show a 10 percent increase in area. The area of deep and medium-depth water, almost none of which has become part of the non-estuarine areas, has nevertheless been reduced by 16 percent.

As a result of both kinds of change, the "profile" of the estuary (the proportions among the five estuarine habitat types) has changed considerably. Figure 6 illustrates this well. Whereas in 1870 four of the five habitat types had roughly equal acreages with only the area of tidal marshes about half that of the others, at present the profile is jagged with a great peak in the center (shallows and flats). The ratio of largest to smallest has changed from 2.5 to 6.5.

The largest estuary-wide net change in any single estuarine habitat type is in the tidal swamp category, which shows a reduction in area of 77 percent since 1870. Swamps and marshes together now cover only a little more than a third the amount of area they formerly covered.

Changes among the subareas range from virtually no change (neither

Table 2. Past and Present Acreages of Each Habitat Type: River Mouth

Habitat type	1870 acreage	Present acreage	Change	
(1) Deep water	8,900	10,580	+ 1,680	(18.9%)
(2) Medium depth	4,480	2,640	- 1,840	(41.1%)
(3) Shallows/flats	2,980	1,680	- 1,300	(43.6%)
(4) Tidal marshes		250	+ 250	
(5) Tidal swamps				
(6) Developed floodplain				
(7) Uplands - natural & filled	530	1,300		
(8) Non-estuarine swamp		130		
(9) Non-estuarine marsh		360		
(10) Non-estuarine water	50			

1870 estuarine acreage	16,360	
Present estuarine acreage	15,150	(92.6%)
Estuarine acreage removed	1,210	(7.4%)
Non-estuarine wetlands added	440	

Table 3. Past and Present Acreages of Each Habitat Type: Mixing Zone

Habitat type	1870 acreage	Present acreage	Change	
(1) Deep water	8,450	8,360	- 90	(1.1%)
(2) Medium depth	10,780	10,330	- 450	(4.2%)
(3) Shallows/flats	9,540	9,490	- 50	(0.5%)
(4) Tidal marshes	10	10	0	
(5) Tidal swamps				
(6) Developed floodplain				
(7) Uplands - natural & filled		590		
(8) Non-estuarine swamp				
(9) Non-estuarine marsh				
(10) Non-estuarine water				

1870 estuarine acreage	28,780	
Present estuarine acreage	28,190	(97.9%)
Estuarine acreage removed	590	(2.1%)
Non-estuarine wetlands added	0	

Table 4. Past and Present Acreages of Each Habitat Type: Youngs Bay

Habitat type	1870 acreage	Present acreage	Change	
(1) Deep water	810	850	+ 40	(4.9%)
(2) Medium depth	1,120	870	- 250	(22.3%)
(3) Shallows/flats	4,400	3,860	- 540	(12.3%)
(4) Tidal marshes	7,210	980	- 6,230	(86.4%)
(5) Tidal swamps	3,000	130	- 2,870	(95.7%)
(6) Developed floodplain		6,670		
(7) Uplands - natural & filled	350	1,070		
(8) Non-estuarine swamp		1,370		
(9) Non-estuarine marsh		930		
(10) Non-estuarine water		160		

1870 estuarine acreage	16,540	
Present estuarine acreage	6,690	(40.4%)
Estuarine acreage removed	9,850	(59.6%)
Non-estuarine wetlands added	2,460	

Table 5. Past and Present Acreages of Each Habitat Type: Baker Bay

Habitat type	1870 acreage	Present acreage	Change
(1) Deep water	1,800	450	- 1,350 (75.0%)
(2) Medium depth	4,700	1,350	- 3,350 (71.3%)
(3) Shallows/flats	4,830	8,450	+ 3,620 (74.9%)
(4) Tidal marshes	1,640	730	- 910 (55.5%)
(5) Tidal swamps	3,480	0	- 3,480 (100.0%)
(6) Developed floodplain		3,420	
(7) Uplands - natural & filled	1,050	1,600	
(8) Non-estuarine swamp		1,260	
(9) Non-estuarine marsh		170	
(10) Non-estuarine water		70	

1870 estuarine acreage	16,450	
Present estuarine acreage	10,980	(66.7%)
Estuarine acreage removed	5,470	(33.3%)
Non-estuarine wetlands added	1,500	

Table 6. Past and Present Acreages of Each Habitat Type: Grays Bay

Habitat type	1870 acreage	Present acreage	Change
(1) Deep water	2,270	1,690	- 580 (25.6%)
(2) Medium depth	2,230	2,040	- 190 (8.5%)
(3) Shallows/flats	3,790	4,330	+ 540 (14.2%)
(4) Tidal marshes	310	760	+ 450 (145.2%)
(5) Tidal swamps	4,410	510	- 3,900 (88.4%)
(6) Developed floodplain		3,270	
(7) Uplands - natural & filled		120	
(8) Non-estuarine swamp		200	
(9) Non-estuarine marsh		40	
(10) Non-estuarine water		50	

1870 estuarine acreage	13,010	
Present estuarine acreage	9,330	(71.7%)
Estuarine acreage removed	3,680	(28.3%)
Non-estuarine wetlands added	290	

Table 7. Past and Present Acreages of Each Habitat Type: Cathlamet Bay

Habitat type	1870 acreage	Present acreage	Change
(1) Deep water	6,390	5,590	- 800 (12.5%)
(2) Medium depth	8,190	5,700	- 2,490 (30.4%)
(3) Shallows/flats	13,330	14,250	+ 920 (6.9%)
(4) Tidal marshes	5,580	5,960	+ 380 (6.8%)
(5) Tidal swamps	7,950	4,060	- 3,890 (48.9%)
(6) Developed floodplain		4,150	
(7) Uplands - natural & filled		920	
(8) Non-estuarine swamp		110	
(9) Non-estuarine marsh		430	
(10) Non-estuarine water		270	

1870 estuarine acreage	41,440	
Present estuarine acreage	35,560	(85.8%)
Estuarine acreage removed	5,880	(14.2%)
Non-estuarine wetlands added	810	

Table 8. Past and Present Acreages of Each Habitat Type: Upper Estuary

Habitat type	1870 acreage	Present acreage	Change	
(1) Deep water	6,520	5,060	− 1,460	(22.4%)
(2) Medium depth	2,710	2,790	+ 80	(3.0%)
(3) Shallows/flats	1,770	2,710	+ 940	(53.1%)
(4) Tidal marshes	1,430	510	− 920	(64.3%)
(5) Tidal swamps	11,180	2,250	− 8,930	(79.9%)
(6) Developed floodplain		6,440		
(7) Uplands - natural & filled		1,990		
(8) Non-estuarine swamp		250		
(9) Non-estuarine marsh		1,200		
(10) Non-estuarine water		410		

1870 estuarine acreage	23,610	
Present estuarine acreage	13,320	(56.4%)
Estuarine acreage removed	10,290	(43.6%)
Non-estuarine wetlands added	1,860	

Figure 6. Past and Present Estuary-Wide Acreages of Each Estuarine Habitat Type

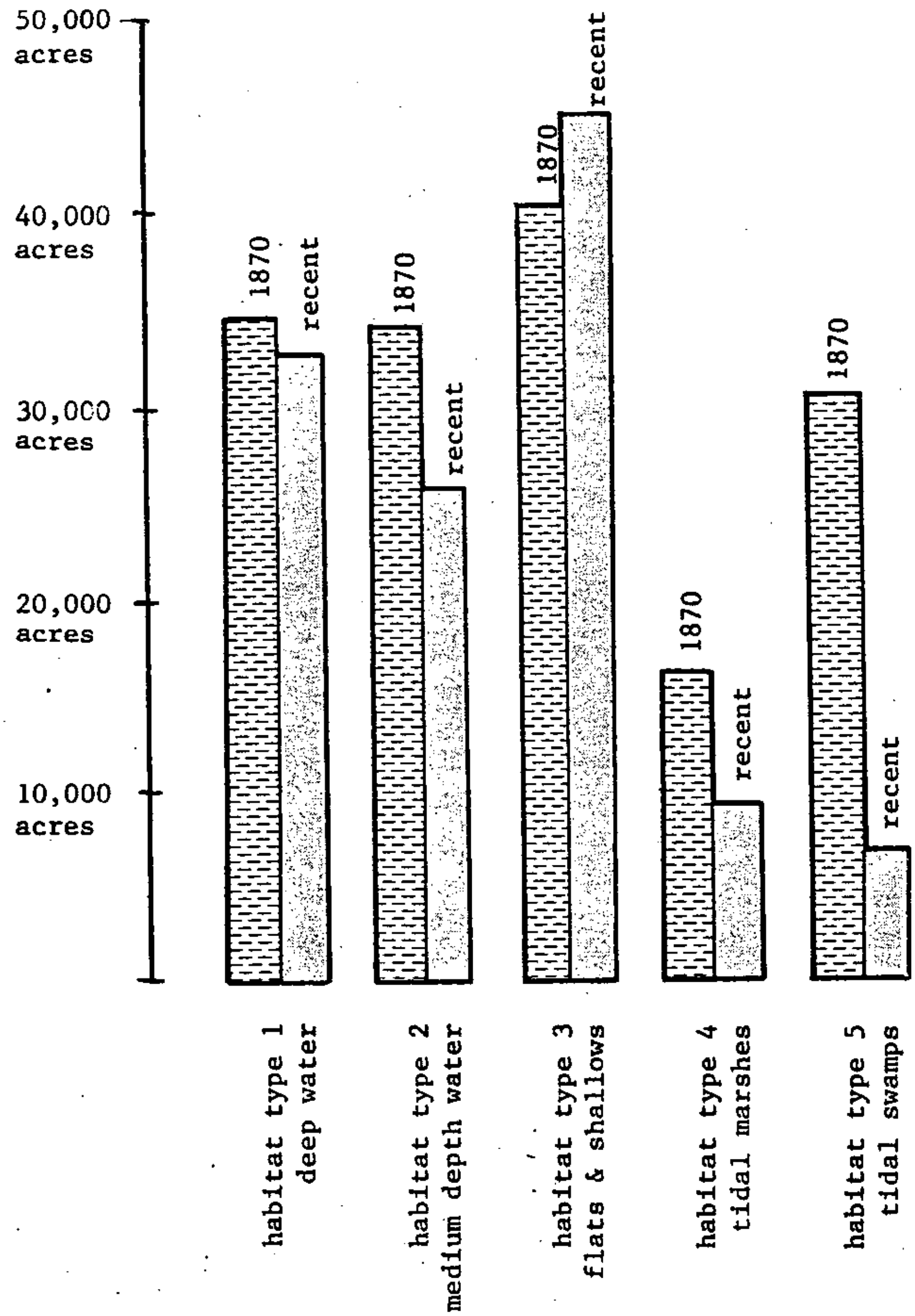
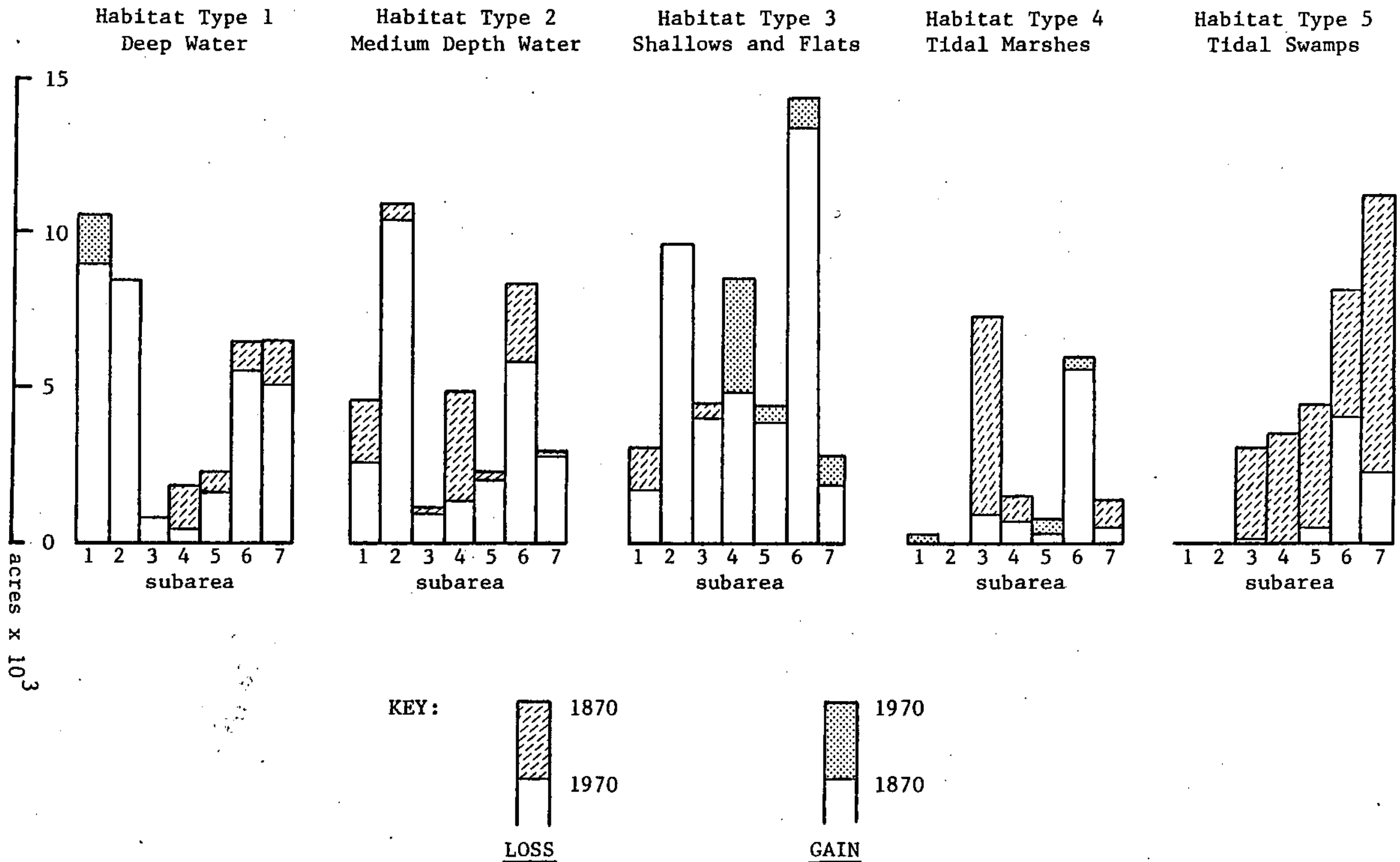


Figure 7. Acreage Gains and Losses per Subarea for Each Estuarine Habitat Type



loss nor reapportionment) in the Mixing Zone to a total net loss in estuarine area of nearly 60 percent in Youngs Bay and a vast redistribution of acreages in Baker Bay, where the net loss figure of 33 percent masks a much larger gross change: the area of shallows and flats has increased by 75 percent while deep and medium depth water have been reduced by 72 percent and swamps have been totally eliminated. The largest single change datum, in acres, is the loss of nearly 9,000 acres (almost 14 square miles) of tidal swamps in the Upper Estuary.

A comparison of subarea figures demonstrates that the estuary-wide totals in Table 1 conceal considerable locational redistribution of each habitat type. Figure 7 demonstrates this graphically. Figure 7 is in effect five separate bar graphs, one for each estuarine habitat type, each figure showing the net gain or loss per subarea for that habitat type.

Although the acreage data are very important for analysis, the two enclosed maps reveal far more than the quantitative data extracted from them. An examination of the maps makes clear that each gain or loss measured (per habitat type per subarea) is the net result of both gains and losses and may conceal considerable movement. Further, the maps yield information for each subarea habitat type about which other habitat types contributed to the gains and which accounted for the losses. To quantify this information was considered neither practical nor very desirable. The information is better conveyed by the maps themselves together with an analysis in narrative form.

The remainder of this section provides that narrative, organized by habitat type, and should be read in conjunction with an examination of the maps. Reference to Figure 7 may also be helpful. The presentation makes reference to the principal causes whose effects are being described only in order to facilitate that description. A full discussion of these causes can be found in Section 4.

3.1 DEEP WATER HABITAT TYPE

The estuary-wide figures show a reduction of 2,560 acres or 7 percent of the 1870 figure in this habitat type. On a subarea basis, the highest salinity areas show both gains and losses with a 1,680 acre (19 percent) increase in the River Mouth subarea and a 1,350 acre (75 percent) decrease in Baker Bay. This reflects the migration of Sand Island, formerly in the middle of the River Mouth, into Baker Bay. This had occurred naturally by 1885. Such large scale movement was common in the high energy environment of the River Mouth until jetty construction sheltered the area and caused the retention of Sand Island in more or less its present location. Other factors reflected in deep water changes in these subareas are the maintenance dredging of the bar and navigation channel in the River Mouth and shoaling in Baker Bay. In brackish water areas, Youngs Bay and the Mixing Zone show little change in the total acreage of deep water although its distribution has altered with channel migration. The largely freshwater subareas, Grays Bay, Cathlamet Bay and the Upper Estuary, show a significant decrease in the acreage of deep water (2,840 acres or 19 percent overall). Most of the lost acreage is now medium depth water or shallows as a result of shoaling, but some former deep water areas are now filled uplands.

3.2 MEDIUM DEPTH WATER HABITAT TYPE

A net loss estuary-wide was noted, totaling 8,490 acres or 25 percent of the 1870 acreage. The most marine areas show considerable acreages altered to deep water in the River Mouth subarea and to tideflats in Baker Bay. Losses in these two subareas total 5,190 acres or 57 percent. In Youngs Bay and the Mixing Zone, losses of medium depth water have been small. Further upriver, in the freshwater subareas, there have been considerable losses of this habitat type through shoaling in Cathlamet Bay (2,500 acres), with a smaller loss in Grays Bay and a slight gain in the Upper Estuary. The reason for these differences in the effects of shoaling on medium depth water is that it produces both gains (from deep water) and losses (to shallows and flats). In each subarea the net effect on medium depth water of both exchanges depends on the original proportion of deep to medium depth water. In 1870 the Upper Estuary had more deep water than medium depth water and consequently the net exchange from deep to medium depth water was greater than that from medium depth water to shallows and flats. The reverse proportions held in Cathlamet Bay, while in Grays Bay the original acreages of habitat types 1 and 2 were almost identical.

The extent of shoaling per subarea can be better appreciated when the change data for habitat types 1 and 2 are combined. Table 9 shows that the net acreage reductions in the subtidal habitat types is quite consistent (ranging from 11 percent to 23 percent) except in Baker Bay, where circulation has been exceptionally reduced, and in the River Mouth and the Mixing Zone, where channelization has kept shoaling to a minimum.

Table 9. Loss of Habitat Types 1 and 2 between 1870 and the Present

Subarea	Acres lost	% change
1. River Mouth	160	1.2
2. Mixing Zone	540	2.8
3. Youngs Bay	210	10.9
4. Baker Bay	4,700	72.3
5. Grays Bay	770	17.1
6. Cathlamet Bay	3,290	22.6
7. Upper Estuary	1,380	15.0
Estuary Total	11,050	15.9

3.3 SHALLOWS AND FLATS HABITAT TYPE

This is the only habitat type to show an estuary-wide increase in acreage during the past century. Shallows have been created mostly from deeper water areas by shoaling. To a much lesser extent, shallows and flats are created through the erosion of marshes and swamps by estuarine currents. Shallows and flats are lost either by erosion, creating deeper water areas, or through the creation of marsh when the flat is colonized by emergent vegetation, or because of filling and diking.

When the subareas are considered, the River Mouth is unusual since a significant loss of flats and shallows has occurred. There are two reasons for this. First, there has been considerable accretion of sand in this subarea following the construction of the South Jetty and this has resulted in sand dune formation (habitat type 7) on the site of former shallows and flats. The second reason is the migration of Sand Island mentioned above. By contrast, the adjacent Baker Bay subarea shows an enormous increase in shallows and flats totaling 3,620 acres or 75 percent of the 1870 area. These areas replaced deeper water for the reasons already discussed.

In brackish water areas, the Mixing Zone shows no significant change in the acreage of shallows and flats although extensive redistribution caused by channel migration has occurred. The Youngs Bay subarea shows a significant reduction in the acreage of shallows and flats. Losses to non-estuarine habitat types caused by diking and filling have exceeded shoaling gains from subtidal habitat types. This is a surprising result since other studies in Youngs Bay (Montagne-Bierly Associates 1977; Boley et al. 1975) have emphasized the problem of shoaling, particularly around the Highway 101 causeway. The reason for this discrepancy is that this shoaling occurred in areas which in 1870 were already shallow enough to be categorized in habitat type 3 and was therefore not measured as a habitat change by the criteria used in this study.

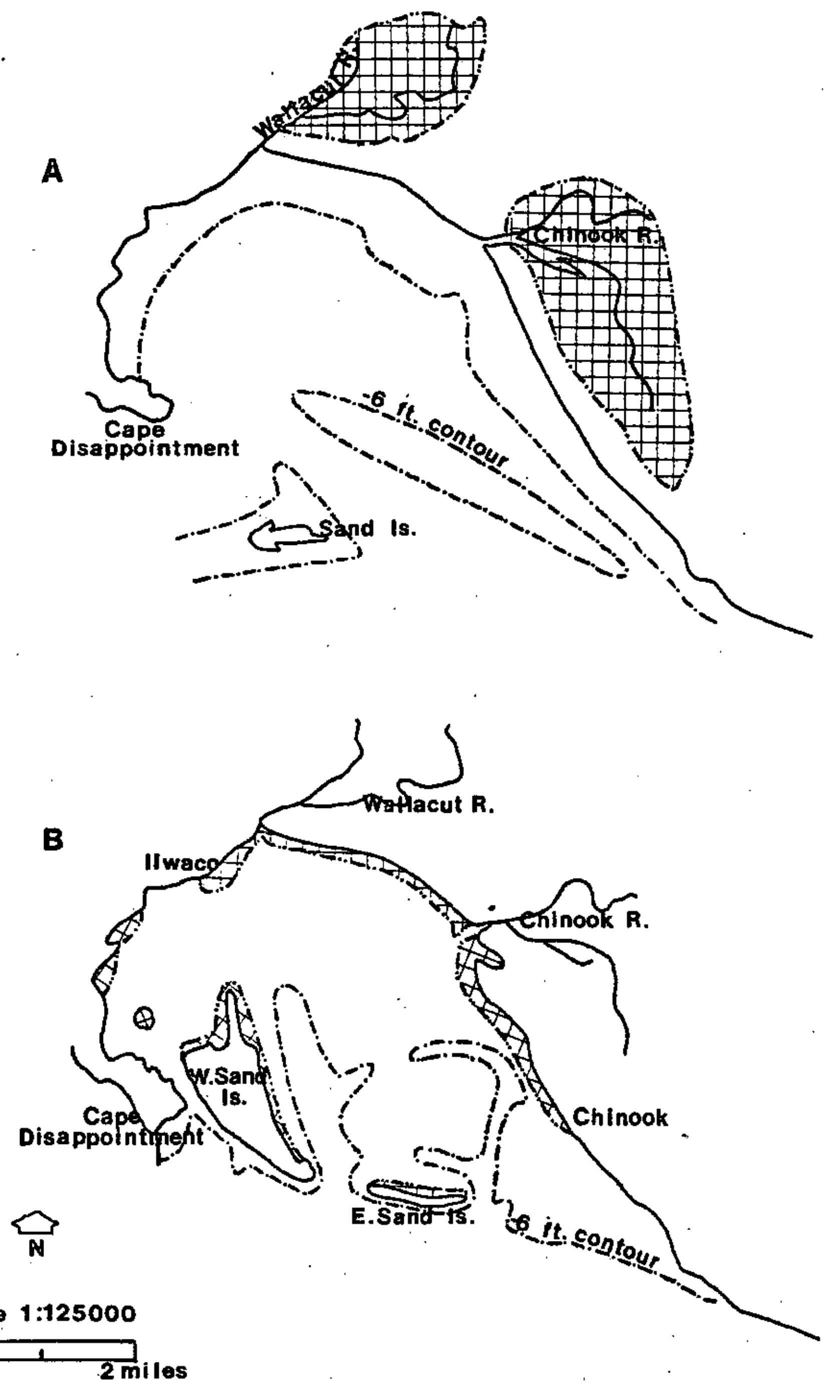
All of the freshwater subareas show a significant increase in the acreage of shallows and flats, most of the new acreage occurring in places that were subtidal in 1870.

3.4 TIDAL MARSH HABITAT TYPE

Overall, more than 10,500 acres (65 percent) of the 1870 tidal marshes have been lost, mainly through diking, while about 3,500 acres of new marshes have formed, resulting in the observed net loss of about 7,000 acres. High elevation marshes have been more extensively diked than lower elevation marshes, particularly in the western half of the estuary. New marshes have largely resulted from the colonization of dredged material. Table 10 shows details per subarea of the process of recent marsh formation, including estimated recent marsh acreages, the proportion of total marshes that are recently formed, and the probable causes of recent marsh formation.

On a subarea basis, the River Mouth has shown a gain of about 250 acres of brackish marshes, about two thirds of which are dominated by

Figure 8. Changes in Baker Bay between 1870 (A) and the Present (B)



Note: 1) the change in location of the tidal marshes (crosshatched areas);
2) the increase in area of shallows and flats (between the shoreline and the -6 ft. contour line);
and 3) the change in position and size of Sand Island.

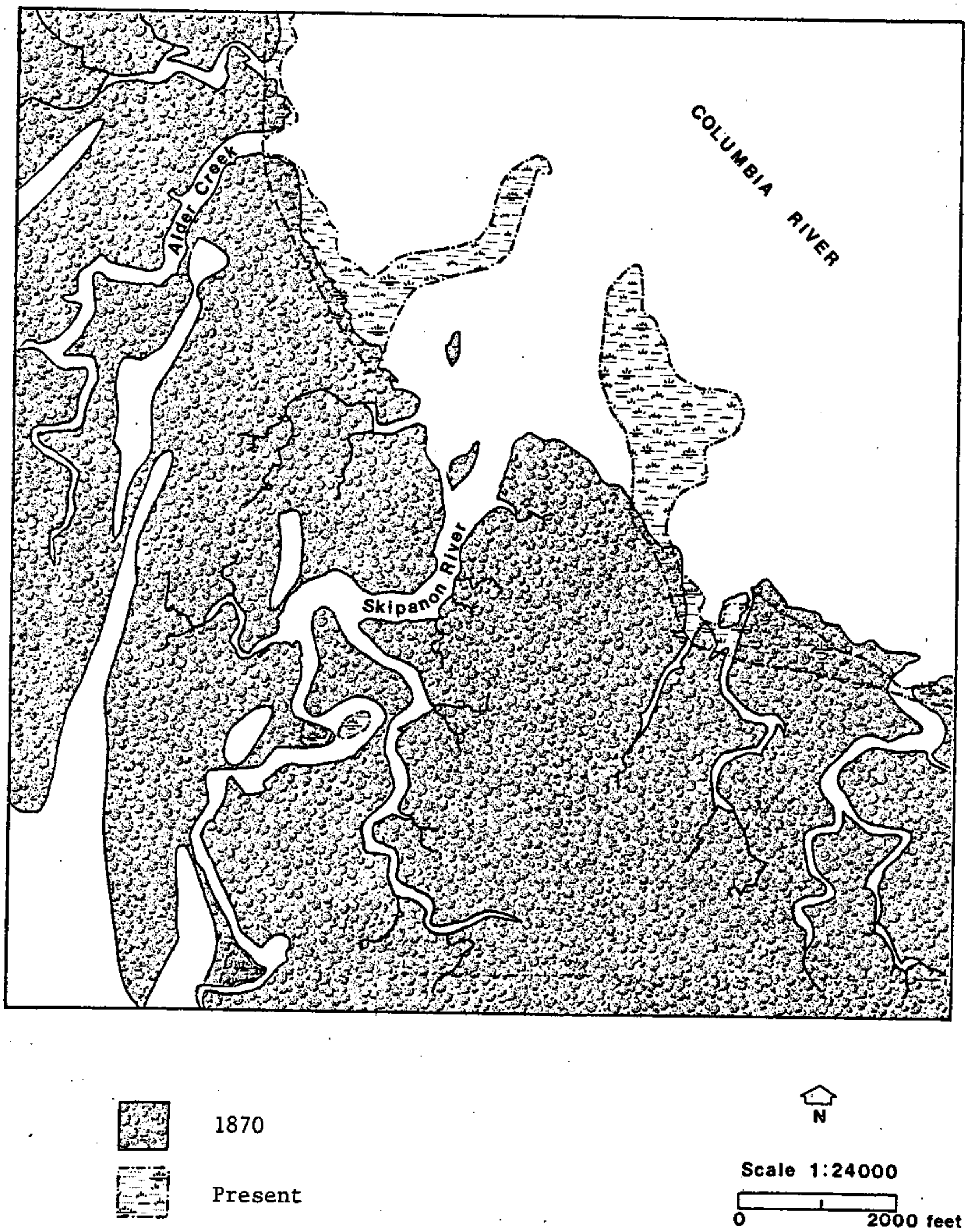
Table 10. Estimated Recent Marshes per Subarea

Subarea	estimated acres of recent marsh	recent marsh as %age of present total	probable causes of recent marsh formation
1. River Mouth	250	100	colonization of natural shoreline and flats
2. Mixing Zone	0	-	-
3. Youngs Bay	400	41	colonization of dredge spoil shoreline & flats
4. Baker Bay	730	100	colonization of natural shoreline and flats
5. Grays Bay	450	59	colonization of flats
6. Cathlamet Bay	1300	22	colonization of dredge spoil shoreline & flats
7. Upper Estuary	510	100	colonization of dredge spoil shoreline & flats
Estuary total	3640	40	

Lyngby's sedge. In 1870, this subarea was very exposed and wave energy probably prevented the establishment of tidal marshes. Since the construction of the jetties, extensive marshes have formed in the sheltered Trestle Bay area of Clatsop Spit. There is also a small salt marsh on Clatsop Spit. In Baker Bay, it is hard to distinguish marshes from swamps on the historical maps, probably because high marshes and swamps occurred as a complex mosaic. The former marsh acreage of 1,600 acres is therefore an estimate. The former marshes were, however, much more extensive than the present-day ones. They were also in different places. The former marshes were located around the Wallacut and Chinook Rivers and have all been diked. The 700 acres of present-day marshes have all formed along shorelines in recent times in areas formerly too exposed to wave action to support vegetation (Figure 8). Similarly, in Youngs Bay the former marshes and swamps occurred together as a mosaic covering some 10,000 acres, which is now reduced by diking to about 1,000 acres, about half of which appear to have developed recently on filled or otherwise shoaled areas (Figure 9).

In Grays Bay, tidal marshes are still extensive despite diking

Figure 9. Historical and Present-Day Tidal Marshes of the Skipanon River Region of Youngs Bay



along Grays and Deep Rivers, since the diked area was formerly swamp dominated. Low-elevation bulrush marshes appear to be spreading over accreting tideflats, accounting for the net gain of 450 acres of marsh in Grays Bay. Cathlamet Bay also shows a net gain in the acreage of tidal marshes. There has been some loss of former marsh areas through diking, but most of the diked floodplain in Brownsmead and elsewhere formerly supported swamp. On the other hand, extensive formation of new marshes has occurred around recently-created dredge spoil islands. In the Upper Estuary subarea, there has been a large reduction in marsh area from 1,400 to 500 acres. This is the net result of the diking of Tenasillahe Island, which formerly supported the only extensive marsh in this swamp-dominated floodplain, offset by the formation of new marshes on dredge spoil.

3.5 TIDAL SWAMP HABITAT TYPE

This is the most heavily impacted estuarine habitat type, with a net loss of 23,000 acres or 77 percent of the 1870 total, almost all of which are now one of the diked habitat types (6, 8, 9, or 10). Swamps occur at the highest elevation of any estuarine habitat type, from just below MHHW up to the line of non-aquatic vegetation (Figure 4), and may occur in areas of irregular tidal influence. They are therefore the easiest habitat type to dike.

On a subarea basis, swamps have never been extensive in the River Mouth and Mixing Zone. In Youngs Bay and Baker Bay, tidal swamps developed under brackish conditions have lost 96 percent and 100 percent of their former acreages respectively, virtually eliminating brackish water swamps from the estuary. In freshwater areas losses have been 88 percent in Grays Bay, 49 percent in Cathlamet Bay and 80 percent in the Upper Estuary. Freshwater tidal swamps are still extensive, particularly in Cathlamet Bay around Blind Slough and Prairie Channel.

3.6 NON-ESTUARINE HABITAT TYPES

About 24,000 acres of developed floodplain (habitat type 6) and about 7,000 acres of non-estuarine wetlands (habitat types 8, 9 and 10) have been created by diking. Most of these areas formerly were tidal swamps, most of the remainder were tidal marshes, and about 500 acres that were shallows and flats have been diked. An exception to these proportions is Youngs Bay, the only subarea where marshes were formerly more extensive than swamps, but these were mostly high elevation marshes.

Non-estuarine swamps and marshes occur mostly in diked floodplain areas that either were never cleared of woody plants or were cleared and later abandoned. In addition, about 500 acres of these habitat types have formed independently of diking on Clatsop Spit deflation plains in the River Mouth subarea. Generally, the proportion of present non-estuarine swamp to non-estuarine marsh is similar to the proportion of former tidal swamp to tidal marsh. The exceptionally large acreage of non-estuarine marsh in the Upper Estuary is on Tenasillahe Island, which formerly was marsh dominated, and is a result of dike failure. In Youngs Bay, the high proportion of non-estuarine swamp, surprising in view of the former predominance of tidal marsh, occurs mostly west of the Skipanon River, where the sandy soils are not well suited for agriculture.

The acreage of natural and filled upland (habitat type 7) has increased from about 1,900 acres to about 7,600 acres. The original acreage was mostly sand dunes and islands around the mouth of the river and these have increased by about 1,300 acres with accretion of sand on Clatsop Spit and in Baker Bay. The remainder of the increase in uplands (about 4,400 acres) is due to filling, mostly for the purpose of disposing of dredge spoils. All estuarine habitat types have lost acreage to uplands. Dredge spoil islands have been created in areas which were formerly deep or medium depth water or shallows and flats (Table 11). Shoreline areas which formerly were marshes and swamps have also been filled.

Table 11. Examples of Dredge-Material Islands in the Estuary (Habitat Type 7)

Locality	Subarea	Acreage
Rice Island	2/5	285
Mott Island	6	67
Lois Island	6	260
Miller Sands	6	180
Jim Crow Sands	6	80
Sandbar near Tenasillahe Island	7	35
Sandbar near Puget Island	7	150

4. DISCUSSION

This section is in two parts. The first analyzes the causes of the changes reported in the previous section. Certain major factors - shoaling, diking, filling - are obviously involved and have been referred to in the preceding narrative presentation; the discussion here will take a close look at these and other factors in an attempt to explain the processes contributing to the overall dynamics of change in the estuary. The second part is a discussion of the "habitats, resources, functions and processes" (referred to collectively as "estuarine values") associated with each habitat type. The relationship of the various causes to the gain or loss of the various values will be the subject of the concluding section.

The results provide a firm factual data base for the following discussions, but it is a narrow base from which to address such broad qualitative issues. The situation requires a liberal, sometimes speculative approach. The remainder of this report, therefore, draws extensively on the author's professional judgment based on previous fieldwork in the Columbia River Estuary, as well as on published studies of the estuary and of estuarine ecology in general. In the future, new quantitative data may shed a different light on these issues.

4.1 CAUSES

The results presented in Section 3 are like two snapshots of the estuary taken a century apart which have been compared to note and measure the differences between them. In themselves they tell us nothing about how the former estuary became the present one, about what was going on and why, except that the habitat type definitions refer broadly to diking and filling, and shoaling is a universal feature of estuaries. This discussion attempts to explain the processes that caused the changes. Any number of explanations could be concocted that lead from the first snapshot to the second; the information sources act as parameters for this discussion but not as criteria for testing it. Nevertheless, it is hoped that these speculations are sufficiently informed to be worthwhile.

The first step toward understanding what has brought about the changes in the estuary is to distinguish between natural processes and human activities. The distinction is complicated by the fact that the human activities involved create their effects either by altering natural processes or by making direct artificial changes in the estuary, or both.

The primary factor in the natural "aging" process of the estuary is shoaling. Shoaling is the deposition of river and ocean derived sediment in the bays and to a lesser extent the main stem of the estuary. The principal human activities to be considered are diking, dredging, disposal of dredge spoils, filling, jetty construction, construction of upriver dams, and watershed activities that cause soil erosion. All of these activities affect the shoaling process, although in some cases (for instance diking) these effects are insignificant both in relation to other effects of the activity and in relation to other activities that affect shoaling.

The following discussion begins by postulating a natural estuarine aging process. Human factors are then considered, first in terms of their effects on the natural (shoaling) process, secondly in terms of their direct or artificial effects. Finally, information on the gross exchanges of acreages between habitat types is combined with the preceding analysis of causes in an attempt to illustrate the overall dynamics of change in the estuary over the past century.

4.1.1 The Natural Estuarine Aging Process

The accumulation of sediment in estuaries is a natural process resulting from the differences in current velocities and water chemistry between the riverine and oceanic water masses. Water-borne fine sediments are constantly being deposited and resuspended, while coarser material is transported as bedload. With time, more sediment enters the estuary than leaves it. This leads to a net gain of sediment, particularly in shallow areas with low current velocities, and to a net loss of water volume.

In the long term, the Columbia River Estuary is responding to changes in environmental conditions, particularly sea level, brought about by climatic changes. At the present time, the sea level is rising only very slowly; in the San Francisco Bay area the rate is a few inches per century (Krone 1979) and rates in the Pacific Northwest are probably comparable. The result of rapid sea level rises, such as those which occurred in early post-glacial times, would have been the formation of a drowned river valley, with a large subtidal area. Gradual infilling with sediment probably created extensive shallows and flats and extended the river mouth seawards.

The effects of plant species are a secondary factor in estuary aging which becomes operative as shoaling produces new mud flats. Flats are colonized locally by emergent marshes, some of which prograde into swamps. Although a simplistic view of plant succession is no longer generally acceptable to ecologists (Drury and Nisbet 1973), in intertidal areas there are plant species which alter their environment and make it more suitable for other species, following the "facilitation" model of Connell and Slayter (1977). In the Columbia River Estuary, the most important dominant species in brackish and freshwater areas is Lyngby's sedge (Carex lyngbyei), which, after colonizing low marsh areas, traps sediment and thereby causes the elevation to rise gradually. Near and above MHHW, growth of Lyngby's sedge is much less vigorous and a species-rich high marsh develops. High marsh subsequently develops into a willow and spruce swamp, but whether this results solely from continued sediment accumulation or whether additional factors such as nurse logs are involved is unclear. Low marsh species which die back to below the sediment surface in the fall, such as soft-stem bulrush, appear to be less important than Lyngby's sedge in marsh progradation in the Columbia River Estuary.

Swamps are the end-product of accretion, and the process of estuary aging outlined here tends to result in the the accumulation of swamp-dominated floodplain. Conditions resembling an equilibrium state in the Columbia River would probably consist of deep channels surrounding swamps or marshes with high elevation wetland communities, probably spruce swamp or high marsh. Such conditions were formerly found on Puget Island and in Youngs and Baker Bays before diking and still occur in parts of Cathlamet Bay. Equilibrium conditions where no further net loss of water volume occurred would still be highly dynamic, because freshets and storms cause frequent alterations and because erosion is a continual factor offsetting the effects of accretion.

It is impossible to say what changes would have occurred in the estuary over the past century without human intervention. The long-term effect of shoaling is a reduction in water volume, but the aging process may last thousands of years and the average rate per century would be very low. Furthermore, changes in climate could be very significant, causing wide variations from one century to the next.

4.1.2 Human Activities

The principal human activities to be considered are mentioned above: diking, dredging, disposal of dredge spoils, filling, jetty construction, construction of upriver dams, and watershed activities that cause soil erosion. The sorting out of their relationship to the changes measured in this study is most manageable if they are considered first in terms of their effects on the shoaling process and secondly in terms of their individual direct or artificial effects.

Effects on Shoaling

The rate and extent of shoaling is properly measured in terms of reduction in estuarine water volume. In this study, areas were measured as exactly as possible but subtidal depths were lumped together in three habitat types. Since it was not possible to measure the average depths of the two completely subtidal habitat types or to subdivide shallows (below MLLW) and flats (above MLLW), no estimates of water volume reduction are offered. However, noting the area reductions of the subtidal habitat types provides a good idea of shoaling trends in the estuary.

It is evident that in the Columbia River Estuary the last hundred years have seen the deposition of sediment in quantities far in excess of anything that would occur naturally, barring catastrophes. Table 9 shows a loss in acreage from medium and deep water habitat types averaging more than 100 acres per year over the study period. Baker Bay has been much more drastically affected than other areas, but considerable acreages have also been lost in Grays Bay, Cathlamet Bay and the Upper Estuary. While some of this acreage loss involves sites where the dumping of dredge spoils has created artificial uplands, by far the larger portion is due to accelerated shoaling.

Shoaling is accelerated where circulation and current velocities are reduced and also when the concentration of the sediment in the water is increased.* These will be considered separately. It is possible to identify several human factors which have contributed to these changes but not to quantify the contribution of each factor.

Circulation and Current Velocities

Where circulation and current velocities are reduced, more and finer sediments will settle and less will be resuspended and flushed out of the estuary. The channeling of the river mouth by jetties and pile dikes and the dredging of the bar and main navigation channel have resulted in increased current velocities along the whole length of the channel and corresponding velocity reduction elsewhere. Jetty construction is clearly the major factor in Baker Bay. Circulation in the bay has been greatly reduced, while the lowering of current and wave energy has caused the retention of Sand Island in its present location, obstructing the mouth of the bay (Roberson et al. 1980). Another major factor throughout the estuary is the reduction in the size of freshets as a result of impoundment behind upriver dams. Large quantities of sediment were formerly resuspended and moved into the ocean by freshets, and this process has now been much reduced (Jay and Good 1977). Other possible contributing factors include the local effects of structures such as causeways (for example, the Highway 101 causeway across Youngs Bay) which, by diverting currents, create stagnant areas where accretion will occur.

Suspended Sediment Concentration

While it is clear that reduced circulation has contributed to accelerated shoaling, it is not clear whether the concentration of suspended sediments in the estuary is greater than it was formerly and therefore it is unknown whether this factor has played a part in accelerated shoaling. Large amounts of sediment have been settling out behind upriver dams, and while the control of freshets has reduced the amount of sediments flushed out of the estuary, it has also reduced the amount that enters the estuary. Probably the peaks of suspended sediment concentration were far greater in 1870, but at the same time the amount of sediment that settled out during those peak periods was probably not great.

Regardless of these uncertainties, however, it is clear that some human factors tend to increase the concentration of suspended sediments. One such factor is that portion of watershed activities, especially forestry, that erode soil and put other debris into the river below Bonneville Dam; this includes a large portion of the Willamette River watershed. In-water disposal of dredge spoils would be another factor increasing suspended sediments, but it is very difficult to estimate what portion of these spoils remain suspended long enough to contribute to shoaling. (The portion that settles rapidly becomes subject to bedload sediment transport.) Currently about 3,000,000 cubic yards of

*Another possible factor contributing to accelerated shoaling is the increased marine water intrusion resulting from the maintenance of the bar at navigable depths. This alters the water chemistry which is a factor in the natural sedimentation process.

dredge spoils are deposited at in-water estuary sites annually (McColgin 1979). Haushild et al. (1966) have estimated that the total annual suspended sediment load entering the estuary is 9,500,000 tons, or about 6,000,000 cubic yards, but this can vary threefold from year to year. Thus at present in-water dredge spoil disposal would increase the concentration of suspended sediments somewhere between zero and 50 percent. Historically this figure would be lower, but dredging began in the 1880's and so has been a factor throughout the past century. Probably the safest conclusion is that in-water dredge material disposal contributes to accelerated shoaling in areas near intensively used disposal sites. One such site, Site D, is near the entrance to Baker Bay. The effects of dredging itself on suspended sediment concentration are probably not great. The main navigation channel follows natural channels and is to a considerable extent self-scouring, both naturally and as a result of pile dikes and jetties. The area of the most intensive dredging, the bar, is an area of sediment instability and the additional disturbance would be hard to distinguish from natural factors.

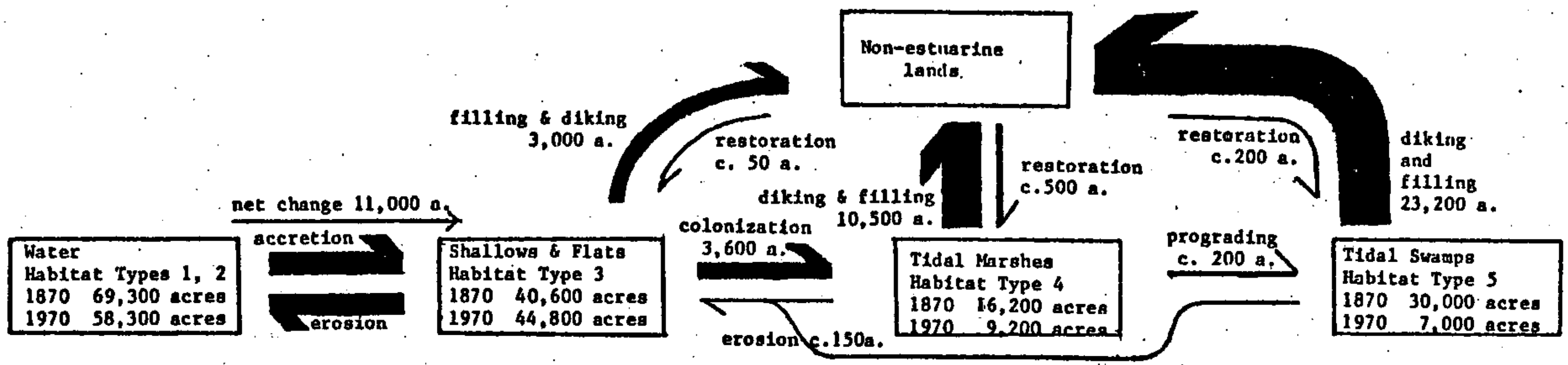
Direct Effects

Diking has caused more of the changes measured in this study than any other single factor, natural or human. The number of acres affected is more than twice that of shoaling, the next most significant factor. Furthermore, the effect of diking is to remove areas entirely from the estuarine system, reducing surface area as well as water volume, rather than to change areas from one estuarine habitat type to another. Most diked lands have been drained and cleared of trees and shrubs. Large acreages of diked floodplain (habitat type 6) are found in every subarea except the River Mouth and the Mixing Zone. They are used mostly for pasturage, but in a few locations, such as Warrenton, significant acreages of floodplain have been converted to residential or industrial use.

Generally, the degree to which habitat types and their component communities have been impacted by diking is proportional to their elevation. The higher the elevation, the heavier the impact. In consequence, diking has impacted swamps more than any other habitat type. Virtually the entire net loss of swamp acreage, 23,070 acres or 77 percent of the former total, is due to diking, and the gross loss is slightly larger since some marsh acreage has prograded into swamp during the study period. Marshes have been impacted less heavily by diking except in Youngs Bay where, uniquely among the subareas, marshes were more extensive than swamps in 1870; these were, however, high marshes with swamp occurring as scattered clumps.

The first settlers utilized the marshes as pasture, by grazing cattle on the marsh vegetation at mid and low tide. By the time of the 1868-73 survey, the first dikes were already in place, low structures built to protect local areas of high marsh from regular inundation. These were followed in the early twentieth century by more extensive structures, which converted large areas of floodplain to pasture. The diking was followed by clearing of forest and scrub and the creation of grassland swards. The last tidelands to be diked were those of the

Figure 10. The Dynamics of the Exchange of Acreage among the Habitat Types over the Past Century



Chinook and Wallacut Rivers, where the diking process was completed in the 1930's. Since then, the elevations of the dikes have been raised to withstand floods.

Small acreages of diked floodplain have returned to the estuarine system in areas where dikes have washed out and not been repaired. Examples of this are Karlson Island and Mary's, Bear, and Ferris Creek marshes in Cathlamet Bay, and part of the Walluski River floodplain in Youngs Bay.

Dredge spoil disposal is really a subcategory of filling when the discussion is of direct effects, since the direct effects of dredge spoil disposal occur when it constitutes a fill. Most of the filled uplands identified in this study were filled with dredge spoils, mostly for the sole purpose of disposing of those spoils, but some fills for specific human uses used other fill material. There are now about 4,400 acres of filled uplands. Every subarea has been affected, especially the Upper Estuary (almost 2,000 acres). Like diking, filling reduces both the surface area and the water volume of the estuary. Currently about 1,500,000 cubic yards of dredge spoils are deposited annually at upland sites (McColgin 1979). These include not only island sites (Table 11) but also shoreline sites, resulting in extensive disruption of riparian habitats. Formerly lined by riparian forests, many shoreline areas are now filled with sparsely vegetated dredge spoils.

Jetty construction cannot be said to have had any direct effects measured in this study, but only because the subarea boundaries follow the river edges of the jetties and do not include the jetties themselves. The jetties have, however, had one major indirect effect other than that on shoaling: they are responsible for the substantial accretion of sand in the River Mouth and Baker Bay subareas, carried by littoral currents as well as wind, resulting in about 1,300 additional acres of "natural" uplands (these are considered natural here because their formation was a natural process even though it was induced by a human activity).

Direct effects of dredging are discernible only at the River Mouth, with the conversion of 1,680 acres of medium-depth water to deep water. However, considering the extent of shoaling evident from the results as a whole, it is likely that dredging also has artifically minimized estuary-wide losses in the deep water habitat type.

4.1.3 The Dynamics of Change, Combining Natural and Human Factors

Figure 10 illustrates the dynamics of the processes and activities discussed in this section. The boxes represent the various habitat types; past and present acreages from Table 1 are shown in each box for easy reference. The arrows represent change from one habitat type in the past to another in the present. The estimated gross amount of change along each pathway is shown in acres and illustrated by the width of the arrows, and the principal cause of each change is shown. Note that for each arrow there is a second arrow in the opposite direction; this illustrates that each shift of acreage from one habitat type to another is the net result of a two-way exchange. The bottom row of boxes and arrows illustrates the exchange of acreage among the estuarine habitat types, a natural process influenced and accelerated by human activities. On top of this is shown the removal (actually a one-sided exchange) of estuarine acreage to the non-estuarine categories, an artificial process resulting largely from diking and filling.

The exchange of acreage between deeper water and shallows and flats is a highly dynamic process brought about by the migration of channels within the estuary. Thus, the total acreage exchanged between these habitat types over the past century is very large, and the net gain in shallows and flats from this exchange is a small percentage of the total.

Tidal marsh establishment appears to be a slow and uncertain process at low tidal elevations (2 or 3 feet above MLLW), although at high elevations, such as along the shorelines of newly created dredge-spoil islands, colonization is relatively rapid. Marsh establishment may depend on features of a site such as sediment type and stability, exposure to rough water, and the proximity of seed and other propagule sources. Once established however, tidal marshes are relatively stable structures which consolidate the sediments with living and dead root material. The net gain of marshes from flats is therefore a high percentage of the gross gain.

Under natural circumstances, marshes would probably prograde into swamps at a somewhat slower rate than the colonization of flats by marshes, but at a much faster rate than suggested by Figure 10. The estimated acreage of marsh that has prograded to swamp is low because the marshes most suitable for the establishment of swamps are generally those which, because of their higher elevation, have been most heavily impacted by diking.

Figure 10 does not distinguish between diking and filling, nor does it distinguish among the five non-estuarine habitat types lumped together as non-estuarine lands. Generally, however, filling has been the major cause of the removal of shallows and flats, while diking is the more significant factor in the removal of marshes and swamps. Filled areas are now categorized predominantly as uplands, while diked areas are now predominantly developed floodplain and non-estuarine wetlands.

4.2 VALUES

The purpose of this subsection is to translate "habitat types," a conceptual tool defined by largely quantitative criteria, into qualitative values. The word "values" is used broadly here to refer to "habitats, resources, functions and processes," itself a very broad phrase. The use of the word "values" derives from the ecological principle that all the elements of the ecosystem are linked in a vast network of connections, and therefore every element (biological or physical) is of some value to (i.e., has some effect on) every other element, including human beings. Given that definition, a complete discussion of values would be infinite. The following discussion, however, is short and is meant to be suggestive rather than definitive.

Fox (1981) provides an excellent review of Columbia River estuarine values; it was important for this study, however, to organize such a review by habitat type and to include the non-estuarine habitat types.

In the following discussion the ten habitat types are considered one by one. Subsequently, two further short discussions are offered. The first is an attempt to estimate to what extent the estuary's salinity levels may have changed in the past century. The second briefly addresses how the estuary's changes may have affected salmon.

4.2.1 Deep Water

The importance of habitat type 1 to the estuarine ecosystem is hard to define. Generally, the water volume of the estuary is important for fish usage, and deep areas provide habitat diversity necessary for maintaining populations of white sturgeon in particular (Kujala 1975). Ocean water and associated organisms are transported into the estuary mainly in deep water. This results in a greater diversity of prey for fish. Migrating salmonids prefer to use the channel areas when passing through the estuary, and a large water volume may be necessary so that estuarine fish can escape predators, particularly at low tide. Apart from these there is little indication at present that loss of water volume and the degradation of fish habitat are very closely correlated, even when volume changes on the scale considered here are concerned.

4.2.2 Medium Depth Water

Like the deep water habitat type, medium depth water is important to pelagic (in the water column) and demersal (bottom) fish and to the zooplankton (minute, passively floating animal life) which support them. In addition, large numbers of epibenthic organisms (invertebrates at or near the bottom) are present, particularly in the brackish water areas.

4.2.3 Shallows and Flats

Shallows and flats (and low marshes) are the most productive habitat type for the values most often associated with estuarine systems, including primary productivity (uptake of nutrients into the food web through photosynthesis), processing of detritus by detritivores, nursery area for juvenile fish, and waterfowl habitat. McIntire and Amspoker (1980) state that by far the most important benthic primary producers are microalgae (mostly diatoms) distributed throughout the estuary on shallow subtidal or intertidal sediments. They are particularly productive where the sediments are stable. Benthic infauna (invertebrates), including both surface deposit feeders and burrowing deposit feeders, consume both microalgae and detritus. These in turn are extremely important food items for fish and shorebirds.

The values associated with habitat type 3 vary widely among the subareas and in many cases may have changed from 1870 to the present.

At the River Mouth, it is probable that the former shallows and flats were very different from the present ones. In 1870, they were exposed to a high energy environment and probably had medium or coarse sandy sediments with low macroalgal productivity. There may have been extensive eelgrass beds subtidally since black brant, which feed on this plant, were formerly common (Thwaites 1959) and are now uncommon. Most of the present-day flats and shallows are in the sheltered area in and around Trestle Bay. They probably have finer sediments and much richer benthic communities. Also at the River Mouth are unique shallows along the jetties. The large boulders used for construction allow tidal water to ebb and flow between them and the jetties are therefore still part of the estuary system. The rocky shore and subtidal rocky areas provide additional habitat diversity.

The extensive shallows and flats in Baker Bay are important areas for benthic organisms and the small clam Macoma balthica is particularly abundant. The shallows here contain extensive sparse eelgrass beds.

The shallows and flats in Youngs Bay are particularly important to benthic infauna (Higley et al. 1976) because of the sheltered conditions and fine silty sediments.

4.2.4 Tidal Marshes

This habitat type is actually composed of a number of different vegetative communities which occur under characteristic salinity regimes and tidal elevations. Appendix E contains a detailed description of the fifteen marsh and four swamp vegetation communities described by Thomas (1980), plus a breakdown of the present acreages of each vegetation type per subarea (Table 12) and a comparison of the present importance versus the estimated former importance of each of the nineteen vegetation types (Table 13).

Emergent marsh vegetation is an important primary food source in the estuarine food web. Fox (1981) notes that tidal marsh production is utilized in part through consumption of detritus (biogenic material in various stages of microbial decomposition) and, to a much lesser extent, direct grazing on live plants. Detritivores live or feed in adjacent sloughs or flats. Additionally, marshes and their associated tidal channels provide important habitat for birds, mammals, fish, and aquatic and terrestrial invertebrates.

Lewis and Clark, who overwintered in Youngs Bay in 1805, recorded an abundance of birds: snow brant, two races of Canada geese, ducks, swans, coots, sandhill cranes, and California condors. That many of these species are no longer found in the area may be related to the net loss of over 6,000 acres (86 percent) of Youngs Bay marshes.

As noted in the Results section, of the more than 16,000 acres of marsh in 1870 only about 5,500 remain, mostly in Cathlamet Bay, while about 3,500 acres of new marshes have formed, typically fringing marshes around dredge spoil islands and shoreline sites. Even when they have been established for several decades, these new marshes differ in some respects from the older marshes. Mature island-type marshes tend to have perimeters of higher elevation than centers, highly developed tide channel systems, and a relatively large number of plant species. New fringing marshes tend to have highest elevations on the upland side sloping toward the water, poorly developed tidechannel systems, and relatively few (and different) plant species. Thus not only the number of acres of the tidal marsh habitat type but also its values to the various vegetative communities have changed over the past century (Table 13). Medium to high elevation natural marsh vegetation from the lower estuary was much more abundant formerly, while similar vegetation from the mid and upper estuary, where high marshes have been less extensively diked, was somewhat more abundant formerly. On the other hand, vegetation types typical of disturbed marshes or early colonizing stages of low marsh are probably more abundant now than formerly, or if not more abundant in terms of acreage at least more important as a percentage of the total marsh vegetation.

For the same reason, the average rate and timing of detritus "export" from marshes have probably changed. Fox (1981) speculates that detritus export from mature marshes probably occurs mainly during the highest winter tides, making detritus available to the estuary in short pulses, whereas the immature marshes, because of their slope and greater exposure to open water, may export detritus on a more continuous basis.

4.2.5 Tidal Swamps

Because of their high elevation, swamps are generally less important to the estuary than marshes as fish and estuarine invertebrate habitat and as a source of detritus. In swamps, probably the most important features for the estuarine system are the tidechannel systems and associated riparian vegetation. Otherwise, swamps may harbor large populations of insects, amphibians, birds, and mammals, but they should probably be regarded as a semi-independent wetland ecosystem associated with the estuary rather than as an integral part of the system like habitat types 1, 2, 3, and 4.

As with tidal marshes, the swamps in Youngs Bay and Baker Bay have been most heavily impacted. It is no longer easy to ascertain the former structures of the vegetation in these subareas since only about 130 acres remain, most of which is recent growth on dredge spoil. It is likely that the former swamps lined tide channels and also formed clumps of trees and shrubs in the marshes. The vegetation was probably a diverse assemblage of shrubs (dominated by hooker willow), with scattered spruce trees. In upriver subareas, the former swamps probably resembled the present-day ones, which are still extensive in Cathlamet Bay and the Upper Estuary (6,310 acres remaining out of 19,130 acres formerly) and are dominated by Sitka willow, creeping dogwood, and Sitka spruce.

4.2.6 Developed Floodplain

This habitat type includes all areas of the diked floodplain which are at present used as agricultural land or as residential and industrial areas. Most of the 24,000 acres included here are managed as cattle pasture. Depending on how they are maintained, these may have a grass sward, or may include wetland species such as common rush (_Juncus effusus_) and slough sedge (_Carex obnupta_). (Pastures with a more than

90 percent cover of wetland plants are included under habitat type 9.) Areas included in this category generally make little contribution to the estuarine ecosystem. Since they are behind dikes with tidegates, they have minimal hydrological connections with the estuary, and they are often too disturbed through human use to have high value as habitat for estuarine birds and mammals.

4.2.7 Natural and Filled Uplands

Of the 7,600 acres in this category, about 3,200 acres are natural sand-dune systems, mostly on Clatsop Spit and Peacock Spit. These support some semi-natural (planted) grassland of moderate wildlife and recreational value. The remainder, about 4,400 acres, are filled uplands that were created either for human use (airport, port facilities, the Astoria waterfront, highways) or as a side-effect of dredge material disposal both in the river (Table 11) and along the shoreline. While they frequently support emergent fringing marshes, dredge material uplands themselves are sparsely vegetated and of little habitat value. However, because of their isolation and lack of human disturbance, the islands are important areas for some bird and mammal species, which breed there and also utilize them when all the wetland areas are submerged.

4.2.8 Non-Estuarine Swamp

This habitat type makes a significant contribution (3,320 acres) to the floodplain wetland acreage, and to some extent offsets the loss of estuarine swamps. The vegetation of non-estuarine swamps is similar to that of the estuarine swamps, dominated by willows and Sitka spruce, and also by red alder. The major difference is the lack of tidechannels and of flooding by estuarine water. Non-estuarine swamps are usually parts of the floodplain which either were never cleared for agriculture or were cleared and then abandoned and reverted to swamp. They tend to occupy distal portions of the estuary floodplain, often in valleys in the surrounding forested hills. In this situation, they function in wetland systems associated with the surrounding upland forests and supply habitat diversity to the forest ecosystem. In particular, non-estuarine swamps (and other non-estuarine wetlands) are of value to breeding water birds such as mallard, hooded merganser, woodduck, green-winged teal, green herons, and, possibly, ring-necked duck. They are also of moderate habitat value for beaver, deer and elk.

In addition to forested swamps, this habitat type also includes non-estuarine wetlands dominated by shrubs. Such areas are usually in the process of reverting from pasture to forested wetland, and salmonberry (Rubus spectabilis) is a common dominant. However, there are a few areas, the upper Skipanon for example, with climax shrub and small tree communities dominated by willow.

4.2.9 Non-Estuarine Marsh

Floodplain diking has resulting in the creation of a significant acreage (3,130 acres) of non-tidal freshwater marshes. These marshes are mainly on the site of pastureland, and may be either abandoned or minimally maintained for rough grazing. These marshes have a 90 to 100 percent cover of wetland plants, with common rush (Juncus effusus) and slough sedge (Carex obnupta) being common dominants. On abandoned pasture, this community is a stage in the development of forested swamp and with time will develop towards the latter vegetation type. All stages in this seral process can be found in the wetlands categorized under habitat types 8 and 9.

Very little of the marsh vegetation is of sufficiently low elevation to develop into natural marshes. The non-estuarine marshes have little hydrological connection with the estuarine system, and their main value is as additional wetland habitat for the area's waterfowl and mammals. In addition to abandoned pasture (common around Warrenton in particular), at any given time a small percentage of the floodplain pasture will be tidal or non-tidal marsh due to the failure of drainage systems, the malfunctioning of tidegates or damage to dikes. This situation is usually corrected by the landowner in time, giving rise to a cyclical process whereby pasture land gradually reverts to marsh and is then returned to farmland.

4.2.10 Non-Estuarine Water

This habitat type consists mainly of diked sloughs - former tidal channels which were cut off from estuarine circulation by tidegates when the floodplain was diked. These are now functionally lakes or drainage ditches, and serve to contain the runoff from the surrounding floodplain. They provide habitat for waterbirds, and the larger ones support populations of warm-water fish such as white crappie, yellow perch and brown and yellow bullheads (Fies 1971) which in turn are preyed upon by birds and mammals (including human beings). Their habitat value is improved if a riparian fringe of trees or shrubs is present. These sloughs have little connection to the estuarine system when the tidegates are well-maintained and fully functional. (When this is not the case, they may be utilized by estuarine fish such as juvenile salmonids.) Their main value is as self-contained lacustrine ecosystems which increase the wetland acreage and habitat diversity in the floodplain area.

4.2.11 Salinity

The degree to which saline ocean water and fresh river water mix and the distance upriver to which mixed water intrudes have profound effects upon the ecology of the estuary, although it is beyond the scope of this report to discuss those effects. Here, the purpose is to estimate changes in salinity, and unfortunately it is not possible to do more than speculate on how the former salinity regimes in the estuary would compare with those found today, as summarized by Fox (1981).

At the present time, salinities in the lower estuary vary enormously, depending on the stage of the tide, the spring/neap cycle and the fresh water flow of the river. For example, during low flow periods surface salinities in excess of one part per thousand extend beyond Tongue Point (Jay 1983). The approximate limit of salt water intrusion is a line from Mott Island to Harrington Point, although intrusion at depth in the channels may extend to Pillar Rock and Svensen Island (D. Jay personal communication).

The salt water intrudes mainly along the bottoms of the channels, particularly the main navigation channel, and mixes to varying degrees with the overlying fresh water. Given these conditions it is possible to advance several hypotheses concerning the former salinity regime:

(1) Before control of the river above Bonneville was effected, flows were more extreme: the freshets, particularly those resulting from spring run-off in the Rockies and Cascades, were larger and the late summer lows were lower. Consequently, one might expect greater salinity ranges to have occurred. Salinity intrusion would have been further upriver during low flow periods.

(2) Intrusion of ocean water into the estuary may have been impeded by the shoals across the river mouth and further upriver. Depths less than thirty feet were present at the bar, compared to the forty-eight feet of today's channel. High salinity therefore may not have intruded as far upriver, although this would not necessarily have affected the intrusion of mixed, brackish water.

(3) The river mouth was much wider and was further eastward, about four miles in Oregon and two miles in Washington, although an extensive off-shore bar was present. This would probably have tended to raise salinity levels in the estuary.

The combined effect of these influences would have been that former salinity levels in the estuary fluctuated even more than they do at present. Virtually the entire water column was probably fresh at all stages of tide during large spring freshets. Salinities at all depths were probably greater during periods of very low flow. Evidence for this is hard to come by. Members of the Lewis and Clark expedition, camped near Gray's Point November 8 through 15, 1805, found the river water there too brackish to drink (Thwaites 1959). This would suggest salinities in the five to ten part per thousand range, which is slightly greater than the maximum surface salinities (low flow, neap tide cycle, flood tide) found there now.

4.2.12 Salmon

The history of the area's salmon industry has been well documented (Smith 1979, Netboy 1980). If their former behavior was the same as now, the anadromous fish runs used the Columbia River Estuary mostly as a conduit to upriver spawning areas in the Columbia, Snake, Willamette and other watersheds. Use of the estuary for feeding by adult salmonid runs is minimal, although many of the small tributaries supported native runs of chum salmon which spawned above the heads of tide. Ocean-bound juveniles, particularly fall chinook fingerlings, use the estuary for feeding before moving on to the ocean. The environment of the estuary has not necessarily deteriorated as a habitat for juvenile salmon and in some respects, such as the more extensive flats and the large acreage of low elevation marshes, it may have improved. This may offset adverse effects on juvenile salmon from the losses through diking of high marshes and swamps, including their tidal channel systems. The major reasons for the continued decline of these fish runs lie elsewhere: dam-related mortality and loss of spawning grounds upstream from the estuary, and overfishing in the ocean.

5. CONCLUSIONS

The purpose of this section is to draw conclusions regarding the relationship of the various causes discussed in Section 4.1 to the gain or loss of the various values discussed in Section 4.2. This is a difficult and speculative task. The "hard" results of this study - the maps and the acreage data based on habitat types - do not directly measure or illustrate either causes or values; thus the only bases for conclusions are the interpretations of the results rather than the results themselves. Furthermore it is clear that there are many processes at work in the estuary, each of which involves many causative factors and has many effects, including effects not only on biological values but also on other processes. These concluding remarks are therefore of a general nature and, to narrow the scope to more manageable proportions, deal only with biological values.

It is useful here to briefly outline the estuarine food web. For convenience, three groups will be distinguished: primary producers, invertebrates, and vertebrates. To break these groups into trophic levels is beyond the scope of this review.

Primary producers are the plant life which, through photosynthesis, first incorporate the chemical and mineral nutrients available in the estuary. (No attempt will be made here to estimate changes in the level and composition of nutrients.) There are three categories of primary producers. Phytoplankton grow in the water column. They are probably more productive in shallow areas. Benthic microalgae grow in the sediments, particularly fine sediments, of shallows and flats. Emergent vegetation in marshes and, to a lesser extent, swamps is the third category. It is utilized primarily through the consumption of detritus and also directly for grazing.

Invertebrates include various minute forms of animal life. They are the principal consumers of, and depend on, the primary producers. These organisms can also be classified into three categories. Zooplankton live in the water column. Their main food sources are phytoplankton, detritus, and each other. Epibenthic organisms live at or near the bottom while the third category, benthic infauna, live in the sediments. Both are found at all depths but particularly in shallows and flats and both feed mainly on benthic microalgae and detritus.

Vertebrates include everthing else, most importantly fish, birds and mammals. Many are at the top of the food chain and invertebrates are their primary or only food source. Some vertebrates consume primary producers and some prey on other vertebrates.

It would appear that some of the biological values of the Columbia River Estuary have improved over the past century. The increased area of shallows and flats and emergent low marshes, particularly where the

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It is useful here to briefly outline the estuarine food web. For convenience, three groups will be distinguished: primary producers, invertebrates, and vertebrates. To break these groups into trophic levels is beyond the scope of this review.

Primary producers are the plant life which, through photosynthesis, first incorporate the chemical and mineral nutrients available in the estuary. (No attempt will be made here to estimate changes in the level and composition of nutrients.) There are three categories of primary producers. Phytoplankton grow in the water column. They are probably more productive in shallow areas. Benthic microalgae grow in the sediments, particularly fine sediments, of shallows and flats. Emergent vegetation in marshes and, to a lesser extent, swamps is the third category. It is utilized primarily through the consumption of detritus and also directly for grazing.

Invertebrates include various minute forms of animal life. They are the principal consumers of, and depend on, the primary producers. These organisms can also be classified into three categories. Zooplankton live in the water column. Their main food sources are phytoplankton, detritus, and each other. Epibenthic organisms live at or near the bottom while the third category, benthic infauna, live in the sediments. Both are found at all depths but particularly in shallows and flats and both feed mainly on benthic microalgae and detritus.

Vertebrates include everthing else, most importantly fish, birds and mammals. Many are at the top of the food chain and invertebrates are their primary or only food source. Some vertebrates consume primary producers and some prey on other vertebrates.

It would appear that some of the biological values of the Columbia River Estuary have improved over the past century. The increased area of shallows and flats and emergent low marshes, particularly where the reduction of circulation and of freshets has allowed the accumulation of fine silt sediments, would be beneficial to benthic microalgae and might increase, or at any rate stabilize, the availability of detritus (last paragraph, Section 4.2.4). Thus both the physical habitat and the food source for epibenthic organisms and benthic infauna would be improved. The situation for phytoplankton and zooplankton is more difficult to speculate on. The (unmeasured but clearly significant) loss of estuarine water volume would have a negative effect, but this may be offset by the increased area of more productive shallow water and by the control of freshets, which have been known to flush out zooplankton populations so thoroughly that they take over a year to recover to normal levels (Haertel 1969).

From the foregoing it could be inferred that some estuarine values have improved for those vertebrate (mostly fish and bird) species that feed primarily on epibenthic organisms and on benthic infauna. For those (mostly fish) species that consume primarily zooplankton it is impossible to speculate. However, for all vertebrates, other habitat changes must be taken into consideration.

The loss of fish habitat (i.e., water volume) may not have had a significant overall impact (Sections 4.2.1 and 4.2.2), but other factors may be important. For instance, the control of freshets and water flow may have affected some species' ability to adjust to salt water. The cumulative impacts of all the changes in the estuary on specific fish species would vary widely depending on their preferred habitats and food sources.

For many bird species the estuarine food supply may have improved, but the very large reduction in tidal marsh and swamp acreage constitutes a significant loss of waterbird habitat. The severity of this loss is however mitigated by two considerations: one, of the two habitat types the less heavily impacted (marshes) is somewhat more important as waterbird habitat, and two, the addition of over 7,000 acres of non-estuarine wetlands somewhat offsets the loss of 30,000 acres of tidal swamps and marshes. Again, the cumulative impact of all changes would vary widely from species to species.

For mammals, no doubt the most significant consideration is the habitat loss represented by the almost 24,000 acres of developed floodplain and over 4,000 acres of filled upland. Furthermore, the reapportionment of marsh acreage favoring low emergent marsh over high mature marsh, perhaps beneficial for invertebrates, would be detrimental to grazing mammals and would reduce that aspect of the value of marshes as primary producers. It should be noted, however, that much of the lost acreage just mentioned represents a habitat gain for domesticated mammals - and for that matter, human beings.

It may now be possible to conclude with some general remarks about the impacts of specific human activities. To the extent that human activities have increased the rate of shoaling and have accelerated the estuarine aging process their net impact would appear to be ecologically beneficial, at least in the short term. Large areas of highly productive shallows, flats and low marshes have been created, and these conditions, characteristic of a mid-stage of estuarine development, are optimal for many of the most important values associated with estuarine systems. It might be argued that these values are diminished as conditions approach the equilibrium state and that to accelerate the aging process, or at least to continue to do so, would be detrimental in the long term. However, the natural aging process would probably be measured in thousands of years, and even if it were accelerated, it is not unlikely that climatic and/or geological factors would intervene dramatically before aging would result in a significant loss of values. It could therefore be concluded that the dredging (as such) of the bar and navigation channels, the construction of the jetties, and the impoundment of freshets behind upriver dams have on balance had a positive impact on Columbia River estuarine values.

On the other hand, there is no escaping the conclusion that diking and filling, having as direct effects the removal of 28,350 acres (developed floodplain plus filled uplands) or more than 18 percent of the 1870 acreage from almost all connection with the estuarine system, have had a significantly negative impact, at least as far as the estuary is concerned. While the reduction of estuarine water volume due to accelerated shoaling has many mitigating aspects, the loss of both water volume and surface area due to diking and filling constitutes an almost unmitigated loss of estuarine values.

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APPENDIX A

Excerpts from the Annual Reports of the Superintendent of the United States Coast Survey (Benjamin Pierce) concerning the Columbia River survey during the years 1868-73

1868.

Topography of the Columbia River, Oregon. - The plane-table survey of this season, by Assistant Cleveland Rockwell, has been confined to the southern bank of the river. Commencing at Astoria on the 1st of July, the topographical survey was carried, in the course of the season, eastward somewhat beyond the mouth of John Day's River, and westward to include part of the seacoast of the Pacific beyond Point Adams. Assistant Rockwell was aided by Mr. L.A. Sengteller. The following is a synopsis of the statistics field-work:

Shore-line surveyed, (miles)	39
Marsh, islands, etc. (miles)	59
Area of topography, (square miles)	19

This survey is comprised on two sheets, of which one includes the peninsula of Point Adams, the location of the military post of Fort Stevens, and the south side of the river as far as Young's Bay. The second sheet represents the vicinity of Astoria, Tongue Point, and other features within the plane-table limits. The surface details of the two sheets mark plainly the change of character that occurs at Young's Bay, the shore of the river above it being high and bold.

"The whole country is not only covered with a heavy growth of the largest evergreen timber, but densely clothed with thick and impenetrable bushes, chiefly of the berry-bearing class. This dense jungle is the principal impediment in prosecuting the topographical survey. The north (or Washington Territory) side of the river is very bold, almost mountainous. Cliffs and precipices occur at almost every point.

"Above the remarkable neck of land called Tongue Point, where the river widens into a large sheet of water known as Cathlamet Bay, there are again large areas of tide lands, or swamps, intersected by numerous channels. Some of these channels are navigable, and are used by the small steamers plying between Astoria and Portland.

"The smoke from fires in the forest became quite troublesome at the end of August, and soon after enveloped the whole country, obscuring the sun and seriously impeding navigation even at sea. For this reason no work could be done on a third plane-table sheet, which was projected to include part of the north side of Columbia, above Cape Disappointment."

The party of Assistant Rockwell is now engaged on the shore of the Santa Barbara Channel.

Hydrography of the Columbia River, Oregon, (Sketch No. 26) - This important survey, commenced at the outset of the present working season, was prosecuted during the winter by Assistant Edward Cordell with a party in the schooner Marcy, and was completed near the end of last April, leaving at that date outstanding the development of the bar and approaches. Relative to the survey of the river between Three Tree Point and Gray's Bar, Mr. Cordell reports: "A careful examination of the waters to the northward of the Snag Islands developed a new channel, wider and straighter, and with 1½ feet more water than the channel heretofore used, to the southward of those islands. Since the discovery of the new channel obviates the necessity of passing over two other bars of 14½ feet in the old channel, vessels will hereafter, when the new one is buoyed, avail themselves of it and find only one spot, of 16 feet shoalest water, obstructing its passage."

The inside channels and passages between Tongue Point and Cathlamet Head, used by river-steamers only, were also sounded out, and the outlines were traced of the islands, marshes, flats, and bare shoals existing in Cathlamet Bay.

1869.

Topography of the Columbia River, Oregon - The topographical survey of the Columbia River has been continued by Assistant Cleveland Rockwell, who reached this section on the 30th of July and commenced operations at Cape Disappointment. The establishment of a military post at the extremity of the cape, with its numerous improvements and changes since the survey of 1851, rendered a resurvey of that part desirable, and it was done. The work executed embraces the bold ocean headlands to the low sand beach which runs northward to Point Grenville, only broken by Shoal Water Bay and Gray's Bay entrances. On the inner shore of the cape, forming Baker's Bay, the work was carried to Chinook and was in progress beyond at the date of the last field-report. Sandy Island has been re-surveyed and found altogether changed in shape and position from the results of last year's examination.

Mr. Rockwell reports the interior of Cape Disappointment so densely wooded and covered with undergrowth as to be impenetrable for ordinary operations with an observing instrument. The first part of the season was smoky from the great fires raging in the forests of Oregon and Washington territory. Early rains extinguished the fires, and were succeeded by fogs. The latter part of the season was favorable. Mr. Rockwell had the use of the Coast Survey schooner Humboldt, and was accompanied by Sub-Assistant L.A. Sengteller.

Hydrography of the Columbia River, Oregon. - The condensed statistics of the hydrography of the Columbia River, commenced in November, 1867, and closed in August, 1868, were not included in my report of last year. There were 2,445 miles of soundings run, 21,282 angles observed, and 91,479 soundings made.

Between the beginning of November of 1868, and the end of May, 1869, Assistant Cordell plotted and inked the soundings on three hydrographic sheets of Columbia River from Three Tree Point to Tongue Point, on a scale of 1/10000; and on two sheets, including the bar and entrance from Cape Disappointment to Tongue Point, on a scale on 1/20000. Duplicate tracings of this work were made for the Coast Survey Office, and for General B.S. Alexander, United States Corps of Engineers. A comparative chart was then drawn, showing the change in the hydrography of the approaches and entrance of the Columbia since 1854. A current-chart was also made, exhibiting the positions of seventeen current-stations in the north and south channels, and in the approaches to the main channel from the entrance of the river up to Astoria.

1870.

Topography of the Shores of the Columbia River. - Assistant Cleveland Rockwell continued the plane-table survey on the north bank of the Columbia until the end of November, 1869, and completed the details between Chinook Point and Gray's Bay. The country being almost inaccessible on the north side of the river, the work of contouring was very difficult.

During the winter of 1869, Mr. Rockwell inked and traced the topographical sheets of the previous season. These sheets have been received at the office. He projected three sheets for the work of the year just closed, and in May reorganized his party and resumed the topography of the shores and islands of the Columbia, basing it on the triangulation which was made by Assistant Cutts in 1852. In the interval some of the marks of the tertiary stations had been hidden by a growth of timber, but nearly all of them were found.

The work of the season, which closed in November last, includes both banks of the river and the numerous low, marshy islands in it as far up as Cathlamet Point and Three Tree Point, where the river contracts to a width of two miles. The widest part, from the head of Gray's Bay to the south shore, is nearly nine miles across. The mud flats of Gray's Bay, and the flats, marshy islands, and sloughs on the southern side of the river, were mapped carefully, and pains were taken to delineate the low-water lines.

The statistics of the topography are:

Main shores of river	50.75 miles
Shore-line of islands	114.00 miles
Shore-line of creeks	52.25 miles
Area, (Square miles)	49.00 miles

Assistant Rockwell used for transportation the schooner Humboldt.

Early in August Mr. George H. Wilson joined him as aid, and is yet attached to the party.

The shores of the Columbia River are rocky and high, densely covered with large timber and thick undergrowth, and impenetrable for any distance with the plane-table. Some points on the crest of the ridges nearest to the river shores have been approximately determined in position, and the general characteristics of the topography have been sketched in.

1871.

Triangulation and Topography of the Columbia River, Oregon. - Assistant Cleveland Rockwell resumed the survey of the Columbia River in May. Many difficulties were encountered in advancing the triangulation. The shores are covered with heavy timber, through which at high points lines of sight were required to bring stations into view that otherwise would be hid by the dense growth of timber on the islands in the river. By well-conditioned triangles, however, Mr. Rockwell succeeded in extending the preliminary work to Westport, which by the river course is about twelve miles above Cathlamet Point.

The topography was taken up at Three Tree Point, on a sheet projected by Mr. Rockwell to take in the river shores as far as the lower end of Puget Island. His plane-table survey includes both banks of the Columbia, which between the limits stated, is nearly three miles wide. All the islands between Cathlamet Point and Puget Island are represented on the sheet. The river banks are shown as being high, abrupt, and broken; densely timbered and covered with thick underbrush. In the site of work occupied by this party this year there is no river valley; the shores have a steep pitch at the water-line. The basin of the Columbia is from two to five miles wide, and the area between the shores is filled with an intricacy of low marshy islands, which are covered with spruce, cotton-wood, and alder. The islands are overflowed by freshets and by high tides.

While carrying on the triangulation, Assistant Rockwell determined the positions of notable mountain peaks and ridges that were in view from the stations occupied for his work.

The operations of this party, as of the parties generally on the western coast, were retarded by dense smoke from the burning woods of Oregon and Washington Territory.

1872.

Topography of the Columbia River. - In May, Assistant Cleveland Rockwell transferred his party from a site of work on the coast of California, and resumed the detailed survey of the shores of the Columbia River. East and west of Cathlamet, the triangulation and topography were advanced so as to include the whole of Puget Island and both banks of the river as far up as Westport. The topographical features are much the same as were found nearer the mouth. There is properly no valley to the river, but between the steep walls of the original channel of the river lie timbered lowlands and timbered and marshy islands. The banks of the Columbia are basaltic, and are covered with spruce of great size.

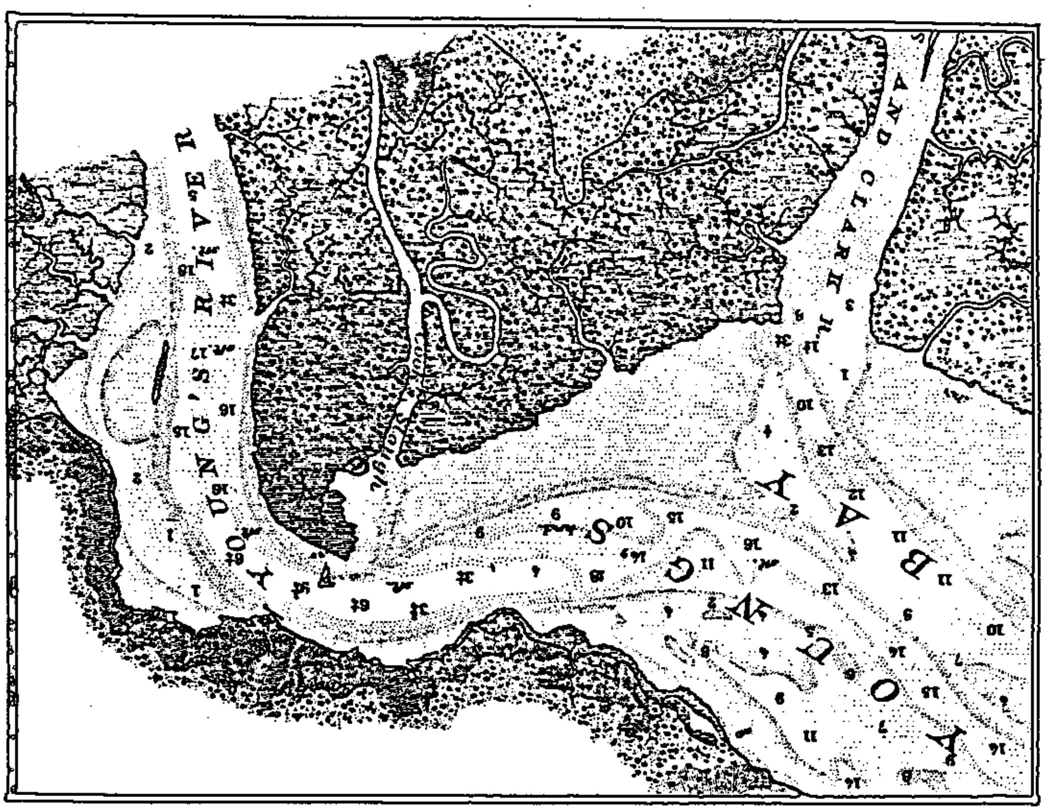
1873.

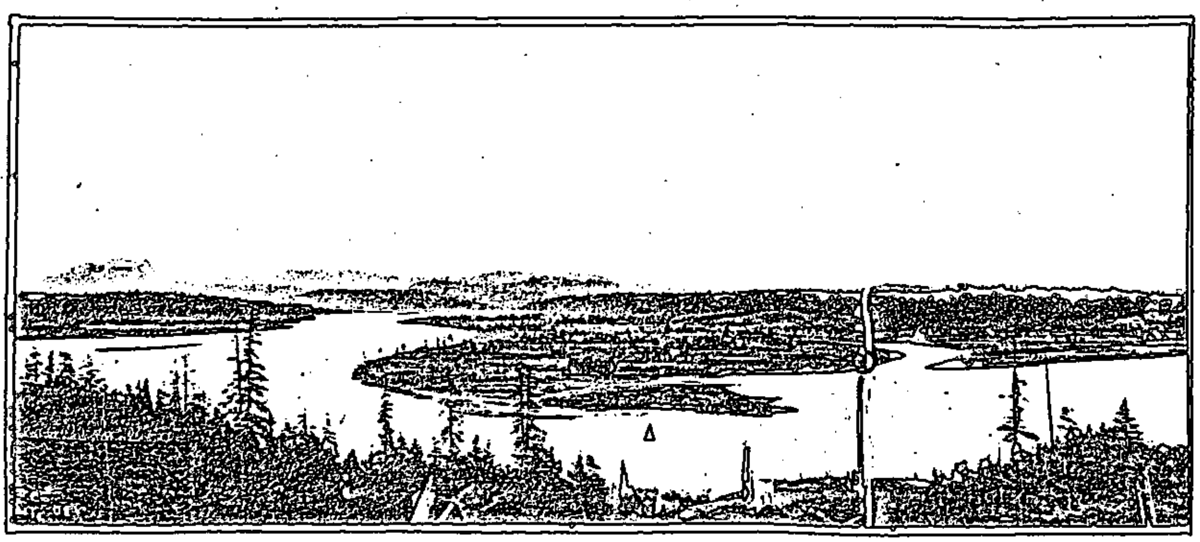
Triangulation of the Columbia River. - In May, Assistant Cleveland Rockwell transferred his party from the southern coast of California to the Columbia River to continue the work of previous seasons. As it was important to adjust the survey of the Columbia by observing at a point for longitude, instead of continuing the topography of the river shores, the triangulation was pushed forward from Westport to Kalama a distance of 32 miles. At the last-named point the Northern Pacific Railroad leaves the Columbia River and passes northward toward Puget Sound. The valley of the Columbia is heavily wooded, and progress through it is impeded by a dense undergrowth. The old limits of the river are steep, rocky, basaltic banks, heavily timbered, wherever trees can find room. Within the original banks lie extensive timbered flats, and broad marshes everywhere eat up by sloughs. A boat furnished the only means of transportation for the party, and the work was consequently very laborious, especially when the freshets of June were running. In making the reconnaissance and reaching the stations, the only practicable route was through sloughs. Lines of sight had to be opened from each station, and every forward line was studied under great disadvantages; but the sketch of the triangulation exhibits a satisfactory scheme, and the progress made is evidence of special energy in the service. On the Columbia the weather was favorable, and only a few days were lost by reasons of the prolonged smoky season.

APPENDIX B

Verification of the U.S. Coast Survey charts

Figure 11. The U.S. Coast Survey 1870 Chart of the Youngs Bay Area, and a 1908 Photograph of the Same Area





Information contained in the U.S. Coast Survey Charts was verified using three methods:

(1) Old photographs.

These could be compared with the vegetation shown on the charts, using the symbol interpretations described in Section 2.2.2. Such photographs proved very difficult to locate; the most productive source was the Clatsop County Historical Museum, where a small number were found. These were of the following areas:

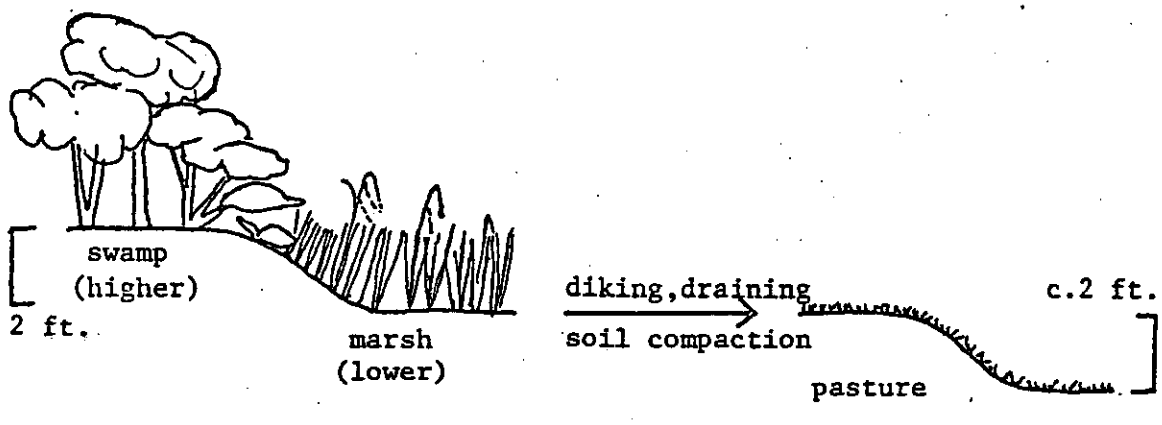
(a) photographs taken across Youngs Bay from Astoria in 1908 and 1911, showing the tidal marshes and swamps in the background;
(b) photographs of the Walluski River, probably of the same date or earlier than (a), showing sedge-dominated marshes with patches of spruce swamp;
(c) a photograph of Deep River, showing willow swamp, probably taken at about the turn of the century; and
(d) photographs of horse seining on Sand Island and other locations in Baker Bay, showing unvegetated and apparently sand shorelines, probably taken during the early decades of this century.

The areas of (b) and (c) are not covered by the U.S. Coast Survey charts; while they are interesting records of the vegetation, they cannot be used as tests of cartographic accuracy. The photographs of horse seining in Baker Bay confirm the unvegetated condition of the shorelines shown on the 1870 chart, and the Youngs Bay pictures show a distribution of marsh and spruce swamp similar to that on the 1870 chart (Figure 11). It should be noted that the chart predates the photograph by forty years, although human disturbance during this time was relatively light. This limited photographic verification indicated that the charts appear to accurately delineate flats, emergent marshes and forested swamps.

(2) The relative elevations of former marsh and swamp areas.

This method is based on the observation that tidal swamps, dominated by trees and shrubs, tend to occur at higher elevations than tidal marshes, dominated by emergent vegetation. When the floodplain is diked, the marshes cease to build up sediment, and instead become drained; the soils shrink as they lose water and as organic matter oxidizes. However, since this shrinkage is more or less uniform over an area of floodplain, the relative elevations of different points will remain the same (Figure 12). This test was applied only to diked floodplain, not to present day estuarine areas, since the latter are likely to have undergone extensive changes. Large numbers of diked floodplain elevations were taken by CH2MHill (1976) in the course of a flood insurance study. An unfilled area near Clatsop County Airport and another near Blind Slough were selected which met the criteria of having sufficient present-day elevations readings and having been mapped during the 1868-73 survey. The results were different for the two areas. Around the airport, no difference was observed between the elevation of former swamps and that of former marshes, and the relatively high

Figure 12. How Differences in Elevation of Marshes and Swamps Can Be Preserved in a Diked Pasture

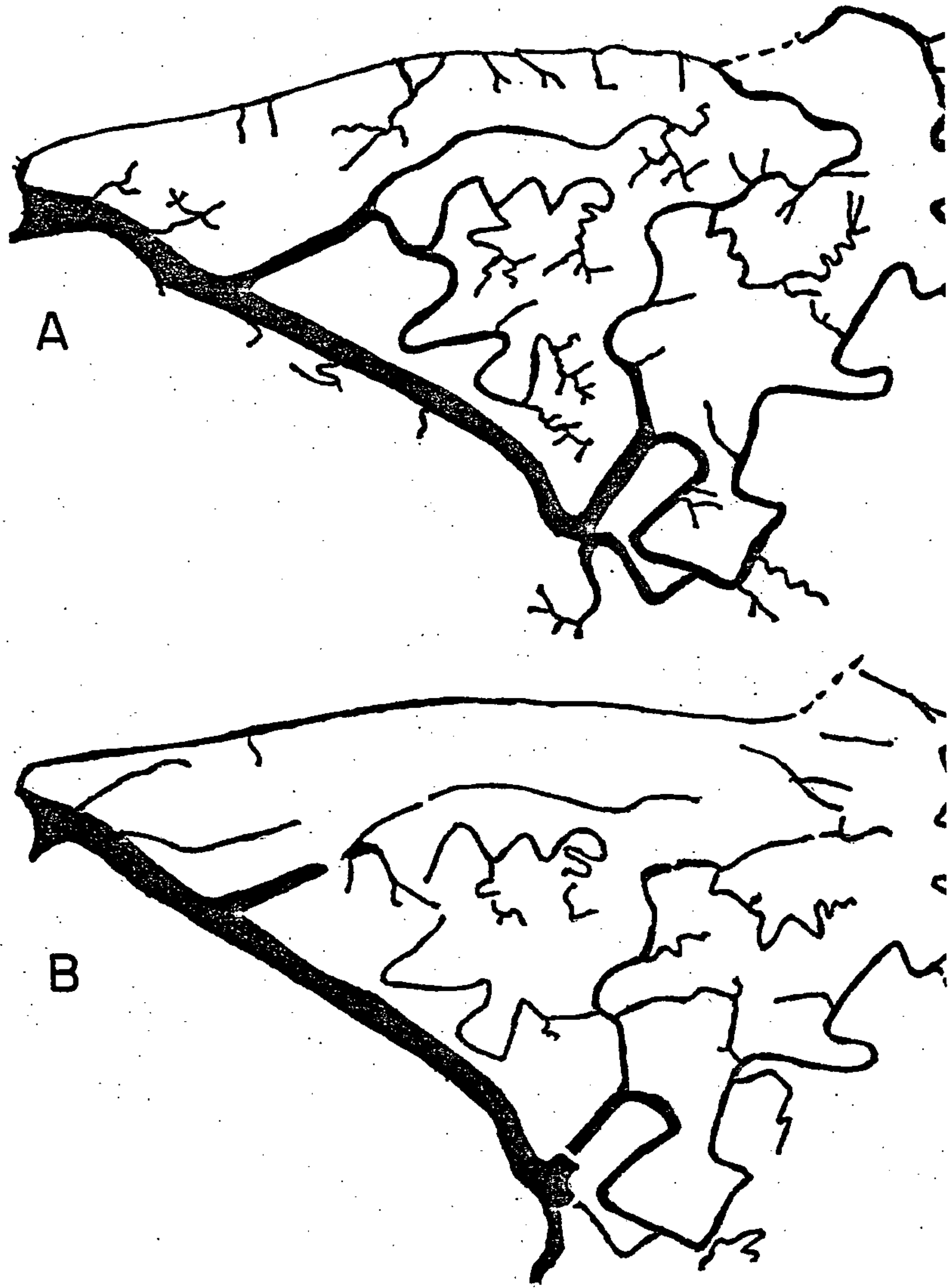


elevations suggest that the latter were mostly high marshes. Near Blind Slough, a former marsh area is now about two feet lower than the surrounding former swamp area. The latter result tends to support the accuracy of the charts, but insufficient information was obtained to determine the usefulness of this method.

(3) Tidal channels.

When the floodplain was diked, the tidal channel systems of the marshes and swamps became the drainage ditches of the new farmland. These tidal channel systems still remain where they have not been realigned or filled in, and they are easily located on aerial photographs. It is therefore possible to check the accuracy with which the tide channels were mapped by comparing their configuration on the charts with that on aerial photographs. This was done for several areas, and one of these (Brownsmead) is reproduced in Figure 13. The correlation is high. Since at the time of survey the only way in which these channels could be mapped was to triangulate them individually using a small boat, it is evident that the surveying parties explored the marshes and swamps very thoroughly and were in a position to map the vegetation accurately.

Figure 13. Tidechannels in the Brownsmead Area from the U.S. Coast Survey 1875 Chart (A) and from 1977 Aerial Photographs (B)



APPENDIX C

An explanation of the boundaries of
the historical subarea map (Figure 5)

The historical study area is the maximum extent of the Columbia River Estuary during the past hundred years. It mainly follows the floodplain boundary indicated in the 1870, 1875, and 1878 Coast Survey charts, with artificial boundaries following easily found locations or political boundaries at the mouth and the upriver end, delineating a region roughly corresponding to the CREST planning area.

At the western (seaward) end, it is defined by a line drawn between the tip of the North Jetty and the furthest (1913) extent of the South Jetty. On the Washington side, the boundary follows the North Jetty and then the shoreline of Cape Disappointment round into Baker Bay. The landward edge of the 1870 floodplain forms the study area boundary in Pacific and Wahkiakum Counties, as far as the upriver boundary east of Puget Island. The eastern boundary follows the Clatsop/Columbia County line in Oregon, the inter-state line, and an arbitrary boundary east of Puget Island in Wahkiakum County.

On the Oregon side, the boundary follows the South Jetty, and then includes most of Clatsop Spit and Point Adams within the area. West of the Skipanon River, the study area boundary represents the interface of the Columbia floodplain with the coastal dune/deflation plain system. East of the Skipanon, the line follows the former floodplain around Youngs Bay up to the heads of tide on tributary rivers, and then the former shoreline around Astoria and Tongue Point. It then follows the former floodplain boundary up to the Clatsop County line.

The study area was divided into seven subareas, which have distinctive biological and physical features. The boundaries are designed to roughly delineate these seven distinctive areas using easily located features; the boundaries between subareas are listed below (see Figure 5 for locations). Comments on the relationship between these boundaries and ecological units have been supplied by J.T. Durkin (personal communication).

Subareas 4/1 — A line draw from the tip of Jetty A to near Megler Point, Washington. In recent times, the part of subarea 4 with deeper water, south of the two islands and the channels around them, have more in common with subarea 1.

Subareas 1/2 — A line from the Washington end of the Astoria Bridge to a point at the N.W. corner of Hammond. From the point of view of present-day fish usage, the west end of subarea 2 belongs in subarea 1.

Subareas 1/3 — This allows the Youngs River/Lewis and Clark River/Skipanon River marshes to form a single unit. The deep water area between Tansy Point and Hammond is ecologically part of subarea 1.

Subareas 2/3 — Follows the south side of the main shipping channel: the deeper water in Youngs Bay to the south of this line has ecological affinities with subarea 2.

Subarea 2/5 — This mainly follows the state line: the shallows and channels of subarea 5 grade into those of subarea 2.

Subareas 2/6 — From Tongue Point to the state line. The deeper water at the west end of subarea 6 often has measurable salinity, making this part distinct from the largely freshwater central and eastern parts, and more similar to subarea 2.

Subareas 5/6 — Follows the state line, then continues in a straight line to the Washington shore at a point just west of Elliott Point.

Subareas 6/7 — This boundary is between Tenasillahe and Welch Islands and then follows the state line past Skamokawa. The northern part of subarea 6, with the main channel and the steep Washington shore, belongs in subarea 7 but was included in subarea 6 for ease of mapping.

A more ecologically meaningful approach to delineating subareas would use criteria such as bathymetric contours: at the river mouth, this would involve including the deep water in the mouth of Baker Bay in subarea 1, and delineating Trestle Bay as a separate subarea. However, although the objective was to produce subareas significantly different from each other ecologically, it was also important that boundaries be kept as short and straight as possible, for ease of transference between maps of different dates and scales, which often have few reference points in common.

Key to subareas:

1 - River Mouth
2 - Mixing Zone
3 - Youngs Bay
4 - Baker Bay
5 - Grays Bay
6 - Cathlamet Bay
7 - Upper Estuary

APPENDIX D

Subarea reports

1. River Mouth........................D-1
2. Mixing Zone........................D-4
3. Youngs Bay.........................D-5
4. Baker Bay..........................D-8
5. Grays Bay..........................D-10
6. Cathlamet Bay......................D-12
7. Upper Estuary......................D-14

1. RIVER MOUTH

The River Mouth has a preponderance of subtidal habitats, with more than three quarters of the area below the six foot bathymetric contour. The highest salinities in the estuary are found here, together with the greatest diversity of marine species. The physical and biological characteristics of the River Mouth have been summarized by Fox (1981), who notes a strong marine influence on the area's biological attributes. Besides the large expanse of water, the subarea has miles of artificial boulder shoreline along the jetties and some cliffs and sand beaches near Cape Disappointment. It also includes Clatsop Spit, which has an extensive sand dune system and a small sheltered bay, Trestle Bay, which supports brackish tidal marshes and sparse subtidal eelgrass beds and is used by large numbers of overwintering waterfowl.

The River Mouth has changed dramatically since 1868. At that time, it was an exposed stretch of channels, shallow water and shifting sand-banks extending about seven miles from Cape Disappointment to Point Adams. A large sand bank occupied the location of Clatsop Spit and another surrounded Sand Island, then in the middle of the river. The area had an environment high in physical energy, with breakers over the sand banks and shallows. The present-day tidal marshes at Swash Lake on Clatsop Spit appear to have been a coastal lagoon in 1868 and may well have supported a small salt-marsh, the only tidal marsh in the subarea at that time.

By 1885, natural changes involving a net movement of marine sediments northward across the Columbia River Mouth had resulted in movement of part of the Sand Island bank into Baker Bay, where it has continued to occupy more or less the same location.

The drastic changes which have occurred around the River Mouth have resulted from jetty construction and also from the dredging and other maintenance of the forty-eight foot bar and forty foot river channel for shipping. The history of the jetties has been described by Hickson and Rodolf (1950). Construction of the south jetty began in 1885 and was done in two stages: the first four and one half miles were completed in 1895, followed by a further two and one quarter miles in 1913. During and following construction of the north and south jetties, a rapid accumulation of sand occurred on Clatsop and Peacock Spits, forming the present day sand dune systems at Fort Stevens State Park in Oregon and Fort Canby State Park in Washington. The accretion of sediment was not limited to the mouth of the river; new sand dunes formed along Clatsop Plains, between the Columbia River and Gearhart, and along the Long Beach Peninsula (Kidby and Oliver 1965). These unstable dunes became a serious problem and were stabilized using beach grass and various woody plants by the U.S. Soil Conservation Service during the 1930's (McLaughlin and Brown 1942).

A relatively small estuarine acreage has been removed from the River Mouth subarea. About 1,500 acres formerly occupied by flats and water have become upland and non-estuarine wetlands. There is a difference between the acreage lost in this and other subareas. Although brought about indirectly by man's activities, the formation of

Clatsop Spit was a largely natural phenomenon, an extension of the process which had previously formed the peninsula of northwest Clatsop County, west of the Skipanon River. The upland so formed is of minimal use for agriculture or human settlement and has therefore remained as a natural sand dune/deflation plain system.

River Mouth Habitat Types

(1) Deep Water.

There has been a significant gain in the acreage of this habitat type, probably because of the increased channelization of the river mouth, with the deepening and narrowing of the river cross-section.

(2) Medium Depth Water.

There has been a large (41 percent) acreage reduction in this habitat type. The increased scouring from channelization of the river has deepened this habitat type, causing a loss of medium-depth water to deep water. The loss in area of medium depth water is roughly equivalent to the gain in the area of deep water.

(3) Shallows and Flats.

Unlike most estuary subareas, the River Mouth has lost shallows and flats. While in upriver locations alterations such as causeways and jetties which restrict circulation result in the gradual infilling of the estuary and the extension of flats, in the high-energy environment of the river mouth the same alterations lead to the creation of upland sand dune systems. In consequence, the gain was mostly in uplands and tidal marsh, not flats. Also, the natural movement of sediments formerly caused the migration of sand banks across the river mouth. The Sand Island bank included in subarea 1 in 1870 had migrated into area 4 by the turn of the century, with a loss of flats and upland in subarea 1 and a corresponding gain in subarea 4.

It is probable that the former flats and shallows in subarea 1 were very different from the present-day ones. In 1868, they were exposed to a high energy environment and probably had medium or coarse sandy sediments. There may have been extensive eelgrass beds subtidally, since black brant, which feed on this plant, were formerly common (Thwaites 1959) and are now uncommon. Most of the present-day flats and shallows are in the sheltered area in and around Trestle Bay. They probably have finer sediments and much richer benthic communities.

(4) Tidal Marshes.

There has been a gain of 250 acres of tidal marshes (over none, approximately, in 1870), which have colonized Trestle Bay. About 2/3 are Lyngby's sedge dominated in low and medium elevation marshes, while the remaining 1/3 is high marsh. These are brackish marshes, as shown by the presence of _Triglochin_ species and also _Agrostis alba_ and _Potentilla pacifica_ dominated communities, typical of brackish high marsh elsewhere in Oregon (Jefferson 1975). This area represents a significant gain of brackish tidal marshes to the estuary. There is a small salt marsh on Clatsop Spit.

(5) Tidal Swamps.

None recorded. Some swamps on Clatsop Spit which have developed since its formation could be considered "tidal" in that they are adjacent to the estuary; they are probably never flooded by tides, and have been included as deflation plains under non-estuarine swamps.

(6) Developed Floodplain.

None.

(7) Fills and Uplands.

There has been a net gain of 770 acres of uplands, in the form of the Clatsop and Peacock Spit sand dune systems. For the most part, this supports semi-natural (planted) grassland of moderate wildlife and recreational value. A small acreage has been developed as roads, parking lots, and park facilities.

The estuarine acreage filled during jetty construction was not measured. The large boulders used for construction have large spaces between them and the jetties are therefore still part of the estuary system. The rocky shore and subtidal rocky areas provide additional habitat diversity.

(8) Non-Estuarine Swamp.

Some deflation plains on Clatsop Spit support shrub and forest dominated wetlands, with red alder (Alnus rubra) and hooker willow (Salix hookeriana) as the main dominants. This represents a gain of wetlands of a type common in Warrenton and the Clatsop Plains.

(9) Non-Estuarine Marsh.

Clatsop Spit deflation plains often support emergent wetland dominated by slough sedge. These wetlands are generally flooded during high rainfall periods and have the surface well-drained at other times.

440 acres of non-tidal wetlands have formed since 1870. These support natural vegetation, often in early successional stages, and are of moderate wildlife value.

(10) Non-Estuarine Water.

There has apparently been a small loss since Swash Lake was a coastal lake cut off by a sand bar and is now fully tidal. There are few permanent lakes on Clatsop Spit; the water table in the young dunes falls to the deflation plain level during dry seasons.

2. MIXING ZONE

This subarea is characterized topographically by a network of channels surrounding extensive areas of flats and shallows, including the large Desdemona and Taylor sand banks. The water is brackish; ocean water intrudes at depth along the channels and more or less mixes with the overlying river water. This gives rise to widely fluctuating salinity values, varying between zero and twenty parts per thousand in response to diurnal tides, the spring/neap cycle, and river flow. The physical and biological properties of the Mixing Zone have been summarized by Fox (1981), who emphasizes its importance to zooplankton and epibenthic organisms, which are an important food source for higher trophic level organisms, particularly fishes.

As far as could be measured by the techniques employed in this survey, there has been little change in the net acreages of the habitat types. Salinities in the late nineteenth century were probably comparable to those found today; even if they averaged slightly higher or lower they certainly showed the same wide fluctuations which they now exhibit.

Since tidal marshes and swamps are of negligible extent, diking has had no impact. There has been extensive shoreline alteration on both sides of the river, with the construction of the Astoria waterfront in Oregon and filling for a highway in Washington. This subarea appears to be less impacted by shoaling than most others (Roy et al. 1982), but even so, it is apparent that a large volume of sediment has accumulated since 1868.

<u>Mixing Zone Habitat Types</u>

(1) Deep Water.

There has been no significant change in this extensive habitat type.

(2) Medium Depth Water.

Slight loss of acreage for this extensive habitat type.

(3) Shallows and Flats.

The large acreage of this habitat type has shown no significant net change, although there have been considerable changes in the spatial distributions of habitat types 1, 2, and 3 caused by the migration of river channels.

(4) Tidal Marshes.

There are a few acres of fringing marshes, dominated by <u>Carex lyngbyei</u> and <u>Scirpus americanus</u>; no measurable change.

(5) Tidal Swamps.

There are no tidal swamps in subarea 2.

(7) Uplands.

Fills at Astoria, totaling about 590 acres, have created upland from flats, subtidal areas and fringing marshes along a steeply to gently sloping shoreline. This development and the construction of Highway 404 along the Washington shore have altered the riparian habitat of this subarea.

3. YOUNGS BAY

This subarea is a shallow bay into which drain several small tributaries of the Columbia, notably (east to west) the Walluski River, Klaskanine River, Youngs River, Lewis and Clark River, and Skipanon River. Youngs Bay has brackish water with surface salinity ranging from zero to fifteen parts per thousand. There is a salinity gradient, with highest values near the mouth of the bay, decreasing up the tributary rivers (Durkin and Emmett 1980).

The physical and biological characteristics of Youngs Bay have been summarized by Fox (1981), who emphasizes the importance of benthic infauna because of the sheltered conditions and the fine silt sediments in the areas of flats and shallows. These organisms constitute an important food source for fish, including juvenile salmonids, and also for estuarine birds.

Major changes have taken place in this subarea during the past hundred years. The broad floodplains which supported mid to high elevation tidal marshes and swamps were ideal for conversion to pasture land. The first dikes were already in place by the time of the 1868 survey, and since then most of the floodplain has been diked, the marshes drained, and the vegetation changed to pasture. The present-day tidal marshes are mostly of recent origin and typically fringe dikes and dredge spoil uplands (Figure 9). Some swamps remain towards the heads of tide on tributary rivers where the narrow floodplain and steep surrounding topography made diking and clearing economically unattractive. A few areas of the broad floodplain were undiked; the best examples are Cooperage Slough and some nearby marsh islands in Youngs River, and some Walluski River marshes.

<u>Youngs Bay Habitat Types</u>

(1) Deep Water.

There has been little change in deep water acreage.

(2) Medium Depth Water.

There has been a significant loss in the acreage of this habitat type as a result of shoaling in the bay.

(3) Shallows and Flats.

There has been a significant reduction in the acreage of shallows and flats, presumably because gains through shoaling have been exceeded by losses through filling, diking, and new tidal marsh establishment. This is an interesting result, because other studies in Youngs Bay (Montagne-Bierly Associates 1977; Boley et al. 1975) have emphasized the importance of shoaling, particularly around the Highway 101 causeway. It would be interesting to have calculations of estuarine volume changes in this subarea.

(4) and (5) Tidal Marshes and Swamps.

In Youngs Bay, these two habitat types are not easily distinguished on historical charts: high marshes are often dominated by a mixture of herbs and shrubs, while swamps with tall shrubs and trees occur as scattered clumps (possibly established on mounds of driftwood) in the high marsh or on natural levees lining tidechannels. Diking has impacted both marsh and swamp very heavily. The combined net loss of these two types of habitat is 9,100 acres, or 89 percent of the original acreage. Furthermore, much of the present-day acreage is new and occupies sites which were formerly flats or shallows along the Skipanon peninsulas and along the extensive dikes (this can be seen by studying the relative distribution of former and recent marshes around the Skipanon River, shown in Figure 9). Also, some of the recent marshes are on floodplain which was once diked and drained but has since reverted back to a tidal regime, such as certain areas along the Walluski River. These new marshes, particularly on sites of former flats and shallows such as the east Skipanon peninsula, differ in many ways from the original marshes. Their angle and direction of slope is different: present-day fringing marshes shelve more or less steeply, inclined or in steps from high marsh down to tideflats. The original marshes, on the other hand, appear to have been more mature, with natural levees alongside the flats, sloping downwards on the shoreward side, with lowest elevations often found at the marsh/upland boundary. This is because the fastest accretion rates in tidal marshes are often found in the areas closest to the tidal water body. These old marshes were drained via extensive dendritic tidechannel systems, while in new marshes tidechannels are poorly developed. The relative present-day and former importances of tidal marsh vegetation types are described in Table 13 (Appendix E). Of particular relevance to subarea 3 are types 11 and 13 which, it is thought, were formerly much more abundant, and types 9, 10, and 16, which were probably less important historically.

These former marshes were probably very important fish and wildlife habitat: Lewis and Clark, who overwintered in subarea 3 in 1805, recorded an abundance of birds, some no longer found in the area: snow brant and two races of Canada geese, ducks, swans, coots, sandhill cranes and, surprisingly, California condors (Thwaites 1959).

(6) Developed Floodplain.

A large area, 6,670 acres or about 40 percent of the former estuarine acreage, has been removed from the estuary by diking and converted to habitat type 6. Most of this acreage is now pasture, used primarily for dairy cattle. These pastures have low value as wildlife habitat but may be flooded by run-off during high rainfall periods. From time to time these pastures may support wetland vegetation if drainage ditches become blocked or if tidegates malfunction. Pasture is very extensive along the valleys of Youngs River and the Lewis and Clark River and in the intervening Miles Crossing area. Residential development of the floodplain has taken place particularly in Warrenton and the Jeffers Garden area. This has been accompanied by numerous small fills to support buildings and more extensive fills for roads and railroads, all of which are included in habitat type 6.

(7) Fills and Uplands.

The major fills have been the peninsulas at the mouth of the Skipanon, Port of Astoria Airport, west and south Astoria, and the mouth of the Walluski river (total of 720 acres). In addition, there are 350 acres of natural upland within the boundary of subarea 3, mostly old sand dunes in Hammond and Warrenton. Most residential development in Hammond and the older developed areas of Warrenton are an old dunes.

(8) Non-Estuarine Swamp.

Not all of the diked floodplain has been converted to agricultural or urban use. Extensive swamps are present, particularly west of the Skipanon River, where the sandy soils are less suitable for agriculture. These swamps are dominated mainly by red alder (Alnus rubra) and shrubs such as hooker willow (Salix hookeriana), crabapple (Pyrus tusca), and Spirea (S. douglasii). Skunk cabbage (Lysichitum americanum) and slough sedge (Carex obnupta) are understory dominants. These swamps have moderate habitat value for wetland birds, deer and beaver, and also for elk in the upper Skipanon area.

(9) Non-Estuarine Marsh.

Most of the acreage of non-tidal freshwater marsh is abandoned pasture in the Warrenton area and has low to moderate habitat value. Natural marsh is rare, the best example being in the Old Skipanon Channel, and this has high value as a natural wetland ecosystem.

(10) Non-Estuarine Water.

160 acres of non-tidal waters are now found within subarea 3. These are the former tidechannels of the once-extensive tidal marshes. The larger of thse sloughs are effectively lakes, while the smaller function as drainage ditches or have filled in with vegetation. These sloughs take the run-off from surrounding floodplain pasture and uplands and drain through tidegates into the estuary. They have moderate habitat value for freshwater fish and for waterfowl and this value is improved if a riparian fringe of trees or shrubs is present.

4. BAKER BAY

This subarea is a broad, shallow bay stretching from Cape Disappointment to Megler Point on the north shore of the estuary adjacent to the River Mouth. Shorelands include the ports of Ilwaco and Chinook and the floodplain of the Wallacut and Chinook Rivers. The wide entrance to the bay is partially blocked by a sand bar formed by the east and west Sand Islands.

The physical and biological properties of Baker Bay have been summarized by Fox (1981), who emphasizes the importance of the brackish water benthic communities with extensive sparse eelgrass beds and high biomass due to large populations of clams. Salinities in the bay are brackish and fluctuate from zero to twenty parts per thousand at the surface in response to tidal and river flow factors. The shoreline is fringed with brackish tidal marshes having Lyngby's sedge and three-square bulrush as dominants, a unique combination in the estuary.

Extensive changes have taken place in this subarea since 1868. Originally, Baker Bay formed the northern part of the high-energy river mouth area. It appears that coarse sediments moved across the mouth and down the river, forming sandbanks which tended to move northwards and cause shoaling before being flushed out of the estuary by freshets. This constant movement of sediments made Baker Bay sometimes open to breakers from the Pacific and at others relatively sheltered by sand bars. For example, in 1868 there was a sand bank and an island in the middle of the river, leaving the bay relatively exposed. Fifteen years later, part of the bank had moved naturally into the broad entrance of Baker Bay, which then became more sheltered. Subsequent jetty building and dredge spoil disposal have resulted in the bank and the Sand Islands remaining there ever since (Roberson et al. 1980). In 1868, there was a low ridge of sand dunes around the perimeter of the bay with a sandy shoreline lacking vegetation. The shoreline of Sand Island was similarly devoid of marshes. Behind this sand bar were extensive tidal marshes, presumably brackish and probably resembling those of Youngs Bay (Figure 8). These were drained by the network of tidal channels surrounding the Wallacut and Chinook Rivers, which were large tidal sloughs. By the 1930's, the valleys of these two rivers had been diked, drained, and converted to agricultural land, eliminating all the original marshes and swamps. With the bay becoming more sheltered, however, new marshes rapidly developed on formerly unvegetated shorelines around the bay, and today these cover more than 700 acres. The circular clones of colonizing plants can be clearly seen on aerial photographs of the bay, providing additional evidence for the recent origins of the marshes.

Comparison of the 1868 data with those from the present shows that extensive shoaling occurred in Baker Bay in the intervening time. Part of this was due to the movement of Sand Island into the subarea but there was also massive in-filling of deep and medium depth water, creating flats and shallows.

Baker Bay Habitat Types

(1) Deep Water.

The area of deep water in the bay has been substantially reduced by shoaling. 75 percent has been lost.

(2) Medium Depth Water.

71 percent of medium depth water has been lost through shoaling. This massive reduction in the area (and, presumably, the volume) of medium and deep water habitat may have reduced the use of Baker Bay by fish species.

(3) Shallows and Flats.

This habitat type has shown an enormous increase in acreage over the past century, reflecting the huge loss of medium depth and deep water habitats caused by shoaling. The extensive flats and shallows are important areas for benthic organisms, and the small clam Macoma balthica is particularly abundant. There are also sparse eelgrass beds in this habitat type.

(4) and (5) Tidal Marshes and Swamps.

There has been a large net reduction in the acreage of these habitat types in Baker Bay. The diking of the Wallacut and Chinook floodplain resulted in the loss of the entire area which was tidal marsh and swamp in 1868, amounting to about 5,100 acres. Since the bay has become more sheltered, however, new marshes have formed on the formerly high-energy sandy beaches of the bay and sheltered parts of the Sand Islands. These new marshes, which total 730 acres, are formed on more or less shelving shorelines; they tend to be species-poor, often exhibiting the circular clones characteristic of recent colonization, and have poorly-developed tidechannel systems. Out of 730 acres of marsh, 416 acres or 57 percent are vegetation types 9 and 10, characteristic of low-medium elevation marshes, while a further 246 acres (34 percent) are of vegetation type 11, characteristic of medium elevations (Appendix E). The former wetlands were probably similar to those of Youngs Bay, with extensive brackish high marshes and swamps and natural levees along numerous tidechannels and sloughs. Mid-elevation marsh dominated by Carex lyngbyei with Agrostis alba was probably common (similar to type 11), together with species-rich high marsh and scrub resembling type 13. Forested swamp, dominated by Picea sitchensis and various shrubby species probably occurred at higher elevations. In areas of driftwood accumulation a tideline community would develop resembling vegetation type 12, species-rich with high marsh and tideline species and often with low cover on account of driftwood and bare ground. Such a community is currently developed on the east side of the Chinook estuary.

(6) Developed Floodplain.

The large acreage of diked floodplain in the Wallacut and Chinook valleys is mostly used as pasture.

(7) Fills and Upland.

The acreage of this in subarea 4 is mostly upland, not fill (although in some places upland sites have been used for dredge material disposal, as on East and West Sand Islands). The uplands are composed of wind-blown sand which forms low dune ridges. Such a sand dune ridge rimmed Baker Bay in 1878, separating the tidal marshes of the Wallacut and Chinook Basins from the flats and shallows of the outer bay. Now, following diking of the marshes, the dune ridge forms a sandy shoreline along the bay and its higher elevation and good drainage properties have made it an excellent site for residential development, particularly at Chinook, in an area otherwise predominantly low-lying and marshy. There may be other, smaller sand bars behind the major one described above, but these were not identified in this project. The acreage of sandy upland has shown a large increase since 1868; this is attributable to the movement and expansion of the sand islands into subarea 4.

(8), (9), and (10) Non-Estuarine Wetlands.

There are diked sloughs and some associated marshes in the floodplain comprising the former Wallacut and Chinook tidechannel systems which are warm water fish habitat. The largest acreage, however, is of swamps. This is because the floodplain is very irregular in shape and interdigitates extensively with the hills of the watershed. These hills are forested, and the narrow tongues of swamp have not been cleared for agriculture since there was less incentive to farm in predominantly forested areas.

5. GRAYS BAY

This subarea is a shallow bay on the Washington side of the estuary into which drain Deep River and Grays River, two small tributaries of the Columbia. Because of its location, parts of this subarea are very exposed and the eastern shore in particular receives winds and swells from the southwest. As a result, these areas experience sediment instability and high turbidity.

The physical and biological characteristics of Grays Bay have been reviewed by Fox (1981), who emphasizes the importance of the fresh/brackish water benthic infauna community and the extensive, low-elevation tidal marshes in sheltered areas and contrasts these with the lower productivity of exposed parts of the bay. Salinities in the bay are mostly low, and the surface water is fresh for much of the year.

As with other bays, shoaling has occurred here, resulting in a decrease in the acreage of medium depth and deep water and an increase in the acreage of shallows and flats. Circulation has probably been reduced and shoaling rates increased by the construction of pile dikes in the vicinity of the main navigation channel, in or near Grays Bay. Diking has altered large areas of floodplain along Grays and Deep Rivers.

Grays Bay was incompletely mapped by the 1870 expedition; the floodplain extends far up the valleys of Grays and Deep Rivers, but only the area immediately adjacent to the main body of the estuary is shown on the charts. As a result the type of vegetation which occupied this area has been deduced from less accurate sources. It seems likely that scrub and forested marshes covered most of the floodplain; where tidal wetlands still exist in the floodplain, they are predominately forested. Also, a photograph of Deep River from the late nineteenth or early twentieth century shows a boardwalk extending out into a forested swamp. The small area of vegetation which was mapped along these rivers in 1870 shows tree and shrub dominated swamps. The principal vegetation types in the unmapped area were probably shrub and forested swamps, dominated by willows (Hooker and/or Sitka), creeping dogwood, and Sitka spruce, while wetter areas may have supported low shrubs mixed with emergent vegetation.

It is interesting that the 1870 map of Grays Bay shows tideflats with scattered patches of marsh vegetation. This corresponds closely to the growth pattern of the soft-stem bulrush which occupies those same locations today. This suggests that bulrush marsh, in this location at least, may be in equilibrium with the environmental conditions and does not prograde rapidly into other vegetation types.

Grays Bay Habitat Types

(1) and (2) Deep and Medium Depth Water.

Shoaling in Grays Bay has led to a significant reduction in the acreage of deep water within this subarea and a small reduction in the acreage of medium depth water.

(3) Shallows and Flats.

The same process of shoaling has led to a significant increase of habitat type 3.

(4) Tidal Marshes.

The results show an increase in tidal marshes in Grays Bay over the last century. This result may have been affected by the lack of historical charts for part of the floodplain, which was estimated entirely as swamp. Even if there were some marshes in that area, the results still show a large increase in the acreage of low elevation bulrush marshes, which appear to be spreading over the accreting tideflats.

(5) Tidal Swamps.

The diking, draining, and clearing of land in the valleys of Grays and Deep Rivers has led to a large reduction in the acreage of tidal swamp. There are still sufficient undiked areas along these rivers to demonstrate the nature of the natural swamp vegetation of the area, which is dominated by a mixture of willows, creeping dogwood and Sitka spruce.

(6) and (7) Developed Floodplain and Fills and Uplands.

Diking has accounted for extensive loss of estuarine area, particularly swamps. In the rural environment of the area, most of this land is used as pasture for cattle grazing. There have been some fills associated with the local lumber industry.

(8), (9), and (10) Non-Estuarine Wetlands.

The diked area contains a small but significant acreage of non-tidal freshwater wetland. This is mostly forested swamp, but there are also some marshes and diked sloughs.

6. CATHLAMET BAY

This large subarea is an expanse of channels and islands in a wide part of the estuary between Tongue Point and Aldrich Point. For convenience, this subarea includes areas which differ in character from the main (freshwater channel-with-islands) portion. The westerly part of the subarea, a strip from Lois Island to Miller Sands, has slight salinity intrusion and resembles the adjacent portion of the Mixing Zone. The northern edge of the subarea has the steep rocky Washington shore and the deep water area along the main navigation channel, lined with dredge spoil islands. This area would be better described as part of the Upper Estuary, but that would have made a very difficult mapping unit.

Physical and biological characteristics of Cathlamet Bay have been summarized by Fox (1981), who emphasizes the importance of the extensive marshes and the locally abundant benthic infauna to juvenile salmonids, which are the dominant fish at certain times of year, and also to waterfowl, which overwinter in large numbers. Cathlamet Bay is largely a freshwater subarea, with extensive acreages of all the freshwater vegetation types. At times of maximal salinity intrusion into the estuary, the salt wedge extends into the channels in the western part.

As in most subareas, shoaling and diking have had a major impact on Cathlamet Bay. Shoaling (including the effects of dredge spoil disposal) has resulted in the loss of over 22 percent of the acreage below the six foot bathymetric contour. Diking, however, has had less impact on the marshes and swamps than in other subareas. There has probably been a slight increase in the acreage of marsh, and about half of the former swamps still remain. This is because diking and clearing for agriculture, which did occur in the Brownsmead area, was not possible on most of the extensive marshy islands. Filling had a major impact in this subarea, with the disposal of large quantities of dredge spoil material in intertidal and shallow subtidal areas, creating nearly 1,000 acres of sandy uplands.

Cathlamet Bay Habitat Types

(1) and (2) Deep and Medium Depth Water.

Shoaling has resulted in the loss of some deep water habitat and a significant percentage of the medium depth acreage in this subarea.

(3) Shallows and Flats.

Shoaling has resulted in a significant gain to the already huge acreage of shallows and flats.

(4) Tidal Marshes.

Although some tidal marshes have been lost through the diking of wetlands in this subarea, there has been an overall gain in acreage: this is mainly because of the development of extensive fringing marshes around dredge spoil islands, particularly Lois, Mott, and Miller Sands. These fringing marshes on dredge spoil, even when they have been established for several decades, differ in some respects from the older marshes, particularly in topography and species composition. They tend to have a different angle of slope and to lack well-developed tidechannel systems (see account of marshes in the Youngs Bay subarea report). Also, marsh plants such as reed canary grass (Phalaris arundinacea) and a species of cattail (Typha domingensis), typical of sites with a significant level of disturbance, tend to be more important.

The former tidal marshes were probably of similar species composition to present day mature marshes that have never been diked, with important dominant species being Carex lyngbyei, Juncus oxymeris, Eleocharis palustris, Deschampsia cespitosa, Equisetum fluviatile, and Scirpus validus. An interesting feature of the vegetation is the domination of extensive areas of high marsh by annuals, particularly Impatiens capensis (Thomas 1980). These tidal marshes are of great importance to fish and to marsh and water birds, and may make a significant contribution to the estuary's primary productivity (Fox 1981).

(5) Tidal Swamps.

Heavily impacted by diking, particularly in the Brownsmead area and Svensen Island and adjacent shorelands, nearly 50 percent of the tidal swamps of this subarea have been diked and cleared. This habitat type is usually the most heavily impacted by diking in freshwater areas, since it is the vegetation type which is most widespread at higher elevations. This loss of acreage is relatively small when a comparison is made with subareas 5 and 7, both of which have a net acreage reduction in excess of 80 percent for the same vegetative communities. The tidal swamps and their associated tidechannel systems are important habitat for some estuarine bird species such as wood ducks, and also harbor populations of insects, amphibians, and mammals.

(6) Developed Floodplain.

The large acreage of tidal marshes and swamps which have been diked is now agricultural land used as pasture for cattle grazing. The broad floodplain around Brownsmead is mostly productive agricultural land; the smaller disjunct areas of diked floodplain between Brownsmead and Tongue Point are generally less well managed and in some cases have reverted back to estuarine marshes following tidegate failure.

(7) Fills and Upland.

Disposal of dredge spoil from around the Tongue Point Docks and Marad Basin area and from the dredging of the main navigation channel has resulted in the creation of upland islands of material which is mainly medium sand. The larger islands are listed in Table 11. It is likely that these uplands, isolated as they are from human disturbance, are important for the bird and mammal species (including seals) which utilize the estuary and require undisturbed upland with various types of habitat for breeding, feeding, or resting at high tide.

(8), (9), and (10) Non-Estuarine Wetlands.

There are about 810 acres of diked sloughs and non-estuarine marshes and swamps. These are important as non-estuarine wetland habitats for wildlife species, which may also use the estuary. The larger sloughs also support populations of warm water fish, which are preyed upon by some birds and mammals.

7. UPPER ESTUARY

This subarea is extensively freshwater, though strongly tidal; current reversals may occur and the diurnal range is about 6½ feet.

Physical and biological properties of subarea 7 have been reviewed by Fox (1981), who emphasizes the predominantly riverine nature of this subarea and its importance to the endangered Columbian white-tailed deer.

In the eastern part of the study area, the Columbia River is funnelled into a narrower channel between steep shores at Bradwood in Oregon and Cathlamet in Washington. In this area, the estuarine habitat types 3 and 4, shallows, flats, and tidal marshes, are less important than in other subareas. Instead, the area is characterized by deep channels between steep shorelines, and floodplain areas that formerly supported about eight times more swamp vegetation than marsh. This suggests that subarea 7 is more stable than other subareas and that the relative locations of channels and shallow areas have remained unchanged over long periods of time, since extensive natural swamp communities take a long time to develop.

The Upper Estuary extends from Aldrich Point in Oregon and Three Tree Point in Washington upstream to the end of the study area. Two large islands are present in the middle of the river, namely Tenasillahe Island and Puget Island. There is an extensive floodplain area between Skamokawa and Cathlamet which still includes extensive natural swamps in the Hunting Islands area. On the Oregon shore the floodplain is of more limited extent, at least up to the survey limit (Clatsop County line). Around Skamokawa Creek in Washington, the extent of the former floodplain is difficult to establish; the floodplain is of high elevation, and much of it may have supported forest with many upland characteristics. As a result, only a small floodplain acreage around Skamokawa Creek has been included in the study area. Although this study was confined to an area limited by the Clatsop County line it is evident that tidal marshes and swamps similar to those found in Cathlamet Bay and the Upper Estuary subareas once extended far upriver. Columbia County in Oregon, for example, had a huge floodplain supporting extensive tidal marshes, which has now been drained.

Alterations to the Upper Estuary have involved a loss in the subtidal area, a gain in acreage of shallows and flats, and large losses of marshes and swamps. These losses resulted mainly from the diking of Tenasillahe and Puget Islands and the floodplain area between Skamokawa and Cathlamet.

Upper Estuary Habitat Types

(1) and (2) Deep and Medium Depth Water.

There has been a 22 percent loss of deep water acreage and a slight gain in medium depth water.

(3) Shallows and Flats.

There has been a significant gain in the acreage of shallows and flats. This has probably resulted at least partially from the construction of pile dikes, particularly to the east of Puget Island, and the disposal of dredge spoil in the area.

(4) Tidal Marshes.

There has been a large percentage loss of tidal marshes in subarea 7. This is the result of diking, particularly of Tensillahe Island.

The loss of the original marshes is greater than the net loss, since most or all of the present day marshes are of recent origin, developed on dredge spoil or fringing dikes (Table 10). These marshes probably differ from the original ones in having reed canary grass (Phalaris arundinacea) and cattails (Typha species), typical of disturbed sites, common or even dominant whereas they would formerly have been rare or absent altogether.

(5) Tidal Swamps.

The greatest loss has been in the acreage of tidal swamp. This was lost in the course of diking and clearing, particularly on Puget and Little Islands, on the floodplain between Skamokawa and the Elochoman River, and along Skamokawa Creek. Fine examples of the vegetative communities of this habitat type can still be seen on the Hunting Islands and adjacent Elochoman River swamps, with smaller examples elsewhere in the subarea. Two communities in particular have been identified by Thomas (1980), one dominated by tall shrubs, principally Salix sitchensis and Cornus stolonifera, the other dominated by tideland spruce trees (Picea sitchensis) and a diverse assemblage of shrubs and small trees. These communities, also found in subarea 6, were formerly very widespread in the freshwater tidal area.

(6) Developed Floodplain.

Diked areas in subarea 7 are mainly in use as pasture. Principal areas are Skamokawa Creek and east to the Elochoman River, Puget and Little Islands, and around Westport. Pastures on Tenasillahe Island are described as marshes (see below).

(7) Fills and Uplands.

There has been extensive creation of uplands through filling in subarea 7. Principal areas are south of Tenasillahe Island and south and east of Puget Island, and on the Oregon shore near Wauna, where the fill supports industrial sites. Also, there has been extensive disposal of dredge material along the main dike on Puget Island, making it of sufficient acreage to be included as habitat type 7. This dike supports a road and numerous lots with houses.

(8), (9), and (10) Non-Estuarine Wetlands.

There is a large acreage of non-tidal freshwater wetlands in subarea 7. The large (1,200 acres) marsh area is on Tenasillahe Island, and this is likely to return to pasture (habitat type 6) now that the dike has been repaired.

APPENDIX E

The nineteen intertidal vegetation communities of
the Columbia River Estuary identified by Thomas (1980),
with tables showing their present acreages per
subarea and their estimated former acreages and importance

#1. PEM5N - Jo/Ep 58 hectares

Major dominants: Juncus oxymeris, Sagittaria latifolia, Sium suave, Eleocharis palustris

Important species: Boltonia asteroides, Epilobium watsonii, Alisma plantago-aquatica, Lilaeopsis occidentalis, Bidens cernua

Occurs at low - mid elevations, usually mixed with #2, Cathlamet Bay Islands.

Related to #2 & #14: Differs from wet variations of #2 by the absence of Carex lyngbyei. Differs from #14 by the absence of Scirpus validus. (Although the dominant lists for #1 and #14 are markedly dissimilar, both are rather variable in composition and have been separated in the field by the presence or absence of S. validus.)

Probably 10% of measured area is bare mud/tide channels, with 1 or 2% covered with #5.

Since this vegetation type usually grows mixed with #2 this community has probably been under-represented.

#2. PEM5N - Cl 1,123 hectares

Major dominant: Carex lyngbyei (This is replaced by Equisetum fluviatile as the main dominant over about 15% of the total area.)

Other dominants: Juncus oxymeris, Deschampsia caespitosa, Sium suave, Boltonia asteroides

Other species: Mimulus guttatus, Caltha asarifolia, Bidens cernua, Sagittaria latifolia, Eleocharis palustris

A well-defined vegetation type, with wetter areas Cl/Jo dominant, drier areas Cl/Dc. The most extensive non-woody vegetation in the estuary, mostly occurring on the Cathlamet Bay islands at medium elevations, covered by at least 1 foot of water at high tide.

In July and August the white umbels of Sium suave distinguish this community, while in September Boltonia asteroides, a composite with pink-white rays, is the visual dominant.

The area covered by water, mud, and other communities is small, probably around 1 - 2%. Other communities include probably #1, #14, and a little #4.

#3. PEM5N - Sv 618 hectares

Main dominant: Scirpus validus

Other dominants: Juncus oxymeris, Eleocharis palustris, Carex lyngbyei, Scirpus fluviatilis

Other species: few; Sagittaria latifolia

A species-poor vegetation type, normally at low elevations (but higher on dredge spoil), typically where sand/mudflats are being invaded by emergent vegetation. All such colonizing vegetation in the estuary, with the exception of that dominated by Scirpus americanus (#9) is included here.

Other communities: very small area.

Mud: large areas, probably at least 50% of the area mapped.

#4. PEM5N/6N - no dominants 229 hectares

A species-rich herb community occurring at high elevations in the Cathlamet Bay area. Almost impossible to define dominants without a quantitative survey. Important species are:

Aster subspicatus	Lotus corniculatus
Deschampsia caespitosa	Potentilla pacifica
Phalaris arundinacea	Lysichitum americanum
Festuca arundinacea	Equisetum fluviatile
Carex lyngbyei	Salix sitchensis
Helenium autumnale	S. lasiandra
Bidens cernua	etc.

Differs from #6, which occurs at similar elevations, by the almost total absence of Impatiens capensis, and by the importance of Aster subspicatus, Festuca arundinacea, Helenium autumnale, and Lupinus polyphyllus. It differs from #12, tideline vegetation from the lower estuary, by the absence of Agrostis alba as a dominant. It occurs in more exposed sites than #6, which is typically in the interior of marshy islands. Hardly any mud or water.

#5. PEM4N - Lo/Ta Not measurable

Mud bank community, with Gratiola neglecta, Limosella aquatica, Tillaea aquatica, Elatine triandra, Callitriche sp., Eleocharis palustris. Excluded, since, though widespread, it was seldom extensive enough to map. Included in areas of #1, #2, #3, & #14.

#6. PEM6N/P - Ic 348 hectares

Main dominant: Impatiens capensis

Other important species: Lotus corniculatus, Myosotis laxa, Carex obnupta, Leersia oryzoides, Potentilla pacifica, Lysichitum americanum, Equisetum fluviatile. Patches of scrub (#7) occur, with Salix sitchensis, S. lasiandra, Cornus stolonifera.

Other communities: The boundary between #6 and #7 is usually very complex, and the two interdigitate to a considerable extent. Also, #6 frequently intergrades with #2.

High elevation vegetation, mainly Cathlamet Bay islands.

A very species-rich vegetation type, occasionally with Carex lyngbyei as a dominant where it intergrades with #2. The area mapped as #6 in Grays Bay is atypical, since, although very species-rich, Impatiens capensis is not the main dominant; it is probably intermediate between #6 and #13.

#7. PSS1P - Ss 1,554 hectares

Main dominant: Salix sitchensis (Salix sitchensis scrub)

Other dominants: S. lasiandra, Cornus stolonifera, Spiraea douglasii

Important species: Physocarpus capitatus, Pyrus fusca, Picea sitchensis, Lysichitum americanum, Rosa pisocarpa

High elevations, upper estuary. Tongue Point to Puget Island. Very extensive, impenetrable vegetation. Often covering the interiors of the tidal islands in Cathlamet Bay. There is good evidence that some inaccessible areas away from tidechannels are dominated by Spiraea douglasii, rather than Salix sitchensis, but this community was not mapped separately.

A well-defined type; some areas were mixed with #6, #8, or #17. This type is probably even more extensive than the high acreage shows, since undiked areas of scrub, not mapped here, occur on several of the smaller rivers.

#8 PFO4P - Ps 429 hectares

Picea sitchensis-dominated forest. This is probably the climax vegetation at high elevations throughout the estuary, but I doubt that it is often developed except on a few Cathlamet Bay islands.

Other species: Acer circinatum, Thuja plicata. Usually mixed with #7, Salix sitchensis, Cornus stolonifera.

#9. E2EM5N - Sa 73 hectares

Dominant species: Scirpus americanus

Other species: Species-poor; may have Lilaeopsis occidentalis, Triglochin maritimum

Low elevations, Trestle Bay/Baker Bay, up to Lois/Miller Islands. Usually developed as a narrow band at the lower edge of the emergent vegetation on sandy shore.

#10. E2EM5N - Cl 148 hectares

Dominant species: More or less 100% cover of tall Carex lyngbyei

Other species: Agrostis alba, Triglochin maritimum

Developed at low - medium elevations on shorelines, lower estuary.

#11. E2EM5N - Cl 158 hectares

Dominant species: Lower cover of Carex lyngbyei, short, less than 80 cm.

Other dominants: Agrostis alba, Scirpus americanus, Juncus balticus, Triglochin maritimum, Lilaeopsis occidentalis, Deschampsia caespitosa

#9, #10, #11, & #12 are classified as "E" rather than "P" since they are thought to develop under brackish conditions. Types #11 and #12 are also widespread in neighboring Willapa Bay.

#12. E2EM5/6P - Aa/Pp/As 64 hectares

Dominants: Agrostis alba, Aster subspicatus, Potentilla palustris

This is high elevation/lower estuary vegetation. It is rather a dustbin category, since although the typical vegetation is well defined, all mappable lower estuary tideline is included here; areas may have Lotus corniculatus, Agropyron repens, or a diverse weedy community growing among driftwood logs. This is the lower estuary equivalent of #4, and tidelines in Grays Bay (included in #4 and #6) are intermediate in nature between #4, #6, #12, and #13. Tidelines are, however, of low area, and no attempt at a meaningful extensive classification of them has been attempted here.

#13. PEM1/SS2P - No dom/Sh   89 hectares

Important/locally dominant herbs: Carex obnupta, Athyrium filix-femina, Phalaris arundinacea, Lathyrus palustris, Aster subspicatus, Agrostis alba, Festuca arundinacea, Potentilla pacifica

Important shrubs: Salix hookeriana, Lonicera involucrata, Spiraea douglasii, Rubus spectabilis

Species-rich herb/shrub vegetation; lower estuary equivalent of #6.

This vegetation usually occurs as a mosaic of herb and shrub patches, and the two have therefore not been separated as two vegetation types.

#14. PEM5N - Sv   301 hectares

Dominant: Scirpus validus

Other locally dominant/important species: Polygonum hydropiperoides, Scirpus fluviatilis, Oenanthe sarmentosa, Bidens cernua, Sagittaria latifolia, Alisma plantago-aquatica, Isoetes echospora, Lilaeopsis occidentalis

Low to mid-elevation vegetation, resembles dense #3 in appearance, but has well-developed understory. Occurs in the middle part of the estuary. Well-developed in Grays Bay, unnamed islands, and Youngs River.

Quite a lot (estimated 10%) of mud in this type.

#15. PEM1N - No dominant   80 hectares

A vegetation type from old diked fields on Karlson Island, species-rich and intermediate between #6 and #2. Presumably vegetation resembling #6 developed when the dikes were intact, which is now reverting to #2 with tidal flooding.

#16. PEM5N - Pa/Td/Cl   177 hectares

Main dominants: Phalaris arundinacea, Typha domingensis, Carex lyngbyei

Other locally dominant/important species: Juncus oxymeris, Festuca arundinacea, Deschampsia caespitosa, Sium suave, Aster subspicatus

Mid to high elevation; appears to occur on dredge spoil. Extensive around Puget Island and along the shipping channel to Tongue Point.

#17. PFO1P - Pt 189 hectares

Main dominants: Populus trichocarpa forest; also #7 understory: Salix sitchensis, Cornus stolonifera, Alnus rubra

High elevation, mostly around Puget Island area. Often mixed with Picea sitchensis forest.

#18. PSS1P - Sh/Ar 13 hectares

Dominants: Salix hookeriana, Alnus rubra; scrub

Important species: Picea sitchensis, Athyrium filix-femina, Rubus spectabilis

Very common around the lower estuary, but for the purpose of this study considered to be mainly above tidal influence (hence the low total area).

#19. PEM5N - Sv/Td/Cl 56 hectares

Dominants: Scirpus validus, Typha domingensis, Carex lyngbyei

Mid - high elevation, lower estuary, mostly in the Youngs Bay area. A lower estuary variant of #16.

Other local dominants: Sometimes a clone of an unusual species dominates a large area within one of the types enumerated above:

Ef - Equisetum fluviatile - local dominant in #2 (common)
Ep - Eleocharis palustris - colonist of sandbanks in #3 (common)
Td - Typha domingensis - local dominant in #2 (rare)
Pc - Phragmites communis - local dominant in #2 (rare)
Zm - Zostera marina - herb of mudflats at very low elevations, or, more usually, of subtidal zones. Apparently covers extensive areas in Trestle Bay and Baker Bay; absent elsewhere.

Table 12. Acreages of Nineteen Marsh and Swamp Vegetation Types per Subarea

Vegetation Type	Subarea 1	2	3	4	5	6	7	Estuary Totals
1						143		143
2					59	2,815	86	2,960
3			251		369	906		1,526
4					46	485	34	565
6					25	705	130	860
9	8		7	166				181
10	83	5	33	250				371
11	54		144	246				444
12	82		5	72				159
13	2		390					392
14			37		175	531		743
15						198		198
16					86	178	258	522
19	24		133					137
Total Marshes	253	5	980	734	760	5,961	508	9,201
7					291	2,943	1,403	4,637
8					222	1,006	484	1,712
17 & 18			134			108	358	600
Total Swamps	0	0	134	0	513	4,057	2,245	6,949
Total Marshes & Swamps	253	5	1,114	734	1,273	10,018	2,753	16,150

Figures in acres. Classification and acreage data based on Thomas (1980).

Table 13. A Comparison of Present-Day and Estimated Former Importance of the Nineteen Vegetation Types in Table 12

Vegetation Type	1980 Acres	*	**	Estimated former acreage and importance (proportion of vegetation)
1	140	L-M	F	Greater acreage, same importance in s-a 6 and 7
2	2,960	M	F	Greater acreage, similar importance in s-a 6 and 7
3	1,530	L	F(-B)	Smaller acreage and importance (seems to have increased in s-a 5 and 6)
4	570	H	F	Similar acreage and importance
6	860	H	F	Greater acreage, same importance s-a 6 and 7
7	4,640	H	F	Greater acreage and importance in s-a 5, 6, and 7
8	1,710	H	F	Greater acreage and importance in s-a 5, 6, and 7
9	180	L	B	Less or none formerly
10	370	L	B	Less acreage and importance
11	440	M	B	Greater acreage and importance - formerly important in s-a 3 and 4
12	160	H	B	Less important/lower acreage
13	390	H	F-B	Much more important, greater acreage in s-a 3 and 4
14	740	M	F(-B)	Similar acreage
15	200	M	F	None formerly
16	520	M	F-B	None formerly
17 and 18	600	H	F-B	Much greater importance in s-a 3 and 4; less upriver, where #17 tends to colonize dredge spoil
19	140	M	B	None formerly

*Low, Medium, and High elevation. Approximate values where diurnal range (MLLW-MHHW) averages 8 feet: Low = 2.5 to 4 feet above MLLW; Medium = 4 to 6.5 feet above MLLW; High = above 6.5 feet.

**F = freshwater; B = brackish.