DISTRIBUTION ABUNDANCE. AND SIZE-CLASS STRUCTURE OF DUNGENESS CRABS IN THE COLUMBIA RIVER ESTUARY, A RIVER-DOMINATED ESTUARY

by
George T. McCabe, Jr.
Robert L. Emmett
Travis C. Coley,
and
Robert J. McConnell

Coastal Zone and Estuarine Studies Division
Northwest and Alaska Fisheries Center
National Marine Fisheries Service
National Oceanic and Atmospheric Administration
2725 Montlake Boulevard East
Seattle, Washington 98112

January 1987

ABSTRACT

The distribution, abundance, and size-class structure of Dungeness crabs, *Cancer magister*, in the Columbia River estuary (Oregon and Washington) were studied monthly from November 1983 through October 1985. Seasonally, crabs were generally distributed from the mouth of the estuary (bar) to River Kilometer 27. 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 when young-of-the-year crabs were relatively abundant. Densities of crabs on the bar were significantly greater during the second year of the study than during the first year. In areas upstream from the bar, densities were not significantly different between the two years; generally, there were no significant seasonal differences among upstream densities. Large changes in monthly densities indicated movements of crabs within the estuary and/or between the ocean and estuary. Young-of-the-year crabs were captured in the estuary beginning in May of both years; no young-of-the-year crabs were collected in intertidal areas of the estuary. Many young-of-the-year crabs remained on the bar during the spring and summer and did not move upstream. Our data indicate that the Columbia River estuary provides valuable habitat for Dungeness crabs, particularly for crabs <130 mm in carapace width.

CONTENTS

PAGE

INTRODUCTION....................1

METHODS....................2

Study Area....................2

Sampling....................2

Data Analysis....................5

RESULTS....................6

Estuarine Distribution and Abundance....................6

Ocean Catches....................12

Movements....................12

Salinity and Temperature....................16

Width/Weight Relationship....................16

DISCUSSION....................18

Distribution and Abundance....................18

Growth....................21

Ocean Sampling....................22

Sampling Efficiency and Populated Estimates....................23

CONCLUSIONS....................24

ACKNOWLEDGMENTS....................27

LITERATURE CITED....................28

INTRODUCTION

The Columbia River estuary, one of the major estuaries in Washington and Oregon, has high numbers of Dungeness crabs, Cancer magister (Emmett and Durkin 1985). Dungeness crabs support an important commercial fishery in coastal areas of Washington and Oregon; during the 1982-83 commercial season, which was a poor season, coastal landings in Washington and Oregon exceeded 3.6 million kg (PMFC 1984).

Researchers working in other west coast estuaries have noted the value of estuarine areas to Dungeness crabs. Orcutt (1977) estimated that up to 80% of the Dungeness crab population offshore from San Francisco, California, used the "bay" at some time. Stevens and Armstrong (1984) found that both subtidal and intertidal areas of Grays Harbor estuary, Washington (about 80 km north of the Columbia River estuary), supported large numbers of Dungeness crabs. They observed that Grays Harbor was used as a nursery area, and estimated that crabs reared in the estuary could provide a substantial contribution to the offshore commercial fishery.

Initial studies of Dungeness crabs in the Columbia River estuary showed an extensive population of Dungeness crabs and also identified the temporal occurrence of 0+ age crabs (young-of-the-year) (Emmett and Durkin 1985). However, a comprehensive study of Dungeness crabs in the estuary was needed to provide data that could be used to assist in reducing the impact of dredging activities in the estuary. Specific objectives of our study were to describe distribution, abundance, and size-class structure of Dungeness crabs in the Columbia River estuary. In addition, the size-class structure of crabs in the Columbia River estuary was to be compared to that in near offshore areas.

METHODS

Study Area

Unlike many other west coast estuaries, the Columbia River estuary is a river-dominated system. The estuary, a drowned river mouth, is strongly influenced by river flows, with highest flows typically in the spring. Lowest flows generally occur during late summer and fall. During the study period, estimated flows (monthly averages) ranged from 3,121 m^3/s in August 1985 to 14,091 m^3/s in May 1985 (flow estimates supplied by U.S. Geological Survey, Portland, Oregon). Estuarine salinities fluctuate widely depending upon river flow, tidal stage, and distance from the ocean (Neal 1972). Salinity intrusion is generally lowest during the spring (highest river flows) and greatest during late summer and fall (lowest river flows). During low-flow seasons (about 4,400 m^3/s), minimum bottom salinities in most of the lower 22 km of the estuary range from 0.5 to 15 ppt, with maximum salinities $\geq$30 ppt. Minimum bottom salinities in much of the lower 22 km of the estuary reach zero during high-flow seasons (about 8,800 m^3/s) (Jay 1984).

Sampling

Sampling was done from November 1983 through October 1985. A maximum of 28 estuarine and ocean sites were sampled each month (Fig. 1). Because crabs were not captured upstream from Stations 15 and 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 1.6 km 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.

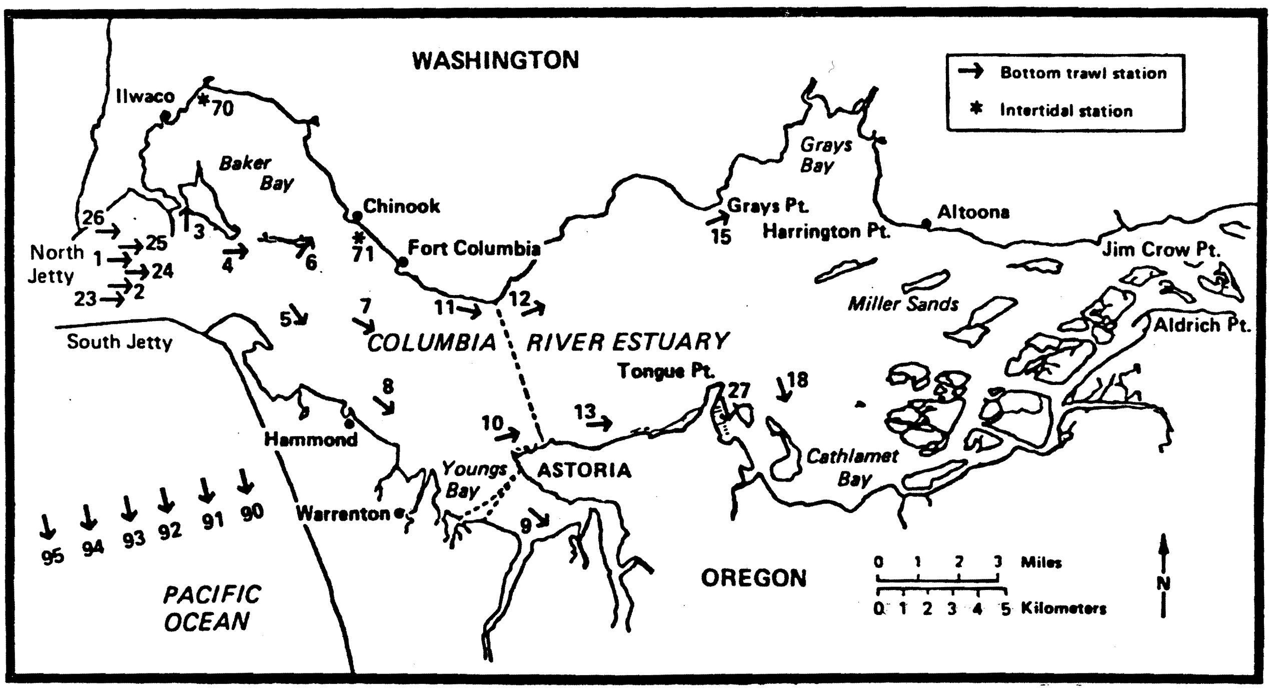

Figure 1.--Map of the Columbia River estuary and adjacent coastal areas, showing sampling sites for the 2-year Dungeness crab study.

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. 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 9.5-mm mesh liner was inserted in the cod end of the net to ensure retention of 0+ age crabs. 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 during times of higher salinity (early flood to early ebb 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. Two intertidal sites in Baker Bay were sampled (when exposed) by walking along transects perpendicular to shore. The vegetation and substrate along these transects were examined for crabs.

Generally a subsample of at least 100 crabs ($\geq$20 mm) from each sample was measured (mm) across the carapace anterior to the tenth anterolateral spines, weighed (g), sexed, and checked for eggs and the nemertean _Carcinonemertes errans_, which is an egg predator (Wickham 1979; McCabe et al. 1987). Crabs not individually measured and weighed were counted. When large numbers of early instar crabs ($\leq$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[1/] salinometer and temperature probe. Bottom values were not obtained at the deeper ocean stations because the probe's cable was not long enough.

Data Analysis

Using catch data, fishing width of the trawl (5 m), and distance traveled during sampling, we estimated the density of crabs (number/hectare) at each station for each month. Crab densities were calculated for four size classes: Size Class I (< 50 mm), Size Class II (50-99 mm), Size Class III (100-129 mm), and Size Class 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). For making seasonal comparisons, 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. 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.

[1/] Reference to trade names does not imply endorsement by the National Marine Fisheries Service, NOAA.

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, measured 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. The bar was defined as the area at the mouth of the estuary extending from River Kilometer (RKm) 1.1 to 4.5. 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 of crab in each area was calculated and corrected for gear efficiency. Population estimates for each area were then determined and summed to obtain a total crab population estimate for the Columbia River estuary for each season.

RESULTS

Estuarine Distribution and Abundance

Seasonally, crabs were generally distributed from the mouth of the estuary to about RKm 27 throughout the 2-year study. The farthest upstream distribution of crabs occurred during winter of both years when Size Class I crabs were captured at Station 15 (RKm 32). No crabs were captured in Youngs Bay (Station 9), Cathlamet Bay (Stations 18 and 27), or intertidal areas of Baker Bay; crabs were captured infrequently at Grays Point (Station 15) and off central Astoria (Station 13). Because crab numbers were generally zero at the aforementioned stations, these stations 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, there was a significant difference among the seasons for the second year, 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 among the seasons on the bar 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 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 on the bar were significantly less than densities 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 for the six bar stations when all 24 months of data were combined (Kruskal-Wallis, $P<0.05$). Station 26, 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 and 6 (Baker Bay) 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.

Crab densities by size class and month were examined for the bar and the estuary upstream from the bar (Table 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. Most 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. On the bar, Size Class I crabs were much more abundant during June-August 1985 than during the same period in 1984. 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

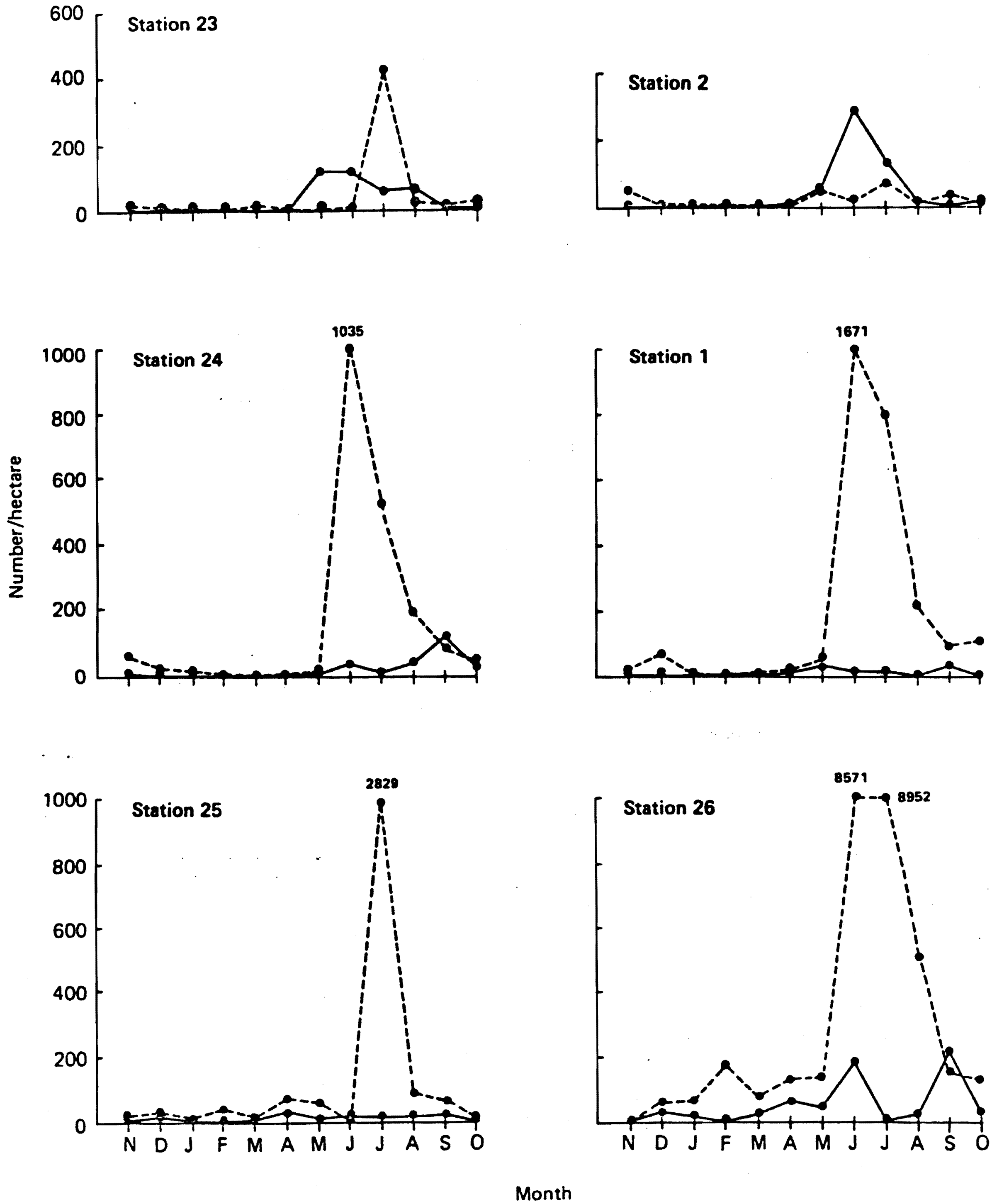

Figure 2.--Estimated densities of Dungeness crabs at six sampling stations on the Columbia River bar. The solid line represents the first year of the study (Nov. 1983 through Oct. 1984) and the dashed line represents the second year (Nov. 1984 through Oct. 1985).

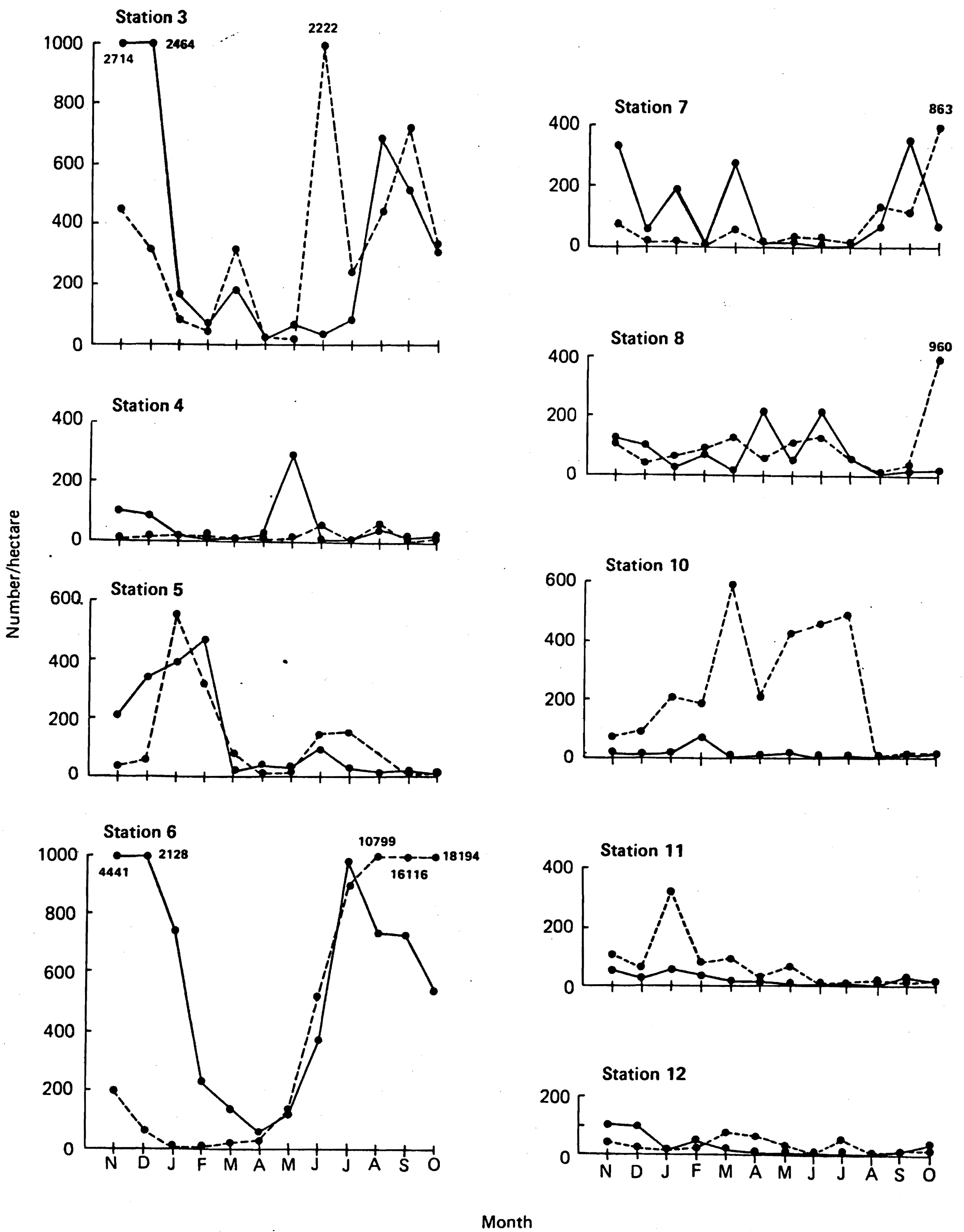

Figure 3.--Estimated densities of Dungeness crabs at nine sampling stations upstream from the Columbia River bar. The solid line represents the first year of the study (Nov. 1983 through Oct. 1984), and the dashed line represents the second year (Nov. 1984 through Oct. 1985).

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

Month	Size Class I		Size Class II		Size Class III		Size Class IV	
	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 ± 31.8	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

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 (Stations 3 and 6). In the estuary upstream from the bar, densities of Size Class IV crabs were lower than those of Size Class II and III crabs.

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. 4-6); however for many of the months it was 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 carapace width in the ocean catches, although this size group was always present in the estuary. In June and July 1985, crabs $\leq$20 mm in width were abundant in the estuary, specifically on the bar, but they were not abundant in ocean catches.

Movements

Dramatic monthly increases and decreases in crab densities at individual stations seem to indicate movements to and from the ocean and/or movements within 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

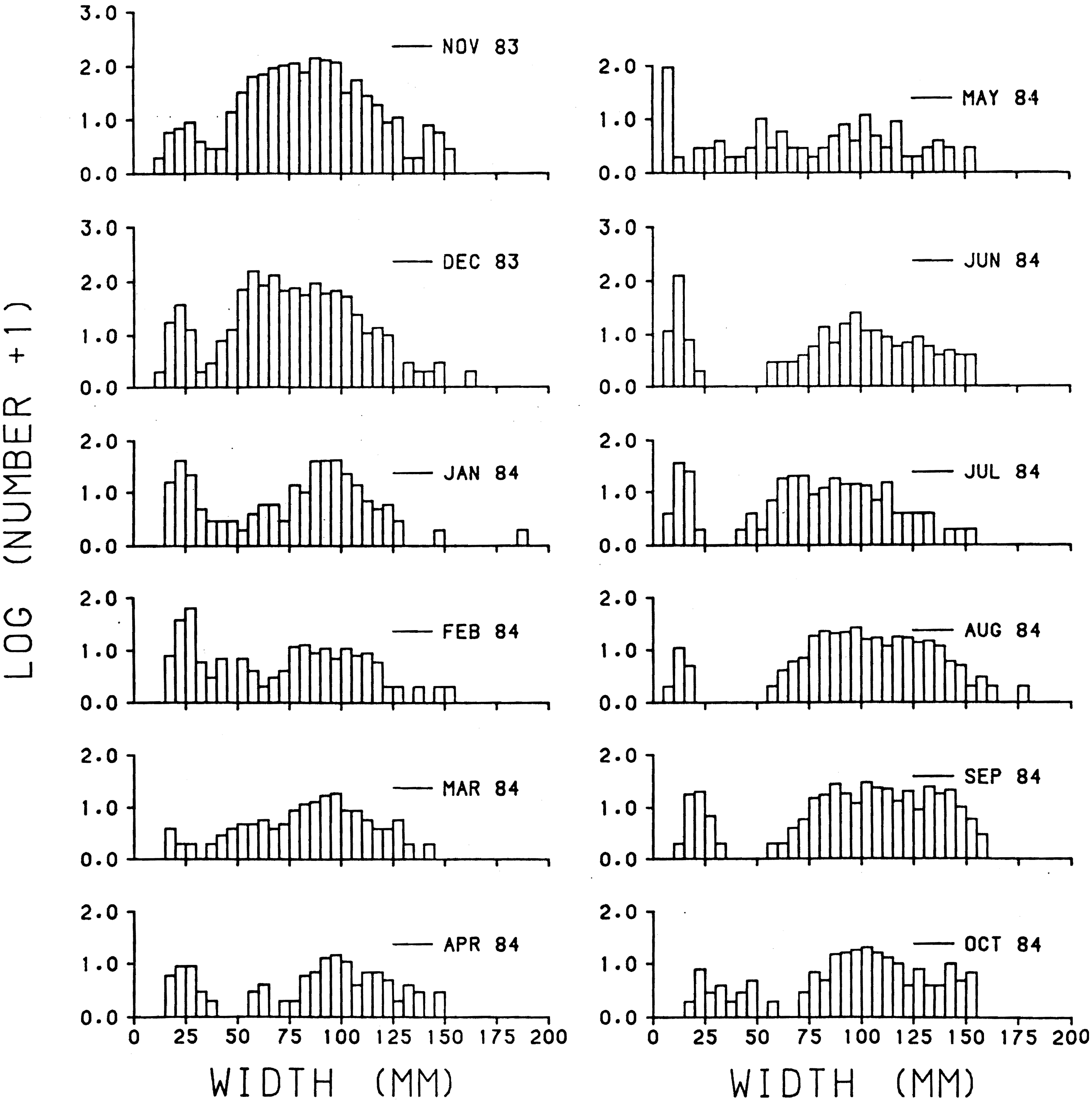

Figure 4.--Width frequency histograms for Dungeness crabs collected in the Columbia River estuary from November 1983 through October 1984.

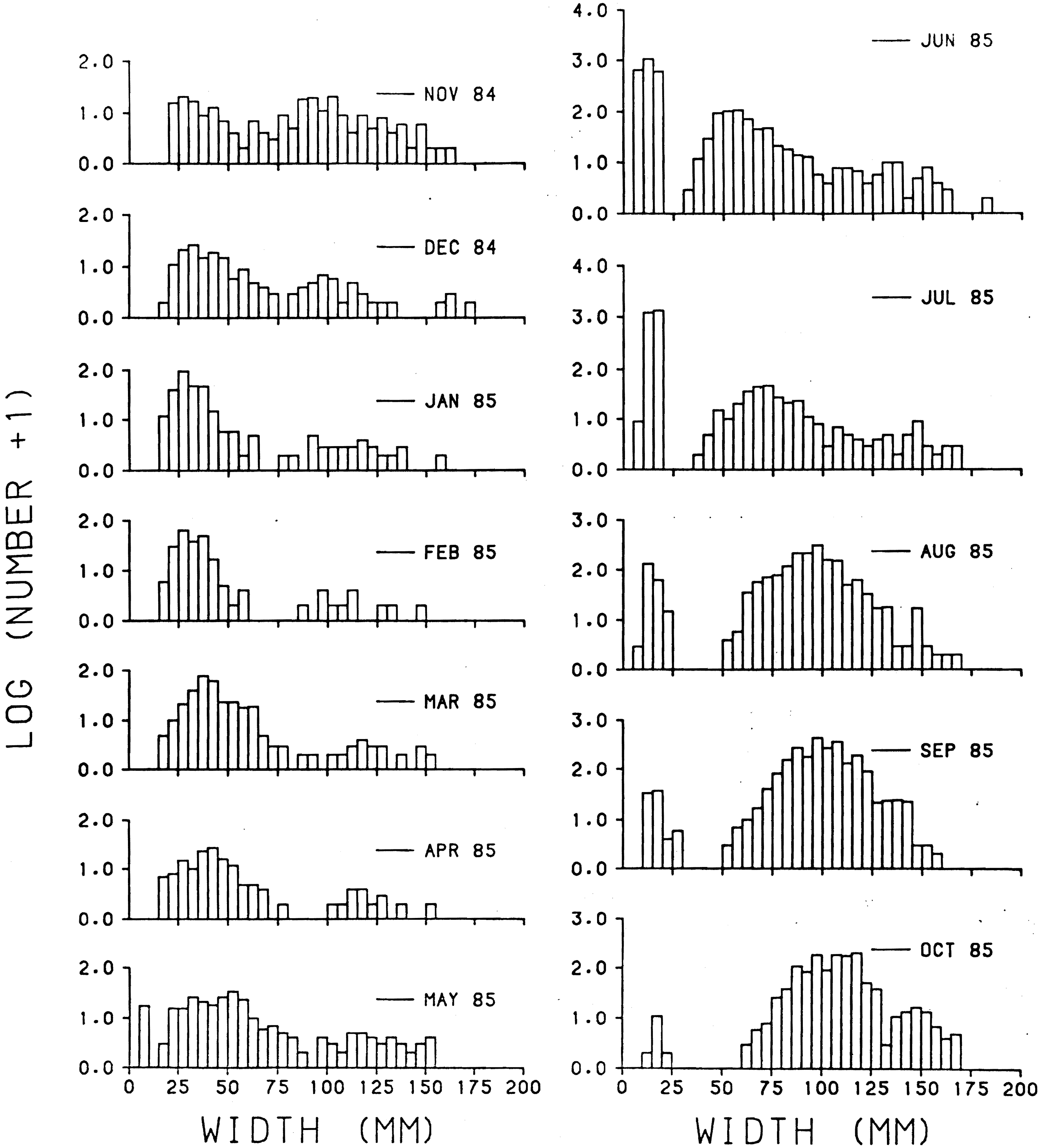

Figure 5.--Width frequency histograms for Dungeness crabs collected in the Columbia River estuary from November 1984 through October 1985.

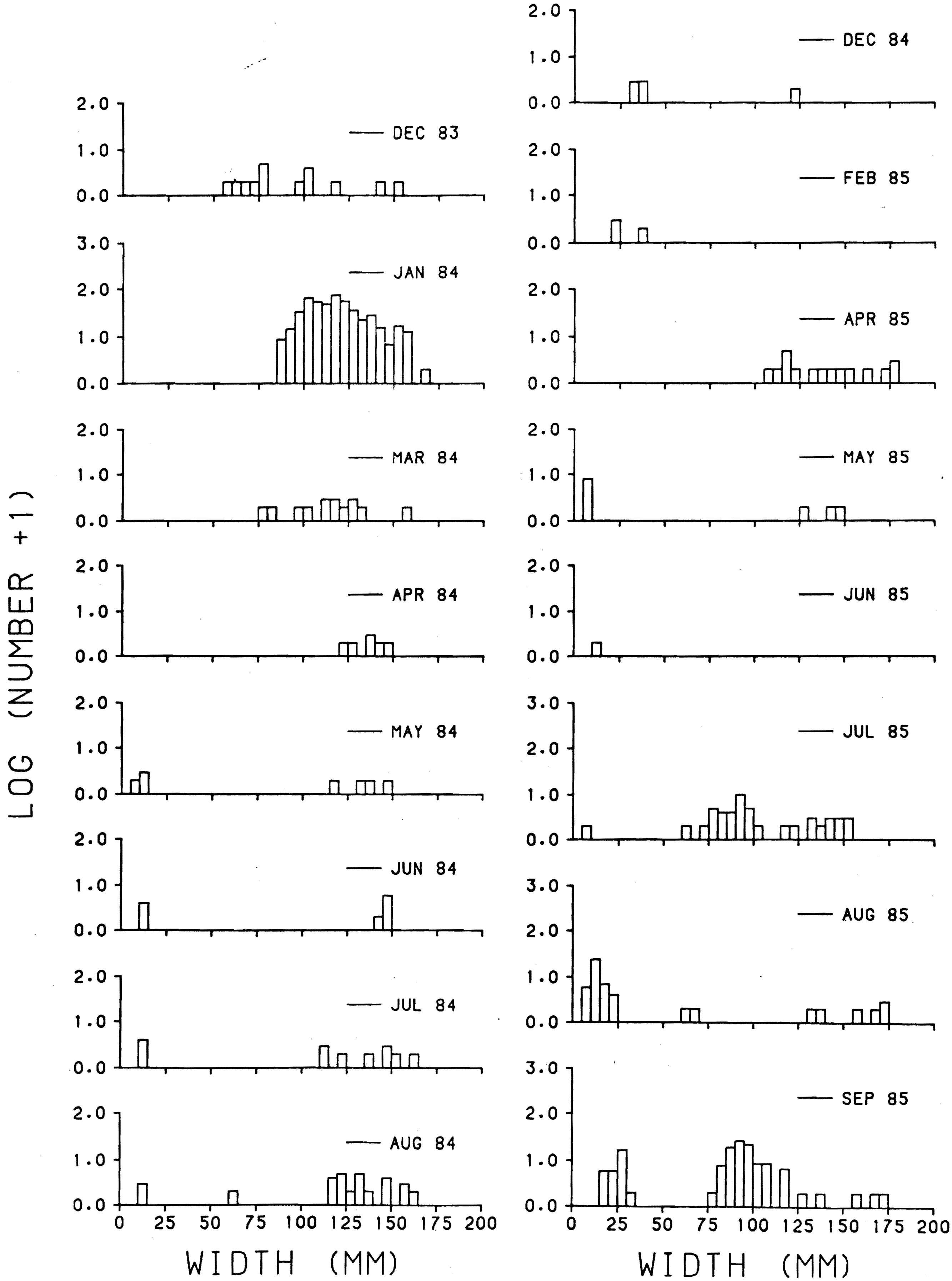

Figure 6.--Width frequency histograms for Dungeness crabs collected in nearshore areas of the Pacific Ocean from December 1983 through September 1985.

that metamorphosed to first instar juveniles. Many early instars remained on the bar during spring and summer and did not move upstream during this period (Table 1). Virtually all 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). 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.

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; $r^2 = 99.6\%$.

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 also 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

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, which is located about 80 km 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, do not provide suitable habitat for early instar Dungeness crabs; extensive eelgrass beds are not found in Baker Bay. 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 would have been much higher. During a 1-year benthic study (1980-81) in northwestern Baker Bay, Furota[2/] collected only one Dungeness crab. Furota sampled monthly along an intertidal and subtidal transect.

2/ T. Furota, Toho University , Chiba, Japan, pers. commun., December 1985.

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 $\geq$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 in Baker Bay during summer and fall. These shallow channels, which are lower water velocity areas, 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 (Bottom et al. 1984; Fox 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 carapace width.

In November-December 1984, crab densities at 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 at Station 6 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 (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 (Baker Bay), 10 (RKm 19-20--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.

In 1984, the U.S. Army Corps of Engineers (COE) deepened the Columbia River entrance channel from 14.6 to 16.8 m (mean lower low water). The COE (1983) estimated that during the initial deepening, 7.6 million m^3 of material would be removed from the entrance channel; annual maintenance dredging for the entrance channel was estimated to be 5.4 million m^3 of material. 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. In 1985, the hopper dredge entrained large numbers of 0+ age crabs when dredging the bar (Larson[3/]).

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

---

3/ K. Larson, COE, Portland, OR, pers. commun. June 1986.

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 only 10-20 mm).

Growth rates of Dungeness crabs have been estimated in other areas (MacKay 1942; Cleaver 1949; Butler 1961; Poole 1967; Collier 1983; Tasto 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 spines) 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, located 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. In two previous bottom trawl surveys near the mouth of the Columbia River (Durkin and Lipovsky 1977; Emmett and Durkin 1985), catches of Dungeness crabs <50 mm in carapace width were greater than ours; none of their sampling sites were located as far south as our ocean sampling sites. Emmett and Durkin noted that crabs 50-100 mm in carapace width were poorly represented in ocean catches (both surveys), whereas smaller and larger crabs were much more abundant. Their limited data indicate that many of the 50-100 mm crabs had moved into the estuary. Future studies of crabs in offshore areas adjacent to the Columbia River estuary should include sampling transects north, directly off, and south of the mouth.

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 Stevens and Armstrong's (1984) efficiency factors and grouped months into the same seasons--June-August = Summer, September-February = fall-winter, and March-May = spring. 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 fall-winter 1983-1984, we used data from 4 months because our sampling did not begin until November 1983. Each estimate represents a mean for a 3- to 6-month period, depending upon the season. Populations of Size Class I crabs were generally greater than any other size class (Table 3). 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 (1984) estimated that 1980-1981 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 create 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.

CONCLUSIONS

Although the Columbia River estuary is a river-dominated estuary with widely fluctuating salinities, subtidal areas provide valuable habitat for Dungeness crabs. Unlike Grays Harbor estuary, Washington (a more saline

Table 3.--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

estuary), young-of-the-year Dungeness crabs do not intensively utilize intertidal areas of the Columbia River estuary (Baker Bay). During the 2-year study in the Columbia River estuary, Dungeness crabs are generally distributed from the mouth of the estuary to RKm 27. Because of the economic and ecological importance of crabs, it is important to minimize the effects of dredging by reducing dredging (when feasible) in specific areas during periods of high crab abundance.

ACKNOWLEDGMENTS

For assistance in sampling, we thank Larry Davis, Edward Koller, Maurice Laird, David Miller, William Muir, Roy Pettit, and Nick Zorich.

The U.S. Army Corps of Engineers provided partial funding for the study.

LITERATURE CITED

Armstrong, D. A., and D. R. Gunderson.
1985. The role of estuaries in Dungeness crab early life history: A case study in Grays Harbor, Washington. In B. R. Melteff (editor), Proceedings of the symposium on Dungeness crab biology and management, p. 145-170. Univ. of Alaska, Alaska Sea Grant Rep. 85-3.

Armstrong, D. A., B. G. Stevens, and J. C. Hoeman.
1982. Distribution and abundance of Dungeness crab and *Crangon* shrimp, and dredging-related mortality of invertebrates and fish in Grays Harbor, Washington. Tech. Rep. to Wash. Dep. Fish. and U.S. Army Corps of Engineers, 349 p.

Bottom, D. L., K. K. Jones, and M. J. Herring.
1984. Fishes of the Columbia River estuary. Final Rep. of Fish Work Unit of Columbia River Estuary Data Development Prog., Astoria, Oreg., 113 p. with appendices.

Butler, T. H.
1961. Growth and age determination of the Pacific edible crab *Cancer magister* Dana. J. Fish. Res. Bd. Canada 18(5): 873-891.

Carrasco, K. R., D. A. Armstrong, D. R. Gunderson, and C. Rogers.
1985. Abundance and growth of *Cancer magister* young-of-the-year in the nearshore environment. In B. R. Metleff (editor), Proceedings of the symposium on Dungeness crab biology and management, p. 171-184. Univ. of Alaska, Alaska Sea Grant Rep. 85-3.

Cleaver, F. C.
1949. Preliminary results of the coastal crab (*Cancer magister*) investigation. Wash. Dep. Fish., Biol. Rep. 49A:47-82.

COE (U.S. Army Corps of Engineers).
1983. Final environmental impact statement navigation channel improvements--Columbia River at the mouth, Oregon and Washington. .. Appendix B. U.S. Army Engineer District, Portland, Oreg., 6 p.

Collier, P. C.
1983. Movement and growth of post-larval Dungeness crabs, *Cancer magister*, in the San Francisco area. In P. W. Wild and R. N. Tasto (editors, Life history, environment, and mariculture studies of the Dungeness crab, *Cancer magister*, with emphasis on the central California fishery resource. p. 125-133. Calif. Dep. Fish Game, Fish Bull. 172.

Durkin, J. T., and R. L. Emmett.
1980. Benthic invertebrates, water quality, and substrate texture in Baker Bay, Youngs Bay, and adjacent areas of the Columbia River estuary. Final Rep. to U.S. Fish Wild. Serv. by U.S. Nat. Mar. Fish. Serv., Seattle, Wash., 44 p. with appendixes.

Durkin, J. T., and S. J. Lipovsky.
1977. Aquatic disposal field investigations, Columbia River disposal site, Oregon. Appendix E: Demersal fish and decapod shellfish studies. U.S. Army Corps Eng., Waterways Exp. Stn., Vicksburg, Miss., Tech. Rep. D-77-30, 184 p.

Elliott, J. M.
1977. Some methods for the statistical analysis of samples of benthic invertebrates. Sci. Publ. 25, Freshwater Biological Assoc., Ferry House, Ambleside [Eng.], 160 p.

Emmett, R. L., and J. T. Durkin.
1985. The Columbia River estuary: an important nursery for Dungeness crabs, Cancer magister. Mar. Fish. Rev. 47(3):21-25.

Fox, D. S., W. Nehlsen, S. Bell, and J. Damron.
1984. The Columbia River estuary, atlas of physical and biological characteristics. Columbia River Estuary Data Development Prog., Astoria, Oreg., 87 p.

Gotshall, D. W.
1977. Stomach contents of northern California Dungeness crabs, Cancer magister. Calif. Fish Game 63(1): 43-51.

Gotshall, D. W.
1978. Relative abundance studies of Dungeness crabs, Cancer magister, in northern California. Calif. Fish Game 64(1): 24-37.

Jay, D.
1984. Circulatory processes in the Columbia River estuary. Final Rep. of Circulation Work Unit of Columbia River Estuary Data Development Prog., Astoria, Oreg., 169 p. with appendices.

MacKay, D. C. G.
1942. The Pacific edible crab, Cancer magister. Fish. Res. Bd. Canada Bull. 62, 32 p.

McCabe, G. T., Jr., R. L. Emmett, T. C. Coley, and R. J. McConnell.
1987. Effect of a river-dominated estuary on the prevalence of Carcinonemertes errans, an egg predator of the Dungeness crab, Cancer magister. Fish. Bull., U.S. (in press).

Neal, V. T.
1972. Physical aspects of the Columbia River and its estuary. In A. T. Pruter and D. L. Alverson (editors), The Columbia River estuary and adjacent ocean waters, bioenvironmental studies, p. 19-40. Univ. Wash. Press, Seattle.

Orcutt, H. G. (compiler)
1977. Dungeness crab research program report for the year 1977. Calif. Dep. Fish Game, Mar. Res. Admin. Rep. 77-21, 55 p.

PMFC (Pacific Marine Fisheries Commission).
1984. 36th Annual Rept. Pac. Mar. Fish. Comm., Portland, Oreg., 37 p.

Poole, R. L.
1967. Preliminary results of the age and growth study of the market crab (Cancer magister) in California: the age and growth of Cancer magister in Bodega Bay. In Proceedings of the symposium on Crustacea, Part II, p. 553-567. Mar. Biol. Assoc. India, Symp. Ser. 2

Stevens, B. G., and D. A. Armstrong.
1984. Distribution, abundance, and growth of juvenile Dungeness crabs, Cancer magister, in Grays Harbor estuary, Washington. Fish. Bull., U.S. 82(3): 469-483.

Stevens, B. G., D. A. Armstrong, and R. Cusimano.
1982. Feeding habits of the Dungeness crab Cancer magister as determined by the Index of Relative Importance. Mar. Biol. (Berl.) 72: 135-145.

Tasto, R. N.
1983. Juvenile Dungeness crab, Cancer magister, studies in the San Francisco Bay area. In P. W. Wild and R. N. Tasto (editors), Life history, environment, and mariculture studies of the Dungeness crab, Cancer magister, with emphasis on the central California fishery resource, p. 135-154. Calif. Dep. Fish Game, Fish Bull. 172.

Waldron, K. D.
1958. The fishery and biology of the Dungeness crab (Cancer magister Dana) in Oregon waters. Fish Comm. Oreg., Contribution 24, 43 p.

Warner, R. W.
1985. Age and growth of male Dungeness crabs, Cancer magister, in northern California. In B. R. Melteff (editor), Proceedings of the symposium on Dungeness crab biology and management, p. 185-187. Univ. Alaska, Alaska Sea Grant Rep. 85-3.

Wickham, D. E.
1979. Predation by the nemertean Carcinonemertes errans on eggs of the Dungeness crab Cancer magister. Mar. Biol. (Berl.) 55:45-53.