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## Distribution, Density, and Size-Class Structure of Dungeness Crabs in the River-Dominated Columbia River Estuary

### Abstract

Dungeness crabs, *Cancer magister*, are important to the large west coast commercial fishing industry, and estuaries are important habitats for the crabs. To better understand the basic dynamics of crab populations, we studied the distribution, density, and size-class structure of Dungeness crabs in the Columbia River estuary (Oregon and Washington) monthly from November 1983 through October 1985. Crabs were generally distributed from the bar (mouth of the estuary) to River Kilometer 28. Overall, crab densities on the bar (mean =  $210 \pm 1061$  (SD) crabs/hectare) were significantly less than densities upstream from the bar (mean =  $395 \pm 1844$  crabs/hectare). Densities on the bar were greatest in spring and summer when young-of-the-year (0+ age) crabs were relatively abundant. Densities of crabs on the bar were significantly greater during the second year of the study (mean =  $391 \pm 1483$  crabs/hectare) than during the first year (mean =  $28 \pm 53$  crabs/hectare). 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. Zero+ age crabs were captured in the estuary beginning in May of both years; no 0+ age crabs were collected in intertidal areas of the estuary. Densities of 0+ age crabs on the bar increased during late spring and summer; however, there was no corresponding increase in densities upstream from the bar. Our data indicate that the Columbia River estuary provides valuable habitat for Dungeness crabs, particularly for crabs <130 mm in carapace width.

### 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 (Pacific Marine Fisheries Commission 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 percent of the Dungeness crab population offshore from San Francisco, California, used the San Francisco-San Pablo Bay complex 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 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.

### Methods

#### Study Area

Unlike many other west coast estuaries, the Columbia River estuary is a river-dominated system. The Columbia River estuary, a drowned river mouth, is strongly influenced by river flows. The highest flows typically occur in the spring, the lowest during late summer and fall. During the study period, estimated flows (monthly averages) ranged from 3,121 m<sup>3</sup>/s in August 1985 to 14,091 m<sup>3</sup>/s in May 1985 (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<sup>3</sup>/s), minimum bottom salinities in most of the lower 22 km of the estuary range from 0.5 to 15.0 ppt, with maximum salinities  $\geq 30$  ppt. Minimum bottom salinities in much of the lower 22 km of the estuary reach 0.0 ppt during high-flow seasons (about 8,800 m<sup>3</sup>/s) (Jay 1984).

### Sampling

Sampling was done from November 1983 through October 1985. A maximum of 22 estuarine sites were sampled each month (Figure 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.

An 8 m semiballoon shrimp trawl, with overall mesh size of 38.1 mm (stretched), was used at 20 of the sampling sites. A 9.5 mm mesh liner was inserted in the cod end of the net to ensure reten-

tion of 0+ age crabs. Fishing width of the trawl was estimated by the manufacturer to be about 5 m. Trawling at each site in the estuary was generally done for 5 min during times of higher salinity (early flood to early ebb tide). 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 10th 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 ( $< 20$  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 ( $^{\circ}$ C) were measured at the surface and near the bottom before each sampling effort using a Beckman

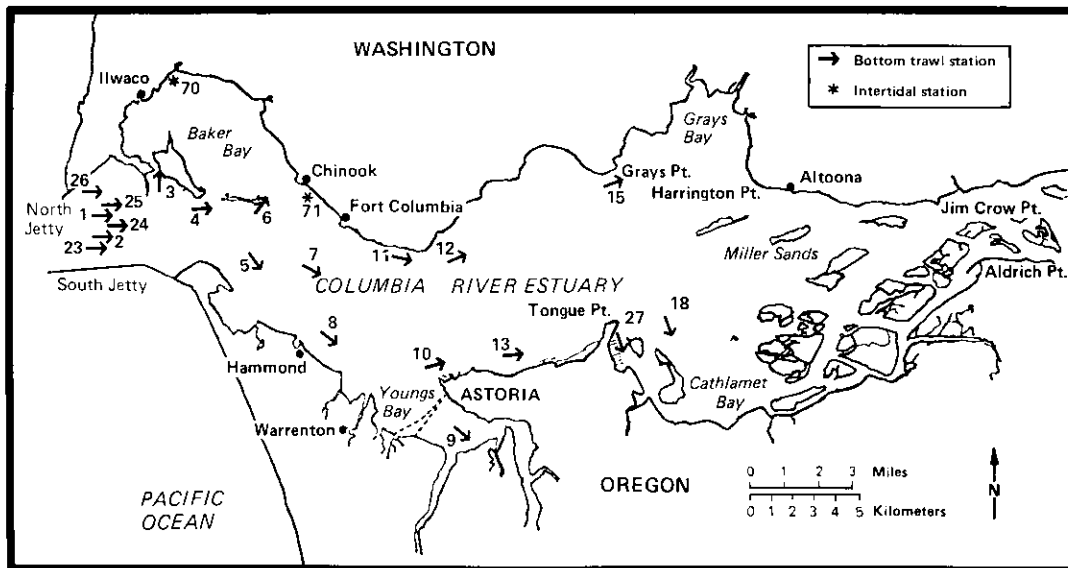


Figure 1. Map of the Columbia River estuary, showing sampling sites for the 2-year Dungeness crab study.

RS5-3 salinometer and temperature probe (Reference to trade names does not imply endorsement by the National Marine Fisheries Service, NOAA).

#### 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 ( $\geq 130$  mm).

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. Densities at the mouth of the estuary [bar (Stations 1, 2, 23-26)] were compared with densities in the area upstream from the mouth (Stations 3-8 and 10-12). 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/hectare + 1) prior to employing regression.

#### Results

Crabs were generally distributed from the mouth of the estuary to about River Kilometer (Rkm) 28 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 density comparisons.

Crab densities (all size classes combined) in the estuary varied considerably among individual stations; also, monthly densities at individual stations frequently varied (Figures 2, 3). Overall, crab densities on the bar (mean =  $210 \pm 1061$

(SD) crabs/hectare) were significantly less than densities in the estuary upstream from the bar (mean =  $395 \pm 1844$  crabs/hectare) (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 (Table 1).

TABLE 1. Seasonal mean densities (number/hectare) of Dungeness crabs (all size classes combined) on the Columbia River bar and in the estuary upstream from the bar; standard deviations are also shown. See text for season descriptions.

Year	Season	Bar		Upstream	
1983	Fall	5.7 $\pm$	10.2	744.7 $\pm$	1284.5
1984	Fall	25.4 $\pm$	22.5	103.3 $\pm$	138.7
1984	Winter	3.5 $\pm$	6.7	122.0 $\pm$	174.9
1985	Winter	27.0 $\pm$	43.0	127.9 $\pm$	161.4
1984	Spring	58.2 $\pm$	75.9	64.2 $\pm$	97.3
1985	Spring	659.3 $\pm$	2022.6	181.2 $\pm$	432.6
1984	Summer	43.9 $\pm$	57.8	164.3 $\pm$	291.2
1985	Summer	839.0 $\pm$	2127.8	1171.5 $\pm$	3701.5

On the bar, densities during the second year (mean =  $391 \pm 1483$  crabs/hectare) were significantly greater than during the first year (mean =  $28 \pm 53$  crabs/hectare) (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 (Table 1).

In the area upstream from the bar, there was no significant difference in densities between the two years (Mann-Whitney,  $P < 0.05$ ). Mean densities for the two years were  $221 \pm 593$  crabs/hectare and  $570 \pm 2539$  crabs/hectare, respectively. 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,  $P < 0.05$ ) (Table 1).

Crab densities by size class and month were examined for the bar and the estuary upstream from the bar (Table 2). Densities of Size Class

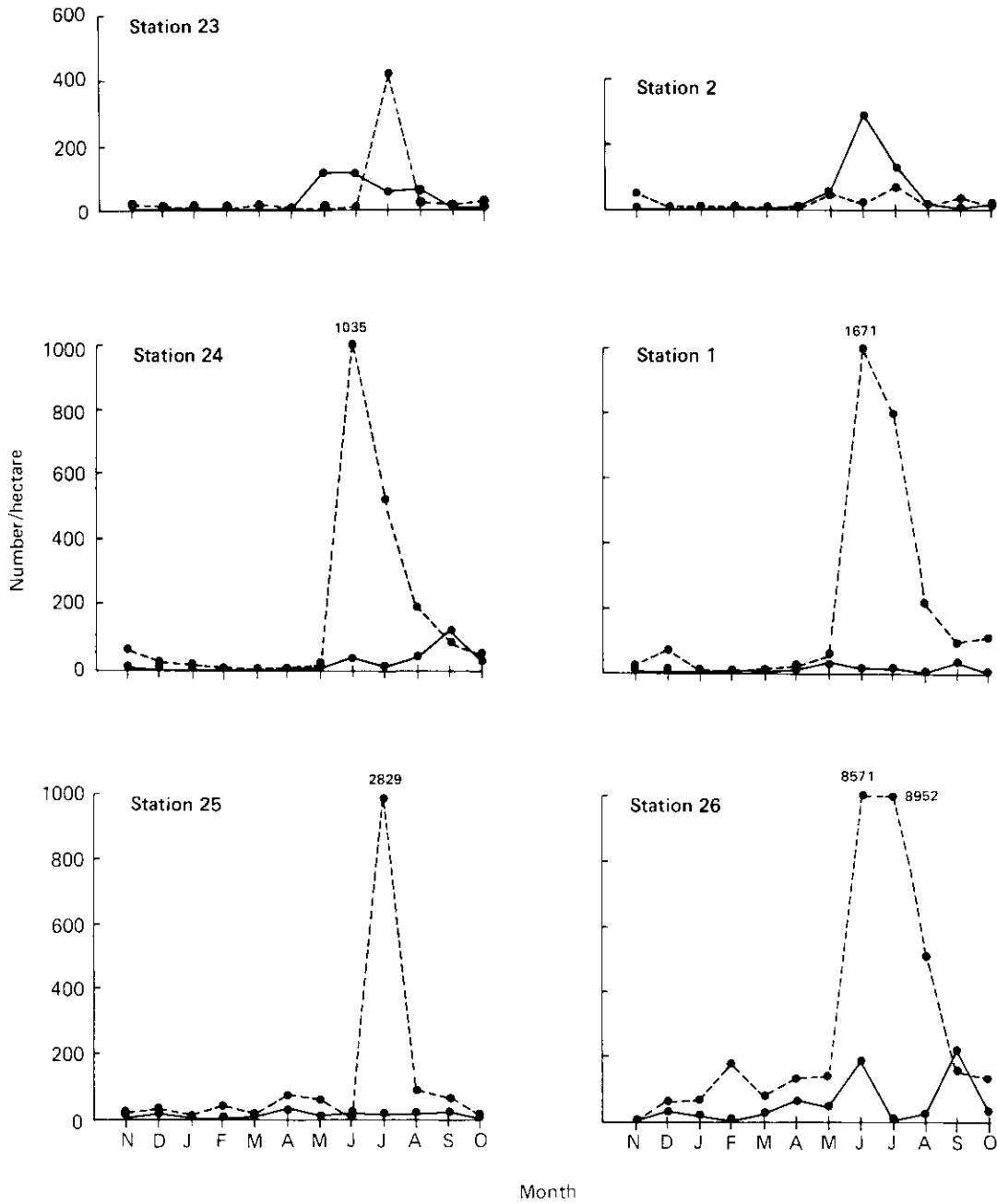


Figure 2. Estimated densities of Dungeness crabs (all size classes combined) at six sampling stations on the Columbia River bar. The solid line represents the first year of the study (Nov. 1983 through Oct. 1984) and the dashed line represents the second year (Nov. 1984 through Oct. 1985).

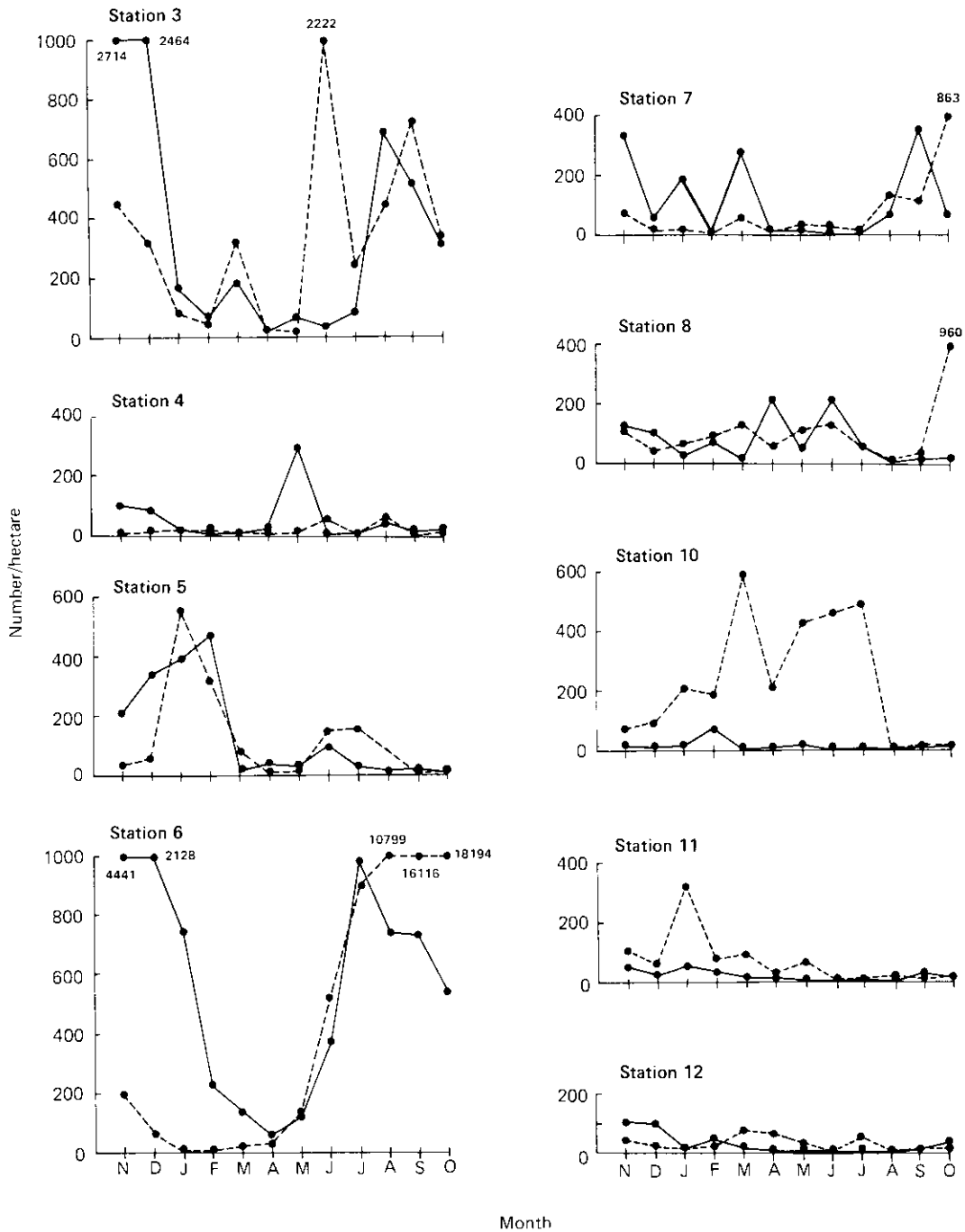


Figure 3. Estimated densities of Dungeness crabs (all size classes combined) at nine sampling stations upstream from the Columbia River bar. The solid line represents the first year of the study (Nov. 1983 through Oct. 1984), and the dashed line represents the second year (Nov. 1984 through Oct. 1985).

TABLE 2. Mean densities (number/hectare) of four size classes of Dungeness crabs on the Columbia River bar and in 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 ± 4290.6	6.9 ± 10.2	122.0 ± 296.5

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. On the bar, Size Class I crabs were much more abundant during June-August 1985 than during the same period in 1984. Mean monthly densities on the bar during June-August 1985 ranged from 153 to 2251 crabs/hectare and during June-August 1984 ranged from 6 to 96 crabs/hectare. 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.

The 0+ age crabs, which began to enter the estuary by early May, entered as early instars or as megalops larvae that metamorphosed to first instar juveniles. Many early instars remained on the bar during spring and summer (Table 2). 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.

Densities of Size Classes II, III, and IV were typically low on the bar (Table 2). 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 (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.

Bottom salinities and temperatures varied spatially and temporally during the study (McCabe *et al.* 1986). 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 percent of the variation explained by salinity or temperature.

## Discussion

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 relatively 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<sup>2</sup>. 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<sup>2</sup> in May and 2/m<sup>2</sup> in July. Densities of early instars in shell debris were even greater than those in eelgrass; they reported densities as high as 115/m<sup>2</sup> 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 and large amounts of shell debris are not found in Baker Bay. Although we examined only two intertidal sites in Baker Bay and did not examine the substrate as thoroughly as did the researchers working in Grays Harbor estuary, 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. Furthermore, during a 1-year benthic study (1980-81), which included monthly sampling along an intertidal and subtidal transect in northwestern Baker Bay, Furota collected only one Dungeness crab (T. Furota, Faculty of Science, Miyama 2-2-1, Funabashi, Chiba 274, Japan, pers. comm.).

Our observations in the Columbia River estuary were similar to those made in Grays Harbor estuary by Stevens and Armstrong (1984), who noted widely fluctuating crab densities (all size classes combined) at individual stations; 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 sampled by them in October-November had >200 crabs/hectare. In the Columbia River estuary, densities were also high at some stations during late spring and summer (Figures 2, 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/hectare) was observed in Baker Bay (Station 6) in October 1985. The primary value of the comparisons is to indicate seasonal differences in relative densities 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 about 80 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 (Figure 3). The lower densities in November 1984 may have resulted in part 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 percent.

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<sup>3</sup> of material would be removed from the entrance channel; annual maintenance dredging for the entrance channel was estimated to be 5.4 million m<sup>3</sup> 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 (K. Larson, U.S. Army Corps of Engineers, P.O. Box 2946, Portland, OR, pers. comm.).

In conclusion, although the Columbia River estuary is a river-dominated estuary with widely fluctuating salinities, subtidal areas provide valuable habitat for Dungeness crabs. Unlike in Grays Harbor estuary, Washington (a more saline estuary), 0+ age Dungeness crabs do not intensively utilize intertidal areas of the Columbia River estuary (Baker Bay).

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