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Impact of Dredging and Dredged Material Disposal on Dungeness Crab,  
Cancer magister, in Grays Harbor, Washington During October, 1985

by

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## INTRODUCTION

The port of Grays Harbor (Fig. 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 with an average annual dredging of 1.5-1.7 million cubic yards (cy) for annual maintenance dredging.

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.

The newly proposed and funded W&D project required that an Environmental Impact Statement (EIS) be prepared to address potential impacts of the project. As a consequence, Armstrong et al. (1982)

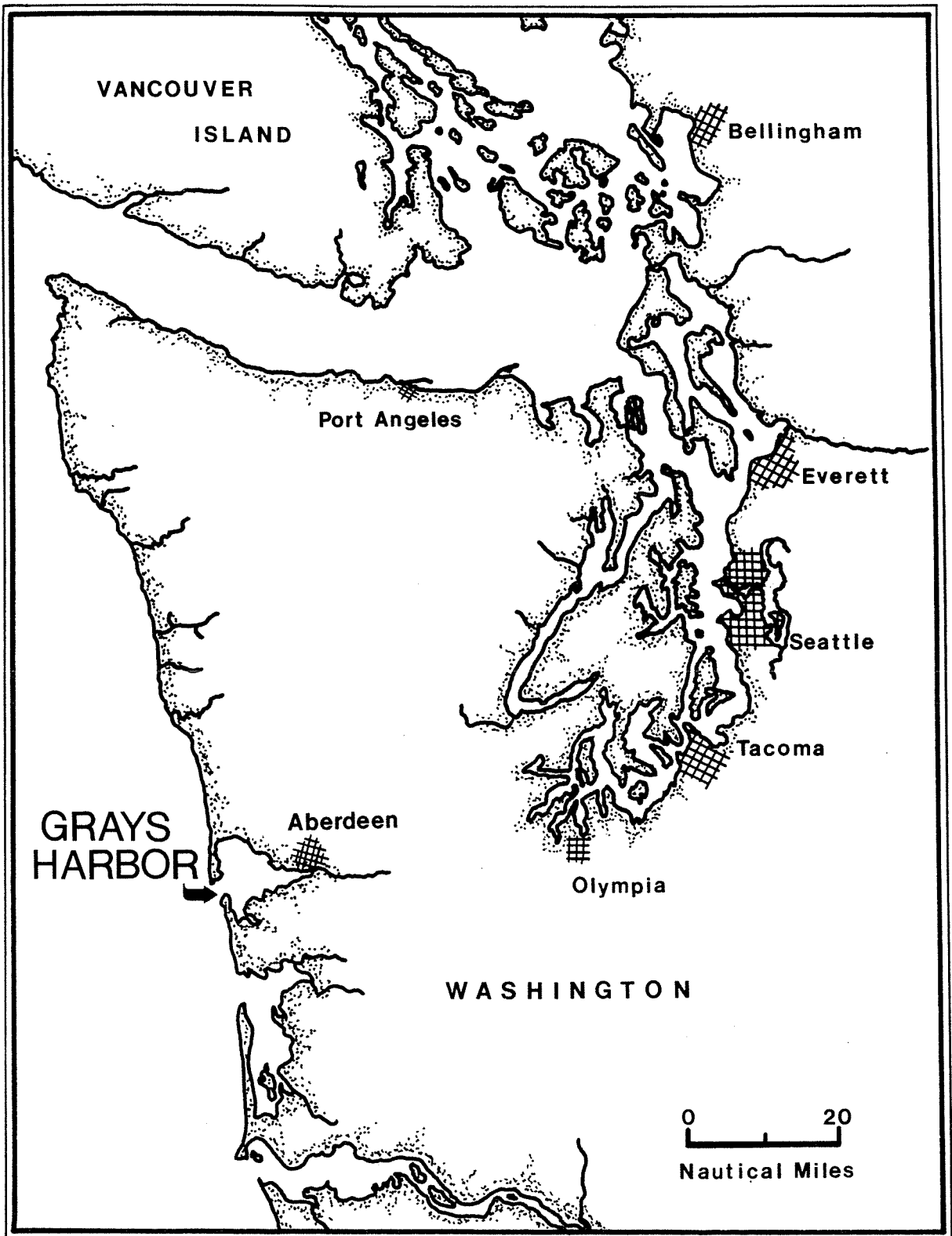


Figure 1. Map of Washington State showing the location of Grays Harbor.

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 organisms. Armstrong et al. (1982) found hopper dredge entrainment rates ranging from 0.035 to 0.502 crabs/cy with an average mortality of 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 to Dungeness crab during the W&D project, COE is investigating and evaluating methods to reduce entrainment and mortality to this species. The work reported here is part of that effort. This report details the results of entrainment studies during a period of dredging in Grays Harbor in October, 1985 by the COE hopper dredge Yaquina. The specific objectives of this study were four-fold:

- 1) Determine number and density of crabs before and during dredging in both the Dredge and Dredged Material Disposal Sites by sampling with a 3-m beam trawl.
- 2) Determine age class of crabs caught in the samples.
- 3) Determine if significant correlations exist between crab densities and important physical or biological factors.
- 4) Compare number of crabs entrained during dredging by the Yaquina with number of trawl-caught crab and estimate the proportion and significance of the crab population entrained during dredging.

## MATERIALS AND METHODS

Sampling for Dungeness crab was carried out by two different methods simultaneously. First, entrainment of crabs by the dragheads of the COE hopper dredge Yaquina was monitored on board the dredge by diverting the dredged material plume through screening baskets before the material entered the hopper. Second, crabs in the dredge area were sampled with a 3-meter beam trawl fished from a separate vessel in conjunction with, 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 (with holes approximately 10 mm in diameter) for 30 to 60 seconds and counting and measuring all crabs so obtained. Further details of the dredge Yaquina, the on-board sampling by the COE, and the comparison of crab entrainment by two different types of dragheads are discussed in a separate report (Memorandum-For-The-Record) by the Seattle District COE (COE 1986).

Beam trawl operations were conducted on board the chartered fishing vessel Karelia out of Westport, Washington. Crabs and other epifauna were sampled by five- to ten-minute tows of a 3-m beam trawl specifically designed to capture crabs (Gunderson et al. 1985) and used in other Dungeness crab studies in Grays Harbor (Armstrong and Gunderson 1985), Willapa Bay, and Puget Sound (Dinnet et al. 1985). All Dungeness crab from each trawl were counted, sexed, measured, assessed for obvious damage, 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 in two locations within the study area (Fig. 2): 1) The Dredge Site located in the "South Reach" section of the navigation channel and 2) The Dredged Material Disposal Site located in the entrance to Grays Harbor just north of Pt. Chehalis (Fig. 3). Trawls within the Dredge Site were subdivided into three areas: 1) the Primary Dredge Site (between flasher buoys "17" and "21"); 2) west of the Primary Dredge Site (between flasher buoys "15A" and "17"); and 3) east of the Primary Dredge Site (between flasher buoys "21" and "24"). Within the Primary Dredge Site six trawl stations were established (Fig. 4) and trawled on a day vs. night schedule before the initiation of dredging (October 15, 1985) and during dredging (October 22, 1985). Each trawl within the Primary Dredge Site covered a distance of approximately 400 meters (ten-minute tow) yielding an area swept by the net of approximately 925m<sup>2</sup>. Distance covered was usually determined by radar range readings using the various channel marker buoys as reference points. Trawls east and west of the Primary Dredge Site (October 22 and 23) and within the Dredged Material Disposal Site (October 23, 24 and 27) were generally random within those areas.

In addition to location, each trawl within the Dredge Site was in one of three "configurations" relative to the dredge Yaquina: 1) parallel to the Yaquina while dredging was being conducted (approximately 30-40 meters between vessels); 2) behind the Yaquina and in line (as much as possible) with one of the dragheads while dredging proceeded; or 3) independent of the dredging operation. Trawls in the Disposal Site were always independent of the dredge, although several trawls were conducted shortly after disposals were made. Trawling at the Disposal Site was also conducted on a pre-dredging basis (Oct. 15) and during dredging (Oct. 23, 24 and 27).

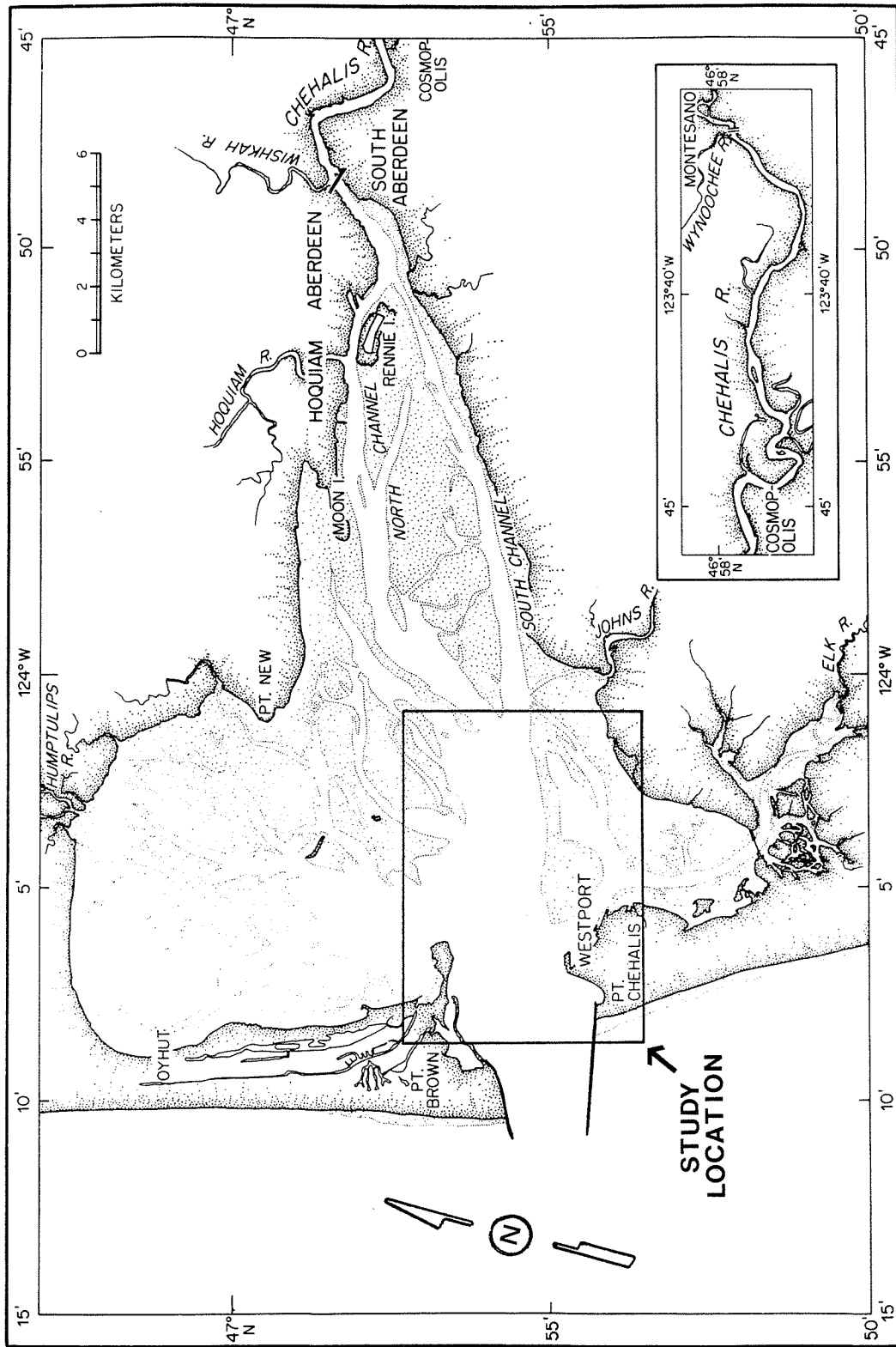


Figure 2. Map of Grays Harbor showing the boundaries of the dredging study.

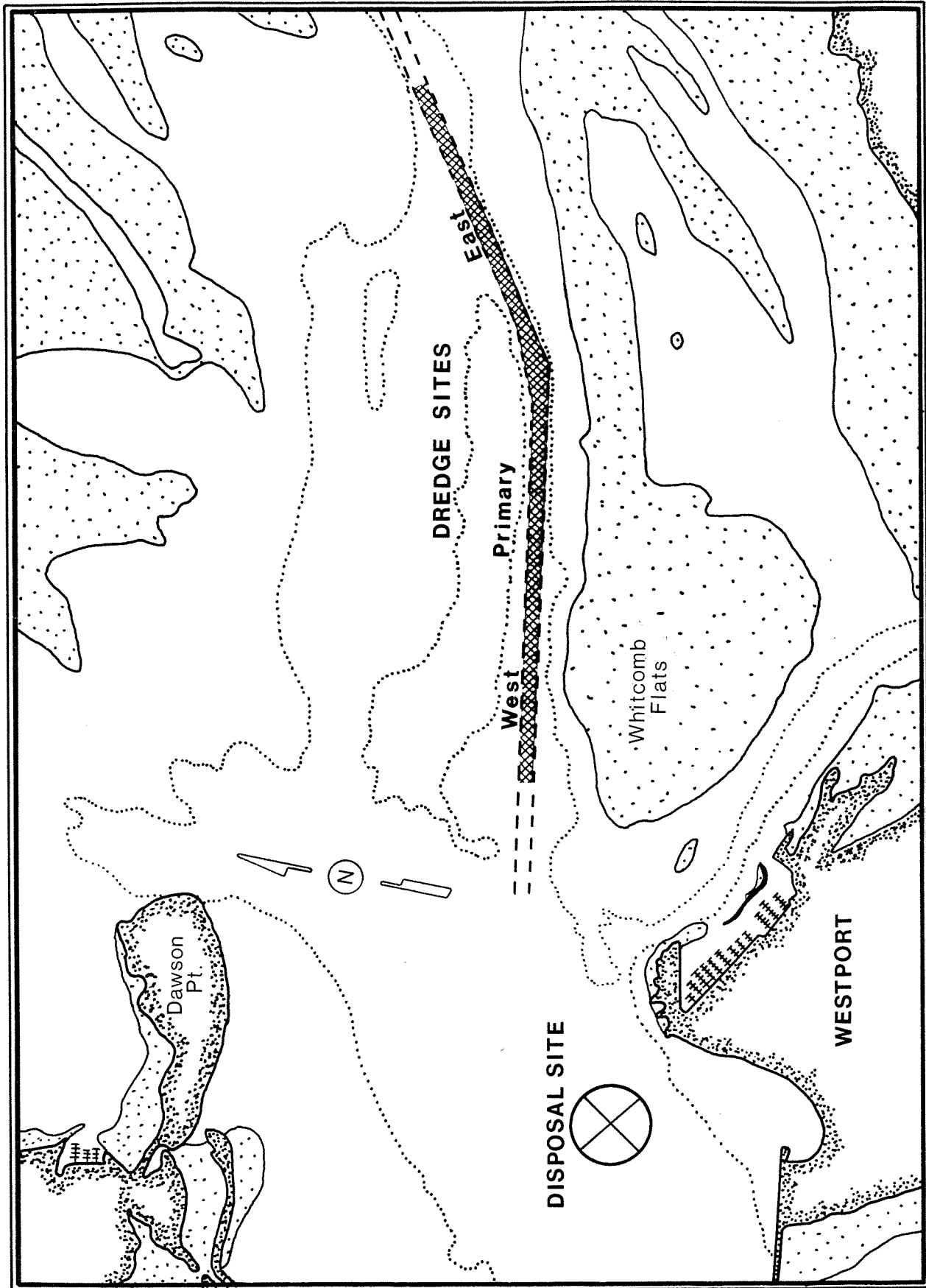


Figure 3. Map of outer Grays Harbor showing the dredge sites (hatched) and the Dredged Material Disposal Site.

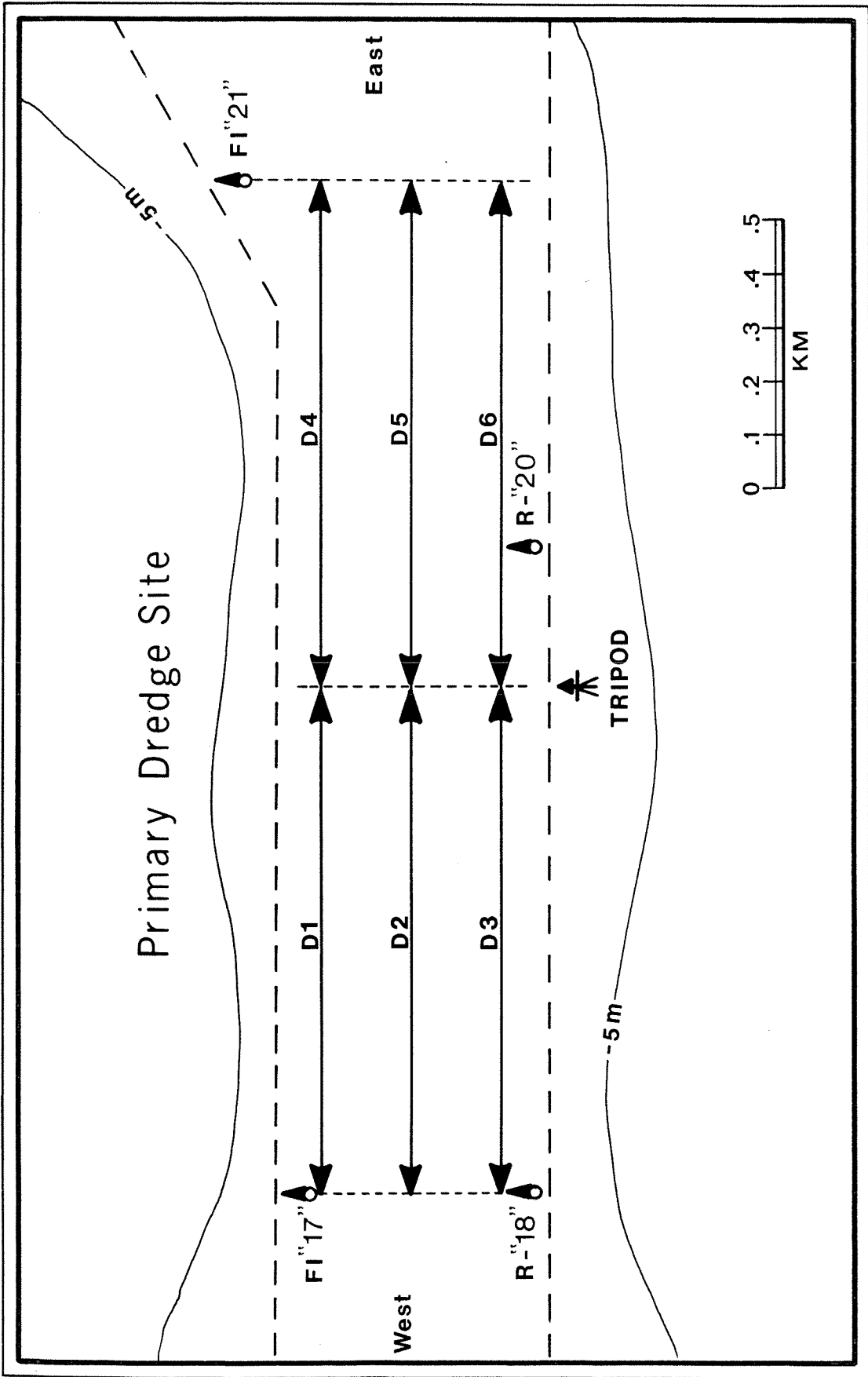


Figure 4. Map of the Primary Dredge Site showing the approximate locations of the beam trawl stations within the south channel.

## Data Analysis

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

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

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

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), using a Student's "t"-test, or bivariate correlation analysis by the following formula:

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

where x 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).

## RESULTS AND DISCUSSION

### Beam Trawl Crab Catches

Dungeness crab densities summarized by area, time of month, time of day (day vs. night), and trawl configuration are presented in Table 1. A total of 45 trawls was completed resulting in an average density of  $638 \pm 463$  crabs/ha over all areas sampled.

Crab densities within the Primary Dredge Site (Figs. 3 and 4) were not significantly different ( $p=0.05$ ; Student's "t"-test) before dredging (15 Oct.) vs. during dredging (22 Oct.) nor were there significant differences between day and night crab catches for either period (Table 1). There were also no significant differences ( $p=0.05$ ; one-way ANOVA) in crab catches to the east or west of the Primary Dredge Site (Fig. 3; Table 1).

Crab densities within the Disposal Site (Fig. 3) were again not significantly different ( $p=0.05$ ; "t"-test) between sample dates (15 Oct.

Table 1. Average densities of trawl-catchable Dungeness crabs (#crab/hectare) broken down by location, sampling period (before or during dredging), day vs. night, and trawl configuration relative to the dredge Yaquina.

Sample Group	Number of Samples (n)	Average Crab Density Crabs/hectare	Standard Deviation
<u>All Trawls</u>	45	638	463
<u>Primary Dredge Site</u>			
All trawls	22	654	331
Before dredging (15 Oct.)	10	506	167
During dredging (22 Oct.)	12	777	387
Day only	12	686	395
Night only	10	616	250
<u>West of Dredge Site</u>			
All trawls	4	1108	741
Day only	2	1741	214
Night only	2	476	30
<u>East of Dredge Site</u>			
All trawls (day only)	6	543	571
<u>Dredge Site Combined</u>			
Primary + east + west	32	690	456
<u>Disposal Site</u>			
All trawls	13	509	473
Before dredging	4	845	801
During dredging	9	360	116
Day only	10	584	521
Night only	3	259	18
<u>Trawl Configuration*</u>			
Parallel to dredge	9	837	599
Behind dredge	4	663	696
Independent of dredge	19	626	320

\*For Dredge Site only

vs. 23/24 Oct.) but were significantly different ( $p=0.016$ ; "t"-test) between night and day (Table 1). However, small sample sizes ( $n=3$  for night samples) and difficult trawl conditions at the Disposal Site must temper the interpretation of these data on day vs. night difference.

Comparisons of crab densities between the Primary Dredge Site and the Disposal Site show that there was no significant difference in crab catches between the two areas on 15 Oct. ( $p=0.05$ ; "t"-test) but that there was a highly significant difference ( $p=0.007$ ; "t"-test) in catches between the Primary Dredge Site (778/ha) and the Disposal Site (360/ha) for the 22-24 Oct. sampling period (Table 1). Again, difficult trawling conditions at the Disposal Site must temper this degree of significance. The trawl effectiveness was much more uncertain at the Disposal Site due to the existence of large sand and gravel mounds on the bottom and strong currents within the channel entrance, problems which were also encountered in the past during trawling work in this same area by Tegelberg and Arthur (1977).

All of the trawls within the Dredge Site were conducted either parallel to, directly behind, or independent of the dredge as it was operating. A comparison of crab catches from each trawl configuration showed no significant catch differences ( $p=0.05$ ; one-way ANOVA) between the three configurations (Table 1).

#### Crab Entrainment During Dredging

Sixty-four samples of 30 sec. duration each (except one = 60 sec.) were collected during a 24-hr period on board the Yaquina from baskets placed at the end of the hopper distribution trough, or diffuser. Each sample consisted of simultaneous collections of crabs from each of two dragheads: one designed to exclude crab greater than approximately 72 mm width from the intake and one unmodified (COE 1986). Only 44 crabs were

collected in the baskets during the 24-hr sampling effort (modified draghead = 20, unmodified = 24), equal to 1.35 crabs/minute of sampling time, 123 crabs/ha of area swept by the dragheads, or 0.118 crabs/cubic yard of dewatered solids (i.e., settled sediments drained of water).

#### Comparison Between Dredge and Beam Trawl Crab Catches

The best estimate of Dungeness crab density in the dredging area comes from beam trawl catches from the dredged area (Primary + East + West, Fig. 3) while dredging was in progress (22-23 Oct., 1985). Twenty-two trawls produced an estimated density of 773 crabs/ha for this time and area. This density compares with a calculated entrainment of 123 crabs/ha of area swept by the dragheads of the Yaquina. Thus, entrainment by the Yaquina was 15.9% of those crabs estimated to be present by the beam trawls.

#### Total Crabs Entrained by the Yaquina

The Yaquina operated for a 14-day period in October (17-30 Oct.) 1985 during which time approximately 67,625 cy of solids were dredged (COE 1986). An average of 0.118 crabs/cy were entrained during sampling aboard the Yaquina on 22 and 23 October. Assuming that this average value is representative of entrainment during the 14-day period, then approximately 7,980 Dungeness crabs would have been entrained by the Yaquina. Extrapolating from sizes of crabs caught in samples, approximately 200 (5%) would have been young-of-the-year (YOY) crabs (i.e., less than 55 mm in carapace width); 7,180 (90%) would have been of the 1984 year class (56 to 125 mm); and 200 (5%) of the crabs would have been of 1983 and earlier year classes (>126 mm).

### Damaged Crabs in Beam Trawls

Crabs showing signs of damage of a type probably caused by the dredge dragheads (i.e., crushed or mutilated) were found from several trawls made in the Disposal Site and from trawls behind the Yaquina while dredging was in progress (Table 2). Catches of damaged crabs from the Disposal Site would be expected since past crab entrainment studies have documented extensive damage to entrained crabs with average mortality approximating 73% (Armstrong et al. 1982).

Damaged crabs were found in two of four trawls made directly behind one of the dragheads of the Yaquina while dredging was in progress (Table 2). A total of 252 crabs was caught in the four trawls taken behind the dredge, including three (1.2%) which were damaged. Past crab entrainment studies (Tegelberg and Arthur 1977; Stevens 1981; Armstrong et al. 1982) have based all estimates of dredge-related crab impacts on crabs actually entrained by the dredge and deposited in the hoppers. These data show that there is an additional small component of damage to crabs that are contacted by the dragheads but not entrained by the dredge.

### 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 carapace width and 85.6% for crabs  $\geq$ 50 mm. Using these estimates for mortality, the approximate number of entrained crabs killed by the Yaquina in October 1985 was:  $0.459 \times 320$  crabs (only 4% of crabs were <50 mm) +  $0.856 \times 7,660$  crabs (96% of crabs were  $\geq$ 50 mm) = 6,704 for a total entrainment mortality rate of 84.0%.

Table 2. Trawls with Dungeness crabs showing damage of a type (i.e., crushing or mutilation) caused by the dredging process.

Tow #	Location	"Configuration"	Total <u>C. magister</u>	Damaged <u>C. magister</u>	Percent Damaged
B-1	East of Dredge Site	Behind Dredge	28	2	7
B-4	"	"	12	1	8
S-6	Disposal Site	Independent of Dredge	17	1	6
S-7	"	"	15	1	7
3S-3	"	"	21	1	5

(All other tows (n=40) had 0% damaged crabs)

Beam trawl catches taken behind the Yaquina during dredging showed that some crabs were severely damaged yet not entrained by the dragheads. Assuming an average density of crabs in the dredge area of 773/ha and a mortality of 1.2% due to crushing by the dragheads, then the additional number of crabs killed but not entrained would equal approximately 1,210 crabs (assuming an area swept by the dragheads of  $9.612 \text{ m}^2/\text{cy}$  of solids dredged). Thus, the total estimated crab mortality due to the dredging by the Yaquina in October, 1985 was approximately 7,914 crabs.

#### Dungeness Crab Size and Sex Composition

Measurable crabs (n=29 of 44) entrained in samples aboard the Yaquina averaged  $91.2 \pm 25.7$  (1 standard deviation) mm carapace width. Males (n=22) averaged  $89.9 \pm 26.3$  and females (n=7)  $95.1 \pm 25.3$  mm. Males accounted for 76% and females 24% of the entrained (and unutilated) crabs.

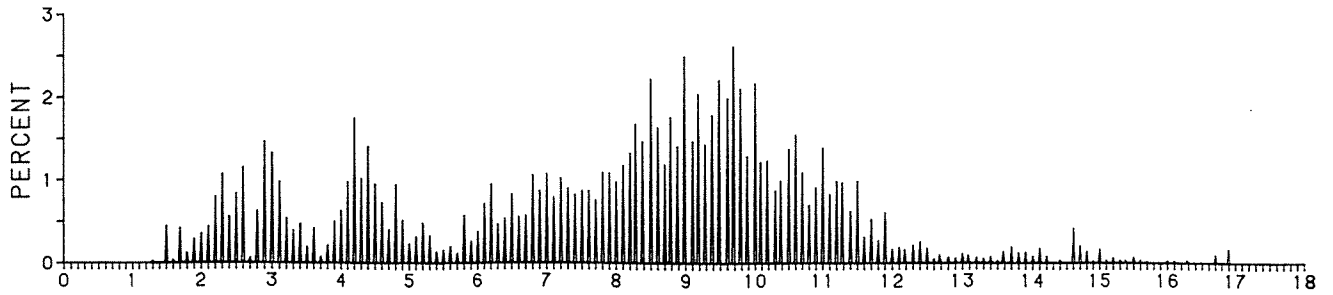
The average carapace width of all crabs caught in the beam trawls (Dredge + Disposal Sites) was  $85 \pm 25.2$  mm and average sizes in the Dredge and Disposal Sites were  $87.7 \pm 22.6$  and  $67.0 \pm 33.1$  mm, respectively. The smaller average size of crabs in the Disposal Site was due to a greater abundance of the 1985 0+ year class and lesser numbers of the 1984 1+ year class as illustrated by Figure 5. This figure also shows an interesting distribution for two apparently distinct cohorts of the 1985 year class. Two distinct peaks are apparent in the top plot (all samples combined) of Figure 5; one peak between 15 to 37 mm and the second from 38 to 55 mm. Crabs of the small size range were uncommon at the Dredge Site but comprised the dominant size class at the Disposal Site. The smaller crabs probably settled and grew offshore over the summer of 1985 while the larger crabs of that year class are characteristic of settlement and growth (much

SPECIES 68020  
CANCER MAGISTER  
DUNGENESS CRAB

DREDGING ENTRAINMENT STUDY OCT 85

MEAN LENGTH = 8.5 cm

All crabs

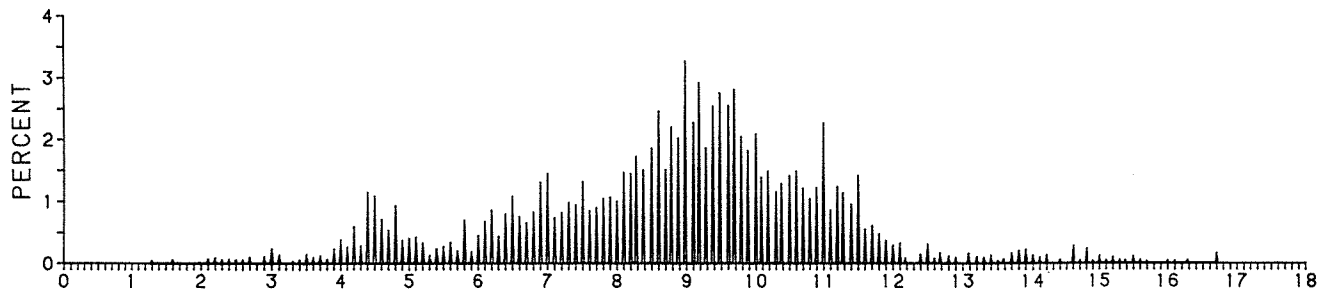


SPECIES 68020  
CANCER MAGISTER  
DUNGENESS CRAB

DREDGING ENTRAINMENT STUDY OCT 85

MEAN LENGTH = 8.8 cm

Dredge Site only

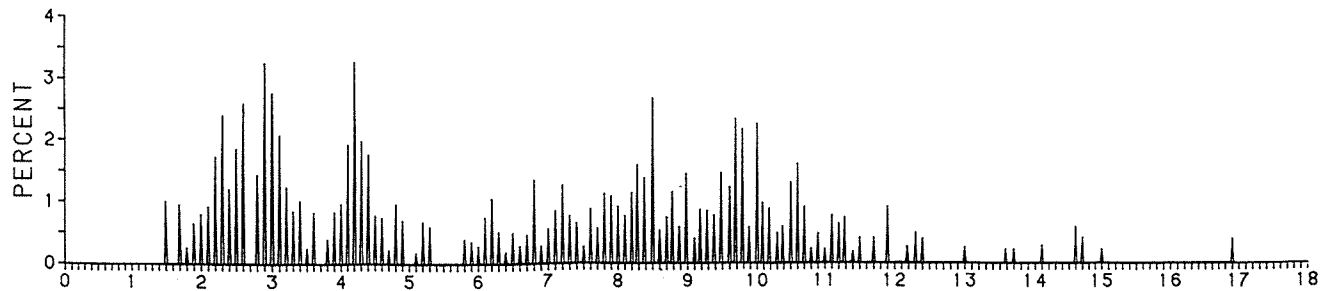


SPECIES 68020  
CANCER MAGISTER  
DUNGENESS CRAB

DREDGING ENTRAINMENT STUDY OCT 85

MEAN LENGTH = 6.6 cm

Disposal Site only



Width (cm)

Figure 5. Size-frequency histograms for all Dungeness crabs (top) from the October 1985 beam trawls and for crabs caught only in the Dredge Site (middle) or the Disposal Site (bottom).

faster than offshore) within Grays Harbor estuary (Armstrong and Gunderson 1985).

The composition of crabs by sex for the Dredge and Disposal Sites combined was: male = 43.5% and female = 56.5%. The composition by sex within the Dredge Site only was male = 43.2% and female = 56.8%. The composition by sex for the Disposal Site was 45.4% male and 54.6% female. Size-frequency distributions for male and female crabs (Fig. 6) show that the maximum size of the females caught was 124 mm while the size range for the males extended up to 169 mm. Past work (Cleaver 1949; Armstrong et al. 1982; Armstrong and Gunderson 1985) has documented the fact that mature females are very rare in Grays Harbor and evidently migrate out of the estuary by the beginning of their third year. Figure 6 shows that older males (>120 mm) also were relatively scarce within the estuary at this time of year.

#### Dungeness Crab Population Estimates

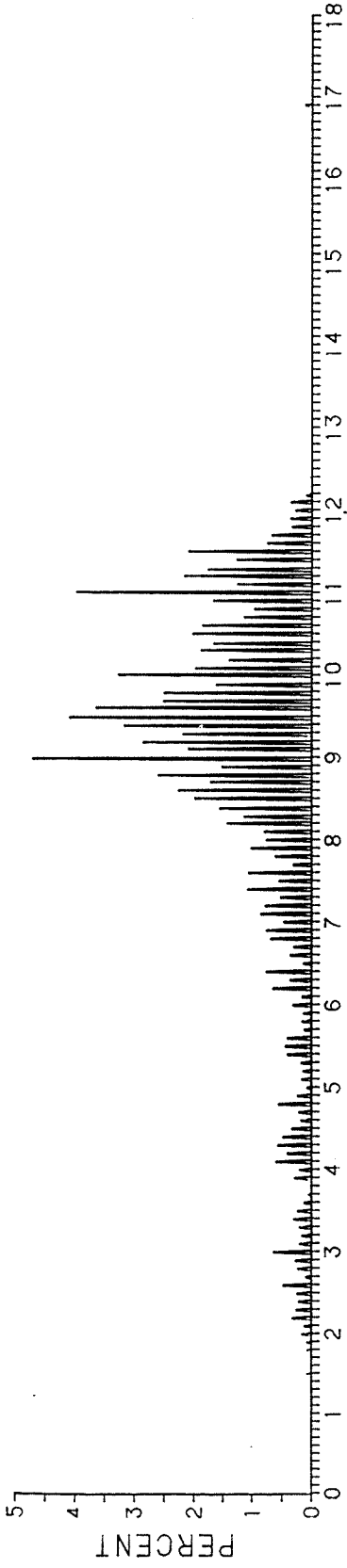
Population estimates for Dungeness crab were calculated for October 1985 by routine beam trawl sampling at specific stations conducted as part of a related crab study (Armstrong and Dumbauld, in progress; Gunderson et al. 1985). The estimates calculated for four areas (strata) of Grays Harbor (Fig. 7, Table 3) show that slightly over 3 million crabs were present in Stratum 1 around the estuary mouth which includes the Dredge Site. Smaller populations of crab were estimated in other strata of the estuary but 2.1 million were calculated for North Bay. A total of about 6.7 million crab was present throughout the total estuary in October, 1985 (Table 3).

Given a population estimate of approximately 3.1 million crabs (Table 3) for the estuary mouth stratum and an estimated dredge-related crab

SPECIES 68020  
CANCER MAGISTER  
DUNGENESS CRAB

DREDGING ENTRAINMENT STUDY OCT 85

MEAN LENGTH = 8.7 cm FEMALE



SPECIES 68020  
CANCER MAGISTER  
DUNGENESS CRAB

DREDGING ENTRAINMENT STUDY OCT 85

MEAN LENGTH = 8.2 cm MALE

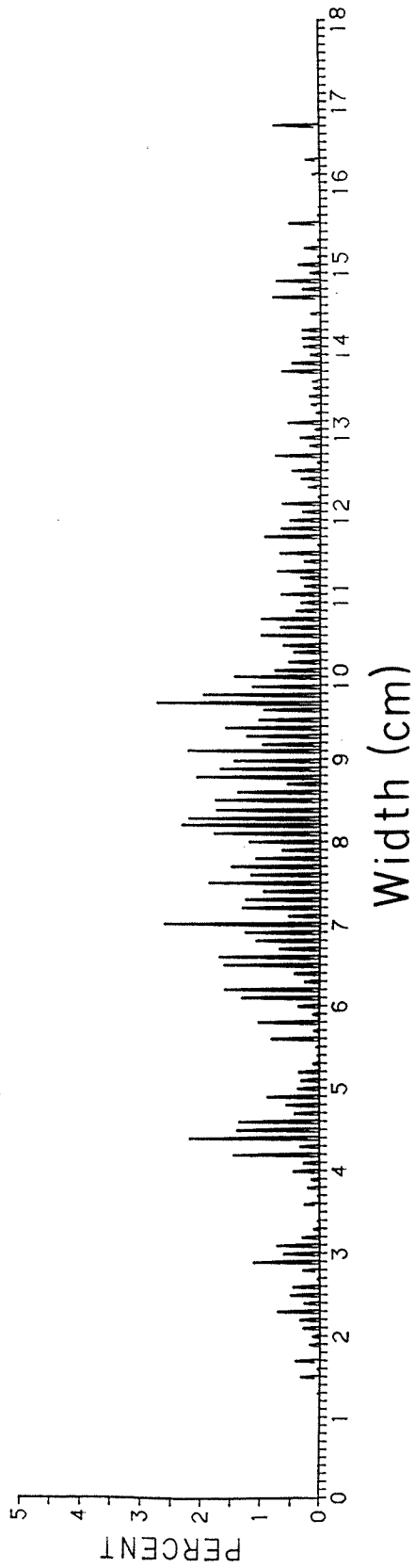


Figure 6. Size-frequency histograms for female (top) and male (bottom) Dungeness crabs caught in the beam trawls from 15 to 27 October, 1985. Crabs from both the Dredge and Disposal Sites are combined.

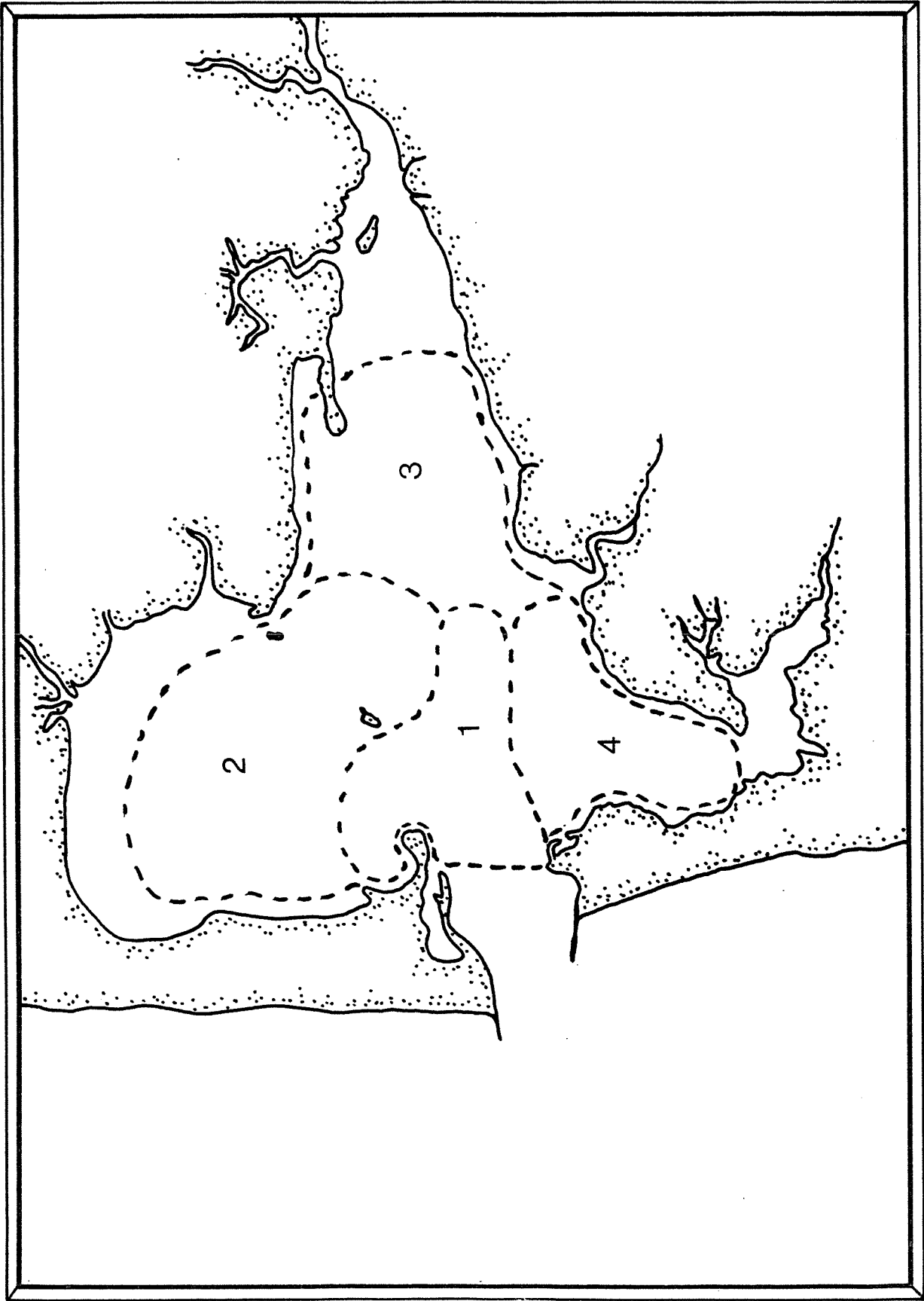


Figure 7. Map of Grays Harbor showing the estuary divided into four separate strata for purposes of making comparative population estimates.

Table 3. October, 1985 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 $\pm$ 2 S.E.)	Population Estimate (Millions $\pm$ 2 S.E.)	Proportion
1 = Estuary Mouth	3651	837 $\pm$ 407	3.055 $\pm$ 1.488	0.46
2 = North Bay	2516	831 $\pm$ 256	2.091 $\pm$ 0.644	0.31
3 = South & Crossover Channels	1548	539 $\pm$ 195	0.835 $\pm$ 0.302	0.12
4 = South Bay	830	849 $\pm$ 823	0.705 $\pm$ 0.684	0.11
Total Estuary	8545	782 $\pm$ 973	6.686 $\pm$ 1.785	100.0

mortality of 7,914 crabs during October 1985, then the overall mortality would be approximately 0.26% of the total crabs within Stratum 1 and approximately 0.12% of those estimated to be present in the total estuary.

Similar trawl-based estimates were also made in the fall of 1983 and 1984 (Armstrong and Gunderson 1985). The estimated numbers of crabs for October 1983 were  $11.9 \pm 7.5$  ( $\pm 2$  S.E.) million for the entire estuary and  $3.0 \pm 1.5$  million for Stratum 1. Crab estimates for September 1984 (no October samples) were  $41.3 \pm 19.2$  million for the entire estuary and  $10.5 \pm 12.5$  million for Stratum 1. Although the error factors are very high, these estimates suggest that Dungeness crabs can be at least 3 times as abundant at the South Reach Dredge Site as they were during the present study conducted in October, 1985. Hence, crab entrainment and mortality may be at least three times greater than observed in this study if dredging is conducted during the fall of a high crab abundance year.

#### Correlation of Crab Catches with Physical Factors

Bivariate correlation analysis of Dungeness crab catches with seven factors associated with trawling and trawl catches failed to identify any significant correlations or even a suggestion that a correlation might exist (Table 4) since all  $r^2$  values were  $\leq 0.05134$ .

#### Beam Trawl Fish Catches

Data on fish species and abundances were collected from six stations within the Primary Dredge Site on a one-time basis on 22 October. Juvenile stages of English sole (Parophrys vetulus) and Butter sole (Isopetta isolepis) and Sanddabs (Citharichthys spp.) were most abundant followed by sculpins (various species) and Tomcod (Microgadus proximus) (Table 5). All fish species collected were common to Grays Harbor estuary based on previous beam trawl samples taken during 1980 and 1981 (Armstrong et al.

Table 4. Bivariate correlation analysis of Dungeness crab densities with other physical factors (n=45 in all cases).

Factor	r	r <sup>2</sup>
Depth	-0.11338	0.01285
Tow speed	0.01595	0.00025
% shell	-0.09875	0.00975
% terrestrial material	0.07817	0.00611
% macro algae	-0.07877	0.00620
% gravel/cobble	0.04274	0.00183
% mud/sand	-0.22659	0.05134

Table 5. Number of fish sampled from six trawls in the Dredge Site, 22 October 1985.

Fish Species	Sample #					
	D-14	D-15	D-16	D-17	D-18	D-21
English Sole	15	29	5	2	3	10
Butter Sole	1	2		4	17	4
Sand Sole	1		1	1	1	
Sanddabs	7	8	13	20	14	12
Gunnels	12					3
Sculpins	19	8	8	27	14	22
Surfperchs	5			1	2	4
Greenling		1				
Pipefish		1	2	1	6	3
Tomcod			1	11	8	34
Anchovy				1	2	12
Dogfish				1		
Pricklebacks				1	2	3
Smelts						2

Table 6. Temperature and salinity data collected during the dredging/  
trawling study.

<u>Date</u>	<u>Site</u>	<u>Temperature (°C)</u>		<u>Salinity (‰)</u>	
		<u>Surface</u>	<u>Bottom</u>	<u>Surface</u>	<u>Bottom</u>
15 Oct. (day)	Dredge	12.1	12.0	31.0	31.0
15 Oct. (night)		12.5	12.5	28.5	30.0
15 Oct.	Disposal	11.8	11.6	32.5	32.5
22 Oct.	Dredge	12.0	12.5	28.0	28.0
23 Oct.	Dredge	12.5	12.0	24.0	28.0
24 Oct.	Disposal	12.5	12.5	30.5	30.0
27 Oct.	Disposal	8.0	n.s. <sup>1</sup>	18.0	n.s. <sup>1</sup>

<sup>1</sup> n.s. = not sampled

1982; Rogers 1985).

### Temperature and Salinity

Water temperature and salinity data were collected during each sampling day (Table 6). Surface and bottom temperatures averaged  $12.2 \pm 0.3^{\circ}\text{C}$  and  $12.2 \pm 0.4^{\circ}\text{C}$ , respectively, from 15 to 24 October, 1985 indicating a well mixed water mass. Surface and bottom salinities for these same dates averaged  $29.1 \pm 3.0$  ‰ and  $29.9 \pm 1.7$  ‰, respectively, indicating only a slight contribution of freshwater to the outer estuary during this time frame.

A major storm moved through the Grays Harbor area on 25 and 26 October. One surface sample after the storm on 27 October showed declines in surface water temperature ( $8.0^{\circ}\text{C}$ ) and salinity ( $18.0$  ‰) at the Disposal Site. This depression in surface temperature and salinity documents a substantial increase in freshwater runoff from the storm event. A broken water sampling bottle precluded bottom water sampling so it is not known to what extent bottom-dwelling fauna might have been influenced by the freshwater.

### CONCLUSIONS

1. Beam trawl samples for Dungeness crab in October, 1985 indicated an average density of 773 crabs/ha in the South Reach area during dredge operations by the Yaquina and 509 crabs/ha at the Dredged Material Disposal Site.

2. There were no significant differences in beam trawl crab catches between 15 Oct. (prior to dredging) and 22-24 Oct. (during dredging); between day and night catches, or between the Dredge vs. Disposal Site except that significantly greater catches were made during the day (vs. night) at the Disposal Site (23/24 Oct.) and greater catches were made at the Dredge Site (vs. the Disposal Site) during the 23/24 Oct. period. However, difficult sampling conditions at the Disposal Site preclude reliable interpretation of these data.
3. There was no significant difference in trawl catches of crab at the Dredge Site due to "trawl configuration" relative to dredging (i.e. parallel to dredge vs. behind dredge vs. independent of the dredge).
4. Forty-four Dungeness crab were entrained aboard the dredge Yaquina during a total of 32.5 minutes of sampling (n=64 samples). These catches were equal to 1.35 crabs/minute of sampling time, 123 crabs/ha of area swept by the dragheads, or 0.118 crabs/cubic yard of solids dredged.
5. Based on areas swept by the beam trawl and the dragheads, entrainment of crabs by the Yaquina was 15.9% of those caught by beam trawl.
6. The estimated number of Dungeness crabs entrained by the Yaquina during 14 days of dredging (67,625 cy of solids dredged) would have been 7,980, of which an estimated 84% (6,704) would have been killed (based on mortality estimates from a prior study).
7. Trawls made behind the Yaquina during dredging indicated that 1.2% of the crabs had dredge-related damages (crushing and mutilation) that were probably fatal. This equates to an additional estimated crab mortality of approximately 1,210 crabs in addition to the estimated entrainment mortality.

8. Crab size-frequency distributions from trawl samples show two distinct cohorts for the 1985 (0+) year class crabs. One cohort (15 to 35 mm) occurred mainly at the Disposal Site, and was representative of crabs that settled and grew offshore of Grays Harbor. The second cohort (36 to 55 mm) occurred in both the Dredge and Disposal Site (but not further offshore) and was characteristic of young-of-the-year which settled and grew within the estuary.
9. Dungeness crab population estimates for October, 1985 indicated the presence of  $6.7 \pm 1.8$  million crabs in the total estuary and  $3.1 \pm 1.5$  million crabs in the vicinity of the estuary mouth where dredging was taking place. Given an estimated dredge-related mortality of 7,914 crabs (entrainment plus draghead damage), 0.26% of the crabs present in the vicinity of the estuary mouth were killed and 0.12% killed relative to the total estuary.
10. Past population estimates for September-October from 1983 and 1984 showed that crab abundances in the estuary mouth area can be as high as  $10.5 \pm 12.5$  million crabs, a factor approximately three times as high as October 1985. Hence, the number of crabs killed by dredging can be expected to vary between years.

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