Distribution, Abundance, and Size-Class Structure of Dungeness Crabs in the Columbia River Estuary

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COASTAL ZONE AND ESTUARINE STUDIES

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CONTENTS

INTRODUCTION

In 1984, the U.S. Army Corps of Engineers (CofE) deepened the Columbia River entrance channel [River Mile (RM)[1/] -2.0 to +3.0] from 14.6 to 16.8 m (mean lower low water). The CofE (1983) estimated that during the initial deepening, 9.9 million yd^3 (7.6 million m^3) of material would be removed from the river bar's entrance channel; annual maintenance dredging for the entrance channel was estimated to be 7.0 million yd^3 (5.4 million m^3) of material. Deepening of the channel upstream from the entrance is also being considered. Resource agencies are concerned with the effect this increase in dredging will have on the biota of the Columbia River estuary (Ellifrit 1982).

One of the commercially and recreationally important aquatic species that could be affected by the dredging project is Dungeness crab, *Cancer magister*. Initial studies of Dungeness crabs in the Columbia River estuary showed an extensive population and also identified the temporal occurrence of 0+ age crabs (young-of-the-year) (Emmett et al. 1983). However, comprehensive information regarding the distribution, abundance, size-class structure, and movements of crabs between the ocean and estuary was not available.

In 1983, prior to the start of the bar deepening project, the National Marine Fisheries Service (NMFS) entered into a cooperative agreement with the CofE for a 2-year study on Dungeness crabs in the Columbia River estuary. Specific objectives of the study were to describe the Dungeness crab's estuarine distribution, abundance, size-class structure, and location and timing of movements across the bar (RM 0.7 to 2.8). In addition, the size-

1/ RM is used in this report because of its common usage in navigation charts.

class structure of crabs in the Columbia River estuary was to be compared to that in near offshore areas.

METHODS

Sampling

Sampling was done from November 1983 through October 1985. A maximum of 28 estuarine and ocean sites were sampled each month (Fig. 1); 15 of the estuarine sites were near former NMFS sampling sites (Emmett et al. 1983). Geographic locations of the sampling sites are listed in Appendix Table A1. Because crabs were not captured upstream from Grays Point (Station 15) and North Channel of Cathlamet Bay (Station 18) in past surveys, these two stations were not always sampled if less than two crabs were collected at nearby downstream sites. In November 1984, the location of Station 10 was moved about 1 mile to the west to avoid bottom obstructions at the original site. The six ocean sampling sites were located along a transect perpendicular to the shore. Depth was the major criterion in selection of the ocean sites. The easternmost station (Station 90) was as close to shore as possible in approximately 5-12 m of water. The location of Station 90 varied depending on ocean conditions. The water depths at the other stations were: Station 91, 18 m; Station 92, 37 m; Station 93, 55 m; Station 94, 73 m; and Station 95, 91 m. All ocean trawls were along the initial depth contours.

An 8-m semiballoon shrimp trawl, with overall mesh size of 38.1 mm (stretched), was used at 26 of the sampling sites. A 12.7-mm mesh liner was inserted in the cod end of the net to ensure retention of 0+ age crabs. The fishing width of the trawl was estimated to be 5 m (manufacturer's estimate). Trawling at each site in the estuary was generally done for 5 min

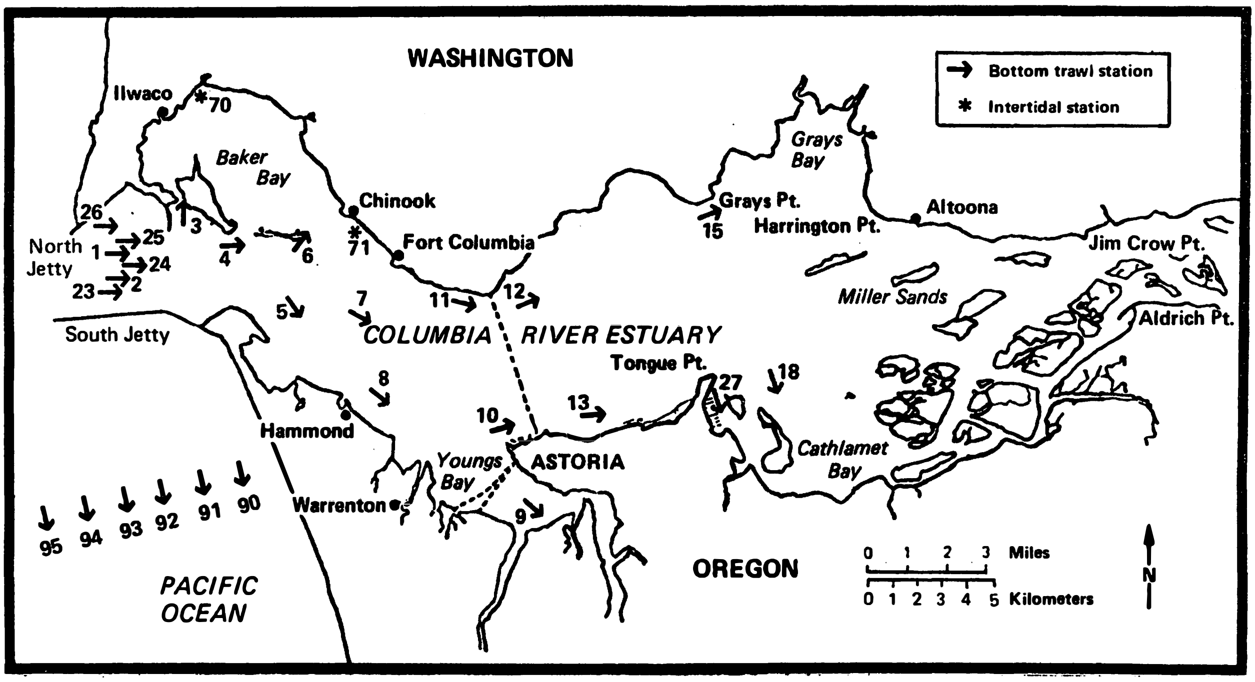

Figure 1.--Map of the Columbia River estuary and adjacent coastal areas, showing sampling sites for the 2-year Dungeness crab study.

during the flood tide; ocean trawls were 10 min in duration. Distance traveled during a sampling effort was estimated using either a radar range finder or Loran-C navigational equipment, so that relative crab abundance (crabs/hectare) could be estimated. Two intertidal sites in Baker Bay were sampled (when exposed) by walking along transects away from shore. The vegetation and substrate along these transects were examined for crabs.

Replicate trawls were done at Stations 5, 6, and 10 to evaluate catch variability and describe the types of crab distributions in different areas of the estuary. On 6 and 8 December 1983, five replicate tows were made at Stations 5 (RM 6) and 10 (RM 13). Six consecutive replicate tows were made in Chinook Channel (Station 6) on 19 December 1983.

Generally a subsample of at least 100 crabs (≥20 mm) from each sample was measured (mm) across the carapace anterior to the tenth anterolateral spine, weighed (g), sexed, and checked for eggs and the nemertean *Carcinonemertes errans*, which is an egg predator (Wickham 1979). Specific body areas--the undersurface of the abdomen, the thoracic area covered by the abdomen, and the pleopods--were examined for *C. errans*. When the crab catch exceeded 100, the remainder was counted and weighed as a group. When large numbers of early instar crabs (<20 mm) were captured, a minimum of 50 were measured and weighed. Size variations of the early instar crabs were much less than those of the larger crabs.

Salinity (ppt) and temperature (C) were measured at the surface and near the bottom before each sampling effort using a Beckman RS5-3[2/] salinometer and temperature probe. Bottom values were not obtained at the deeper ocean

2/ Reference to trade names does not imply endorsement by National Marine Fisheries Service, NOAA.

stations because the probe cable was not long enough. During the beginning of the study, water samples were collected coincident with measurements by the field salinometer, to verify some field salinity measurements. The water samples were analyzed in the laboratory with a Beckman RS-7-B induction salinometer.

Data Analysis

Using catch data, the fishing width of the trawl (5 m), and the distance traveled during sampling, we estimated the density of crabs (number/hectare) at each station for each month. Crab abundance data were used to construct distributional maps of Dungeness crabs in the Columbia River estuary. Information in the maps is presented by season and size class. The seasons were defined as: winter - January, February, and March; spring - April, May, and June; summer - July, August, and September; and fall - October, November, and December. Crabs were enumerated by four size-classes: I (<50 mm), II (50-99 mm), III (100-129 mm), and IV (≥130 mm). Crabs were not separated into age classes because we were unable to consistently assign age groups using width frequency distributions. Different age groups often had overlapping carapace width distributions, particularly the older groups.

Various statistical tests were used to analyze the data. Comparisons of crab densities were made using the nonparametric Mann-Whitney U-test and Kruskal-Wallis test (Elliott 1977). Replicate trawls (adjusted for effort) at Stations 5 and 6 were compared using a chi-square test (variance to mean ratio; Elliott 1977); replicate trawls at Station 10 were not compared because some of the catches were too small. Regression, both simple and multiple, was used to examine relationships between density and physical parameters (bottom salinity and temperature). Densities were transformed to $\log_{10}$ (number/ha + 1) prior to employing regression. A width-weight relationship for Dungeness crabs was calculated by transforming (log_{10}) the widths and wet weights, then using simple regression.

Population estimates of Dungeness crabs in the estuary were calculated using density data from Stations 1-8, 10-12, and 23-26 (Fig. 1). The estuary was divided into four subtidal areas to estimate populations. The areas, determined by planimetry, were: 1) Columbia River bar ($\geq$6 m mean lower low water)- 1191 ha; 2) Baker Bay- 685 ha; 3) shallow subtidal areas (<6 m mean lower low water)- 2109 ha; and 4) deep subtidal areas ($\geq$6 m mean lower low water)- 4466 ha. Only the subtidal areas of Baker Bay in the proximity of our sampling sites were included. Because the 8-m trawl was not 100% efficient, we used the efficiency factors employed by Stevens and Armstrong (1984) to obtain population estimates (see Discussion). A mean density (number/ha) for each size class in each area was determined and then corrected for gear efficiency. Estimates for each area were added for a total population estimate.

RESULTS

Estuarine Distribution and Abundance

Seasonally, crabs were generally distributed from the mouth of the estuary to about RM 17 throughout the 2-year study[3/]. No crabs were captured in Youngs Bay (Station 9), Cathlamet Bay (Stations 18 and 27), and intertidal areas of Baker Bay; crabs were captured infrequently at Grays Point (Station 15) and off central Astoria (Station 13). Because crab numbers were

3/ Catch information (including number captured, number/ha, weight, and weight/ha) by station and month is included in Appendix C; the catches are also separated by size class. This lengthy appendix has not been included in this report, but is available upon request.

generally zero at the above stations, they were not included in comparisons of densities between years and areas and among seasons.

Densities of crabs in the estuary were significantly greater during the second year of the study (November 1984 through October 1985) than during the first year (November 1983 through October 1984) (Mann-Whitney, $P < 0.001$). Densities among the four seasons were not significantly different for both years combined and for the first year of the study (Kruskal-Wallis, $P > 0.05$); however, for the second year there was a significant difference among the seasons, with highest densities during summer (Kruskal-Wallis, $P < 0.05$).

Density comparisons were also made for two areas of the estuary--the bar and the estuary upstream from the bar. During the second year, densities on the bar were significantly greater than during the first year (Mann-Whitney, $P < 0.001$). For both years, combined and separate, densities on the bar among the seasons were significantly different (Kruskal-Wallis, $P < 0.001$), with the highest densities in spring and summer. In the area upstream from the bar there was no significant difference in densities between the two years (Mann-Whitney, $P > 0.05$). Upstream from the bar, for both years combined and for the second year, there were no significant differences among the four seasons (Kruskal-Wallis, $P > 0.05$); however, during the first year there was a significant difference among seasons, with highest densities in fall (Kruskal-Wallis, $P < 0.05$).

Overall, crab densities on the bar were significantly less than densities in the estuary upstream from the bar (Mann-Whitney, $P < 0.001$). On a seasonal basis, densities were significantly less on the bar than in the upstream area during fall and winter of both years (Mann-Whitney, $P < 0.05$); however, there were no significant differences between the two areas during spring and summer of both years.

Crab densities in the estuary varied considerably among individual stations; also, monthly densities at individual stations frequently varied (Figs. 2 and 3). There was a significant difference in crab densities among the six bar stations when all 24 months of data were combined (Kruskal-Wallis, $P < 0.05$). Station 26, which is the northernmost station, had the highest densities. When densities at the six stations were seasonally compared, there were no significant differences among stations. Although there were no significant differences among the bar stations during spring and summer of 1985, densities tended to be higher on the northern portion of the bar (Stations 1, 24, 25, and 26) than on the southern portion (Stations 2 and 23) during June and July 1985 (Fig. 2).

At stations upstream from the bar, Stations 3 (Ilwaco Channel) and 6 (Chinook Channel) had densities > 2,000 crabs/ha during some months (Fig. 3). Densities at Station 6 were extremely high during August, September, and October 1985, up to 18,194 crabs/ha. At Station 10, densities during the second year were higher than during the first year.

A major product from the 2-year study is a series of distribution and abundance maps for Dungeness crabs in the Columbia River estuary (Appendix Figures B1-B16). The maps depict seasonal distributions and densities (number/ha) by size class. Data limits for Baker Bay are indicated with dashed lines. Several broad observations can be made from the maps:

1. Densities of Size Class I crabs increased on the bar during spring and summer of both 1984 and 1985; overall, Size Class I was the most numerous size class on the bar. Although it cannot be seen in the maps, most of the Size Class I crabs captured on the bar were 0+ age crabs which had entered the estuary from the ocean. Megalops larvae and early instar crabs were first collected in the estuary in May of both years.

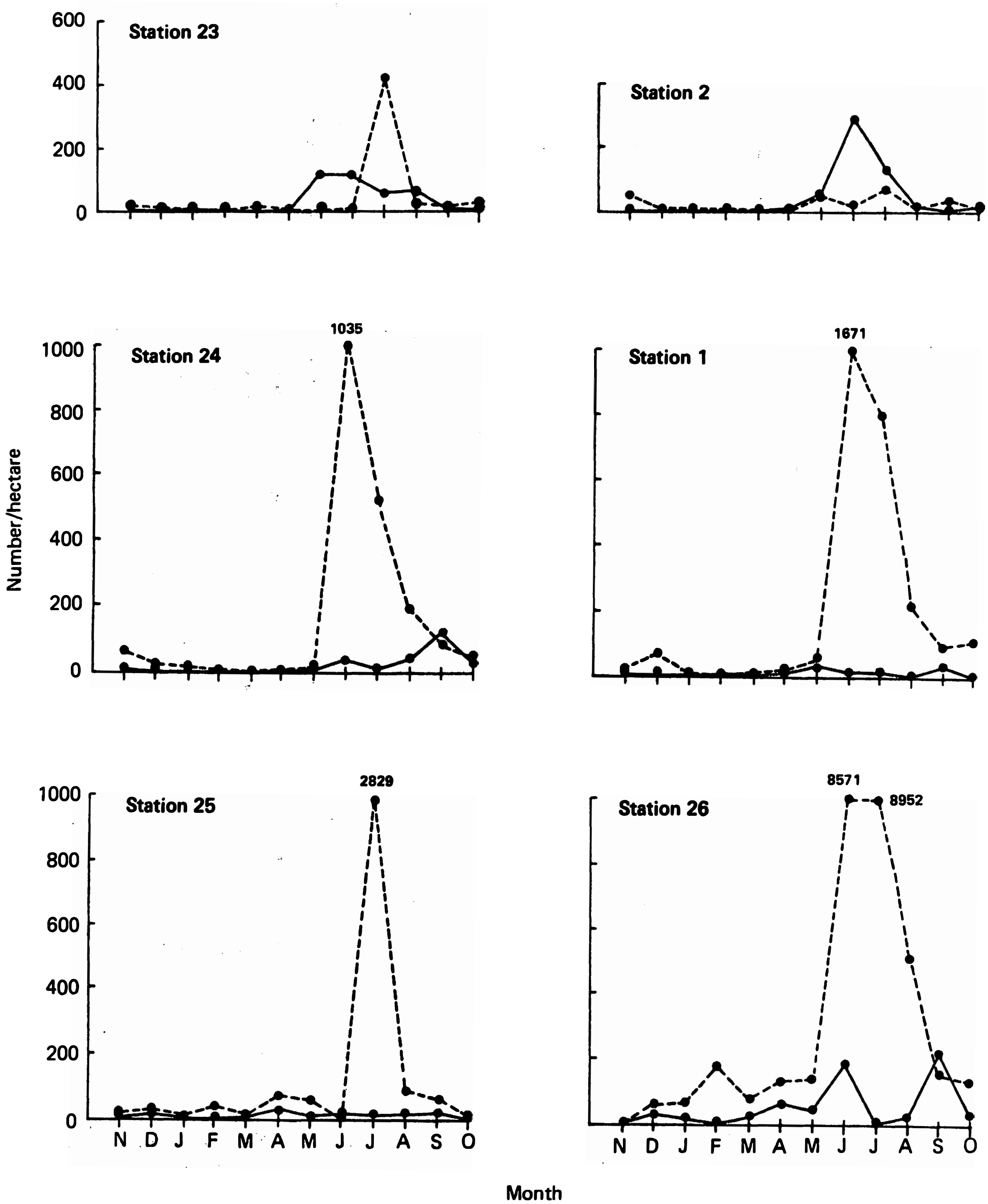

Figure 2.--Estimated densities of Dungeness crabs at six sampling stations on the Columbia River bar. The solid line represents the first year of the study (Nov. 1983 through Oct. 1984) and the dashed line represents the second year (Nov. 1984 through Oct. 1985).

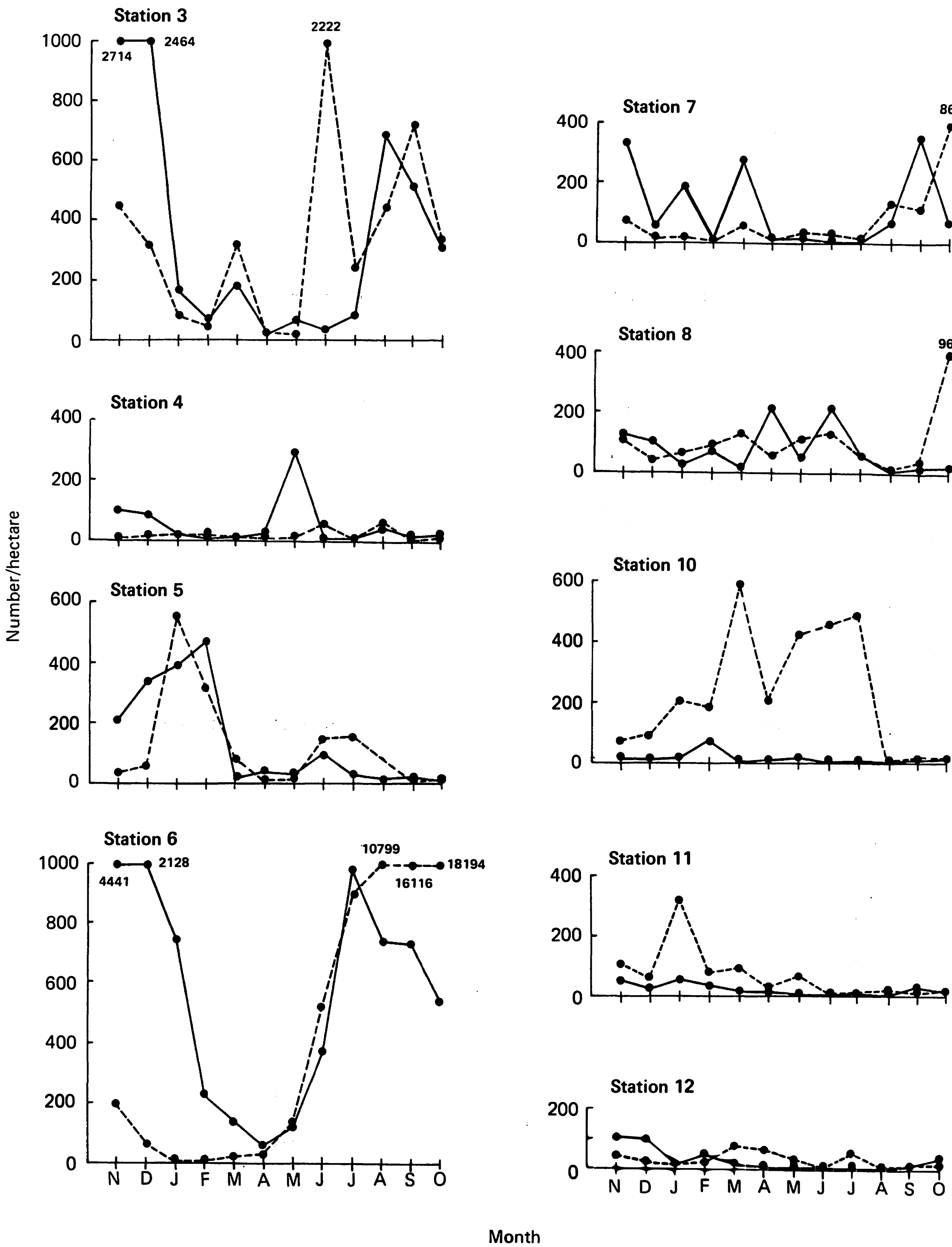

Figure 3.--Estimated densities of Dungeness crabs at nine sampling stations upstream of the Columbia River bar. The solid line represents the first year of the study (Nov. 1983 through Oct. 1984) and the dashed line represents the second year (Nov. 1984 through Oct. 1985).

2. In contrast to Size Class I crabs which were numerous on the bar, Size Class II and III crabs were particularly numerous in channel areas of Baker Bay (Ilwaco and Chinook Channels).

3. Size Classes I and II were generally distributed farther upstream on the north side of the estuary than on the south side.

4. The farthest upstream distribution of crabs occurred during winter both years when Size Class I crabs were captured at Grays Point (RM 20).

5. The upstream distribution of Size Classes III and IV tended to be less during spring (1984 and 1985) than during other seasons.

Crab densities by size class and month were examined for the bar and the estuary upstream from the bar (Table 1). On the bar, Size Class I crabs were much more abundant during June-August 1985 than during the same period in 1984; these crabs were virtually all 0+ age crabs. As densities of Size Class I crabs increased on the bar during late spring and summer, there was no corresponding increase in densities upstream from the bar. In the estuary upstream from the bar, densities of Size Class I crabs were generally highest during late fall and winter.

Densities of Size Classes II, III, and IV were typically low on the bar (Table 1). In the area upstream from the bar, densities of Size Classes II and III were usually higher than densities on the bar. Densities for these two size classes (upstream from the bar) were high in fall 1983 and summer and early fall 1985; these high densities were largely due to high catches in Baker Bay (Ilwaco and Chinook Channels). In the estuary upstream from the bar, densities of Size Class IV crabs were lower than those of Size Class II and III crabs.

Table 1.--Mean densities (number/hectare) of four size classes of Dungeness crabs on the Columbia River bar and the estuary upstream of the bar; SDs are shown in parentheses. See text for size range for each class.

	Size Class I		Size Class II		Size Class III		Size Class IV	
Month	Bar	Upstream	Bar	Upstream	Bar	Upstream	Bar	Upstream
Nov 83	1.4 ± 2.3	15.9 ± 17.1	0.0 ± 0.0	718.2 ± 1350.7	0.0 ± 0.0	154.1 ± 299.9	0.6 ± 1.4	11.1 ± 13.6
Dec 83	2.0 ± 3.4	46.2 ± 98.3	0.0 ± 0.0	437.1 ± 864.9	6.1 ± 10.3	103.5 ± 248.2	1.2 ± 1.9	3.3 ± 6.3
Jan 84	1.4 ± 3.4	46.8 ± 119.6	0.7 ± 1.7	97.2 ± 186.3	0.7 ± 1.6	35.2 ± 55.4	1.4 ± 2.1	0.0 ± 0.0
Feb 84	0.7 ± 1.8	57.4 ± 144.2	0.0 ± 0.0	33.0 ± 45.4	0.7 ± 1.8	18.7 ± 28.0	0.0 ± 0.0	2.4 ± 5.5
Mar 84	3.8 ± 9.3	2.9 ± 4.4	0.0 ± 0.0	48.7 ± 69.6	0.0 ± 0.0	22.5 ± 41.1	1.1 ± 2.6	1.4 ± 4.2
Apr 84	11.0 ± 18.4	5.0 ± 10.4	0.8 ± 2.0	23.5 ± 34.1	5.9 ± 3.9	14.3 ± 35.5	2.8 ± 2.2	1.6 ± 2.4
May 84	13.3 ± 19.6	35.9 ± 87.4	2.8 ± 4.9	22.0 ± 33.0	18.3 ± 27.1	7.8 ± 8.2	10.0 ± 15.0	0.6 ± 1.9
Jun 84	96.2 ± 100.1	2.4 ± 3.9	0.0 ± 0.0	46.6 ± 86.2	3.9 ± 4.5	28.6 ± 45.6	9.7 ± 12.0	4.4 ± 9.1
Jul 84	33.6 ± 51.0	4.3 ± 9.4	0.0 ± 0.0	97.2 ± 253.8	2.7 ± 3.2	27.6 ± 61.0	1.6 ± 2.7	2.1 ± 4.9
Aug 84	6.0 ± 14.7	1.6 ± 3.4	0.0 ± 0.0	93.3 ± 203.0	6.7 ± 11.0	62.7 ± 131.0	15.0 ± 17.1	15.5 ± 30.5
Sep 84	47.9 ± 79.6	4.6 ± 9.6	0.0 ± 0.0	66.3 ± 120.3	8.3 ± 16.6	70.5 ± 107.6	9.7 ± 13.3	47.3 ± 70.5
Oct 84	9.0 ± 10.7	2.8 ± 3.6	0.0 ± 0.0	46.9 ± 99.5	1.9 ± 3.0	48.1 ± 76.1	1.1 ± 2.6	15.4 ± 13.8
Nov 84	16.4 ± 17.6	36.9 ± 34.4	0.0 ± 0.0	43.9 ± 80.5	2.8 ± 4.3	32.9 ± 40.0	9.8 ± 9.5	6.4 ± 6.8
Dec 84	29.9 ± 24.5	43.9 ± 50.2	0.9 ± 2.1	23.5 ± 47.7	2.6 ± 4.8	7.8 ± 6.2	2.0 ± 3.4	1.5 ± 2.3
Jan 85	16.1 ± 23.6	123.6 ± 183.0	0.0 ± 0.0	12.4 ± 20.7	2.6 ± 3.5	4.3 ± 7.4	0.6 ± 1.4	1.8 ± 3.8
Feb 85	37.9 ± 65.4	77.3 ± 107.9	0.0 ± 0.0	5.1 ± 10.5	1.2 ± 2.4	2.7 ± 6.4	0.0 ± 0.0	1.1 ± 2.2
Mar 85	18.0 ± 25.3	106.4 ± 132.4	0.4 ± 1.0	44.4 ± 73.1	2.3 ± 2.7	4.0 ± 5.7	1.8 ± 2.1	0.7 ± 2.0
Apr 85	35.6 ± 49.6	31.2 ± 38.5	0.0 ± 0.0	14.3 ± 27.5	5.1 ± 8.1	2.4 ± 4.0	0.6 ± 1.5	0.5 ± 1.4
May 85	40.9 ± 41.8	38.7 ± 55.1	1.5 ± 2.3	52.3 ± 78.0	5.4 ± 8.6	3.5 ± 4.9	5.1 ± 5.2	1.5 ± 2.3
Jun 85	1876.1 ± 3347.8	62.5 ± 107.0	0.0 ± 0.0	306.0 ± 615.2	1.1 ± 2.6	15.6 ± 19.7	6.5 ± 4.5	15.2 ± 31.4
Jul 85	2250.7 ± 3410.7	31.9 ± 48.3	0.0 ± 0.0	160.9 ± 255.9	1.6 ± 2.6	12.3 ± 30.3	10.4 ± 11.3	9.4 ± 15.9
Aug 85	152.9 ± 153.1	10.8 ± 23.8	16.2 ± 35.1	902.3 ± 2346.1	1.5 ± 2.4	493.7 ± 1370.3	7.0 ± 7.7	28.9 ± 75.7
Sep 85	35.0 ± 29.6	1.4 ± 2.9	33.0 ± 31.3	844.2 ± 2267.8	6.2 ± 4.4	989.3 ± 2915.8	2.4 ± 3.8	58.9 ± 160.5
Oct 85	10.1 ± 12.5	0.0 ± 0.0	27.5 ± 30.8	599.5 ± 1490.7	13.2 ± 15.7	1548.2 ± 4200.6	6.9 ± 10.2	122.0 ± 296.5

Replicate Sampling

Chi-square analysis of catches from six consecutive trawls in Chinook Channel (Station 6) showed highly significant differences among the replicates ($P < 0.001$). Similar results were observed for five consecutive replicates at Station 5 (RM 6). Results from the chi-square analyses showed a contagious distribution of crabs at Stations 5 and 6 (Elliott 1977)[4/].

Ocean Catches

Dungeness crabs in the ocean were sampled during 16 months of the 2-year study. Rough ocean conditions, mechanical problems, or the lack of a commercial trawler precluded sampling during the other 8 months. Ocean densities in the first year were not significantly different from densities in the second year (Mann-Whitney, $P > 0.25$). Crab densities in the estuary were significantly greater than densities in the ocean during both years of the study (Mann-Whitney, $P < 0.001$). For some months, the size-class structure of crabs captured in the ocean was different from the structure in the estuary (Figs. 4, 5, and 6); however, for many of the months it is difficult to make valid comparisons because of low ocean catches. From December 1983 through April 1984 there was an absence of crabs < 50 mm in the ocean catches, although this size group was always present in the estuary. In June and July 1985, crabs ≤ 20 mm were abundant in the estuary, specifically on the bar, but were not abundant in ocean catches.

4/ In the first annual report, we stated that additional analyses of the replicate sampling would be presented in the final report; however, we now believe further analyses would not add to the report. This was discussed with the Contracting Agent.

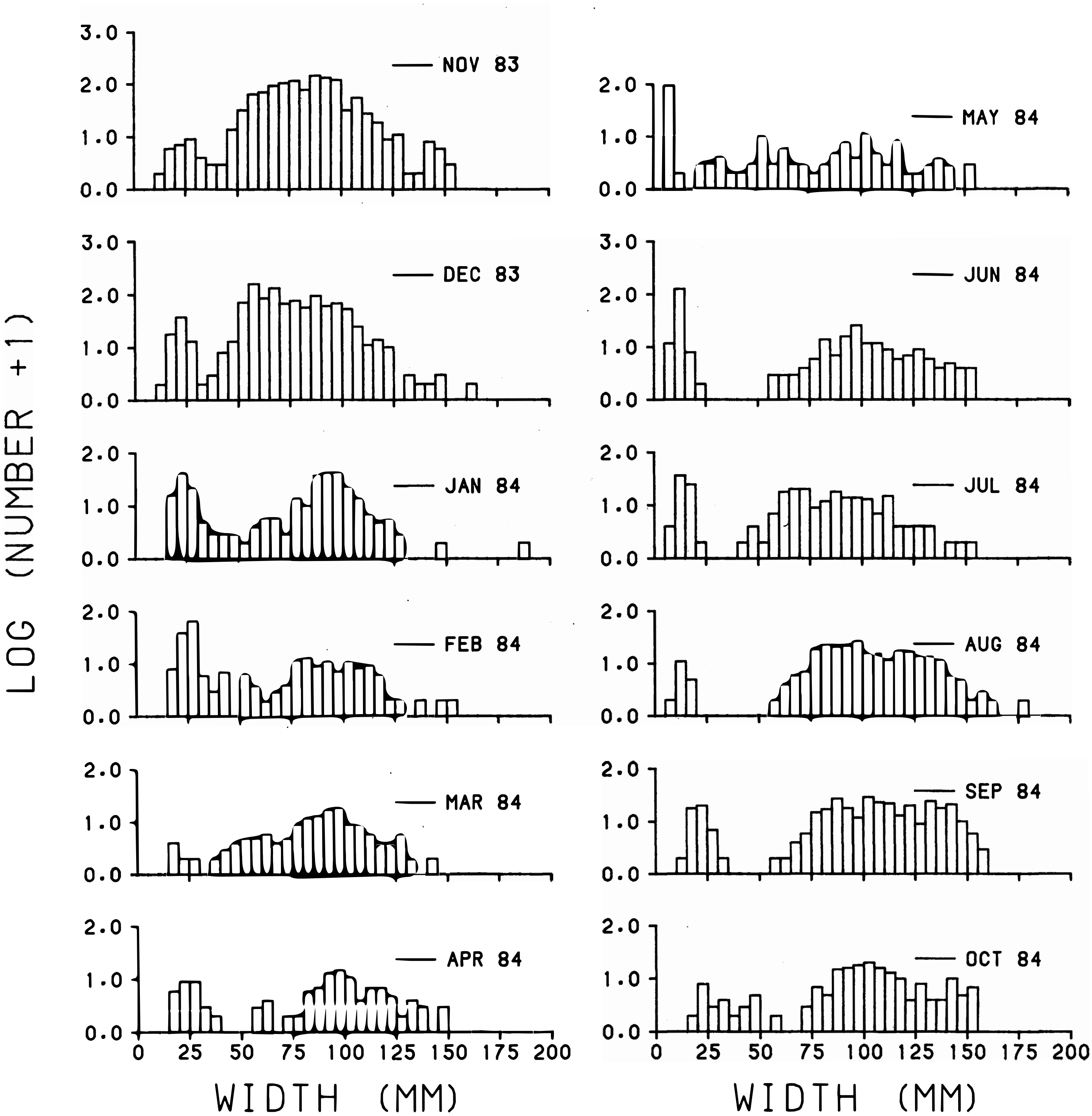

Figure 4.--Width frequency histograms for Dungeness crabs collected in the Columbia River estuary from November 1983 through October 1984.

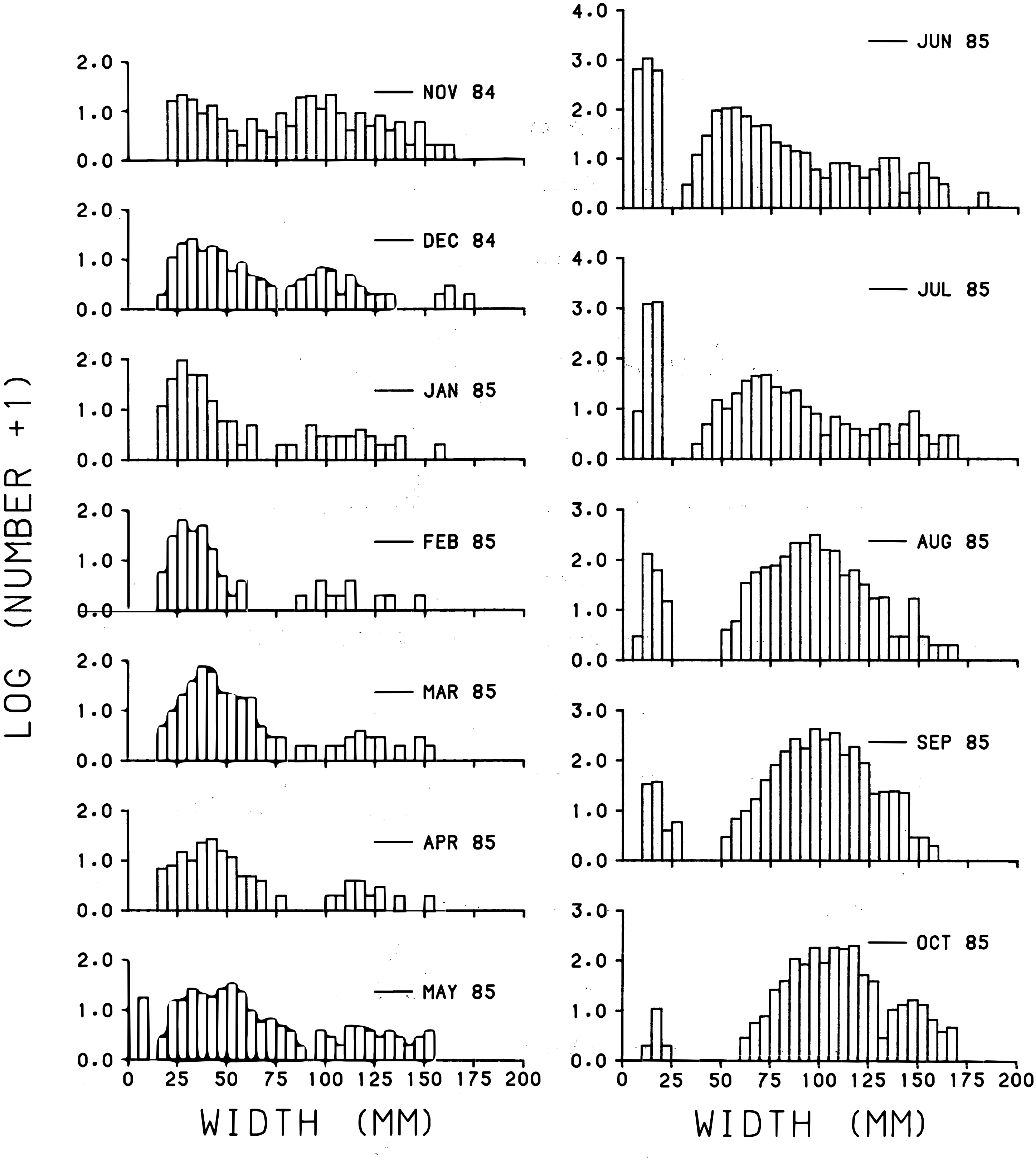

Figure 5.--Width frequency histograms for Dungeness crabs collected in the Columbia River estuary from November 1984 through October 1985.

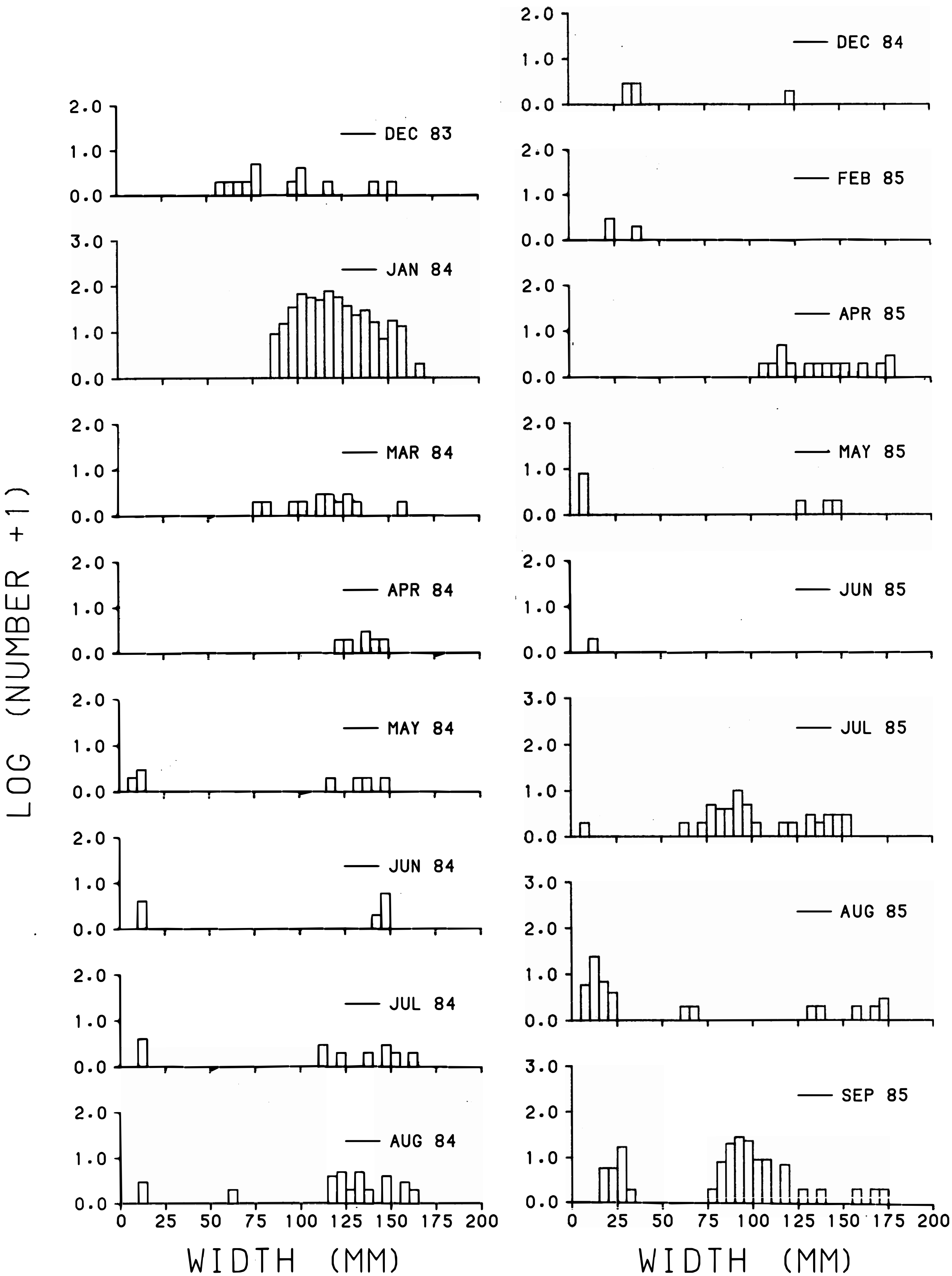

Figure 6.--Width frequency histograms for Dungeness crabs collected in nearshore areas of the Pacific Ocean from December 1983 through September 1985.

Movements

Dramatic monthly increases and decreases in crab densities at individual stations seem to indicate movements to and from the ocean and/or movements to and from other areas of the estuary (Figs. 2 and 3). Zero+ age crabs, which began to enter the estuary by early May, entered as early instars and/or as megalops larvae that metamorphosed to first instar juveniles. Many of the early instars remained on the bar during spring and summer and did not migrate upstream during this period (Table 1). Virtually all the Size Class I crabs captured on the bar during spring and summer were 0+ age crabs. During 1985, when 0+ age crabs were more abundant on the bar than in 1984, densities of early instars were greater on the north end of the bar. Densities of 0+ age crabs on the bar generally decreased by early fall, probably due to mortality and movement from the bar to the ocean. Some movement of 0+ age crabs from the ocean and/or bar to upstream estuarine areas apparently occurred during late fall and/or winter (Table 1), assuming that many crabs in Size Class I were 0+ age crabs (Figs. 4 and 5).

Salinity and Temperature

Bottom salinities and temperatures varied spatially and temporally during the study (Table 2)[5/]. Results from simple and multiple regression indicated that bottom salinity and temperature, both individually and together, were poor predictors of crab densities for all size classes combined and for individual size classes. In no case was more than 24% of the variation explained by salinity and/or temperature.

5/ Physical data for each station by month are in Appendix D, not included in this report, but available upon request.

Table 2.--Mean depths, bottom salinities, and bottom temperatures measured at 20 sampling sites in the Columbia River estuary from November 1983 through October 1985. Standard deviations are shown for each observation.

Station	Depth (m)	Salinity (ppt)	Temperature (°C)
1	15.0 ± 2.8	32.9 ± 1.2	9.2 ± 1.9
2	12.9 ± 2.4	31.9 ± 3.2	9.0 ± 1.8
3	6.3 ± 0.6	20.2 ± 10.1	10.3 ± 2.8
4	23.6 ± 2.2	30.2 ± 3.7	9.3 ± 1.2
5	18.7 ± 1.7	28.6 ± 6.1	9.3 ± 1.4
6	5.0 ± 0.5	25.4 ± 5.9	10.0 ± 2.2
7	7.0 ± 0.5	23.4 ± 7.0	9.9 ± 2.4
8	16.6 ± 0.7	26.5 ± 6.3	10.1 ± 2.4
9	4.4 ± 0.7	7.1 ± 4.7	11.0 ± 5.0
10	13.0 ± 1.5	20.2 ± 10.0	10.4 ± 3.2
11	12.2 ± 0.8	14.9 ± 8.3	10.6 ± 3.8
12	16.5 ± 1.6	18.6 ± 8.6	10.6 ± 3.1
13	13.2 ± 0.6	15.9 ± 10.2	10.9 ± 3.6
15	15.0 ± 1.8	3.5 ± 5.4	9.9 ± 5.5
18	12.9 ± 1.2	1.8 ± 4.7	12.2 ± 5.9
23	10.4 ± 1.8	31.6 ± 4.1	9.0 ± 1.7
24	16.9 ± 1.4	32.6 ± 1.7	9.0 ± 1.5
25	13.6 ± 2.7	32.8 ± 1.3	9.1 ± 1.5
26	14.4 ± 3.0	32.6 ± 1.5	9.2 ± 1.6
27	6.2 ± 1.4	2.3 ± 4.4	11.0 ± 5.9

The accuracy of the field salinometer was determined to be acceptable based on a comparison with a Beckman RS-7-B induction salinometer. The regression equation for the comparison is: Y (field value) = 1.46 + 0.991X (lab value), $r^2 = 0.94$. Using the above equation, field values of 4 and 34 ppt correspond to lab values of 2.6 and 32.8 ppt, respectively.

Oil Spill

On 19 March 1984, the tanker MOBILOIL ran aground near St. Helens, Oregon, resulting in the largest oil spill in Columbia River history. The oil spread throughout the Columbia River and its estuary, reaching virtually all habitats of the estuary. Our March estuary sampling was completed prior to the spill; however, we conducted additional bottom trawling at four estuarine sites in late March to check for oil, which was found on the bottom. About 1 week later, sampling indicated that much of the oil at the four sites was gone. During the April, May, and June samplings, small amounts of oil were detected downstream from the Astoria-Megler Bridge on the Oregon side of the estuary (Station 10). The acute and chronic effects of petroleum hydrocarbons on Dungeness crabs in the Columbia River estuary are unknown.

Incidence of *Carcinonemertes errans*

The incidence of the egg predator *C. errans* on crabs collected in the estuary (6%) was much less than the incidence on crabs in the ocean (79%) (Tables 3 and 4). Incidence by size class was lowest for Size Class I, both in the estuary and ocean. Five percent of the males and 8% of the females in the estuary were infested, whereas 80% of the males and 76% of the females in the ocean were infested. Only three egg-bearing females were collected during the entire study; they were collected on the bar and in the ocean during December 1984.

Table 3.--Incidence of the egg predator *Carcinonemertes errans* on Dungeness crabs collected in the Columbia River estuary from November 1983 through October 1985.

A. By month:

Month	Number examined	Number infested	Percent infested
Nov 1983	362	25	7
Dec 1983	345	8	2
Jan 1984	273	3	1
Feb 1984	160	1	1
Mar 1984	130	1	1
Apr 1984	105	9	9
May 1984	84	8	10
Jun 1984	141	15	11
Jul 1984	146	6	4
Aug 1984	250	18	7
Sep 1984	307	9	3
Oct 1984	169	11	7
Nov 1984	218	5	2
Dec 1984	158	4	3
Jan 1985	264	1	0
Feb 1985	59	0	0
Mar 1985	311	3	1
Apr 1985	135	6	4
May 1985	238	6	3
Jun 1985	287	5	2
Jul 1985	301	8	3
Aug 1985	262	12	5
Sep 1985	328	36	11
Oct 1985	424	122	29
Total	5,457	322	

B. By size class:

	Number examined	Number infested	Percent infested
Size Class I	1,273	4	0
Size Class II	2,561	102	4
Size Class III	1,225	101	8
Size Class IV	398	115	29
Total	5,457	322	

C. By sex:

	Number examined	Number infested	Percent infested
Male	3,270	155	5
Female	2,187	167	8
Total	5,457	322	Mean, 6

Table 4.--Incidence of the egg predator Carcinonemertes errans on Dungeness crabs collected in nearshore areas of the Pacific Ocean from December 1983 through September 1985.

A. By month:

Month	Number examined	Number infested	Percent infested
Dec 1983	15	14	93
Jan 1984	139	113	81
Mar 1984	13	11	85
Apr 1984	6	5	83
May 1984	4	3	75
Jun 1984	7	6	86
Jul 1984	10	6	60
Aug 1984	20	17	85
Dec 1984	5	2	40
Feb 1985	3	0	0
Apr 1985	16	15	94
May 1985	3	2	67
Jul 1985	37	29	78
Aug 1985	11	7	64
Sep 1985	130	99	76
Total	419	329	

B. By size class:

	Number examined	Number infested	Percent infested
Size Class I	46	1	2
Size Class II	115	107	93
Size Class III	151	124	82
Size Class IV	107	97	91
Total	419	329	

C. By sex:

	Number examined	Number infested	Percent infested
Male	276	220	80
Female	143	109	76
Total	419	329	Mean, 79

Width-weight Relationship

Regression equations for the carapace width-weight relationship were identical for males (N=3,682) and females (N=2,436): $\text{Log}_{10}\text{Weight (g)} = -3.54 + 2.86\ (\text{Log}_{10}\text{Width, mm})$; $r^2 = 99.6\%$.

DISCUSSION

Distribution and Abundance

During late spring and summer there was a distinct pattern in the densities of 0+ age crabs in the estuary. Densities of early instar crabs were high on the bar, yet subtidal areas upstream from the bar and intertidal areas of Baker Bay generally had much lower densities. In Grays Harbor estuary, about 50 miles north of the Columbia River estuary, Stevens and Armstrong (1984) estimated that intertidal areas with extensive eelgrass beds (*Zostera marina* and *Z. noltii*) had densities of 1-5 early instars/m^2. They found early instars buried just below the surface and in *Callianassa* spp. burrows. In a later study, Armstrong and Gunderson (1985) reported that densities of early instars in eelgrass in Grays Harbor were 7/m^2 in May and 2/m^2 in July. Densities of early instars in shell debris were even greater than those in eelgrass; they reported densities as high as 115/m^2 in May. Apparently the intertidal areas of Baker Bay, which are composed of mud and fine sand, without extensive eelgrass beds, do not provide suitable habitat for early instar Dungeness crabs. Although we examined only two intertidal sites in Baker Bay, we feel that if 0+ age crabs were intensively using the intertidal areas, catches of early instar crabs in subtidal areas of the bay should have been much higher. During a 1-year benthic study (1980-81) in northwestern Baker Bay, Furota (pers. commun., Toho University., Chiba, Japan) collected only one Dungeness crab. Furota sampled monthly along an intertidal and subtidal transect.

Similar to the Columbia River estuary, Stevens and Armstrong (1984) observed that crab densities fluctuated widely at individual stations in Grays Harbor estuary; however, periods of relative abundance differed between the two estuaries. Stevens and Armstrong observed greatest densities during May to August, with lowest densities in October and November. Only one station in October-November had >200 crabs/ha. In the Columbia River estuary, densities were also high at some stations during late spring and summer (Figs. 2 and 3), particularly the bar stations in 1985; however, unlike Grays Harbor estuary, densities of crabs in the October-November period were relatively high at some stations. For example, the highest crab density in our study (18,194 crabs/ha) was observed in Baker Bay (Station 6) in October 1985. The primary value of the comparisons is to indicate seasonal differences in relative abundances within each estuary, since annual crab populations can fluctuate widely (Gotshall 1978; Tasto 1983); it is important to note that the Grays Harbor study and our study were done in different years.

Densities of Size Class II (50-99 mm) and III (100-129 mm) crabs were particularly high at Stations 3 and 6 (Ilwaco and Chinook Channels) in Baker Bay during summer and fall. These shallow channels, of relatively low water velocity, probably provide excellent feeding areas for crabs. Dungeness crabs consume fish and benthic invertebrates, such as amphipods, clams, isopods, and shrimp (Gotshall 1977; Stevens et al. 1982). Durkin and Emmett (1980) found that benthic invertebrate densities in Baker Bay were highest in June, September, and December and lowest in March. During our study, the shrimp *Crangon franciscorum* was frequently observed in the trawl with Dungeness crabs. In Grays Harbor estuary, Washington, *Crangon* spp. were important in the diet of Dungeness crabs with a mean width of 79-81 mm (Stevens et al.

1982). Fishes are also abundant in the shallow channel areas in Baker Bay during summer and fall (Fox et al. 1984; Bottom et al. 1984).

Most of the increase in crab densities at Station 10 during the second year was probably due to the relocation of the station. Station 10 (second year) apparently provides good habitat for crabs, particularly for crabs <100 mm.

In November-December 1984, crab densities in Chinook Channel (Station 6) were extremely low in comparison to fall 1983 (Fig. 3). The lower densities in November 1984 partially resulted from hopper dredging operations that began prior to November sampling. In the absence of hopper dredging, densities at Station 6 might still have been lower than during fall 1983; however, the decline might not have been as great. Crab densities at the other Baker Bay site (Station 3), which was not dredged during fall 1984, were also lower in fall 1984 than during the preceding fall. Crabs in Chinook Channel could have been affected both directly and indirectly by dredging activities through entrainment, reduction of food supply, and loss of suitable habitat. Hoeman and Armstrong (1982, in Armstrong et al. 1982) observed that when Dungeness crab densities were high in Grays Harbor estuary, dredge entrainment rates were correspondingly high. They estimated that the mortality rate for entrained crabs exceeded 70%.

Other stations in the estuary were also in or near areas that were dredged during the 2-year study: Stations 1 (bar), 3 (Ilwaco Channel), 10 (RM 12-13, second year), and 24 (bar). Stations 2 and 25, which were located on the bar, may also have been influenced by hopper dredging. Most of the dredging on the bar was done during spring and summer 1984 and 1985. Catches at the above stations might have been greater in the absence of dredging.

Timing of our sampling in relation to dredging is also an important factor. Catches were probably lower in an area that was dredged immediately prior to sampling than in an area that was dredged days earlier.

Growth

Growth of Dungeness crabs in the Columbia River estuary was not estimated primarily because of the frequent overlaps in size ranges of the age classes, particularly the older ones (Figs. 4 and 5). Also, since crabs probably move to and from the estuary and ocean, it is impossible to separate estuarine and ocean growth. Early instar crabs (0+ age) were first captured in the estuary in May of both years and were easily separated as discrete size classes through September 1984 and October 1985 (Figs. 4 and 5). The mean size of the 0+ age group was less than 25 mm in September 1984 and October 1985. Because these early instar juveniles tended to be concentrated at the mouth of the estuary (bar), it is difficult to make any conclusions about growth in the estuary. Figures 4 and 5 indicate either slow growth or continual recruitment of early instar juveniles from the ocean during spring and summer. Since the egg-bearing period for Dungeness crabs in coastal areas of Washington and Oregon extends over several months during fall and winter (Cleaver 1949; Waldron 1958), it is reasonable to assume that similar-sized instars would enter the estuary during different months. In contrast, Carrasco et al. (1985) observed only one period of settlement for early instars during 1983 in coastal waters offshore from Grays Harbor estuary; growth in the offshore waters was apparently slow (carapace width by September was 10-20 mm).

Growth rates of Dungeness crabs have been estimated in other areas (MacKay 1942; Cleaver 1949; Butler 1961; Poole 1967; Tasto 1983; Collier 1983; Stevens and Armstrong 1984; Warner 1985). Butler (1961) estimated that male crabs collected in the Queen Charlotte Islands, British Columbia, were 24-31 mm in carapace width (widths include tenth anterolateral spine) after 1 year; 97-120 mm after 2 years; 147 mm after 3 years; and 176 mm after 4 years. For females, growth rates were similar for the first 2 years, but slowed thereafter. All ages were calculated from time of hatching. In Bodega Bay, California, average carapace widths were about 63-94 mm 1 year after metamorphosis to the first juvenile instar; 133-152 mm, 2 years after metamorphosis; and 135-170 mm, 3 years after metamorphosis (Poole 1967). Growth for females was similar up to about 133 mm. In Grays Harbor estuary, the following mean widths were observed: 45 mm, 1 year after metamorphosis,; 90 mm, 2 years after metamorphosis; and 135 mm, 3 years after metamorphosis (Armstrong et al. 1982).

Ocean Sampling

Unfortunately, because of the limits of the study, we were unable to sample more areas in the ocean. The six ocean-sampling sites, south of the mouth of the Columbia River estuary, may not be representative of other coastal areas adjacent to the mouth. It is puzzling why larger numbers of early instar juveniles were not captured during spring and summer. Future studies of crabs in offshore areas adjacent to the Columbia River estuary should include sampling transects both north and south of the mouth and directly off the mouth.

Carcinonemertes errans

Carcinonemertes errans is a host-specific nemertean that can destroy large numbers of Dungeness crab eggs (Wickham 1979, 1980). Although the ectosymbiont nemertean is present on males and females, it affects only the egg stage. Wickham (1979) estimated a 55% direct mortality to eggs of Dungeness crabs in central California. High egg mortalities were suggested as a possible cause of the drastic decline in Dungeness crab populations in the San Francisco area (Fisher and Wickham 1976; Wickham 1979). The incidences of C. errans on crabs in the ocean (79%) and the Columbia River estuary (6%) were lower than the incidence reported by Wickham (1980) in the Bodega Bay, California, area; he reported that all non-egg-bearing crabs >20 mm carapace width were infested with C. errans. However, we may have missed some lightly infested crabs by not examining the entire exoskeleton. The major revelation from our examinations for C. errans was the large difference in infestation rates between the ocean and the estuary. Lower salinities in the estuary probably were the major factor in the lower rate. The lower salinities in the estuary may have prevented infestation and/or killed C. errans. Wickham (pers. commun., 12 Nov. 1985) noted that "Pure fresh water will kill worms in 1-2 minutes depending on the worms' size." The lower incidence in the estuary may have little effect on the overall incidence in the ocean. Non-infested crabs migrating from the estuary could be infested in the ocean by larval worms (Wickham 1980) and/or through copulation (Wickham et al. 1984).

Sampling Efficiency and Population Estimates

Crab densities in this report do not represent absolute values. The sampling efficiency of the 8-m bottom trawl in the Columbia River estuary is unknown; in addition, sampling efficiencies for different size-classes of crabs may differ. Gotshall (1978) estimated that the sampling efficiency of his 4.9-m bottom trawl for Dungeness crabs was about 50% in Humboldt Bay, California. To estimate crab populations in Grays Harbor estuary, Washington, Stevens and Armstrong (1984) estimated that the sampling efficiency of their

4.9-m semiballoon otter trawl was 3.3% for early instar crabs (0+ age) in summer (May-August). By autumn-winter and spring, they estimated that sampling efficiency for 0+ age crabs had increased to 25%; for the older age-classes they used Gotshall's 50% efficiency factor.

To estimate populations in the Columbia River estuary, we used the Stevens and Armstrong (1984) efficiency factors. Because we did not separate crabs into age classes, we assumed a sampling efficiency of 3.3% for all Size Class I (<50 mm) crabs during summer and 25% efficiency during fall-winter and spring. We used a 50% efficiency factor for all other size-classes. For population estimates, we grouped months into the same seasons used by Stevens and Armstrong. They defined summer as June-August, fall-winter as September-February, and spring as March-May. For fall-winter 1983-84, we used data from 4 months because our sampling did not begin until November 1983. Each estimate represents a mean for a 3-6 month period, depending upon the season. Populations of Size Class I crabs were generally greater than any other size class (Table 5). The greatest populations of Size Class I crabs occurred during summer, particularly in 1985. Primarily because of a large population of 0+ age crabs on the bar (>51 million), the total crab population in summer 1985 was estimated to exceed 61 million. Stevens and Armstrong estimated that 1980-81 crab populations in Grays Harbor estuary were 39 million in summer, 3.3 million in fall-winter, and 7.8 million in spring. Our population estimates must be considered speculative because of the assumptions of gear efficiency and amount of habitat utilized. Also the contagious distribution of crabs and dredging in the estuary creates additional sources of error. The population estimates are useful in indicating that the estuary is valuable habitat for Dungeness crabs and for showing how widely the Columbia River estuary crab population fluctuates.

Table 5.--Population estimates of Dungeness crabs in the Columbia River estuary for 1983-85. Seasons are according to Stevens and Armstrong (1984); see Discussion.

Season	Population estimate ($X10^3$)
Fall-winter (1983-84)	
Size Class I	1,084
Size Class II	2,322
Size Class III	831
Size Class IV	69
Total	4,306
Spring (1984)	
Size Class I	432
Size Class II	433
Size Class III	323
Size Class IV	39
Total	1,227
Summer (1984)	
Size Class I	2,079
Size Class II	534
Size Class III	375
Size Class IV	106
Total	3,094
Fall-winter (1984-85)	
Size Class I	1,357
Size Class II	280
Size Class III	314
Size Class IV	233
Total	2,184
Spring (1985)	
Size Class I	1,661
Size Class II	458
Size Class III	63
Size Class IV	16
Total	2,198
Summer (1985)	
Size Class I	56,915
Size Class II	3,039
Size Class III	1,044
Size Class IV	193
Total	61,191

CONCLUSIONS

1. Crabs were generally distributed from the mouth of the estuary to RM 17; the farthest upstream distribution was to Grays Point (RM 20) during both winters.

2. No crabs were collected in Youngs and Cathlamet Bays or in intertidal areas of Baker Bay.

3. Overall, crab densities on the bar were significantly less than densities upstream from the bar. Densities on the bar were greatest in spring and summer; early instar crabs were relatively abundant on the bar during this time. Densities of crabs on the bar were significantly greater during the second year of the study than during the first year. During June and July 1985, when large numbers of 0+ age crabs were present, densities tended to be higher on the northern portion of the bar.

4. In areas upstream from the bar, densities were not significantly different between the 2 years. Generally there were no significant seasonal differences among upstream densities, except during the first year when densities were significantly greater during fall.

5. In the estuary there was considerable variation in crab densities among individual stations and also within individual stations at different times.

6. Replicate sampling at Stations 5 and 6 indicated that crabs followed a contagious distribution.

7. Large changes in monthly densities indicated movements of crabs within the estuary and/or between the ocean and estuary.

8. Densities of Dungeness crabs, particularly Size Classes II and III, were greatest in channel areas of Baker Bay (Ilwaco and Chinook Channels)

during fall, spring, and summer. Densities tended to be least during February-May, with a slight increase in March for Ilwaco Channel. Densities of Dungeness crabs in the Flavel area (Station 10, second year) were relatively high from March through July.

9. Bottom salinity and temperature were poor predictors of crab densities for all size classes combined and for individual size classes.

10. Incidence of the egg predator Carcinonemertes errans averaged 6% in the estuary and 79% in the ocean.

Because the Columbia River estuary is extensively populated by Dungeness crabs, it is important to minimize the effects of dredging. Dredging in Chinook Channel should be done during winter and early spring, i.e., late February through early May, when crab densities are low. In Ilwaco Channel, late January through early May, with the exception of March, is the best period for dredging. Further studies need to be done to assess dredging mortality of early instar crabs on the bar. Also a study is needed to estimate the proportion of the early instar population impacted by dredging. In the interim, if practical, the dredging schedule for the bar and adjoining ocean portion of the navigational channel should be adjusted to reduce dredging time in June and July; perhaps dredging could be started earlier.

ACKNOWLEDGMENTS

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APPENDIX A.--Geographic locations of the stations sampled during the Dungeness crab study (November 1983 through October 1985).

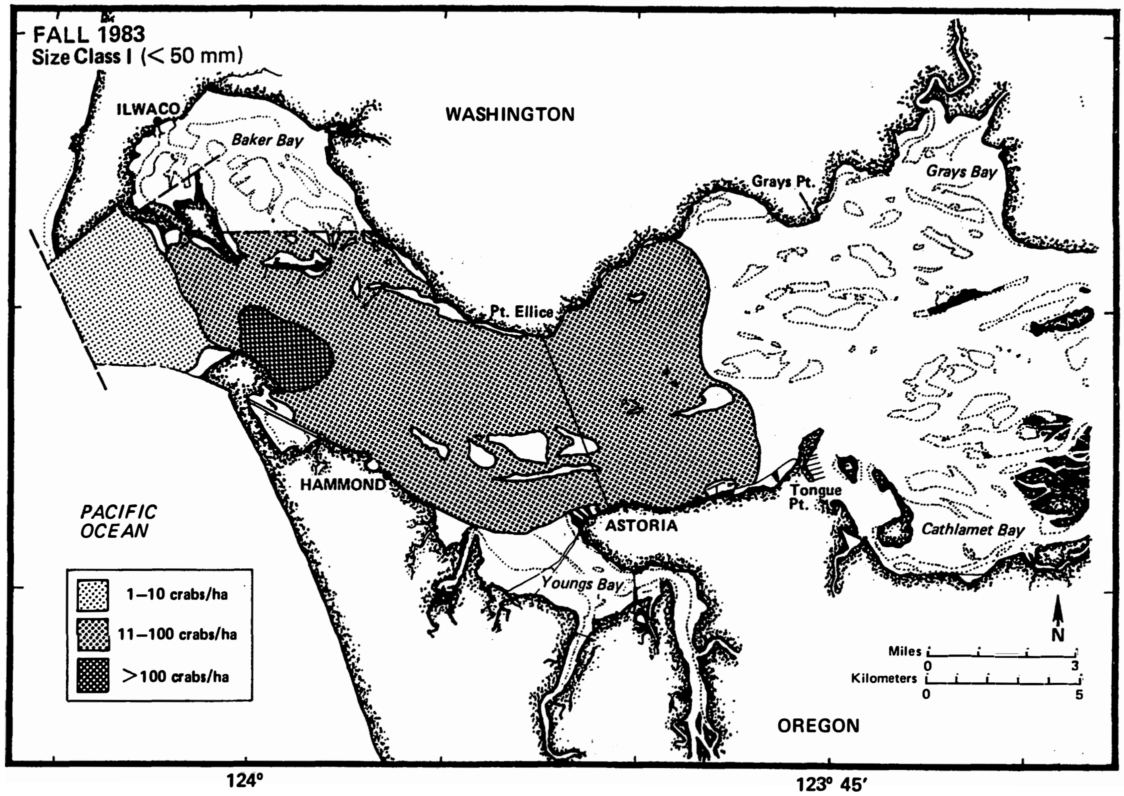
Appendix Table AI.--Geographic locations of sampling stations for Dungeness crabs. All stations were sampled with an 8-m trawl, except Stations 70 and 71, which were visually inspected. Locations are approximate; sometimes the locations varied because of weather conditions, current conditions, fishing activity, or dredging.

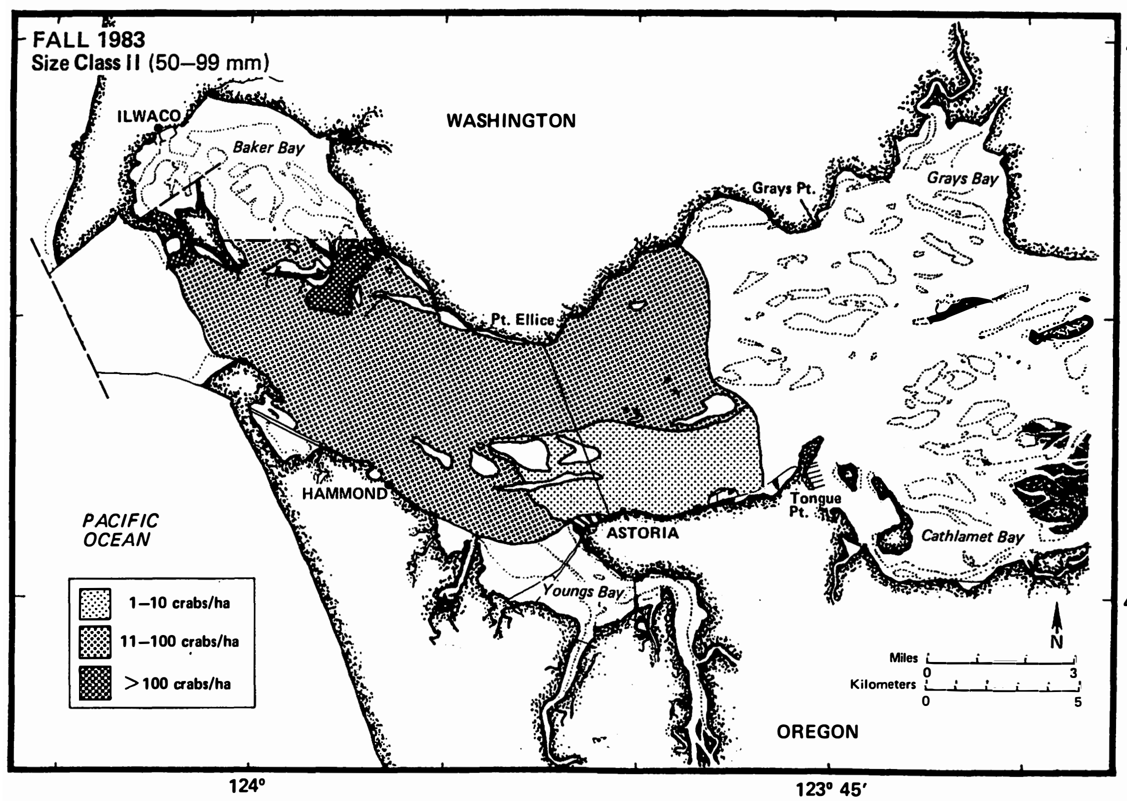
Station		Latitude	Longitude
1		46°15'35" N	124°04'20" W
2		46°15'06" N	124°04'03" W
3		46°16'35" N	124°01'54" W
4		46°15'26" N	124°00'14" W
5		46°14'19" N	123°58'57" W
6		46°15'36" N	123°57'57" W
7		46°13'24" N	123°56'45" W
8		46°11'47" N	123°55'39" W
9		46°10'06" N	123°51'12" W
10	(Nov '83 - Oct '84)	46°11'46" N	123°51'46" W
10	(Nov '84 - Oct '85)	46°11'33" N	123°52'51" W
11		46°14'14" N	123°53'06" W
12		46°14'21" N	123°51'43" W
13		46°12'00" N	123°49'01" W
15		46°16'12" N	123°46'04" W
18		46°12'30" N	123°42'38" W
23		46°14'50" N	124°03'54" W
24		46°15'19" N	124°04'10" W
25		46°15'46" N	124°04'21" W
26		46°15'56" N	124°04'25" W
27		46°12'11" N	123°45'22" W
70		46°18'50" N	124°01'10" W

Appendix Table A1.--Cont.

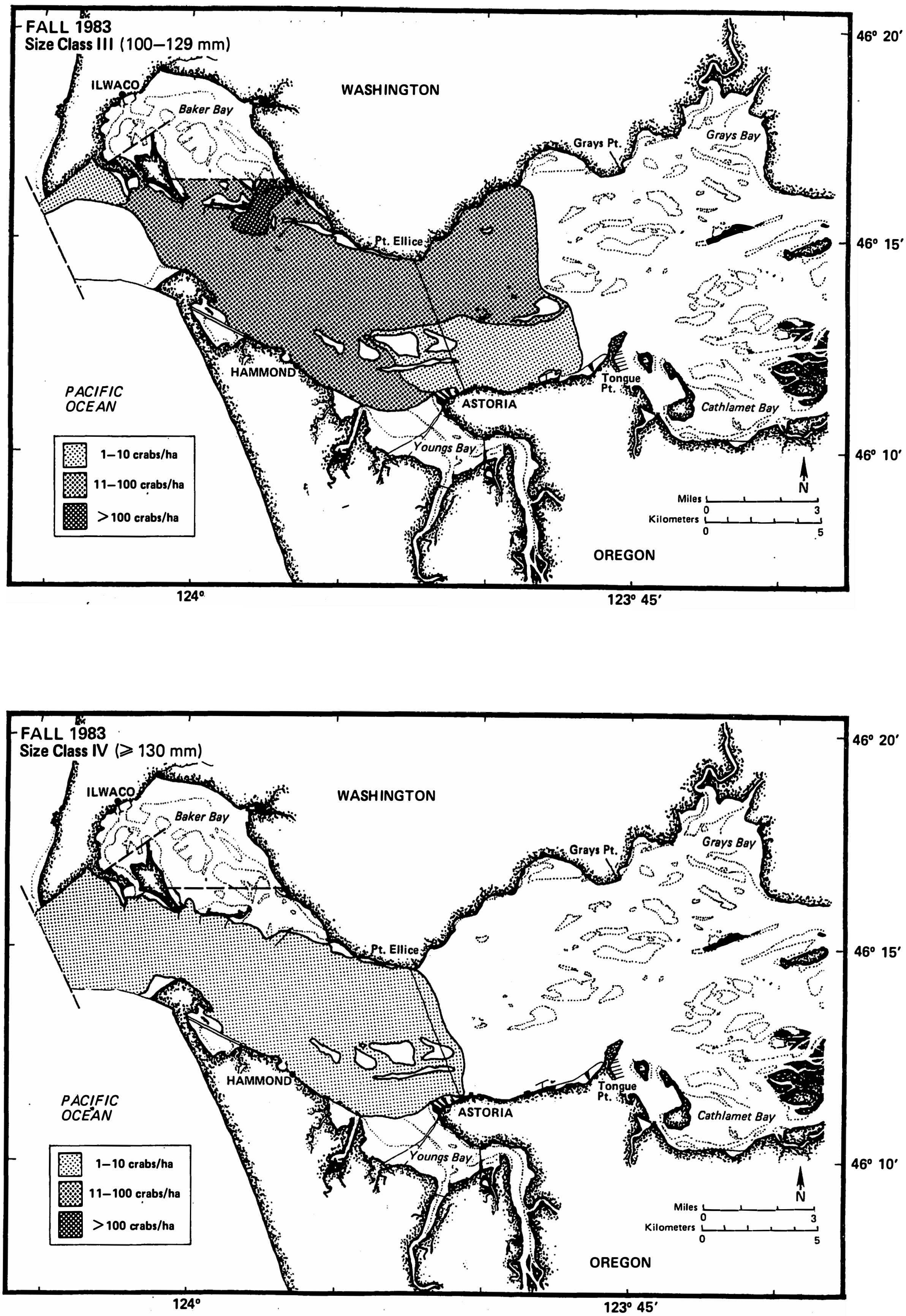
Station	Latitude	Longitude
71	46°15'35" N	123°55'51" W
90	46°10'32" N	123°59'30" W
91	46°10'03" N	124°02'10" W
92	46°09'30" N	124°05'42" W
93	46°09'05" N	124°08'31" W
94	46°08'45" N	124°10'40" W
95	46°08'10" N	124°14'56" W

APPENDIX B.--Distribution and abundance maps for Dungeness crabs collected in the Columbia River estuary from November 1983 to October 1985; information is separated by season and size class.

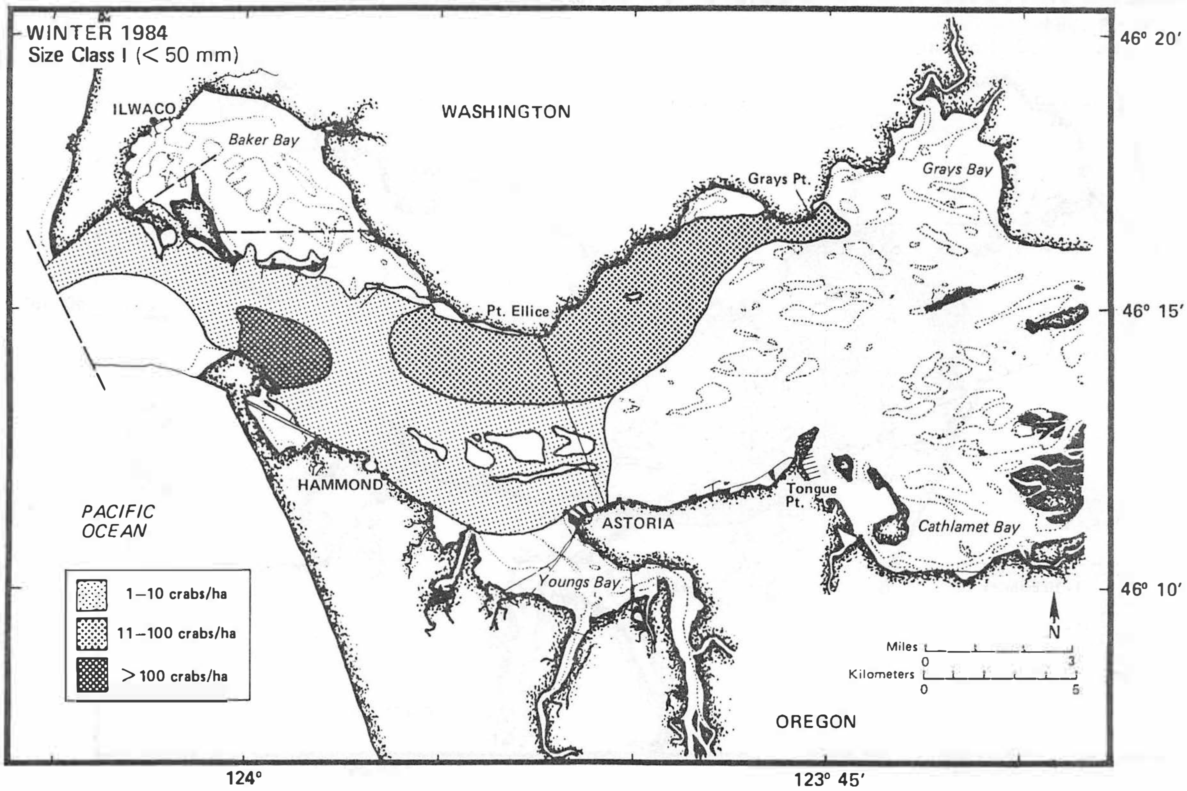


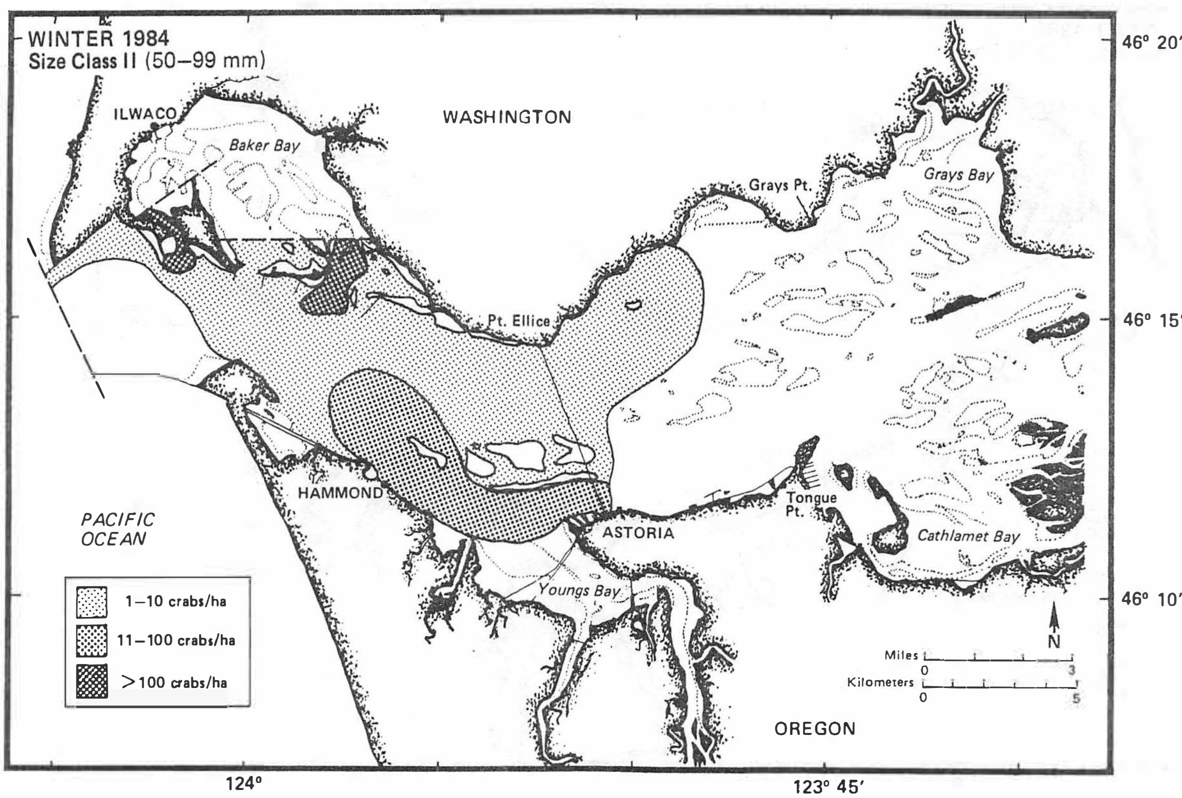


Appendix Figure B1.--Distribution and abundance of Size Class I and II Dungeness crabs in the Columbia River estuary during the fall 1983. Dashed lines represent data limits.

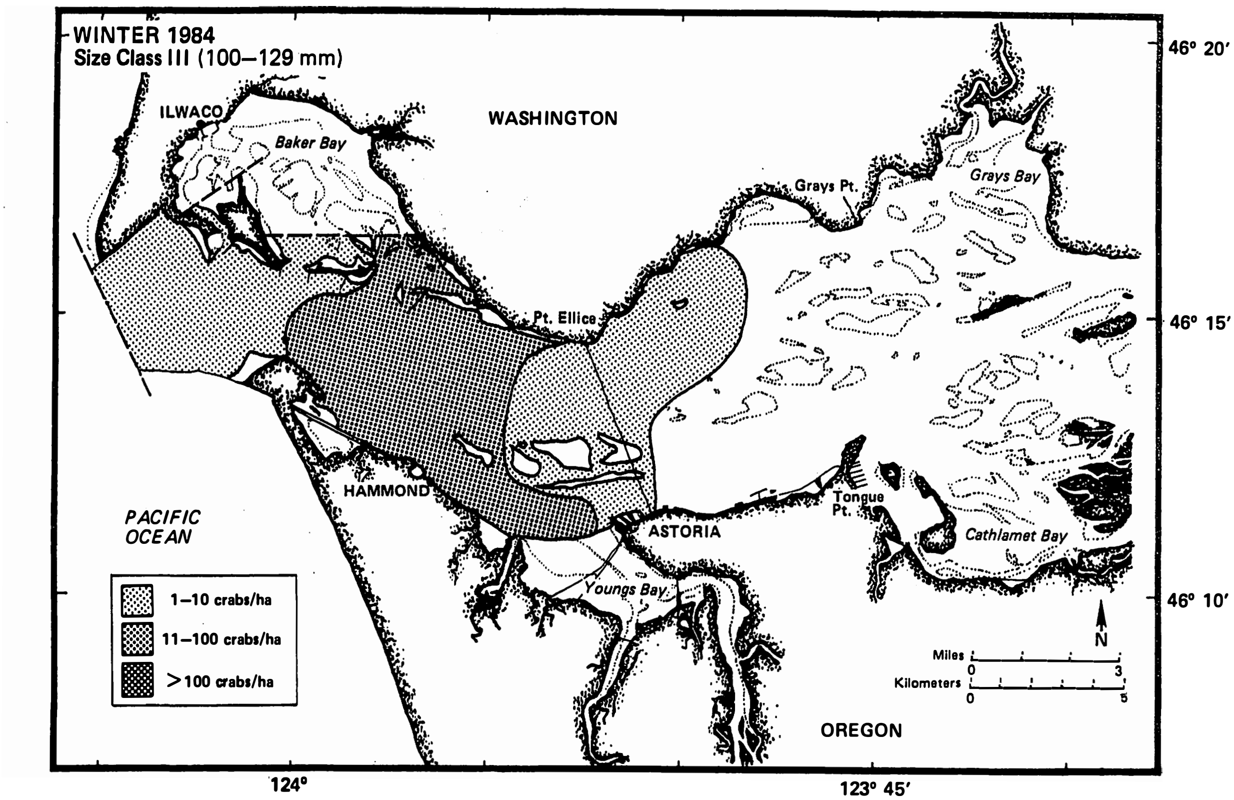


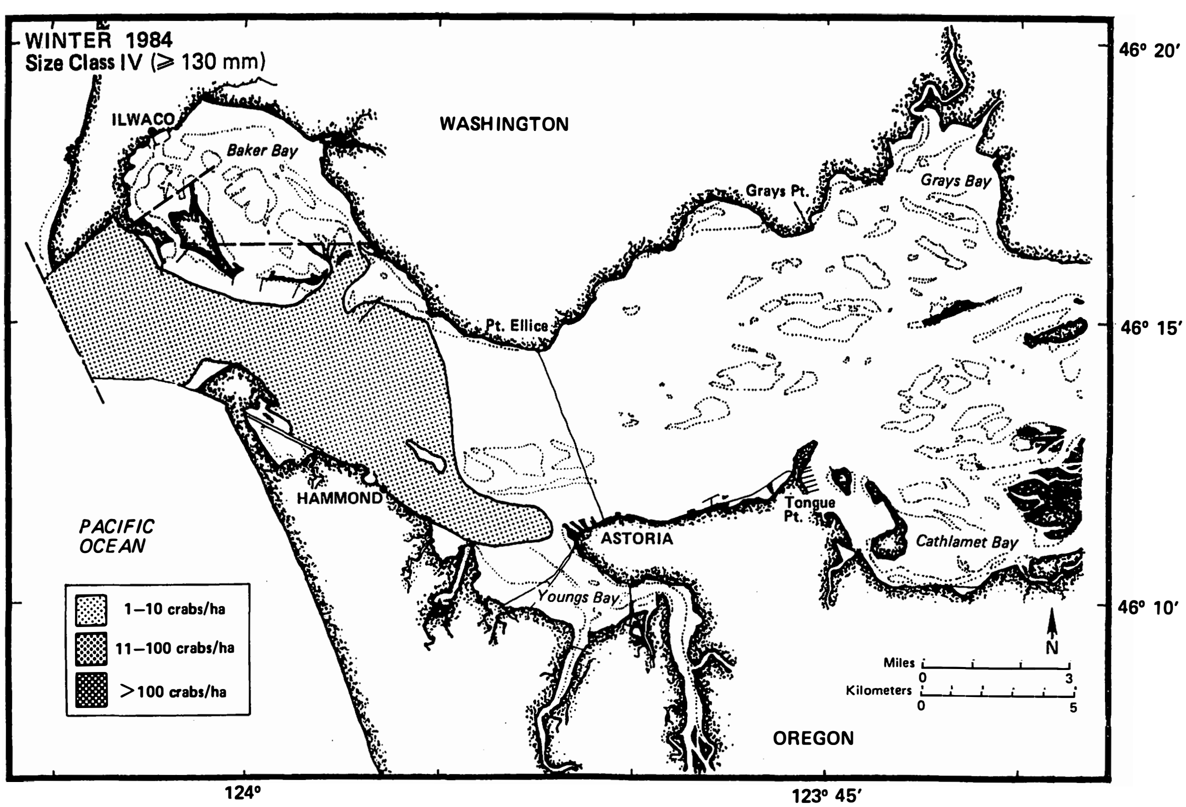
Appendix Figure B2.--Distribution and abundance of Size Class III and IV Dungeness crabs in the Columbia River estuary during the fall 1983. Dashed lines represent data limits.



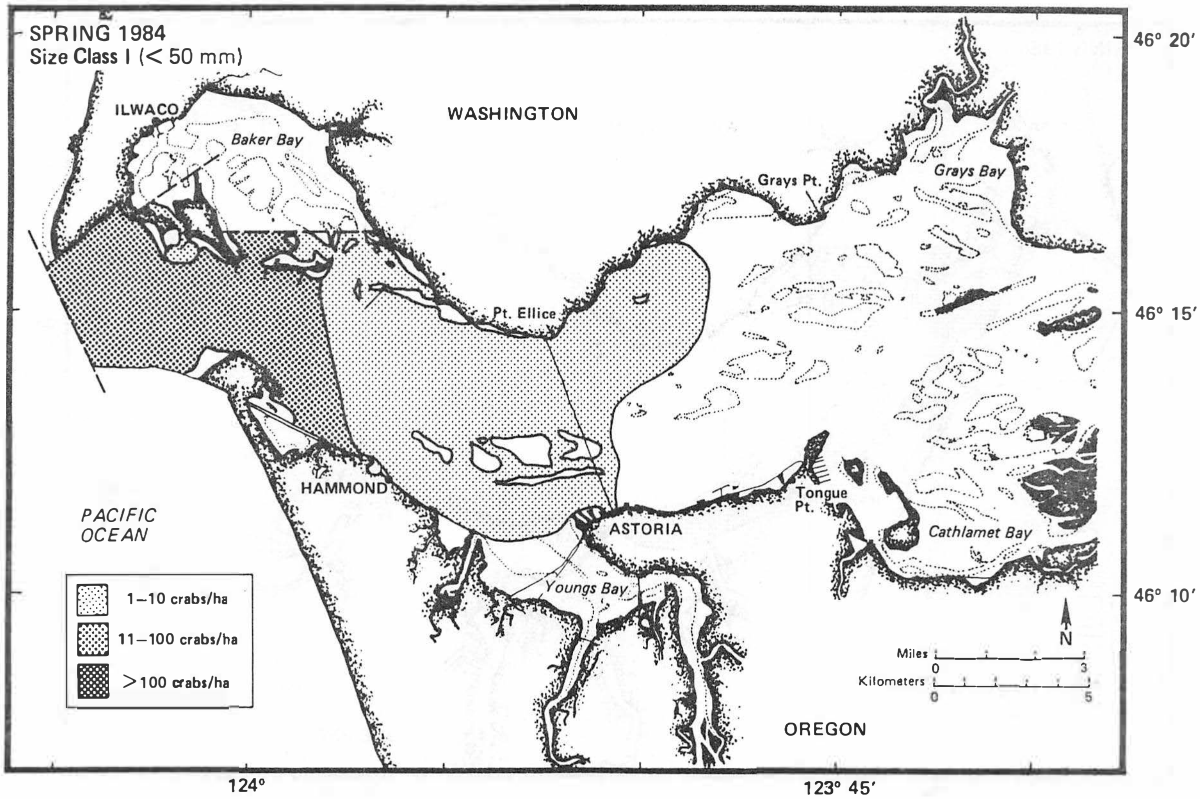


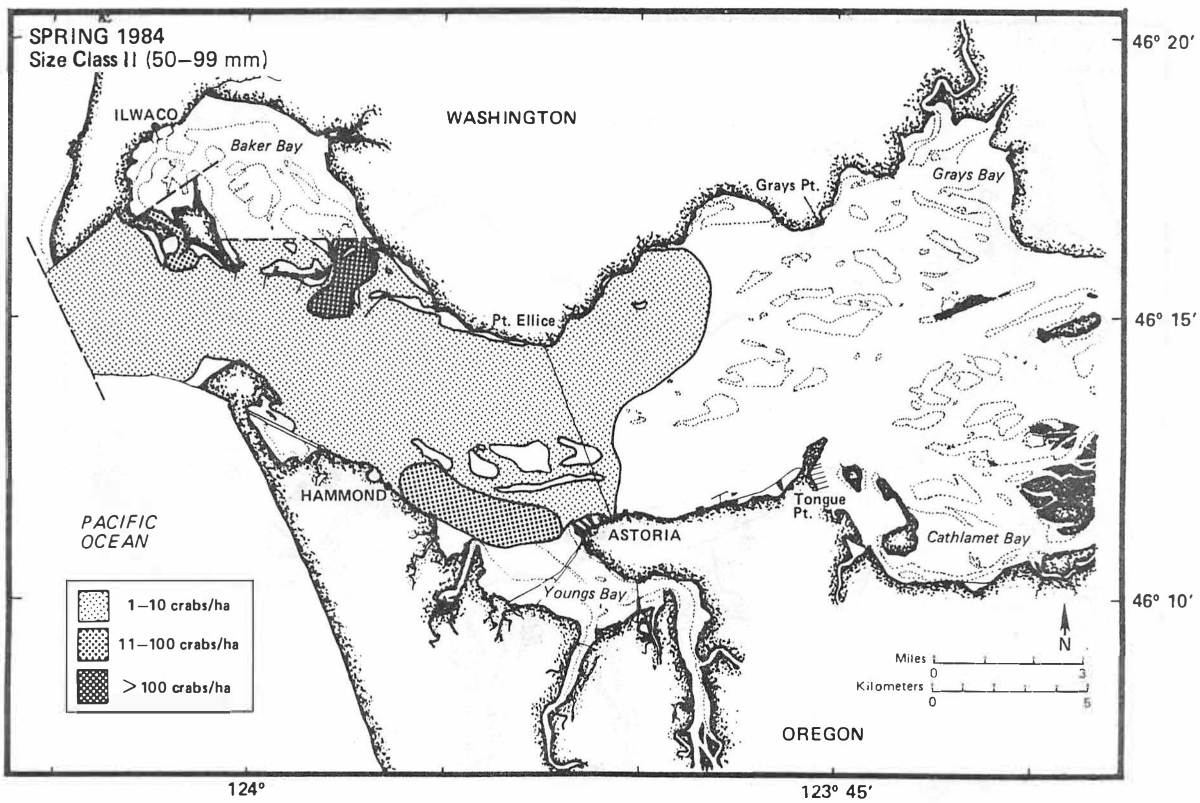
Appendix Figure B3.--Distribution and abundance of Size Class I and II Dungeness crabs in the Columbia River estuary during the winter 1984. Dashed lines represent data limits.



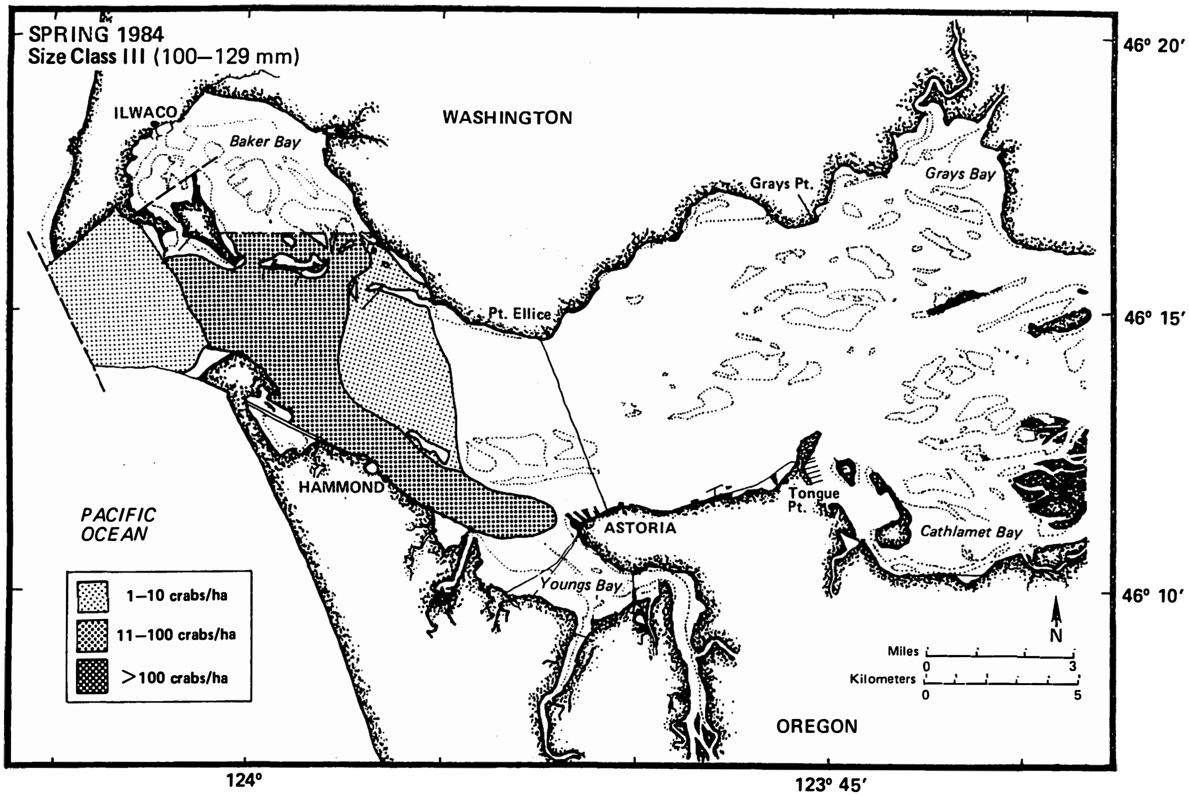


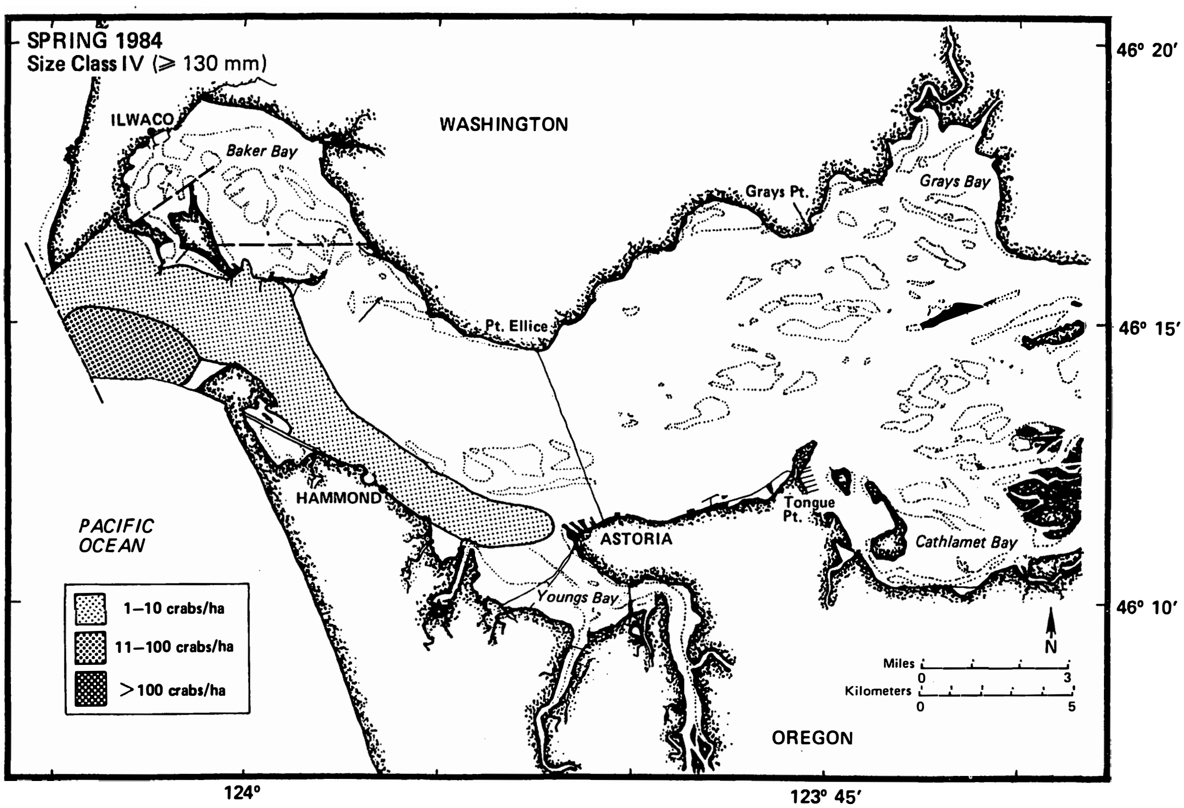
Appendix Figure B4.--Distribution and abundance of Size Class III and IV Dungeness crabs in the Columbia River estuary during the winter 1984. Dashed lines represent data limits.



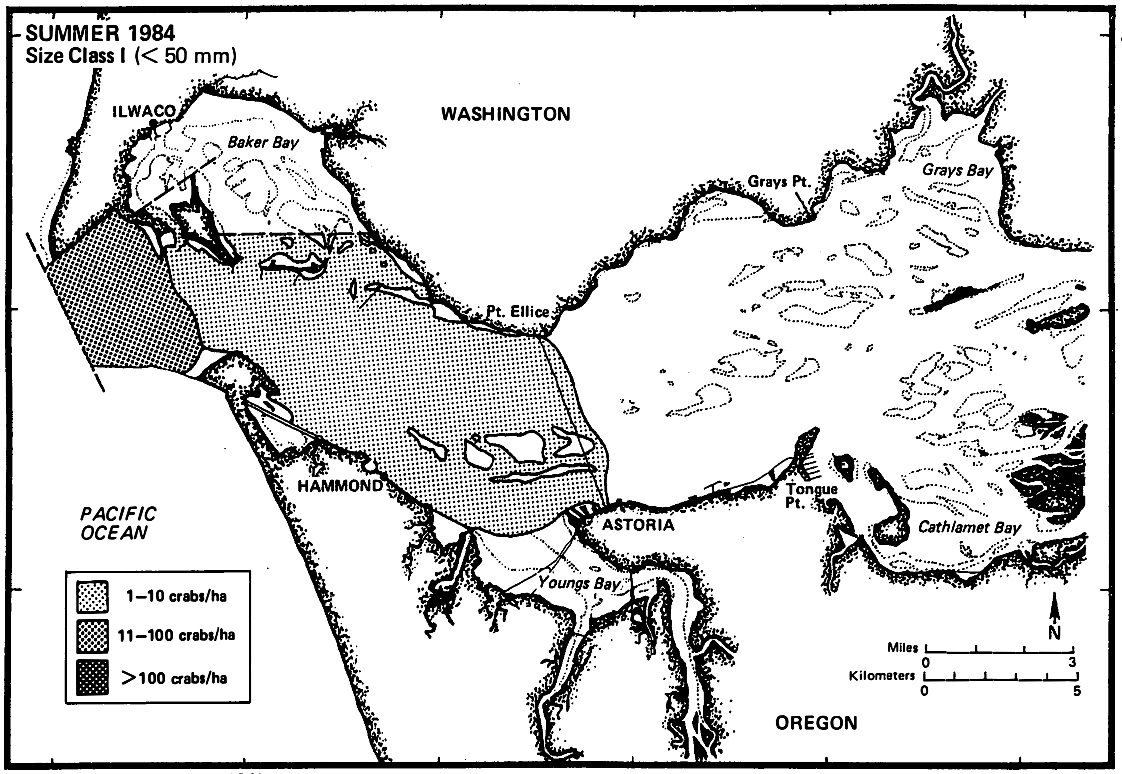


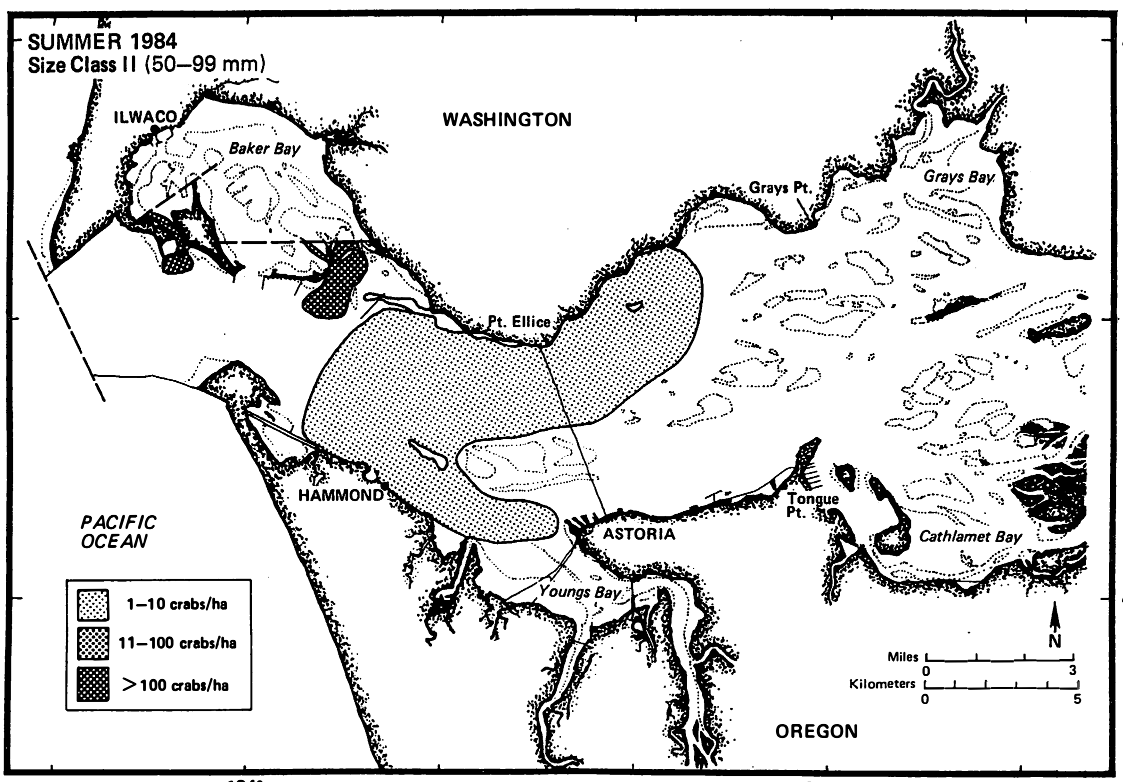
Appendix Figure B5.--Distribution and abundance of Size Class I and II Dungeness crabs in the Columbia River estuary during the spring 1984. Dashed lines represent data limits.



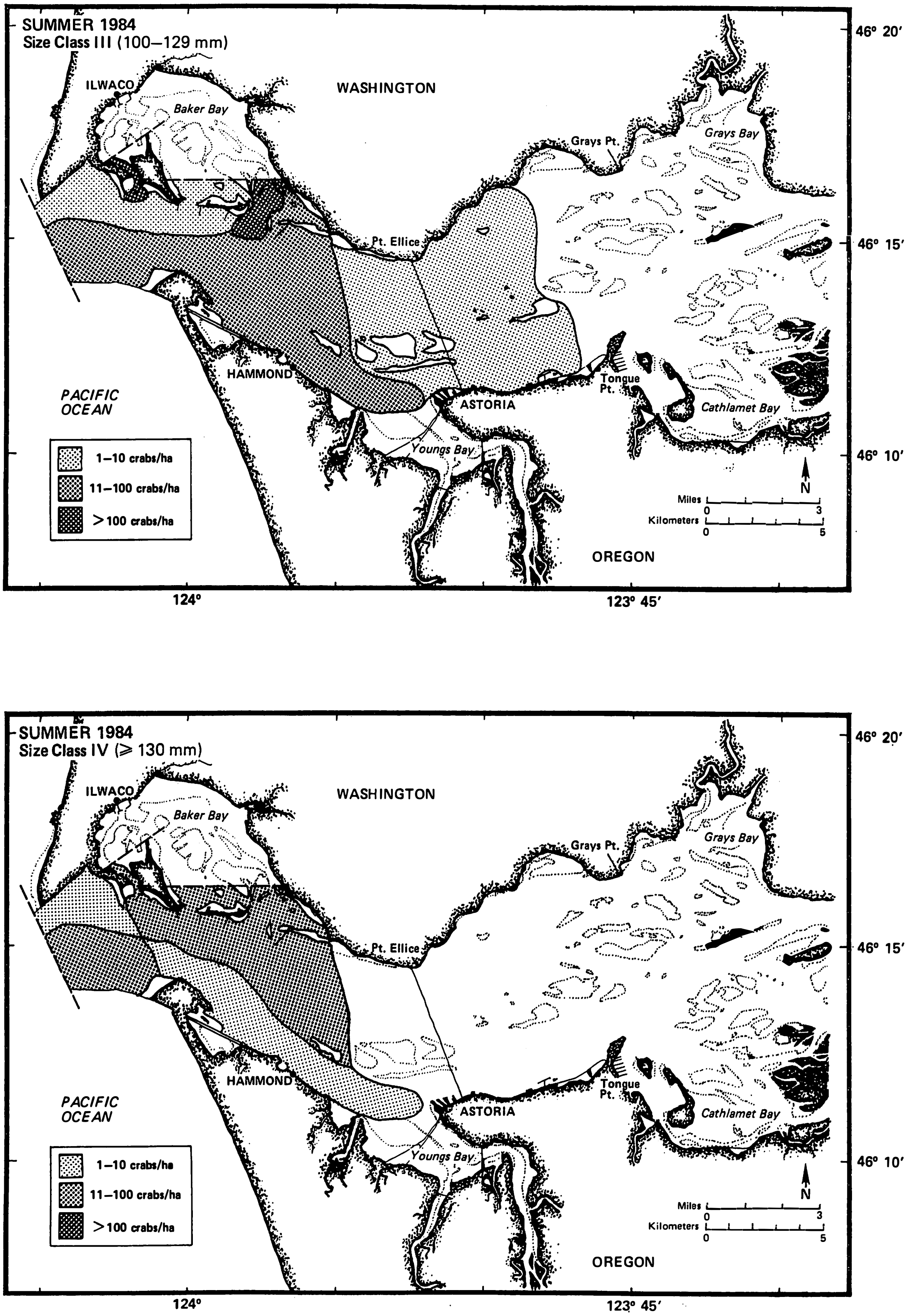


Appendix Figure B6.--Distribution and abundance of Size Class III and IV Dungeness crabs in the Columbia River estuary during the spring 1984. Dashed lines represent data limits.

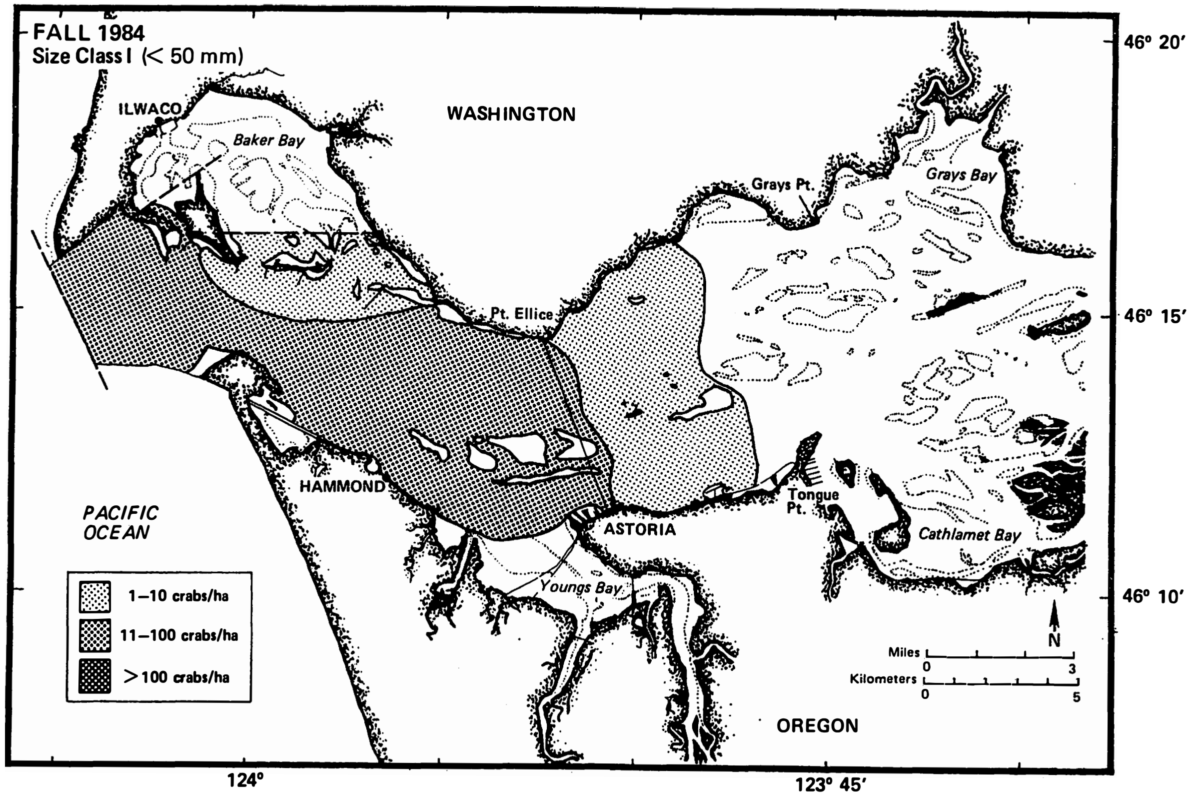


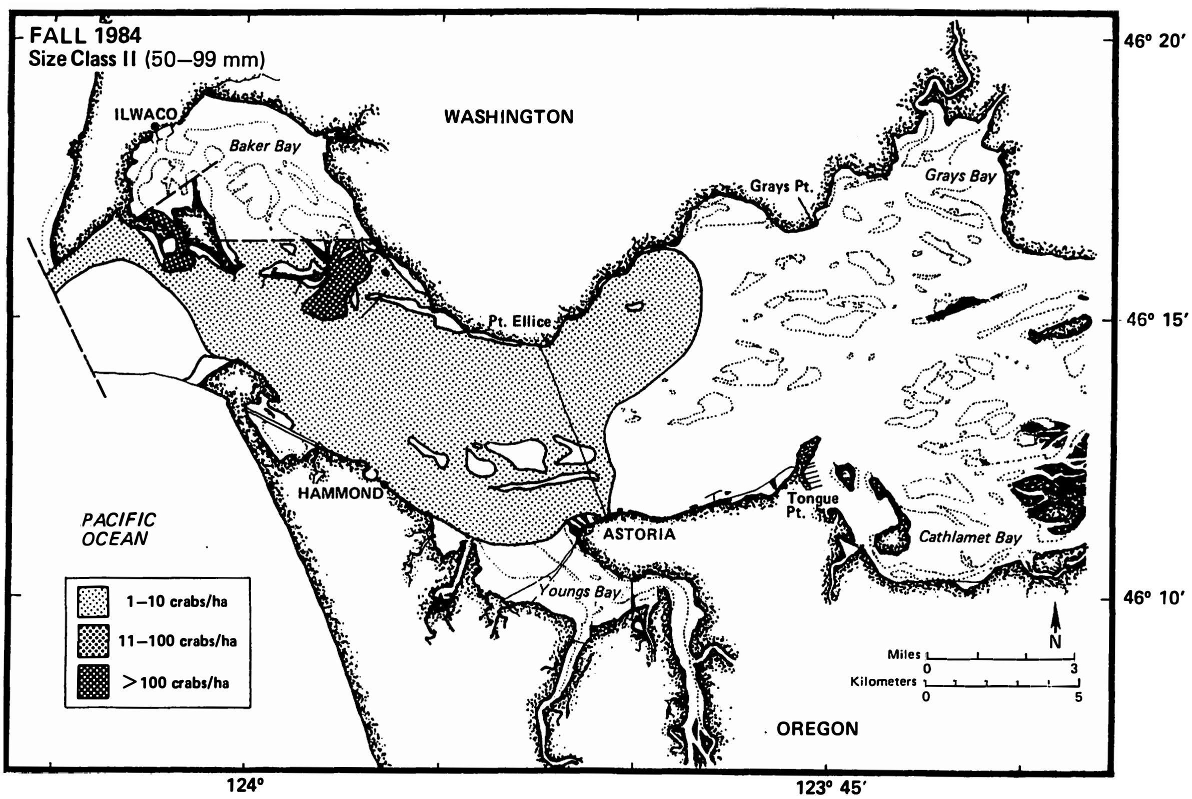


Appendix Figure B7.--Distribution and abundance of Size Class I and II Dungeness crabs in the Columbia River estuary during the summer 1984. Dashed lines represent data limits.

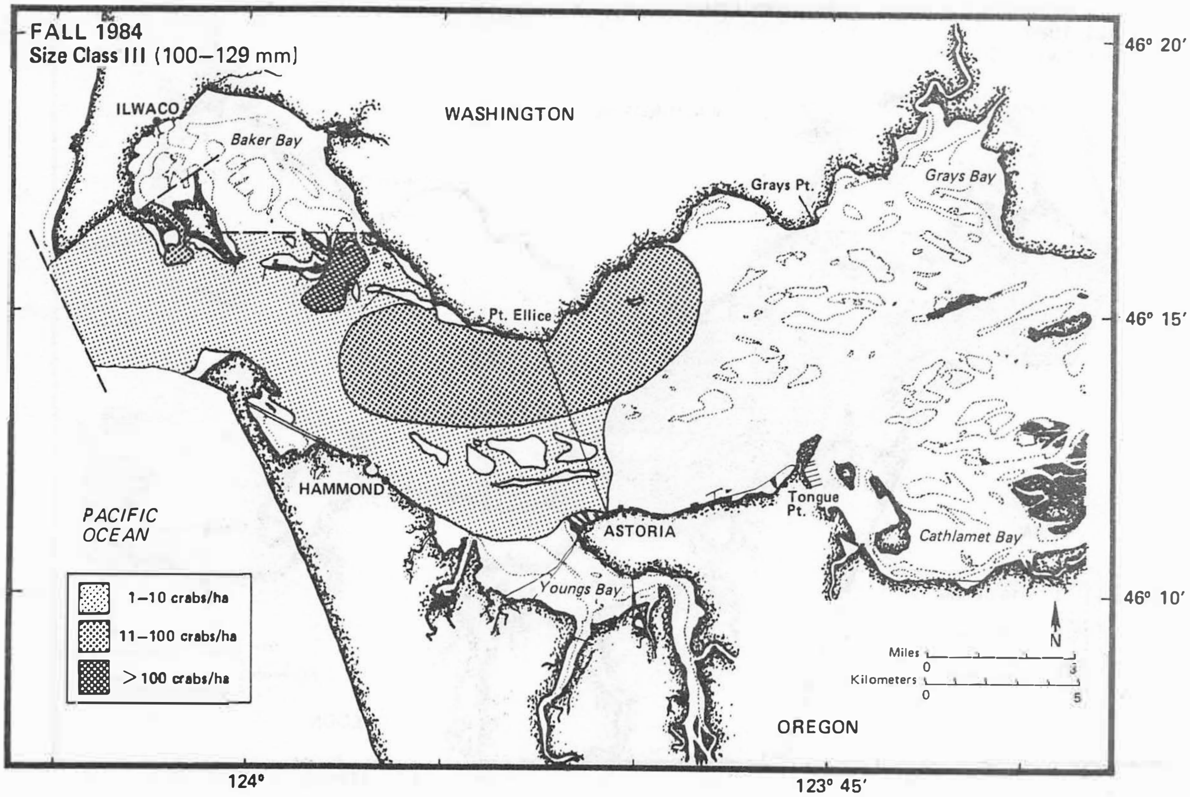


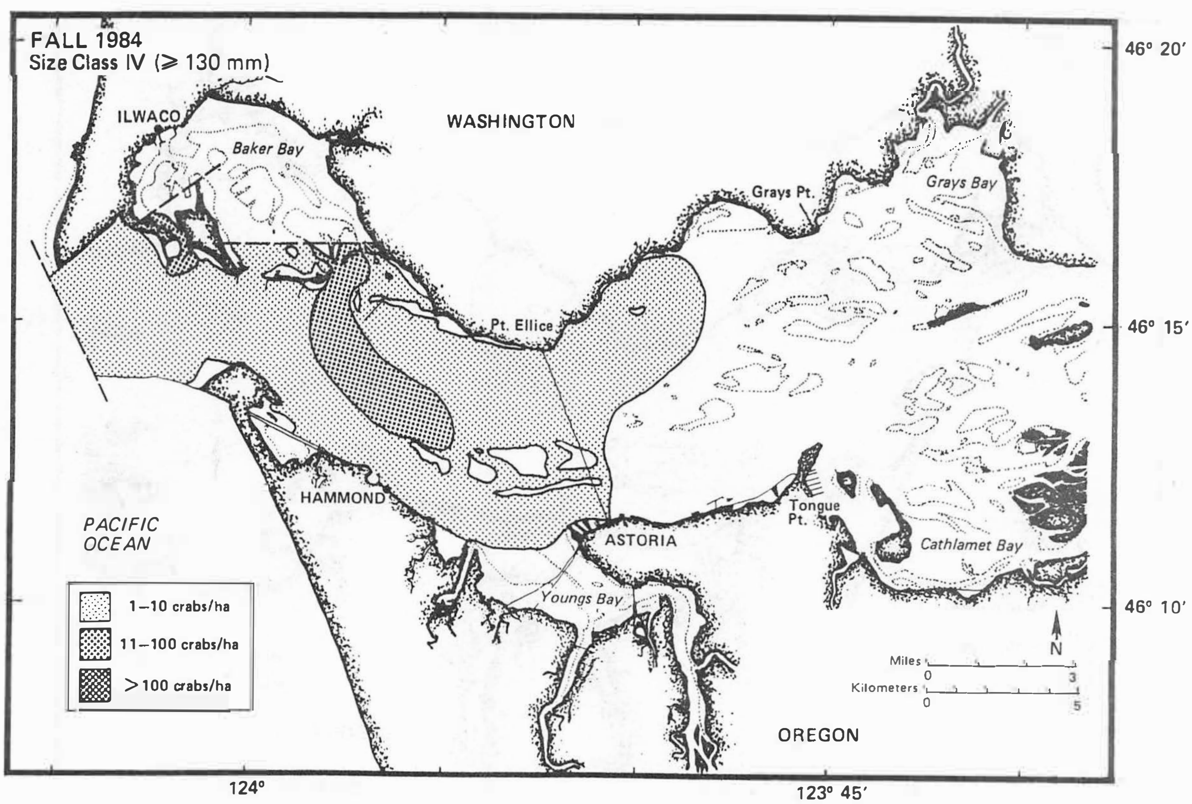
Appendix Figure B8.--Distribution and abundance of Size Class III and IV Dungeness crabs in the Columbia River estuary during the summer 1984. Dashed lines represent data limits.



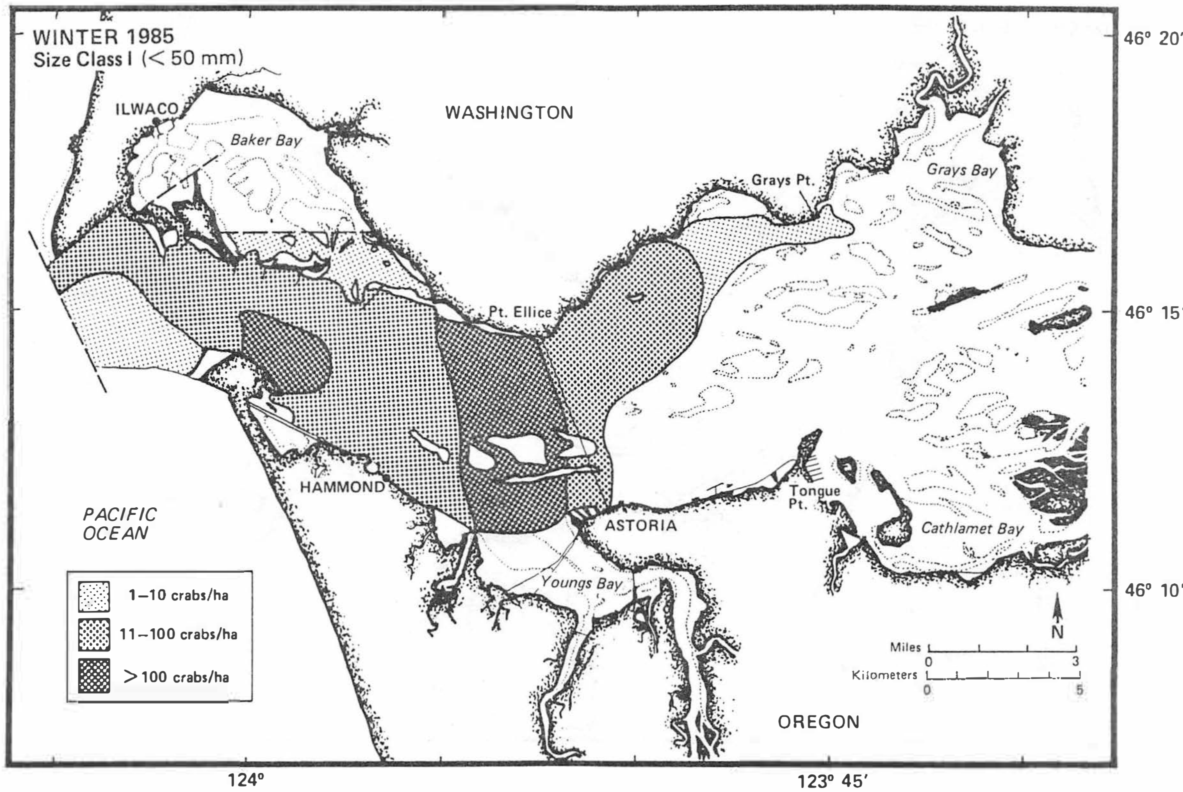


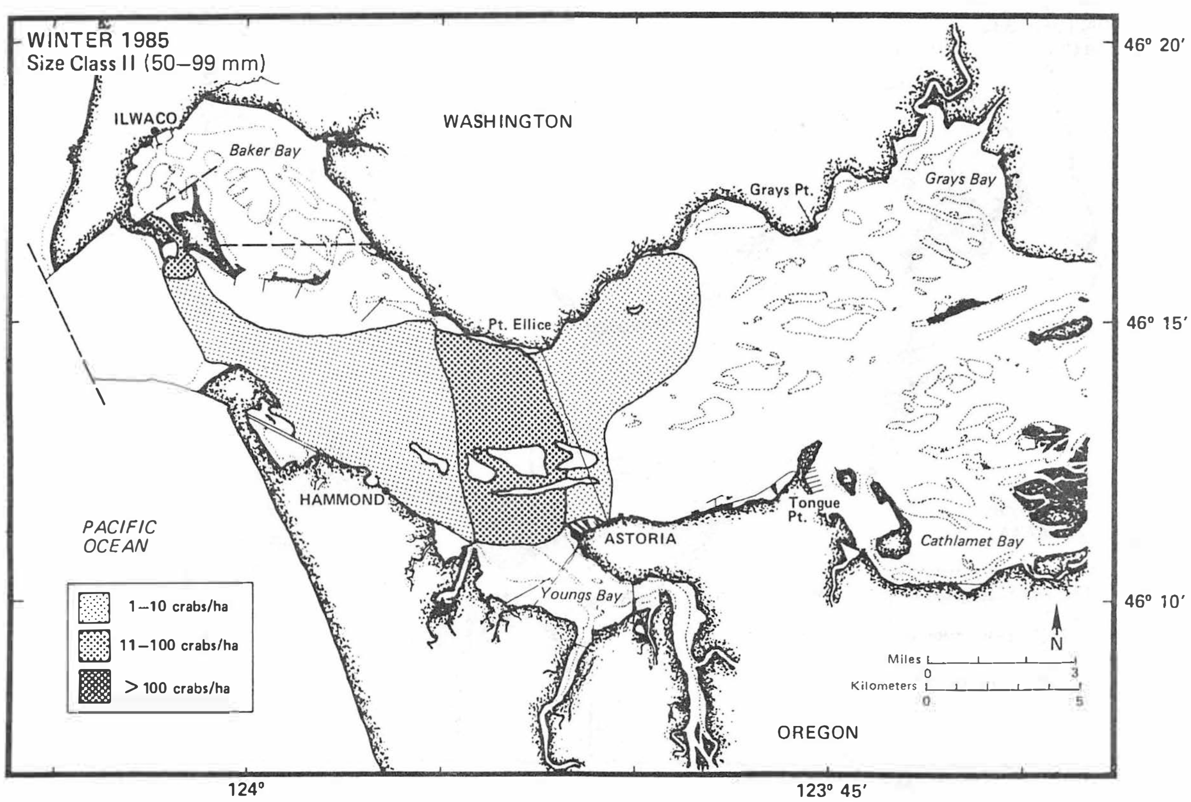
Appendix Figure B9.--Distribution and abundance of Size Class I and II Dungeness crabs in the Columbia River estuary during the fall 1984. Dashed lines represent data limits.



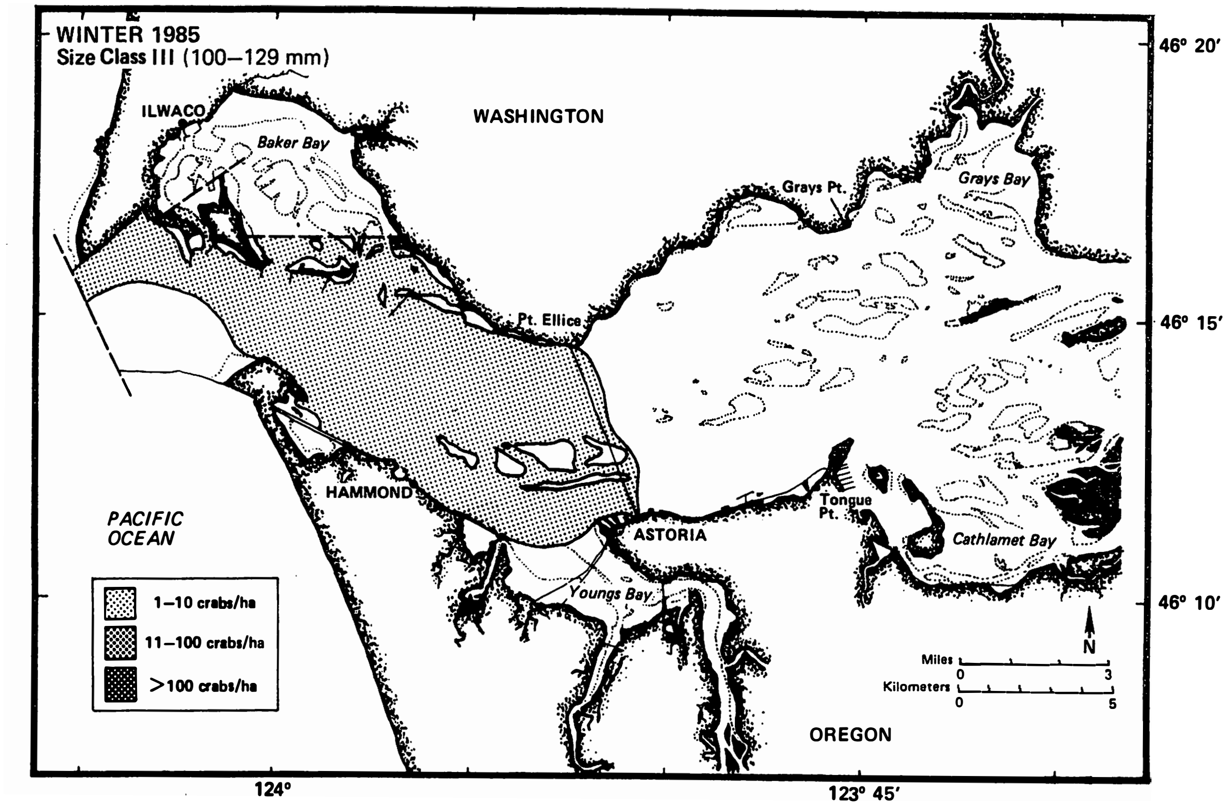


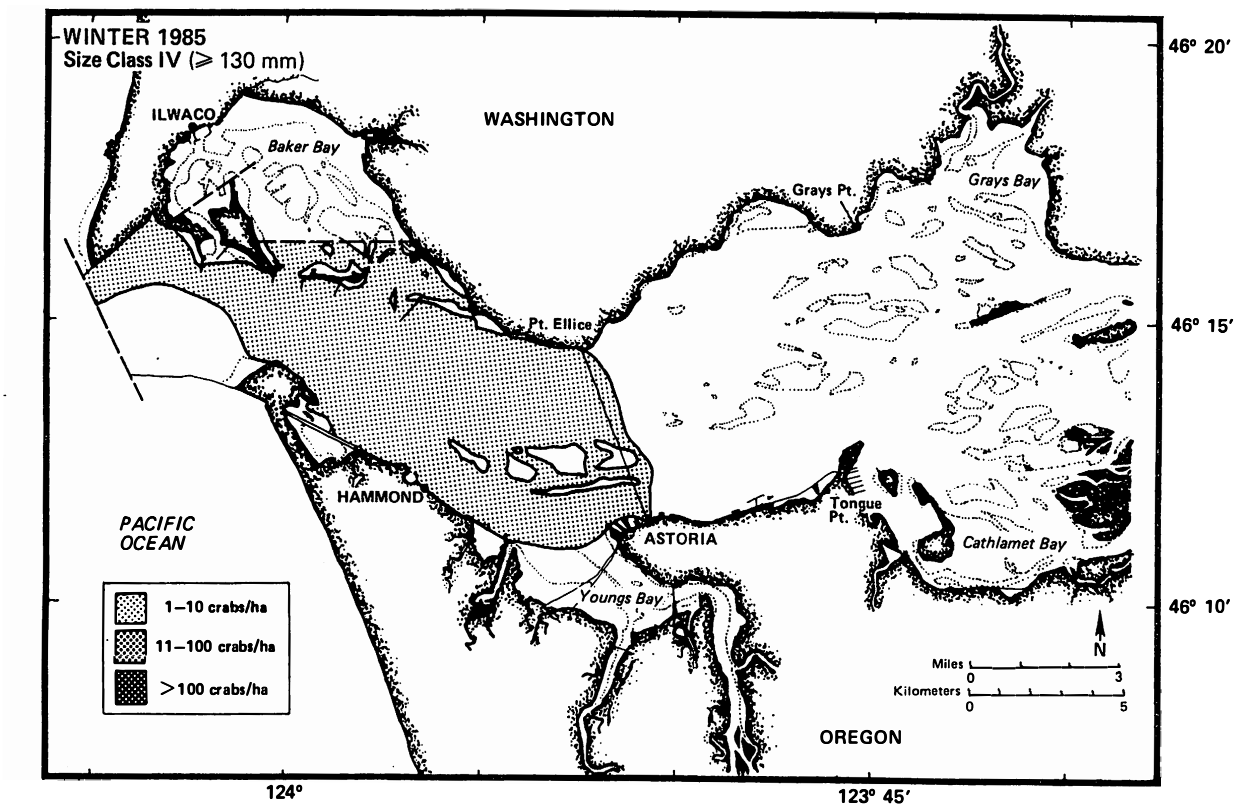
Appendix Figure B10.--Distribution and abundance of Size Class III and IV Dungeness crabs in the Columbia River estuary during the fall 1984. Dashed lines represent data limits.



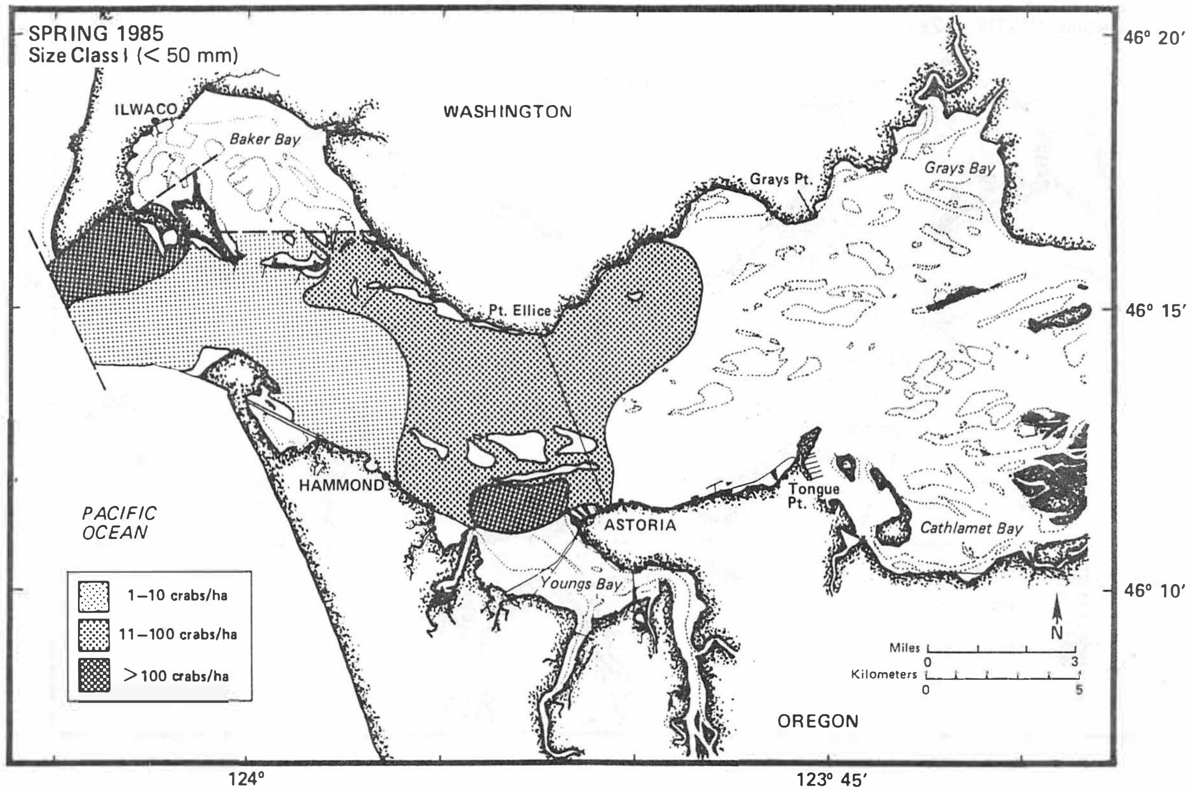


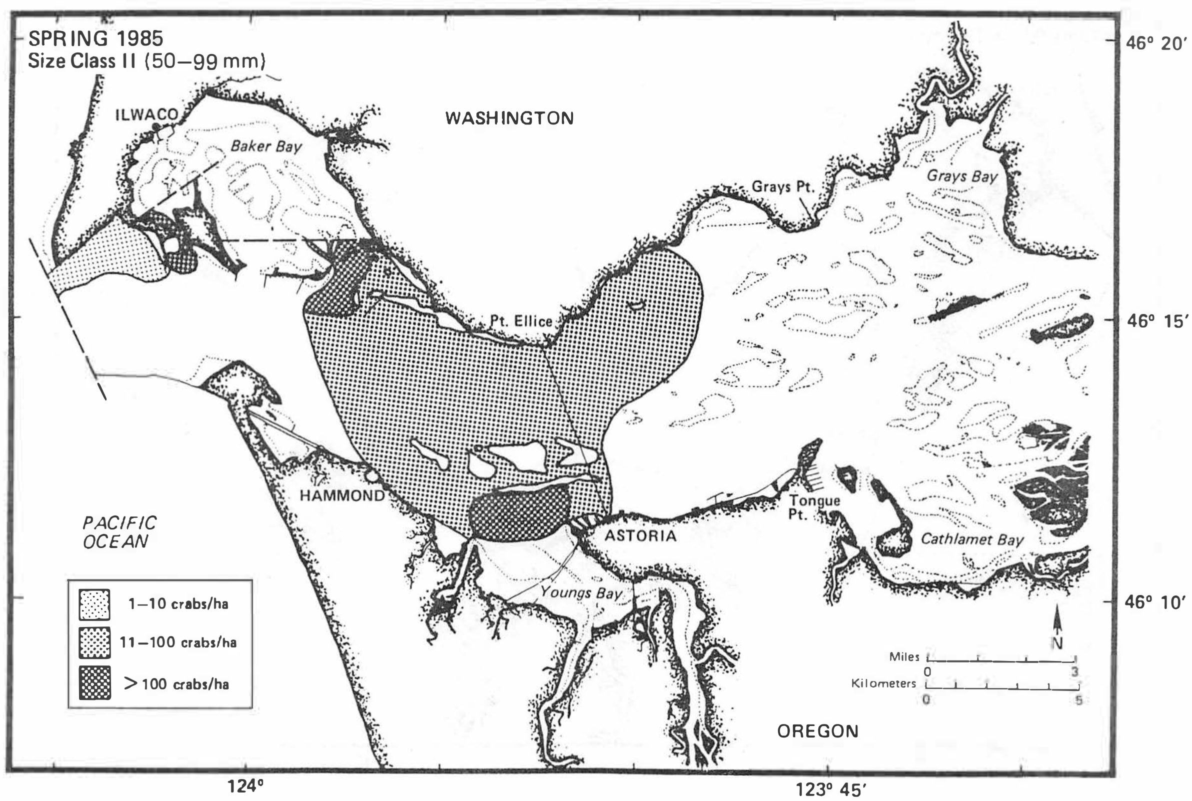
Appendix Figure B11.--Distribution and abundance of Size Class I and II Dungeness crabs in the Columbia River estuary during the winter 1985. Dashed lines represent data limits.



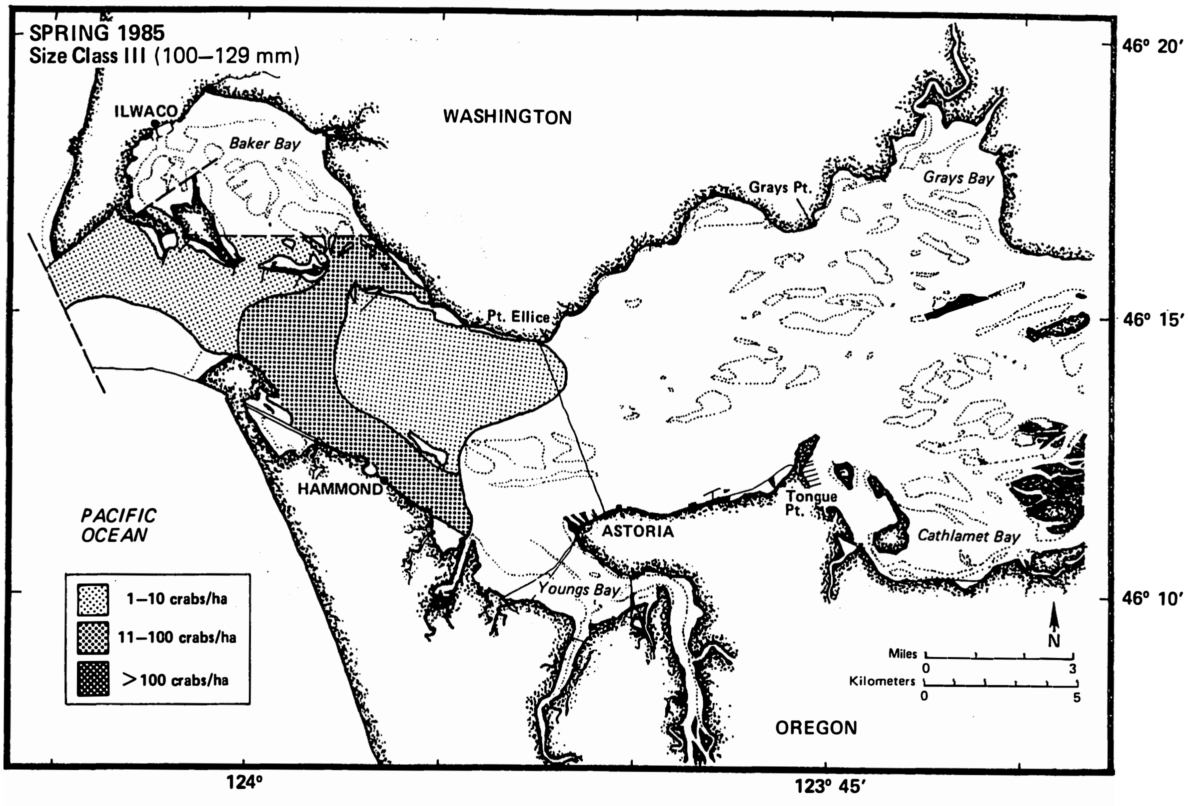


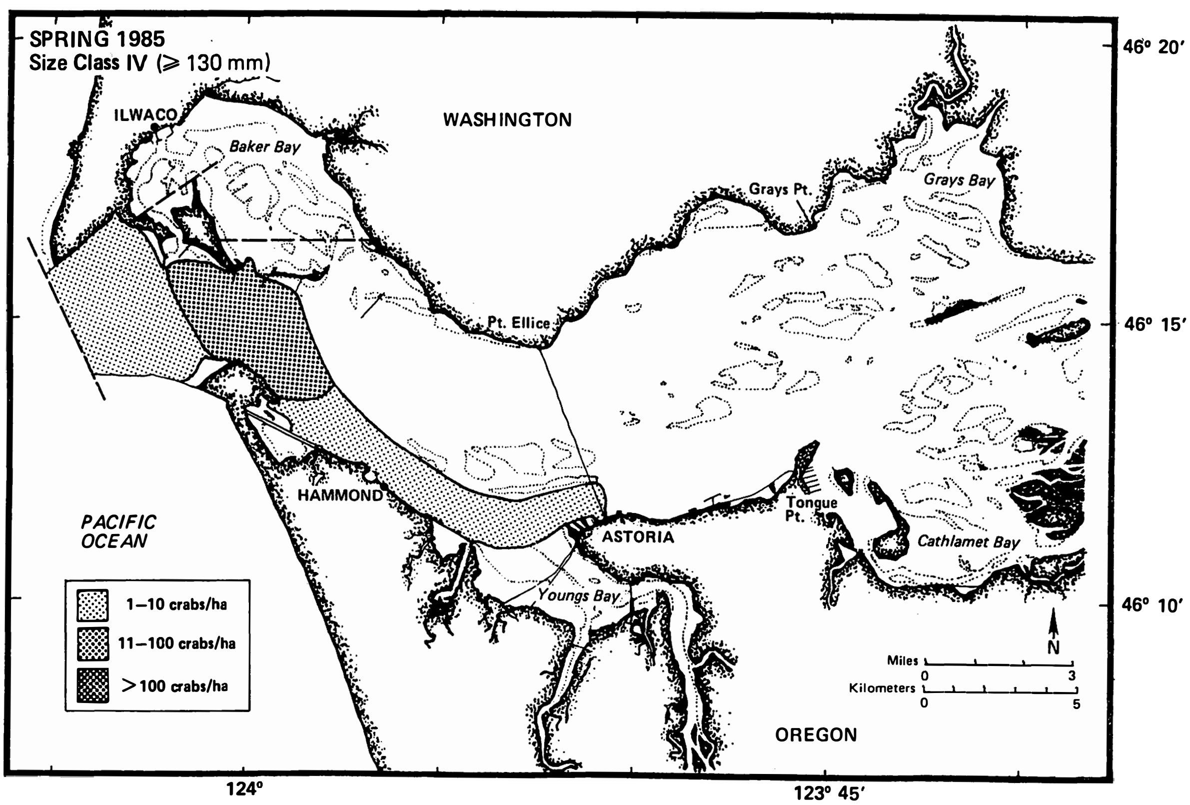
Appendix Figure B12.--Distribution and abundance of Size Class III and IV Dungeness crabs in the Columbia River estuary during the winter 1985. Dashed lines represent data limits.



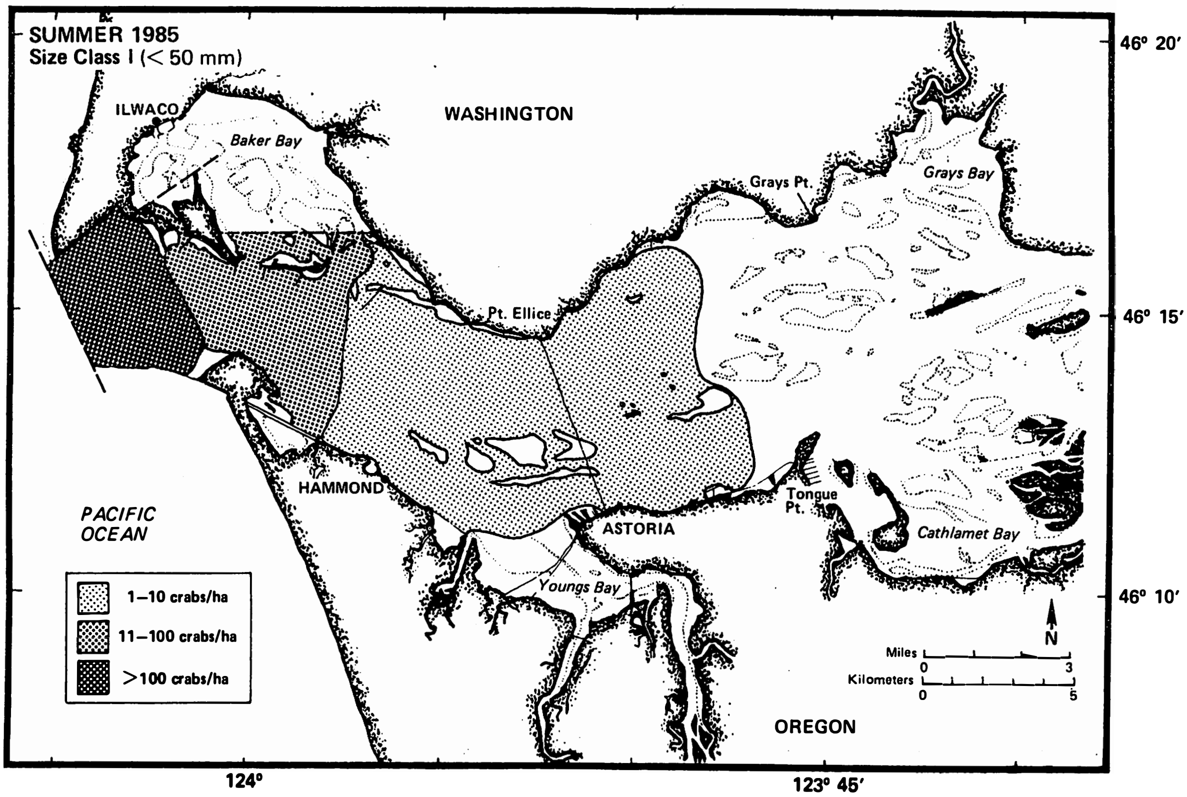


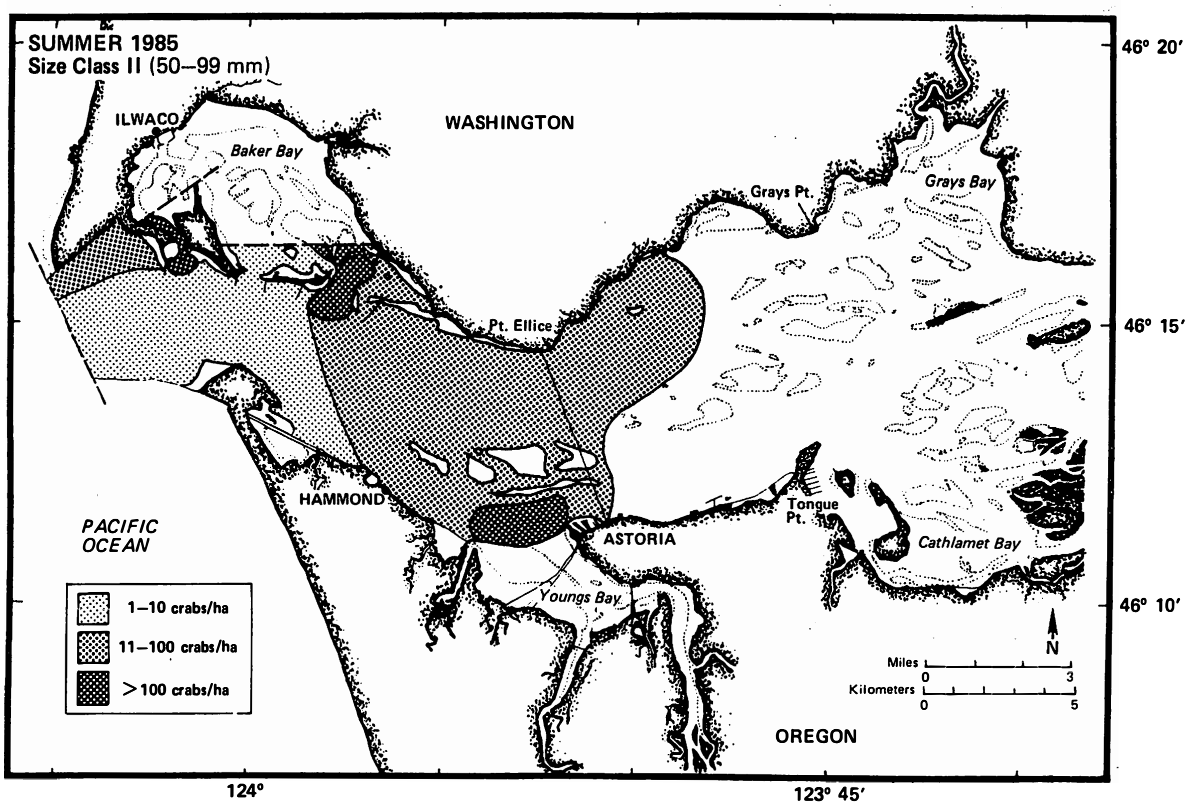
Appendix Figure B13.--Distribution and abundance of Size Class I and II Dungeness crabs in the Columbia River estuary during the spring 1985. Dashed lines represent data limits.



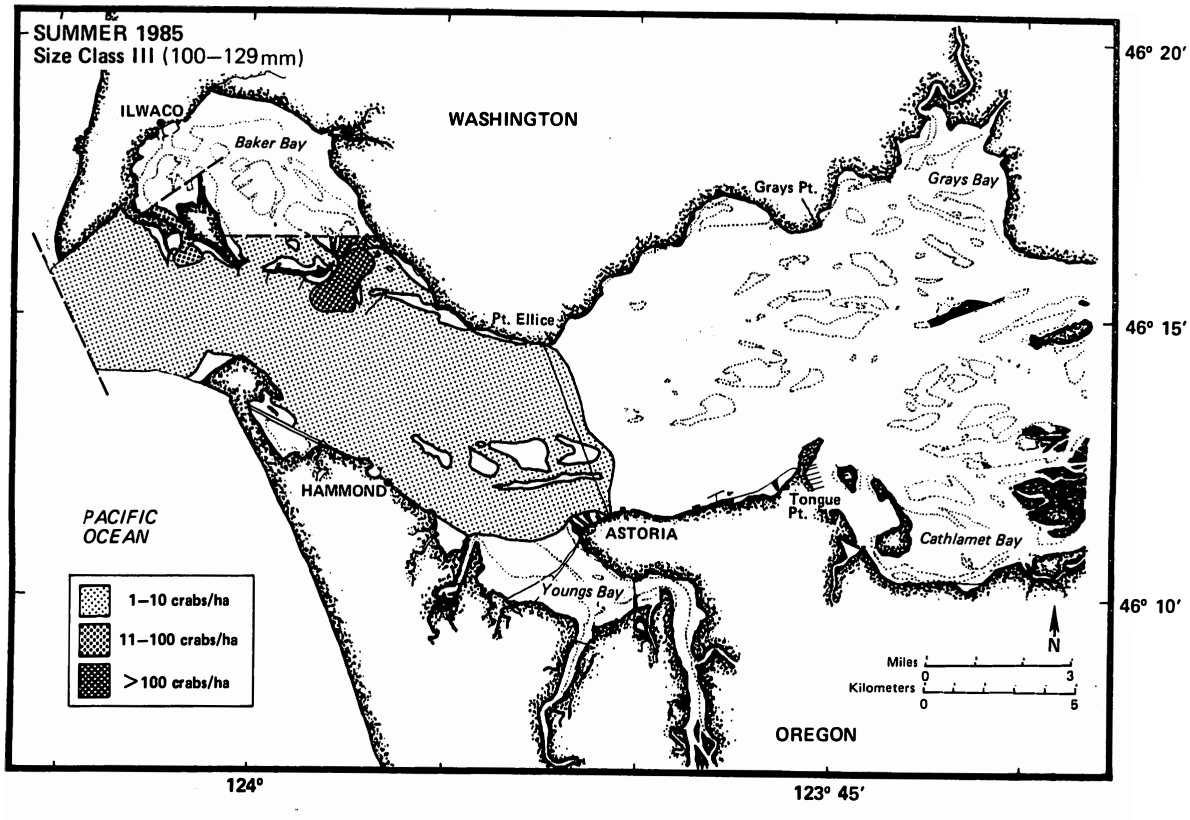


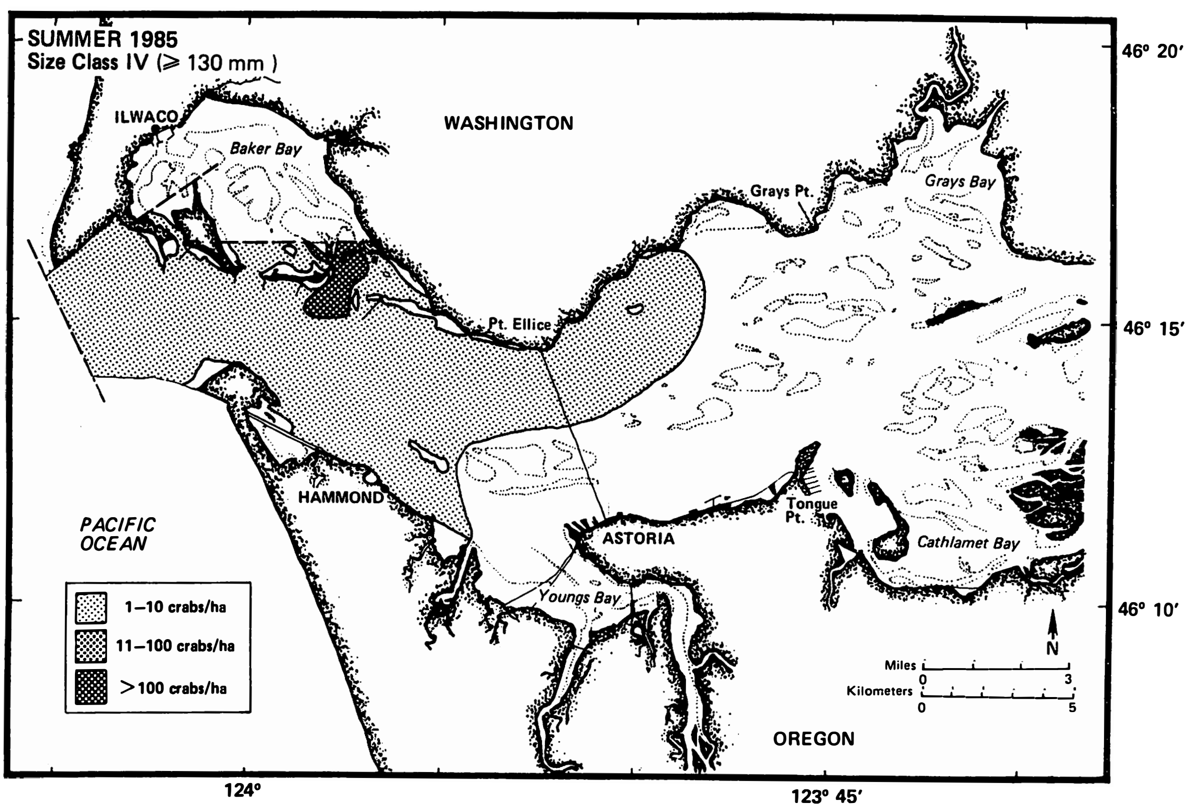
Appendix Figure B14.--Distribution and abundance of Size Class III and IV Dungeness crabs in the Columbia River estuary during the spring 1985. Dashed lines represent data limits.





Appendix Figure B15.--Distribution and abundance of Size Class I and II Dungeness crabs in the Columbia River estuary during the summer 1985. Dashed lines represent data limits.





Appendix Figure B16.--Distribution and abundance of Size Class III and IV Dungeness crabs in the Columbia River estuary during the summer 1985. Dashed lines represent data limits.

APPENDIX C.-- Catch information (not included in basic report, but available upon request to NMFS, Hammond Field Station, P.O. Box 155, Hammond, OR 97121).

APPENDIX D.--Physical data by station (not included in basic report, available upon request to NMFS, Hammond Field Station, P.O. Box 155, Hammond, OR 97121).