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IMPACT OF DREDGING ON DUNGENESS CRAB, *CANCER MAGISTER*, IN GRAYS HARBOR, WASHINGTON DURING AUGUST 1986

by

Paul A. Dinnel, David A. Armstrong, Brett R. Dumbauld
and Thomas C. Wainwright

Fisheries Research Institute, School of Fisheries

University of Washington

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INTRODUCTION

The port of Grays Harbor (Figure 1) has been an important maritime shipping center for the lumber industry since the late 1800's. Growth in this industry required deepening and stabilization of the harbor entrance and navigation channels. The first dredging occurred in 1905 and has continued intermittently at an average annual level of 1.5-1.7 million cubic yards (cy) dredged to maintain the channel.

In 1980 Congress voted to approve funds for a new "Widening and Deepening" (W&D) project for Grays Harbor which would require the removal of 19.4 million cy of sediment with an increase of maintenance dredging to 2.5 million cy per year.

Commercial and sports fisheries for Dungeness crab, Cancer magister, have existed in Grays Harbor since the early 1900's (Cleaver 1949). Sampling activities by the Washington Department of Fisheries (WDF) (Tegelberg and Magoon 1970; Tegelberg and Arthur 1977) provided evidence that Grays Harbor might also be a nursery area for juvenile crab. As a result of this information, the U.S. Army Corps of Engineers (COE) initiated studies to examine the effects of maintenance dredging on Dungeness crabs as part of a larger project entitled "Maintenance Dredging and the Environment of Grays Harbor, Washington" (COE 1977). The results of this study showed that substantial numbers of crabs were entrained and killed by the dredging process (Tegelberg and Arthur 1977). Subsequent work by Stevens (1981) and Armstrong et al. (1982) refined estimates of crab entrainment and mortality by both hopper and pipeline dredges.

An Environmental Impact Statement (EIS) was prepared for the Navigation Improvement Project which addressed potential impacts of the project. As a consequence, Armstrong et al. (1982) and Stevens and

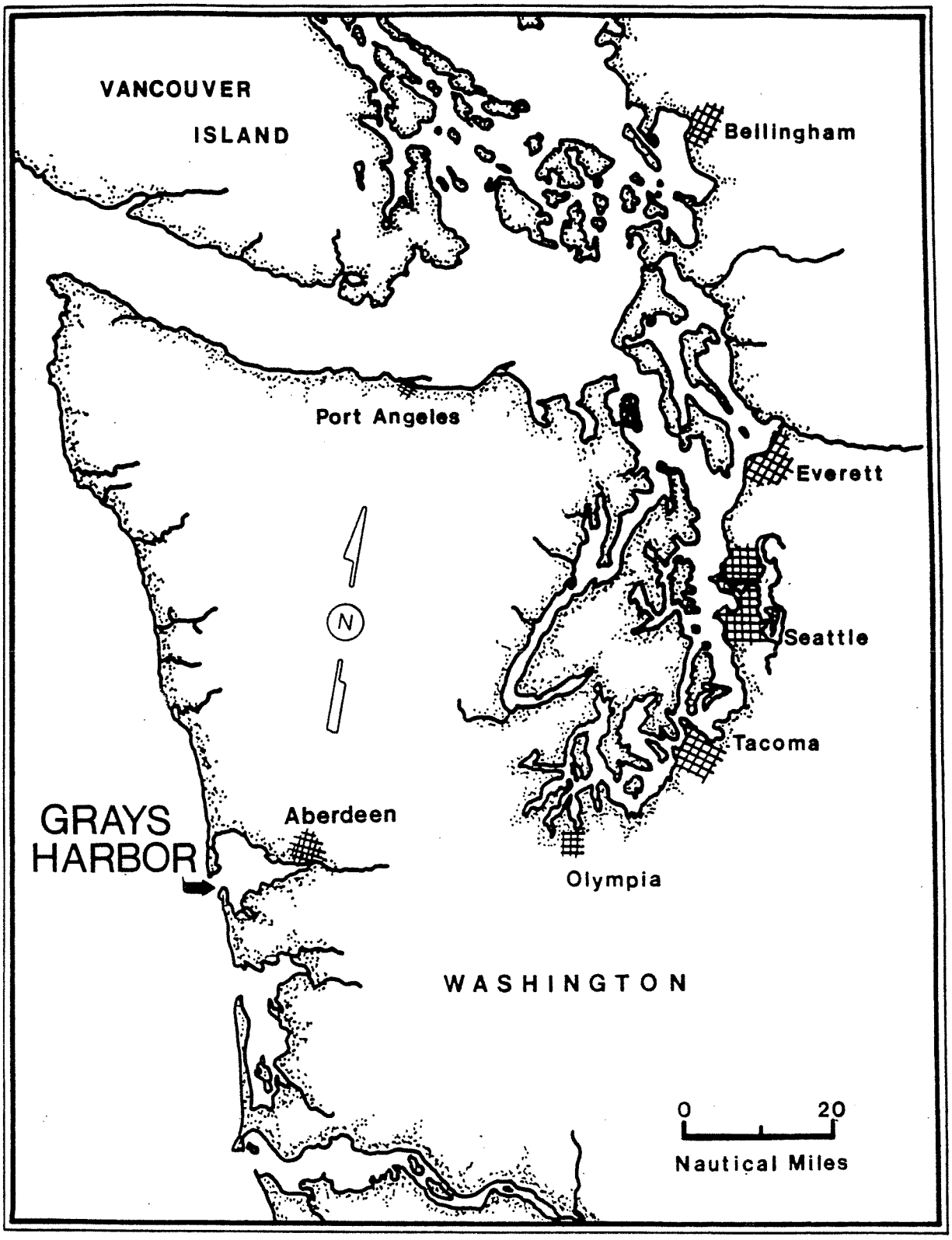

Figure 1. Map of Washington State showing the location of Grays Harbor.

Armstrong (1984) conducted basic ecological studies of crab, shrimp (Crangon spp.) and finfish resources of Grays Harbor and further refined estimates of dredge-related entrainment and mortality for these groups of animals. Armstrong et al. (1982) found that entrainment rates for a hopper dredge ranged from 0.035 to 0.502 crabs/cy and mortality averaged 73.1% of those crabs entrained. Based on this information, the potential crab mortality associated with the W&D project was calculated to range from 1.5 to 2.6 million crabs (depending on dredging scenario and based on estimates of 1981 crab population abundance) during the project, and an additional 203,000 to 338,000 crabs during annual maintenance dredging.

Because of the expected dredge-related impacts on Dungeness crab during the W&D project, COE is investigating and evaluating methods to reduce entrainment and mortality of this species. Joint studies were conducted by COE (McGraw et al. 1987) and the University of Washington (Dinnel et al. 1986) in Grays Harbor in October 1985. COE monitored Dungeness crab entrainment aboard the hopper dredge Yaquina which was equipped with dual dragheads, one modified by screens to reduce crab entrainment and one unmodified. The University Team conducted a separate assessment of crab resources in and around the dredge and dredged materials disposal site. The results of this joint study showed that there was no significant difference in crab entrainment between the two different dragheads which entrained 44 Dungeness crab in 32.5 minutes of sampling. These crab catches were equivalent to 1.35 crabs/min of sampling time, 123 crab/ha of area swept by the dragheads, or 0.118 crabs/cy of solids dredged (McGraw et al. 1987). Crab catches by the beam trawl averaged 773 crab/ha in the dredge sites and 509 crab/ha at the disposal site (Dinnel et al. 1986). Comparison of these data showed that the dredge Yaquina entrained approximately 15.9% of the crabs estimated to be present by the trawls.

The work presented in this report is a continuation of the joint COE-University of Washington dredge/trawl studies in Grays Harbor initiated in October 1985. This report details the results of the trawling studies in the dredge sites during early August 1986 and compares these results to simultaneous crab entrainment studies conducted by COE aboard the dredge Yaquina. Additional information about the 1986 dredge entrainment work will be found in a parallel report by COE (Mc/graw et al., 1987).

The specific objectives of the trawl study were:

1) Estimate density of crabs before and during dredging in three sites by sampling with a 3-m beam trawl.
2) Characterize the population according to age and sex of crabs caught in the samples.
3) Determine if significant correlations exist between crab densities and physical or biological factors.
4) Compare units of crabs entrained by the Yaquina with units caught by the trawl and estimate the proportion and significance of the crab population entrained during dredging.

MATERIALS AND METHODS

Sample Protocol

Dungeness crab were simultaneously sampled by two different methods. First, entrainment of crabs by the dragheads of the COE hopper dredge Yaquina was monitored on board the dredge by diverting the dredged material discharge plume through screening baskets before the material entered the hopper. Second, crabs in the area were sampled with a 3-m beam trawl fished from a separate vessel during, or independent of, the actual dredging runs.

Sampling aboard the Yaquina was conducted by biologists of Seattle and Portland Districts COE. Generally, replicate samples of the dredged material were obtained by diverting the entire intake from each draghead through screening baskets (mesh approximately 10 mm in diameter) for 30 seconds and counting and measuring all crabs so obtained. Further details describing the dredge Yaquina, on-board sampling by COE, and the comparison of crab entrainment by two different types of dragheads are discussed in a separate report (McGraw et al. 1987).

Beam trawl operations were conducted on board the chartered fishing vessel Karelia out of Westport, Washington. Crabs and other epifauna were sampled by 5 to 10 minute tows of the beam trawl (Gunderson and Ellis 1986) presently used in other Dungeness crab studies in Grays Harbor (Armstrong and Gunderson 1985), Willapa Bay, and Puget Sound (Dinnel et al. 1985). All Dungeness crab from each trawl were counted, sexed, measured and returned live to the general area of capture. All fish from selected trawls were also retained for later laboratory analysis to provide a general indication of species present.

Trawling was conducted at three stations within the study area (Figures 2 and 3). Station 1 was located between Flasher Buoys "15" and "15A" in the western portion of the "South Reach". Station 2 was located between Flasher Buoys "18" and "21" in the eastern portion of the "South Reach". Station 4 was located in the "Crossover Channel" between Flasher Bouys "25" and "27" (Figure 3).

Within each station, 10 beam trawl tows were made in the pattern illustrated in Figure 4. All trawls were conducted on 1, 2 and 3 August 1986. The experimental design called for equal partitioning of trawls between the 3 stations on any given day and between day and night. However, night sampling was restricted to only one night due to dense fog

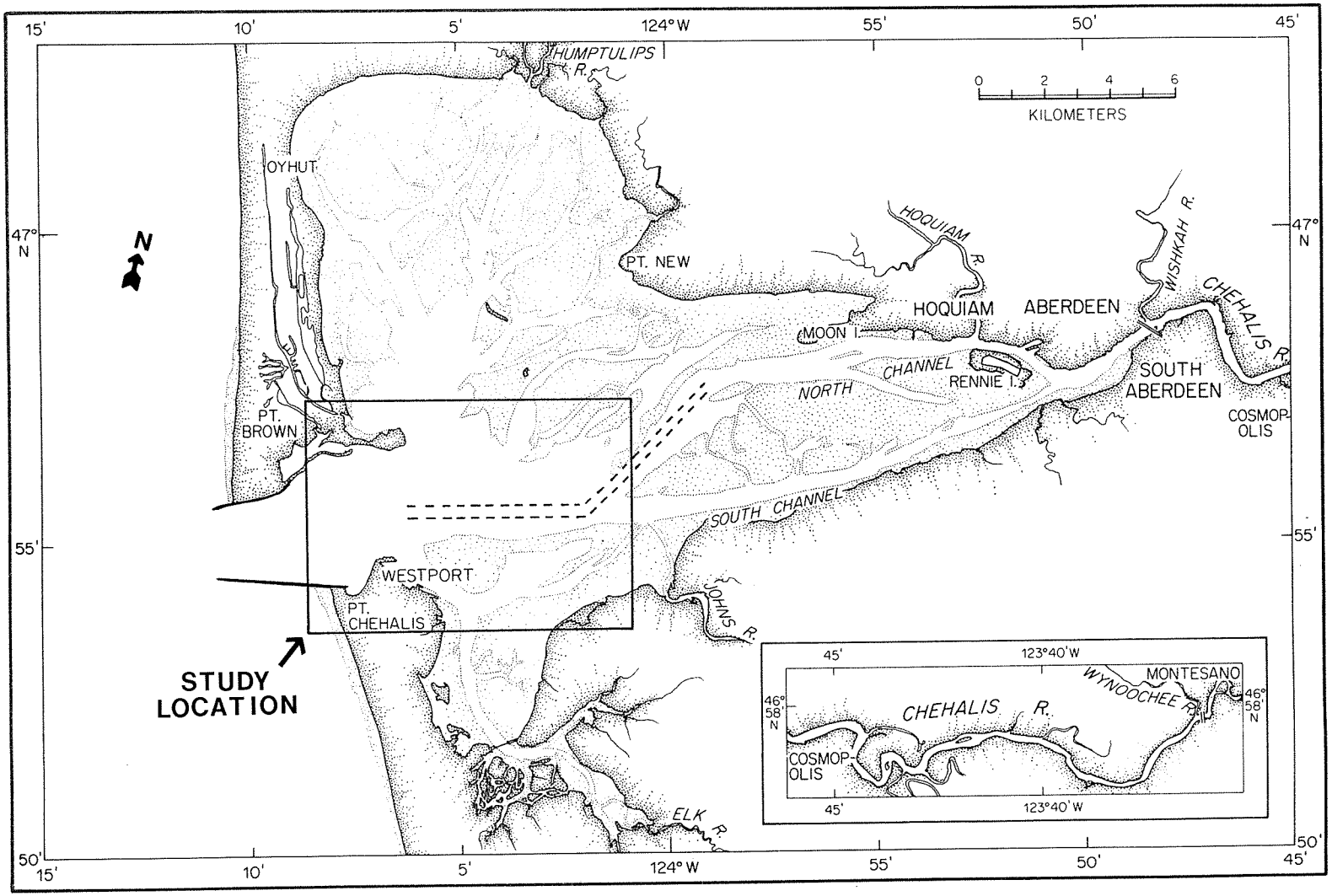

Figure 2. Map of Grays Harbor showing the approximate boundaries of the dredging study.

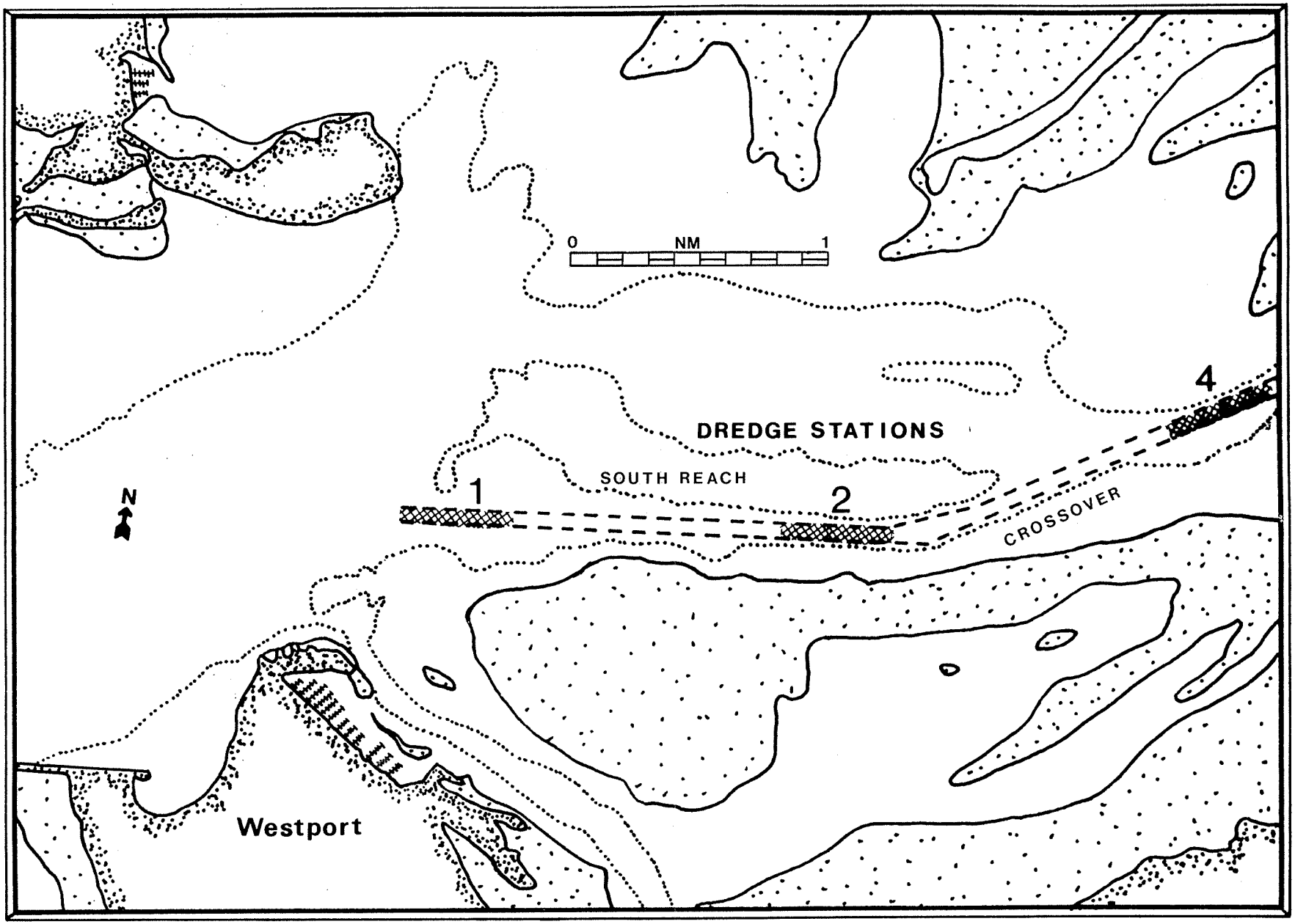

Figure 3. Map of outer Grays Harbor showing dredge Stations 1, 2 and 4.

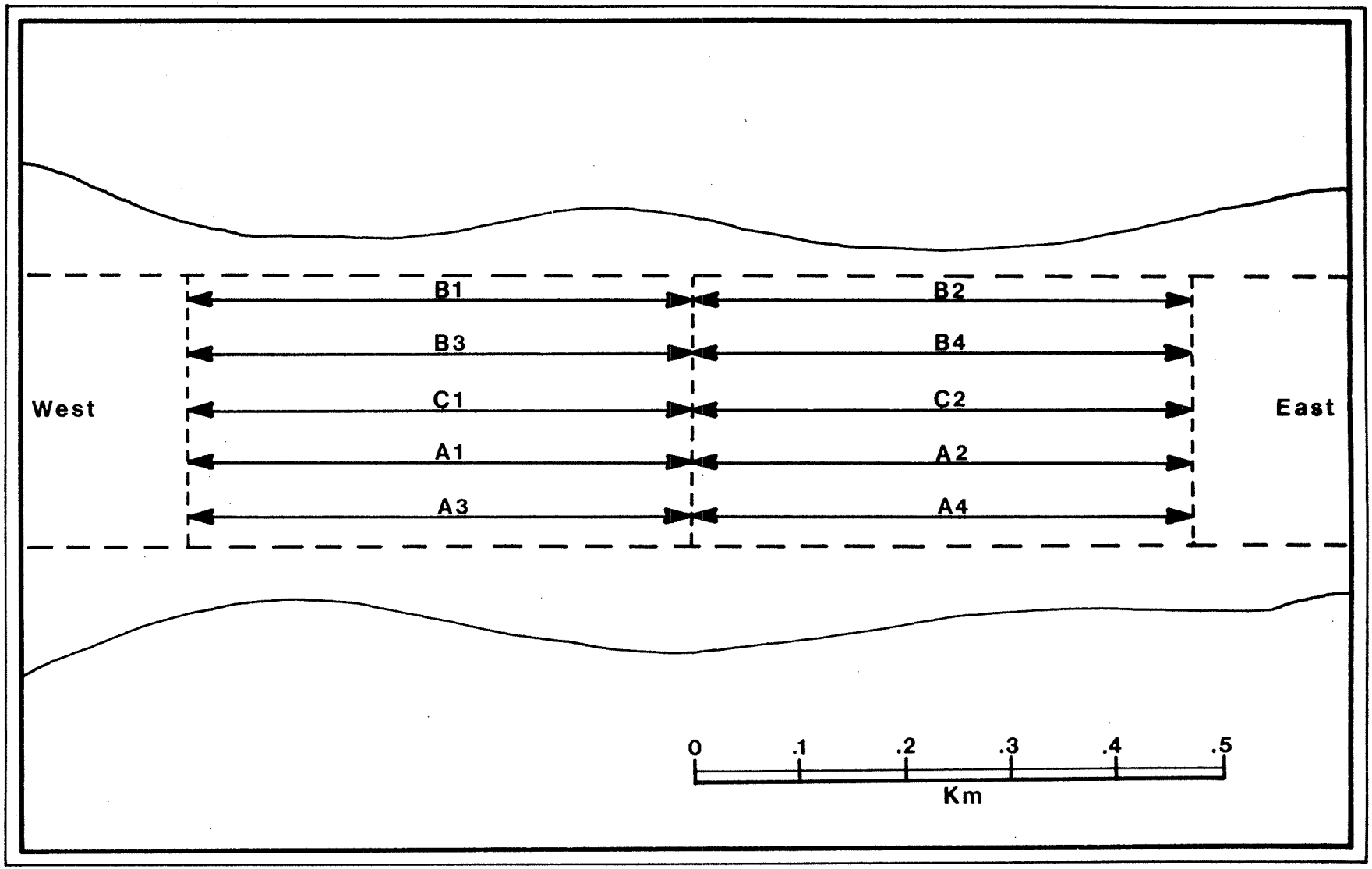

Figure 4. Diagram of a typical dredge station showing the placement of the ten trawl sites within each station.

on the other two nights.

In addition to day/night and location, trawls were done in three "time configurations" relative to the dredge Yaquina: 1) Before dredging in each location; 2) After dredging in each location; or 3) Concurrent with dredging in each location.

Each trawl within the three stations took about 10 minutes, was approximately 463 m (1/4 nautical mile) and covered an area swept by the net (2.3 m fishing width) of approximately 1,065 m^2. Distance traversed was determined by radar range readings using the various channel marker buoys as reference points.

Surface and bottom water samples were collected from each station on a daily basis and measured for temperature and salinity.

Data Analysis

Catches of Dungeness crab from each trawl were converted to estimated densities per hectare (ha) by the following formula:

$$\text{Catch} \times 10{,}000/\text{area swept} = \text{estimated \# crab/ha}$$

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

Counts of benthic or epifaunal invertebrates usually show a contagious (non-random) distribution (Elliott 1977), hence, all crab density data were transformed prior to analysis of variance (ANOVA), use in a Student's "t"-test, or in bivariate correlation analysis by the following formula:

$$X_t = \text{Log}_{10}(\text{Density} + 1)$$

where X_t is the transformed variable (Elliott 1977). All data analyses utilized the SPSS programs BREAKDOWN (with one-way ANOVA), T-TEST or REGRESSION (Nie et al. 1975).

Crab Density

Dungeness crab density was estimated to be 960 (± 1 S.D.)/ha over all days and locations (total of 39 trawls), and individual statistics by day vs. night, and by "time configuration" relative to the dredge Yaquina are summarized in Table 1.

The highest average estimated crab density was at Station 2 (1,413 crab/ha; Table 1); however, there was no statistically significant difference in crab densities between the three stations (p=0.0677; ANOVA) nor was there a significant difference in day vs. night densities (p=0.599; "t"-Test).

All of the trawls were conducted either independent of the dredge's activities (n=27) or beside the dredge (n=12). There was no significant difference in crab catches between these two trawl configurations (p=0.375; "t"-Test). Ten trawls were done before dredging at the stations while 17 trawls were made after disruption of the stations by dredging. There was a significant difference between "before" and "after" trawl crab catches (1,434 and 717 crabs/ha, respectively; p=0.038; "t"-Test) suggesting that crab density was lower after dredging activity in the area.

Size, Sex and Shell Condition

The average carapace width (CW) of all crab caught by beam trawl was 101 ± 30 (± 1 S.D.) mm with average sizes of 110 ± 23 mm, 111 ± 21 mm and 74 ± 33 mm CW for Stations 1, 2 and 4, respectively (Appendix Table 1). There was a highly significant difference (p=0.000; ANOVA) in size between stations with crabs at Station 4 significantly smaller than at the other two stations. The size frequency histograms (Figure 5) show that most (92%) of the crab caught at Stations 1 and 2 were a mix of large 1+ and 2+

Table 1. Average densities of Dungeness crab caught by beam trawl arrayed by station (location), day vs. night, and "time configuration" (before, during, after) relative to the dredge Yaquina.

Sample Group	Number of Samples(n)	Average crab density (Crabs/hectare)	Standard Deviation
All trawls	39	960	854
Day only	30	1037	931
Night only	9	705	481
Station 1			
All	14	816	387
Day only	10	967	345
Night only	4	437	149
Station 2			
All	13	1,413	1,249
Day only	10	1,611	1,374
Night only	3	752	131
Station 4			
All	12	639	513
Day only	10	532	364
Night only	2	1,174	1,009
Trawl Configuration			
Before Dredging	10	1,434	1,110
After Dredging	17	717	419
During Dredging	12	911	981

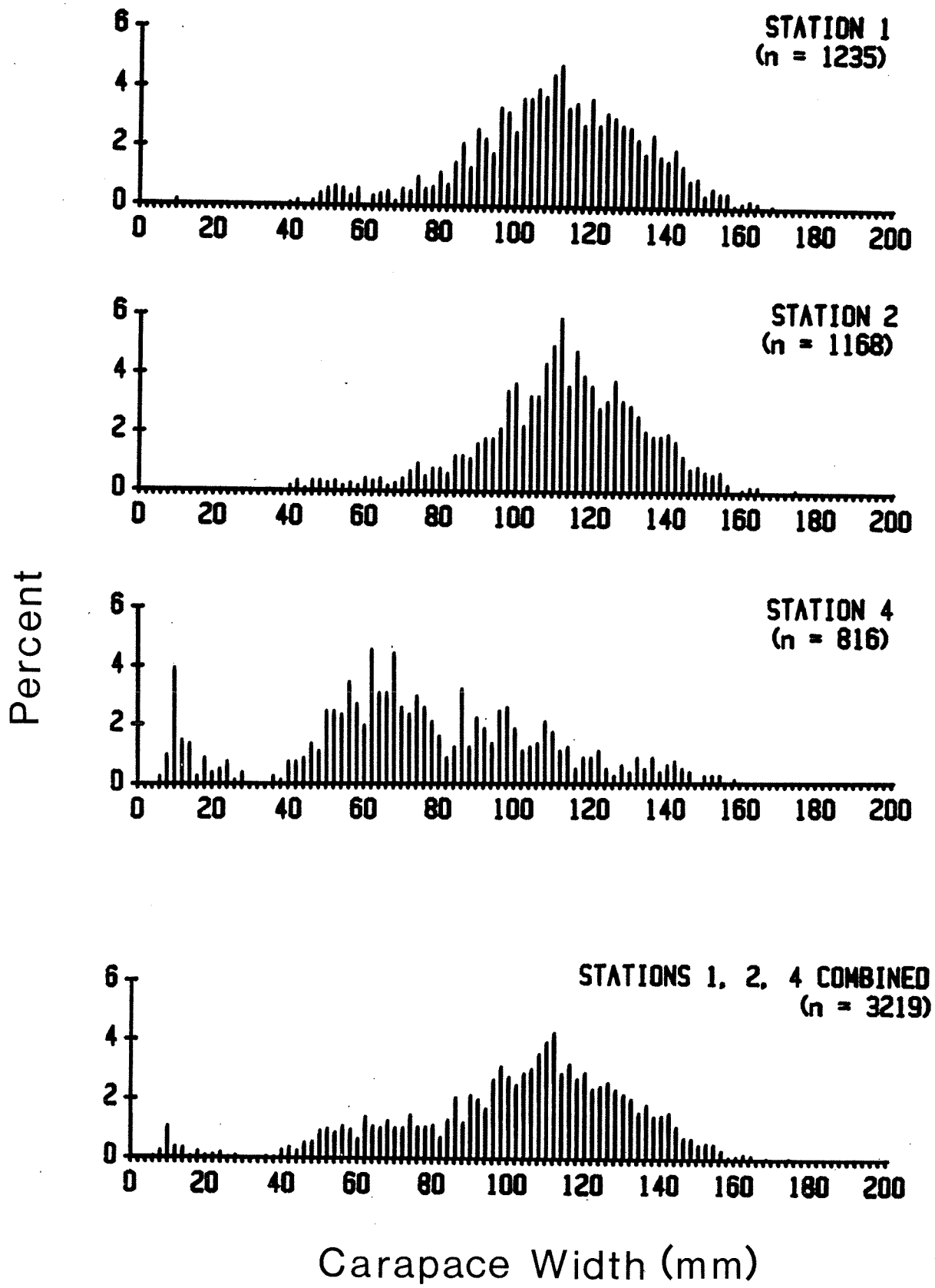

Figure 5. Size-frequency histograms for Dungeness crabs caught by beam trawl at Stations 1, 2 and 4 and for all stations combined (bottom) (see Figure 3), August 1-3, 1986.

age classes while the highest proportion (59%) of the catch at Station 4 was of the 0+ and smaller crab of the 1+ year classes (<80 mm CW). Male and female crab were significantly different (p=0.000; "t"-Test) in average CW at 108 ± 26 mm and 88 ± 24 mm CW, respectively (Figure 6; Appendix Table 1).

The sex distribution of the crab was highly skewed. Eighty-three percent of all crabs sexed were males, and individual station percentages were 80%, 95% and 60% at Stations 1, 2 and 4, respectively. The more balanced sex distribution at Station 4 was a relection of the abundance of smaller crabs which had not yet aggregated by sex.

Thirty-four percent of all crab caught by the net had either "soft" or "very soft" shells indicating that these crabs had recently molted. There was a slightly higher percentage of soft crabs at Station 2 (44%) than at either Station 1 (26%) or Station 4 (29%).

Correlates to Crab Densities

Bivariate correlation analyses were conducted with log transformed crab densities versus depth, tow speed and substrate materials caught in the trawls. Only one factor, % macro algae (primarily Enteromorpha), was significant at p=0.05 with an r value of -0.4777 (Table 2). The negative correlation with algae may have been a result of reduced fishing efficiency of the net when significant amounts of algae (or eelgrass, Zostera marina, as in Puget Sound) was present. Excessive algae and eelgrass tend to wrap around the tickler chain and lead line of the net and cause it to ride up off the bottom, thereby allowing some crab to escape underneath the net. Algae can also clog the mesh of the net with the result that water (and crabs) can be pushed away from the net opening rather than entrained.

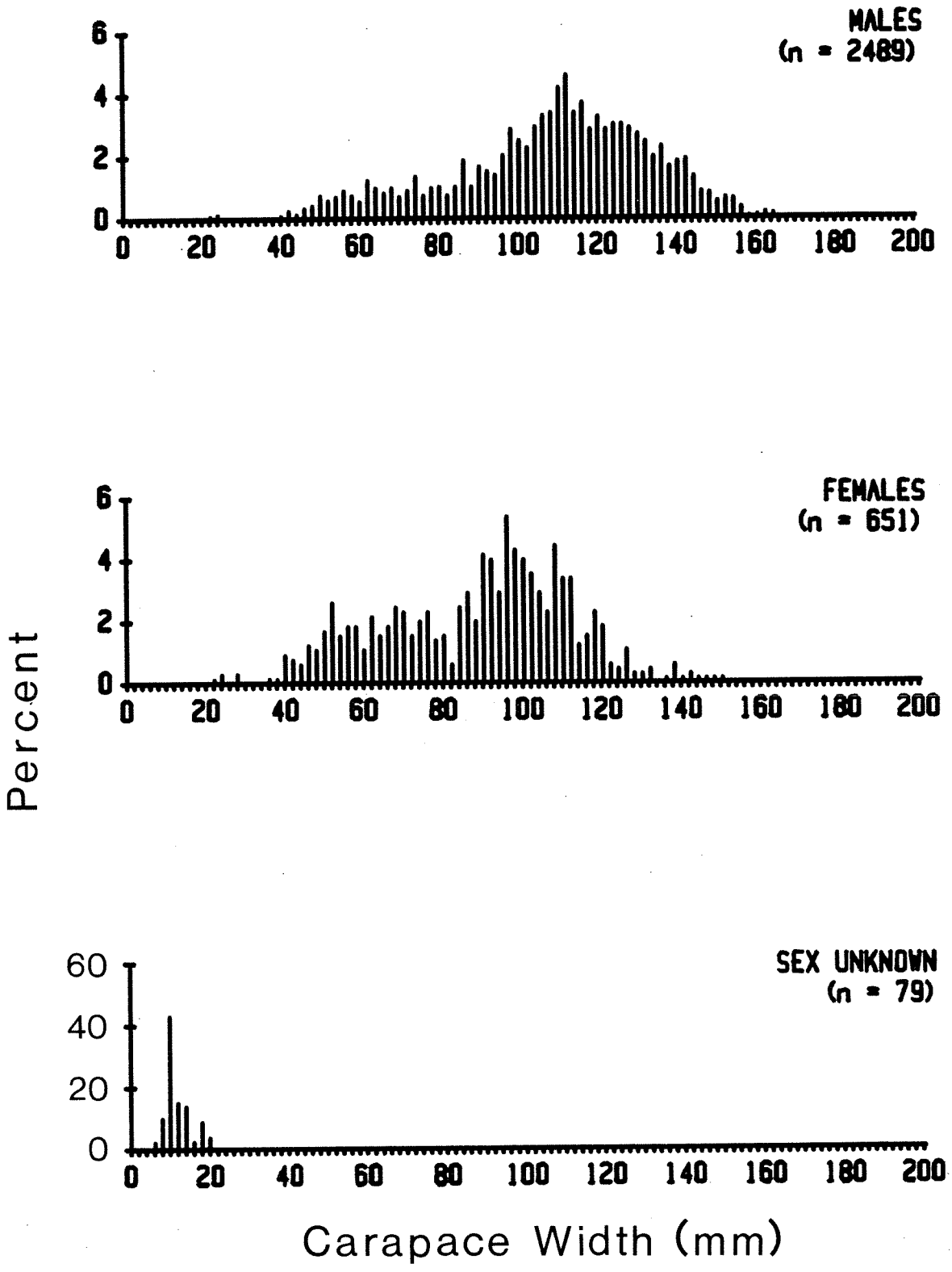

Figure 6. Size-frequency histograms partitioned by sex for all Dungeness crabs caught by beam trawl at Stations 1, 2 and 4; August 1-3, 1986.

Table 2. Bivariate correlation analysis of Dungeness crab densities with several factors (n=39, in all cases).

Factor	r	r^2
Depth	0.1746	0.0305
Tow speed	0.0895	0.0080
% shell	0.2671	0.0713
% terrestrial materials	0.2042	0.0417
% macro algae	-0.4777*	0.2282
% gravel, cobble	0.1286	0.0165

* Significant at p=0.05

Table 3. Number of fish caught in five beam trawl samples from Stations 1, 2 and 4 on August 1-3, 1986 (See Figures 3 and 4 for sample plan).

	Station Number and Replicate					
Fish Species	1B1	2A4	2C2	4B2	4C2	TOTAL
English sole	7	100	55	96	11	269
Flathead sole					1	1
Sanddabs	14	18	8	22	8	70
Gunnels	1			23	1	25
Sculpins	3	47	17	78	4	149
Surfperches	1		1	1		
Tomcod		5	39	7	2	3
Anchovy					1	53
Dogfish	1	1	2		9	1
Pricklebacks		2	4		2	13
Smelts			2		52	8
Pacific herring				1		54
Sandlance	4					1
						4

Fish

Samples of fish were collected from five of the beam trawls conducted at Stations 1, 2 and 4. Thirteen species common to Grays Harbor were present and the three most common species were juvenile English sole (Parophrys vetulus), sanddabs (Citharichthys spp.) and staghorn sculpin (Family Cottidae) (Table 3).

Temperature and Salinity

Surface and bottom water samples were collected daily from each station and temperatures and salinities recorded. Surface temperatures ranged from 11.0 to 19.5°C and bottom temperatures from 11.0 to 18.0°C. Salinities ranged from 22.0 to 27.0 /oo at the bottom (Table 4). These values are typical during summer months and the fluctuations between consecutive days reflect tidal exchange, the state of ebb and flood tides at collection (varied between samples) and wind.

Crab Entrainment During Dredging

Two-hundred-sixty-five samples of 30 sec duration were collected from baskets placed at the end of the hopper distribution trough, or diffuser during a three day period on board the Yaquina. Pairs of samples were collected simultaneously from each of two dragheads: one designed to exclude crabs greater than approximately 72 mm CW from the side slots and one unmodified (McGraw et al., 1987). A total of 207 crabs was entrained in the samples during the three day period, equal to 0.78 crabs/sample, 1.56 crabs/min of sampling time, 276 crabs/ha of area swept by the dragheads, or 0.274 crabs/cy (i.e., cy of settled solids). Average entrainments at Stations 1, 2 and 4 were 0.135, 0.592 and 0.088 crabs/cy, respectively.

Crab Density vs. Dredge Entrainment

The overall average crab density as estimated by all trawls (n=39) at Stations 1, 2 and 4 combined was 960 $\pm$ 854 crabs/ha. The dredge entrained

Table 4. Temperature and salinity data collected during the August 1986 dredging/trawling study.

Date	Station	Temperature (°C)		Salinity °/oo	
		Surface	Bottom	Surface	Bottom
1 August	1	15.0	N.M.[1]	25.0	N.M.
	2	17.0	15.0	26.5	27.0
	4	19.5	18.0	26.5	26.0
2 August	1	12.0	11.0	22.0	27.0
	2	18.0	12.0	24.5	27.0
	4	17.0	14.5	24.5	25.0
3 August	1	11.0	11.0	26.5	26.5
	2	14.5	14.0	24.5	25.0
	4	16.0	15.0	25.5	26.0

[1] NM = Not measured

276 crab/ha; equivalent to about 28.8% of the regional density estimated from the beam trawl data. The apparent entrainment efficiency did, however, change between the three stations with average calculated entrainments of 22.1%, 32.6% and 8.8% (relative to trawl densities) at Stations 1, 2 and 4, respectively (Table 5).

Total Crabs Entrained by the Yaquina

The Yaquina operated for a three day period during which time approximately 12,000 cy of solids were dredged at Stations 1, 2 and 4 (McGraw et al. 1987), and an average of 0.274 crabs/cy was entrained during sampling. Assuming this value is representative of overall entrainment during this period, then approximately 2,568 Dungeness crabs would have been entrained by the Yaquina during the three day dredge period.

Sizes and Sex Composition of Entrained Crab

The average CW of all crabs entrained by the dredge was 100 $\pm$ 34 mm, essentially the same as crab caught by beam trawl (101 $\pm$ 30 mm CW) The biggest difference in sizes of crab caught by trawl or the dredge was at Station 4 where the dredged crabs were 28 mm larger on the average (Table 5). One possible explanation for this apparent difference is that major difficulties were encountered at Station 4 with the dredge sampling baskets due to clogging of the mesh with mud and debris. This clogging led to frequent overflows which could have allowed smaller crabs (more common at this station; Figure 5) to escape.

The sex distribution of crabs entrained by the dredge was 86% male and 14% female; a distribution essentially equal to the trawl samples (male = 83%, female = 17%).

Table 5. Total and station comparisons of beam trawl versus dredge-entrained Dungeness crab catches in Grays Harbor during August 1986.

	Number of samples(n)	Estimated Crab Density (crabs/ha)	Proportion Entrained by dredge (Trawl = 100% Assumed Efficiency)	Average crab Carapace width (mm ± 1 S.D.)
Station 1:				
Trawl	14	816	100%	110 ± 23
Dredge	122	192	23.5%	88 ± 41
Station 2:				
Trawl	13	1,413	100%	111 ± 21
Dredge	96	519	36.7%	105 ± 28
Station 4:				
Trawl	12	639	100%	74 ± 33
Dredge	60	58	9.0%	102 ± 51
All Stations Combined				
Trawl	39	960	100%	101 ± 30
Dredge	278	276	28.8%	100 ± 34

Estimated Crab Mortality Due to Dredging

Not all crabs entrained during dredging are killed. Armstrong et al. (1982) estimated mortality rates for Dungeness crab entrained by the hopper dredge Sandsucker. They found that mortality was size-dependent with estimated mortality of 45.9% for crabs <50 mm CW and 85.6% for crabs ≥50 mm CW. Using these estimates for mortality, the approximate number of entrained crabs killed by the Yaquina at Stations 1, 2 and 4 in August 1986 was: 0.459 x 113 crabs (only 4.4% of crabs were <50 mm) + 0.856 x 2,455 crabs (95.6% of crabs were ≥50 mm) = 2,153 or 83.8% mortality of those entrained. This mortality estimate does not include crabs that may have been damaged by the dragheads yet not entrained by the dredge. Dinnel et al. (1986) estimated that an additional 1.2% of the crabs present at the dredge site in October 1985 were severely damaged (but not entrained). Hence, an additional mortality of approximately 109 crabs (assuming an area swept by the draghead of 7.90 m^2/cy of solids dredged and an average crab density of 960 crabs/ha) would be expected in addition to entrainment mortality.

Shell condition (i.e., degree of softness of the shell) may also be a significant factor affecting mortality. Approximately 34% of the crabs caught by trawl had soft (30%) or very soft (4%) shells which could have been damaged by entrainment to a greater extent than the hard-shelled crabs. However, quantification of this factor is not presently possible.

Dungeness Crab Population Estimates

Estuary

Population estimates for Dungeness crab were calculated for August 1986 by routine beam trawl sampling at specific stations conducted as part of a related Sea Grant crab study (Armstrong and Gunderson 1985; Gunderson et al. 1985). The estimates calculated for four areas (Strata 1-4) of

Grays Harbor (Figure 7) show that approximately 1.4 million crabs were present in Stratum 1 in the Outer Harbor area which includes dredging Stations 1 and 2 and is close to Station 4 (Table 6). A substantially larger number of crabs (5.3 million) were present in North Bay (Stratum 2) and approximately 0.5 million present in each of the other two strata. A total of about 7.7 million crabs was estimated to be present throughout the subtidal portion of the estuary in August 1986 (Table 6).

An important difference between the Sea Grant vs. dredge trawls was the estimated crab densities. Randomized trawls made at stations in Sea Grant Stratum 1 (Figure 7) resulted in an average estimated crab density of 383 $\pm$ 104 crabs/ha as contrasted to the Dredge Study trawl densities of 816 $\pm$ 387 and 1,413 $\pm$ 1,249 crabs/ha for Stations 1 and 2, respectively (average for Station 1 and 2 combined = 1,103 crabs/ha) (Tables 1 and 6). The five stations of Sea Grant Stratum 1 occur throughout the area and only one is in the navigation channel. All trawl samples taken during the present entrainment study were in the channel as shown in Figure 4. Thus, the estimated density of crab in the channel at dredge Stations 1 and 2 was approximately three times greater than the overall density of the Outer Harbor (Sea Grant Stratum 1). This suggests that Dungeness crab may aggregate preferentially in deeper channels and, hence, may be disproportionately more subject to dredge entrainment than general population estimates within the estuary may indicate.

Given a population estimate of approximately 1.4 million crabs for the Outer Harbor (Stratum 1; Table 6), then the estimated dredge-related crab mortality of 2,262 crabs during August 1986 would be approximately 0.16% of the total crabs present within Stratum 1 and approximately 0.03% of those estimated to be present in the total subtidal of the estuary.

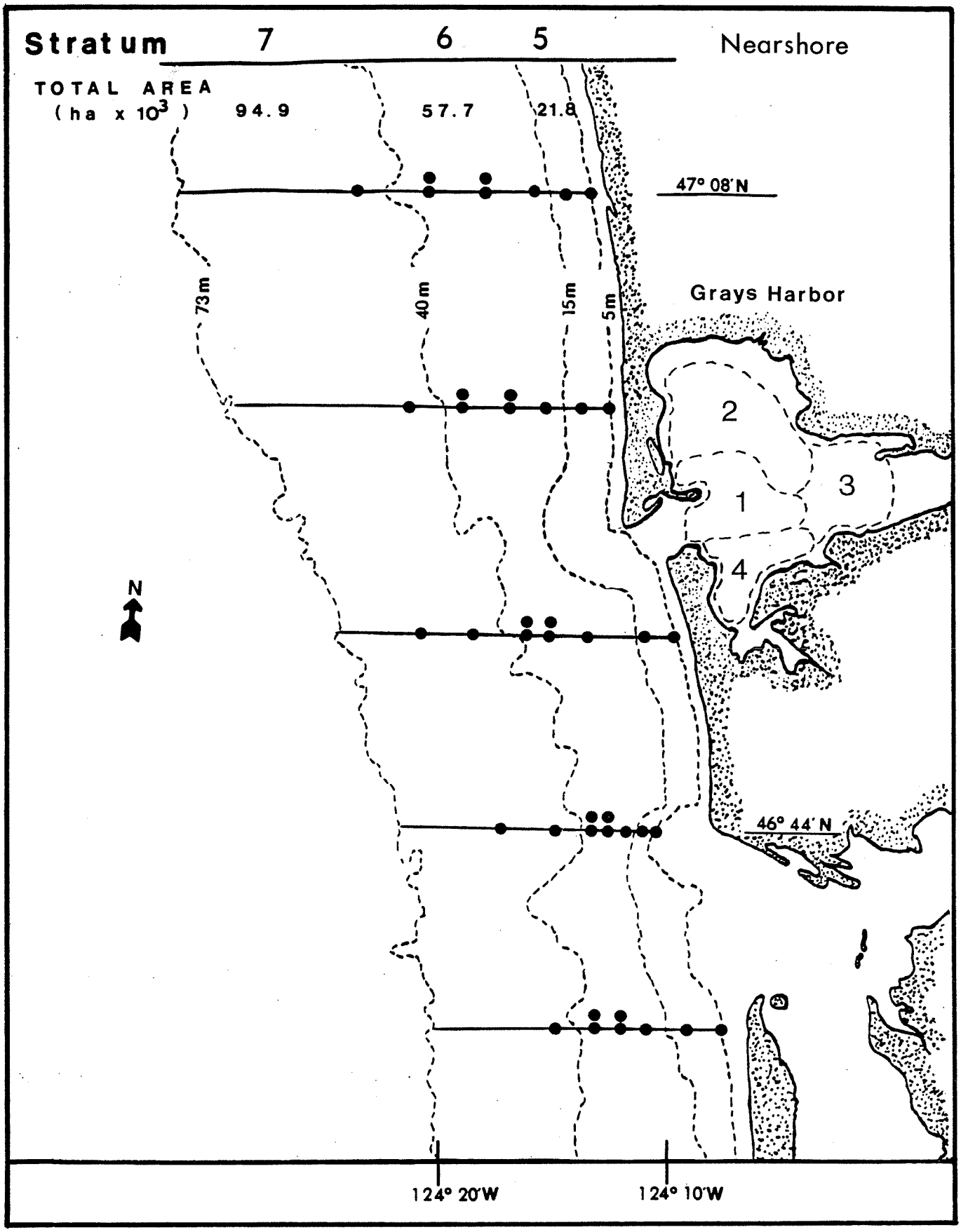

Figure 7. Map of the Grays Harbor area showing the estuary divided into four separate strata and the offshore area divided into three strata (by depth contours) for purposes of making comparative population estimates. There are 18 trawl stations within Grays Harbor used for such estimates.

Table 6. August 1986 Dungeness crab population estimates from Grays Harbor Sea Grant stations. Refer to Figure 7 for a description of the strata boundaries.

Stratum	Area (Hectares)	Crab density (#/hectare ± 2 SE)	Population estimate (Millions ± 2 SE)	Proportion
ESTUARY				
1 = Outer Harbor (Entrance and South Reach)	3,651	383 ± 104	1.398 ± 0.382	0.18
2 = North Bay	2,516	2,101 ± 729	5.286 ± 1.833	0.69
3 = Inner Harbor (Crossover and North Channels)	1,548	299 ± 123	0.463 ± 0.191	0.06
4 = South Bay	830	656 ± 49	0.545 ± 0.040	0.07
Total Estuary	8,545	900 ± 429	7.692 ± 1.081	100.0
NEARSHORE				
5 = 5-15m depth	21,800	85 ± 16	1.968 ± 0.359	0.03
6 = 16-40m	57,700	53 ± 25	3.387 ± (not calculated)	0.05
7 = 41-73m	94,900	627 ± 416	59.535 ± 39.453	0.92
Total Nearshore	174,400	350 ± 188	64.890 ± 17.844	100.0

The dominant age class of all crabs caught during the August Sea Grant program in Grays Harbor was 1+ and ranged in CW from about 40 to 80 mm (Figure 8). Average crab size varied with location in the estuary, generally declining to the east as a function of distance into the estuary with mean CW's of 97, 61, 56 and 81 mm for Strata 1 through 4, respectively (Figure 8). Trawling at dredge Stations 1, 2 and 4 showed this same pattern of decreasing crab size with distance into the estuary. Crabs caught at Stations 1 and 2 averaged about 110 mm while those at Station 4 further east averaged 75 mm CW. The major size-frequency peak for both Sea Grant Stratum 1 (Figure 8) and dredge Stations 1 and 2 (Figure 5) is in the range of 100 to 120 mm (a mix crabs of the 1+ and 2+ age classes). For both Stratum 3 and dredge Station 4, the size peak shifts downward to the 50-80 mm range (1+ year class) with good representation of 0+ crab in the 10-35 mm range.

Nearshore

Nearshore Sea Grant sampling in August 1986 occurred along 5 east-west transects from Willapa Bay to Copalis Head (Figure 7). This sampling area was divided into 3 strata by depth: Stratum 5 = 5-15 m, 6 = 16-40 m and 7 = 41-73 m. The August 1986 population estimate for the total nearshore area was 64.9 million crabs with estimates of 2.0, 3.4 and 59.5 million crabs for Strata 5, 6 and 7, respectively (Table 6). This population estimate for the nearshore is almost an order of magnitude higher than that for Grays Harbor estuary (7.7 million crabs). However, age class structure is a very important difference between the two areas. Roughly 95% of the crabs caught nearshore in August 1986 were 0+ less than 20 mm CW (Table 6; Figure 9). These crab suffer a very highly mortality rate (typically 90+% through their first summer) compared with older year class crab. Hence, only a few million of these roughly 60 million 0+ crab will probably

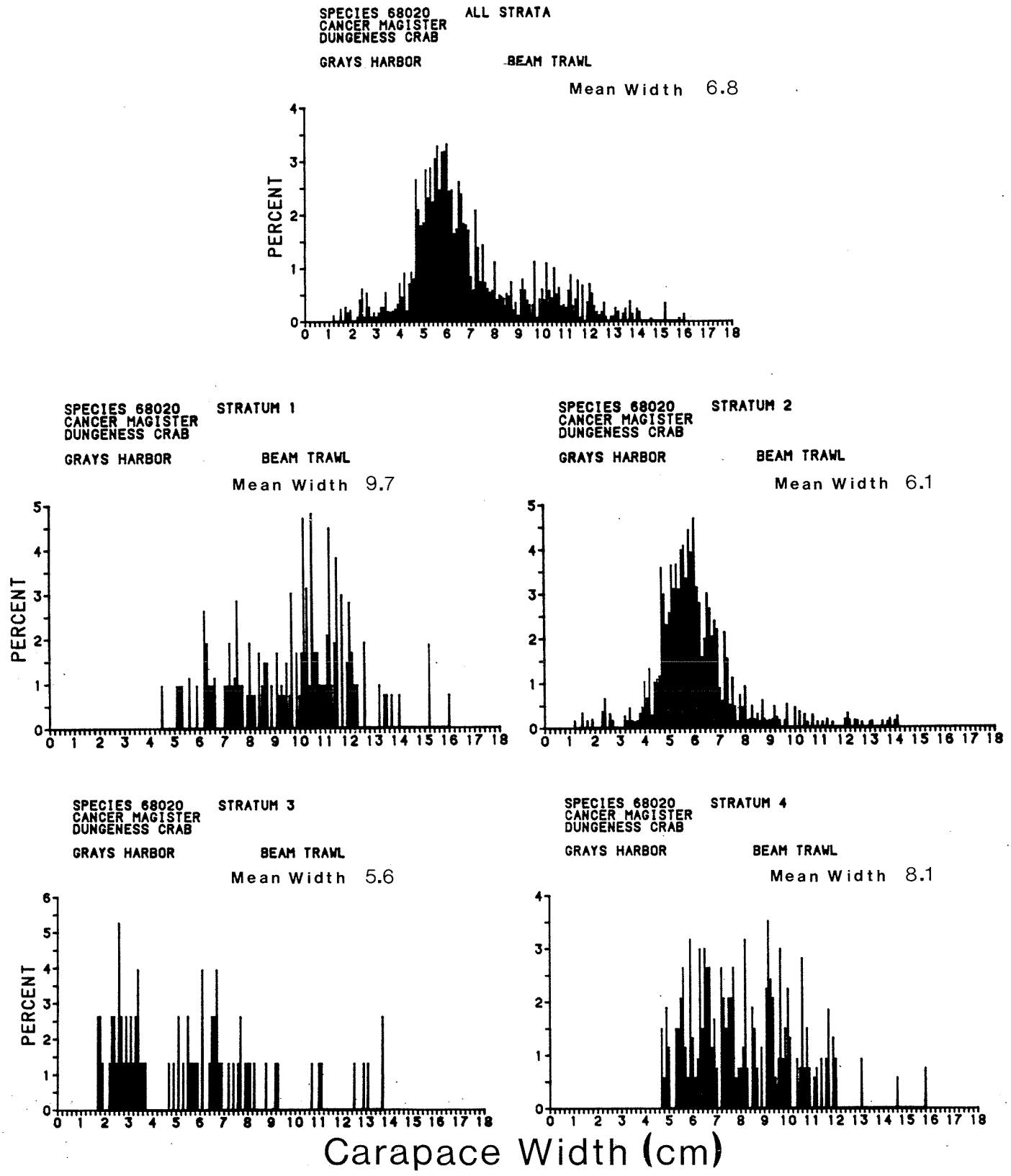

Figure 8. Size-frequency histograms for all Dungeness crabs (top) caught in Grays Harbor in August, 1986 during routine sampling to estimate the resident population. The lower four histograms show the size-frequency distributions for each estuary stratum (see Figure 7 for locations).

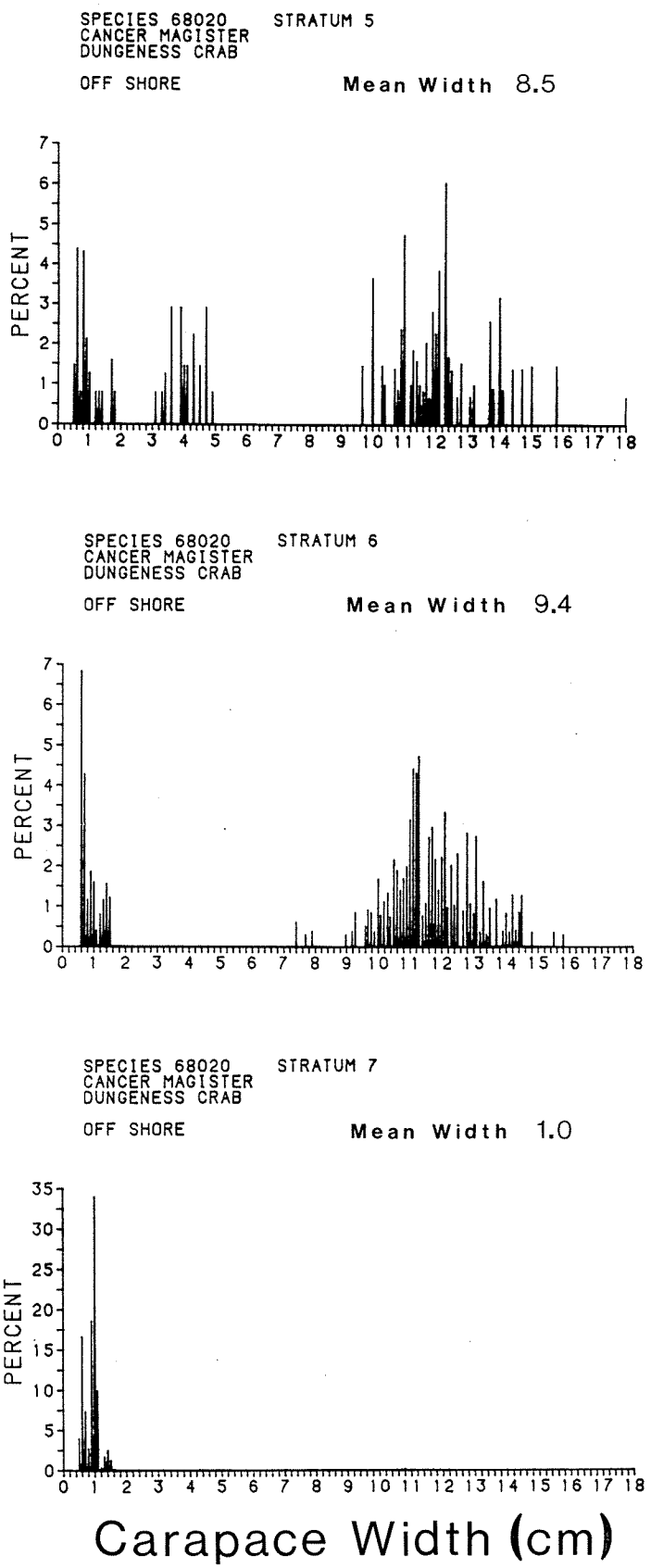

Figure 9. Size-frequency histograms for Dungeness crab caught at each of three offshore strata in August 1986 (see Figure 7 for strata locations). Note the difference in scale for the bottom histogram.

survive to the following year. In contrast, both Sea Grant and dredge-related trawls in the estuary caught very few 0+, and most crabs were of the 1+ and 2+ age classes which are subject to substantially lower mortality rates. Hence, the relative importance of the 7.7 million crabs in the estuary to the fishery (or to reproductive effort by females) may be as great or greater than the eventual contribution of the August offshore population.

CONCLUSIONS

1. Beam trawl samples for Dungeness crab in August 1986 indicated average estimated densities of 816 and 1,413 crab/ha at two stations in the South Channel of Grays Harbor and 639 crab/ha at one station in the Crossover Channel. The average estimated crab density for all trawls (n=39) was 960 crab/ha.
2. There were no significant differences in density of crab between the three stations, between day and night catches or relative to the trawl-dredge "time configuration" (i.e., before, after or during dredging). There was a significant difference, however, in crab catches from trawls made before disruption by dredging versus during dredging.
3. There was a highly significant difference in crab sizes between station (Station 4 < Stations 1 and 2) and between sex (females < males).
4. Crab entrainment sampling aboard the dredge Yaquina caught 207 Dungeness crab during a total of 132.5 minutes of sampling (n=265, 30 sec samples). These catches were equal to 0.78 crabs/sample, 1.56 crabs/min of sampling time, 276 crabs/ha of area swept by the dragheads, or 0.274 crabs/cy of solids dredged.

5. Based on the areas swept by the beam trawl and the dragheads, estimated entrainment of crabs by the Yaquina ranged from 9.0% to 32.7% (average = 28.8%) of those caught by the beam trawl.

6. The estimated number of Dungeness crabs entrained by the Yaquina during 3 days of dredging (12,000 cy of solids dredged) would have been 2,568, of which an estimated 83.8% (2,153) would have been killed. An additional 1.2% (= 109 crabs) also may have been killed by contact with the dredge dragheads but not entrained in the hopper (mortality estimates based on the results of prior studies).

7. Crab size-frequency distributions from trawl samples show that at least 3 year classes (0+, 1+ and 2+) of crabs were sampled at the three dredge stations. Overall, crabs entrained by the dredge averaged the same size as crabs caught by the trawls. The male:female ratio was also the same for both sample methods with males outnumbering females by the approximate ratio of 5.5:1.

8. Thirty-four percent of the crabs caught in the trawls had either "soft" or "very soft" shells indicating that these crabs had recently molted. Degree of softness of crabs present during dredging might affect the percent mortality of entrained crabs.

9. Dungeness crab population estimates for Grays Harbor estuary during August 1986 indicated the presence of 7.7 $\pm$ 1.1 million crabs in the subtidal of the estuary and 1.4 $\pm$ 0.4 million crabs in the Outer Harbor (Stratum 1) where dredging took place. Given an estimated dredge-related mortality of 2,262 crabs (entrainment plus draghead mortality), 0.16% of the crabs present in the vicinity of the estuary mouth were killed and 0.03% killed relative to the estuary total.

10. Beam trawl sampling nearshore of Grays Harbor and Willapa Bay in August 1986 indicated a population of 64.9 $\pm$ 17.8 million crabs. However, roughly 95% of the nearshore crab were small 0+ (CW < 20 mm) which typically suffer high mortality at this size. Thus, the generally older and larger crabs in the estuary are more directly vulnerable to dredge impacts and are more important to the fishery than are 0+ crab that characterize the nearshore population.

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A P P E N D I X

Appendix Table 1. Dungeness crab catches and average carapace widths (± 1 S.D.) summarized by tow, by station, by sex, and by day and night trawls in Grays Harbor during August 1-3, 1986. Note: Size data presented below do not include a small number of crabs <20mm in size which were not sexed.

	All Crabs		Male		Female	
Tow	Number	Average Size(mm)	Number	Average Size(mm)	Number	Average Size(mm)
Station 1						
Day						
1A1	73	114	62	116	10	103
1A2	164	112	126	114	38	104
1A3	144	113	112	115	32	106
1A4	52	108	46	112	6	80
1B1	108	110	85	113	23	100
1B2	52	102	46	107	9	80
1B3	108	106	85	110	23	93
1B4	87	107	62	113	25	93
1C1	127	118	114	120	13	106
1C2	112	108	92	111	19	96
Average Day	103±37	110±22	83±29	114±21	20±10	99±20
Night						
1A1	35	107	26	111	8	106
1A2	57	99	44	103	13	84
1A4	31	90	28	92	3	65
1B4	63	113	45	117	18	103
Average Night	46±16	104±27	36±10	107±27	10±6	95±24
Average Station 1	87±41	110±23	70±33	113±22	17±10	98±21

Appendix Table 1 (continued)

Tow	All crab Number	All crab Average Size(mm)	Male Number	Male Average Size(mm)	Female Number	Female Average Size(mm)
Station 2						
Day						
2A1	395	115	177	116	7	107
2A2	20	105	17	108	2	86
2A3	77	100	67	103	9	73
2A4	98	108	94	109	4	94
2B1	245	118	93	119	4	93
2B2	355	111	100	112	7	88
2B3	45	107	40	110	5	78
2B4	341	115	175	115	7	105
2C1	92	108	80	108	12	104
2C2	48	103	42	107	6	80
Average Day	172±146	111±22	88±53	113±21	6±3	92±22
Night						
2A1	96	114	89	115	7	98
2B1	74	109	64	115	10	73
2B2	70	112	65	112	5	113
Average Night	80±14	112±21	73±14	114±18	7±3	88±31
Average Station 2	150±133	111±21	85±47	113±20	7±3	91±25
Station 4						
Day						
4A1	83	78	42	80	38	81
4A2	101	63	53	76	26	77
4A3	24	35	6	82	2	104
4A4	114	67	60	67	51	70
4B1	51	65	20	91	17	81
4B2	86	77	49	83	33	77
4B3	1	57	1	57	0	--
4B4	13	50	3	121	3	75
4C1	61	84	33	77	28	93
4C2	33	82	21	82	12	84
Average Day	57±39	70±33	29±22	78±30	21±17	79±23

Appendix Table 1 (continued)

Tow	All crab Number	All crab Average Size(mm)	Male Number	Male Average Size(mm)	Female Number	Female Average Size(mm)
Night						
4A1	201	76	90	78	104	78
4B1	49	110	36	117	11	98
Average Night	125±107	82±30	63±38	89±31	58±66	80±21
Average Station 4	68±55	74±33	34±26	81±31	27±29	79±22
Average ALL Stations	102±91	101±30	64±41	108±26	17±19	88±24