FRI-UW-8616
July 1987

Fisheries Research Institute
University of Washington
Seattle, WA 98195

Distribution and Abundance of Dungeness Crab, *Cancer magister* in Grays Harbor, Washington, and in the Adjacent Nearshore During Fall/Winter 1985/1986

by

B.R. Dumbauld, D.A. Armstrong, and A.R. Black

School of Fisheries
University of Washington

Final Report

for

Seattle District, U.S. Army Corps of Engineers
Seattle, Washington
Contract No. DACW67-85-0033

Submitted July 20, 1987

Approved:

Robert C. Francis
Director

TABLE OF CONTENTS

LIST OF FIGURES

Figure		Page

LIST OF TABLES

Table | Page

ACKNOWLEDGEMENTS

Funding for this study was provided by a contract from the Seattle District Army Corps of Engineers (DACW67-85-0033). The assistance of Army Corps of Engineers personnel Jim Waller, Ann Uhrich, Fred Weinmann, and Kay McGraw is gratefully acknowledged. The authors thank Greg Jensen, Yun Bing Shi, Brandt Gutermuth, Raul Palacios, Ginger Phalen, M.C. Howie of the University of Washington School of Fisheries for their invaluable assistance with the field work and data analysis. Research vessel support was supplied by the fishing vessel Karelia of Westport, Washington and we thank the captain, Vern Heikkila, for his help in completing an often difficult winter field schedule. Some of the data reported on herein was collected as part of a coastal crab research program funded by Washington Sea Grant. Use of the Burroughs mainframe computer at the National Marine Fisheries Service Center in Seattle is appreciated. Thanks also to Carla Norwood, Maureen Phillips-Mead and Jenni Hewes for their help preparing the manuscript and Paul Dinnel, Ron Thom, Kay McGraw, and Jim Waller for reviewing it.

DISTRIBUTION AND ABUNDANCE OF DUNGENESS CRAB (CANCER MAGISTER) IN GRAYS HARBOR, WASHINGTON, AND IN THE ADJACENT NEARSHORE DURING FALL/WINTER 1985-1986

1.0 INTRODUCTION

The Port of Grays Harbor has required maintenance dredging to deepen and stabilize navigation channels since 1905. Increasing demands for improvements to the channel in the mid 1970's led to concerns about possible environmental problems associated with dredging and initiation of studies by the U.S. Army Corps of Engineers (COE) to investigate potential environmental effects. Results indicated that the Dungeness crab, *Cancer magister*, was one of the most important species to be considered, as it supports both a viable sport fishery and the most valuable commercial crustacean fishery in Washington State and would be most impacted by dredging operations (COE 1977; Tegelberg and Arthur 1977). Interest in a major modification to the existing Grays Harbor navigation channel continued to increase, and in 1980 Congress voted to approve funds for studies on the proposed Grays Harbor Navigation Improvement Project, which would remove an estimated 14.2 million cubic yards (mcy) of sediment from the harbor and substantially increase the maintenance dredging from 1.5 to 2.6 mcy per year.

A number of studies on the potential impacts of dredging to juvenile crab populations in Grays Harbor were initiated by the Army Corps of Engineers (Stevens 1981; Armstrong et al. 1982; Stevens and Armstrong 1984). An extensive amount of additional research funded by Washington Sea Grant, particularly a four-year program initiated in 1983, improved preliminary estimates of population abundance in the estuary and, for the first time, measured populations of crab in nearshore coastal regions (Armstrong et al.

1984; Armstrong et al. 1985a; Armstrong and Gunderson 1985; Carrasco et al. 1985; Armstrong et al. 1986). Systematic surveys have indicated variable recruitment of young-of-the-year (YOY = 0+) juveniles to both systems and use of the estuary by a major fraction of 1-year-old (1+) juveniles in spring and summer of each year.

This study is part of a continuing effort by COE to investigate methods of reducing expected crab entrainment and mortality during project construction and future maintenance dredging. This investigation is the result of recommendations by a crab study panel organized by COE to discuss the optimal course of action for avoidance or mitigation of potential crab losses during dredging in Grays Harbor (Pearson 1985). The panel anticipated that operational changes, particularly those involving scheduling, will have the greatest potential effect in reducing crab entrainment, and recommended that (1) tests be run with a modified draghead, (2) crab population studies be conducted in fall and winter to evaluate movement and abundance of populations during seasons in which Sea Grant data were not available, and (3) pilot studies be conducted to determine the feasibility of introducing intertidal shell habitat for juvenile crab as a mitigation technique. Previous work (Armstrong and Gunderson 1985) had shown a high degree of association between intertidal 0+ crab density and shell refuge.

This report covers the results of the recommended crab population studies that took place from October 1985 through March 1986. Data from the summer of 1985 collected by the Sea Grant research team and reported by Armstrong et al. (1986) are also utilized extensively to complete a year-long series of crab population estimates and distribution. The outcome of the draghead modification experiments (McGraw et al. 1987), the shell mitigation field test and intertidal crab survey (Dumbauld and Armstrong 1987), and studies to further quantify dredge entrainment of crab relative to trawl survey estimates (Dinnel et al. 1986a; Dinnel et al. 1986b) are reported elsewhere. Results from all of these studies have been incorporated in an effort to model the potential impacts of dredging on the Dungeness crab population in Grays Harbor and the nearshore coastal area (Armstrong et al. 1987).

The primary objectives of the crab population study were as follows:

1. Determine the timing and extent of crab movement from the estuary to the nearshore region adjacent to the estuary mouth in order to minimize dredge impacts during crab outmigration.
2. Determine the number and relative density of crabs at locations near the estuary mouth and nearshore where dredging and disposal might impact juvenile crab.
3. Determine the age class of crabs and presence of ovigerous females.
4. Sample for crabs buried in the bottom sediments during winter months to improve the accuracy of overwinter abundance estimates for the estuary.
5. Compare the results of this study with those from previous work and indicate the significance of seasonal patterns in crab abundance relative to dredging operations and disposal site locations.

1.1 Approach

The focus of the fall/winter sampling effort as stated in objective 1 above was to answer the question: Do crab emigrate from the estuary and overwinter in nearshore areas? Two approaches to this problem were taken. The first considered the circumstantial evidence of decreasing estuarine crab abundance as indicative of emigration. This approach, referred to herein as the "population reduction" approach, was based on continued sampling of stations throughout the estuary to complete a series of estimates of population abundance and density from summer (Sea Grant Data series) through fall to winter. The second approach was to trace movement patterns of crab as abundance shifted east to west from inside the estuary to the mouth, and finally to the nearshore coastal zone. This approach, referred to herein as the "movement" approach, relied on more frequent sampling of a new array of stations in the estuary mouth and nearshore coastal area during the fall. This approach also addressed objective 2 above regarding the relative density of crabs in locations near the estuary mouth and just offshore where dredging and disposal operations could impact juvenile crab populations. The results from both approaches were applicable to objective 5.

Two additional questions regarding the overwinter distribution of juvenile crab were also addressed: (1) Do crab that overwinter in the estuary bury during cold winter months? Information on this aspect of crab behavior would influence the interpretation of estuarine time series data and the results of both approaches to the question of emigration. If crab were found in dredge samples but not in trawl catches, then winter trawl data could not be considered representative. (2) If crab emigrate to the nearshore coastal areas, do they remain in an area close to the estuary mouth or do they distribute themselves more widely by depth?

2.0 MATERIALS AND METHODS

2.1 Sampling Gear

Dungeness crab were sampled with a 3m plumb staff beam trawl (Fig. 1) which has become the standard survey gear for both newly settled 0+ and older

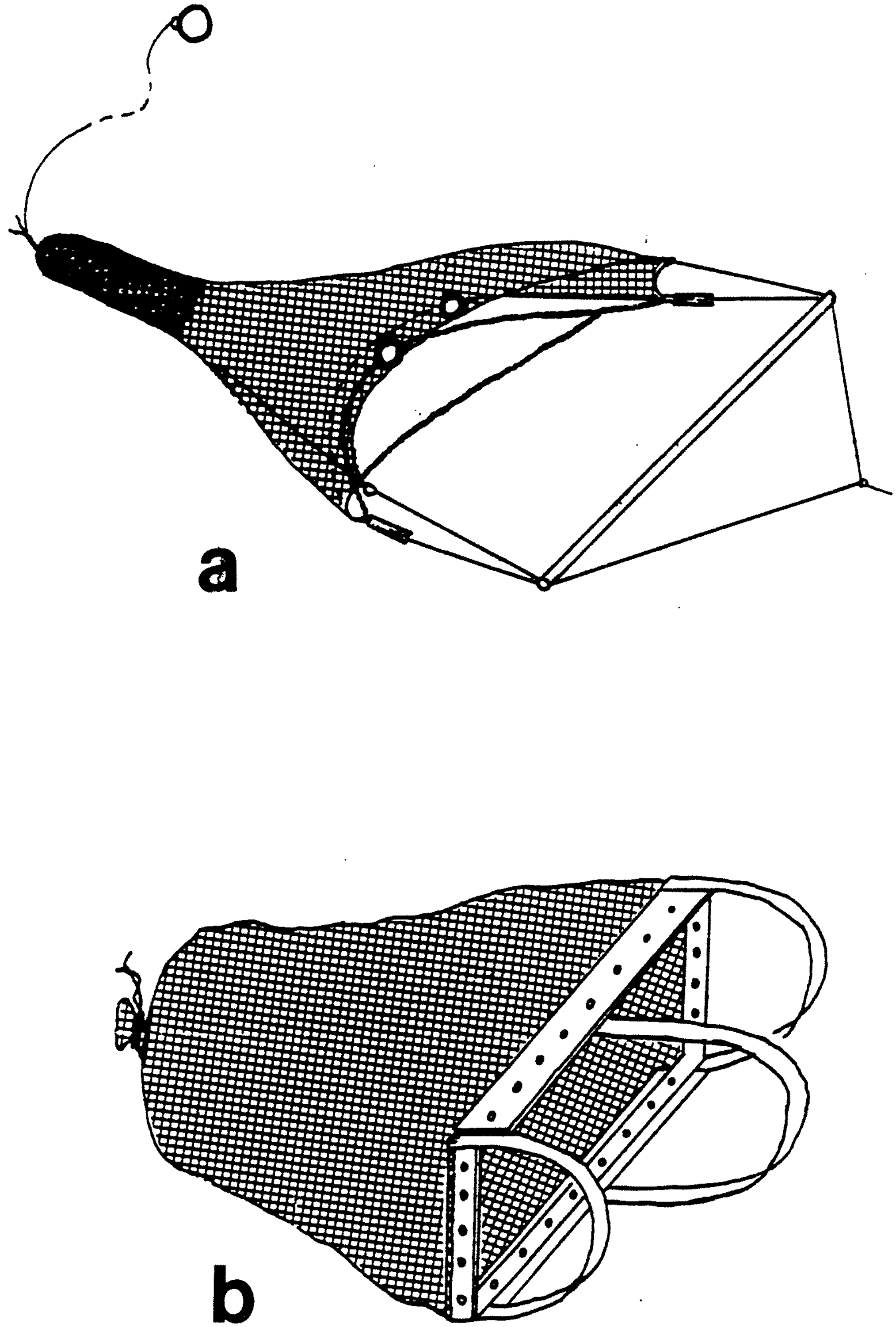

Figure 1. Fishing gear used to sample Dungeness crab in this study included A) a modified plumb staff beam trawl with a 3m beam and B) a 1m rock dredge designed to excavate buried crab (note figures are not drawn to scale).

crab along the Washington coast (Armstrong and Gunderson 1985; Gunderson and Ellis 1986) and in Puget Sound (Dinnel et al. 1985). Three trips to sample for buried crab utilized a 1.0m biological rock dredge which has been used to sample juvenile king crab (as small as 3 mm length) in the Bering Sea (Fig. 1, Armstrong et al. 1985b). Most operations were conducted from the Karelia, a chartered fishing vessel out of Westport, Washington. When weather permitted, a Boston Whaler was used to sample stations in the estuary, particularly those that were inaccessible to the larger vessel. All captured Dungeness crab were counted and sexed. Carapace width (CW) was measured to the nearest millimeter and crabs were returned live to the area of capture. Fish from selected stations were also retained for later laboratory analysis and are being processed as part of a thesis project at the University of Washington (Shi, unpublished results). Surface and bottom water temperature and salinity samples were taken at selected stations with a Niskin bottle.

2.2 Survey Design

Bimonthly cruises were made from October through December, 1985 and monthly cruises in January, February, and March 1986 for a total of 9 trips and 315 trawl samples (335 trawl samples were taken by Sea Grant researchers in the summer of 1985 for a total of 650 reported on herein, Table 1). The station arrays and stratified groupings of these stations were structured to answer the questions regarding possible movement and winter distribution of juvenile crab discussed in Section 1.1 as explained below.

Table 1. Cruise dates and number of samples taken during Fall/Winter 1985-1986 in Grays Harbor and adjacent nearshore areas.

Cruise	Dates	Rock Dredge Samples	Total No. Trawls
8501-8514	4/85 - 9/86		335*
8515	10/13/85-10/16/85		33
8516	10/23/85-10/29/85		34
8517	11/5/85-11/7/85		31
8518	11/21/85-11/25/85	15	36
8519	12/6, 12/7, 12/11/85		33
8520	12/17, 12/18, 12/20/85		38
8601	1/15/86-1/19/86	15	34
8602	2/20/86-2/22/86	15	36
8603	3/17/86-3/20/86		40
	Total	45	650

* These data were taken as part of a School of Fisheries/Sea Grant study of juvenile crab recruitment (Armstrong et al. 1986) used for a larger time series of crab distribution and abundance.

2.2.1 Population Reduction Approach

The survey design and sampling protocol within Grays Harbor followed that used in during previous work sponsored by Sea Grant (Armstrong and Gunderson 1985; Carrasco et al. 1985; Gunderson et al. 1985) and all stations sampled in the spring and summer were retained for fall and winter (Fig. 2, Appendix A). Stations were sampled at least once a month. Total estuarine population estimates were derived for fall and winter to allow comparison with similar spring and summer estimates and identify trends indicating possible migration. The Sea Grant subtidal trawl survey design was used for this analysis. The design is based on stratified random sampling within 4 geographical strata corresponding to the area below MLLW in: 1) the Outer Harbor, 2) the North Bay; 3) the Inner Harbor, and 4) the South Bay (Fig. 2; Table 2, strata group A, SGA).

2.2.2 Movement Approach

The second approach, which involved a closer assessment of movement patterns on a smaller spatial scale, required the addition of 9 stations to the Sea Grant estuary survey. These stations, located from the region between the north and south jetty to Westport (Fig. 3, Appendix A), were sampled on each trip as weather permitted. The estuary mouth region was divided into 2 new strata (12 and 13) for data analyses (Fig. 3; Table 2, Strata Group B, SGB).

Thirteen stations located on 4 transect lines (TL) just off the Grays Harbor jetty entrance were also sampled (Fig. 4, Appendix A, TL3 through TL6). Each line had an array of 3 stations at depths of approximately 15,

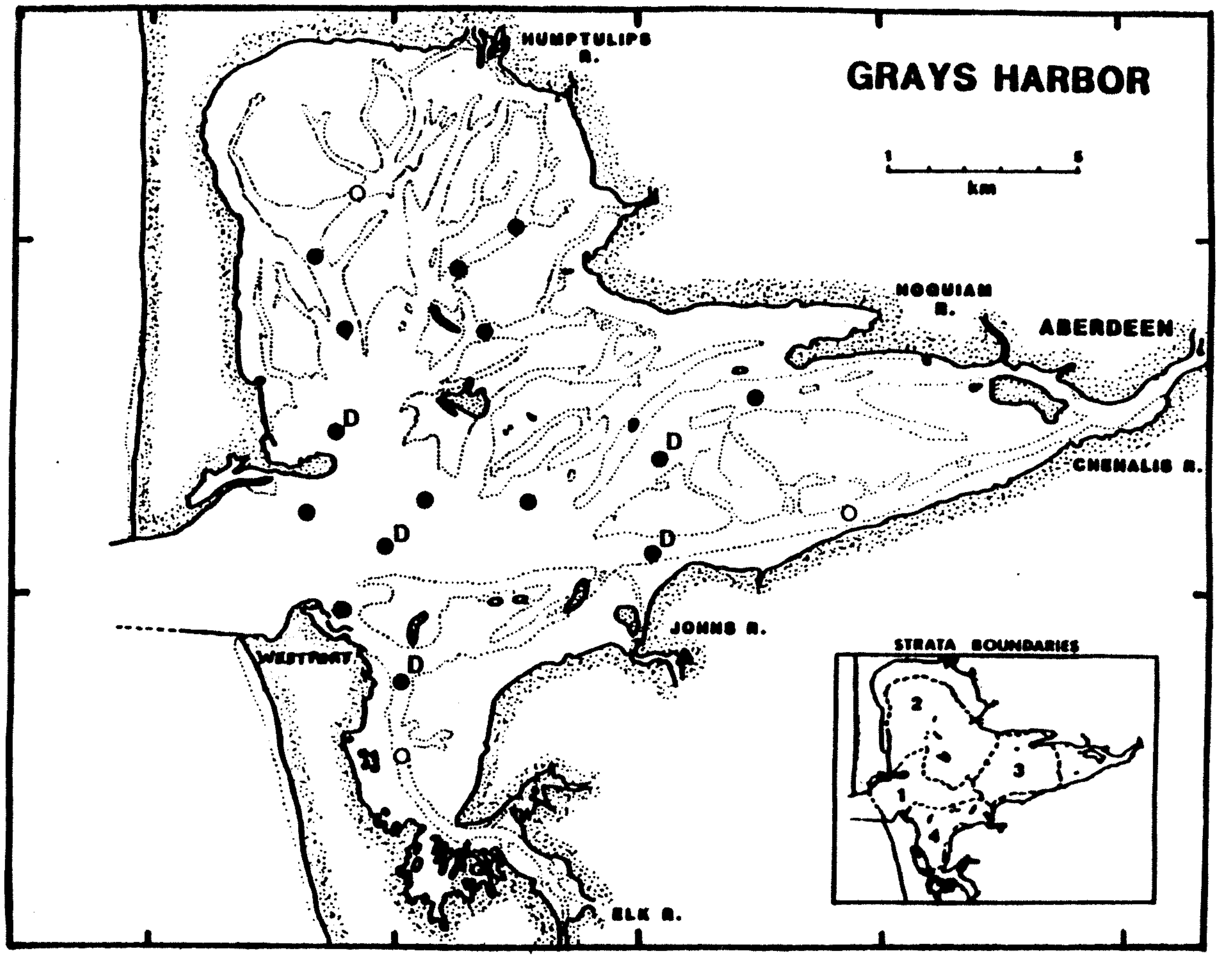

Figure 2. Sea Grant/Army Corps Grays Harbor 1985/1986 survey design. Station locations are indicated by dark circles (see Appendix A for exact locations). Three stations (open circles) were not sampled regularly during the Fall/Winter study. Five stations labeled D were also sampled with a biological rock dredge. Four strata boundaries used in this study and previous Sea Grant surveys are shown in the inset. Intertidal regions are outlined by light dashed lines (boundaries at MLLW).

Table 2. Geographical strata groupings for stations. Strata Group A represented the estuary design used in previous Sea Grant surveys and grouped nearshore coastal stations into 2 large blocks (north and south). Strata Group B utilized two new estuary mouth strata (12 & 13) and 3 nearshore strata with stations grouped by depth (Strata 8 through 10).

Stratum Number	Description	Area (hectares)	Number of Stations Within Stratum
	STRATA GROUP A		
1	Outer Harbor	3651	8
2	North Bay	2516	6
3	Inner Harbor	1548	4
4	South Bay	830	3
14	North Nearshore	5841	6
15	South Nearshore	10714	6
	STRATA GROUP B		
2-4	Same as above	same	same
8	Nearshore (9-22m)	6687	4
9	Nearshore (23-33m)	2553	4
10	Nearshore (34-44m)	7315	4
12	Outer Harbor Mouth	2594	5
13	Jetty	1751	9

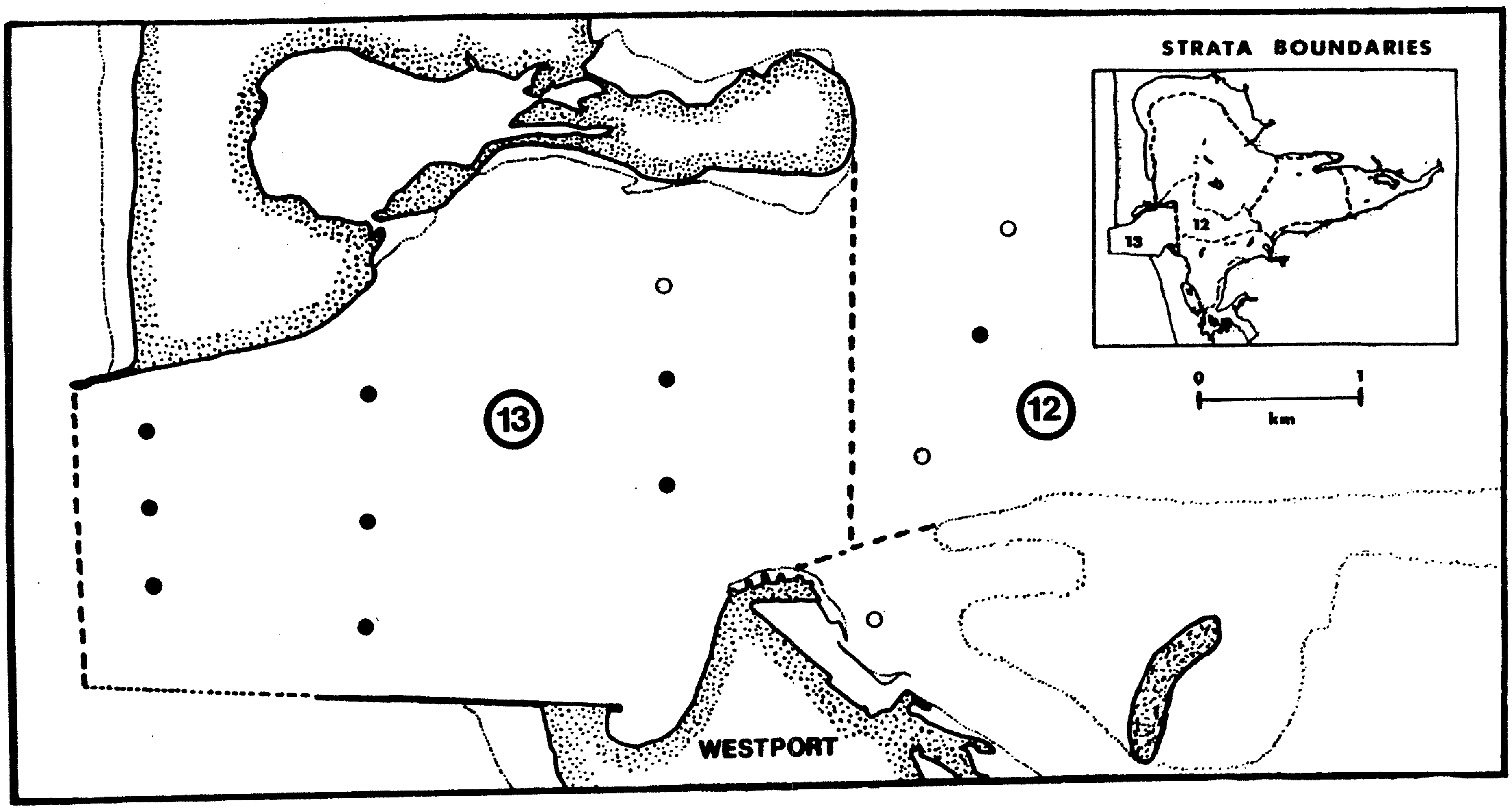

Figure 3. Estuary mouth survey design, Winter 1985/1986. Open circles are standard Sea Grant estuary stations. Nine additional stations (dark circles) were added to detect crab movement patterns (see Appendix A for exact locations). New estuary mouth strata boundaries are also shown (dashed lines, see inset for complete Stratum 12 boundaries).

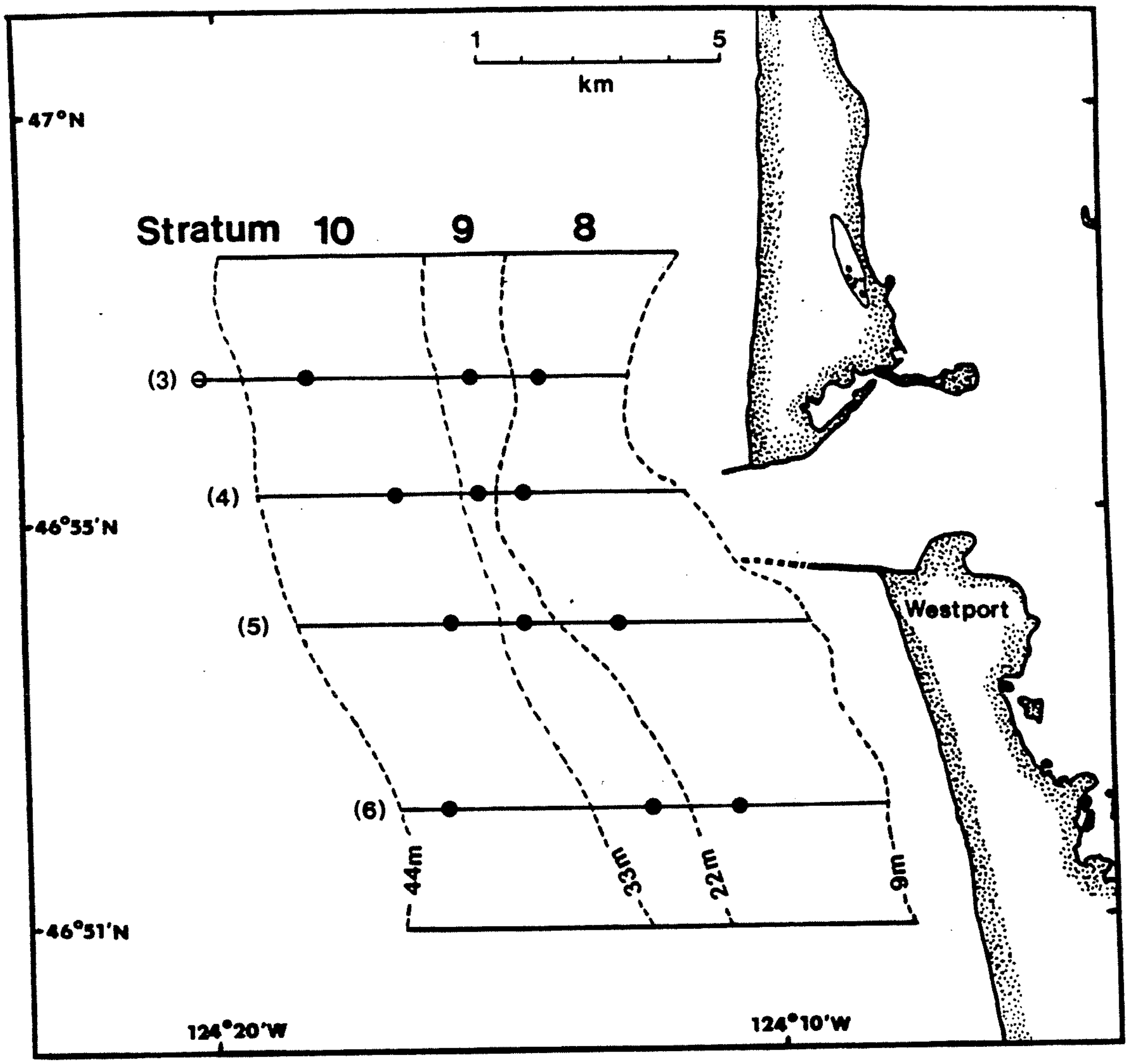

Figure 4. Nearshore survey area design Fall/Winter 1985/1986. Station array includes 3 stations (dark circles) on each of 4 transect lines (TL3-TL6; see Appendix A for exact locations). One station was added to TL3 at 46 m depth to give crab density estimates at the proposed "8 Mile" disposal site (open circle). Strata included stations in common depth intervals; Stratum 8 (9-22 m, 6687 ha), Stratum 9 (23-33 m, 2553 ha), and Stratum 10 34-40 m (7315 ha).

27, and 40m. A station was added at 46m on TL3 to give crab density estimates at the proposed "8 Mile" disposal site. TL6 corresponds to the Westport line previously sampled in Sea Grant surveys (Figs. 4 and 5; Carrasco et al. 1985). TL3 off Point Brown, TL4 off the North Jetty and TL5 off Point Chehalis were all new lines established to monitor crab movement in areas near the mouth and close to proposed offshore dredge disposal sites. A station at 40m depth on the Westport Line (TL6) was located in the southwest towboat lane at a proposed dredge disposal site previously sampled for crabs (Armstrong and Armstrong 1986). Several other stations were in the area associated with the west towboat lane.

Nearshore strata 8, 9, and 10 were based on depth interval 9-22m, 23-33m and 34-44m respectively (Fig. 4, Table 2, SGA). Two additional strata were used to define movement on a larger scale within the nearshore coastal system. Stratum 14 (Str. 14) represented the northern half of the study area (TL3 and TL4) and Str. 15 represented the southern half of the study area (TL5 and TL6) (Table 2, Fig. 6, SGB). Population abundance and density estimates were calculated for crab catches in each stratum. Only density estimates could be directly compared with previous nearshore Sea Grant data because of the difference in area covered (Fig. 5), but because strata 5 through 7, used in the spring and summer Sea Grant survey, were also based on depth, qualitative comparisons of population estimates were also made.

Five estuarine stations were sampled with a biological rock dredge (Fig. 2) on each of 3 trips to address the issue of crab burial and trawl net efficiency. Three replicate tows were made at each station, crabs were counted, measured to the nearest millimeter, sexed, and returned to the sampling area.

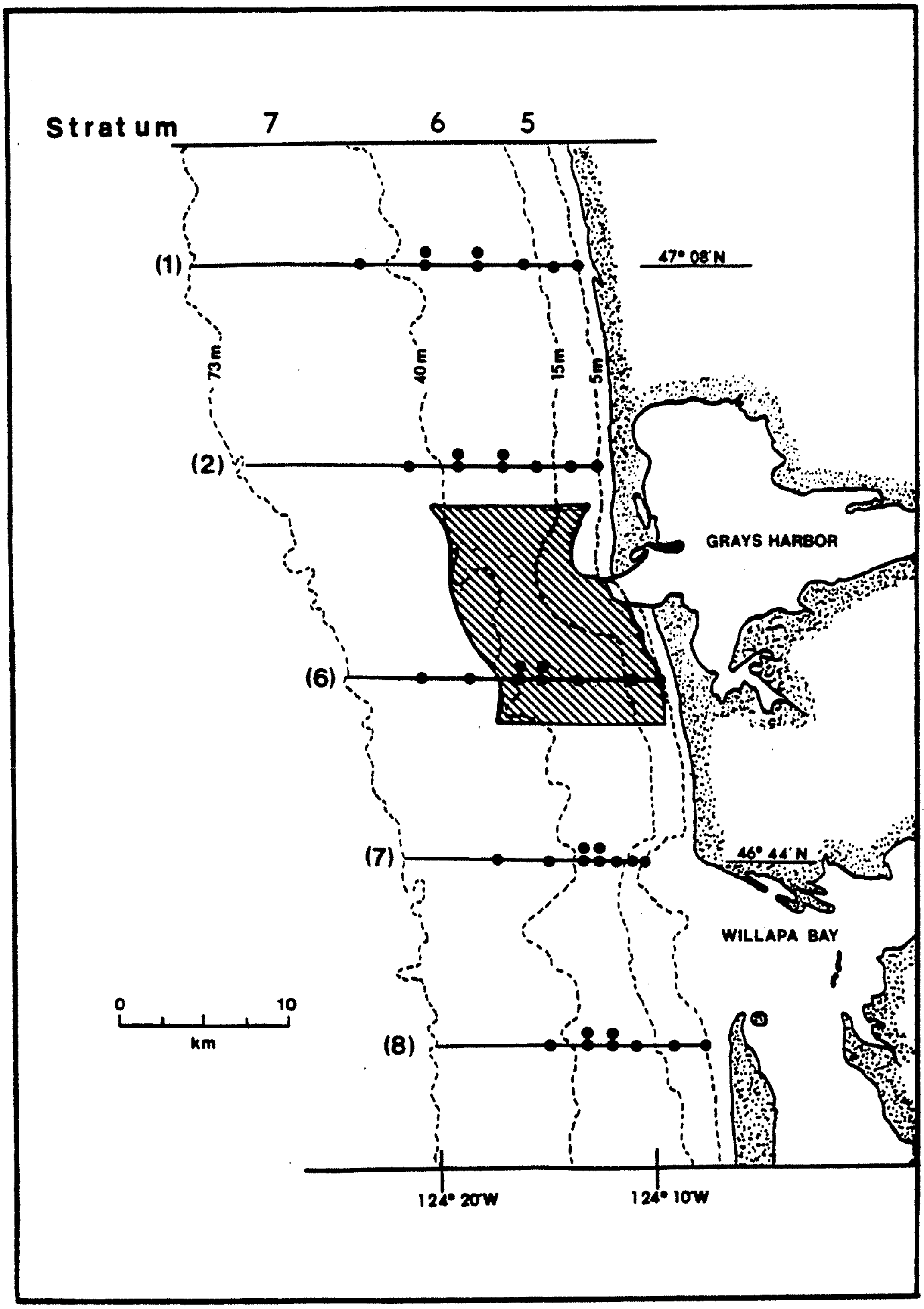

Figure 5. Nearshore survey area design Summer 1985 showing standard Sea Grant station array (dark circles) on 5 transect lines (TL1, TL2, TL6-TL8) used to estimate crab populations for the southern coast of Washington. Strata 5-7 included stations in common depth intervals (5-15m, 16-40m, 41-73m, respectively). Shaded area depicts Winter study area (see Fig. 3).

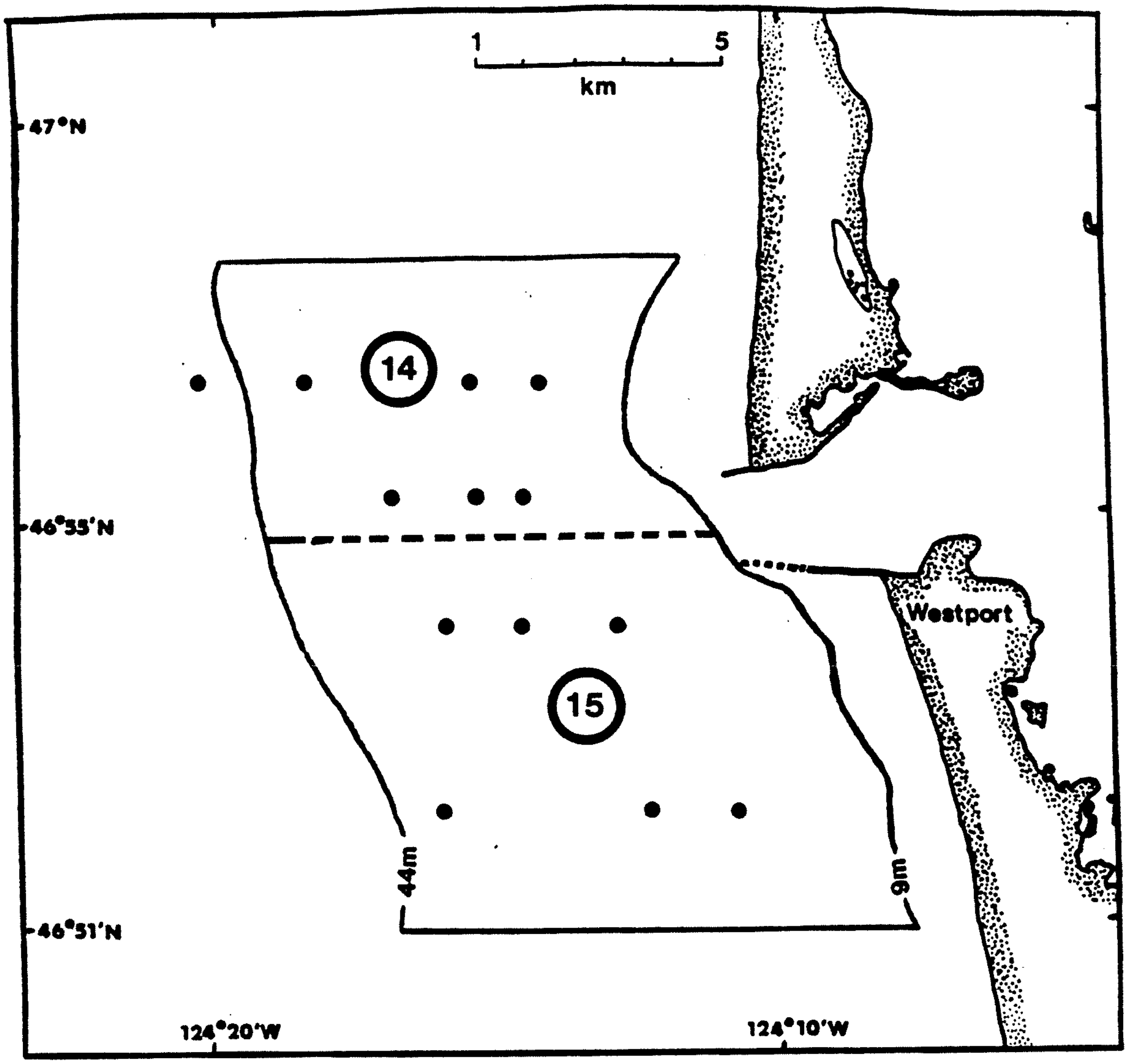

Figure 6. Nearshore survey area Fall/Winter 1985/1986. Stratum 14 (5841 ha) representing the northern half of the study area and Stratum 15 (10,714 ha) representing the southern half, were used to define movement on a large scale in the nearshore system (Table 2, Stratum group B; see also Fig. 4 for alternate stratum design).

2.3 Data Analyses

Data analyses were performed using programs made available on the Burroughs 7800 computer at the National Marine Fisheries Service Center (NMFS) in Seattle. Some statistical analyses and graphs were also made using an IBM XT microcomputer. The catch of crabs at each station was converted to density (number per hectare (ha)) using the following formula:

$$\text{catch} \times \frac{10{,}000}{\text{area swept}(m^2)} = \text{numbers crab/ha}$$

where: area swept = trawl distance towed (m) x width of net opening (2.3m).

Distance towed was obtained from Loran C readings or radar fixes onboard the Karelia or by using buoys and an optical rangefinder on the Boston Whaler. Population estimates were made according to the area swept technique described by Armstrong and Gunderson (1985), and area estimates for each stratum were made with a computerized digitizer at NMFS (Table 2). Size frequency observations were weighted to the density estimates (numbers/ha) and then expanded to obtain estimates of population size per millimeter increment. These estimates were then plotted on a percentage basis to obtain size composition of the population.

Mean crab density and size composition information was generated for biological rock dredge samples to allow comparison on a station by station basis with similar beam trawl data.

3.0 RESULTS

3.1 Estuary

3.1.1 Population Density and Abundance

Abundance estimates for the total subtidal crab population in Grays Harbor from October 1985 through March 1986 suggested a stable population of 5 to 7 million crab with the exception of a marked drop to approximately 1 million crab in December 1985 (Table 3, Fig. 7). These estimates were not much lower than those found in the summer months of June through September 1985 which are also depicted in Fig. 7 (Armstrong et al. 1986, Table 4). The mean ratio of males to females was 56/46 with some variation but no consistent pattern between strata or dates. No females with eggs (ovigerous) were found in the estuary or estuary mouth, which is consistent with previous findings (Stevens and Armstrong 1984).

Population density was greatest in Str. 4 (South Bay) in October and November but variability was high. Density was very low in all strata in December, particularly in the North Bay (Str. 2) where a mean density of 4 crabs per hectare was found. In January and March however, density and population estimates were highest in the North Bay, (1800 - 2,000 crabs/ha), a situation comparable to that found in the summer months of 1985 when densities ranged from 1,000 to 3,000 crab/ha (Armstrong et al. 1986; Tables 3 and 4, Fig. 8). The proportion of the crab population found in Str. 2 dropped from 60% in September to 30% in November and only 1% in December, but rose sharply to 90% again in January (Table 3). Although the proportion of the population found in the Outer Harbor (Str. 1) increased to 70% in December, the total population abundance in this area declined from nearly 3 million in October to less than 1 million from December through March (Fig. 8).

Table 3. Crab density and population estimates in Grays Harbor, Fall/inter 1985, by stratum and total for the estuary by month. The area of each stratum is given below in hectares. SE = standard error.

Month Year	Stratum	Density no/ha	Density ±2SE	Population Estimates (millions) Within Stratum	±2SE	Stratum Proportion	Estuary Total	±2SE
10/85	1	757	361	2.77	1.32	0.40	6.90	2.34
	2	831	256	2.09	0.64	0.30		
	3	473	157	0.73	0.24	0.11		
	4	1579	2178	1.31	1.81	0.19		
11/85	1	659	386	2.41	1.41	0.36	6.66	2.73
	2	761	432	1.92	2.17	0.29		
	3	651	407	1.01	0.63	0.15		
	4	1594	707	1.32	0.60	0.20		
12/85	1	218	99	0.80	0.36	0.70	1.13	0.45
	2	4	9	0.01	0.02	0.01		
	3	94	72	0.15	0.12	0.13		
	4	215	294	0.18	0.24	0.16		
1/86	1	132	98	0.48	0.36	0.09	5.21	3.95
	2	1841	1565	4.63	3.94	0.89		
	3	31	18	0.05	0.03	0.01		
	4	55	16	0.05	0.01	0.01		
2/86	1	249	75	0.91	0.27	-	-	-
	2	n.s.	-	n.s.	-	-		
	3	360	402	0.56	0.62	-		
	4	113	142	0.09	0.12	-		
3/86	1	109	37	0.40	0.14	0.06	6.58	8.54
	2	2326	3255	5.85	8.19	0.89		
	3	173	97	0.27	0.15	0.04		
	4	67	168	0.06	0.07	0.01		

n.s. = not sampled

Strata Areas

1	3651 hectares
2	2516 hectares
3	1548 hectares
4	830 hectares

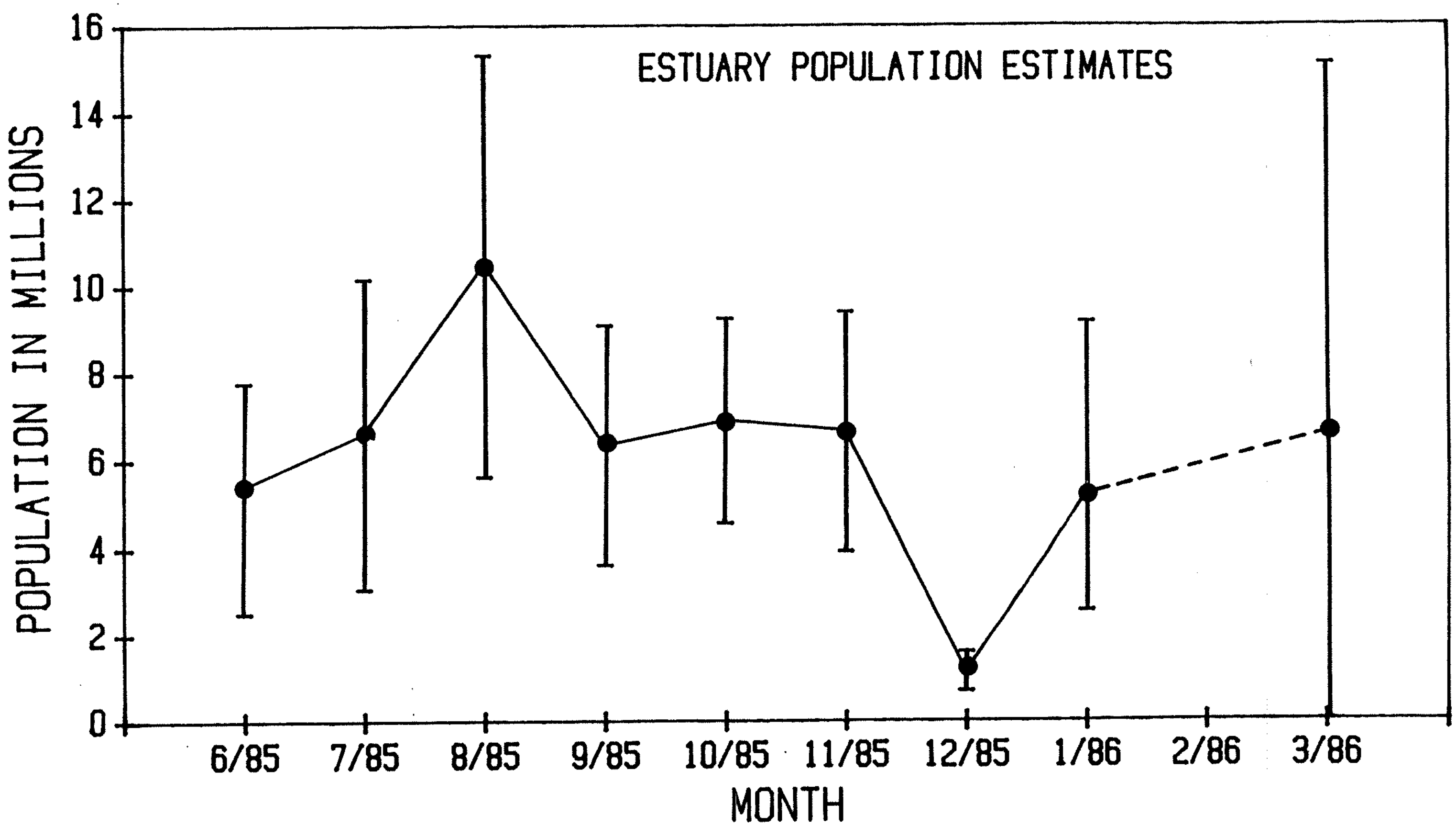

Figure 7. Population estimates for Dungeness crab in Grays Harbor from June 1985 to March 1986. Values given are mean population estimates (4 strata combined). Vertical bars represent ± 2 standard errors (SE) and dashed line indicates missing value for February.

Table 4. Crab density and population estimates in Grays Harbor, summer 1985, by stratum and total for the estuary by month. The area of each stratum is given below in hectares. SE = standard error.

Month Year	Stratum	Density no/ha	Density ±2SE	Population Estimates (millions) Within Stratum	±2SE	Stratum Proportion	Estuary Total	±2SE
4/85	1	197	134	0.72	0.49	0.08	9.16	12.74
	2	3176	5060	7.99	12.73	0.87		
	3	254	120	0.39	0.19	0.04		
	4	64	49	0.05	0.04	0.01		
4/85	1	486	542	1.77	1.98	0.37	4.84	3.18
	2	1036	949	2.61	2.39	0.54		
	3	283	444	0.44	0.69	0.09		
	4	29	37	0.02	0.03	0.00		
5/85	1	109	47	0.40	0.17	0.08	5.21	3.80
	2	1749	1509	4.40	3.80	0.85		
	3	151	65	0.23	0.10	0.04		
	4	208	187	0.17	0.16	0.03		
5/85	1	397	185	1.45	0.68	0.16	9.01	5.55
	2	2624	2185	6.60	5.50	0.73		
	3	414	236	0.64	0.37	0.07		
	4	385	118	0.32	0.10	0.04		
6/85	1	366	434	1.34	1.59	0.25	5.39	2.88
	2	1130	911	2.84	2.29	0.53		
	3	201	70	0.31	0.11	0.06		
	4	1084	850	0.90	0.71	0.17		
7/85	1	752	714	2.75	2.61	0.42	6.61	3.55
	2	1181	936	2.97	2.36	0.45		
	3	190	122	0.29	0.19	0.04		
	4	720	526	0.60	0.44	0.09		
8/85	1	1142	642	4.17	2.35	0.40	10.47	4.85
	2	2326	1686	5.85	4.24	0.56		
	3	103	45	0.16	0.07	0.02		
	4	352	136	0.29	0.11	0.03		
9/85	1	415	445	1.52	1.63	0.24	6.35	2.73
	2	1522	822	3.83	2.07	0.60		
	3	156	100	0.24	0.15	0.04		
	4	920	861	0.76	0.71	0.12		

Strata Areas

1	3651 hectares
2	2516 hectares
3	1548 hectares
4	830 hectares

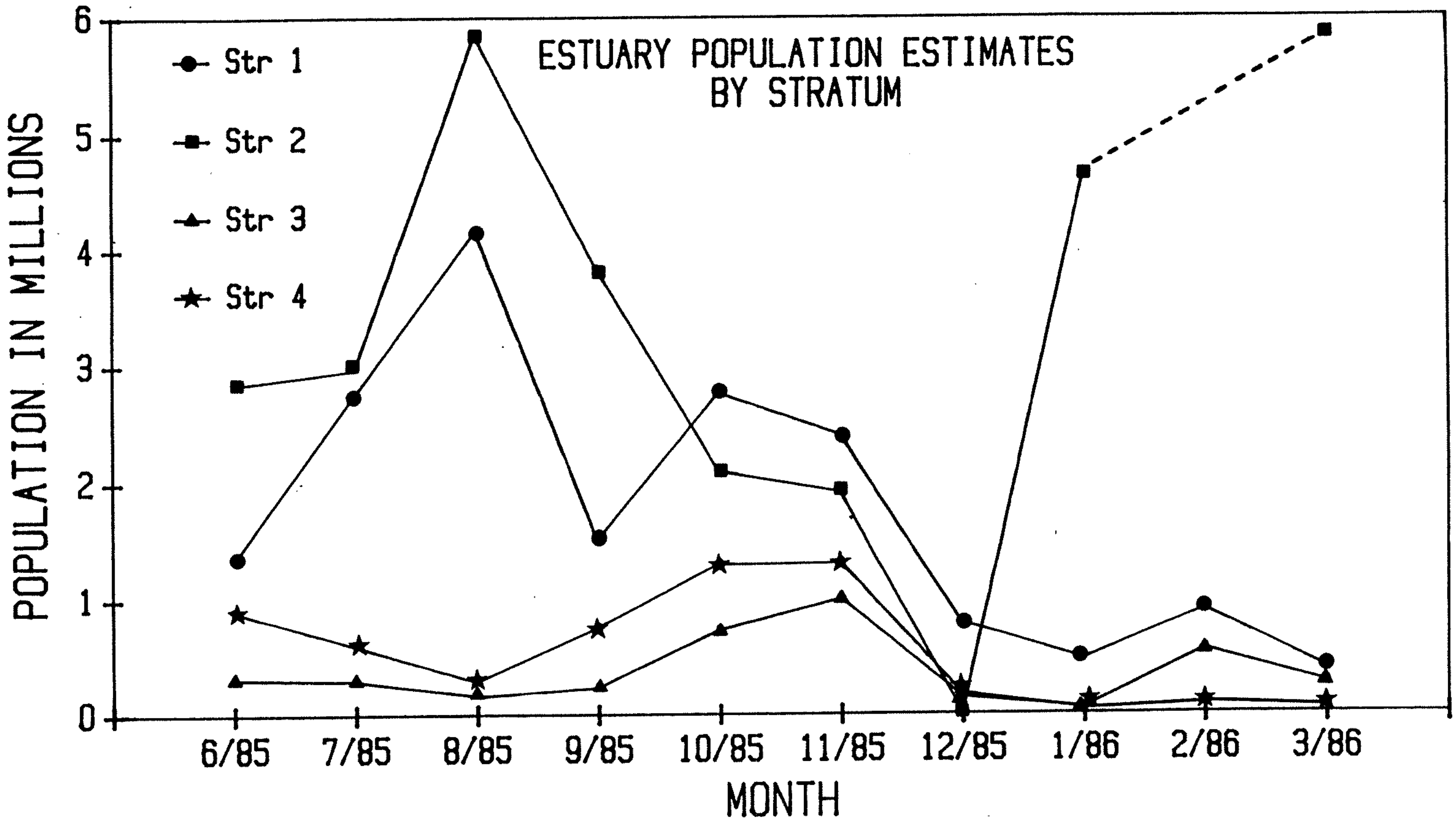

Figure 8. Population estimates for Dungeness crab in Grays Harbor by stratum location (see map Fig. 1). Dashed line indicates missing value for the North Bay in February.

3.1.2 Size Composition

Size frequency histograms for the spring and summer of 1985 indicated 0+ crab (YOY) appeared in Grays Harbor in May at 7 mm CW and by August had grown to between 30 and 40 mm CW (Armstrong et al. 1986; Fig. 9). A second cohort of smaller (20 to 30mm) crabs was also evident in August. Similar histograms of data for fall and winter 1985/86 (Fig. 10) also indicated the presence of 2 distinct cohorts of 0+ crab, particularly in October 1985. The smaller size cohort apparently resulted from later settlement or settlement in an area where growth was slower (e.g. nearshore). Figure 11 shows that this smaller size class was found primarily in the outer harbor (Str. 1, see Dinnel et al. 1986), which is consistent with nearshore origin.

The strong 1984 year class of 1+ juveniles was clearly defined throughout the summer of 1985 (Armstrong et al. 1986, Fig. 9). In April crabs were a mean size of 52 mm CW and ranged from 45 - 75 mm CW. By September, these crabs had molted at least once and reached a mean size of about 80 mm CW. The range of sizes in the age class had expanded dramatically (55 - 110mm CW), perhaps due to continual immigration of smaller individuals from offshore. A broad range in size remained evident through the fall and winter of 1985/86 when crab appeared to molt once again achieving a mean size of approximately 100 mm CW by February, 1986 (Fig. 9, Appendix B). Crab older than 1+ never comprised a substantial part of the estuarine population but ranged in size from a mean of 89mm in June to 127mm in September and 140mm in March 1986 (Figs. 9 and 10).

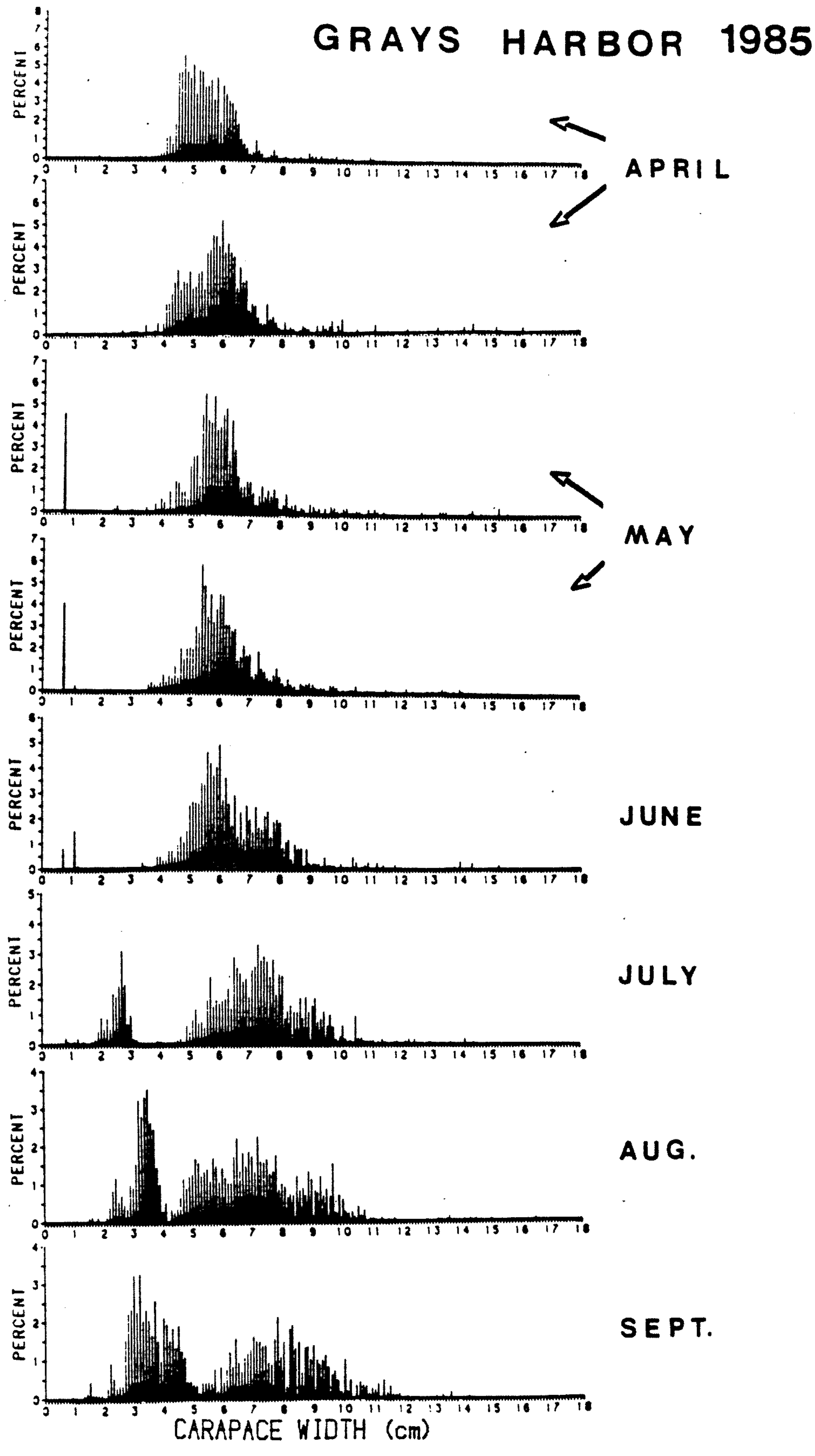

Figure 9. Size composition of Dungeness crab population in Grays Harbor (strata combined) by trip in April to September 1985.

GRAYS HARBOR 1985-1986

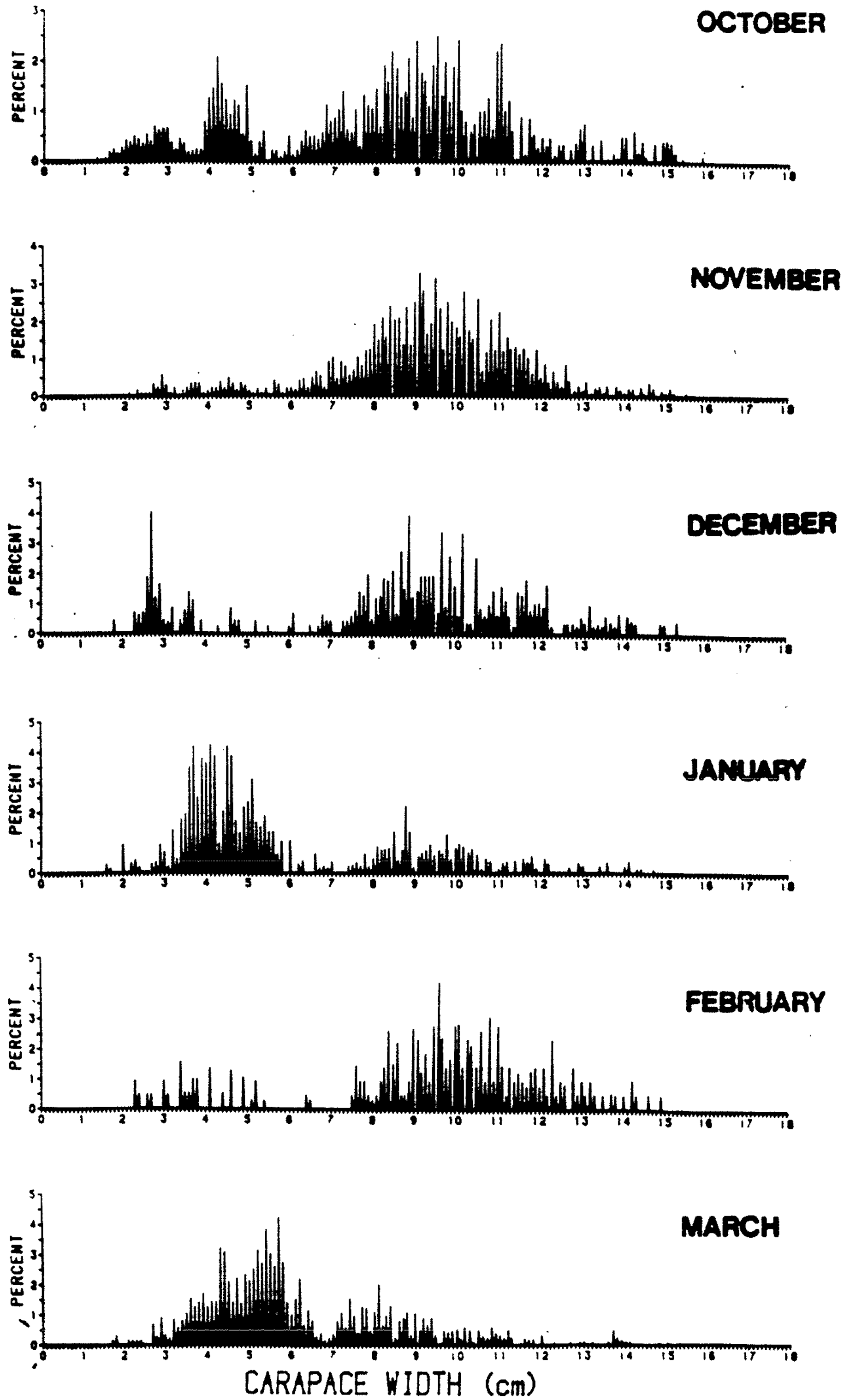

Figure 10. Size composition of Dungeness crab population in Grays Harbor (strata combined) October 1985 to March 1986.

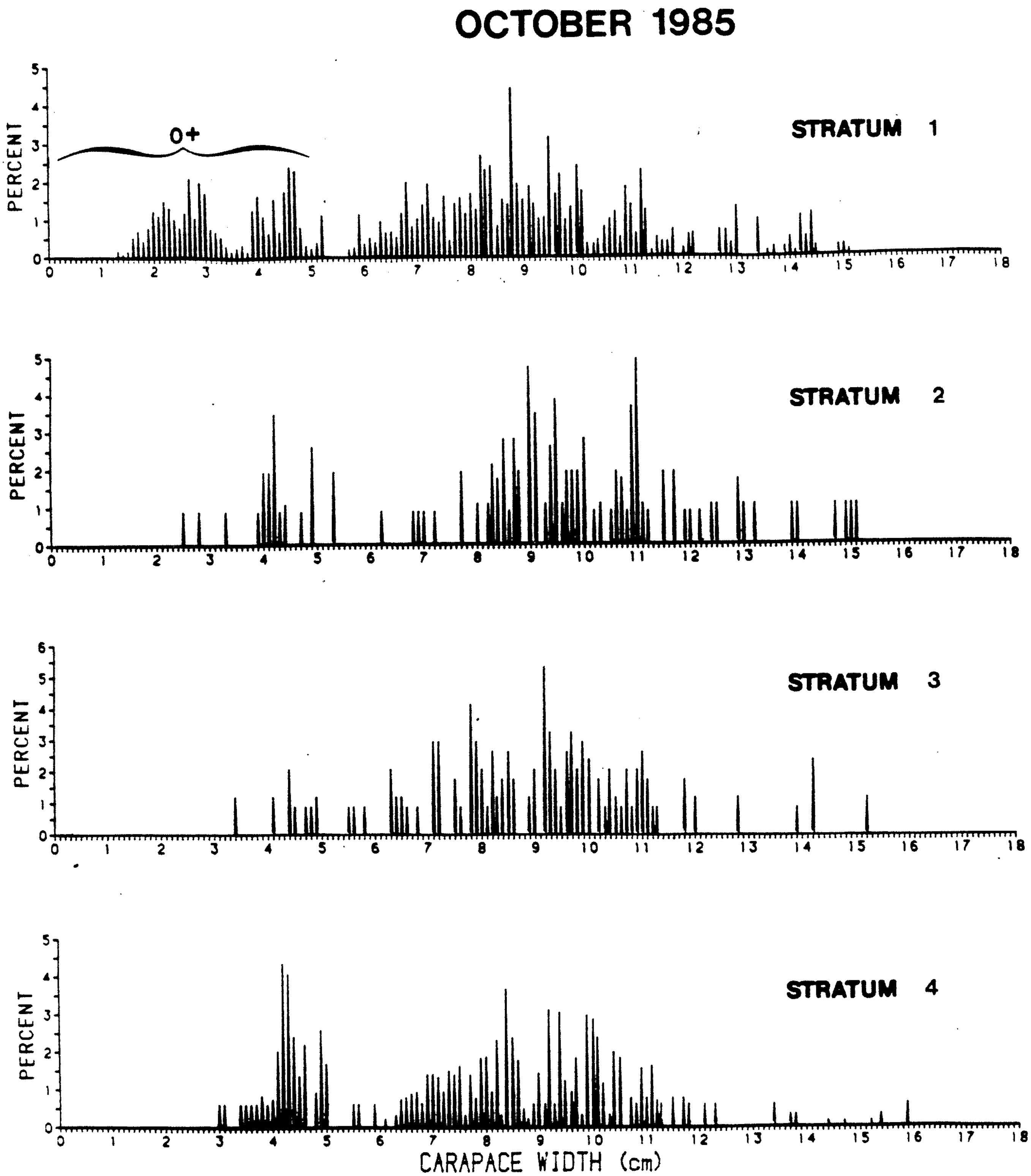

Figure 11. Size composition of Dungeness crab population in Grays Harbor in October 1985 by stratum. Note the cohort of smaller size 0+ crab in the Outer Harbor (Stratum 1) compared to more interior areas.

3.1.3 Population Abundance by Age Class

Size intervals which varied by time (date) were set for each age class using size frequency information (Table 5). Population estimates for each age class were derived (Table 6). The most abundant age class in the subtidal portion of Grays Harbor throughout 1985 was the 1+ (1984) group of crab which fluctuated between 3 to 7 million animals throughout the summer and fall. The 0+ (1985) age class reached a peak of 3.2 million animals in August but never exceeded the number of 1+ crab in 1985 (Table 6, Fig. 12). Older crab (>1+) were numerically least abundant throughout the summer and fall. Crabs in this size group were estimated to range from a high of 700,000 in April to a low of 50,000 crab in October. Most of these animals were found in the Outer Harbor (Str. 1). Population levels of all three age classes reached low levels in December 1985 (Table 6, Fig. 12). In January 1986 numbers of both 1+ (1984) and 0+ (1985) crab increased and the 1985 year class appeared to dominate the total population for the first time (Fig. 12). Population levels (3 to 5 million 0+ crab, 0 to 2 million 1+ crab) were similar to or greater than those estimated for early spring of previous years, but error estimates were also high (Armstrong et al. 1985a, Armstrong et al. 1986). The population level of each age class remained relatively stable through March (bad weather prevented sampling in Str. 2 in February and thus total population levels could not be computed for this month).

Table 5. Size ranges of Dungeness crab used in 1985/1986 age class analyses (carapace width in mm). Ranges are given by month for Grays Harbor (GH) estuary and nearshore (NS) and for three age categories (see Appendices B and C for complete list of mean sizes).

	0+		1+		>1+	
MONTH	GH	NS	GH	NS	GH	NS
APR	0-12		18-76		>76	
MAY	0-14	0-12	30-85	22-65	>85	>65
JUN	7-28	0-12	30-90	22-75	>90	>75
JUL	12-35	0-19	36-100	30-90	>100	>90
AUG	14-45	0-25	46-108	35-100	>108	>100
SEP	14-52	0-29	53-115	36-110	>115	>110
OCT	14-55	0-31	56-125	55-120	>125	>120
NOV	15-55	0-40	56-130	65-125	>130	>125
DEC	15-55	0-40	56-130	65-130	>130	>130
JAN	15-62	0-40	63-130	65-130	>130	>130
FEB	15-65	0-45	70-135	70-130	>135	>130
MAR	18-68	0-45	70-135	70-135	>135	>134

Table 6. 1985/86 Grays Harbor estuary Dungeness crab population estimates by age class (millions of crab) based on the time/size range categories of Table 5.

Sample Date	Age Class 0+	Age Class 1+	Age Class >1+	TOTAL
4/85	0	8.48	0.70	9.18
4/85	0.01	4.40	0.46	4.87
5/85	0.23	4.44	0.54	5.21
5/85	0.37	8.02	0.64	9.03
6/85	0.12	5.04	0.24	5.40
7/85	1.08	5.27	0.26	6.61
8/85	3.23	7.14	0.14	10.51
9/85	2.97	3.32	0.05	6.34
10/85	1.64	4.77	0.49	6.90
11/85	0.45	5.91	0.30	6.66
12/85	0.22	0.82	0.09	1.13
1/86	3.58	1.55	0.08	5.21
2/86	--	--	--	-- *
3/86	4.54	1.95	0.09	6.58

* no samples for stratum 2

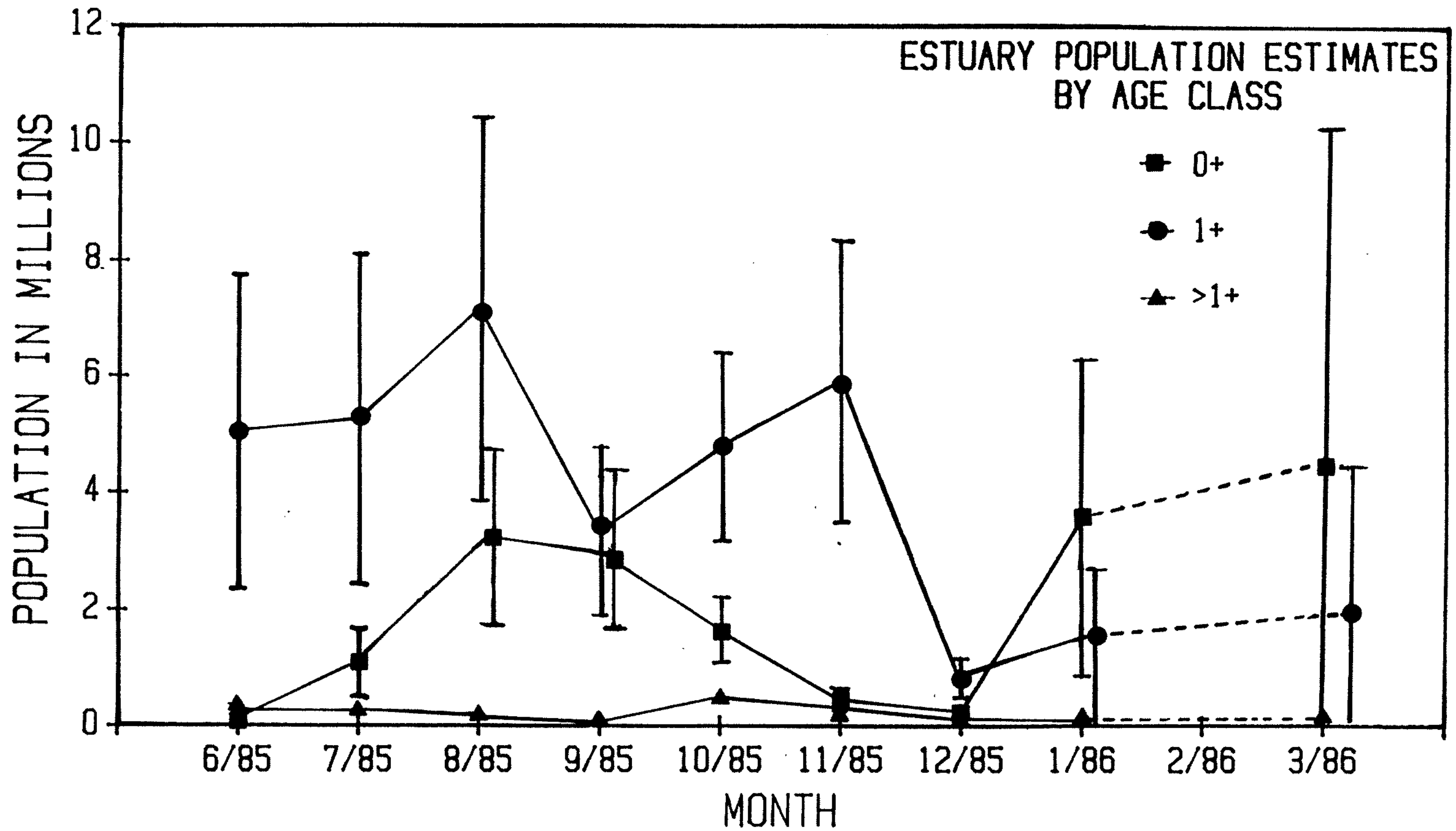

Figure 12. Population estimates for Dungeness crab by age class in Grays Harbor estuary from June 1985 to March 1986. Vertical bars indicate ± 2SE and are shown for 0+ and 1+ age classes only. Dashed lines indicate missing values for February.

3.2 Nearshore Coastal Area

3.2.1 Population Density and Abundance

Population estimates for Dungeness crab in the nearshore coastal area off Grays Harbor in fall and winter cannot be directly compared with those from previous Sea Grant studies due to the limited area covered by this study (total area for this study = 1/10 area covered in Sea Grant offshore investigations, see map Fig. 5). Population estimates from the summer 1985 Sea Grant study were the highest recorded for the three year period of that study (1983 through 1985, Armstrong et al. 1986). Population estimates as high as 1.3 billion were recorded in July but declined to 431 million in September (Table 7).

Crab densities were as high as 22,000/ha in July but declined to averages from 380 to 3,650/ha in September (Table 7). Densities in the fall and winter study never exceeded 1,000/ha with the exception of that in Str. 9 (27 meters depth; Fig. 4) in November (Table 8). The total population estimate for all three nearshore strata from fall through winter declined from about 11 million crab in November to only 1.4 million crab in March. The ratio of males to females was roughly 50:50 through December. Females were caught in greater abundance than males for the remainder of the study period (30:70 ratio in March).

Armstrong et. al. (1986) found the largest proportion (56-97%) of crab in the middle depth zone (Sea Grant Str. 6; 16 to 40m; Fig. 5) in the months of May through August 1985 (Table 7). They also noted an increase in the proportion found at greater depths, particularly at 46m in August and September. Although depths of strata in this study do not correspond to those in the Sea Grant project, the proportion of the total population found

Table 7. Crab density and population estimates for the nearshore Sea Grant study area Summer 1985 by stratum and total for the nearshore by month. The total area and depth range of each stratum is given below. See Fig. 4 for location of strata. SE = standard error.

		Density		Population Estimates (millions)				
Month Year	Stratum	no/ha	±2SE	Within Stratum	±2SE	Stratum Proportion	Nearshore Total	±2SE
5/85	5	494	398	10.77	8.68	0.28	38.97	20.61
	6	477	323	27.56	18.67	0.71		
	7	7	11	0.64	1.03	0.02		
6/85	5	594	438	12.94	9.55	0.13	101.17	88.96
	6	1508	1531	87.10	88.43	0.86		
	7	12	16	1.13	1.49	0.01		
7/85	5	376	242	8.19	5.27	0.01	1291.93	1687.00
	6	21751	29201	1255.98	1686.16	0.97		
	7	292	555	27.76	52.72	0.02		
8/85	5	4362	7886	95.06	171.83	0.18	531.89	441.83
	6	5156	5233	297.72	302.18	0.56		
	7	1466	2874	139.11	272.73	0.26		
9/85	5	379	173	8.25	3.76	0.02	430.71	691.71
	6	1314	934	75.89	53.95	0.18		
	7	3652	7266	346.57	689.59	0.80		

Strata Areas (hectares)	Depth (m)
5 = 21790	5 - 15
6 = 57743	16 - 40
7 = 94908	41 - 75

Table 8. Crab density and population estimates for the nearshore study area off Grays Harbor Fall/iinter 1985/1986 by stratum and total for the nearshore by month. The total area and depth range of each stratum is given below. See Fig. 3 for location of strata. SE = standard error.

		Density		Population Estimates (millions)				
Month Year	Stratum	no/ha	±2SE	Within Stratum	±2SE	Stratum Proportion	Nearshore Total	±2SE
10/85	8	329	206	2.20	1.38	0.16	8.67	6.65
	9	512	422	1.31	1.08	0.12		
	10	705	877	5.16	6.41	0.74		
11/85	8	501	618	3.35	4.13	0.31	10.83	5.50
	9	1066	1061	2.72	2.71	0.25		
	10	650	331	4.76	2.42	0.44		
12/85	8	186	155	1.24	1.04	0.35	3.54	1.95
	9	518	339	1.32	0.87	0.37		
	10	133	192	0.98	1.41	0.40		
1/86	8	171	148	1.14	0.99	0.37	3.04	2.32
	9	630	820	1.61	2.09	0.53		
	10	40	13	0.29	0.09	0.10		
2/86	8	67	58	0.45	0.39	0.24	1.87	0.96
	9	367	263	0.94	0.67	0.50		
	10	66	77	0.48	0.57	0.26		
3/86	8	127	102	0.85	0.69	0.61	1.40	0.72
	9	172	82	0.44	0.21	0.31		
	10	15	10	0.11	0.07	0.08		

Strata Areas	Depth (m)
8 = 6,687 hectares	9 - 22
9 = 2,553 hectares	23 - 33
10 = 7,315 hectares	34 - 40

16,555 hectares total

in the outer depth zone (Str. 10, 34 to 44m) was initially higher (60%) in October 1985. This proportion fell to only 8% in March, 1986 (Table 8) while correspondingly the proportion of crabs in the middle and inner depth zones (Strata 8 and 9) rose from 25% and 15%, respectively, in October, to 61% and 31% in March 1986. Crab density was highest in Str. 9 every month from October through March. Although smallest in area (2,550 ha) compared to Str. 8 and 10 (6,690 and 7,320 ha, respectively), 25% to 50% of the total estimated nearshore population occurred in Str. 9, which is an area of relatively steep slope between the Grays Harbor bar and more gradual slope in Str. 10 (see Fig. 4). There was no consistent trend in distribution on a larger spatial scale with crabs being more abundant in the north half of the nearshore study area (Str. 14, Fig. 6) 4 out of the 6 months sampled, but no significant difference between the 2 halves in any single month (Table 9).

3.2.2 Size Composition

Size frequency histograms for data collected during the Sea Grant project in the summer of 1985 showed that nearshore 0+ crab recruited primarily in June and grew slowly compared to the estuarine 0+ population to a mean size of about 15 mm CW (range 10 to 25mm CW) by September (Armstrong et al. 1986; Fig. 13). Similar size frequency histograms for data collected in fall and winter 1985/86 shows the 0+ age class at a mean size of 21 mm CW in October and about 30 mm in February (Fig. 14). What appear to be at least 2 and possibly 3 cohorts of 0+ crab were evident throughout the study period (Fig. 14, note the months of November and January). A mean CW of 27 mm was recorded for the 1985 0+ age class by March 1986 (Appendix C, Fig. 14).

Table 9. Crab density and population estimates for the nearshore study area Fall/Winter 1985/1986 by spatial strata (Str 14 = north half, Str 15 = south half, see Fig. 5) and total for the nearshore by month.

Month Year	Stratum	CPUE no/ha	CPUE 2SE	Population Millions	Population 2SE	Prop	Nearshore TOTAL* Millions	Nearshore TOTAL* 2SE
10/85	14	456	256	2.66	1.49	0.34	7.91	5.93
	15	490	535	5.25	5.73	0.66		
11/85	14	919	687	5.37	4.01	0.55	9.82	4.72
	15	415	232	4.45	2.49	0.45		
12/85	14	193	137	1.13	0.80	0.24	4.70	2.95
	15	333	265	3.57	2.84	0.76		
1/86	14	389	494	2.27	2.89	0.67	3.41	3.11
	15	106	107	1.13	1.15	0.33		
2/86	14	208	198	1.22	1.15	0.55	2.21	1.42
	15	93	78	0.99	0.83	0.45		
3/86	14	126	94	0.74	0.55	0.53	1.40	0.66
	15	62	35	0.66	0.38	0.47		

*Total nearshore population estimates differ from those produced using depth strata (Table 8) due to the different data grouping procedures.

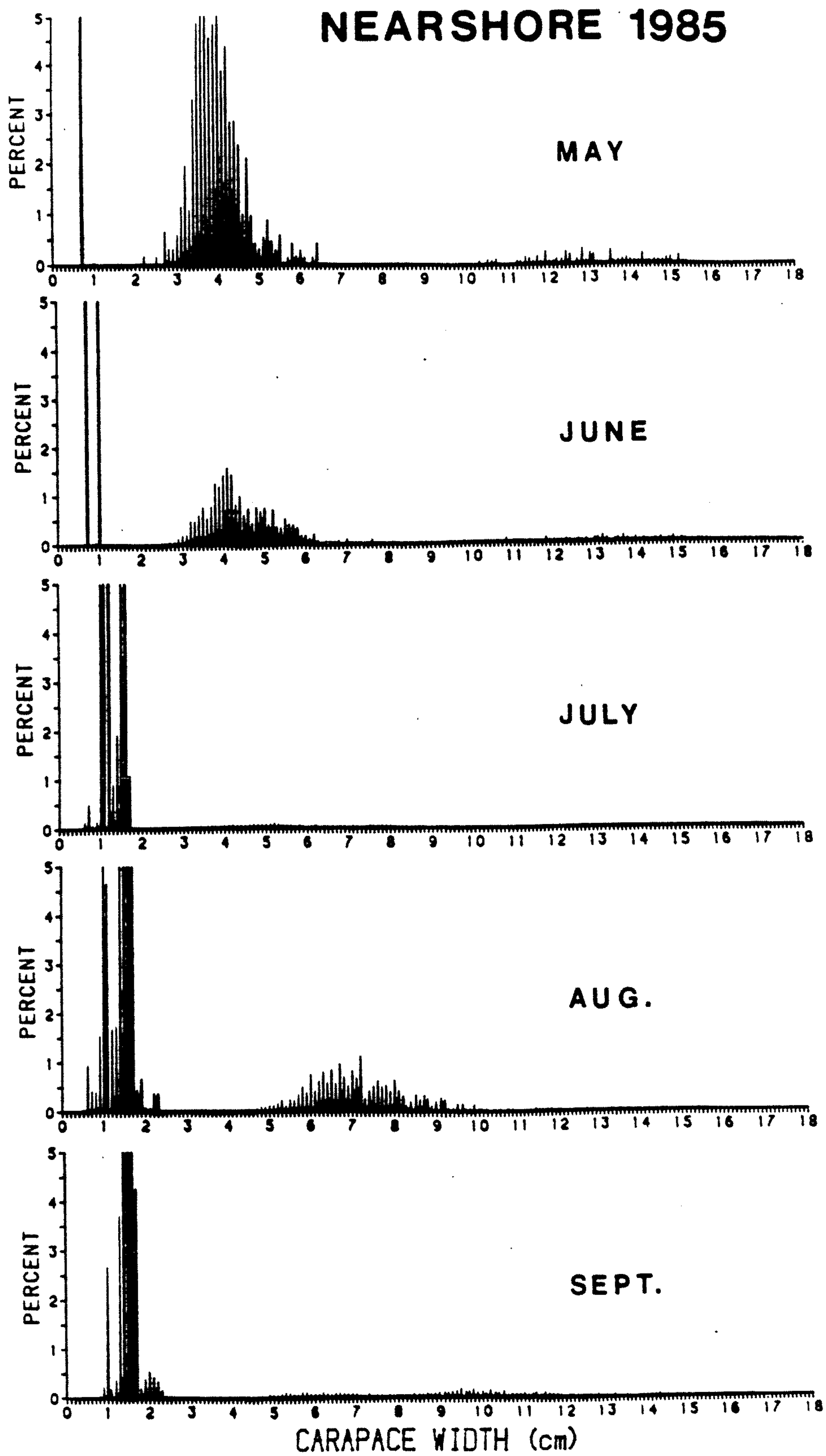

Figure 13. Size composition of nearshore Dungeness crab population (strata combined) by trip in May to September 1985 (Sea Grant study area).

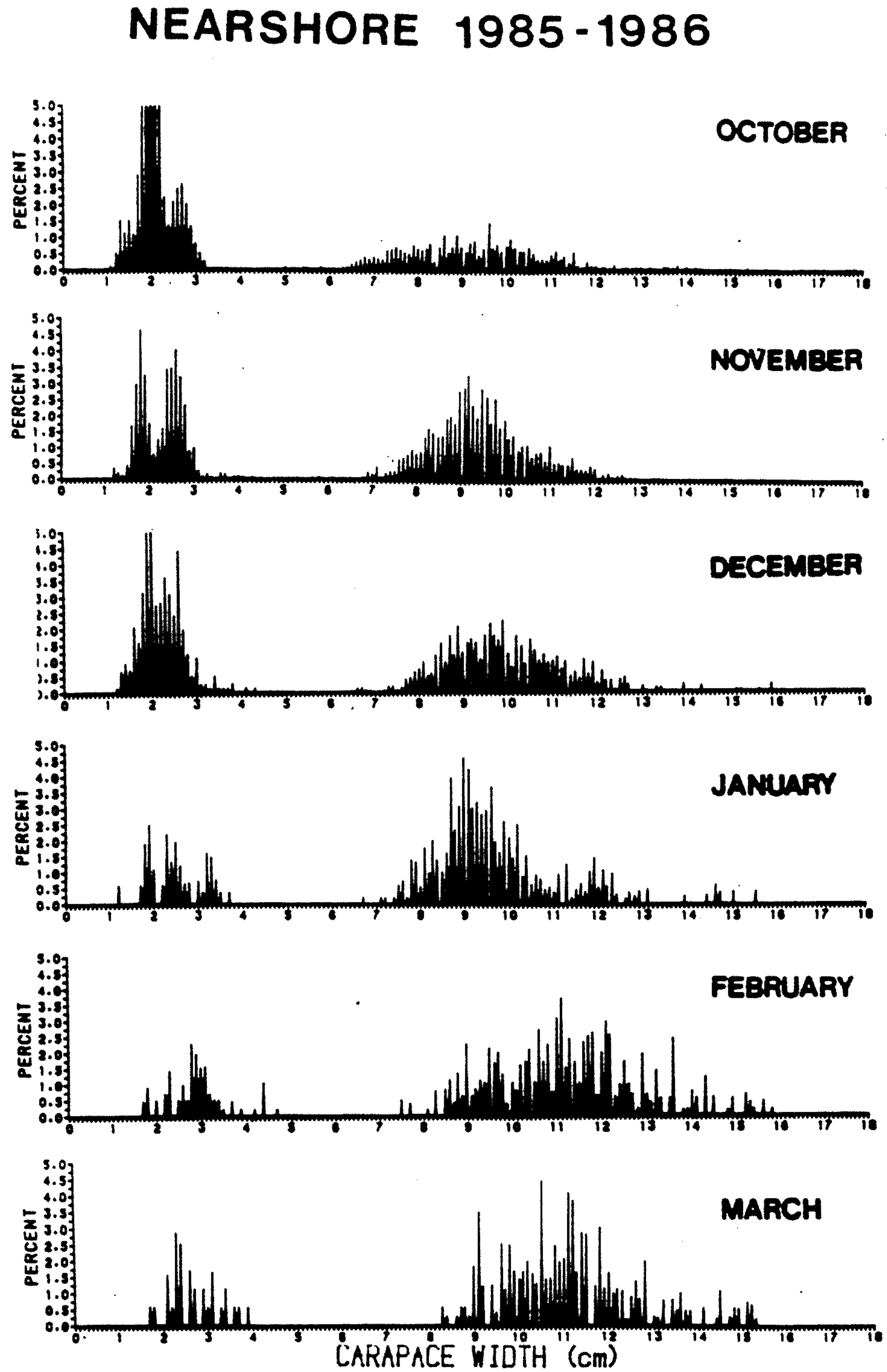

Figure 14. Size composition of nearshore Dungeness crab population (strata combined) from October 1985 to March 1986.

The 1984 year class (1+ crab) nearshore exhibited a distinct mode at 40 mm in May 1985 (Fig. 13) and were smaller than their estuarine siblings which had reached approximately 52 mm CW by this time (Armstrong et al. 1986; Fig. 9). This age class remained distinct, especially in Str. 5 (5-15 m) with little change in mean size through July (Fig. 15). In August a shift up to the range of 50 to 80 mm CW occurred and by September the nearshore 1+ age class was similar in size to estuarine 1+ (55 - 110 mm CW, mean = 82.7 mm; Figs. 13 and 15, Appendix C), perhaps due to mixing of the two populations (emigration of larger estuarine crab to the nearshore area). This broad size range remained evident throughout the fall and winter but an apparent molt occurred between January and February when the mean carapace width increased to approximately 106 mm CW (Fig. 14).

3.2.3 Population Abundance by Age Class

As was done for the estuary, size intervals for each age class were set using size frequency information from each date (Table 5). Population estimates for each age class were then derived from the total. Settlement of 0+ crab nearshore in 1985 was very strong compared to 1983 and 1984 (Armstrong et al. 1986). Population estimates for the entire nearshore area of the Sea Grant program increased sharply from 12 million animals in May to 1.3 billion 0+ crab in July (Table 10, Fig. 16; Armstrong et al. 1986). Unlike 0+ abundance in the estuary, these numbers far exceeded the 1+ population totals of 21 to 26 million crab (Fig. 16). By September the 0+ population level had fallen to approximately 403 million crab. Because the fall/winter survey covered only the area close to the mouth of Grays Harbor, population estimates were not directly comparable with those from summer Sea

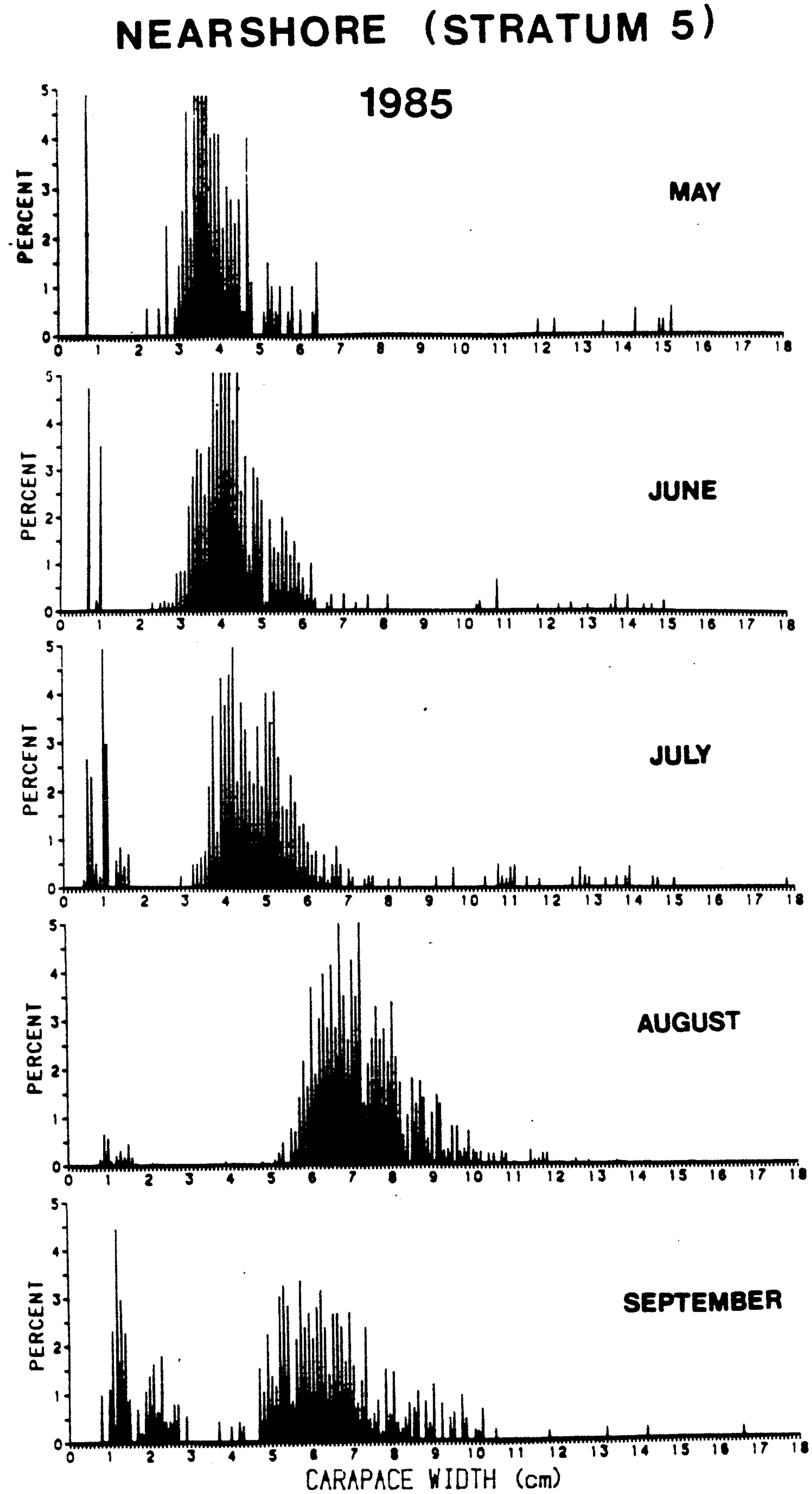

Figure 15. Size composition of Dungeness crab population in Stratum 5 (5-15 m depth) nearshore from May to September 1985.

Table 10. Population estimates of Dungeness crab in the Sea Grant nearshore study area from Copalis to Willapa Bay May-September 1985, by age class and stratum expressed as millions of crab. Area of the population estimate is from the Sea Grant program and equals 174,441ha (Fig. 5).

Month of Trip	Age Group	Stratum Number 5	6	7	Combined
May	0+	0.86	10.41	0.53	11.80
	1+	10.31	15.72	-	26.03
	>1+	0.30	1.48	0.11	1.89
	All ages	11.47	27.61	0.64	39.72
June	0+	1.16	75.45	1.04	77.65
	1+	12.14	9.69	0.09	21.92
	>1+	0.47	2.11	-	2.58
	All ages	13.77	87.25	1.13	102.15
July	0+	1.42	1235.56	27.73	1264.71
	1+	6.78	19.50	0.07	26.35
	>1+	0.52	3.12	-	3.64
	All ages	8.72	1258.18	27.80	1294.70
August	0+	2.94	287.46	138.94	429.34
	1+	95.21	10.30	-	105.51
	>1+	3.07	0.48	0.42	3.97
	All ages	101.22	298.24	139.36	538.82
September	0+	2.21	54.97	346.49	403.67
	1+	6.50	14.63	0.09	21.22
	>1+	0.08	6.42	0.06	7.10
	All ages	8.79	76.02	347.18	431.99

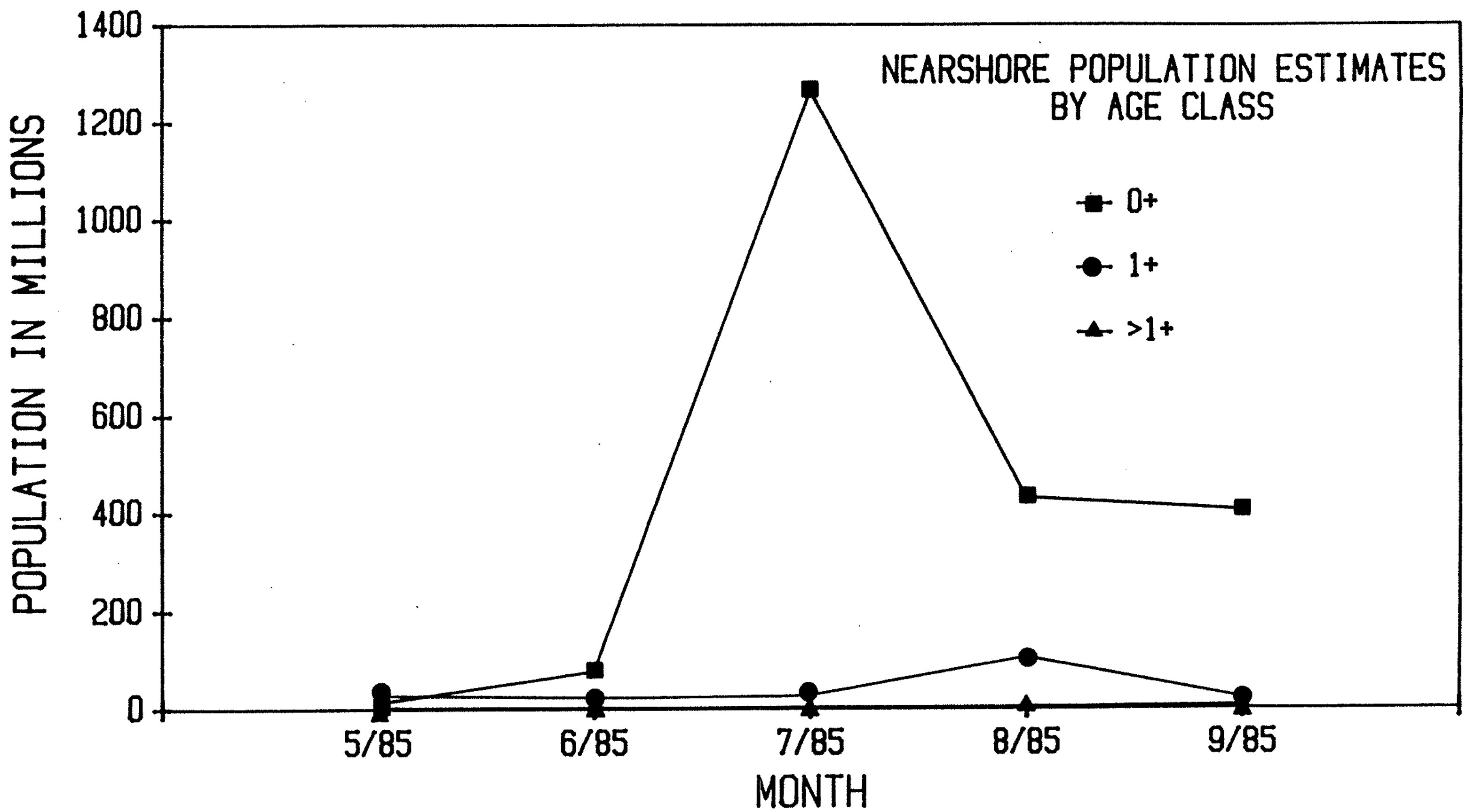

Figure 16. Population estimates of Dungeness crab by age class in the nearshore coastal area from May to September 1985 based on time/size range categories of Table 6. Estimates are derived from the Sea Grant survey area (see Fig. 5).

Grant survey, however population estimates for the smaller area covered (16,555 ha) indicate a continuing decline in 0+ abundance and a corresponding increase in 1+ abundance. By November the 1+ population level again exceeded that of 0+ crab (Table 11, Fig. 17). The 0+ age class settled largely to intermediate depths in 1985 (Sea Grant Str. 6, 16-40 m; Armstrong et al. 1986). However, by September 86% of the surviving 0+ crab found had shifted to Sea Grant Str. 7 (42-73 m) with the greatest density at 46 m (Table 10). This is consistent with the results from October when 80% of the 0+ population in the smaller fall/winter study area was found at 40 m in Str. 10 (Table 11). In November another shift occurred and the 0+ population was split into roughly equal proportions at the deep 40 m stations and the shallow 15 m stations for the rest of the study period.

The 1+ age class was divided between Sea Grant strata 5 & 6 (5 - 46 m) from May - September 1985 (Armstrong et al. 1986; Table 10). Very few 1+ crab were found in Str. 7 (40 - 73m). Results were similar throughout the fall and winter. In October and November roughly equal estimates were obtained for Str. 8 and 9, but by December the greatest population levels were in Str. 9 (23-33m). Relatively few 1+ crab were found at deeper stations (Str. 10, 34 - 44m) throughout the study period (Table 11). Older crabs (> 1+) never reached population levels greater than 150,000 and showed no consistent trend in depth location.

3.3 Estuary Mouth

3.3.1 Population Density and Abundance

The estuary mouth region was divided into 2 new strata, 12 and 13, representing the outer harbor to Westport and the constricted area from

Table 11. Population estimates of Dungeness crab nearshore adjacent to the mouth of Grays Harbor October 1985 to March 1986, by age class and stratum, expressed as millions of crab.

Month	Age Group	Stratum Number 8 9-22m	9 23-33m	10 34-44m	All Strata Combined
October	0+	0.70	0.07	5.00	5.77
	1+	1.41	1.22	0.13	2.76
	>1+	0.09	0.02	0.03	0.14
	All ages	2.20	1.31	5.16	8.67
November	0+	0.68	0.02	3.31	4.01
	1+	2.64	2.68	1.44	6.76
	>1+	0.03	0.02	0.01	0.06
	All ages	3.35	2.72	4.76	10.83
December	0+	0.86	0.00	0.73	1.59
	1+	0.37	1.31	0.23	1.91
	>1+	0.01	0.01	0.02	0.04
	All ages	1.24	1.32	0.98	3.54
January	0+	0.49	0.00	0.15	0.64
	1+	0.59	1.61	0.13	2.34
	>1+	0.06	0.00	0.01	0.07
	All ages	1.14	1.61	0.29	3.04
February	0+	0.10	0.03	0.20	0.33
	1+	0.31	0.86	0.23	1.40
	>1+	0.04	0.05	0.05	0.14
	All ages	0.45	0.94	0.48	1.87
March	0+	0.24	0.06	0.02	0.32
	1+	0.56	0.28	0.08	0.92
	>1+	0.05	0.10	0.01	0.16
	All ages	0.85	0.44	0.11	1.40

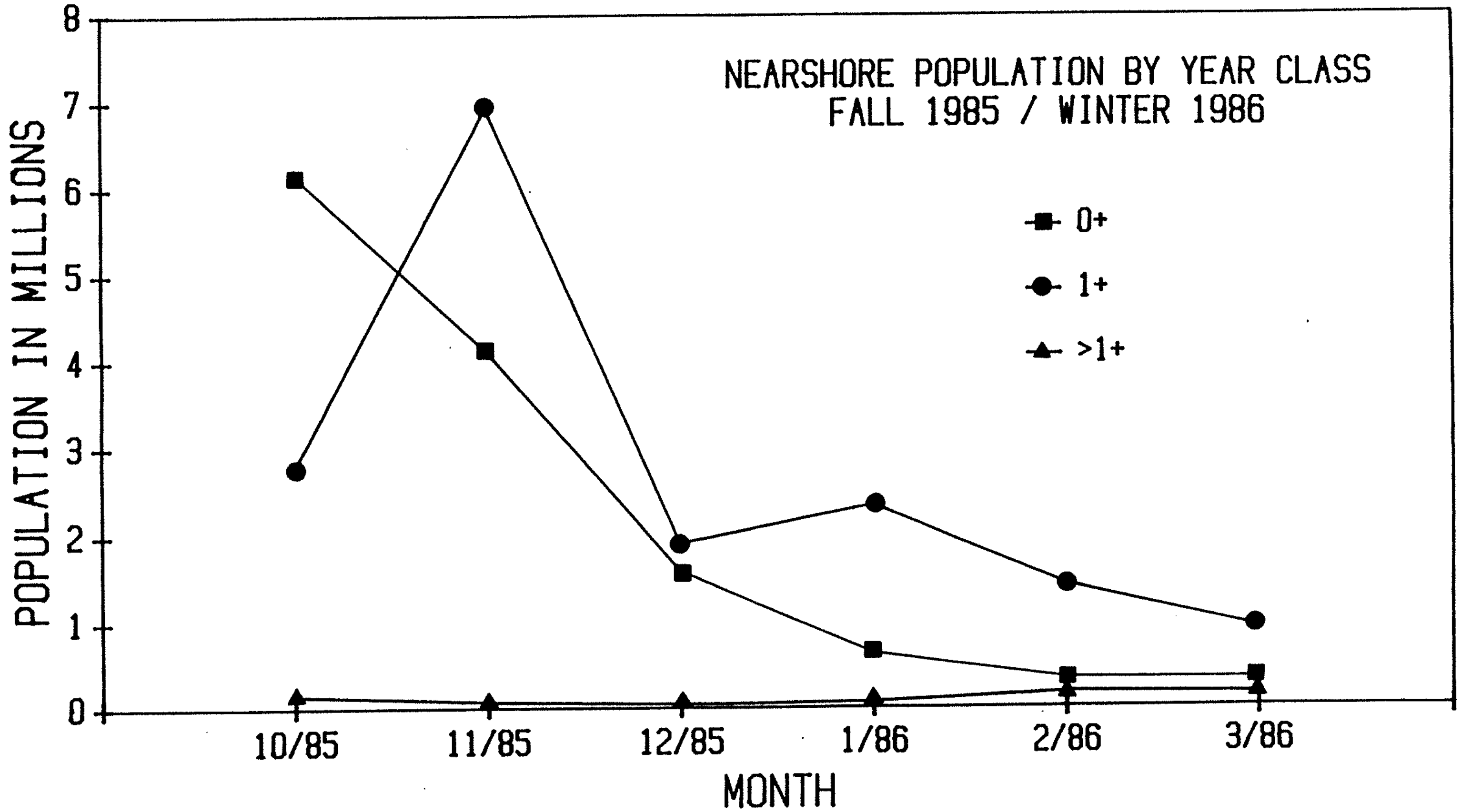

Figure 17. Population estimates of Dungeness crab by age class in the nearshore area adjacent to Grays Harbor from October 1985 to March 1986 based on time/size range categories of Table 6. Estimates are derived from the Fall/Winter survey area (see Fig. 4).

Westport west to the ends of the jetties, respectively (Fig. 3).

Abundance fell from high values of 1 to 2 million animals in October to low values of 150,000 to 300,000 crab in January in both estuary mouth strata (Table 12, Fig. 18). The difference in total population abundance between strata appeared to be related only to the difference in total stratum area (Str. 12, 2,594 ha; Str. 13, 1,751 ha). Crab densities were consistently lower in Str. 13 between the jetties and closer to the mouth, but there were no significant differences (Fig. 18). It must also be noted that sampling was extremely difficult in some parts of the mouth area, primarily due to the velocity of the water moving through the constricted area, the nature of the constantly shifting substrate and winter storms. Corrective measures such as fishing during slack tides and during neap series were taken, but the effect of these factors on the efficiency of the net for catching crab is unknown.

3.3.2 Size Composition

Size frequency histograms for data from the estuary mouth clearly depict the presence of two cohorts of 0+ crab from October through December, with most of the smaller crabs found in the constricted area between the jetties (Str. 13) and larger crab found further inside the estuary (Str. 12; Fig. 19). Although the distinction between these cohorts became less clear as the winter progressed (primarily due to lower total catch), the mean size of 0+ crab in Str. 13 remained lower than that in Str. 12 through February (Table 13). The size distribution of 0+ between the jetties was more similar to that for nearshore populations (Fig. 14) than to the size distribution of 0+ within the estuary (Fig. 10). The 1+ age class were composed of a broad range in sizes in both areas and were not different in mean size between

Table 12. Crab density and population estimates in Grays Harbor estuary mouth by stratum, Fall/Winter 1985/1986. The area of Str. 12 and 13 is 2,594 ha and 1,751 ha, respectively.

Month/ Year	Stratum	Density no/ha	(±2SE)	Population Millions	(±2SE)	Density Proportion
10/85	12	652	(330)	1.69	(0.82)	.56
	13	517	(477)	0.91	(0.83)	.44
11/85	12	799	(595)	2.07	(1.34)	.66
	13	414	(138)	0.73	(0.24)	.34
12/85	12	223	(146)	0.58	(0.38)	.66
	13	117	(63)	0.20	(0.11)	.34
1/86	12	117	(107)	0.30	(0.28)	.58
	13	85	(119)	0.15	(0.21)	.42
2/86	12	235	(118)	0.61	(0.31)	.51
	13	228	(65)	0.40	(0.11)	.49
3/86	12	105	(46)	0.27	(0.12)	.58
	13	75	(50)	0.13	(0.09)	.42

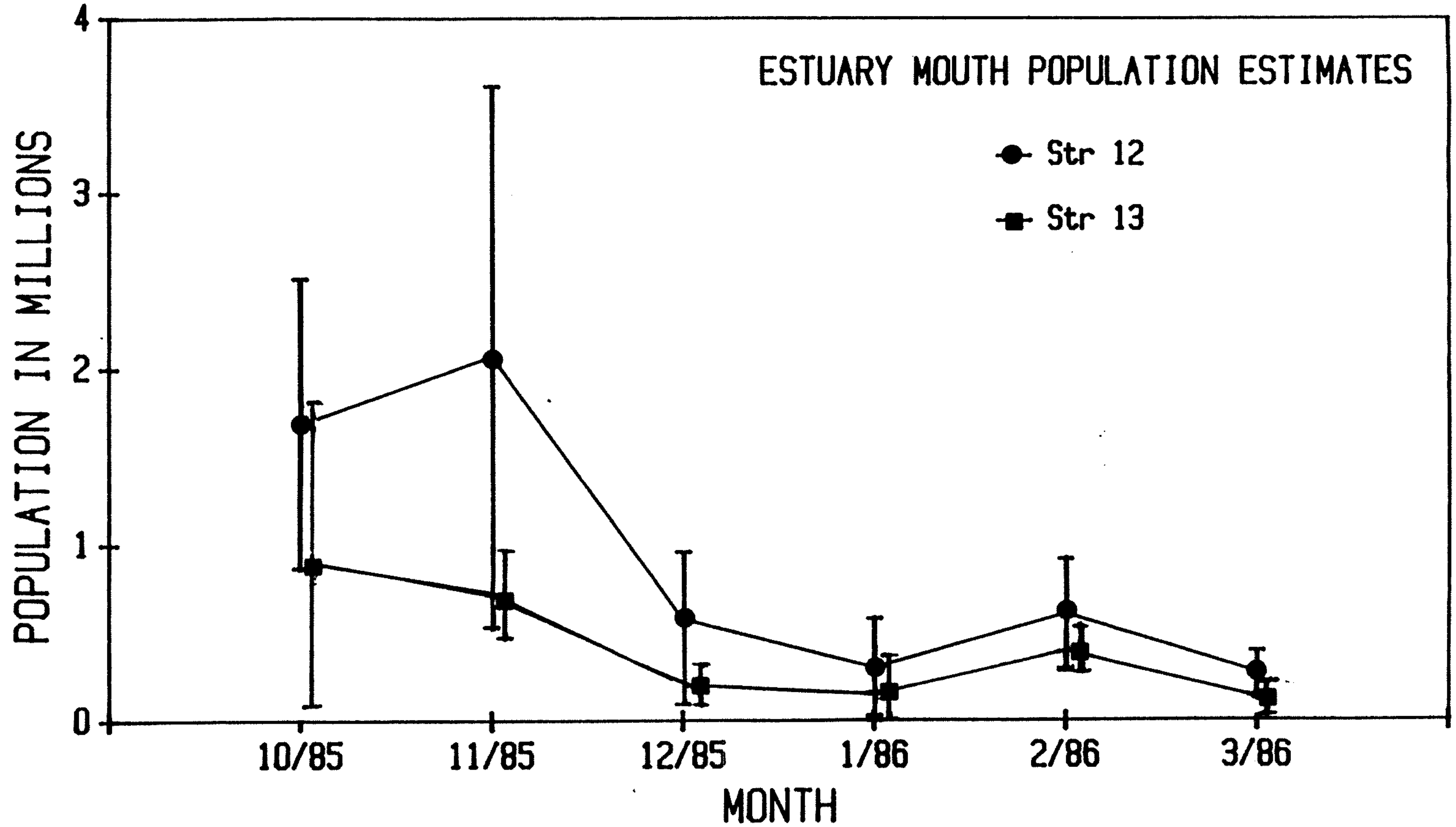

Figure 18. Population estimates of Dungeness crab in the estuary mouth Stratum 12 (Outer Harbor) and Stratum 13 (Westport to the jetties), October 1985 to March 1986 (see map Fig. 3). Vertical bars indicate ± 2SE.

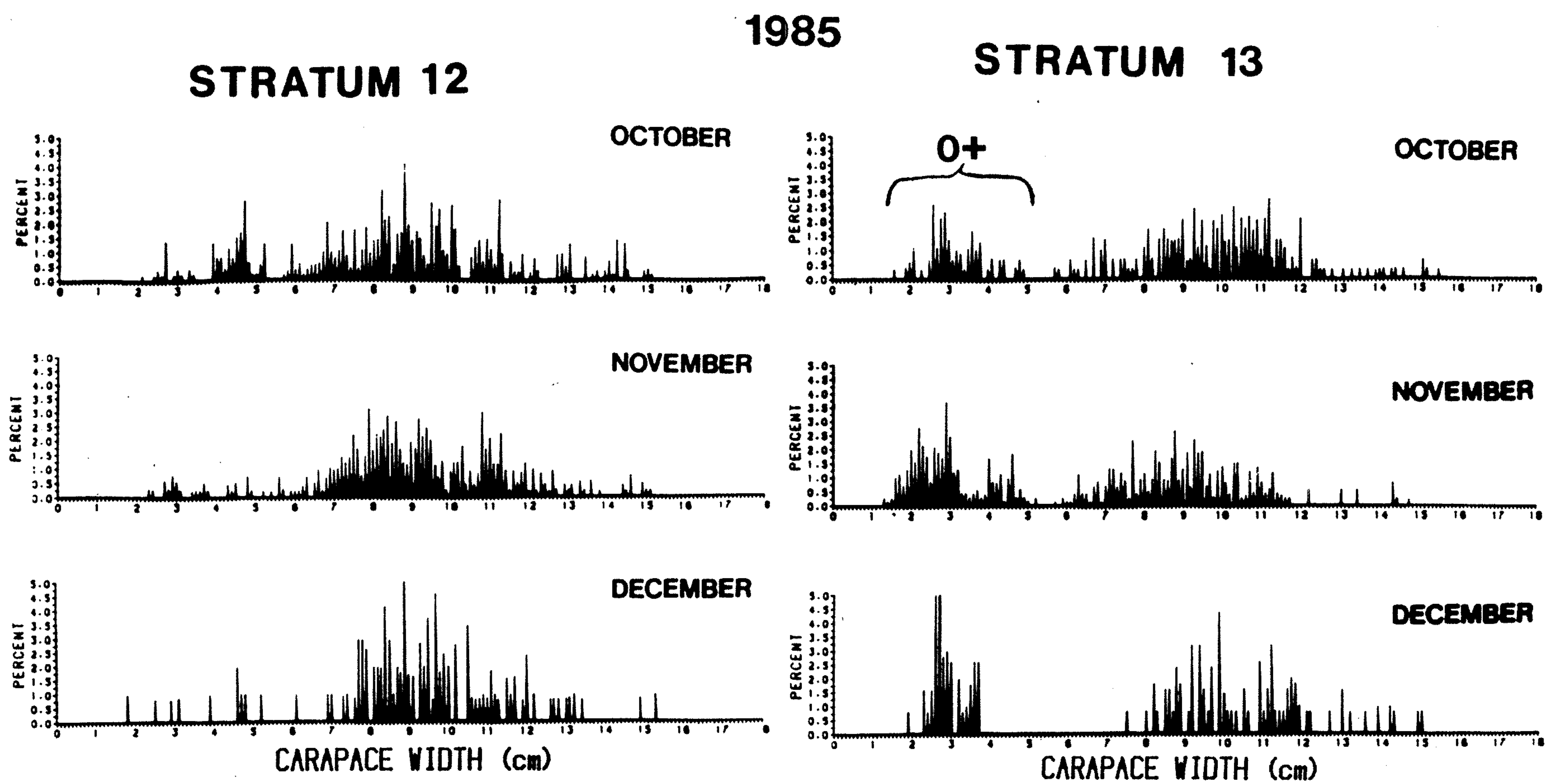

Figure 19. Comparison of size composition of Dungeness crab population in Stratum 12 (Inner Harbor mouth to Westport, see Fig. 3) and Stratum 13 (Westport to the tip of the jetties) from October to December 1985. Note the larger proportion of 0+ crab caught in Stratum 13.

Table 13. Mean size of crab in the Outer Harbor (Str. 12) and estuary mouth (Str. 13) based on the time/size range categories in Table 5. Size expressed as carapace width in mm (±SD).

Month	Stratum	0+	1+	>1+
10/85	12	41.2 (7.7)	86.4 (15.1)	138.7 (7.3)
	13	28.9 (8.9)	87.2 (14.7)	140.2 (6.6)
11/85	12	37.3 (9.1)	92.1 (16.7)	140.6 (7.4)
		31.8 (7.4)	96.7 (15.9)	142.7 (7.5)
12/85	12	38.1 (11.6)	95.3 (15.0)	138.2 (10.1)
	13	29.0 (4.4)	101.5 (13.1)	139.0 (7.6)
1/86	12	33.2 (4.6)	97.9 (9.3)	140.0 (5.7)
	13	29.7 (6.5)	104.3 (14.1)	145.0 (5.7)
2/86	12	43.6 (15.7)	105.4 (15.0)	142.6 (2.2)
	13	34.4 (7.9)	101.5 (13.7)	149.2 (8.0)
3/86	12	36.0 (9.5)	104.6 (13.5)	140.5 (4.9)
	13	35.7 (6.7)	106.5 (11.3)	150.0 (----)

strata but increased in size from 86 mm in October 1985 to 105 mm CW in March 1986. Larger (>1+) crab, although numerically less important, were found in higher numbers in the estuary mouth than further within the estuary and were a mean size of 140 mm. No consistent difference in size was evident between strata for the winter months.

3.3.3 Population Abundance by Age Class

The moving size intervals set for estuary trawl samples (Table 5) were also used to derive population and density estimates for each age class of crab in the estuary mouth. The most abundant age class were the 1984 (1+) crab throughout the fall and winter. Population estimates of 1+ crab fluctuated from a high of 2.3 million in November to a low of 300,000 in March (Table 14). Density estimates for 1+ crab were consistently higher inside the harbor mouth (Str. 12) than between the jetties (Str. 13), especially from October to December (Table 15, Fig. 20). Population estimates for 0+ crab in the estuary mouth fell steadily from 670,000 animals in October 1985 to 60,000 animals in March 1986 (Table 14). Density estimates indicated there were more 0+ crab in Str. 13 (tip of jetties to Westport) than in Str. 12 (outer harbor mouth, Table 15). The estimated population of older (>1+) crab in the estuary mouth also declined from 180,000 crab in October 1985 to 45,000 crab in March 1986. Population and density estimates were greatest for Str. 12.

Table 14. Population estimates of Dungeness crab in the Grays Harbor estuary mouth, October 1985 - March 1986, by age class and stratum, expressed as millions of crab.

Stratum	Month	Age Class 0+	1+	>1+	TOTAL
12	10/85	.29	1.23	0.16	1.69
13		.38	.50	0.02	0.91
TOTAL		.67	1.73	0.18	2.60
12	11/85	0.15	1.83	0.09	2.07
13		0.18	0.51	0.03	0.73
TOTAL		0.33	2.34	0.12	2.80
12	12/85	0.05	0.50	0.03	0.58
13		0.08	0.14	0.01	0.20
TOTAL		0.13	0.64	0.04	0.78
12	1/86	0.04	0.24	0.02	0.30
13		0.03	0.10	0.01	0.15
TOTAL		0.07	0.34	0.03	0.45
12	2/86	0.04	0.53	0.04	0.61
13		0.05	0.32	0.02	0.40
TOTAL		0.09	0.85	0.06	1.01
12	3/86	0.02	0.21	0.04	0.27
13		0.04	0.09	0.00	0.13
TOTAL		0.06	0.30	0.04	0.40

Table 15. Crab density estimates by age class for the estuary mouth (Str 13) and Outer Harbor (Str 12).

		DENSITY (no/ha)			
Stratum	Month	0+	1+	>1+	TOTAL
12	10/85	112	476	64	652
13		217	287	13	517
12	11/85	58	706	35	799
13		103	292	19	414
12	12/85	21	193	9	223
13		45	65	7	117
12	1/86	16	95	6	117
13		19	59	7	85
12	2/86	8	203	24	235
13		30	185	13	228
12	3/86	8	80	17	105
13		23	50	2	75

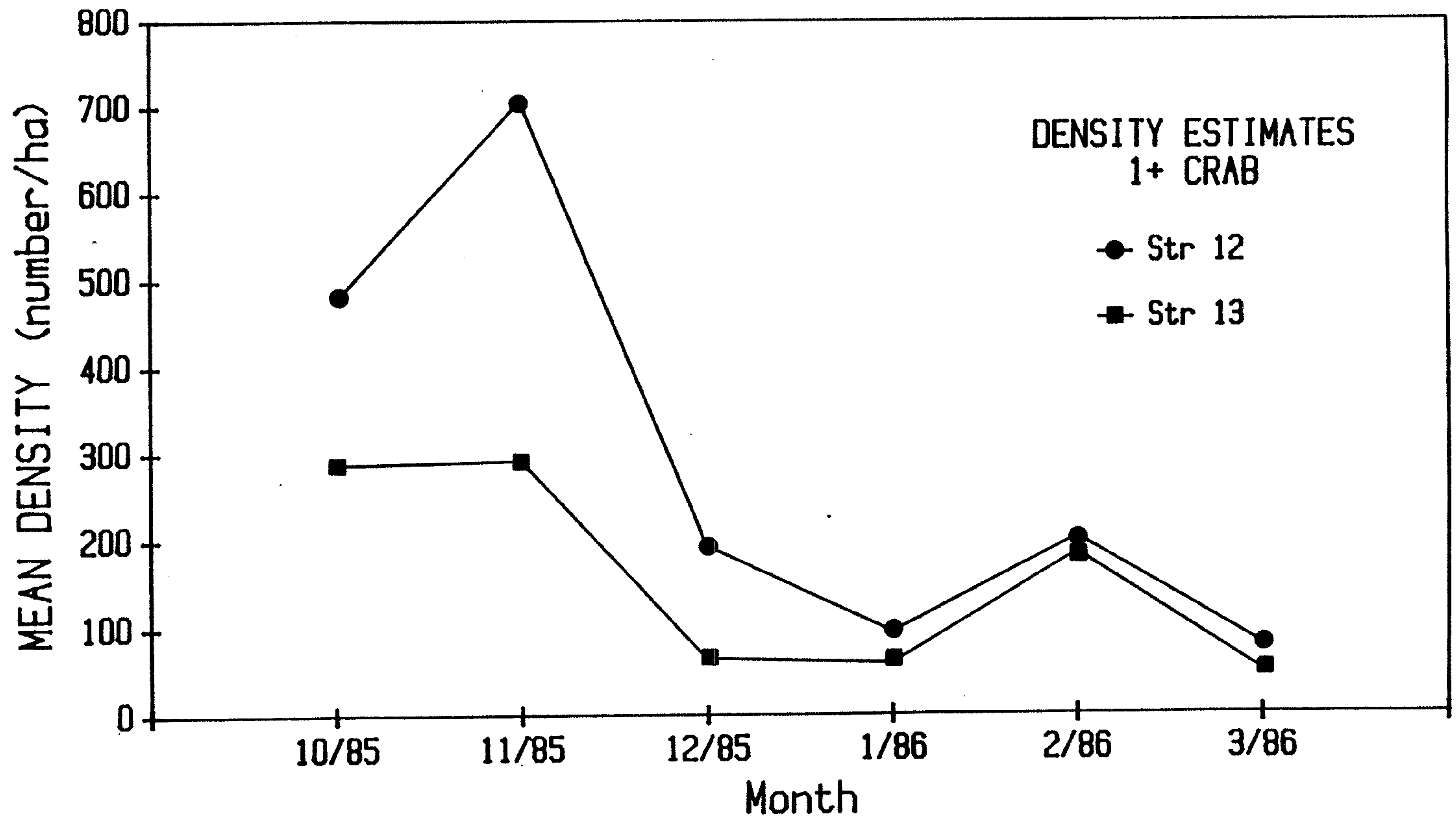

Figure 20. Mean density estimates for 1+ crab in the estuary mouth Stratum 12 (Outer Harbor) and Stratum 13 (Westport to the jetties), October 1985 to March 1986 (see map Fig. 2 and Table 15).

3.4 Biological Dredge

A size frequency histogram of the crabs found in dredge samples compared to one for those found in trawls (Fig. 21) confirmed observations in the field, that smaller 0+ crab were more abundant in the biological rock dredge catches while larger 1+ crab were more abundant in the trawl catches. Density estimates were computed for each age class of crab caught with the rock dredge in November 1985 and January and February 1986 and comparisons were made with trawl data at the same locations (see map Fig. 2, Table 16). Crab density estimates from both dredge and trawl samples were highly variable both in terms of station sampled and by month. Estimates were highest in November at stations in the harbor mouth (Str. 1). Distinct differences between dredge and trawl estimates occurred at single stations in given months, but no consistent trends were evident in overall means (Table 16).

Because the data did not satisfy the assumptions of parametric statistical analysis and sample size was too small to justify higher order designs, non parametric two sample paired tests (Wilcoxan signed rank tests) were utilized. Tests for significant differences between densities computed from biological dredge catches and those computed from trawl catches for each age class of crab were made. Significantly greater catch in the dredge samples would indicate possible burial behavior. Non significant results however, could not be interpreted to indicate that burial did not occur because the efficiency of the dredge at catching crabs that were not buried, relative to trawl efficiency at catching these crab, was unknown.

The test results showed a significant difference in the density of 1+ crab but indicated that more crab were caught by the trawl than the

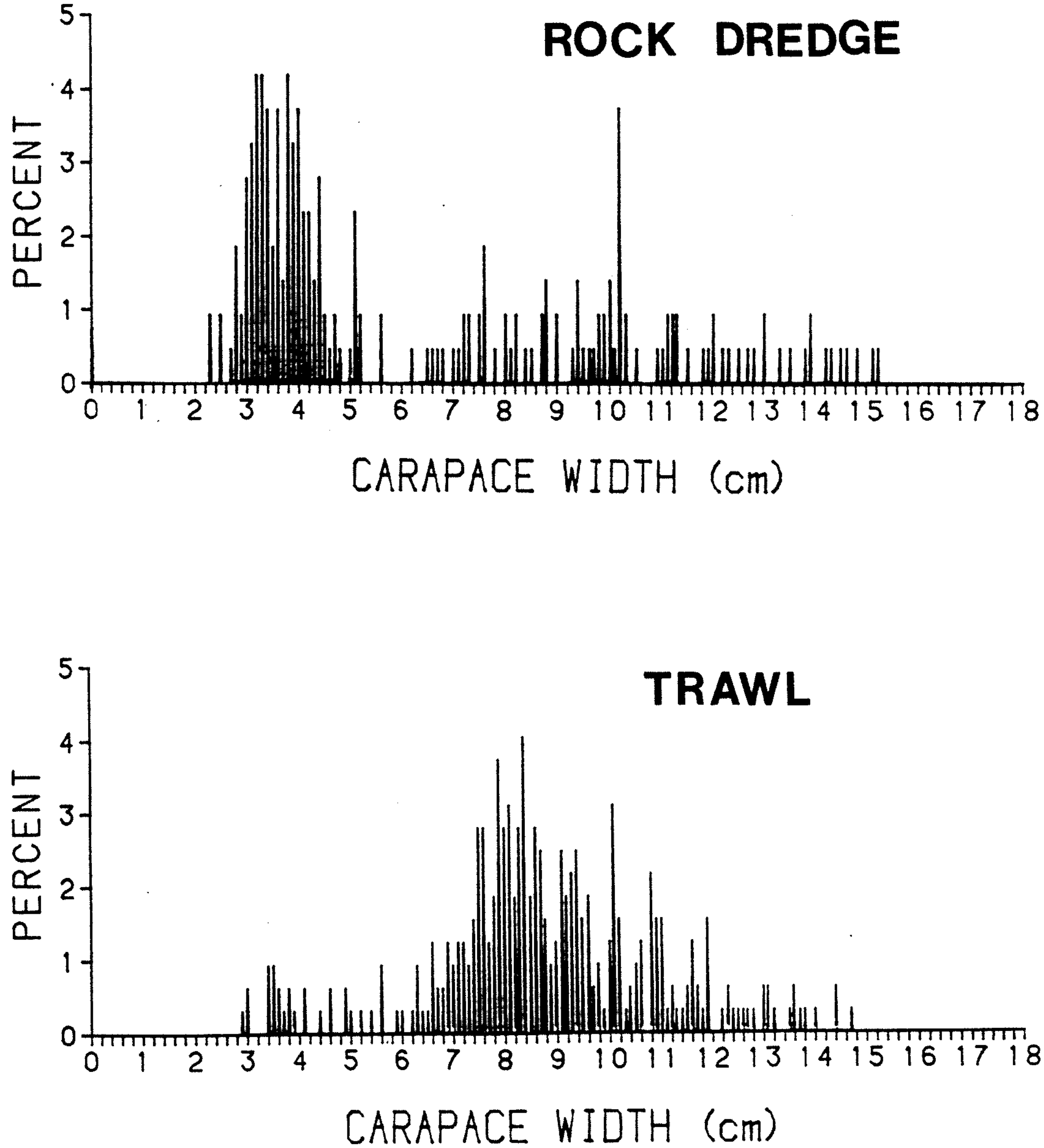

Figure 21. Comparison of size composition of Dungeness crab caught in biological rock dredge samples and those caught in trawl samples from the same locations (see map Fig. 2) in November 1985 and January and February 1986 (months and stations combined).

Table 16. Mean crab density estimates (no/ha) based on biological rock dredge data and trawl data from five locations (see map Fig. 1).

Age Class	Month	Rock Dredge Density (SE)	Trawl Density (SE)
0+	November	43 (21)	20 (12)
	January	307 (238)	6 (4)
	February	89 (56)	47 (40)
1+	November	281 (116)	958 (614)
	January	7 (4)	50 (32)
	February	74 (34)	75 (22)
>1+	November	20 (16)	14 (6)
	January	9 (6)	9 (6)
	February	18 (5)	9 (6)

biological rock dredge. This suggests that the dredge was less efficient than the trawl at catching these larger more mobile crab. No significant difference in the density of either 0+ crab or >1+ crab could be detected.

3.5 Estuary and Nearshore Comparisons

Settlement of 0+ crab in the summer of 1985 was much greater in the nearshore area than in Grays Harbor estuary or Willapa Bay estuary (Armstrong et al. 1986; Tables 6 and 10). Nearshore crab continued to outnumber their estuarine counterparts throughout the fall and early winter. In January of 1986, however, population estimates for 0+ crab caught in Grays Harbor estuary increased (Table 6) and density estimates for the estuary surpassed those for the nearshore study area (Fig. 22), due primarily to large catches in the North Bay (Str. 2, Fig. 23).

The total abundance of 1+ crab was also higher nearshore in the summer of 1985 (Tables 6 and 10; Armstrong et al. 1986). Numbers ranged from 21 to 26 million crab with the exception of a peak of 100 million animals in August, due largely to the catch at one station. Mean density of 1+ crabs however, was higher in the estuary than nearshore throughout the study (Fig. 24).

3.6 Growth

Growth rate as measured by change in carapace width was greater for 0+ crab inside Grays Harbor than for siblings in the nearshore area throughout the summer of 1985-86 (Fig. 25). Crabs in the estuary grew from an initial size of about 5 to 7 mm CW at settlement to a mean size of 34 mm CW in

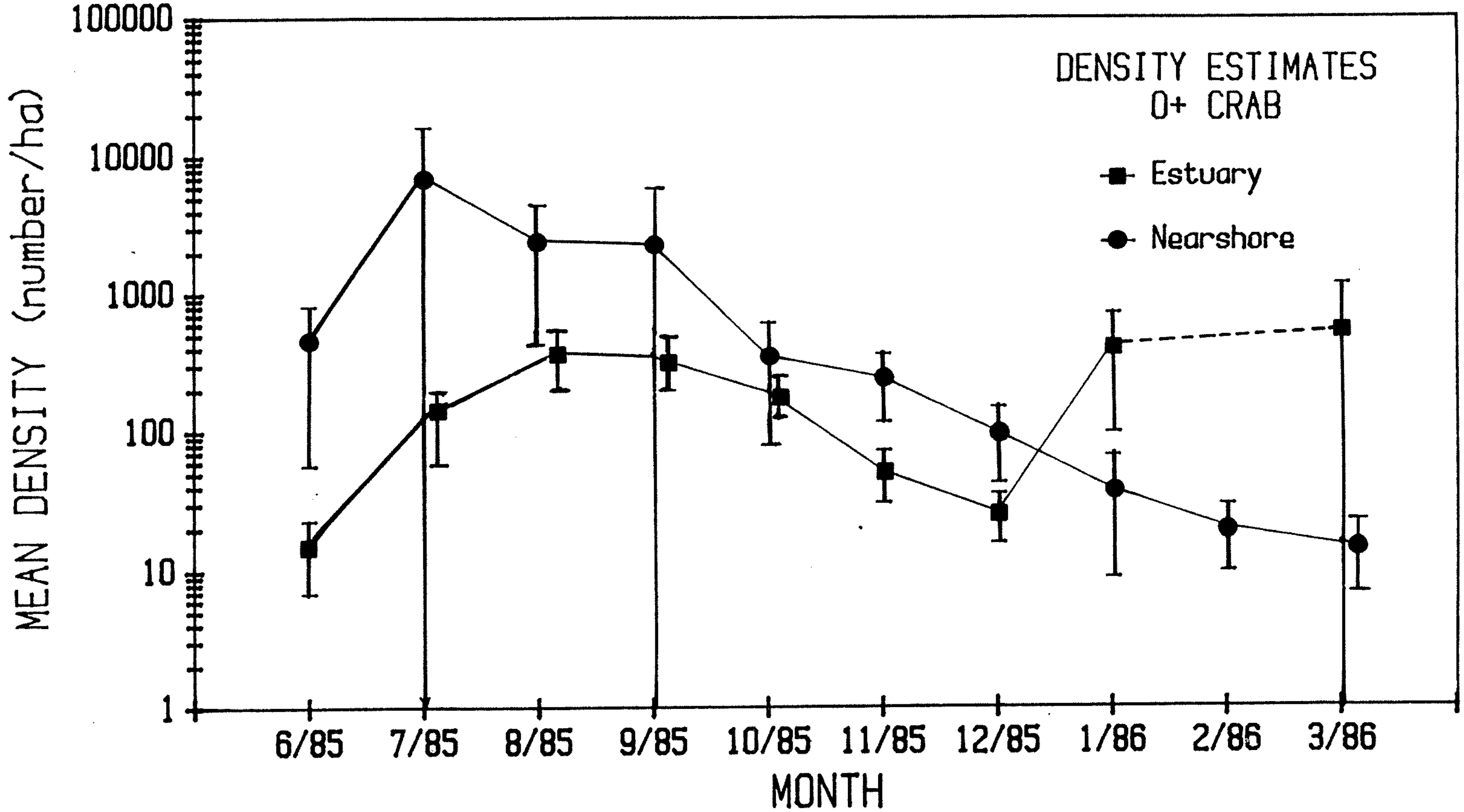

Figure 22. Comparison of mean density estimates of 0+ Dungeness crab in Grays Harbor estuary and nearshore from June 1985 to March 1986. Mean density is represented on a logarithmic scale and dashed line indicates missing value for February. Vertical bars indicate ± 2SE.

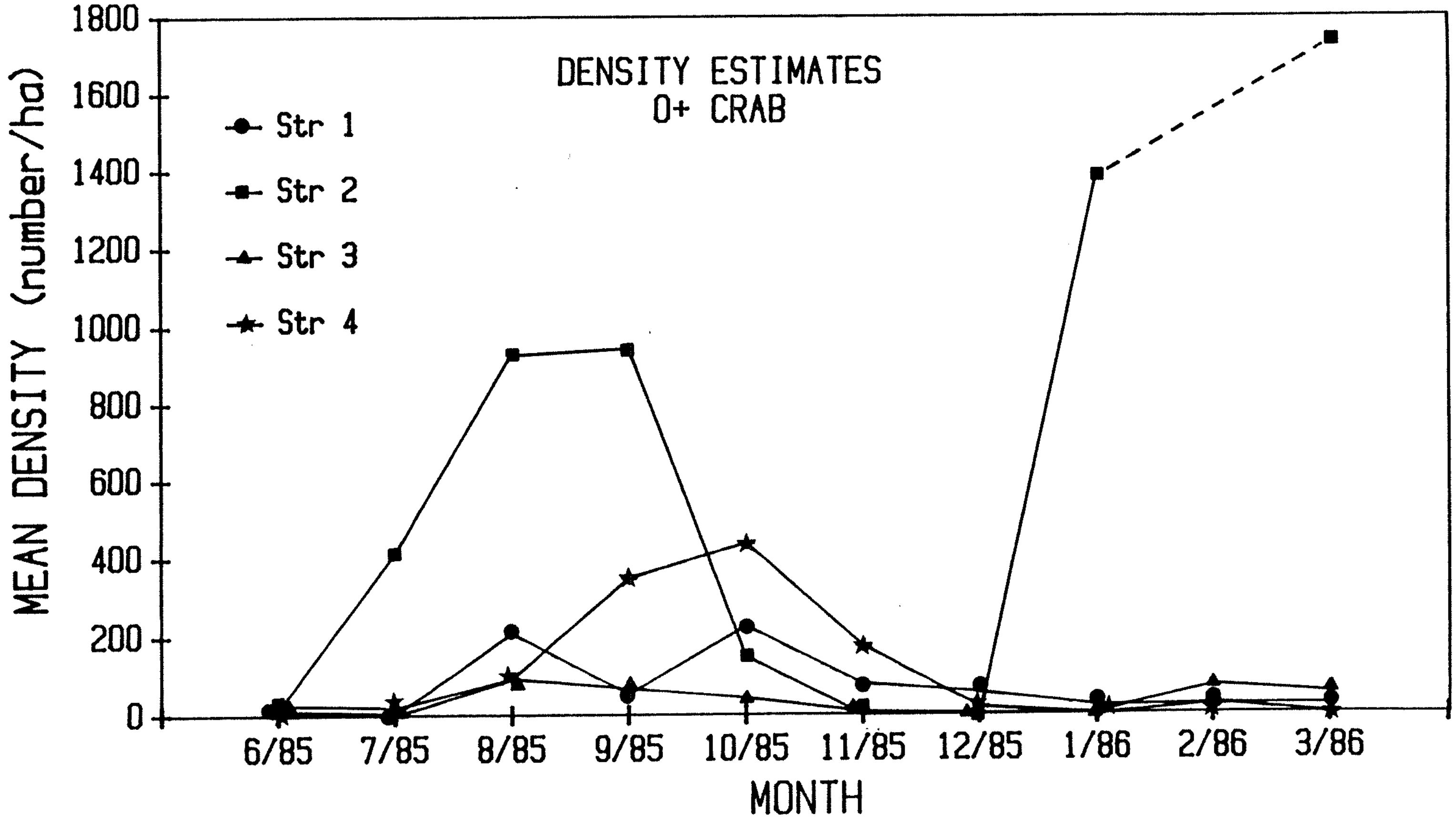

Figure 23. Mean density estimates for 0+ Dungeness crab in Grays Harbor estuary by stratum from June 1985 to March 1986. Dashed line indicates missing value for the North Bay in February.

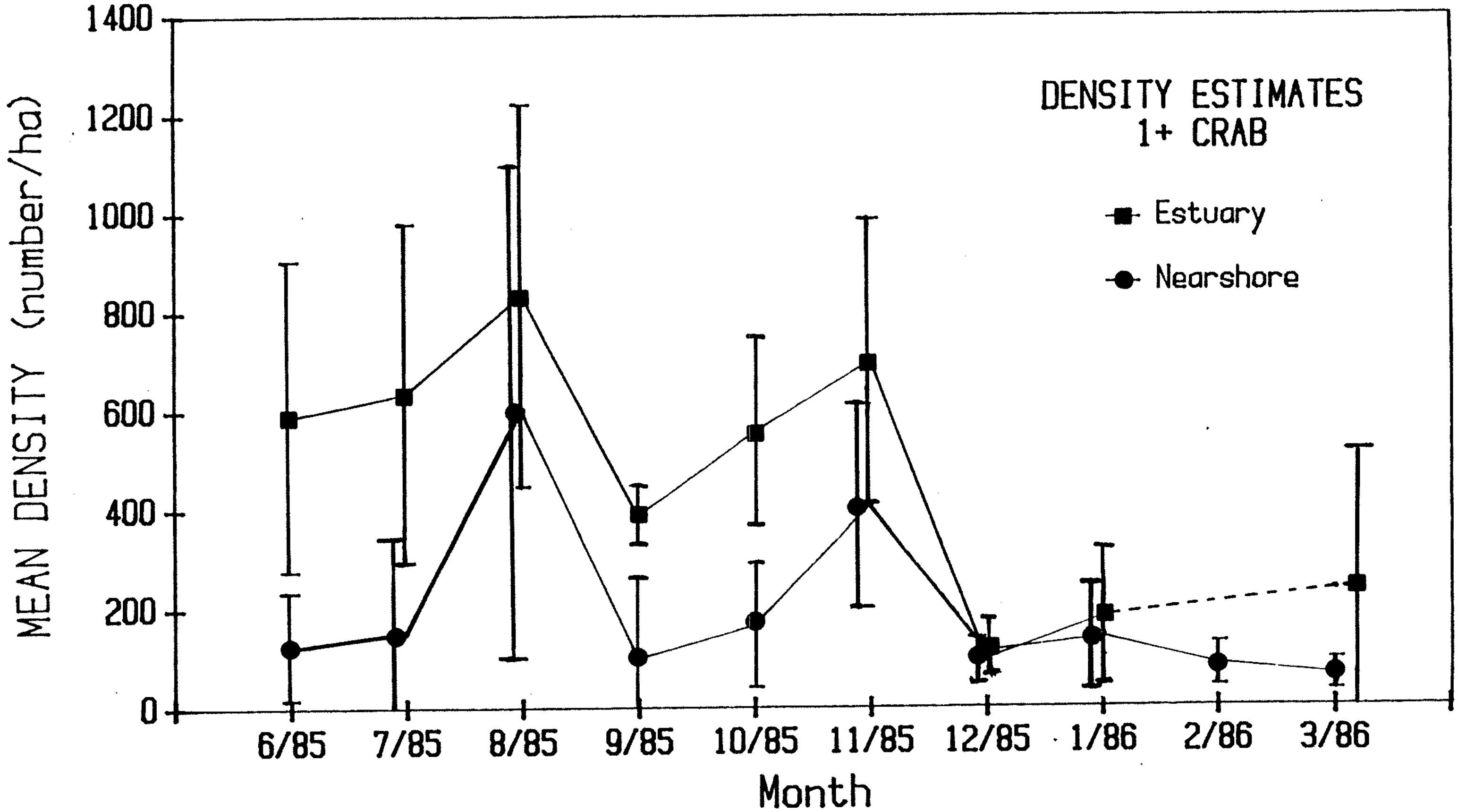

Figure 24. Comparison of mean density estimates of 1+ Dungeness crab in Grays Harbor estuary and nearshore from June 1985 to March 1986. Dashed line indicates missing value for February. Vertical bars indicate ± 2SE.

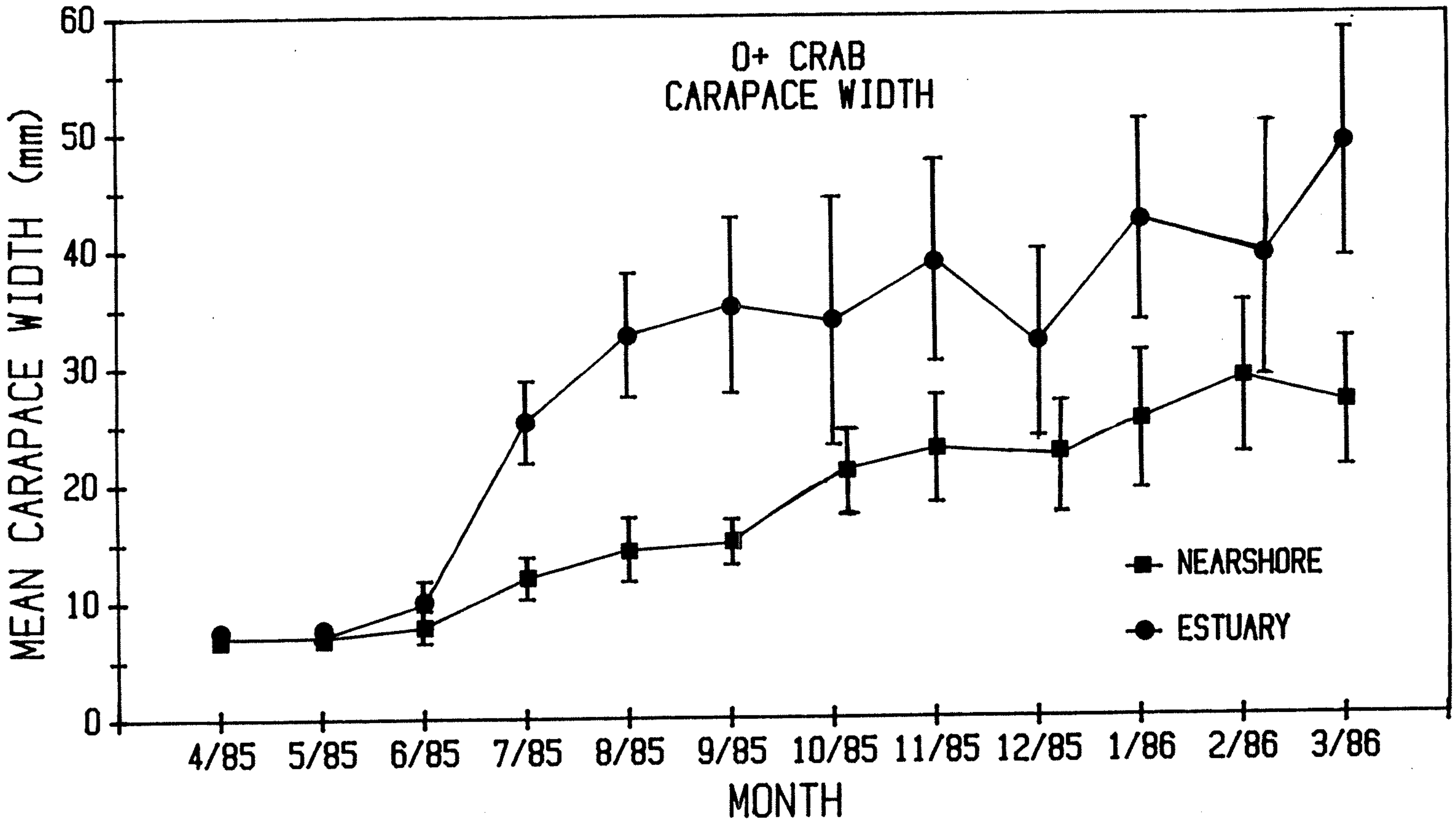

Figure 25. Change in mean size of 0+ Dungeness crab in Grays Harbor and nearshore from April 1985 to March 1986. Vertical bars indicate ± 1SD.

October 1985 (see Appendix B and C for sample size and standard deviations). Their nearshore counterparts had reached a mean size of only 21 mm CW in October. Overwinter growth rate after October appeared similar and slower for both groups with crabs reaching 50 mm CW in the estuary by March and 27 mm CW in the nearshore.

Although the mean size of 1+ crab in the estuary was larger through the summer of 1985, the growth rate of 1+ crab appeared to be similar through June (Fig. 26, Appendix B and C). In July and August growth rate of the nearshore animals increased dramatically and by October, the mean size of both estuarine and offshore animals was indistinguishable. This suggests that the two populations may have mixed (see discussion in Section 4.0 below). The mean size of 1+ juvenile crabs sampled in Grays Harbor in April 1985 was about 53mm CW. In contrast, 1+ crab sampled nearshore in May had a mean size of 40mm. Both groups however, had reached a mean size of approximately 90mm by October, and grew to 100-110mm by March 1986 (Fig. 26).

3.7 Temperature and Salinity

Mean temperature and salinity data were calculated for Str. 2, 3 and 4 in the estuary, Str. 12 and 13 in the estuary mouth, and Str. 8 and 10 nearshore (Appendix D). Mean bottom temperatures for the North Bay (Str. 2), estuary mouth (Str. 13), and nearshore Str. 10 are depicted in Fig. 27. The mean bottom temperature in the North Bay was significantly lower than that in the estuary mouth area and the nearshore study area in November and December when it declined to 5.3^{o}C. This was also true, but to a lesser extent, for other estuary strata (3 and 4; see Appendix D). Bottom salinity data for the same strata are shown in Fig. 28. Mean bottom salinity was also lower in

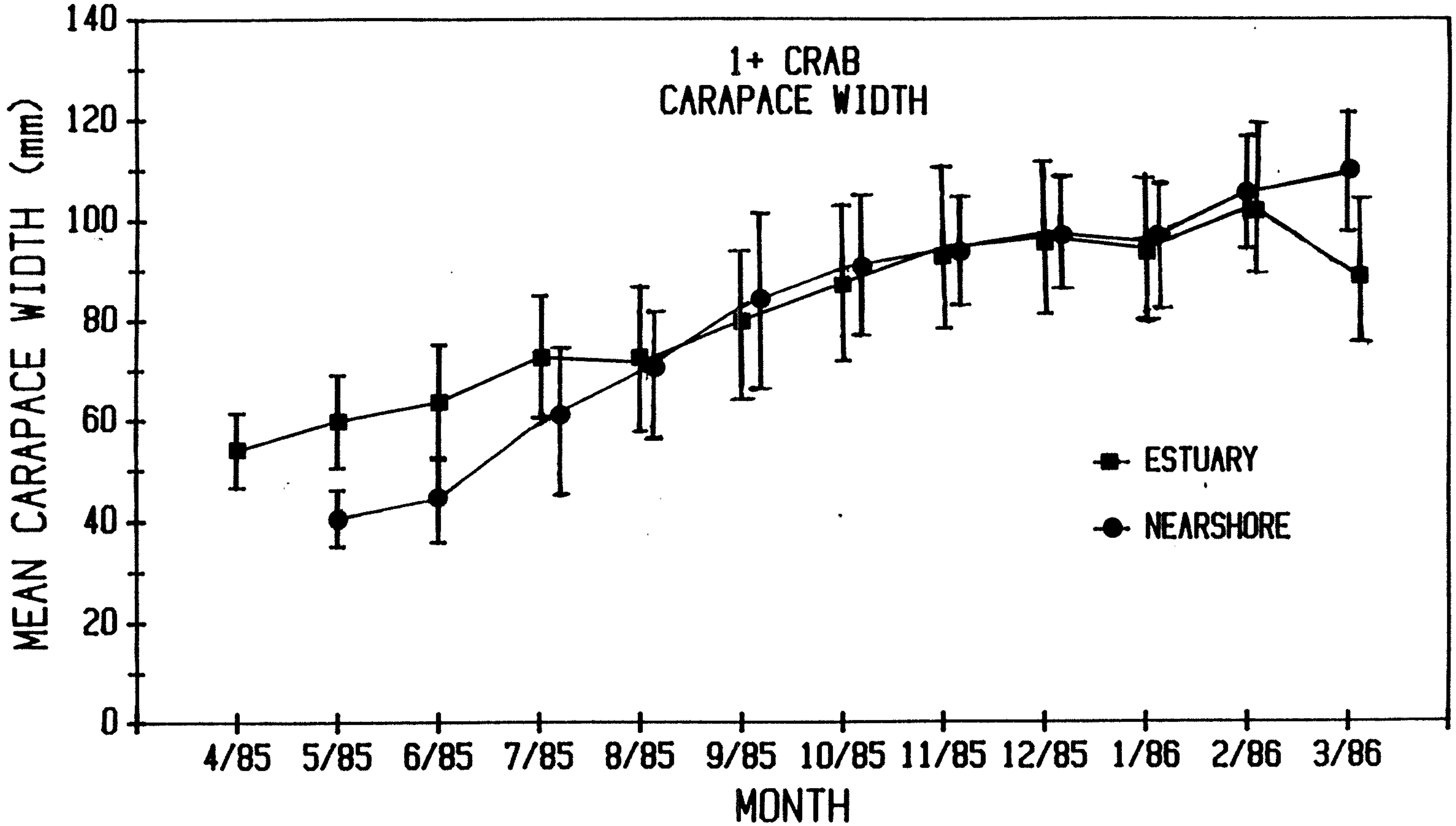

Figure 26. Change in mean size of 1+ Dungeness crab in Grays Harbor and nearshore from April 1985 to March 1986. Vertical bars indicate ± 1SD.

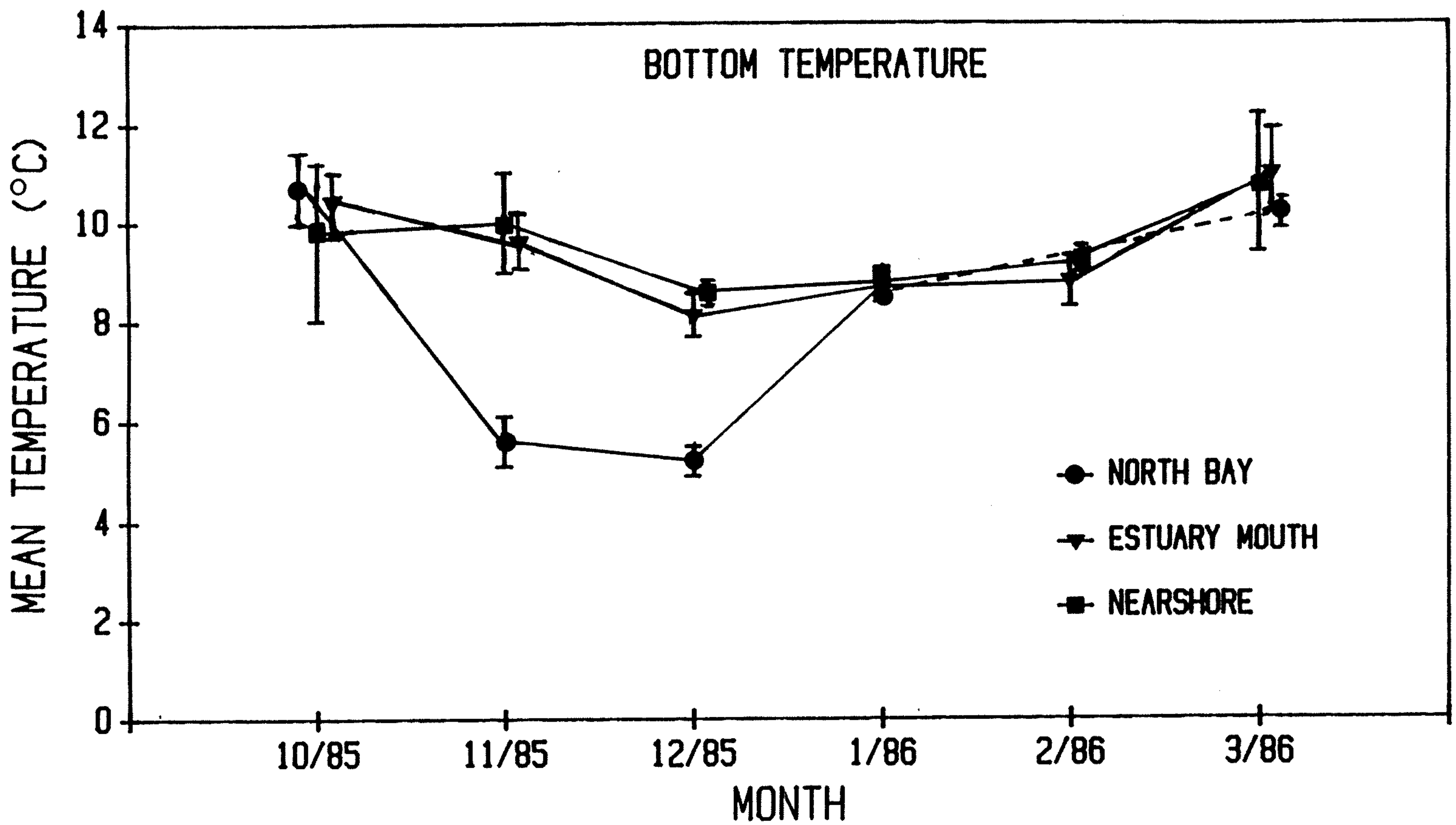

Figure 27. Mean bottom temperature in the North Bay (Stratum 2), the estuary mouth (Stratum 13), and nearshore at 40 m depth (Stratum 10), from October 1985 to March 1986. Vertical bars represent ± 1SD and dashed line indicates missing value for the North Bay in February.

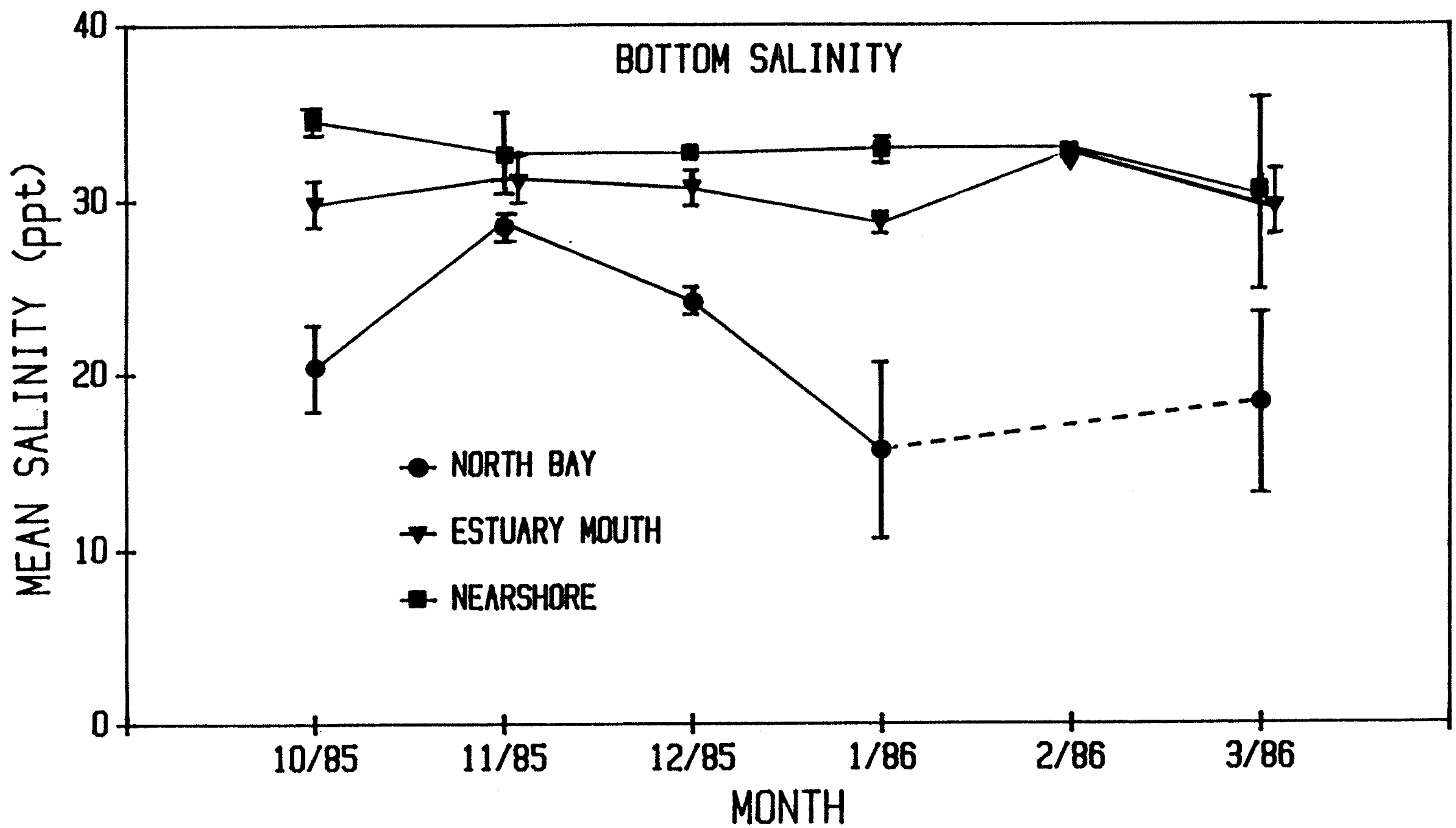

Figure 28. Mean bottom salinity in the North Bay (Stratum 2), the estuary mouth (Stratum 13), and nearshore at 40 m depth (Stratum 10), from October 1985 to March 1986. Vertical bars represent ± 1SD and dashed line indicates missing value for the North Bay in February.

Str. 2 than elsewhere, particularly during January through March when heavy rains and freshwater input decreased salinity to about 15-18 ppt. Mean bottom salinities were higher nearshore and at the estuary mouth and ranged between 29 to 33 ppt (Fig. 28).

4.0 DISCUSSION

One of the primary objectives of the fall/winter study was to collect data that, in the absence of actual tagging studies, would substantiate the hypothesis that juvenile crabs migrate into and out of coastal estuaries such as Grays Harbor (Armstrong et al. 1986). The evidence for migration came from three previous years of research on population dynamics in which an estuarine pattern of increased abundance in spring, relative constancy in summer and apparent decline in late summer, suggested immigration and emigration in accord with higher salinity and temperature in the estuary. The only previous study of crab abundance in Grays Harbor through winter had been done by Stevens and Armstrong (1984) who found a 10 fold decline between summer and winter, although the assumptions used to estimate abundance were tenuous. As outlined earlier in Section 2.1, two approaches were taken to study migration. The first required bimonthly sampling of estuarine stations to document an overall decline in crab abundance in the fall. The second approach was more spatially oriented where stations were sampled in the constricted mouth area of Grays Harbor and in the nearshore area adjacent to the mouth, to increase the chance of detecting movement and allow comparison of density estimates between the nearshore, the estuary, and the entrance that connects them both and through which crab must move to either location. Nearshore data were also analyzed to detect further movement patterns in the coastal area.

The results, which were presented separately by area above, have shown that the growth pattern of a crab population is perhaps the key to separating one population from another and to detecting movement of a population from one area to another (e.g. from the estuary to nearshore). Therefore, results from both sampling approaches will now be discussed separately by age class.

4.1 0+ Crab

Summer Sea Grant data showed that 0+ crab of the 1985 year class recruited to the estuary in much lower numbers than in previous years (Armstrong et al. 1984, 1985a, 1986). Abundance after initial peak settlement in the subtidal in 1983 and 1984 exceeded 50 million 0+ crab (e.g. 211 million in May, 1984), but this age class did not exceed one million animals until July of 1985. A maximum population of only 3.3 million crab was estimated in August 1985 whereas in 1983 and 1984 fairly stable 0+ populations in the range of 5 to 15 million were calculated for the estuary in July and August. Data from the entire time series of April 1985 through March 1986 indicated that 0+ crab density was highest from August through October, depending on the stratum, and then decreased to a low in December (less than 100 crab/ha, Fig. 23). This trend agrees with previous years when the population has remained stable or even increased in the early fall and then decreased to lower values in the winter (Stevens and Armstrong 1984; Armstrong et al. 1985a).

Higher abundance of 0+ crab in late summer, at least 3 months after initial settlement in the estuary (observed in intertidal areas in May and June), was probably due to movement or migration. Although density in the nearshore coastal area was decreasing at this time, migration of 0+ from this area can be ruled out because no concurrent decrease in the growth rate or size frequency pattern of estuarine animals was seen (Figs. 9,10, 26). Crab caught in the estuary had a mean size of approximately 33 mm CW in August while those animals caught nearshore had a mean CW of 15.5 mm and clearly comprised a separate population. Armstrong et al. (1985a) observed a similar increase in abundance of 0+ crab in the fall of 1984 and presumed that these crab came from intertidal areas where densities declined as summer progressed.

In 1985, as in previous years, the abundance of 0+ crab in the North Bay (Str. 2) was far greater than in any other part of the estuary. Trends in the population data for the estuary are controlled by trends for the North Bay (Fig. 23). For example, when the catch of 0+ crab in the North Bay fell to zero in November and December and increased again in January, the estuarine population estimates mirrored this trend. No trawls were made in the North Bay in February, but March catches indicated a population estimate of about 4.4 million 0+ crab in the North Bay and 4.5 million in the entire estuary (approximately 98% of the catch was from the North Bay). Both the decline and the subsequent increase in 0+ crab abundance occurred while nearshore population numbers and mean density estimates were declining. Migration between the nearshore area and the North Bay or between the nearshore and elsewhere within the estuary seems unlikely because the mean CW of the two populations remained distinct through March (Fig. 25).

If the decline in abundance of 0+ crab in the winter and subsequent increase in March was not a result of migration to and from the nearshore then it was possibly caused by movement between the intertidal and subtidal and/or unexplained inefficiency of the gear. Although information from the rock dredge study showed no significant differences between density of 0+

crab computed from trawl and dredge catches, the mean density of 0+ crab was greater from dredge samples in all 3 winter months sampled (Table 16). Furthermore, dredging could not be carried out in the North Bay where the greatest change in abundance took place. Time series records showed that mean bottom temperatures were less than 6^{o}C in November and December in the North Bay. This was significantly colder than in other areas of the estuary (Fig. 27). In January temperatures increased to approximately 8.7^{o}C, a level comparable to other locations. This information, combined with reports indicating similar behavior in Puget Sound (Armstrong and Armstrong 1984), led us to believe 0+ crab buried in the bottom sediments in late fall and early winter of 1985, particularly in the North Bay, and so were unavailable to the trawl gear.

Population dynamics of 0+ crabs located nearshore in 1985 were also different than recorded in previous years (Armstrong et al. 1986). The magnitude of settlement in 1985 was three times greater than any previous 0+ population estimate for the Sea Grant nearshore study area, reaching 1.3 billion crab in early July with the greatest density (21,000 crabs/ha) in Str. 6 between 16 and 40m depth. Population estimates in September fell to 400 million 0+ crab with the greatest density (3,650 crabs/ha) shifting to Str. 7, predominantly at the 46m station. Although reduced in number by September, 0+ abundance was still far in excess of estimates of 127 million in 1984 and 2 million in 1983. Data from this study indicated that the number of 0+ crab continued to decline throughout the fall and winter, at least in the area close to the estuary mouth (from a maximum of 684 crabs/ha at 40m depth in October to 36 crabs/ha at 15m in March). It appears from this study that at least through March, significant numbers did not migrate into the estuary in spring as has been suggested (Armstrong et al 1987), but further analysis of the data collected by Sea Grant researchers from April through the summer of 1986 may help to further define the fate of this 1985 population of 0+ that settled nearshore.

4.2 1+ Crab

Juvenile 1+ crab were found in lower numbers in the estuary in 1985 than might have been expected from the strength of the 1984 year class at the end of the Sea Grant sampling season in September of 1984. Population estimates fluctuated between 3 to 7 million animals throughout the summer and fall, with a mean value of 5.5 million crabs. This was slightly greater than the 4.7 million estimated for 1984 (1983 year class), but lower than 11 million in 1983 (1982 year class).

The number of 1+ crab remained at this level through November when the population estimate was 5.1 million crab, but fell drastically to only 0.8 million crab in December (Fig. 12). A similar pattern was evident in the only other winter data collected in previous Grays Harbor studies (Stevens and Armstrong 1984), but the lowest density was recorded in October. The drop in 1985 was due, in part, to the virtual absence of crabs in the North Bay (Str. 2) in December, but also to a decline in the numbers in the Outer Harbor mouth area (Str. 1, Table 3). In January these crabs reappeared in the North Bay catches, but continued to decrease in number in the Outer Harbor. This suggests that, like the 0+ crab in the North Bay, the 1+ population also was not available to the gear (potential burial) in this stratum. Population estimates for Str. 3 (Inner Harbor) and 4 (South Bay) were rarely as high as those in Str. 1 and 2, but mean density estimates were often comparable, especially for Str. 4 which had a much smaller total area than the other strata.

The 1985 Sea Grant nearshore coastal population estimates for 1+ crab were greater than those for two previous years, ranging between 20 to 26 million crab throughout the summer. Densities were highest in the two shallowest strata (5 and 6, 5-40 m) with virtually no 1+ crab caught at deeper stations. This continued to be the case throughout the fall and winter with fewer 1+ crab caught at the deeper stations in Str. 10 (34-44 m) than at shallower locations. With the exception of two large peaks in August and November, the mean density of 1+ crabs nearshore remained fairly stable at 200 to 300 thousand crab/ha through January and then fell below 100 thousand crab/ha in March (Fig. 24).

Unlike 0+ crab, 1+ crab apparently emigrated from the estuary to the nearshore based on a trend of decreasing abundance in the estuary for the period of June 1985 through January of 1986. The estuarine 1+ population declined from a mean density of 700 crabs/ha to less than 200 crabs/ha, a decline which appeared to be attributable to emigration of larger 1+ crab near the upper end of the size frequency range (see Figs. 9, 13, 15). Large, relatively abrupt increases in the mean carapace width of crabs caught nearshore during this period were inconsistent with growth rates in either the nearshore or the estuary and confirmed that movement takes place (Fig. 26). The sharp increase in size over time of the nearshore coastal population is perhaps even better portrayed in Fig. 29 where data from distinctly separate strata are shown (Str. 6 and 9, offshore 16-40m, and Str. 3 in the eastern portion of the estuary). Growth from a mean carapace width of 56 mm in August to 87 mm in September is not possible for coastal 1+ crab and, therefore, mixing of the two populations was assumed.

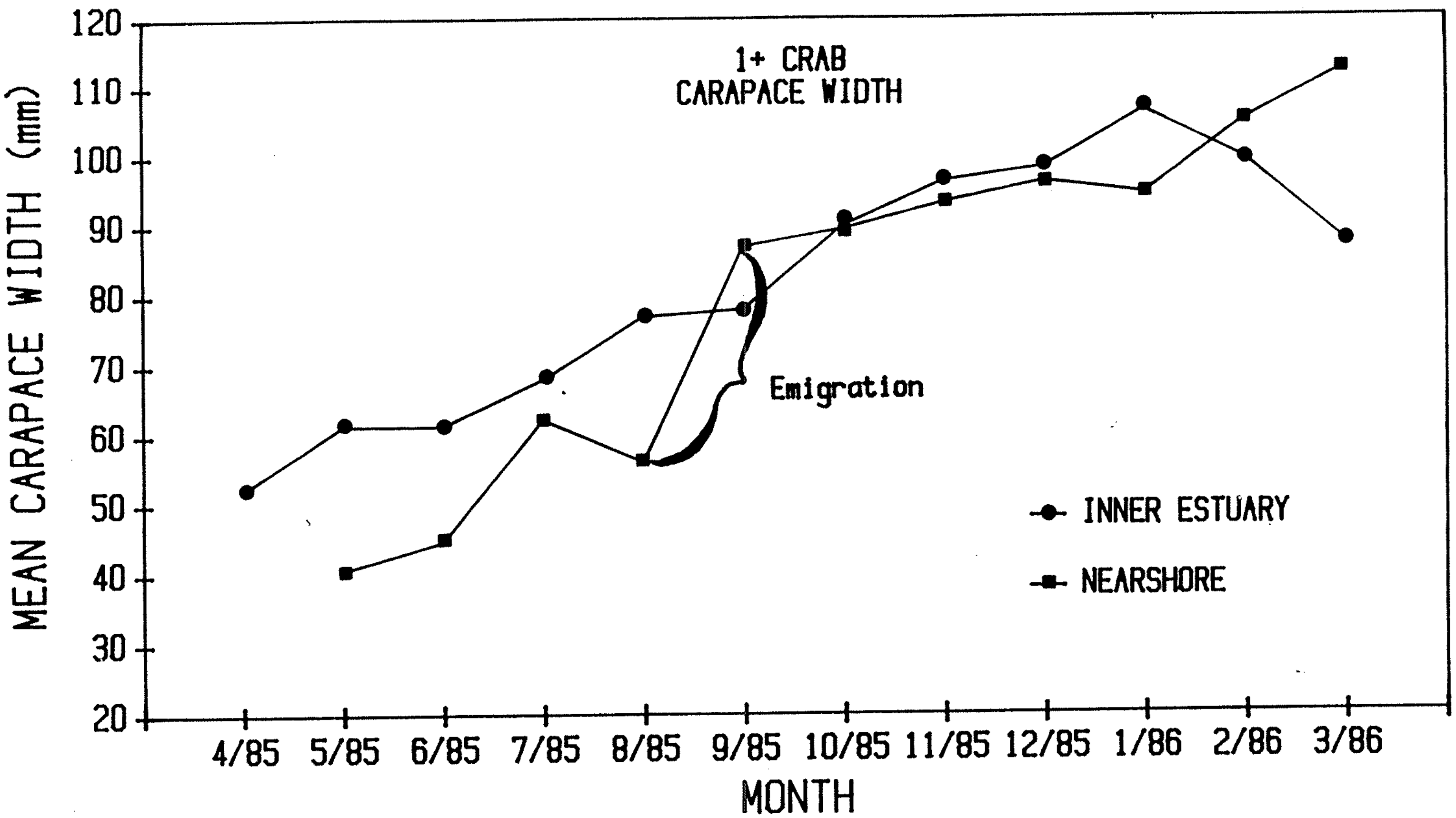

Figure 29. Change in mean size of 1+ Dungeness crab in the inner estuary (Stratum 3) and intermediate depths (15-40m) nearshore (Stratum 6 and 9) April 1985 to March 1986. The sudden increase in size of nearshore 1+ crab between August and September is assumed to be caused by emigration of larger estuarine crab to the nearshore coastal area.

4.3 Implications of Data for Dredging Operations

Initial studies by Tegelberg and Arthur (1977) found that crabs are entrained and killed during dredging operations. Further concern and approval from Congress for studies on the proposed Grays Harbor Navigation and Improvement Project led to the initiation of several studies by COE dealing with the potential effects of dredging on Dungeness crab populations in Grays Harbor. Work by Stevens (1981) and Armstrong et al. (1982) refined mortality estimates and showed that scheduling of dredging operations, particularly with respect to season and location, could greatly reduce potential crab mortality. Additional surveys, funded by Washington Sea Grant, provided an extensive amount of information on the seasonal abundance patterns of crab populations in Grays Harbor and along the nearby Washington coast. Most recently in October 1985 and August 1986, data on entrainment and local crab density in areas of dredging were collected by COE and University of Washington researchers to better gauge and predict the percentage of resident crab entrained and killed under various scenarios of gear, location and time (Dinnel et al. 1986a, Dinnel et al. 1986b, McGraw et al. 1987).

Hopper dredge mortality was shown by Stevens (1981) to be greater for crabs larger than 50mm CW (85.6% of those crabs entrained), than for crabs less than 50mm CW (45.9%). Stevens assumed that all estuarine crabs found in fall and winter were greater than 50mm which is probably not true for a portion of the 0+ crab. For example this was not the case for 1985 0+ crab, which did not reach a mean size of 50mm until March of 1986 (Figs. 9, 10, 25). Recent studies by the Portland District Army Corps of Engineers indicate that 0+ crab less than 15mm CW are rarely harmed by the hopper dredge (Larsen 1986).

Stevens (1981) and Armstrong et al. (1982) predicted that crab mortality could be decreased by limiting dredge operations to winter months (September through February). Although practical considerations would limit operations to the estuary in these months, this study indicates that this window could be adjusted from year to year depending on the strength of both the 1+ and incoming 0+ year classes and the timing of settlement and migration. For example, in 1985 the incoming 0+ year class was not strong, and appreciable numbers in the subtidal parts of the estuary were not noted until July and August when crabs apparently moved off the intertidal. Even these numbers were relatively low, and thus potential impacts to this population would likely be predicted as low when compared to other years. In 1984, settlement in the estuary was very high and a very large peak in 0+ crab abundance was observed in September subtidal trawls. In such a year adjusting the dredge operating window to avoid this peak could be important.

The 0+ crabs did not appear to move out of the estuary in fall 1985 and may have been missed by trawl gear due to burial in the sediment in shallow areas more affected by temperature such as North Bay. Although statistical results from the biological rock dredge studies could not be interpreted to prove that crabs did not bury in the bottom sediments, it appeared that they did not display this behavior, at least in large deeper channels where dredging normally occurs and so the decrease in fall/winter density can be considered accurate when predicting impact of entrainment in those areas. Although biological dredge samples could not be taken in the North Bay to confirm burial, circumstantial evidence is strong (based on abrupt change in winter density) that crab may bury where water temperatures are too cold.

Dredging in the proposed channel locations should not directly impact those crabs burrowing in shallower channels elsewhere in the bay.

Although entrainment rates appear to be lower for 1+ crab due to a number of factors including avoidance behavior (Larsen 1986, McGraw et al. 1987), entrainment mortality is greater for these larger crab. Because they have survived tremendous natural mortality rates in their first year of life and are that much closer to the fishery, the timing of abundance of the 1+ year class in the estuary is potentially more important for scheduling dredge operations than that of the newly settled 0+ juveniles. The present study showed that 1+ crab were migrating out of the estuary during the late summer of 1985. This movement appeared to begin in late July and August when high numbers of larger estuarine crab appeared nearshore, which caused an apparent increase in size and growth rate of 1+ crab outside the estuary (Table 10, Fig. 29). It appears that most movement occurs in the period from August through early November which should be considered as a vulnerable period for hopper and pipeline dredge operations, particularly those in the outer harbor, estuary mouth, and shallow nearshore area (5-15 m).

Several studies have addressed the potential impacts of disposal of dredged material on crab in nearshore areas (Armstrong and Gutermuth 1984; Armstrong and Armstrong 1985; Armstrong and Armstrong 1986). These studies focused entirely on distribution within the 3 proposed offshore disposal areas during individual months, and could not address scheduling over a longer (month to month) period. No work has been done on the direct impact of disposal to the crab population. It is not known to what extent either smaller 0+ or larger 1+ crabs are affected (e.g. buried, suffocated, loss of food), but it can be assumed that impacts on larger 1+ crab are potentially more critical than are impacts on smaller, more numerous 0+ crab.

The results of Sea Grant work (Armstrong et al. 1986) indicated that both 0+ crab and 1+ crab were more abundant in nearshore areas in 1985 than in previous years. The largest populations of 1+ crab were found at shallow to intermediate depths (<40m) in late summer and early fall as crabs moved out from the estuary. This study showed that density estimates remained high at intermediate depths (30m) through November in the smaller study area adjacent to the mouth of Grays Harbor. This area included stations located primarily in the proposed west and southwest tow boat lanes disposal sites. Only 0+ crab were found in great abundance at stations deeper than 35m and at the 46m station located within the proposed 8 Mile disposal site. The potential impact of dredged material disposal to larger 1+ crab could therefore be minimized by limiting disposal operations to depths greater than 35m, particularly during the latter part of the operating window for nearshore disposal (August and September) when crabs are emigrating from the estuary. Although 0+ density may be very high nearshore especially right after settlement, so too is natural mortality. At stations in the southwest towboat lane where 0+ density exceeded 100,000 crab/ha in June 1985 (Armstrong and Armstrong 1986), density was 100 fold less in September. Initial settlement density is a misleading gauge of longer term survival and abundance. Mortality is routinely very high and the 0+ population greatly reduced by September and October.

5.0 SUMMARY

1. Recruitment of the 1985 year class of Dungeness crab to Grays Harbor estuary was weak compared to previous years. Noticeable increases in abundance of 0+ crab in the subtidal occurred later in summer and early

fall (from August-October) and were probably the result of movement off intertidal areas.

2. The estuarine 0+ population estimate declined to its lowest level in December 1985 but increased again in January. This was due entirely to catches in the North Bay where temperature and salinity fluctuated greatly and crabs may have buried in the sediment, thereby escaping trawl gear in December.
3. Recruitment of the 1985 year class to nearshore areas was very strong with population estimates reaching 1.2 billion. Numbers declined rapidly, however, and the mean density of 0+ crab nearshore was always less than that in the estuary.
4. 0+ crab do not appear to move great distances (i.e., either emigrate to nearshore areas or immigrate into the estuary). Some mixing may occur in the estuary mouth, but the mean carapace width of the two populations remained distinct throughout the study, and the growth rate was greater in the estuary during the first summer after settlement.
5. Juvenile 1+ crab were found in lower numbers in the estuary in 1985 than might have been expected based on the strength of the 1984 year class. Estuarine population estimates of crab fell from 5 million in November to 800,000 in December (probable burial), but increased to 2 million again in January, primarily due to increased catch in the North Bay.
6. Population estimates for 1+ crab nearshore in the summer were higher than any previously recorded estimates. Density was highest at shallow to intermediate depths (<40m) throughout the summer and winter sampling periods.
7. Although population estimates were not comparable because of study area size, density estimates indicated no consistent drop in the number of 1+

crab nearshore through January of 1986. This, along with an abrupt change in size frequency and mean carapace width of nearshore animals in the late summer and fall, led to the conclusion that larger 1+ crab emigrated from Grays Harbor to the nearshore area.

8. Comparison of crab density estimates from biological rock dredge samples with those from trawl samples taken in November 1985 and January and February 1986 showed that no apparent burial behavior was occurring at the relatively deep mid-channel locations sampled; however, density estimates for 1+ crab based on trawl samples were significantly greater than those based on rock dredge samples.

9. Older crab (>1+) were present in very low numbers (densities less than 50/ha), but were most abundant in the Outer Harbor (Str. 1), the South Bay (Str. 4), and shallow to intermediate depths nearshore (<40m). Ovigerous females were not found in the estuary and were only taken nearshore.

10. 1+ and >1+ crab populations will be more affected by dredging and disposal operations both in the estuary and nearshore than will be 0+ populations. Periods of movement of 1+ crab through the entrance channel in late summer/early fall and in spring make them more vulnerable to entrainment in that location than at other times.

LITERATURE CITED

Armstrong, D.A. and J.L. Armstrong. 1984. Ship Harbor Dungeness crab study field work, November 1984. Report to KCM, Inc. and Seeward Development Inc., 10 pp.

Armstrong, D.A. and J.L. Armstrong. 1985. Juvenile Dungeness crab distribution and population abundance offshore of Grays Harbor, proposed ocean disposal area, June 1985. Report to the U.S. Army Corps of Engineers, Seattle District Office and Battelle Pacific Northwest Laboratories, 15 pp.

Armstrong, D.A. and J.L. Armstrong. 1986. Juvenile Dungeness crab distribution and population abundance offshore of Grays Harbor, proposed ocean disposal area, September 1985. Report to the U.S. Army Corps of Engineers, Seattle District Office and Battelle Northwest Laboratories, 21 pp.

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. Proceedings of the Symposium on Dungeness Crab Biology and Management. Oct. 1984. Alaska Sea Grant Report No. 85-3; 145-170.

Armstrong, D.A. and B. Gutermuth. 1984. Juvenile Dungeness crab distribution and population abundance offshore of Willapa Bay and a comparison to other areas along the Washington coast. Report to the U.S. Army Corps of Engineers, Seattle District Office, 22 pp.

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 Rpt by School of Fisheries, Univ. Wash. to Wash. Dept. of Fisheries and U.S. Army Corps of Engineers, 349 pp.

Armstrong, D.A., D.R. Gunderson, C. Rogers and K.R. Carrasco. 1984. Juvenile Dungeness crab population dynamics offshore and in estuaries: Review of literature and analysis of data (1983). Report to the Seattle District U.S. Army Corps of Engineers, 75 pp.

Armstrong, D.A., D. Gunderson and J. Armstrong. 1985a. Juvenile Dungeness crab population dynamics in and offshore of the Grays Harbor estuary, spring and summer 1984. Report to the Seattle District U.S. Army Corps of Engineers, 59 pp.

Armstrong, D.A., J.L. Armstrong, R. Palacious, G. Williams, G. Jensen and W. Pearson. 1985b. Early life history of juvenile blue king crab Paralithodes platypus around the Pribilof Islands. Proc. Intl. King Crab Symposium, University of Alaska, Alaska Sea Grant Report, 85-12: 211-230.

Armstrong, D.A., J.L. Armstrong and D.R. Gunderson. 1986. Juvenile Dungeness crab population dynamics in Grays Harbor and Willapa Bay and along the adjacent coast, spring and summer, 1985. Report to the U.S. Army Corps of Engineers, Seattle District Office, 43 pp.

Armstrong, D.A., T.C. Wainwright, Jose Orensanz, P.A. Dinnel, and B.R. Dumbauld. 1987. Model of dredging impact on Dungeness crab in Grays Harbor, Washington. Final report to Battelle Pacific Northwest Laboratories and Seattle District U.S. Army Corps of Engineers, 167 pp.

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. Proceedings of the Symposium on Dungeness Crab Biology and Management., Oct. 1984. Alaska Sea Grant Rept. No. 85-3: 171-184.

C.O.E. (U.S. Army Corps of Engineers). 1977. Maintenance dredging and the environment of Grays Harbor, Washington. Final Report of Studies on Dredging and Dredged Material Disposal Operations in Grays Harbor. Appendices A-N.

Dinnel, P.A., D.A. Armstrong and C. Dungan. 1985. Initiation of a Dungeness Crab, Cancer magister, habitat study in North Puget Sound. Proceedings of the Symposium on Dungeness Crab Biology and Management. Oct. 1984. Alaska Sea Grant Rept. No. 85-3:327-337.

Dinnel, P.A., D.A. Armstrong and B.R. Dumbauld. 1986a. Impact of dredging and dredged material on Dungeness crab, Cancer magister, in Grays Harbor, Washington during October, 1985. Final report to the U.S. Army Corps of Engineers, Seattle District Office, 30 pp.

Dinnel, P.A., D.A. Armstrong, B.R. Dumbauld, and T.C. Wainwright. 1986b. Impact of dredging and dredged material on Dungeness crab, Cancer magister, in Grays Harbor, Washington during August, 1986. Final report to the U.S. Army Corps of Engineers, Seattle District Office, 34 pp.

Dumbauld, B.R. and D.A. Armstrong. 1987. A pilot study for the introduction of intertidal shell habitat to mitigate potential dredging impacts on juvenile crab populations in Grays Harbor, Washington. Draft final report to the U.S. Army Corps of Engineers, Seattle District Office, 50 pp.

Gunderson, D.R., D.A. Armstrong and C. Rogers. 1985. Sampling design and methodology for juvenile Dungeness crab surveys. Proceedings of the Symposium on Dungeness Crab Biology and Management., Oct. 1984. Alaska Sea Grant Rept. No. 85-3: 135-144.

Gunderson, D.R., and I.E. Ellis. 1986. Development of a plumb staff beam trawl for sampling demersal fauna. Fish. Res. 4: 35-41.

Larson, K. 1986. Personal communication, U.S. Army Corps of Engineers, Portland District, Oregon.

McGraw, K., L.L. Conquest and J.O. Waller. 1987. Entrainment of Dungeness crabs by hopper dredge in Grays Harbor, Washington. Report for the U.S. Army Corps of Engineers, Seattle District Office, 50 pp.

Pacific Marine Fisheries Commission (PMFC). 1986. 38th Annual Report of the P.M.F.C. for the year 1985. R.G. Porter, (ed.) Portland, Oregon, 36 pp.

Pearson, W.H. 1985. Options for avoidance and mitigation of crab losses during dredging of Grays Harbor, Washington. Report to the U.S. Army Corps of Engineers, Seattle District Office, 21 pp.

Stevens, B.G. 1981. Dredging-related mortality of Dungeness crabs associated with four dredges operating in Grays Harbor, Washington. Final Rpt. to U.S. Army Corps of Engineers, Seattle District by Wash. Department of Fisheries, 148 pp.

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

Tegelberg, H.C. and R. Arthur. 1977. Distribution of Dungeness crabs (*Cancer magister*) in Grays Harbor, and some effects of channel maintenance *dredging*. Appendix N *In*: Maintenance Dredging and the Environment of *Grays Harbor, Washington*. Final Rept. by U.S. Army Corps of Engineers, Seattle District, 94 pp.

Appendix A. Locations of Estuary, Estuary Mouth and Nearshore Stations (see Figs 1 - 3). Estuary stations (11 - 43) have standard stratum designation as prefix (e.g. within Str. 4 numbers 41, 42, 43). Nearshore stations have transect line prefix and depth suffix (e.g. Sta. 322 was located at 22 fms on transect line 3). Estuary mouth stations (1 - 9) have single digit codes.

Station #	Latitude	Longitude
1	46°55.30'	124°10.26'
2	46°55.09'	124°10.26'
3	46°54.85'	124°10.26'
4	46°55.46'	124°08.88'
5	46°55.02'	124°08.88'
6	46°54.82'	124°08.88'
7	46°55.51'	124°07.30'
8	46°55.09'	124°07.30'
9	46°55.55'	124°06.40'
11	46°55.28'	124°06.36'
12	46°57.43'	124°06.18'
13	46°56.15'	124°03.07'
14	46°55.90'	124°07.30'
15	46°56.07'	124°05.55'
21	47°00.42'	124°05.70'
22	46°59.40'	124°05.87'
23	46°58.68'	124°05.87'
24	46°59.40'	124°03.82'
25	46°58.52'	124°03.82'
26	46°59.32'	124°02.87'
31	46°55.62'	123°59.20'
32	46°55.98'	123°56.35'
33	46°56.32'	124°00.33'
34	46°57.80'	123°57.13'
41	46°54.48'	124°05.93'
42	46°53.85'	124°04.87'
43	46°53.05'	124°04.83'
308	46°56.83'	124°13.44'
315	46°56.83'	124°14.94'
322	46°56.52'	124°18.13'
325	46°57.01'	124°20.84'
408	46°55.29'	124°13.44'
415	46°55.40'	124°14.55'
422	46°55.59'	124°16.98'
508	46°53.67'	124°11.84'
515	46°53.78'	124°13.95'
522	46°53.86'	124°15.92'
608	46°51.46'	124°09.58'
615	46°51.40'	124°12.07'
622	46°51.33'	124°14.31'

Appendix B: Mean Size at Age Summary

1985-1986 GRAYS HARBOR

	0+				1+				>1+			
TRIP	SIZE RANGE (mm)	$\overline{x}$ (mm)	SD	n	SIZE RANGE (mm)	$\overline{x}$ (mm)	SD	n	SIZE RANGE (mm)	$\overline{x}$ (mm)	SD	n
APR	0	NC*			25-70	53.3	7.0	1938	71-170	88.7	19.7	125
APR	0-12	7.0	0	1	25-76	55.7	8.7	826	76-170	97.2	23.2	59
MAY	0-14	7.0	0	67	30-80	59.1	8.4	1086	81-170	100.3	19.4	135
MAY	0-14	7.2	0.9	58	30-85	60.4	10.1	1355	86-170	103.4	18.1	105
JUN	7-28	9.8	2.0	25	30-90	63.7	11.5	1007	91-170	110.0	19.0	43
JUL	12-35	25.3	3.5	183	36-110	72.6	12.4	942	101-170	111.3	11.2	49
AUG	14-45	32.7	5.3	572	46-108	71.6	15.1	1189	109-170	127.5	15.8	22
SEP	14-52	35.2	7.5	538	53-115	79.9	14.0	674	116-170	127.3	9.0	11
OCT	14-55	33.8	10.6	398	56-125	87.4	15.5	727	126-180	140.2	8.1	49
NOV	15-55	39.0	8.6	100	56-130	94.5	16.1	1085	131-180	140.6	6.8	48
DEC	15-55	31.9	8.0	52	56-130	96.5	15.2	215	131-180	138.5	6.2	21
JAN	15-62	42.4	8.6	364	63-130	94.2	14.1	161	131-180	140.2	4.2	9
FEB	15-65	39.9	11.0	32	70-135	102.3	14.4	182	136-180	142.1	4.0	8
MAR	18-68	48.9	9.8	503	70-135	89.6	14.0	249	136-180	140.8	5.7	13

Appendix C: Mean Size at Age Summary

1985-1986 NEARSHORE

TRIP	0+				1+				>1+			
	SIZE RANGE (mm)	x (mm)	SD	n	SIZE RANGE (mm)	x (mm)	SD	n	SIZE RANGE (mm)	x (mm)	SD	n
MAY	0-12	7.0	0.1	870	22-65	40.4	5.5	1090	66-170	128.7	12.5	109
JUN	0-12	7.9	1.4	5904	22-75	44.2	8.4	1324	76-170	130.2	20.2	197
JUL	0-19	12.0	1.8	97568	30-90	59.6	14.4	1943	91-170	119.7	18.3	293
AUG	0-25	14.4	2.7	24868	35-100	69.7	11.7	3621	101-170	120.2	14.7	138
SEP	0-30	15.0	1.9	11675	36-110	82.7	18.5	1567	111-170	126.9	12.5	586
OCT	0-31	20.9	3.6	965	55-120	90.3	13.4	1147	121-180	136.1	13.4	44
NOV	0-40	22.9	4.6	874	65-125	94.1	10.8	2016	126-180	138.7	14.2	22
DEC	0-40	22.2	4.7	301	65-130	97.5	11.6	745	131-180	145.1	10.7	11
JAN	0-40	25.3	5.9	49	65-130	95.6	12.2	351	131-180	144.6	7.8	7
FEB	0-45	28.9	6.5	39	70-130	106.3	11.9	268	131-180	142.0	8.6	28
MAR	0-45	26.7	5.5	33	70-135	109.6	11.8	194	135-180	143.6	6.2	18

Appendix D: Mean Temp (°C) and Salinity (ppt) for Station data grouped by strata.

Cruise # (dates)	Stratum	Mean Temperature Surface	Mean Temperature Bottom	Mean Salinity Surface	Mean Salinity Bottom	n
8520	2	4.8(0.3)	5.2(0.3)	21.6(0.8)	24.2(0.8)	5
	3	5.5(0.0)	6.3(0.8)	25.0(1.0)	28.0(2.6)	3
(12/17-12/20)	4	6.0(0.5)	7.0(1.0)	28.7(0.6)	29.3(1.5)	3
	8	6.8(0.3)	8.1(0.5)	29.8(2.2)	33.0(1.4)	4
	10	6.8(2.5)	8.2(0.3)	30.3(0.6)	33.0(0.0)	3
	12	5.7(0.6)	6.2(1.0)	26.0(2.0)	27.7(2.3)	3
	13	7.3(0.4)	7.5(0.5)	30.2(1.3)	31.0(1.5)	6
8601	2	8.3(0.3)	8.7(0.3)	4.2(1.5)	15.6(5.0)	5
	3	7.2(0.3)	7.8(0.3)	12.3(4.7)	21.3(3.8)	3
(1/15-1/19)	4	8.3(0.4)	8.5(0.0)	29.0(0.0)	28.5(0.7)	2
	8	8.3(0.3)	8.5(0.0)	29.3(0.6)	30.0(1.0)	3
	10	8.5(0.1)	8.8(0.3)	29.3(0.6)	33.0(0.0)	3
	12	8.0(0.4)	8.1(0.3)	25.8(2.4)	26.8(1.5)	4
	13	8.5(0.0)	8.7(0.3)	29.0(0.0)	28.7(0.6)	3
8602	3	7.3(0.3)	7.7(0.3)	26.7(2.5)	28.3(1.2)	3
	4	7.0(0.9)	7.0(1.0)	24.3(2.1)	25.7(2.5)	3
(2/20-2/22)	8	7.5(0.6)	8.5(0.4)	30.0(2.7)	32.8(0.5)	4
	10	7.8(0.3)	9.2(0.3)	30.7(0.6)	33.0(0.0)	3
	12	8.0(0.4)	8.1(0.6)	29.0(0.8)	29.8(0.5)	4
	13	9.1(0.4)	8.8(0.5)	32.5(0.5)	32.8(0.4)	6
8603	2	10.0(0.0)	10.1(0.2)	14.0(5.1)	18.3(5.2)	6
	3	9.3(0.3)	8.7(2.3)	9.0(1.0)	18.7(5.0)	3
(3/17-3/20)	4	10.2(0.3)	10.2(0.3)	20.7(1.2)	22.0(1.0)	3
	8	10.8(0.9)	11.1(0.5)	24.8(2.1)	31.5(2.4)	4
	10	11.0(0.5)	10.8(1.4)	27.3(5.0)	30.3(5.5)	3
	12	10.1(0.3)	10.3(0.3)	17.3(4.2)	26.0(1.2)	4
	13	10.7(0.6)	11.0(0.9)	23.0(3.9)	29.8(1.8)	5

Appendix D (cont.): Mean temp (^{o}C) and salinity (ppt) for station data grouped by strata. Error estimates are given as standard deviation (SD).

Cruise # (dates)	Stratum	Mean Temperature Surface	Mean Temperature Bottom	Mean Salinity Surface	Mean Salinity Bottom	n
8515	4	12.1 -	12.4 -	33.0 -	33.0 -	1
	8	11.5(0.3)	10.8(0.7)	33.0(0.0)	34.0 -	3
(10/13-10/16)	10	11.7(0.4)	9.4(1.8)	33.0(0.0)	34.7(.6)	3
	12	12.0 -	12.0 -	30.0 -	31.0 -	1
8516	2	10.4(0.2)	10.5(0.5)	12.3(3.1)	20.3(2.5)	3
	3	12.5(0.0)	12.2(0.3)	24.3(1.2)	26.3(0.6)	3
(10/23-10/29)	4	11.0(0.7)	10.8(0.4)	22.3(6.4)	28.7(0.6)	3
	8	10.5(0.5)	10.4(0.4)	25.0 -	34.0 -	1 *
	10	10.6(0.4)	11.0(0.3)	27.0 -	34.0 -	1 *
	12	11.0(1.7)	11.2(1.0)	20.8(9.7)	28.5(2.9)	4
	13	10.9(0.9)	10.7(0.7)	28.6(2.2)	29.8(1.3)	5
8517	3	10.7(0.3)	11.0(0.0)	8.0(2.6)	25.3(2.3)	3
	4	11.0(0.0)	11.5(0.0)	26.5(2.1)	29.5(0.7)	2
(11/5-11/7)	8	11.0(0.4)	11.4(0.3)	27.0(0.0)	33.0(0.0)	1 *
	12	10.8(0.6)	10.9(0.6)	18.0(8.3)	28.5(1.3)	4
	13	11.0(0.0)	11.0(0.0)	28.0(3.5)	30.8(1.3)	4
8518	2	3.9(0.6)	5.6(0.5)	27.8(2.4)	28.8(1.1)	5
	3	5.3(0.6)	6.4(0.5)	25.3(0.6)	27.0(1.0)	3
(11/21-11/25)	4	6.3(1.0)	6.6(2.5)	24.5(2.1)	28.0(1.0)	2
	8	8.3(0.6)	10.1(0.3)	31.0(0.0)	33.5(0.6)	4
	10	8.6(0.2)	10.0(1.0)	30.3(0.6)	32.7(2.3)	3
	12	6.7(0.5)	8.3(0.4)	28.0(4.5)	31.5(1.0)	4
	13	7.9(0.9)	8.5(0.9)	25.0(13.1)	31.7(2.8)	6
8519	3	5.3(0.8)	6.3(0.8)	19.0(2.6)	24.7(0.6)	3
	4	7.0(0.0)	7.0(0.0)	26.5(0.7)	27.0(0.0)	2
(12/6-12/11)	8	8.3(0.9)	8.1(0.9)	29.8(0.5)	30.8(1.7)	4
	10	7.8(0.8)	9.0(0.0)	30.7(1.2)	32.3(1.2)	3
	12	5.9(0.5)	7.4(0.8)	22.8(2.4)	27.3(1.7)	4
	13	8.2(0.5)	8.7(0.3)	29.7(2.0)	30.3(0.5)	6 **

* n= 4 for temperature
** n= 5 for bottom temperature