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PADILLA BAY DUNGENESS CRAB, _CANCER MAGISTER_, HABITAT STUDY

by

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ABSTRACT

Dungeness crabs, Cancer magister, were sampled in Padilla Bay from May 1985 to August 1986 using four sampling methodologies. A small beam trawl was used to sample 19 intertidal and subtidal channel stations. Commercial crab pots modified with small-mesh screen to retain small crabs were fished at a subset of 9 of the trawl stations. Diver transect surveys were conducted side-by-side with some of the trawls in an attempt to quantify the efficiency of the trawls. Finally, intertidal quadrat samples (0.25 m^2) were collected along 6 transects in Padilla Bay and 2 transects at March Point.

The results showed that each sampling methodology selected for different size classes of crab. The trawls caught the widest size range of crab but caught relatively few large crab (>140 mm) compared to the crab pots. The pots, however, rarely caught crabs <60 mm in size. Comparisons between diver transects and the trawls indicated that the divers were also missing small crabs. Intertidal quadrat sampling sampled very small young-of-the-year crab very well but rarely caught crabs >30 mm in size.

Habitat preferences for each of the age classes were different. Typically, 0+ (young-of-the-year) crabs (up to about 30 mm size) preferred intertidal or shallow subtidal areas with algae (especially Ulva) or eelgrass cover, although cobble and gravel substrates were also favored with or without plant cover. The 1+ age class (crabs entering their second year of growth) crabs preferred the shallow channels, moving out to the deeper channels as they grew to 2-year-old crabs. Gravid females were essentially absent from Padilla Bay, probably migrating to areas near deep water for mating and egg production.

Historical patterns of Dungeness crab abundances within Puget Sound and

near Anacortes show that major fluctuations in abundance can be expected, probably due to natural (but unknown) causes.

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PREFACE

This work was primarily funded by a grant from the National Oceanic and Atmospheric Administration, Division of Marine and Estuarine Management (Grant #NA85-AA-D-CZ046) and administered by Terry Stevens, Director, Padilla Bay National Estuarine Research Reserve. We sincerely appreciate Terry's efforts and patience on our behalf.

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INTRODUCTION

Padilla Bay, situated just east of Anacortes in northern Puget Sound (Figure 1), contains one of the largest concentrations of eelgrass (*Zostera* spp.) on the Pacific Coast and harbors a collection of invertebrates, fish, birds and marine mammals representative of the inland marine waters of Washington State.

The Padilla Bay National Estuarine Research Reserve, containing approximately 4,500 hectares within the administrative boundary, was jointly established by the state and federal governments in the early 1980's. The reserve is primarily managed by the Washington Department of Ecology for the purposes of conservation, research and public education (W.D.O.E. 1984).

Fishing has been an important part of the history of Padilla Bay. Clams and oysters have been harvested commercially in past years with clams still providing a small sports harvest in selected areas. Crabbing and salmon harvesting occur in and around Padilla Bay although these fisheries are reportedly not as productive as they were at the turn of the century (W.D.O.E. 1984).

Dungeness crab (*Cancer magister*) is the object of a minor commercial and major sports fishery in Padilla Bay and surrounding waters and contributes to an average annual harvest of 1.5 million pounds of crab from the inland waters of Washington (P.M.F.C. 1985). Although the object of an important fishery, very little is known about the distribution, growth, settlement, reproduction, and habitat requirements of Dungeness crab stocks in the Puget Sound region. Previous benthos-related studies have suggested that shallow eelgrass areas provide critical habitat for juvenile fish and invertebrates including Dungeness crab (Webber, pers. comm.; Thayer and Phillips 1977); however, few studies specific to Dungeness crab habitats have been conducted prior to 1985.

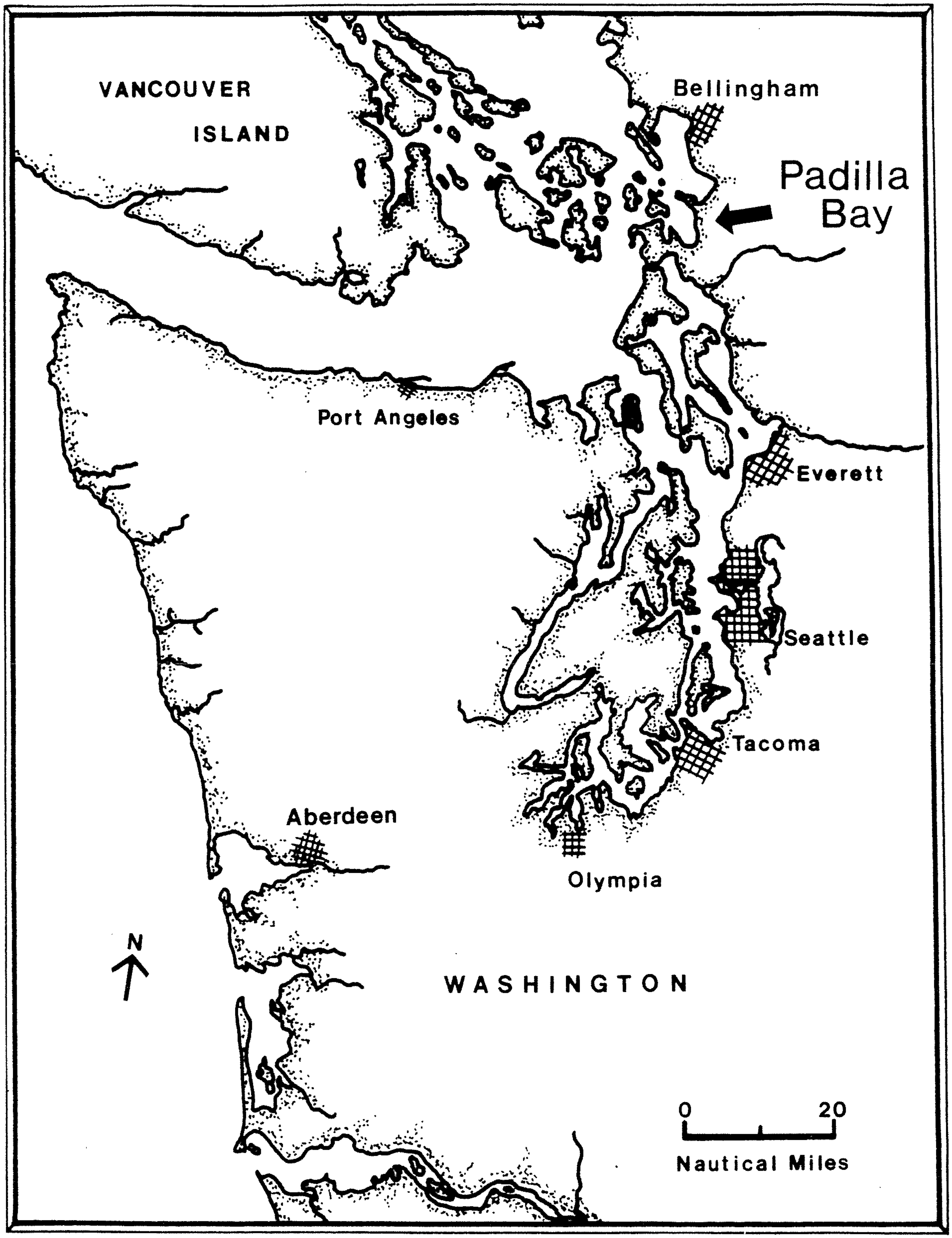


Figure 1. Map of Western Washington showing the location of Padilla Bay.

As a consequence of this lack of habitat information for this important commercial and sport species, this study of Dungeness crab and its habitats in Padilla Bay was initiated by the Padilla Bay Reserve in 1985. The purpose of this study was to identify the importance of different habitats in Padilla Bay to Dungeness crab. The primary objectives of the study were threefold:

1. Sample intertidal habitats in Padilla Bay to assess Dungeness crab distribution in these areas, define periods of settlement of young-of-the-year (YOY) crab and monitor YOY survival and growth.
2. Sample subtidal habitats in Padilla Bay with trawls and crab pots to define use of these areas by all stages of crab.
3. Conduct diver transect surveys at selected trawl stations to provide an estimation of the efficiency of the trawl gear for capturing crabs.

MATERIALS AND METHODS

Sample Methods

Dungeness crab resources and habitat usage in Padilla Bay were assessed using four different sampling methodologies: 1) trawls conducted with a small beam trawl; 2) commerical crab pots modified with small mesh Vexar screen to retain small crabs; 3) intertidal quadrat sampling during periods of low tide; and 4) SCUBA diver surveys along transects set in the subtidal channels.

Beam trawls.

Trawling was conducted with a 3-m plumb staff beam trawl with an effective fishing width of 2.3 m (Figure 2). This trawl was designed by Gunderson and Ellis (1986) for sampling demersal organisms and has been routinely used in the Washington coastal areas of Willapa Bay and Grays Harbor (Armstrong and Gunderson 1985; Gunderson et al. 1985; Dinnel et al. 1986a, 1986b) and in north and central Puget Sound (Armstrong et al.

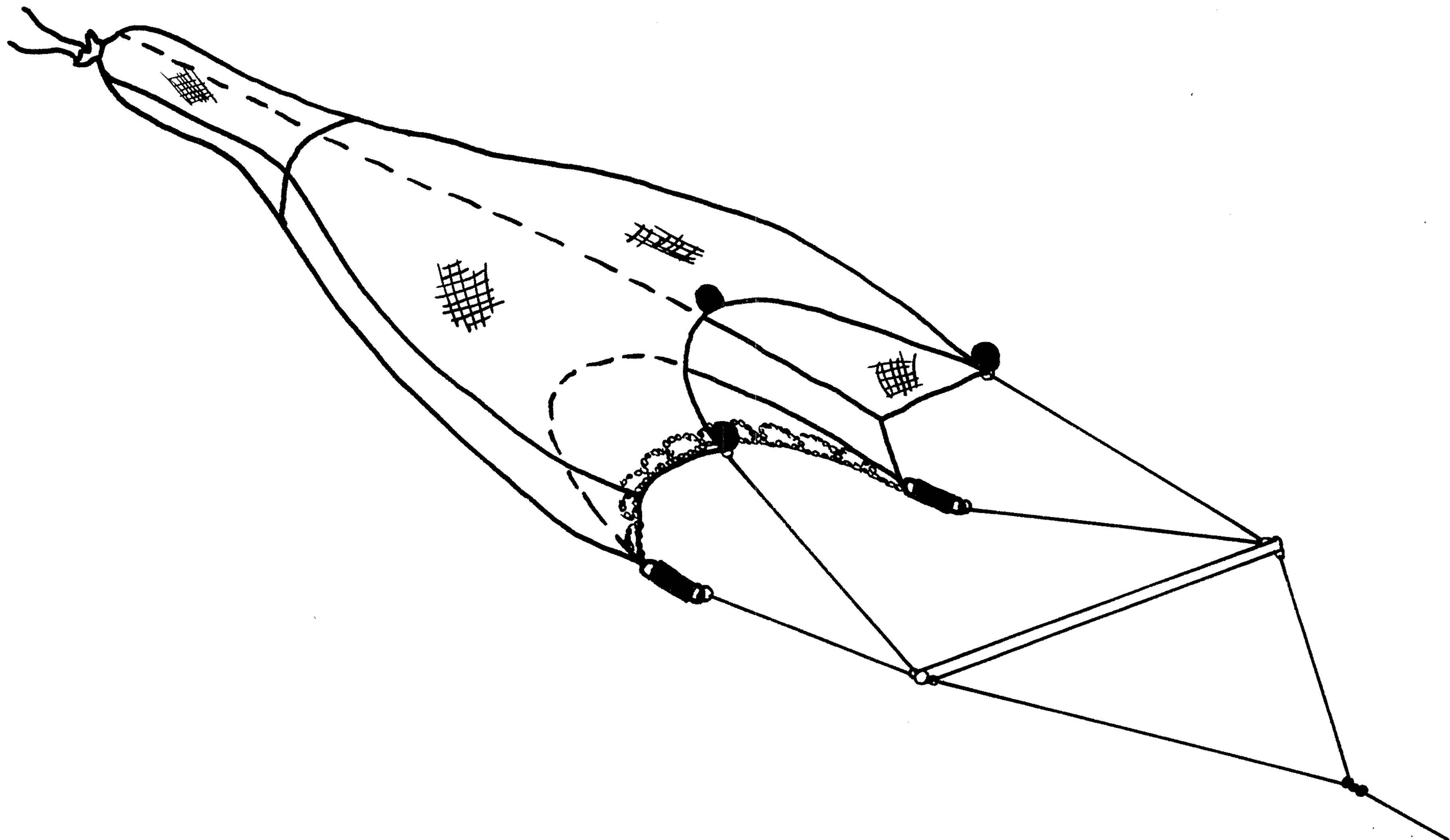


Figure 2. Diagram of the 3-m beam trawl (2.3 m net opening) used for sampling crabs in Padilla Bay.

1987; Dinnel et al. 1985a, 1985b, 1986c, 1986d; Weitkamp et al. 1986).

Intertidal (during high tide) and shallow subtidal trawls were conducted with a 7-m Boston Whaler equipped with a towing frame and winch. Each subtidal tow was 2 to 4 minutes in duration while intertidal tows were all reduced to 2 minutes due to large amounts of algae (especially *Ulva*) and eelgrass (*Zostera*) caught in the trawls.

The contents of all trawls were sorted into various categories including shell, vegetation, rock, wood and debris, fish and invertebrates, and brachyuran crabs (excluding kelp and decorator crabs, *Pugettia* spp. and *Hyas* spp.). During most cruises, items in each category were weighed and recorded, with the exception of crabs, which were identified to species, sexed, measured for carapace width (CW), and checked for molt condition (degree of shell softness) and reproductive stage (eggs present or absent on mature females). Temperature and salinity data were collected during each cruise from surface and bottom waters at selected stations.

Diver surveys.

SCUBA diver surveys were conducted in conjunction with a portion of the beam trawls in an attempt to estimate the efficiency of the trawl for capturing Dungeness crabs. Sixteen diver surveys were conducted during the project at selected beam trawl stations prior to and beside the anticipated trawl path. Each diver survey was conducted by a pair of divers swimming along a 70 to 100 m long weighted transect line and picking up crabs within an arms width on each side of the transect line (effective sampling width of 3.4 m). Divers also searched the bottom by probing to locate crabs buried in the sediments or hidden under shells or vegetation. All crabs caught by the divers were processed as noted for the beam trawls above. Notes were also made of substrate type, degree of shell or vegetation cover and approximate percentage of crabs buried in the bottom.

Crab pots.

Commercial-style Dungeness crab pots were generally fished for 4- to 8-hour periods using fresh or frozen fish or chicken for bait. Each crab pot, including the escape rings, was covered with small mesh (approximately 13 mm by 16 mm diamond mesh) Vexar screen to help retain sublegal-sized (<159 mm) crab. Retention of crabs less than about 100 mm was incomplete, however, since small crabs could still exit through the slots between the trigger apparatus in the entrance channels. All crabs caught in the pots (except kelp or decorator crabs) were processed as noted above for the beam trawls. Crab pot sampling was occasionally hindered by unexplained missing pots.

Intertidal quadrat sampling.

Intertidal samples were collected randomly within habitat types along 8 transects by digging 0.25 m^2 samples to a depth of approximately 3 cm. Each sample was washed through 4-mm mesh nets or screens and sorted in the field. All crabs were identified, measured as above, sexed if greater than 20 mm CW, and returned to the beach. A number of habitat parameters were recorded for each sample. Vegetative cover was broken down into one of eight categories according to the dominant species, and percent cover was estimated visually. Substrate material was identified according to visual observation of grain size. Substrate and water temperatures were recorded along each transect and salinity was recorded for tidal pools and adjacent channels.

Sample Sites

Beam trawls.

Eighteen beam trawl stations were established in Padilla Bay and one station established in the Swinomish Channel leading toward LaConner, Washington (Figure 3). Beam trawl stations were selected to provide a cross-section of areas and habitat types. Stations 1-5 and 19 were located in the north half of Padilla Bay while stations 6-18 were located in the southern portion. Within each area of the bay, some stations were selected to contrast crab catches by location in the channels (e.g., Stations 9, 14 and 16 were located in outer, middle and inner "Bay View Channel" in South Padilla Bay). One set of 7 stations (6-12) was selected to contrast crab catches on an east-west line across the bay and as related to habitat type (i.e., intertidal/subtidal eelgrass vs. deep channel). Another set of stations (7, 17 and 18) were located to provide crab distribution data in the main navigation (Swinomish) channel running from north to south along the western portion of the bay. Beam trawl stations were sampled at monthly intervals from April to October 1985 and at bimonthly intervals from January to August 1986. Occasional bad weather limited sampling during a few months.

Diver surveys.

Diver survey stations were generally located at a subset of the beam trawl stations (Stations 4, 10, 14, 16-19; Figure 3) to provide measures of the trawl efficiency in different areas and under different conditions (i.e., season, depth, etc.).

Crab pots.

Vexar-lined crab pots were set at a subset of the beam trawl stations (Stations 4, 7, 9, 10, 14, 16-19; Figure 3) to provide another

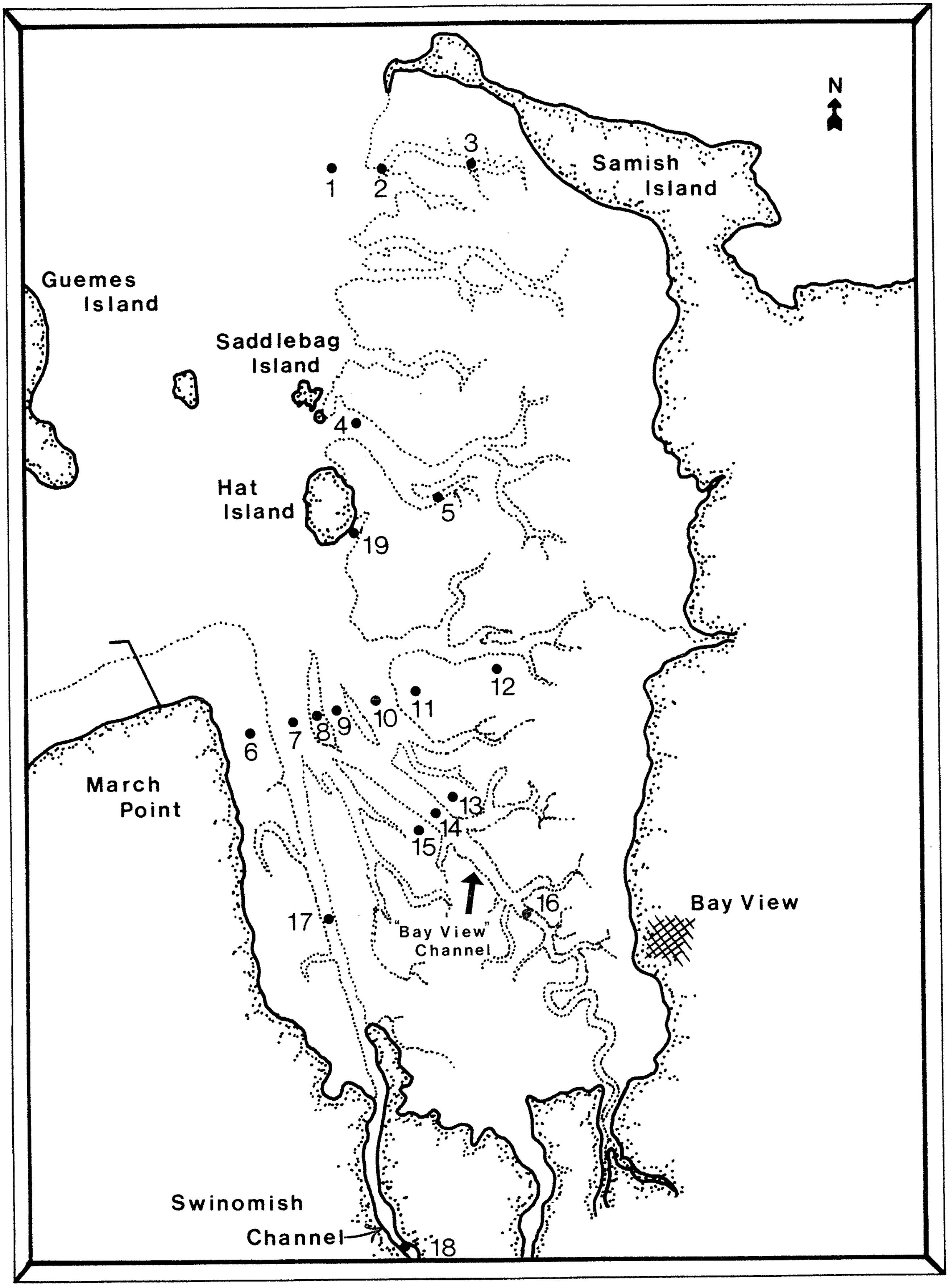


Figure 3. Map of Padilla Bay showing the locations of the beam trawl sample stations. The dotted lines indicate intertidal areas exposed at the lowest tide levels.

measure of crab abundance and sizes at these stations. Stations were sampled as time and weather allowed; hence, not all stations were sampled every month. Stations 14, 16, 17 and 18 were sampled most frequently.

Intertidal quadrat sampling.

Intertidal quadrat sampling was conducted at up to eight stations (transects) in Padilla Bay (Figure 4). Stations 1-3 were located in North Padilla Bay; Stations 5, 6 and 17 located in South Bay and Stations 7 and 8 at March Point. The best intertidal sampling data base was from Station 7 at March Point since this station was readily accessible by road. The intertidal station numbers are different from the trawl station numbers with the exception of Station 17. Intertidal Station 17 lies next to the Swinomish Channel trawl Station 17. Intertidal Stations 5 and 6 are essentially the same sites as intertidal trawl Stations 13 and 15 (Figures 3 and 4). The intertidal stations were specifically selected to contrast different habitat types throughout the bay; they were not selected by a random process.

Data Analysis

Beam trawl tows varied in the distance the net covered due to the interaction of many uncontrollable variables, including wind, currents, motor speed and amount of material caught by the net. Hence, distance towed was determined by setting floats with anchors at the beginning and end of each tow and measuring the distance between the floats with a calibrated optical rangefinder accurate to approximately $\pm$10%. The total area swept by the net was calculated by multiplying the tow distance by the effective fishing width of the net (2.3 m). Crab catches from each tow were converted to a standard abundance measurement of estimated crab/hectare (ha) by the following formula:

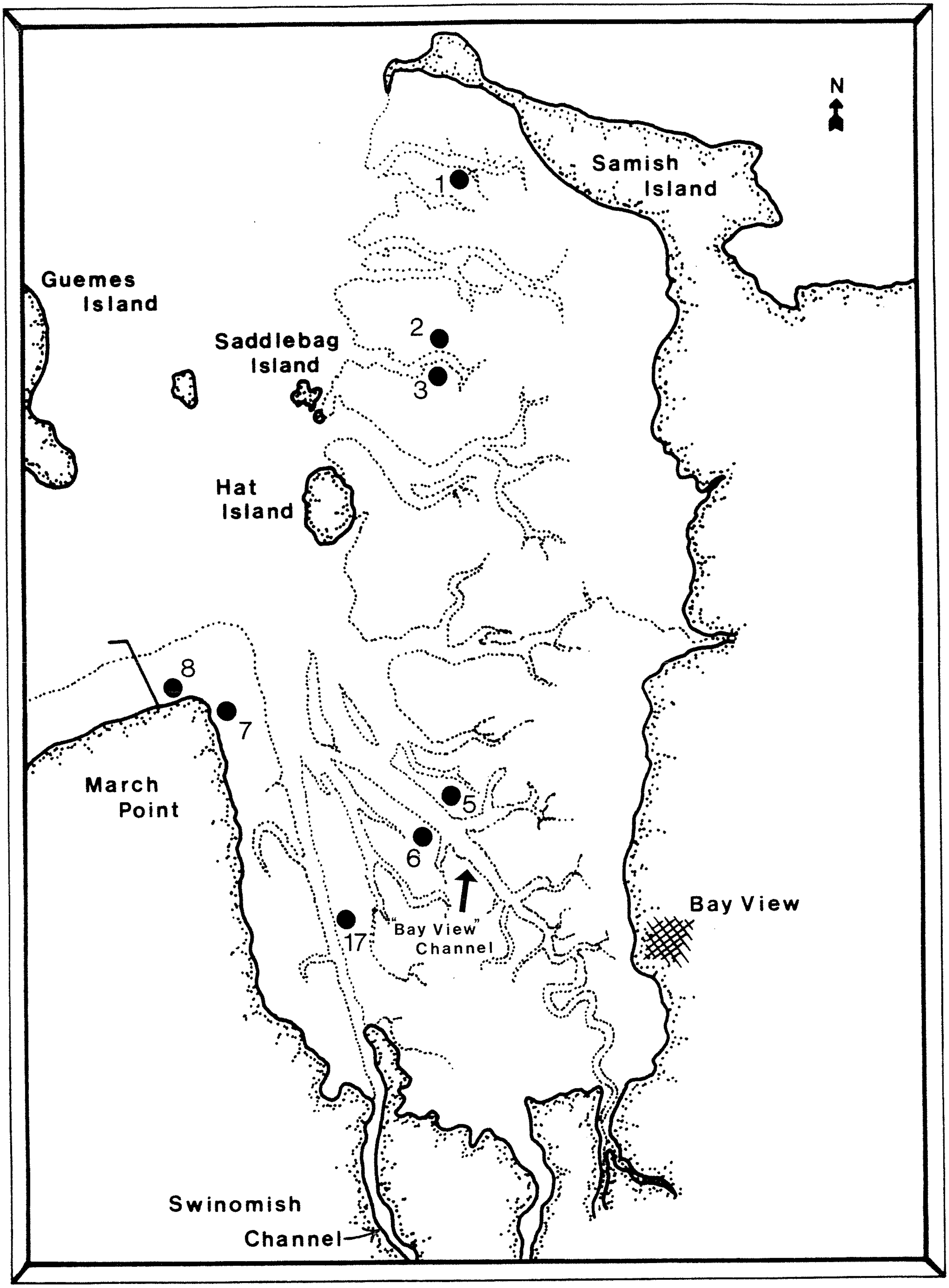


Figure 4. Map of Padilla Bay showing the locations of the intertidal sampling transects. The dotted lines indicate the intertidal areas exposed at the lowest tide levels.

$$\text{Estimated crab/ha} = \frac{10{,}000\ m^2}{\text{area swept by net}} \times \text{(number of crab caught by net)}$$

This estimate can only be interpreted as an index of abundance, not as a true density measure, since the sampling method is not 100% efficient.

Counts of benthic or epifaunal invertebrates usually show a contagious (non-random) distribution (Elliott 1977). Hence, all crab trawl or diver catch data were transformed prior to use in analysis of variance (ANOVA), bivariate correlation analysis or other similar statistical analyses by the following formula:

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

where y is the estimated crab catch/ha (i.e., abundance) and X_t is the transformed variable (Elliott 1977). To calculate average abundance over several trawl samples, the mean of the transformed abundances (X_t) was determined, then "untransformed":

$$\text{mean of } y = \text{antilog } (\overline{X_t}) - 1.$$

To determine confidence intervals, we used Elliot's (1977) method for the log-transformation, determining 95% confidence limits (C.L.'s) for $\overline{X_t}$ using the student's t-distribution, then untransforming the upper and lower C.L.'s:

$$\text{C.L. of } \overline{y} = \text{antilog (C.L. of } \overline{X_t}) - 1.$$

Crab pot catches are reported as raw catches since it is impossible to calculate an "area fished" by a baited pot and the catches per unit of time are probably not linear due to a variety of factors (i.e., number of crabs already in the pot, type and age of the bait, escapement of small crabs back out the entrance channel "triggers," etc.)

Intertidal quadrat crab catches are reported as estimated densities (crabs/m^2) instead of estimated abundances since the quadrat sampling was essentially 100% efficient. Crab/m^2 values were derived by simply multiplying the catches/0.25 m^2 by a factor of 4.

RESULTS

Beam Trawls

Dungeness crab catches.

Combining all samples, the average abundance of Dungeness crab caught by trawl was 138.8 crab per hectare, with a 95% confidence interval from 99.7 to 193.0. Figure 5A displays the abundance (averaged over all stations) of trawl-caught Dungeness crab for each sampling cruise. The general pattern is of moderate, stable abundance during late spring and early summer, somewhat higher overall abundance in the late summer, and apparently low abundance in the winter and early spring. The station-to-station pattern of abundance (averaged over all cruises; Figure 5B) shows that Dungeness crab were caught in highest abundances (approximately 1,600 crab/ha) at Stations 3 and 19 and lowest abundances (<200 crab/ha) at the shallowest stations (Stations 6, 8, 11, 12, 13 and 15).

To examine broader patterns of geographic variation in abundance, the trawl stations were divided into strata based on depth and on broad habitat types as follows:

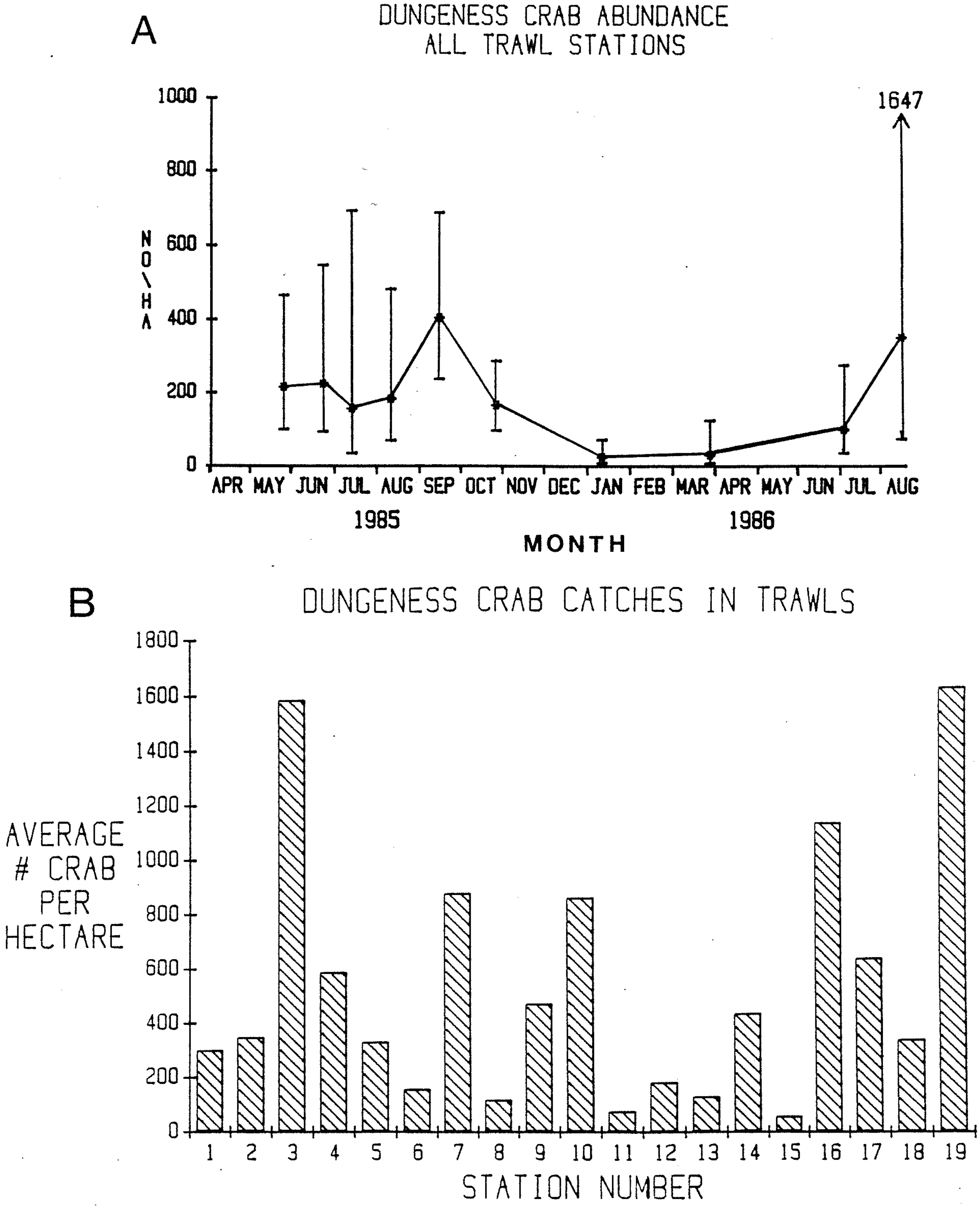


Figure 5. A: Average abundance (with 95% confidence limits) of Dungeness crab in trawl samples during each cruise, all stations combined. B: Average catches of Dungeness crab at each of 19 trawl stations in Padilla Bay, all months combined (see Figure 3 for station locations).

Stratum	Trawl Stations
A. Depth strata:	
0-2 meters	6, 8, 11, 12, 13, 15
3 - 6 meters	3, 4, 5, 16, 19
>6 meters	1, 2, 7, 9, 10, 14, 17, 18
B. Habitat strata:	
Intertidal	6, 8, 11, 12, 13, 15
Inner channel	3, 4, 5, 16
Middle channel	14, 17, 18
Outer channel	1, 2, 7, 9, 10, 19

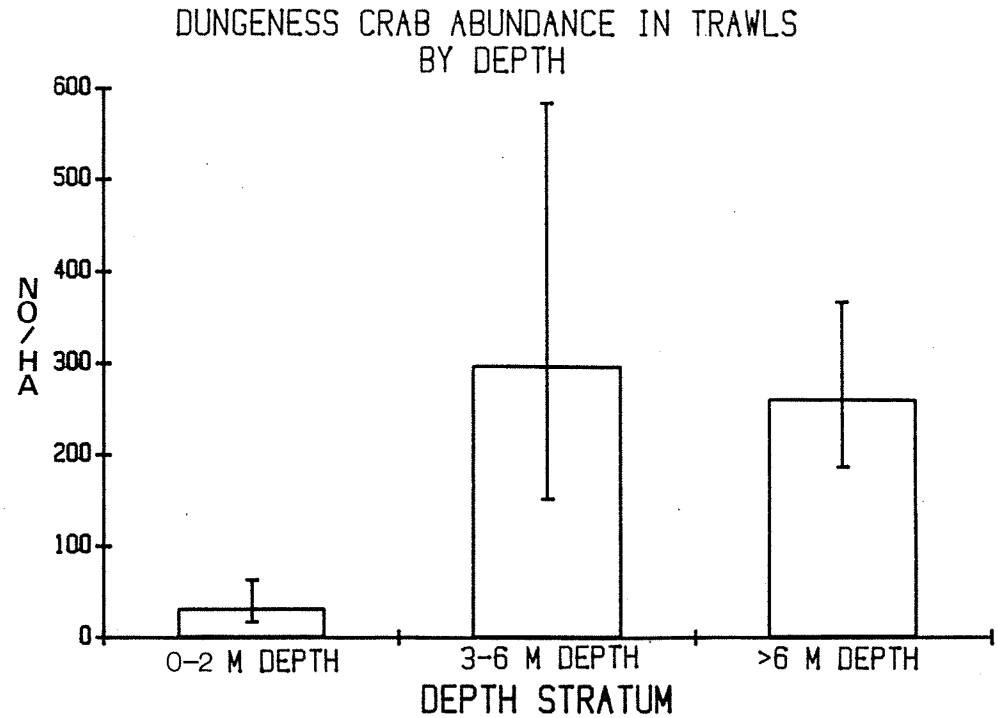
The average abundances (over all cruises) for these strata are shown in Figures 6A and 6B. (Note that these two ways of breaking down the data are by no means independent - there is a strong correspondence between depth strata and habitat strata). These data indicate that significantly fewer crab were caught by trawl in the intertidal than in subtidal areas.

Figure 7 displays the abundances in the three depth strata for each cruise. Due to small sample sizes, confidence intervals for these data are quite extreme, and cannot be conveniently displayed. Thus, while these figures should be interpreted broadly, they do give an idea of general trends in abundance, particularly differences among strata in the seasonal timing of peaks. Dungeness crab catch and size data from each trawl station are summarized in Appendix Table 1.

Patterns of Dungeness crab size.

The average size of Dungeness crab caught at all stations was quite

A



B

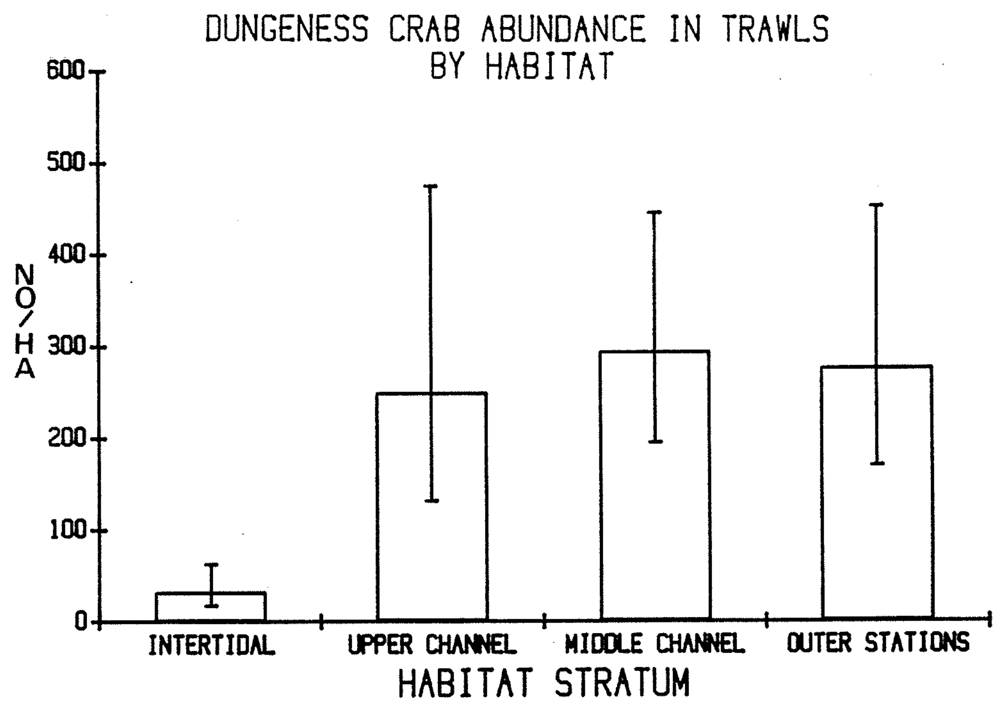


Figure 6. Average Dungeness crab abundances (with 95% confidence limits) in the beam trawl catches for three depth strata (A) and for four habitat strata (B), all months combined.

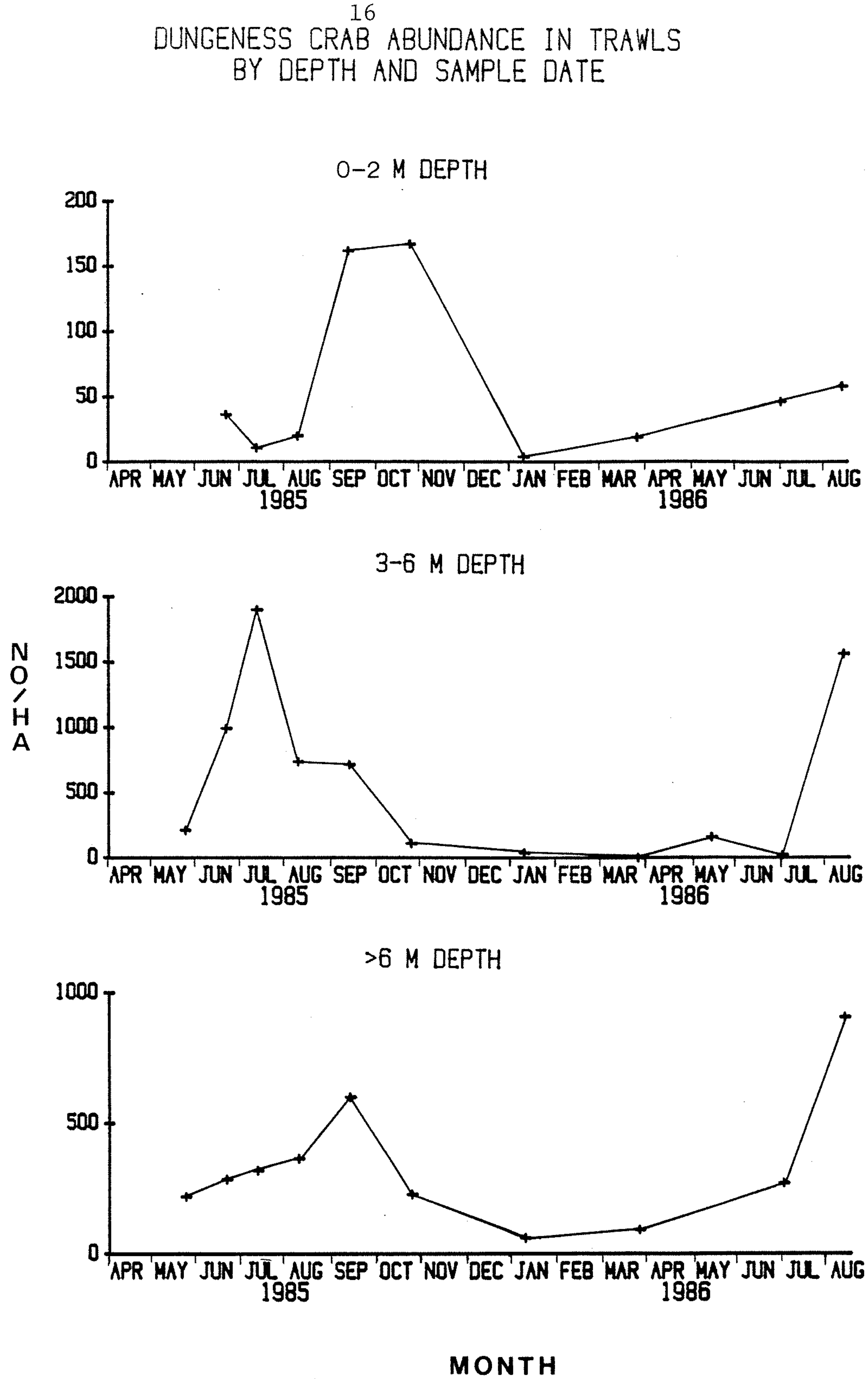


Figure 7. Average Dungeness crab abundance in the beam trawl catches in three depth strata at each cruise date.

variable as illustrated by the means and standard deviations shown in Figure 8. On the average, the largest crab were caught at the outer bay stations (Stations 4, 6 and 19) and the smallest crab at the inner channel stations (Stations 3 and 15).

The beam trawl catches Dungeness crab over its entire size range, although there may be some change in efficiency with size (see Discussion). Averaged over the entire study period, the size distribution of Dungeness crab caught by trawl in Padilla Bay is fairly uniform over a range from about 40 mm to about 120 mm carapace width (CW), tapering off above this range (as shown by the male and female size-frequency distributions, Figure 9). Below 40 mm CW there is more pattern in the distribution, which shows a strong peak at about 28 mm, and relatively few crab below 25 mm (Figure 10). In the range from 0 to 30 mm CW, close examination will reveal suggestions of regularly spaced peaks corresponding to individual instars (instars are growth increments produced by the molting process), although the lack of discrete peaks above 6-7 mm shows that increments of growth at molting for individual animals can be quite variable.

Size-frequency patterns are more interesting when viewed as a progression through time. Figure 11 shows patterns for each cruise, all stations combined. The presence of individuals below 10 mm carapace width (CW) indicates recent settlement, which is seen in July through September 1985, and beginning again in August 1986. The progressive growth of the 1985 year class up to approximately 60 mm CW by August 1986 can also be seen, and is discussed in more detail later.

Figure 12 separates out the Dungeness crab size distributions for the three depth strata by 2- or 3-month intervals, and shows the depth

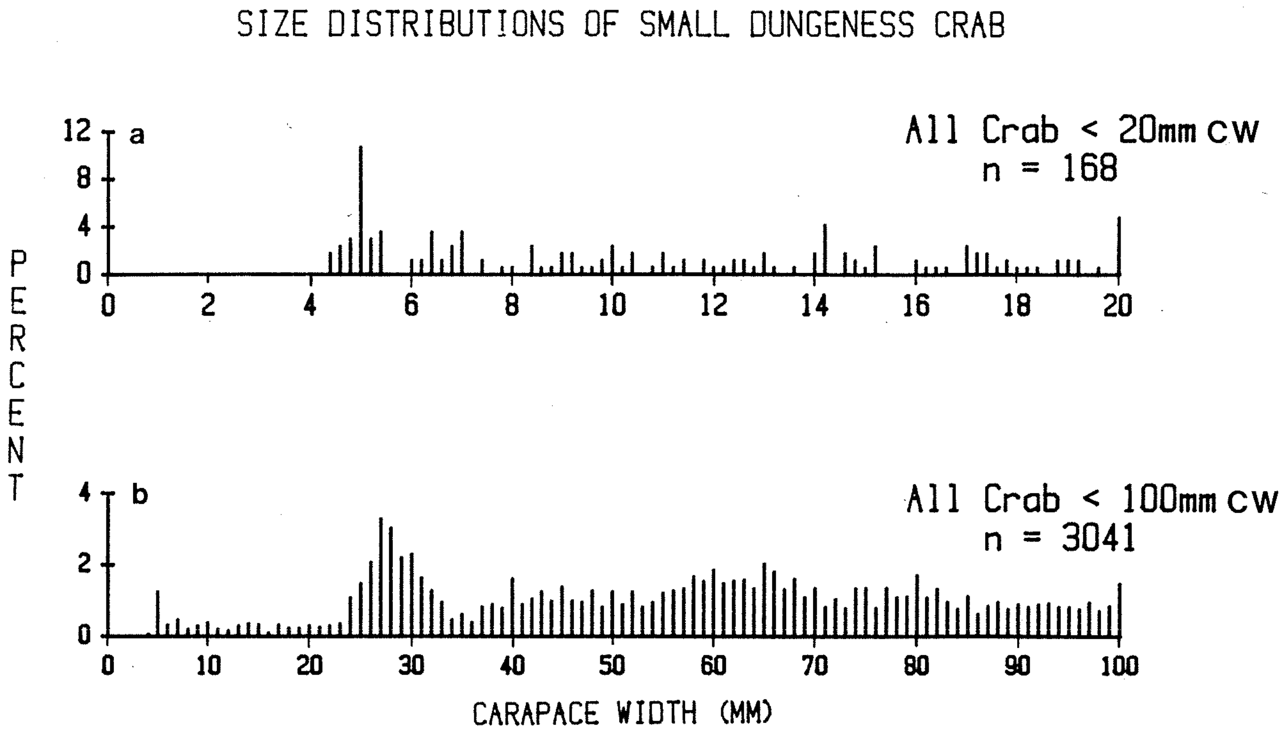


Figure 10. Percent size-frequency of small Dungeness crab, all trawl samples combined: (a) crab less than 20 mm, by 0.2 mm intervals; (b) crab less than 100 mm, by 1 mm intervals.

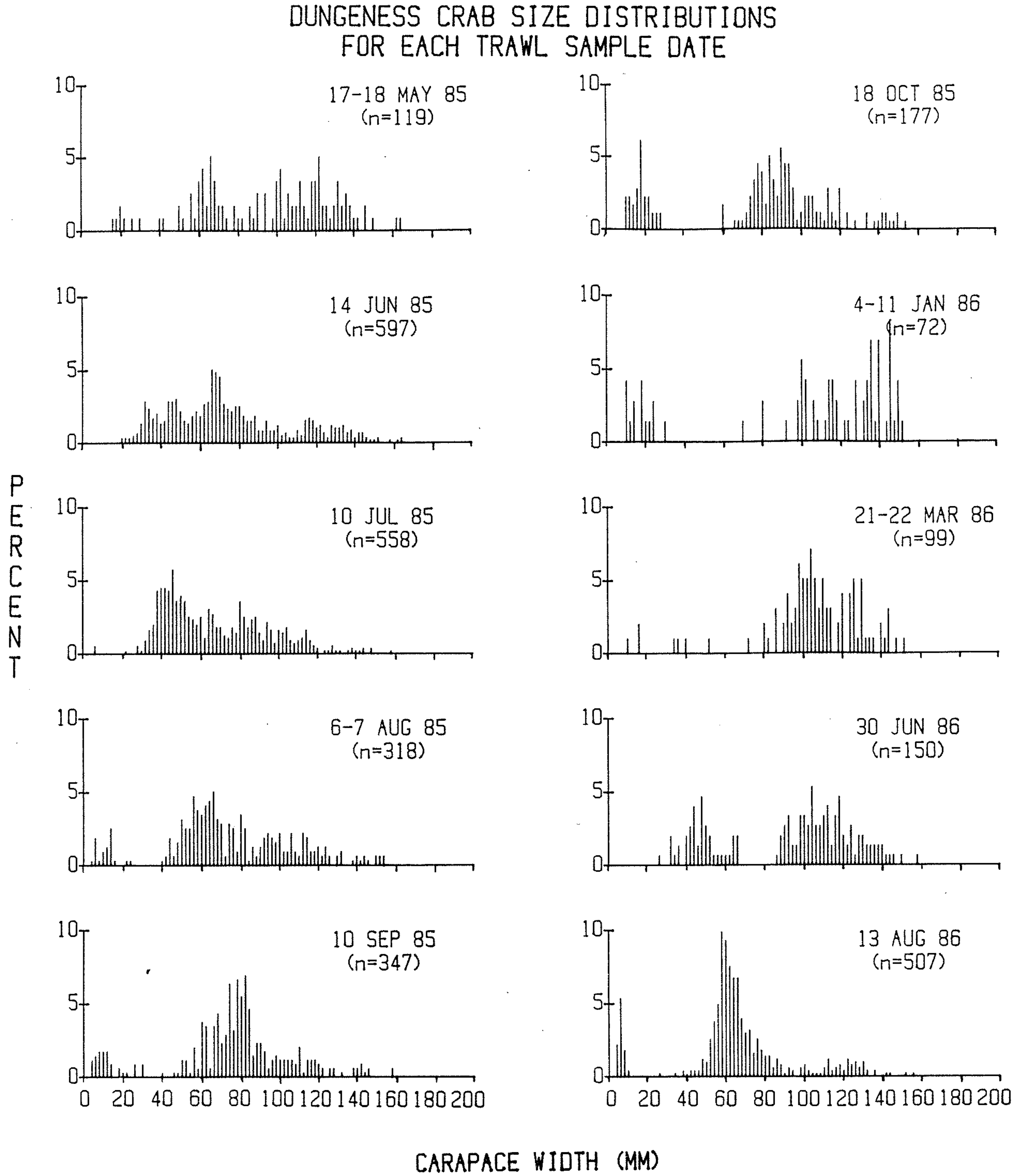


Figure 11. Percent size-frequency of Dungeness crab in trawl samples for each sampling cruise, all stations combined (2 mm intervals).

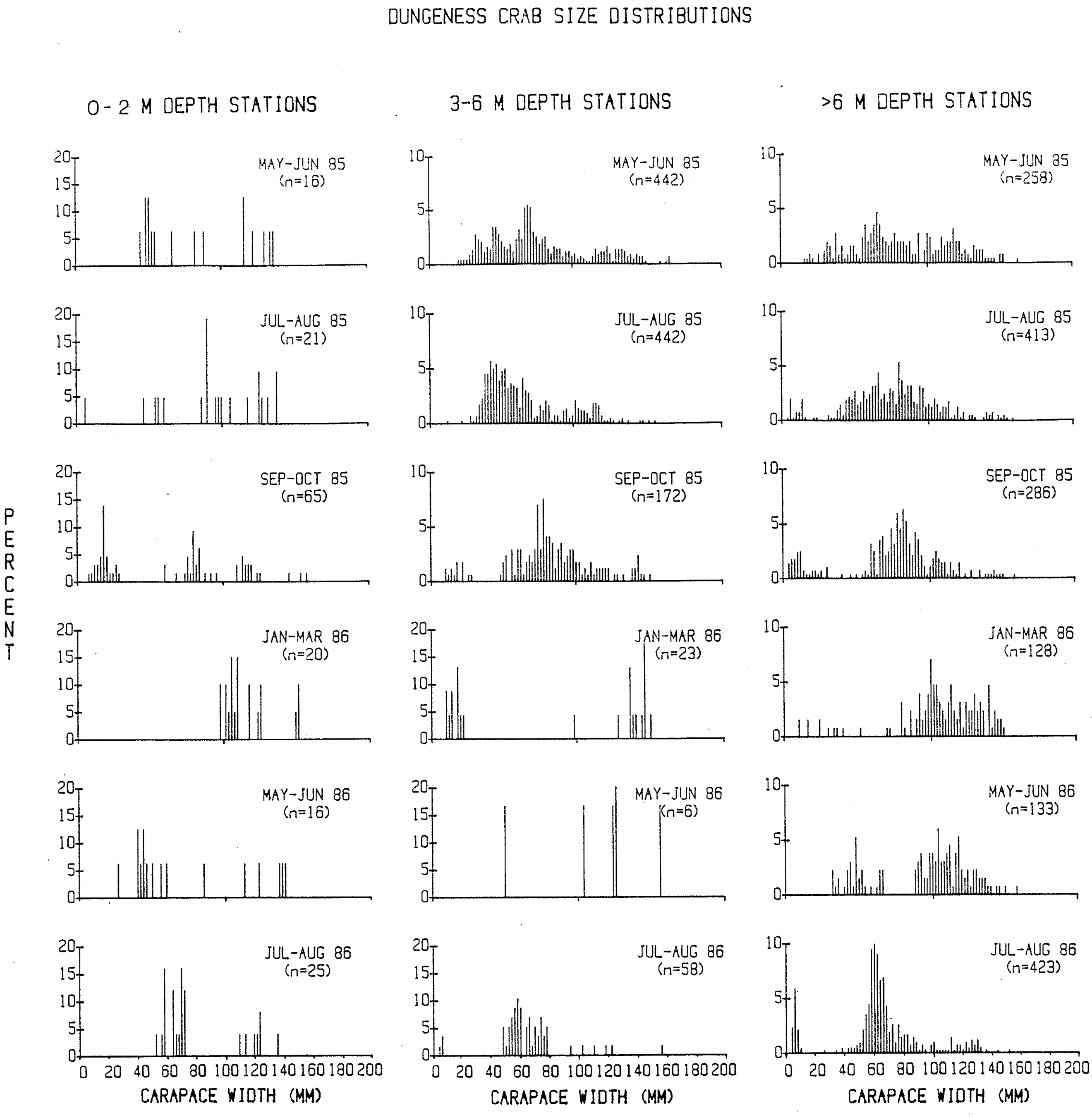


Figure 12. Percent size frequency of Dungeness crab in intertidal (0-2 m depth), shallow channel (3-6 m depth) and deep channel (>6 m depth) trawl samples for 2- or 3-month time periods (2 mm intervals).

pattern of crab settlement and possible patterns of seasonal movement by older crab (see Discussion).

From the size distributions, young-of-the-year (YOY) crab may be easily recognized as a distinct size mode from their first settlement in July or August until the following June, when their size range begins to overlap that of older crab. Figure 13 shows the percentage of the total Padilla Bay Dungeness crab catch from the trawls that these YOY comprise. For the 1985 year-class, this shows a rapid increase from the start of settlement in July, a peak in October, and a decline in relative importance of this year class through the winter and spring.

For the older non-YOY crab, we have calculated the sex ratio in the trawl catch. Over the entire sampling period, this ratio was exactly 1:1 (1377 males to 1377 females), but the ratio changes with the season (Figure 14). Females were significantly ($p = 0.05$) more common in the catch in late spring and summer, and males during the winter.

Early Dungeness crab growth.

In both the trawl and intertidal quadrat sample data, we can follow YOY sizes through almost a full year after settlement. Table 1 gives the estimated mean and standard deviation of size for YOY during each sampling trip. The mean sizes are plotted in Figure 15. Both data sets show slow growth immediately after settlement and through this winter, with more rapid growth the following spring. The mean size of trawl-caught crabs tends to be higher than that of crabs in the intertidal samples. This may be due either to greater abundance of larger individuals in the year class in deeper water, or to a size-bias in the sampling techniques.

The average number of Dungeness crab/ha together with average size

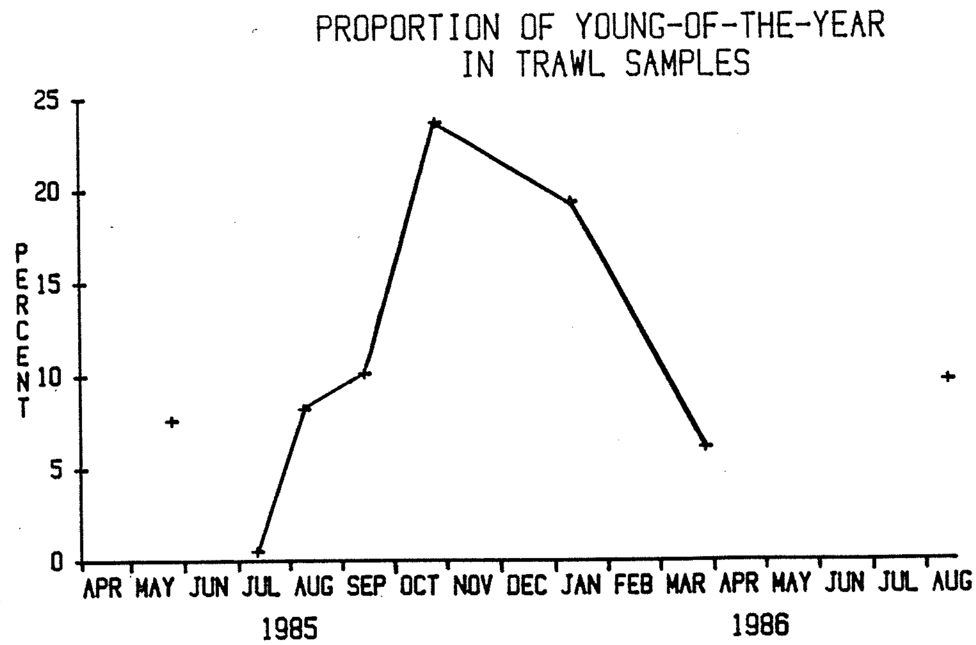


Figure 13. Percent of total Dungeness crab in the trawl catches that were young-of-the-year, by cruise date. Connected points represent 1985 settlement, single points represent 1984 and 1986 settlements.

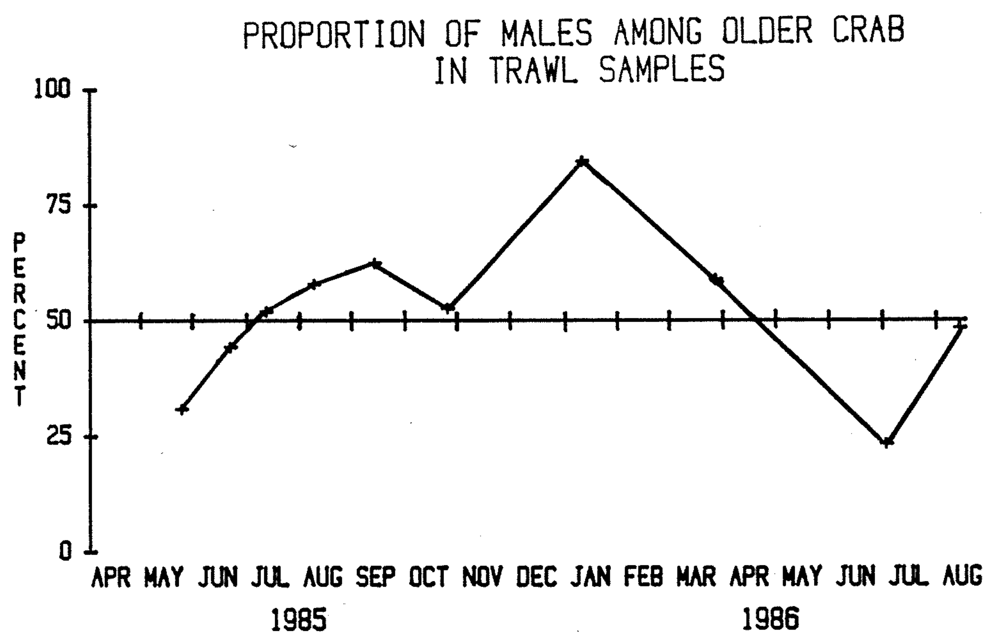


Figure 14. Percent of male non-young-of-the-year Dungeness crab in the trawl catches, by cruise date.

Table 1. Sizes of young-of-the-year Dungeness crabs in trawl and intertidal samples. Crab sizes are carapace widths in mm.

	Intertidal				Trawl		
Date	Average size	Standard deviation	Sample size	Date	Average size	Standard deviation	Sample size
1985							
7 April	19.7	8.7	20				
9 May	25.1	5.3	15	18 May	25.6	9.3	9
5 June	33.8	7.1	15				
3 July	5.2	0.3	8	10 July	6.7	0.2	3
31 July	6.0	1.0	5				
17 Aug.	6.4	2.9	133	7 Aug.	11.5	5.1	26
26 Aug.	7.3	3.0	102				
10 Sept.	8.2	2.8	121	10 Sept.	10.6	4.9	35
14 Nov.	12.5	4.3	14	18 Oct.	17.7	4.8	42
1986							
25 Jan.	12.2	4.1	23	4 Jan.	17.0	5.9	14
28 April	20.5	4.8	34	22 Mar.	24.8	12.9	6
10 June	34.5	3.1	4				
7 Aug.	5.7	0.7	60	13 Aug.	5.8	1.3	49

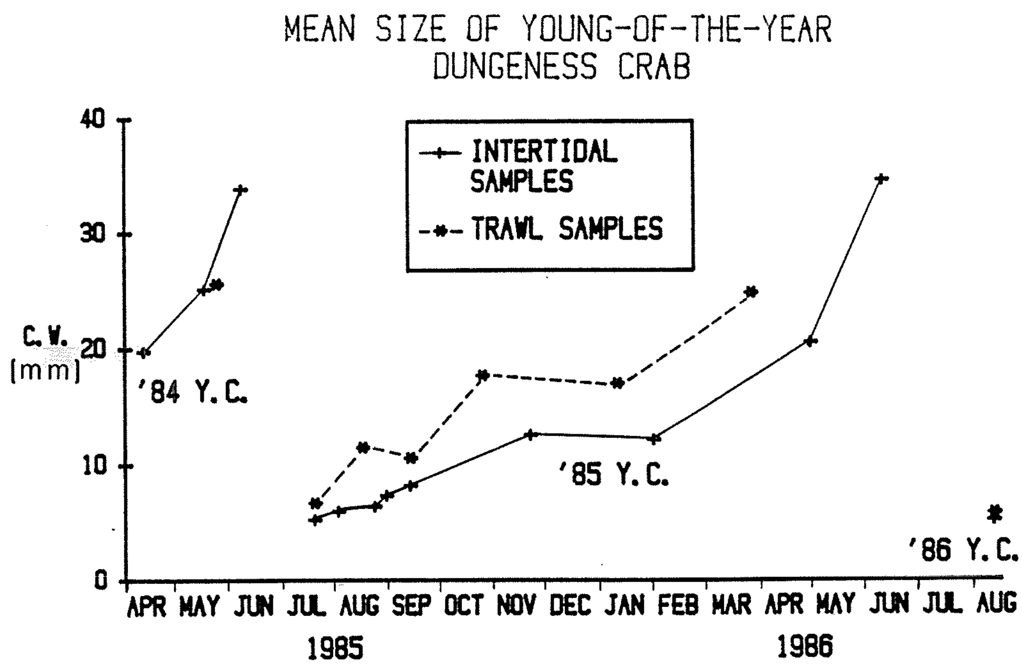


Figure 15. Mean size of young-of-the-year Dungeness crab in trawl and intertidal quadrat samples, by sample date.
Y.C. = Year Class.

data are recorded by trawl station and sample month in Appendix Table 1.

Rock crab catches and sizes.

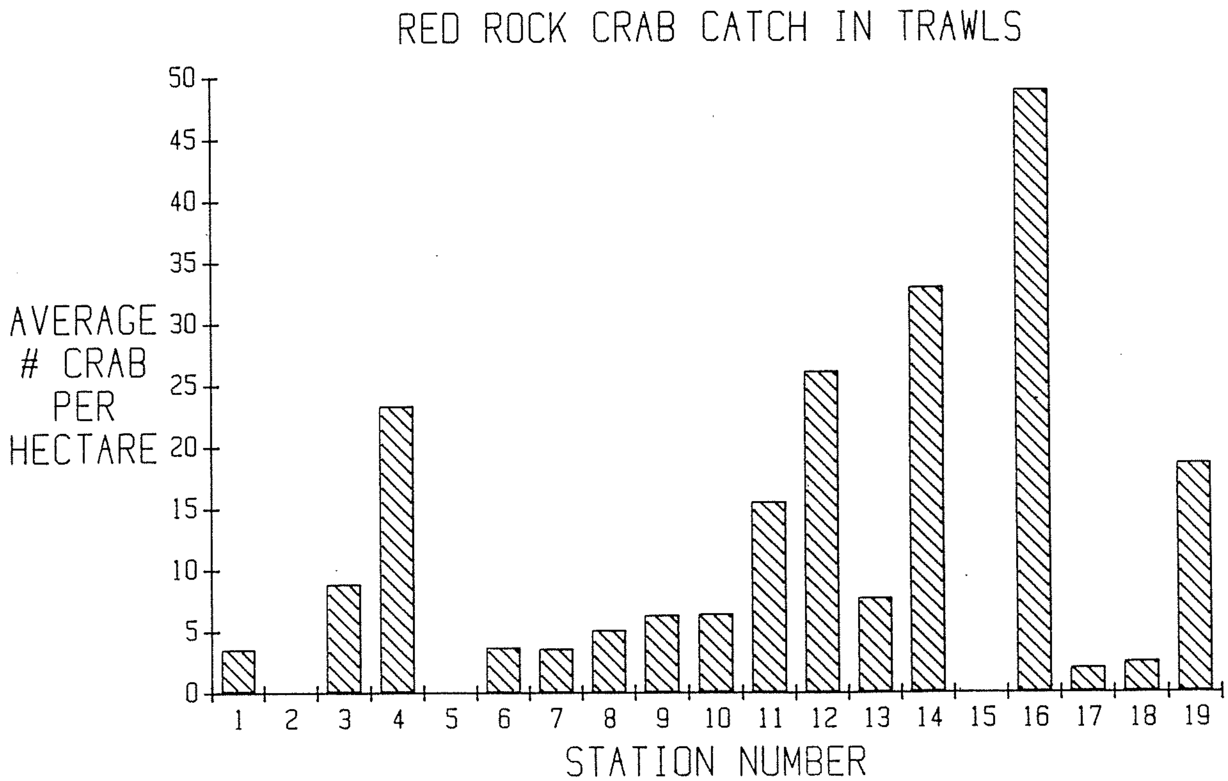
Other species of crabs were caught in the trawls along with Dungeness. Of these species, the red rock crab, *Cancer productus*, and the purple or slender rock crab, *C. gracilis*, were most abundant but substantially less so than Dungeness crab.

The average catch per station of red rock crab varied from zero (Stations 2, 5 and 15) to a high of almost 50 crabs/ha at Station 16 in Inner Bay View Channel (Figure 16, top). The average sizes of red rock crab were quite variable within and between stations as shown in Figure 16, bottom.

Relatively fewer purple rock crabs were caught in the trawls with the highest catches coming from Stations 1, 2 and 3 at the north end of Padilla Bay (Figure 17, top). The average sizes of purple rock crab at these three northern stations (Figure 17, bottom) show that the average sizes are related to location in the bay with the smallest individuals located in the inner channel area and the largest individuals at Station 3 offshore (Figure 3).

Water temperatures and salinities.

Water temperature and salinity samples were collected at selected stations in Padilla Bay. Water temperatures in outer Padilla Bay (Station 7 or 9; Figure 3) followed a cycle typical for Puget Sound with surface temperatures up to 15°C during the summer of 1985 and then a decline to 7°C in January 1986 (Figure 18A). Slight stratification of temperatures was observed during the summer months with bottom water temperatures usually 1-2 degrees cooler than the surface waters. Temperatures during the winter months were essentially isothermal.



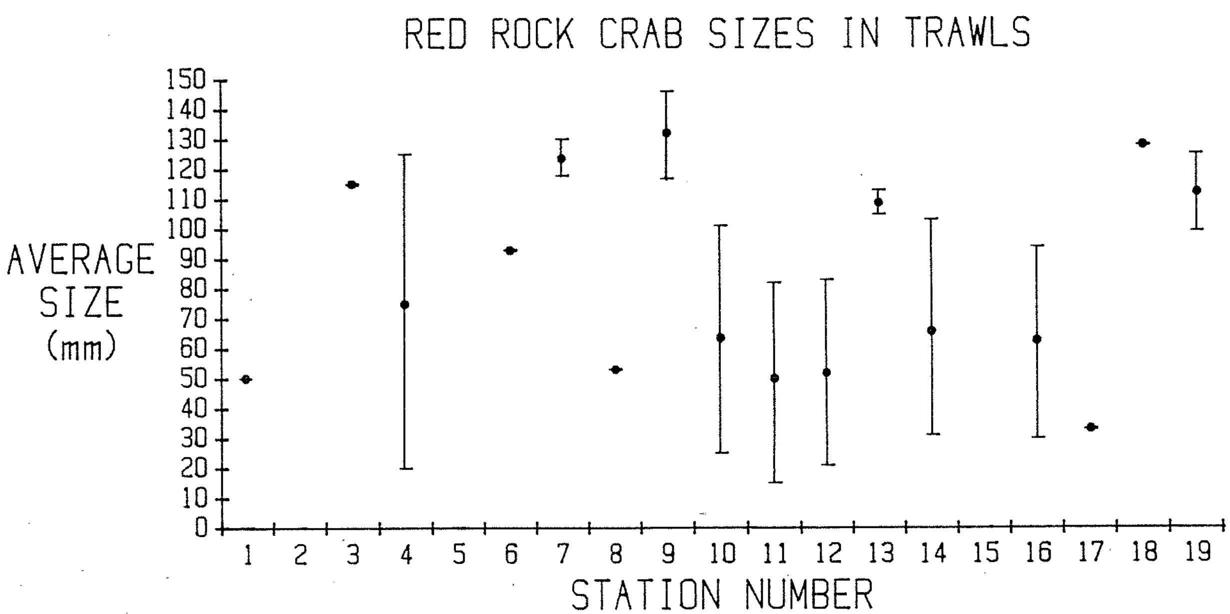
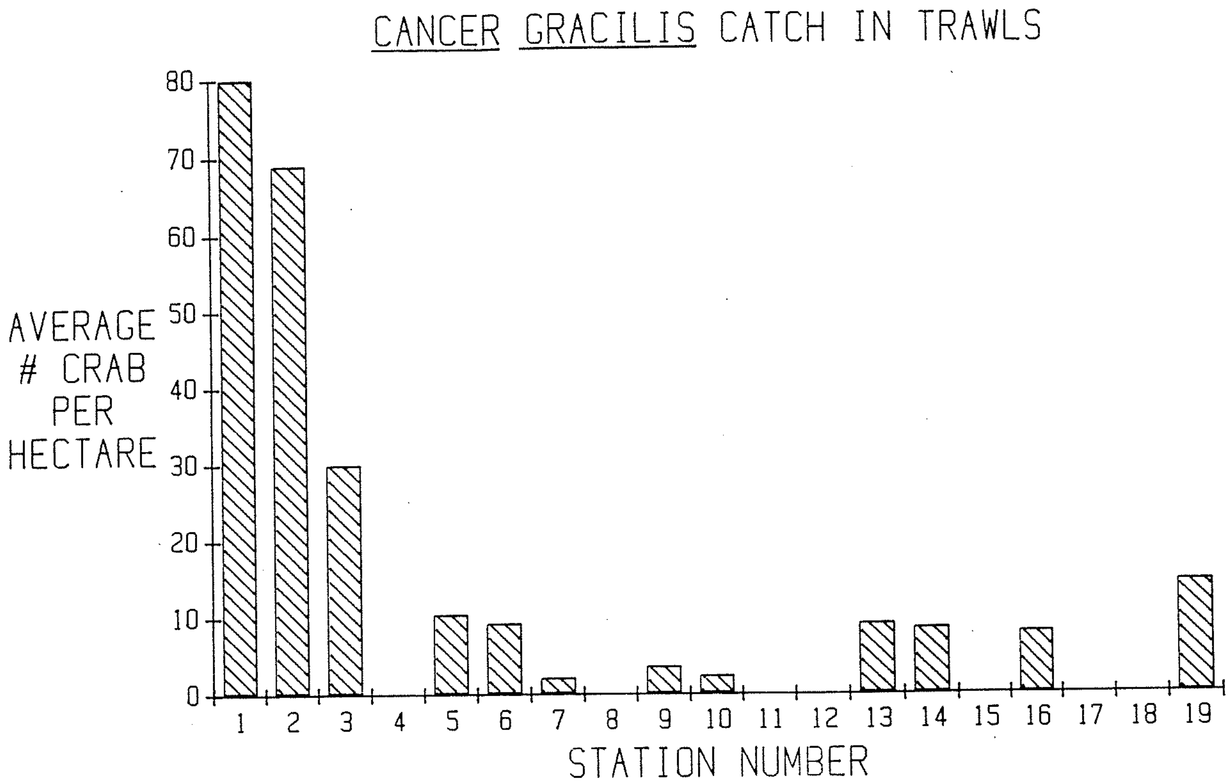


Figure 16. Top: Average catches of red rock crab (Cancer productus) at each of 19 trawl stations in Padilla Bay, all months combined. Bottom: Average sizes (carapace widths) of red rock crab caught at each of 19 trawl stations in Padilla Bay, all months combined. The bars are ± 1SD around the means.



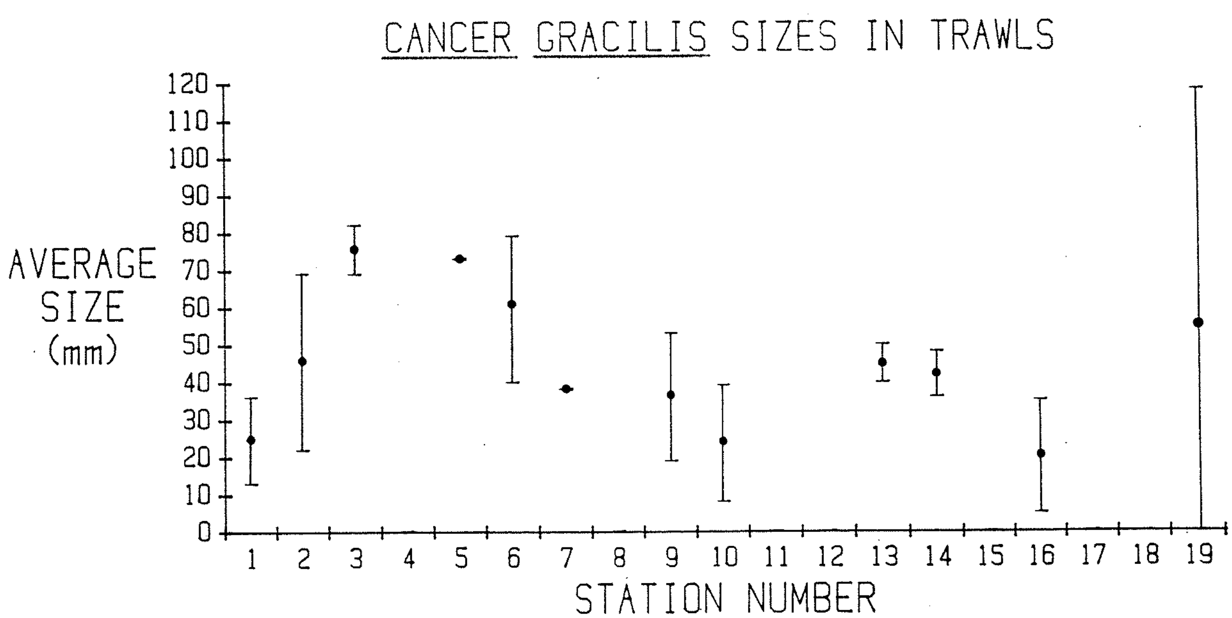


Figure 17. Top: Average catches of the rock crab, Cancer gracilis, at each of 19 trawl stations in Padilla Bay, all months combined. Bottom: Average sizes (carapace widths) of C. gracilis caught at each of the 19 trawl stations in Padilla Bay, all months combined. The bars are ± 1SD around the means.

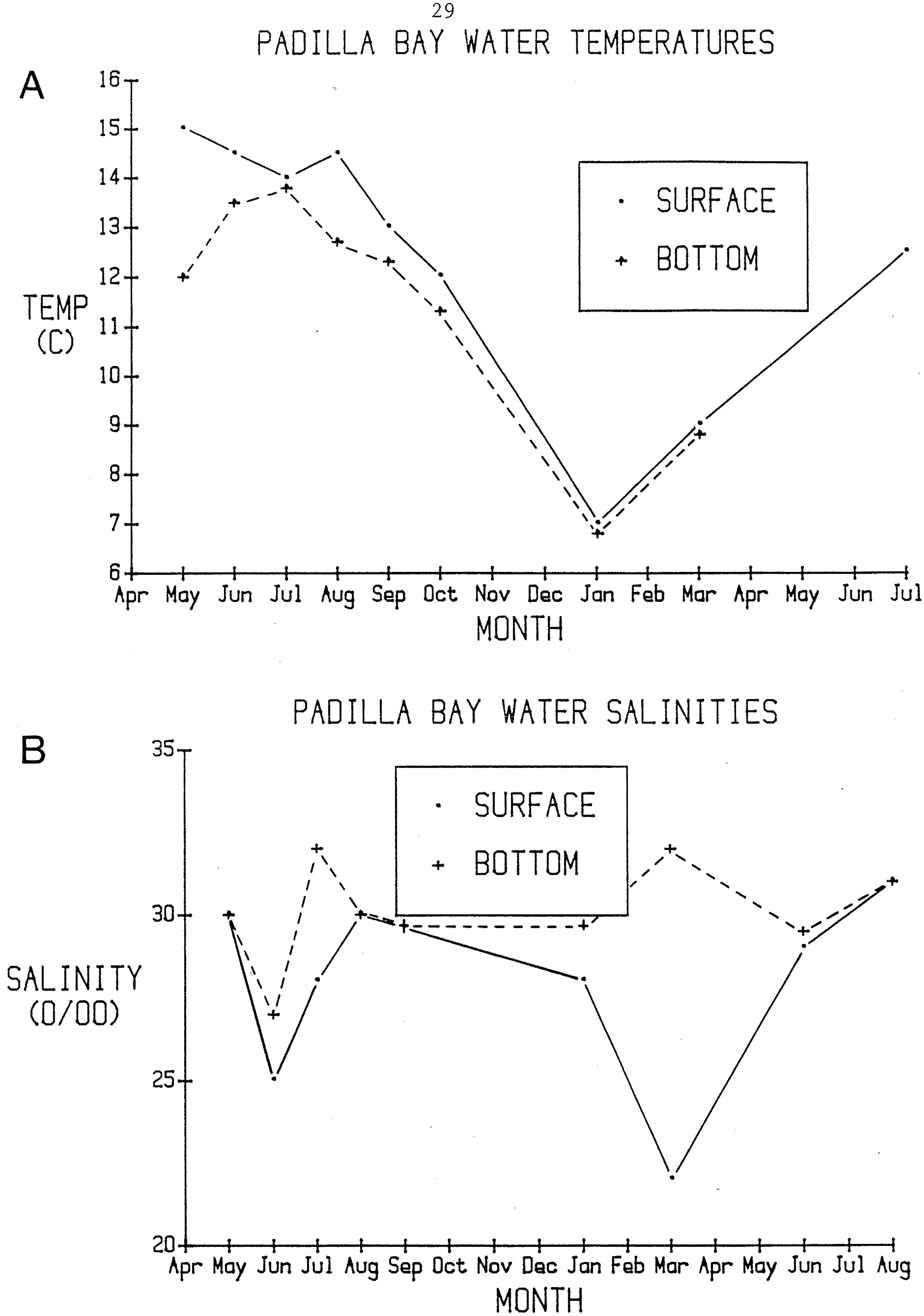


Figure 18. Padilla Bay surface and bottom water temperatures (A) and salinities (B) as measured at Station 9 in outer Bay View channel.

Padilla Bay bottom water salinities stayed fairly constant at the outer bay stations with a range of 27 to 32 $^{o}/oo$ (Figure 18B). Surface water salinities, however, fluctuated substantially more with salinities as low as 22 $^{o}/oo$ in March 1986 and were generally less than bottom salinities. Surface water salinities at Station 18 in the Swinomish Channel were depressed even further (as low as 18 $^{o}/oo$), suggesting that runoff from the Skagit River flowing northward through the Swinomish Channel produced the reduced salinities in Padilla Bay.

Crab Pots

As noted above, Vexar-modified crab pots were fished at a subset of selected trawl stations (Stations 4, 7, 9, 10, 14, 16-19). The highest average catch of Dungeness crab was at Station 18 (25.9 crabs/pot) in the Swinomish Channel and the lowest average catch at Station 9 in outer Bay View Channel (Figures 3 and 19, top). The average carapace width of all Dungeness crabs caught in pots was 121.6 mm. Dungeness crabs caught at Stations 4 and 19 (either side of Hat Island) had the highest average widths at 135.1 and 132.2 mm, respectively (Figure 19, bottom).

The average sizes of Dungeness crab caught in pots from all stations were very similar (120-135 mm) except for Station 18 in the Swinomish Channel where the average size was substantially less at 89.2 mm (Figure 19, bottom). Figure 20, illustrating carapace width-frequency distributions for four areas of South Padilla Bay, shows that crab pots in two areas of Bay View Channel and outer Padilla Bay caught the same size classes of crabs (with frequency peaks between 120 and 160 mm) while crabs caught in the Swinomish Channel were mostly in the 60-100 mm range.

The size-frequency histogram for all Dungeness crab caught in the crab

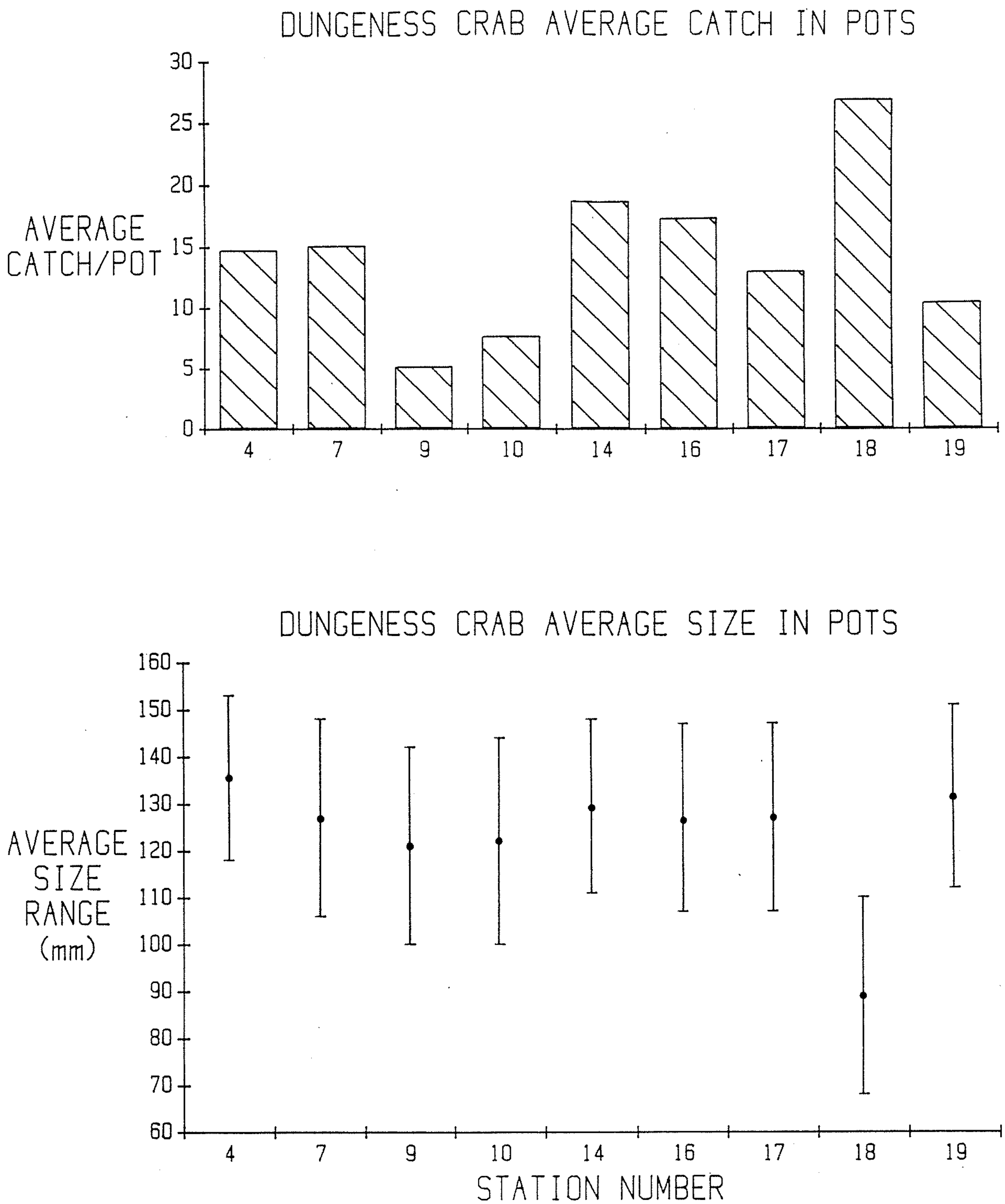


Figure 19. Top: Average catch/crab pot of Dungeness crabs at each of 9 stations (same as the trawl stations; see Figure 3) in Padilla Bay, all months combined. Bottom: Average sizes (carapace widths) of Dungeness crabs caught in the crab pots at each of the 9 stations sampled in Padilla Bay, all months combined. The bars are $\pm$1SD around the means.

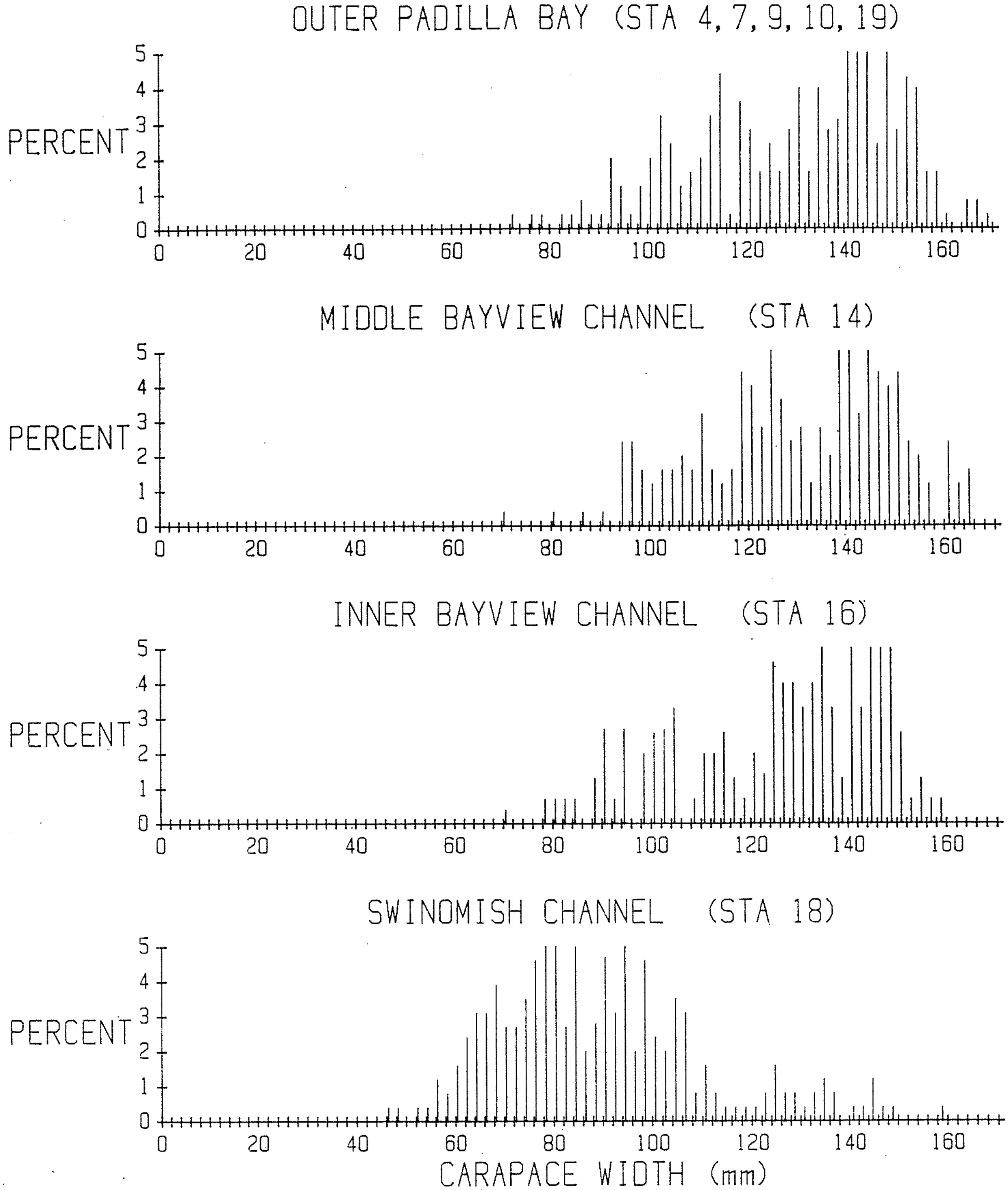


Figure 20. Carapace width-frequency histograms for all Dungeness crabs caught in the crab pots set in Padilla Bay, all months combined. The frequency distributions are grouped by general areas of Padilla Bay illustrating the similar size ranges of Dungeness crabs except for Swinomish Channel.

pots (Figure 21, top) shows that only crabs >50 mm were caught in the crab pots, indicating that YOY crabs (and smaller 1+ age group) did not enter the pots. The size range of male and female crabs caught in the pots was very similar except that a few more large males (150-180 mm) were caught (Figure 21). Dungeness crab catch and size data from each crab pot station are summarized in Appendix Table 2.

Other crabs caught in the pots were almost all red rock crab with the exception of one C. gracilis (Station 19, Sept. 1985) and one Telmessus (Station 16, June 1985). Red rock crab average catches were highest at Stations 7, 10 and 19 in the vicinity of Hat Island. The lowest catches were at Stations 16 (inner Bay View Channel) and 17 (Swinomish Channel) (Figure 22, top). The average carapace width of all red rock crab caught in the pots was 120.3 mm with the average size for all but one station falling between about 120-130 mm. Station 18 was again the exception with an average size of 98.8 mm (Figure 22, bottom). Hence, small red rock crab apparently find good habitat in the Swinomish Channel, as was the case with small Dungeness crab. Red rock crab catch and size data from each crab pot station are summarized in Appendix Table 3.

Diver Transects

Seventeen diver surveys along transects were carried out alongside a selected number of trawls at about a half-dozen of the beam trawl stations. The purpose of this work was to try to quantify the efficiency of the beam trawls, a factor heretofore unknown.

A comparison of the diver catches with the side-by-side trawls (on a catch/hectare basis) showed that there was high degree of variability from one sample period or site to the next (Figure 23) and a relatively poor

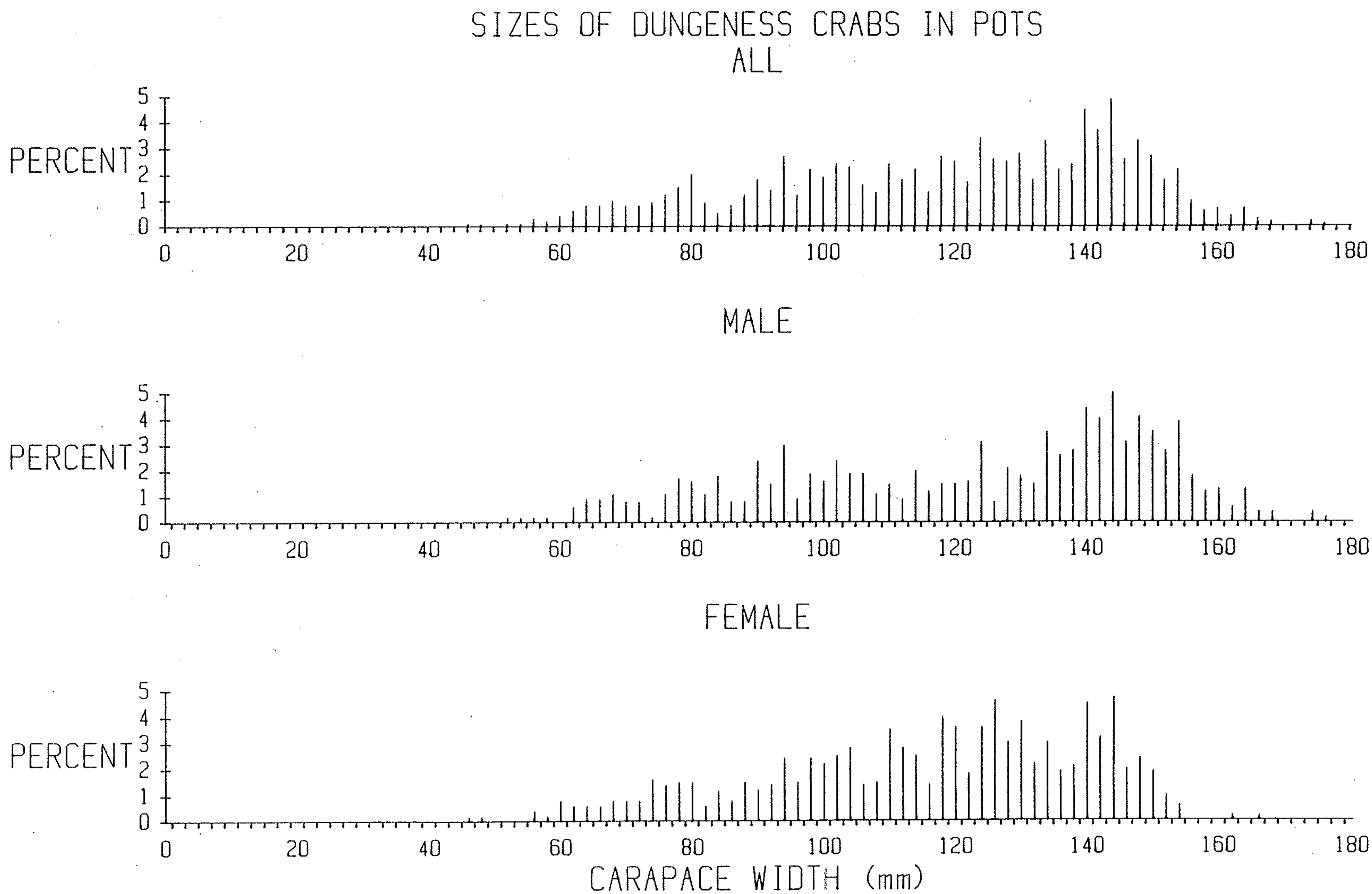
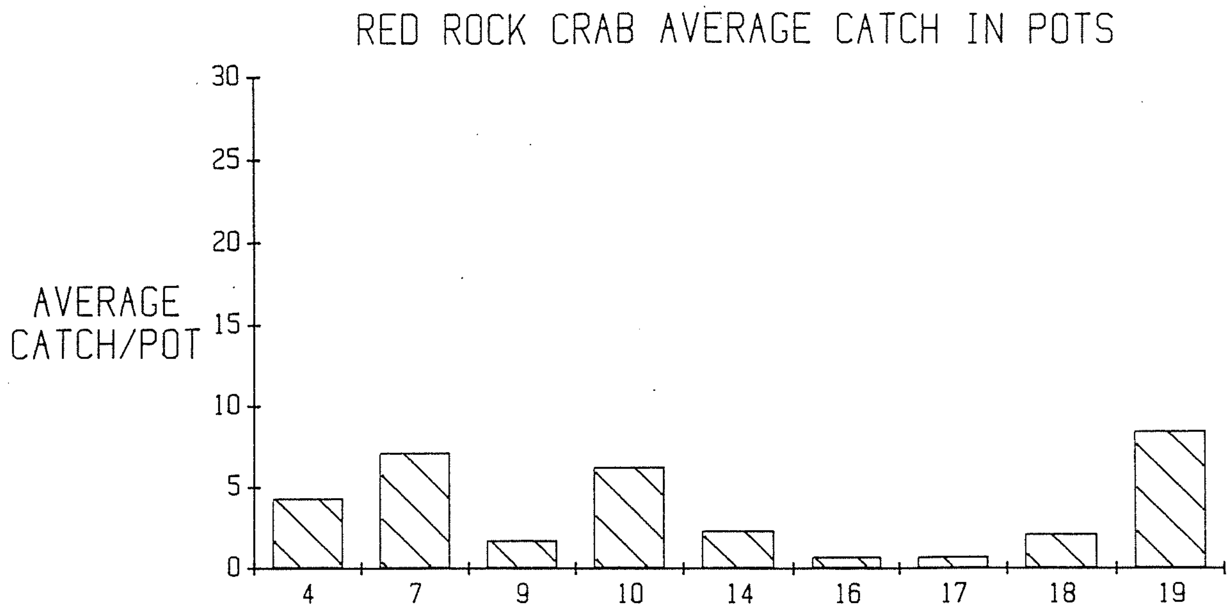


Figure 21. Carapace width-frequency histograms for all crabs caught in the crab pots and by sex showing the slightly larger maximum size range for the males.



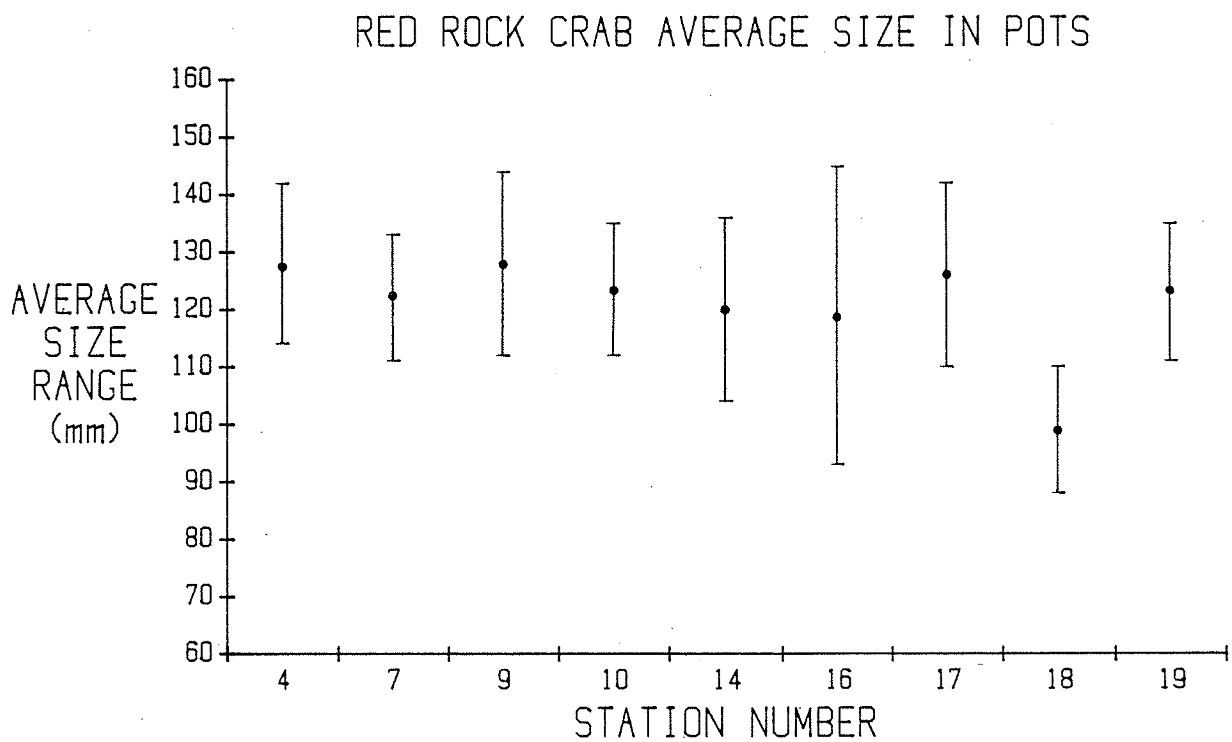


Figure 22. Top: Average catch/crab pot of red rock crabs, Cancer productus, at each of 9 stations (see Figure 2) in Padilla Bay, all months combined. Bottom: Average sizes (carapace widths) of red rock crabs caught in the crab pots at each of the 9 stations in Padilla Bay, all months combined. The bars are ± 1SD around the means.

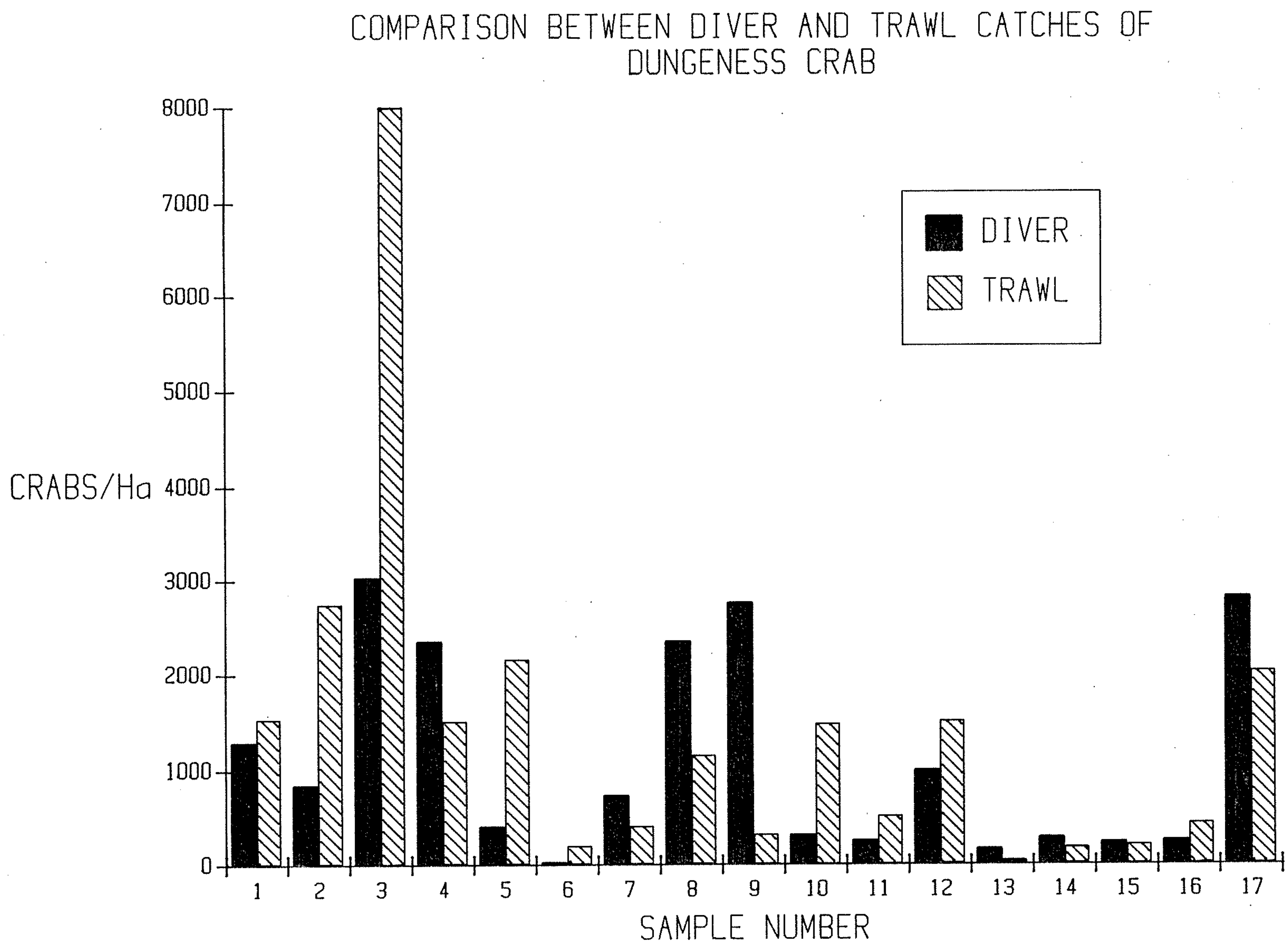


Figure 23. Comparison between diver transect and trawl catches of Dungeness crab for the same sample sites and times.

coefficient of correlation (r = 0.535) between the two sample methods. Using the assumption that the divers were 100% effective in catching all crabs on the transects, the calculated relative efficiencies of the beam trawl ranged from a low of 12% to a high of 529% with an average efficiency for the trawl of 169% (SD = 151%) (Appendix Table 4). This high average efficiency value for the net indicates that, on the average, the divers, not the net, were missing the most crabs. Reasons for this may have been two-fold: 1) crabs could possibly detect the divers and move away before the divers could see them, and 2) divers may not have been as effective at finding buried and hiding crabs as the net was. Indeed, Figure 24 shows that there was a direct relationship between diver and trawl-caught Dungeness crab sizes (r = 0.686) but that the trawls were catching proportionately more small crabs than the divers (more points in Figure 24 fall below the dotted line indicating equivalent sizes for each sample type). Thus, it appears probable that a portion of the small crabs can stay hidden and successfully avoid the searching activity of the divers, possibly under shells and other debris.

Extreme values for net efficiency relative to the divers for particular stations (i.e., 12% and 529% as noted above; see Appendix Table 4) were caused, in part, by the spatial aggregation of crabs in certain areas and the fact that the divers and trawls sampled "equivalent" areas side-by-side, but not the same exact area (same exact areas could not be sampled since both divers and the net removed the crabs). The case where the net was only 12% efficient is a good case in point. In this case the dive transect was set in the Swinomish Channel (Station 18) at the base of the rip-rap slope (to avoid boat traffic) in an area of small rocks while the trawls were in the middle of the channel over bare sand bottom. Divers found that the crabs in the channel were highly aggregated along the rocky margins of the channel where the

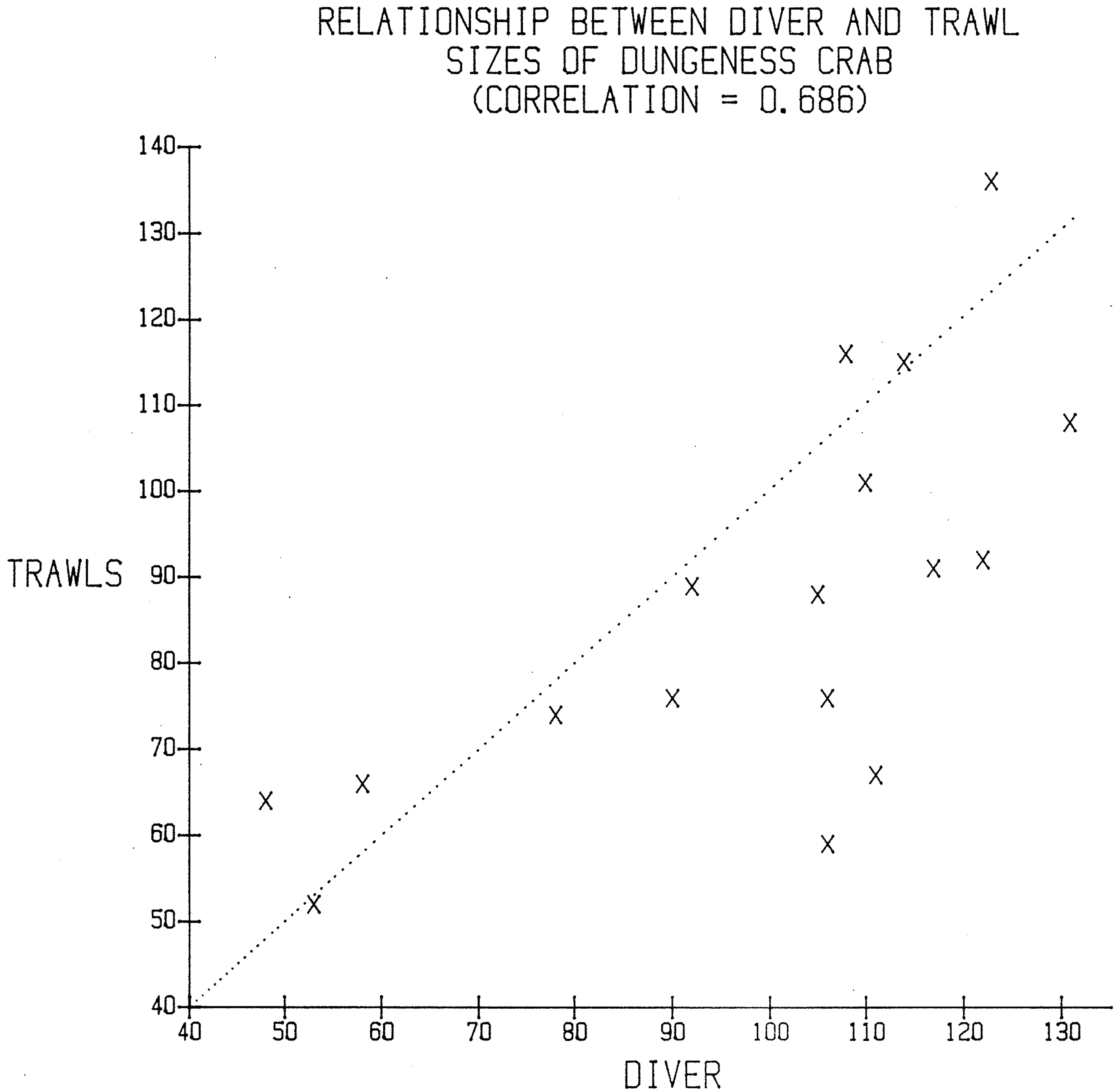


Figure 24. Scattergram showing the relationship between Dungeness crab sizes for animals caught by the trawls versus corresponding diver transects at the same locations. The dotted line indicates the expected regression line if there was perfect agreement in mean sizes of crabs captured by both the trawls and the divers.

transect was set but rare on the open sandy bottom where the "equivalent trawl" had to be made.

The smallest average sizes of Dungeness crabs caught by the divers and the net during these comparisons was from Station 16 (inner Bay View Channel) and from a small tributary channel near Station 16 in June 1985 (Appendix Table 4). These shallow channel areas appear to be favored habitat by the 1-year-old crabs during the summer (beginning of their second year and a time of rapid growth). These small crabs were most often associated with pockets of shell material and other debris which provided hiding places. The largest average size of crabs caught by the divers was at Station 4 (north of Hat Island) during July, August and September 1985. Hence, crabs appear to move outward toward the deeper area of the bay as they grow.

Dungeness Crab Shell Condition

The shell condition (i.e., degree of softness) was assessed for all Dungeness crab over 100 mm carapace width and each crab assigned a grade of 1 to 4 (1 = very soft, recent molt; 2 = soft, new shell; 3 = hard, old shell; and 4 = very hard, very old shell indicated by yellow-brown color and attached barnacles). Figure 25 shows that some soft (including very soft) crab were caught throughout the year but that soft females were most abundant during the summer following a spring molting and mating period. Soft males were least abundant during the fall with slight indications of peaks in softness around June and possibly September of each year.

Figure 25 also shows a comparison of percent soft crab caught by trawl and crab pots. In most cases, the trawls caught a higher proportion of soft (or very soft) crabs than the crab pots. Overall, 17.9% of all crabs (>100 mm in size) caught in the trawls were identified as soft (14.5%) or very soft

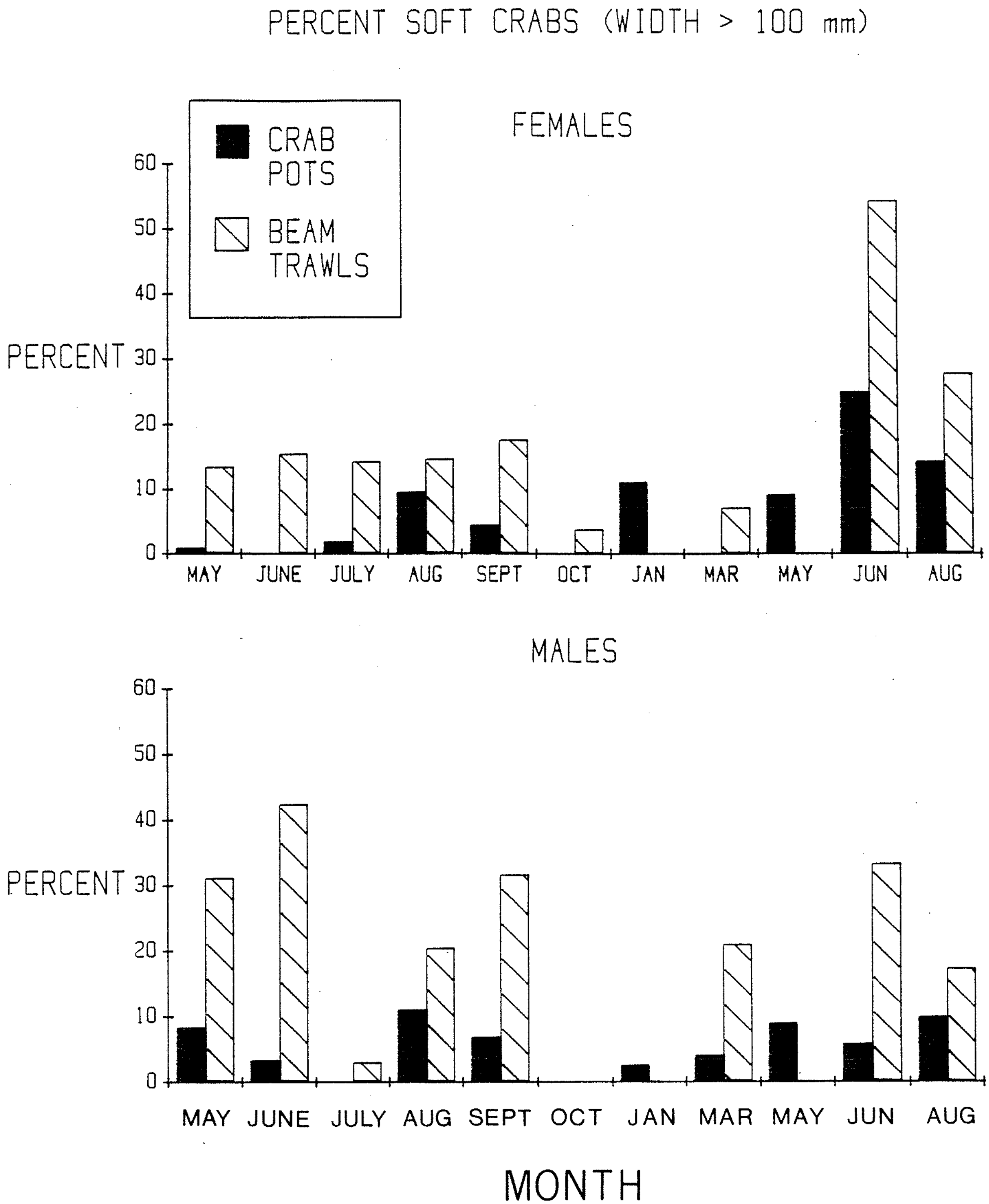


Figure 25. Breakdown of the percent soft (including very soft) Dungeness crabs caught by month by both the crab pots and the beam trawl, all stations combined.

(3.4%) while the equivalent percentages for crabs caught in the pots were 5.2% soft and 0.1% very soft. These data indicate that soft (and especially very soft) crabs are less inclined than hard shell crabs to enter crab pots (where they may be subject to predation) and probably remain somewhat reclusive until their shells harden up.

Most of the soft crabs caught in the trawls were caught at the deeper channel stations since relatively few large crabs were caught at the intertidal or shallow subtidal stations. Of these stations, catches at the deep channel stations in the outer Padilla Bay area (Stations 9, 10 and 19 near Hat Island) had the highest percentages (27% to 40%) of soft crabs.

Intertidal Quadrat Surveys

A total of 16 intertidal surveys was conducted between April 1985 and August 1986. Eight different transects (Figure 4) were sampled during this period although not all were sampled on each survey. The intertidal catch amounted to 893 crabs (excluding kelp or decorator crabs), and was comprised of 5 species. Dungeness crab represented 66.6% of the total catch or 595 crabs, followed in order by *Hemigrapsus* spp., *Cancer productus*, *Telmessus cheiragonus*, and *Cancer gracilis* (Appendix Table 5). The Dungeness crab caught intertidally were primarily YOY crabs with only 9.5% greater than 20 mm carapace width. Of this 9.5%, 52.7% were male and 47.3% were female.

The seasonal pattern of Dungeness crab abundance seen in the intertidal sampling parallels that observed in the trawl catches. This was characterized by a sudden increase in numbers of crab in late July, peaking in August, and followed by a decline from September to November (Figure 26). The abundance of crab remained near the November levels through the winter months until the following April. After April, a steady decline was observed until July when

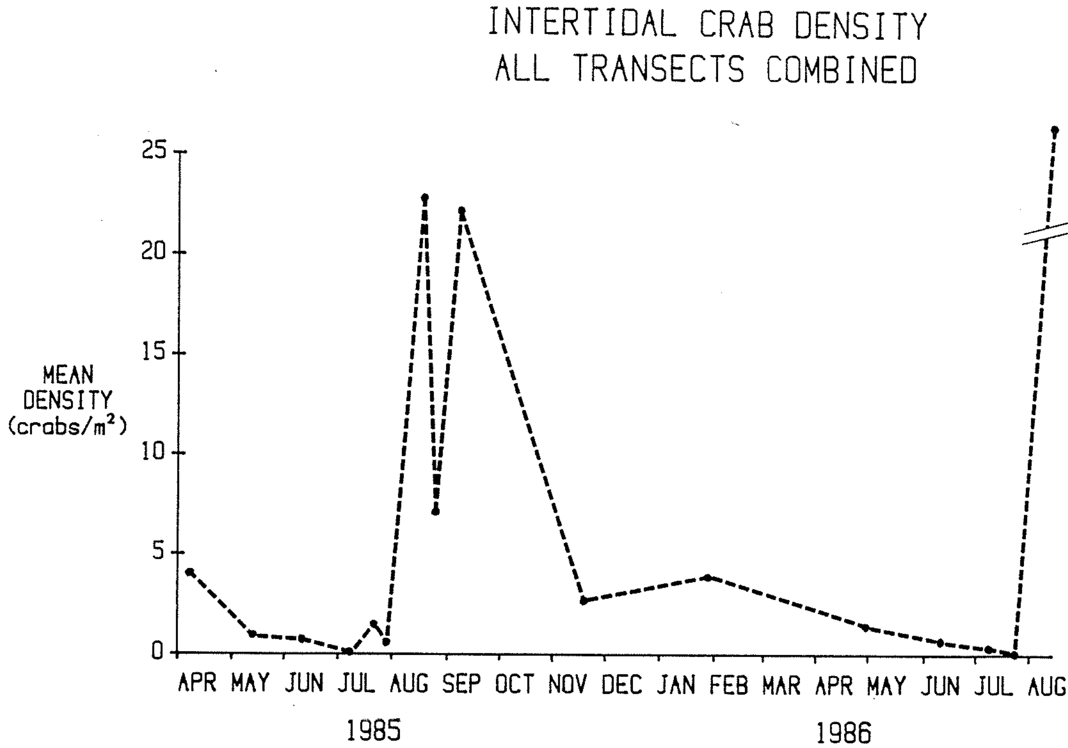


Figure 26. Mean density of Dungeness crab for intertidal samples, all transects combined, April 1985 to August 1986.

the lowest levels were seen for both 1985 and 1986.

The abundance of crabs varied between the transects, particularly during the period of settlement; however, these differences became negligible in time. Beginning in August and through September, the density of crab jumped sharply, most notably in the March Point transects (Figure 27 and Appendix Table 6). By November, these numbers had fallen and levelled off at densities similar to what was seen on the Padilla flats.

The rapid increase in abundance of crabs beginning in late July coincides with the settlement of the new year class. The presence of both megalopae and the first juvenile instars (less than 10 mm carapace width) is evidence of this. In 1985, megalopae appeared in the intertidal catches from early July through late August and peaked in mid-August. Recently metamorphosed first and second instar crabs represented the majority of the catch in July and August and second instars were still the most numerous in the September samples (Figure 28). The first occurrence of megalopae and early instars was one month later in 1986 when they did not appear until early August.

Different habitats within the intertidal region were best characterized by vegetative cover classes, eight of which are identified here. Three of these categories were associated with slightly more than 86% of the total intertidal Dungeness crab catch. These were, in order, *Ulva* sp., *Zostera marina* and mixed *Zostera* and algae (Figure 29 and Appendix Table 7).

The mean density of Dungeness crabs varied over time and between vegetative cover types. The highest crab density was found to be associated with *Ulva* sp., followed in order by *Zostera japonica* and *Enteromorpha* sp. (Figure 30). In contrast, the two categories, "*Zostera marina*" and "mixed *Zostera*" and algae, which together constitute the major portion of the Padilla Bay intertidal region, had relatively low densities. The pattern of seasonal

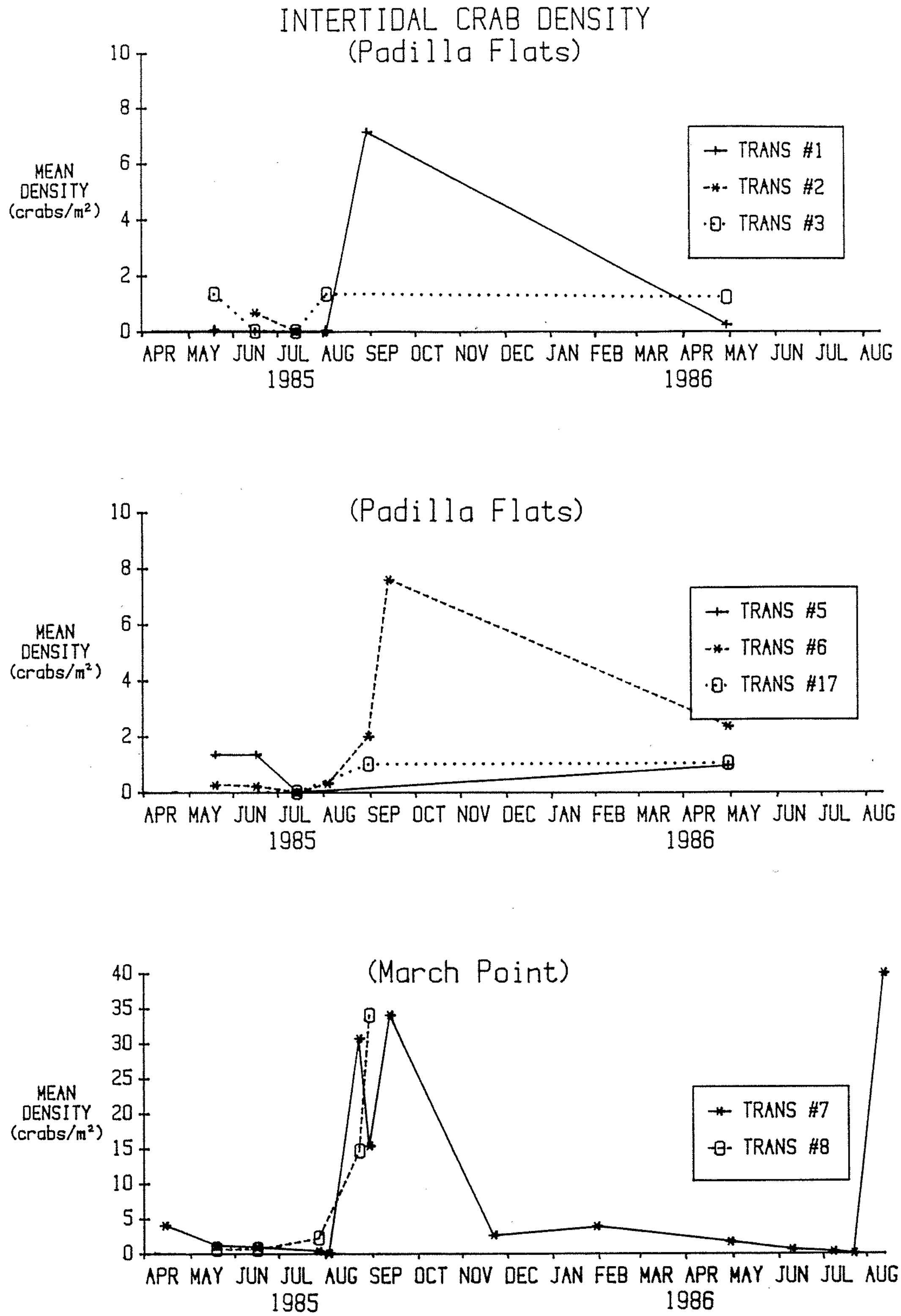


Figure 27. Mean density of Dungeness crab for each intertidal transect, April 1985 to August 1986. (See Figure 4 for intertidal transect locations.)

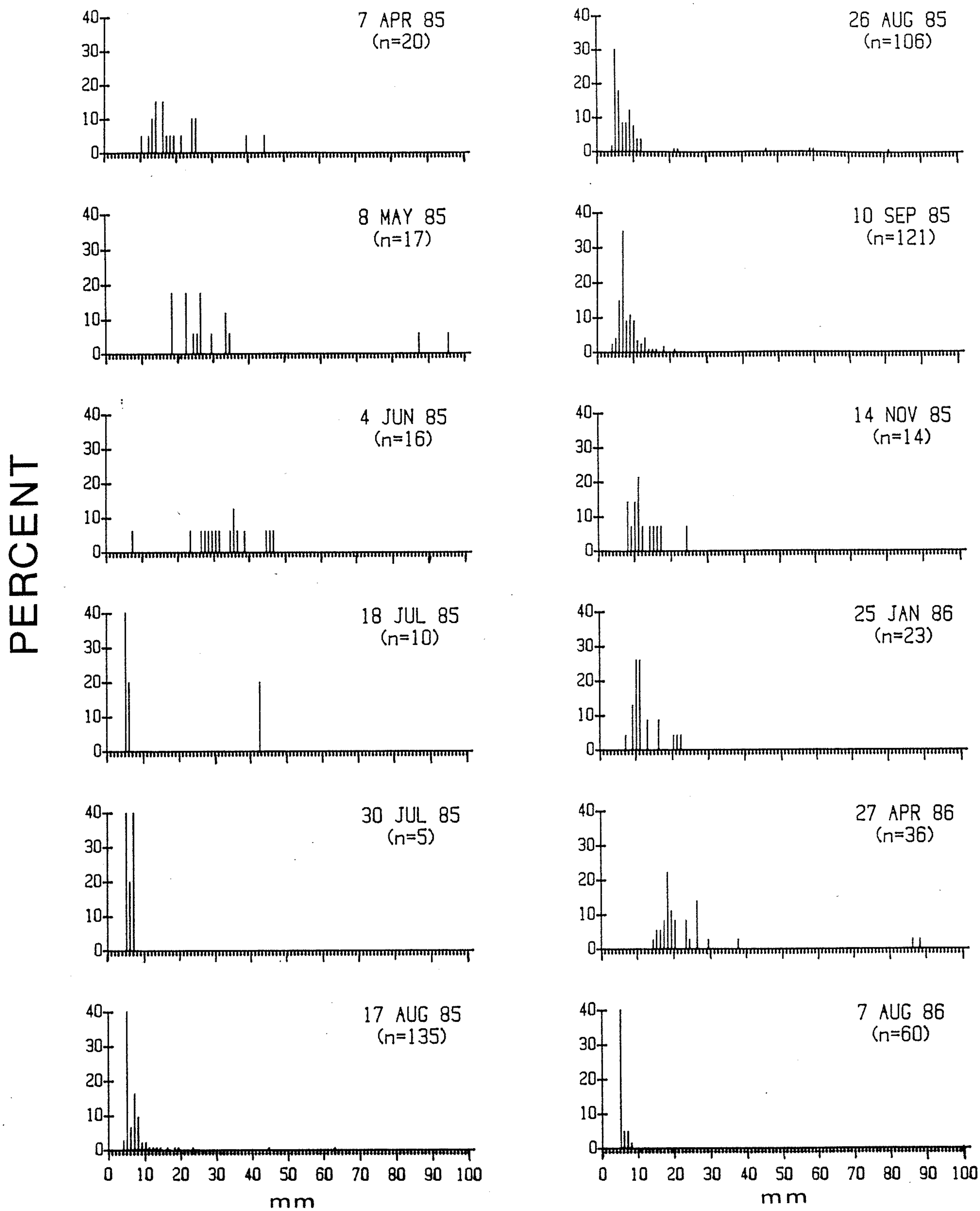


Figure 28. Carapace width-frequencies for Dungeness crabs caught in the intertidal quadrat samples, by survey period, all transects combined. (Survey periods with few crabs not included.)

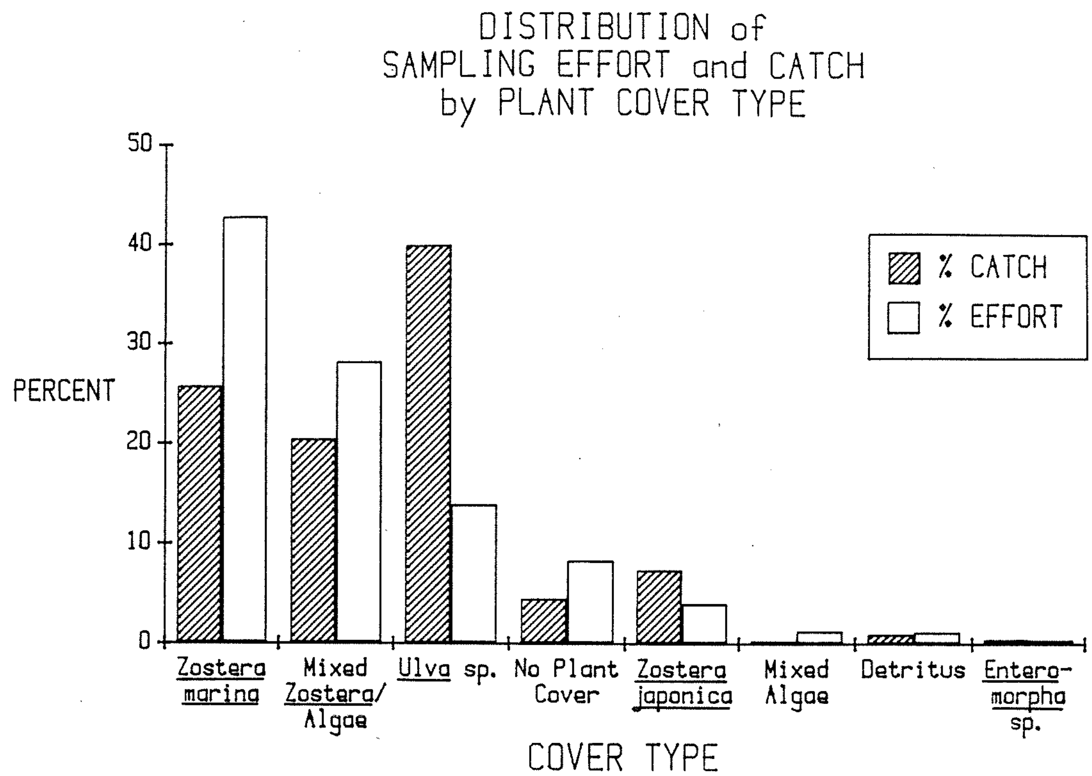


Figure 29. Distribution of intertidal sampling effort and catch between plant cover categories, shown as percent (catch represents Dungeness crab only).

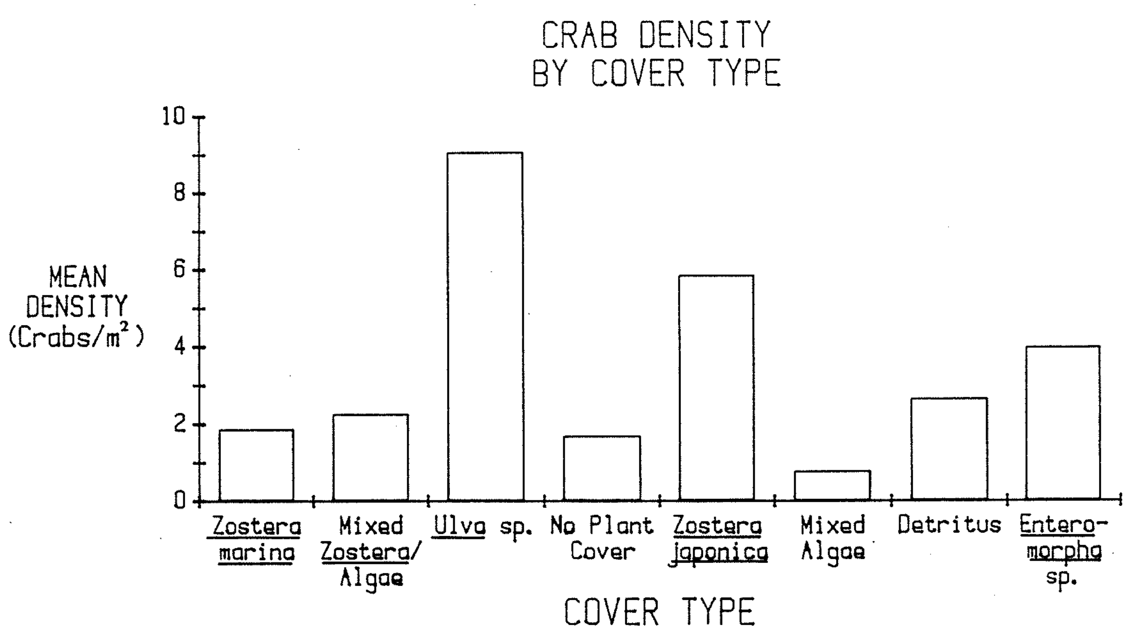


Figure 30. Mean density of Dungeness crab for different intertidal plant cover categories, all surveys combined.

abundance described above is reflected in the crab density of the three prevalent cover types (Figure 31).

Substrate materials were grouped into seven categories which ranged from "mud/silt" to "mixed gravel and cobble". The mean density of crabs associated with the different substrates was calculated with and without vegetative cover (Figure 32). When vegetative cover was present, the mean density of crabs was generally high and varied little with substrate material except for the category: "cobble with sand or silt". The crab density associated with this substrate exceeded the average by nearly eight times. This was due, in part, to the association between this substrate and the plant cover category, *Ulva* sp., which exhibited the highest crab densities of the eight plant cover categories. *Ulva* sp. constituted 90% of the quadrat samples with vegetative cover from the substrate "cobble with sand or silt". In the absence of vegetative cover, crabs were essentially found in only three of the substrate categories, two of which included cobble (Figure 32).

Estimated growth for 1985 and 1986 year classes was obtained from the intertidal catches by following the mean carapace width of a year class through succeeding surveys (Figure 15). After settlement and metamorphosis in July and August, growth was slow and appeared to stop around November. Little or no growth occurred through the winter; however, in April the mean carapace width jumped considerably and continued to increase rapidly through the summer. The mean carapace widths estimated from intertidal catches were somewhat lower than those from trawl catches.

Temperatures were recorded for air, substrate and water in standing pools and adjacent channels (Figure 33). Little fluctuation occurred between different sites along a transect or between transects; however, seasonal fluctuations were high (e.g., substrate temperatures ranged from a high of

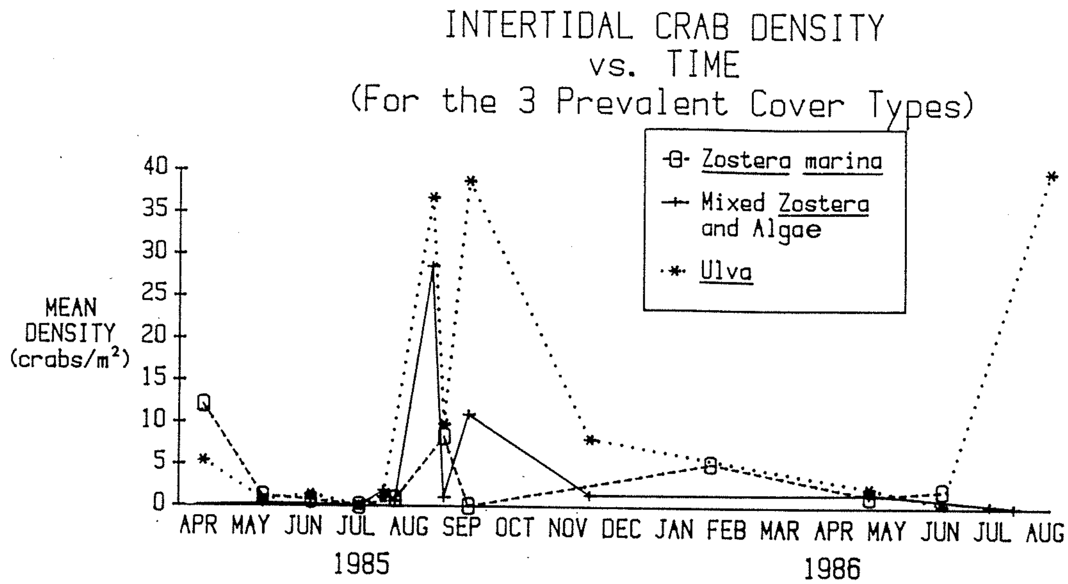


Figure 31. Mean density of Dungeness crab for the three most abundant plant cover types encountered in the intertidal quadrat samples. The categories "Zostera marina" and "Mixed Zostera and algae" constitute the eelgrass meadows.

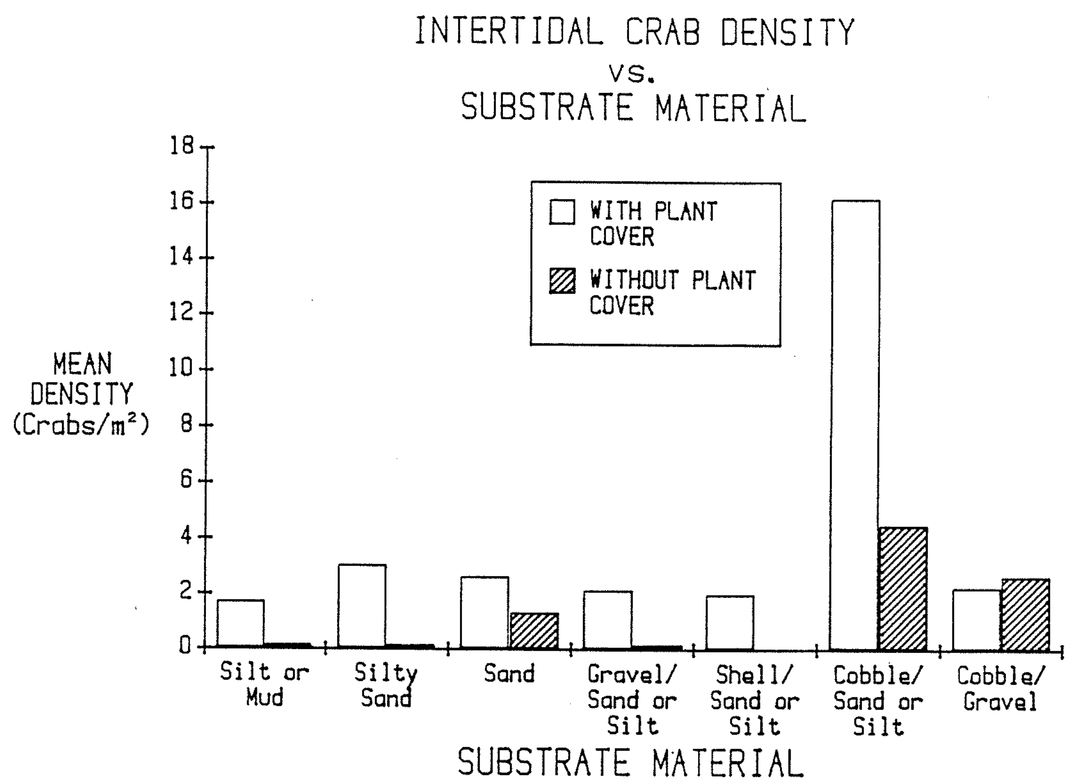


Figure 32. Mean density of Dungeness crab for different intertidal substrate categories, all surveys combined. Values are given for presence and absence of plant cover over each substrate category.

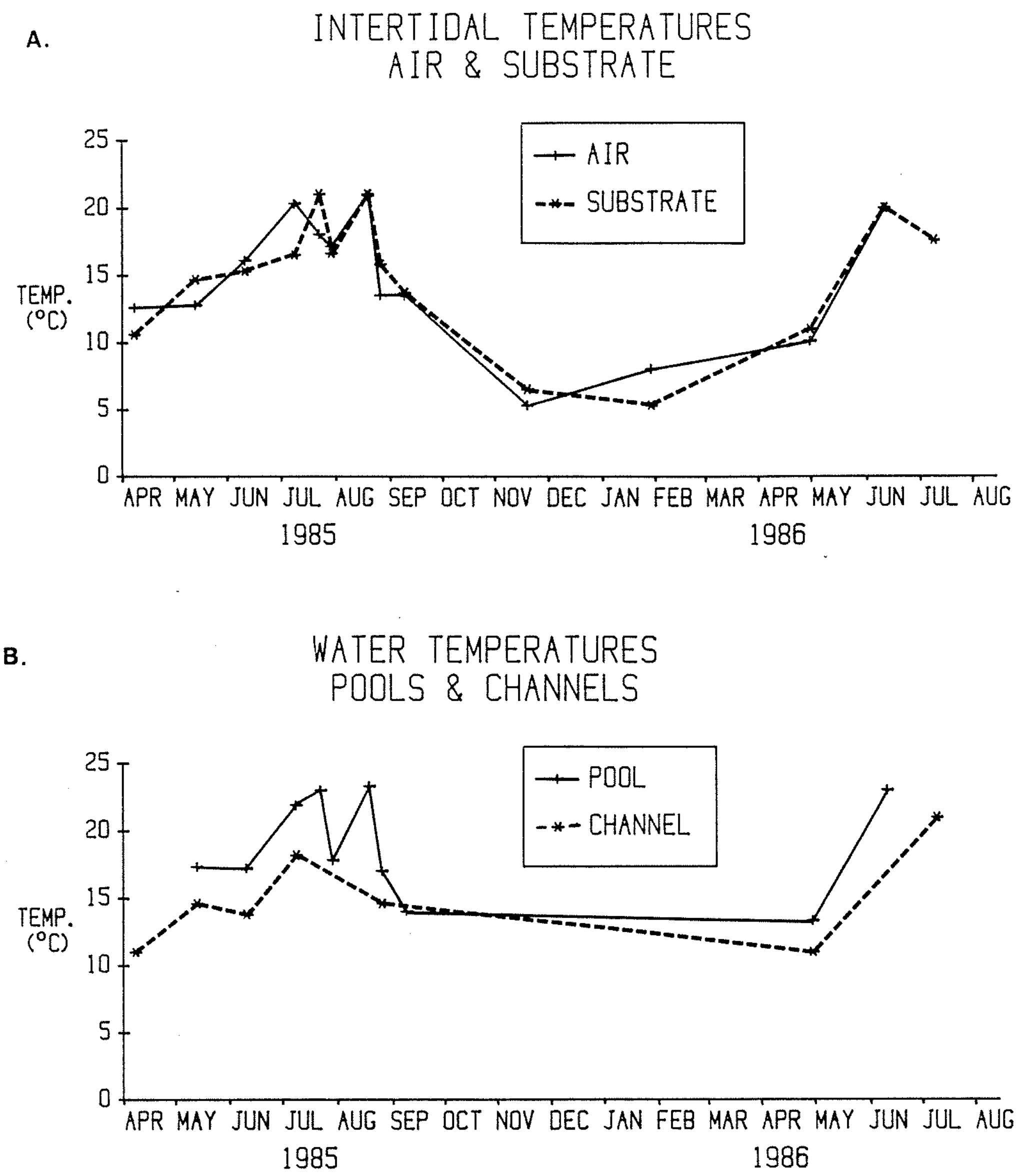


Figure 33. Mean temperatures for intertidal surveys at low tide all transects combined, April 1985 to August 1986. A. Air and substrate temperatures. B. Pool and channel temperatures.

21.0 °C in August 1985 to a low of 5.3 °C in January 1986). Salinity was recorded for pools and channels during the intertidal surveys and found to vary from about 27 to 33 ‰ (Figure 34).

DISCUSSION

Beam Trawls

The trawl survey of Padilla Bay Dungeness crabs at 19 stations showed that there were distinct seasonal trends in apparent crab abundances, that catches varied by trawl station and that substantially more crab were caught in the channels than on the intertidal or shallow subtidal flats.

Abundances of Dungeness crab were greatest during the summer months and least during the winter months (Figure 5A). Peaks in summer abundances were especially noted during August and September when the YOY crabs were settling out of their planktonic phase to begin life as epibenthic crabs. The paucity of crabs caught in the trawls during the winter remains a mystery. Clearly, crabs are present somewhere, but are not being sampled by the net, because abundances increase during the spring and early summer period prior to any new recruitment of YOY. There is increasing evidence to suggest that many crabs simply bury in the bottom sediments during the cold winter period and essentially hibernate for several months. This feature of crab behavior has been documented for juveniles (Dinnel et al. 1986c), gravid females (Armstrong et al. 1987; Dinnel et al. 1987) and reported for young adult crabs in high intertidal areas of Padilla Bay (S. Riggs, pers. comm.).

Trawl catches of Dungeness crab were greater in the channels than on the shallow flats (Figure 5B). While there is little doubt from our many observations of crab distribution in Padilla Bay that larger crabs prefer the

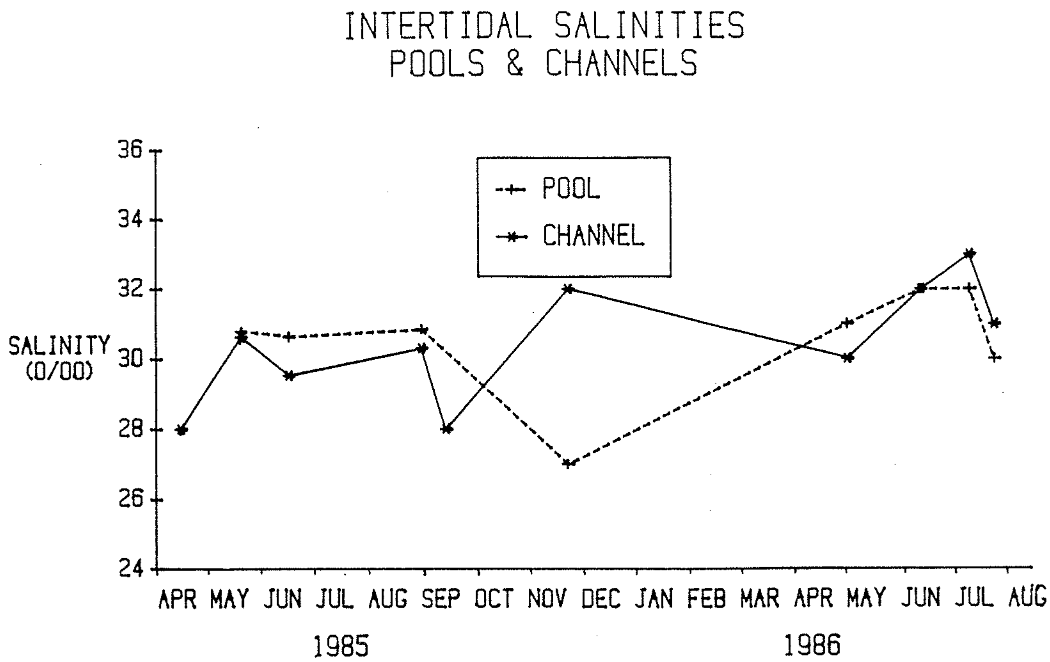


Figure 34. Mean salinities for pools and channels at low tide, all intertidal transects combined, April 1985 to August 1986.

channels to the shallow flats, part of the difference in catches between the two areas is assuredly due to artifacts of the sampling gear. Diver observations of the beam trawl during this study showed this piece of gear to be reasonably efficient for crabs residing on a clean sandy bottom since the net is able to "dig in" and flush out all but the deepest buried crabs (i.e., gravid females and possibly winter "hibernators"). This, however, is not true in areas of significant eelgrass or algae growth. In these areas divers have observed that the tickler chain and foot rope of the net quickly accumulate wrappings of plant material and consequently the net rides up off the bottom by as much as 10-20 cm, thus skimming over many crabs without catching them. This factor is especially true for YOY crabs in eelgrass areas. Trawl Station 15 in South Bay closely coincided with intertidal Transect 6. As an example of the trawl inefficiency for YOY in eelgrass areas, an average of 7.6 crab/m^2 were found in the September 1985 intertidal quadrat samples at Transect 6 (Appendix Table 6). This density of YOY equates to 76,000 crab/ha, yet the trawl catch at this same station in September 1985 produced an abundance estimate of only 96 crab/ha (Appendix Table 1); a factor almost 1,000 times less than the intertidal quadrat-derived estimate.

The crab abundance curves presented by depth strata in Figure 7 combined with the size frequency plots for each strata (Figure 12) document a pattern of crab growth and migration similar to that recently noted for Lummi Bay north of Bellingham, Washington (Dinnel et al. 1986c). Figure 7 (top) shows that peak abundances of crab in the shallow stratum (0-2 m depth) occur from September to October and that these crab are, to a large degree, recently settled YOY (Figure 12). Crabs in the 3-6 m stratum show peak abundances during June-August (Figure 7, middle) and are primarily one-year-old crabs (size range 40-70 mm; Figure 12) that are probably moving off of the intertidal flats where they settled and grew during the previous year. This same age group then appears to move into the deeper channel areas (Stratum 3; Figure 7, bottom) in August and September where they have now grown to a size range of 60-90 mm. Likewise, crabs entering their third year are present in Stratum 3 during spring and early summer of each year (Figure 12) but disappear by August (to even deeper water?) to effectively "make way" for the 1+ crabs moving down from the channels (just as the 1+ crabs moved off the flats to "accommodate" the YOY typically settling in about August). Hence, a more-or-less synchronized cycle of growth and movement takes place that effectively separates each of the year classes from each other, thereby minimizing intraspecific competition for food and habitat.

Gravid female crabs were almost totally absent from all types of samples collected in Padilla Bay. A Dungeness crab study conducted just prior to this study described aggregations of gravid females occurring on the south shore of Guemes Channel, between Anacortes and Ship Harbor, just west of Padilla Bay (Armstrong et al. 1987). Extensive diver observations during that study (as well as during the present study) found that this localized aggregation of gravid females did not extend into the shallow areas of Padilla or nearby Fidalgo bays. Apparently, young females may emigrate from Padilla Bay to areas such as Ship Harbor (adjacent to deep water) to bear their eggs.

Crab Pots

The fact that the average highest crab pot catches were in the Swinomish Channel, together with the small size of crab caught there (Figure 19) clearly shows that the Swinomish Channel provides important habitat for 1- to 2-year-old crab. It is interesting to note that trawl catches of Dungeness crab at Station 18 were only average when compared to catches at all 19 stations.

Crab pots at Station 18 were set at the edge of the Swinomish Channel at the base of the rip-rap bank (to avoid interference with navigation) while the trawls were made in the middle of the channel over a sandy bottom. These data suggested that the typically small crabs present in the channel preferred the protected rocky edges of the channel instead of the open sandy areas. Indeed, this pattern was subsequently confirmed by a diver transect survey at Station 18 in July 1985 which was conducted at the edge of the channel (again, to avoid boat traffic). Diver observations showed an abundance of young crab (94 crab caught on a 100 m-long transect; average size = 57.8 mm; Appendix Table 4) located amongst the small rocks at the foot of the rip-rap slope and very few crabs in the open sand even a few meters away from the rocky area. Divers also observed that about 95% of these small crabs were not buried in the substrate but rather moving about the rocky area and apparently in excellent position to take advantage of any food items swept by them by the usually strong currents in the channel.

Intertidal Transects

The intertidal region is of primary importance to YOY crab which almost exclusively dominated the quadrat sampling catches. The seasonal abundance of these crab is driven by the late-summer/fall settlement. In 1985 this settlement occurred in two waves, one in August and the second in September. The high density then declined rapidly, most likely a function of predation and possibly emigration into the channels by the earlier settling or larger crabs. Density of crab remained more stable through the winter months and into spring probably due to the reduced activity and subsequent lowered vulnerability to predation. During this time the substrate temperatures, to which the buried crab are exposed, were generally below 10°C and the crabs very sluggish when removed from the samples. The following spring, in March and April after temperatures rise above 10°C, the crab resume a more active existence and growth increases rapidly. During May and June the intertidal catches declined substantially at the same time that the channel and offshore trawls began to catch this late 0+ age group. The emigration of these crab from the intertidal region sets the stage for the settlement of the new year-class beginning again in late July.

Habitat within the intertidal region was classified by two parameters, plant cover and substrate. The most important to young Dungeness crab appears to be plant cover, and the different categories of plant cover present in the Padilla Bay samples differed in the associated densities of crab. During the period of settlement, the highest density of Dungeness crab was associated with *Ulva*. This is likely the reason the March Point transects exhibited such high densities at that time. In comparison to the Padilla flats transects which were dominated by eelgrass meadows, the March Point area had a much higher percent of *Ulva* cover. The two cover categories which constitute the eelgrass meadows, *Zostera marina* and mixed *Zostera* and algae, showed a lower initial rise in density during settlement, but by mid-winter the differences in density between these and *Ulva* were small (Figure 27).

The distribution of sampling effort between the plant cover categories is roughly equal to the relative area covered by each in the sampling sites. The three dominant plant categories, *Zostera marina*, mixed *Zostera* and algae, and *Ulva*, the two representing the eelgrass meadows and *Ulva*, collectively cover approximately 85% of the area sampled and account for over 86% of the crab caught intertidally.

Substrate appeared to play a less direct role in microdistribution of YOY crabs than plant cover. Only 4.3% of the crab were caught in the absence of some kind of plant cover during the intertidal quadrat sampling. Cobble with sand or gravel was present where nearly 90% of these crab were caught. Perhaps, in the absence of a preferred cover such as Ulva or eelgrass, the substrate material may serve to provide the same function, presumably refuge from disturbance or predation. Hence, the association with a material such as cobble, under or between which the juvenile crabs are able to hide.

The larger mean carapace widths of YOY calculated for trawl catches versus intertidal sampling (Figure 15) may result from the trawl's inability to catch the smallest juveniles (first and second instars, under 10 mm). Another factor may be the emigration of larger juveniles off the intertidal regions and into the subtidal and channel areas. This does happen as the juveniles approach 1 year in age in the spring and begin to be caught in the channel and offshore trawls. However, the earlier settling and/or faster growing 0+ crabs may become more mobile prior to winter and begin to move into deeper waters in the fall. Should this be the case the year-class size estimates from intertidal catches would be biased towards the smaller crab which might remain there.

Historical Trends in Crab Abundances

The following statement is made in the Padilla Bay National Estuarine Sanctuary Management Plan (W.D.O.E. 1984): "Crabbing and salmon harvesting occur on the (Padilla) bay's fringes but are not as productive as they were at the turn of the century." Echoing this view are comments from some sport crabbers encountered during this study to the effect that "Crabbing isn't what it used to be." Are these comments fact or fiction? Are stocks of Dungeness crab declining and, if so, why?

Answers to these questions depend on a historical data base which can be compared to present sampling data. Unfortunately, very little historical sampling data are available to make these comparisons. Most statistical data on Dungeness crabs comes from catch statistics collected by the Washington Department of Fisheries. The annual landings of Dungeness crab in Puget Sound from 1935 to 1982 and the landings for the Anacortes area from 1943 to 1974 are shown in Figure 35. This figure shows that there have been wide fluctuations in crab catches both within the Puget Sound and in the Anacortes area and that the general pattern at Anacortes follows fairly closely the trends in Puget Sound landings. These data suggest that large fluctuations and "cycles" of abundance are natural and that stocks can remain high or depressed for periods as long as 10 years or more. Caution must be used, however, when viewing catch statistics because these data are uncorrected for "fishing effort" which can vary substantially, especially as related to the offshore crab fishery. When the Washington coastal crab fishery is depressed, more commercial crabbing effort is expended in Puget Sound waters and vice-versa during periods of high crab abundance on the coast.

Only three studies of crab abundance and distribution have been conducted (all since 1974) in the Anacortes area with sampling gear other than crab pots. The present study reported here used three main sampling methods for crabs: (1) beam trawls, (2) crab pots modified to retain smaller than legal-sized crab, and (3) intertidal quadrat sampling for juvenile crab. As indicated in the Results section and shown in Figure 36, each sampling method caught different size classes of crabs. The crab pots rarely caught crabs less than 60 mm but were relatively efficient for larger crabs. The beam trawl was relatively efficient for 2- to 3-year-old crab in the size range of 40 to 120 mm, while the intertidal quadrats sampled 0+ crab (5 - 30 mm) almost exclusively.

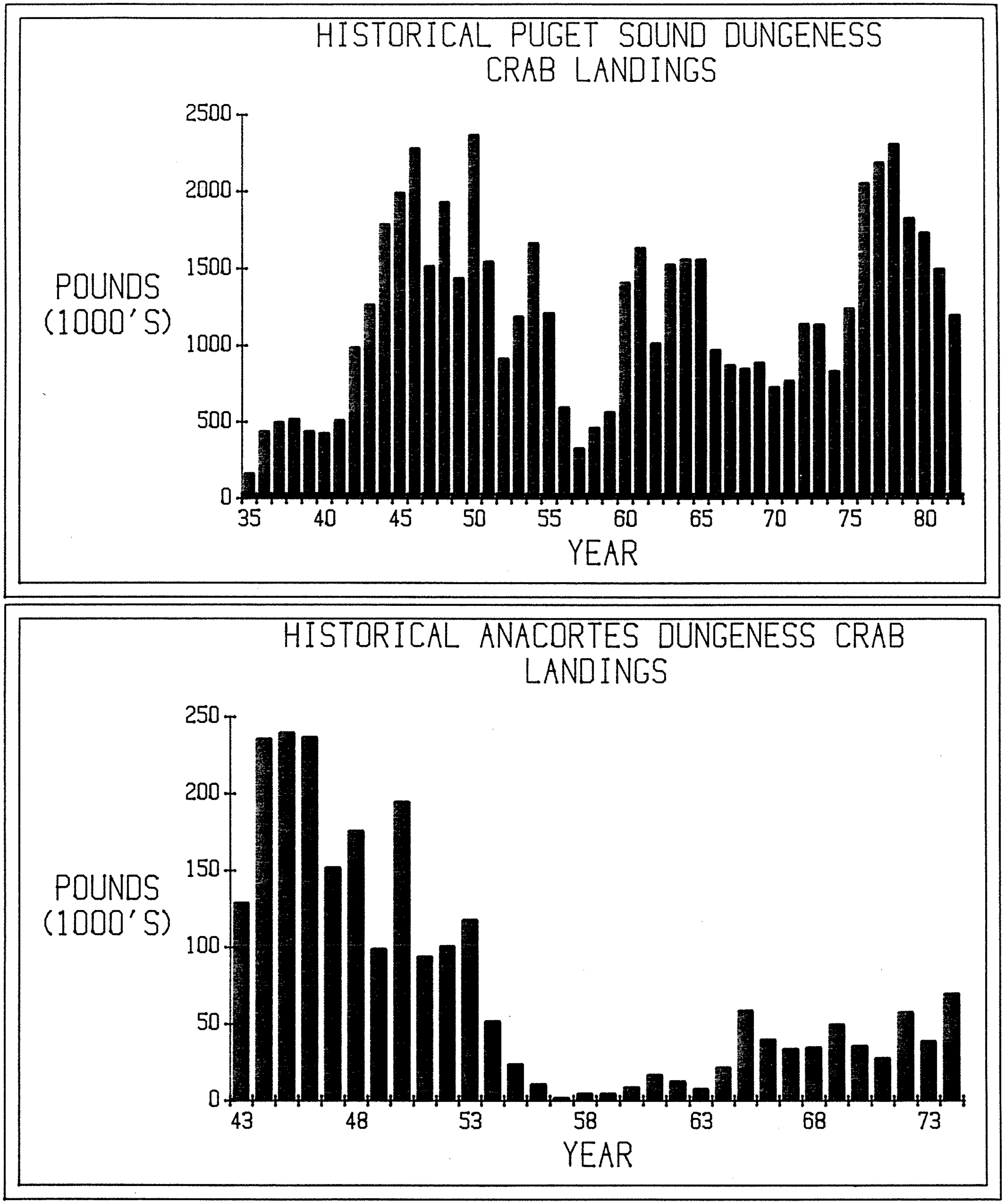


Figure 35. Historical Dungeness crab commercial landings in Puget Sound, 1935-1982 (top) and at Anacortes, 1943-1974 (bottom) near Padilla Bay. Graphs from data in W.D.F. 1974 and 1982.

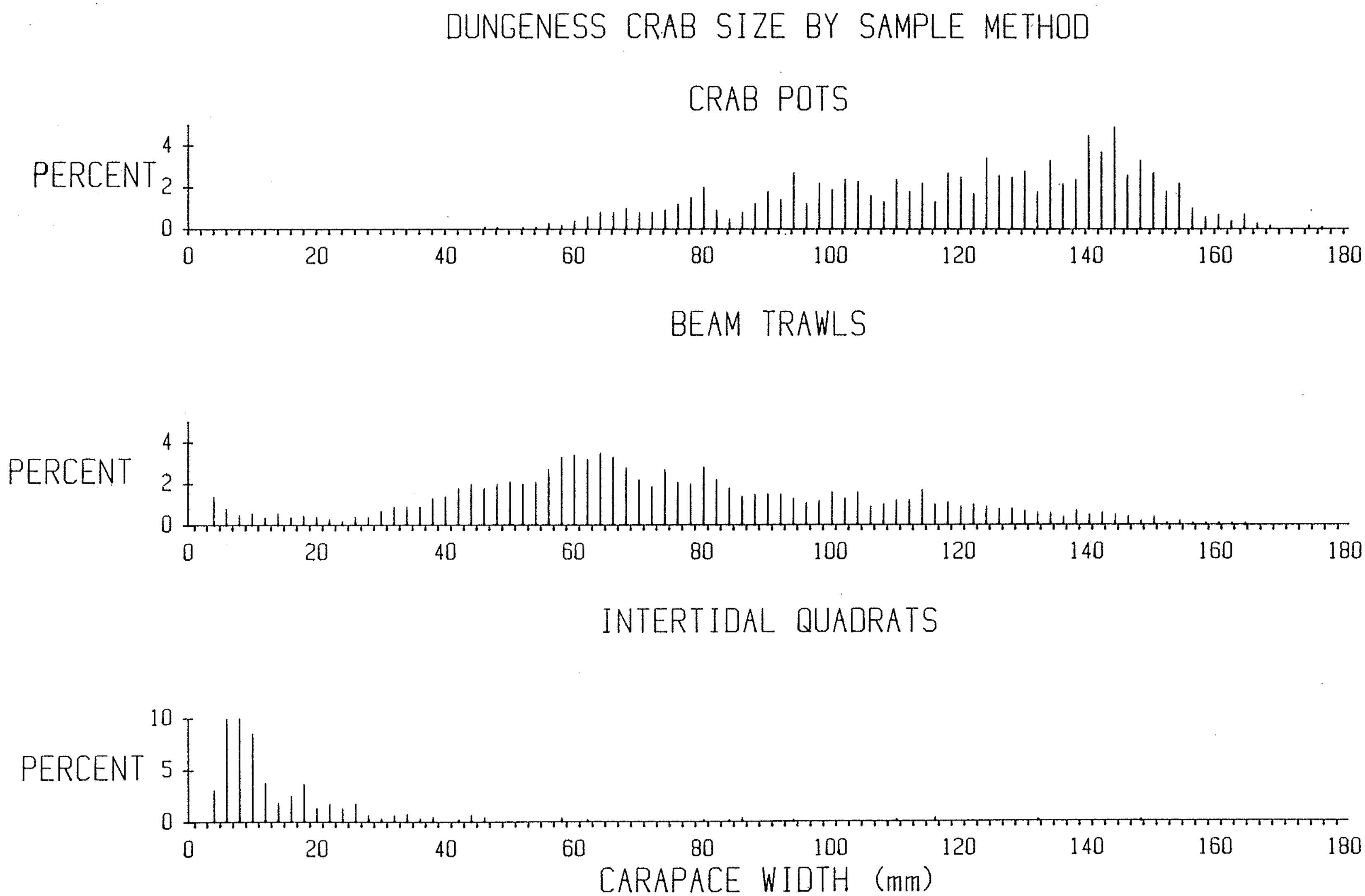


Figure 36. Carapace width-frequency histograms comparing the sizes of Dungeness crab sampled by crab pots, beam trawl and intertidal quadrats in Padilla Bay, all stations and months combined.

One methodology has been used by the three recent quantitative studies, this being a small beam trawl. English (1976) used a small rigid-frame beam trawl at a series of March Point stations in 1974-1975. He generally found average abundances of 300-400 crab/ha at the 5 and 10 meter stations and decreasing abundance (25-200 crab/ha) at 15 to 20 m depth (Figure 37). Armstrong et al. (1987) conducted a trawl study of Dungeness crab at March Point and Ship Harbor (east of Anacortes) during 1984 and 1985 with the same beam trawl and procedures used in this study. They found very high abundances of crab during the summer of 1984 (6,170 ± 4,446 crab/ha in August) and about 400 to 500 crab/ha during the summer of 1985 (Figure 38). However, a large majority of crab caught in 1984 were small YOY that apparently settled in high densities and, if subtracted from the total catch, would result in corrected densities in the range of 400 to 700 crab/ha for non-YOY (Armstrong et al. 1987). The present study found abundances of crab in the March Point area to be similar to those reported by both English (1976) and Armstrong et al. (1987). Trawls at stations closest to March Point (Stations 6-10) averaged 462 (±577) crabs/ha for June through August 1985 and 844 (±1,131) crabs/ha in June and August 1986.

As a first order approximation, there seems to have been little change in overall crab abundances at March Point during the last 10 years despite the knowledge that legal-sized crab abundances can change by an order of magnitude during that period of time (based on catch statistics). Hence, complaints that "crabbing isn't what it used to be" may be valid but probably not based (in a long-term sense) on depleted resources. We suggest that two other factors may account for a perceived reduction in crab catches: 1) increased fishing pressure, especially due to increases in recreational crabbing, and 2) increased "sport" harvesting of sublegal-sized crabs. A recent survey by WDF

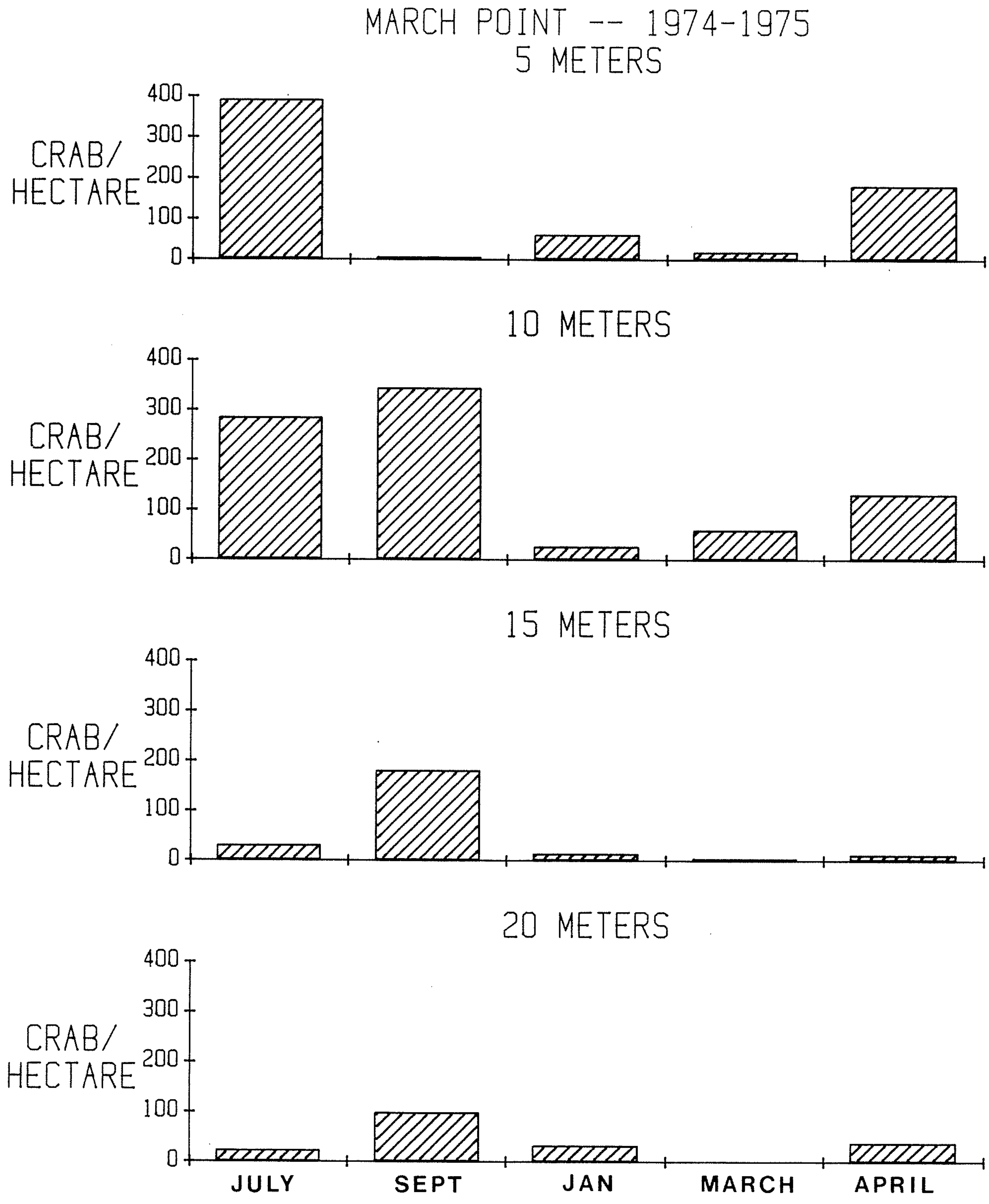


Figure 37. Graphical summary of Dungeness crab catches in a beam trawl survey of the March Point area of Padilla Bay in 1974 and 1975. These catch data were summarized from English 1976.

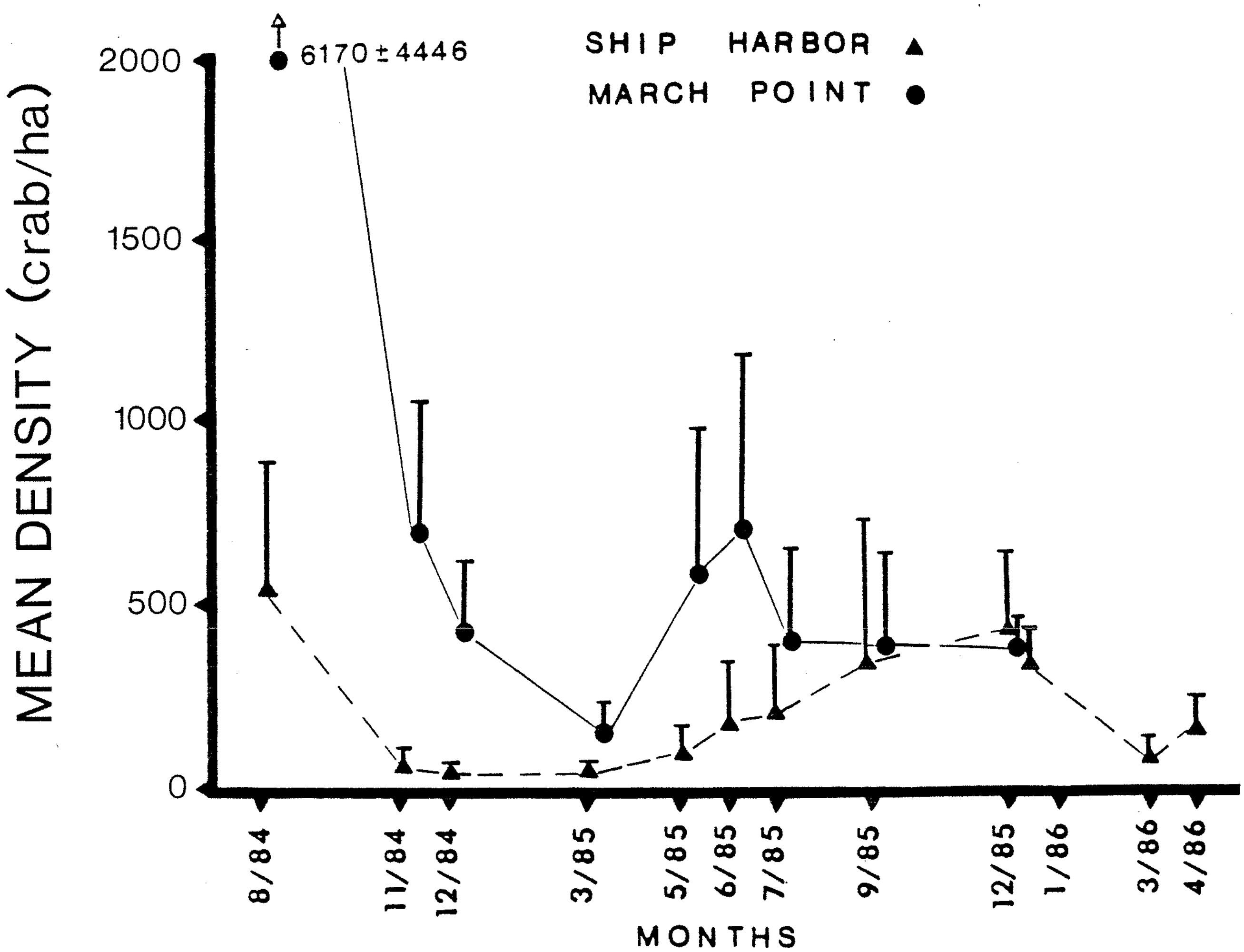


Figure 38. Mean density of Dungeness crab caught by beam trawl at Ship Harbor and March Point from August 1984 to April 1986. Error bars are ±2 standard errors but for clarity only the upper error bar is pictured. From Armstrong et al. 1987.

of discarded sport-caught crab carapaces at March Point showed that more than half were below the legal size limit (Anacortes American 1986). If a substantial portion of sublegal-sized crabs are removed from a local area, these crabs will obviously fail to recruit to the legal fishery, and hence, it will appear to the legal crabber that there has indeed been a decline in the harvestable resource.

CONCLUSIONS

1. The average abundance of Dungeness crabs caught in 153 beam trawl samples from May 1985 to August 1986 was 139 crab/ha. The trawl catches were seasonal with the highest catches during the summer and low catches during the winter.

2. Trawl-caught Dungeness crabs were most abundant in the channels (up to about 1,600 crab/ha at several channel stations) and least abundant at the intertidal stations where average crab catches were typiclly less than 200 crab/ha.

3. The trawl sampling data showed that the intertidal eelgrass flats were rich in 0+, young-of-the-year (YOY) crabs and that the channels were preferred habitat for 1+ and 2+ age class crabs.

4. Settlement of new recruits took place from July through September with young crabs reaching an average size of about 20 mm by winter when growth essentially ceased due to low temperatures. Growth resumed in about April with 1-year-old crab rapidly growing to a size range of about 70-90

mm by the following winter.

5. Commercial crab pots modified with small mesh screen to retain small crabs caught an average of 10 to 15 crab per pot. Pot catches were highest at Station 18 in the Swinomish Channel where young crab averaging about 60 mm in width were plentiful. Diver observations showed that these crabs were highly aggregated in rocks at the base of the rip-rap channel edges. Crab pots sampled crabs in the 80 to 180 mm range effectively but rarely caught crabs less than 60 mm. However, crab pots are of minimal use as quantitative sampling tools since an "area fished" cannot be calculated.

6. Diver transects conducted alongside some of the trawls showed that the efficiency of the net for catching Dungeness crabs varied from a low of 12% to a high of over 500% relative to the diver catches. Three reasons for this high variability were: 1) crabs were often highly aggregated within small areas (i.e., under patches of shell or debris), 2) divers tended to miss some of the smaller crabs, and 3) divers sampled different areas (close, but not the same) than the beam trawl.

7. Dungeness crab with soft shells (indicative of recent molting) were caught throughout the year but soft females were most abundant during the summer following a spring molting and mating period. Soft males were least abundant during the fall with possible peaks in numbers of soft males around June and possibly September. The trawls caught a higher proportion of soft crabs than the crab pots suggesting that soft crabs are less likely to enter crab pots than hard shelled crab.

8. Sixteen intertidal quadrat surveys were conducted along 8 transects from April 1985 to August 1986. Dungeness crab represented 67% of the quadrat sampling crab catch with *Hemigrapsus* spp., *Cancer productus*, *C. gracilis* and *Telmessus cheiragonus* also represented in the catches. Of the Dungeness crab, 90% were YOY crabs with carapace widths less than 20 mm.

9. Settlement of YOY occurred from late July through September with peak densities of about 22 crab/m^2. Mortality was high following settlement with overwintering densities of YOY falling in the 0-5 crab/m^2 range. Comparisons of trawl and intertidal quadrat catches of YOY at a single station in September 1985 showed that the trawl was only about 0.1% as efficient in catching YOY as the quadrat samples dug at low tide. The efficiency of the trawl in intertidal areas was found to be very poor due to eelgrass and algae wrapping around the tickler chain and foot rope, causing the net to ride off the bottom and, hence, miss many large crabs as well as most YOY buried in the bottom.

10. YOY crabs were most highly associated with plant cover of any type but especially *Ulva* when present, and secondarily, the eelgrasses *Zostera marina* and *Z. japonica*. When plant cover was not present, YOY were most often associated with cobble and/or gravel which probably also provided a degree of cover from predation.

11. Historical records of catch statistics together with two other crab studies in the area of March Point suggest that crab stocks are still healthy in and around Padilla Bay but that fluctuations in population

abundances can be on the order of ten-fold within both the Padilla Bay/Anacortes area as well as within Puget Sound in general. The reasons for the fluctuations are presently unknown, but probably of natural origin.

12. It is clear from this study as well as from several other recent related studies that the shallow areas of Puget Sound serve as nursery grounds for Dungeness crab. Areas of special importance to juveniles of this species are extensive flats (such as Padilla Bay) with abundant eelgrass and algae cover over a sand or sand-silt substrate. Embayments that also have a series of channels provide especially attractive habitat for 1- and 2-year-old age groups.

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APPENDIX TABLE 1

Average number per hectare (and average size in mm) of Dungeness crabs caught in the beam trawl tows at each of 19 stations in Padilla Bay from May 1985 to August 1986. N.S. = not sampled.

MONTH	TRAWL STATION																		
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
1985 May	106 (128)	40 (137)	532 (109)	440 (118)	79 (142)	NS	NS	NS	119 (125)	NS	NS	NS	NS	306 (115)	NS	106 (121)	1065 (76)	659 (88)	NS
June	158 (135)	32 (99)	342 (90)	340 (114)	278 (52)	0 -	285 (87)	106 (120)	258 (99)	924 (98)	59 (135)	132 (63)	109 (52)	263 (115)	26 (54)	4511 (61)	1361 (56)	342 (63)	2738 (115)
July	0 -	331 (102)	6886 (48)	1518 (91)	952 (80)	226 (98)	2008 (82)	0 -	475 (103)	422 (88)	0 -	189 (93)	56 (89)	1151 (74)	0 -	1303 (47)	2164 (59)	327 (66)	NS
August	200 (70)	667 (68)	1329 (59)	1483 (92)	374 (79)	100 (115)	88 (80)	238 (96)	411 (78)	925 (71)	83 (100)	0 -	0 -	525 (67)	40 (5)	190 (100)	228 (63)	456 (87)	1514 (76)
September	1524 (56)	782 (49)	NS	222 (108)	544 (81)	95 (142)	1952 (74)	50 (26)	317 (63)	760 (77)	68 -	346 (80)	476 (93)	451 (76)	331 (37)	1061 (69)	173 (69)	380 (85)	2032 (90)
October	75 (15)	225 (105)	95 (47)	79 (39)	95 (60)	612 (88)	589 (101)	95 (23)	892 (84)	67 (46)	211 (137)	272 (25)		NS	38 (17)	203 (87)	NS	NS	NS
1986 January	48 (110)	56 (23)	340 (15)	42 (120)	0 -	73 (134)	437 (118)	NS	21 (135)	15 (148)	0 -	0 -	0 -	41 (138)	30 (150)	26 (135)	55 (86)	190 (101)	238 (141)
March	NS	NS	NS	NS	NS	200 (109)	798 (115)	26 -	83 (92)	10 (120)	84 (107)	0 -	127 (117)	48 (116)	0 -	0 -	48 (66)	375 (89)	-
June	NS	NS	NS	NS	NS	119 (109)	190 (102)	31 (86)	459 (119)	679 (107)	136 (75)	149 (56)	147 (66)	112 (90)	0 -	23 (49)	394 (56)	146 (64)	-
August	NS	NS	NS	NS	NS	0 -	1559 (73)	408 (86)	1700 (71)	3959 (52)	50 (57)	571 (75)	NS	1023 (69)	-	1557 (66)	266 (84)	190 (75)	-

APPENDIX TABLE 2

Average number (and average size in mm) of Dungeness crabs caught in Vexar-lined commercial-style crab pots set in Padilla Bay from May 1985 to August 1986. Not all stations were sampled every month.

	Station								
Month	4	7	9	10	14	16	17	18	19
May, 1985		13 (129)			18 (137)			52 (77)	
June					7 (119)	6 (145)	9 (133)	65 (87)	
July	25 (135)	12 (123)	0	0	20 (116)		22 (123)	55 (91)	24 (133)
August	28 (135)	9 (127)			61 (128)	58 (123)	16 (129)	11 (99)	19 (131)
September	1 (145)	39 (129)	10 (136)	7 (133)	8 (141)	2 (161)	13 (116)	22 (92)	6 (131)
October	7 (140)		9 (102)	16 (118)	13 (134)	8 (134)	7 (125)		6 (133)
January, 1986	13 (132)	1 (100)	2 (136)		2 (112)	11 (137)	13 (131)	20 (93)	2 (138)
March					3 (134)	29 (119)	9 (126)	4 (102)	
May					11 (138)	22 (128)		27 (101)	
June					8 (148)	7 (143)		1 (106)	
August							16 (137)	2 (126)	

APPENDIX TABLE 3

Average number (and average size in mm) of red rock crabs caught in Vexar-lined commercial-style crab pots set in Padilla Bay from May 1985 to August 1986. Not all stations were sampled every month.

	Station								
Month	4	7	9	10	14	16	17	18	19
May, 1985		3 (130)			1 (134)			0	
June					3 (115)	2 (140)	0	0	
July	3 (136)	6 (124)	0	12 (122)	7 (118)		3 (125)	0	3 (141)
August	15 (125)	22 (119)			2 (118)	0	0	0	9 (125)
September	0	1 (151)	6 (122)	6 (124)	2 (122)	1 (63)	1 (124)	0	16 (119)
October	4 (135)		1 (158)	1 (138)	2 (129)	2 (122)	1 (130)		2 (138)
January, 1986	0	0	0		0	0	0	9 (91)	6 (128)
March					30 (117)	0	0	0	
May					4 (133)	0		0	
June					0	2 (122)		4 (100)	
August							0	19 (102)	

APPENDIX TABLE 4

Summary of comparative diver transects and beam trawls conducted side-by-side in Padilla Bay during 1985 and early 1986. N.M. = not measured.

Beam Trawl Station No.		Date	Depth(m)	Area Swept by Diver or Trawl (m^2)	Substrate/ % and Type Cover	Water Temperature (° C)	Number of Dungeness Crab Caught	Crabs/m^2	Percent Relative Efficiency of Trawl (Diver catch/m^2= 100%)	Average (±1 SD) Crab Carapace Width (mm)	Approximate % Crabs Buried
Small Channel in South Bay:											
	Diver	16 June '85	3	340	Sand/	15.5	46	0.129	119	53 ± 22	50
	Trawl			324	35% Eelgrass		50	0.154		52 ± 13	
19:	Diver	16 June	3-5	340	Sand/	12.0	29	0.085	324	114 ± 16	90
	Trawl			251	25% Eelgrass		69	0.275		115 ± 24	
16:	Diver	16 June	4-5	340	Sand/	N.M.	103	0.303	268	48 ± 24	35
	Trawl			315	30% shell 10% *Ulva*		256	0.812		64 ± 18	
4:	Diver	10 July	5	340	Sand/	13.0	80	0.235	65	117 ± 23	95
	Trawl			336	2% Eelgrass		51	0.152		95 ± 25	
17:	Diver	10 July	5	340	Sand/	15.0	14	0.041	529	106 ± 37	90
	Trawl			304	No cover		66	0.217		59 ± 21	
10:	Diver	8 July	6	340	Sand/	12.0	25	0.074	57	105 ± 32	90
	Trawl			377	2% Eelgrass		16	0.042		88 ± 24	
14:	Diver	8 July	8	340	Sand/	17.0	80	0.235	49	78 ± 29	90
	Trawl			251	25% Shell and Wood		29	0.116		74 ± 27	
18:	Diver	8 July	6	340	4-6" Cobble/	14.5	94	0.276	12*	58 ± 19	5
	Trawl			336	2% *Laminaria*		11	0.033		66 ± 15	
4:	Diver	11 Aug	5	340	Sand/	14.0	11	0.032	466	122 ± 27	90
	Trawl			262	No cover		39	0.149		92 ± 23	
14:	Diver	11 Aug	8	340	Sand/	14.0	9	0.026	204	111 ± 39	N.M.
	Trawl			304	5% Shell and Wood		16	0.053		67 ± 17	

APPENDIX TABLE 4

(Continued)

Beam Trawl Station No.		Date	Depth(m)	Area Swept by Diver or Trawl (m^2)	Substrate/ % and Type Cover	Water Temperature (° C)	Number of Dungeness Crab Caught	Crabs/m^2	Percent Relative Efficiency of Trawl (Diver catch/m^2= 100%)	Average (+1 SD) Crab Carapace Width (mm)
19:	Diver	11 Aug '85	3-5	340	Sand/ 20% Eelgrass	14.5	34	0.100	152	90 ± 28
	Trawl			283			43	0.152		76 ± 25
4:	Diver	7 Sep	5	340	Sand/5% Shell	12.0	8	0.024	92	131 ± 7
	Trawl			313			7	0.022		108 ± 21
14:	Diver	7 Sep	8	340	Sand/10% Shell	12.5	9	0.026	205	106 ± 27
	Trawl			419			19	0.045		76 ± 12
19:	Diver	8 Sep	3-5	340	Sand/ 25% Eelgrass	12.0	96	0.282	72	92 ± 31
	Trawl			377			77	0.204		89 ± 23
14:	Diver	22 Mar '86	8	238	Sand/10% Shell	9.0	4	0.017	29	108 ± 26
	Trawl			837			4	0.005		116 ± 16
19:	Diver	22 Mar	3-5	238	Sand/ 10% Eelgrass	9.0	7	0.029	66	110 ± 24
	Trawl			419			8	0.019		101 ± 37

*Trawl was in the middle of Swinomish Channel over clean sand whereas dive transect was at edge of channel at the base of a rip-rap slope. The small crabs were obviously aggregated in cobble at base of rip-rap.

APPENDIX TABLE 5

Crab catches broken down by species for intertidal surveys, April 1985 to August 1986, all transects combined.

Date	Species						Number of quadrat samples
	Cancer magister		Hemigrapsus sp.	Cancer productus	Telmessus cheiragonus	Cancer gracilis	
	Crabs	Megalopae					
1985							
7 April	21	0	16	8	9	1	21
8-9 May	19	0	33	0	1	1	90
3-4, 6 June	17	0	20	2	0	1	108
2-3 July	0	1	5	1	1	1	72
18 July	10	3	19	0	0	0	28
30-31 July	7	1	0	0	0	2	53
17 Aug.	136	10	48	14	2	0	24
25-27 Aug.	107	5	6	9	0	0	60
10 Sept.	121	0	48	3	2	0	22
14 Nov.	15	0	6	2	1	0	23
1986							
25 Jan.	23	0	0	1	1	1	24
27-28 April	54	0	0	1	1	1	162
10 June	4	0	25	1	0	0	28
9 July	1	0	0	0	1	0	17
19 July	0	0	0	3	0	0	20
7 Aug.	60	11	0	0	0	0	6
TOTALS	595		226	45	19	8	758

APPENDIX TABLE 6

Intertidal quadrat sample catch breakdowns by sample date and transect. Data presented are "mean density (crabs/m^2)" and "number of Dungeness crab caught".

Date	Transect								Mean Density / Total Catch
	1	2	3	5	6	7	8	17	
1985									
7 April	4.00								4.00
	21								21
8-9 May	0		1.33	1.33	0.27	1.14	0.67		0.84
	0		7	4	1	6	1		19
3-4, 6 June	0	0.67	0	1.33	0.22	0.89	0.67		0.63
	0	1	0	4	1	6	3		17
2-3 July	0	0	0	0	0			0	0
	0	0	0	0	0			0	0
18 July						0.33	2.25		1.43
						1	9		10
30-31 July	0		1.33		0.33	0			0.53
	0		4		1	0			7
17 Aug.						30.67	14.67		22.67
						92	44		136
25-27 Aug.	7.11				2.00	15.33	34.00	1.00	7.13
	32				6	46	17	2	107
10 Sept.					7.60	34.00			22.00
					19	102			121
14 Nov.						2.61			2.61
						15			15
1986									
25 Jan.						3.83			3.83
						23			23
27-28 April	0.22		1.20	0.95	2.37	1.64		1.04	1.33
	1		9	5	16	16		7	54
10 June						0.57			0.57
						4			4
9 July						0.24			0.24
						1			1
19 July						0			0
						0			0
7 Aug.						40.00			40.00
						60			60

APPENDIX TABLE 7

Intertidal Dungeness crab catches broken down by plant cover categories. Total number of crabs and number of 0.25m^2 quadrat samples are given for each category and survey; blanks indicate no samples were taken. (No. crab/No. samples) All intertidal transects are combined.

Date	Zostera marina	Mixed Zostera & Algae	Ulva sp.	No plant cover	Zostera japonica	Mixed algae	Detritus	Enteromorpha sp.
1985								
7 April	9/3		8/6	0/6	2/3	2/3		
8-9 May	17/60	1/15	1/6			0/3		
3-4, 6 June	8/48	1/30	6/18	2/12				
2-3 July	0/56	0/8	0/4		0/4			
18 July		6/13	4/15					
30-31 July	4/20	3/22			0/7	0/4		
17 Aug.		64/9	55/6	17/9				
25-27 Aug.	68/33	1/4	34/14	0/2	1/4			3/3
10 Sept.	0/3	19/7	58/6	3/3	41/3			
14 Nov.		3/9	6/3	0/2			6/9	
1986								
25 Jan.	18/14			5/10				
27-28 April	26/81	23/60	5/9	0/3	0/9			
10 June	3/6		1/13	0/9				
9 July		1/17						
19 July		0/20						
7 Aug.			60/5	0/1				