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Dungeness Crab, *Cancer magister*, Distribution Recruitment, Growth, and Habitat Use in Lummi Bay, Washington

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Paul A. Dinnel, David A. Armstrong, and Russell O. McMillan

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Lummi Indian Tribe, Bellingham, Washington

In cooperation with Washington Sea Grant, Puget Sound Office of the U.S. Environmental Protection Agency, Washington Department of Fisheries and Shorelands Division of Washington Department of Ecology

UNIVERSITY OF WASHINGTON
SCHOOL OF FISHERIES
FISHERIES RESEARCH INSTITUTE

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Fisheries Research Institute
School of Fisheries
University of Washington

Final Report

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Approved:

Submitted Dec. 15, 1986

Robert C. Francis, Director

ABSTRACT

A study of Dungeness crab, Cancer magister distribution, recruitment, growth and habitat preferences was conducted in Lummi Bay, Washington from July 1984 to September 1985. During this period, Dungeness crab were sampled at 13 stations with a small beam trawl; sampled at 4 stations with commercial-style crab pots modified with small-mesh screen to retain small crabs; and sampled intertidally with $0.25 m^2$ quadrat samples dug at low tide. The primary objective of this study was the collection of Dungeness crab distribution data in the area of a proposed navigation channel to be dredged across the intertidal flats to a new marina.

Average abundances of crabs in the beam trawls were highest during the summer months (up to 969 $\pm$ 414 crab/ha) and lowest during the winter (as low as 1 $\pm$ 1 crab/ha). Crab catches in the trawls were generally highest at the -3 m (below MLLW) contour along the nearshore "dropoff" and least abundant offshore at the -12 m contour. The average sizes of crab caught in the trawls was also a function of depth with the smallest crab being caught in the intertidal areas and the largest crab at the -12 m contour.

Abundances of Dungeness crab in the crab pots followed the same pattern as in the trawls: high during summer, low during winter. The highest average catches and smallest crab were from the inner portions of the north channel.

The intertidal quadrat sampling caught young-of-the-year (YOY) crabs almost exclusively. Settlement of new recruits started in July, peaked in August and continued through September. Average densities of new recruits in the eelgrass beds reached as high as almost 20 $crab/m^2$ during August 1986 but declined in each year to average densities of only about 1 to 3 $crab/m^2$ during the winter. The average overwintering size of the YOY was

in the range of 10 to 20 mm. Growth during the second year was rapid with crabs reaching 80-100 mm by winter of the year following settlement. YOY crabs were highly associated with any type or plant material in the intertidal areas of Lummi Bay; very few young crab were found where protective cover was lacking.

Dungeness crab exhibited preferences for certain habitats by age group. The YOY crabs (up to about 30 mm size) thrived in the intertidal eelgrass/algae areas. One-year-old crab moved off of the flats in about July and were predominately caught in the shallow channels and along the nearshore "dropoff" at -3 m depth. The two-year-old crabs also moved deeper during the summer to the -12 m depth and deeper. Hence, there is a stratification of crab sizes (age groups) by habitat type (depth) with minimal overlapping in time or space.

The potential impacts of channel dredging on Dungeness crab are discussed with recommendations given for monitoring the impacts of the dredging activity.

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Catherine Krueger, U.S. Environmental Protection Agency (Office of Puget Sound)

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FILE COPY

UNIVERSITY OF WASHINGTON
SEATTLE, WASHINGTON 98195

Fisheries Research Institute, WH-10

3 March 1987

Catherine Krueger
U.S. EPA, Office of Puget Sound, M/S 433
1200 Sixth Ave.
Seattle, WA 98101

Dear Catherine:

Please find enclosed five copies of our final report to the Lummi Indian Tribe titled "Dungeness Crab, Cancer magister, Distribution, Recruitment, Growth, and Habitat Use in Lummi Bay." This study was funded, in part, by your office under an EPA/NOAA-Sea Grant Interagency Agreement IAG No. DW13931825-01-1. Submission of this report represents partial fulfillment of this agreement.

We very much appreciate your support of our attempts to establish a long-term data base in Dungeness crab ecology and habitat requirements in Puget Sound. Only through the cooperative efforts of a variety of agencies is this type of project possible.

Should you have any questions or require additional copies of the Lummi Bay report, please call me at 543-7345.

Sincerely,

Paul Dinnel
Principal Research Biologist

PD:cs

Encl.

P.S. Thank you for your kind comments about the Padilla Bay Draft Report.

INTRODUCTION

The Lummi Indian Tribe has proposed to construct a new public commercial fishing boat marina complex within a portion of the existing tribal aquaculture pond in Lummi Bay, Washington. Lummi Bay is situated adjacent to the Strait of Georgia on the Lummi Indian Reservation in Whatcom County, approximately 7 nautical miles north of Bellingham, Washington (Fig. 1). Construction of the marina project in the aquaculture pond would require dredging a navigation channel approximately 2,200 meters long by 30 m wide across the present intertidal flats, an area equivalent to about 14 ha and 493,000 cubic meters of dredged materials (Fig. 2). A major portion of the proposed navigation channel contains eelgrass (*Zostera marina* and *Z. japonica*), which has been shown to be important habitat for many marine animals (Thayer and Phillips 1977), substrate for Pacific herring (*Clupea harengus pallasi*) spawn (Palsson 1984) and food for migratory waterfowl (Phillips 1972).

The nearshore area of Lummi Bay supports a commercial and sports fishery for Dungeness crab (*Cancer magister*) of which the Lummi tribal fishermen share in a major portion of the catch. The shallow intertidal flats of Lummi Bay, especially those areas with eelgrass cover, are suspected to provide valuable nursery habitat for juvenile Dungeness crab. Indeed, Dinnel (1971) documented settlement of post-larval (young-of-the-year; 0+) Dungeness crab in eelgrass beds at densities up to 80 crabs/m^2 in Humboldt Bay, northern California, and Stevens and Armstrong (1984) reported high densities of 0+ juveniles in and near eelgrass in Grays Harbor estuary.

In order to satisfy tribal concerns regarding protection of valuable marine fisheries nursery areas and the environmental impact review process required by state and federal permitting agencies, the Lummi Indian Tribe

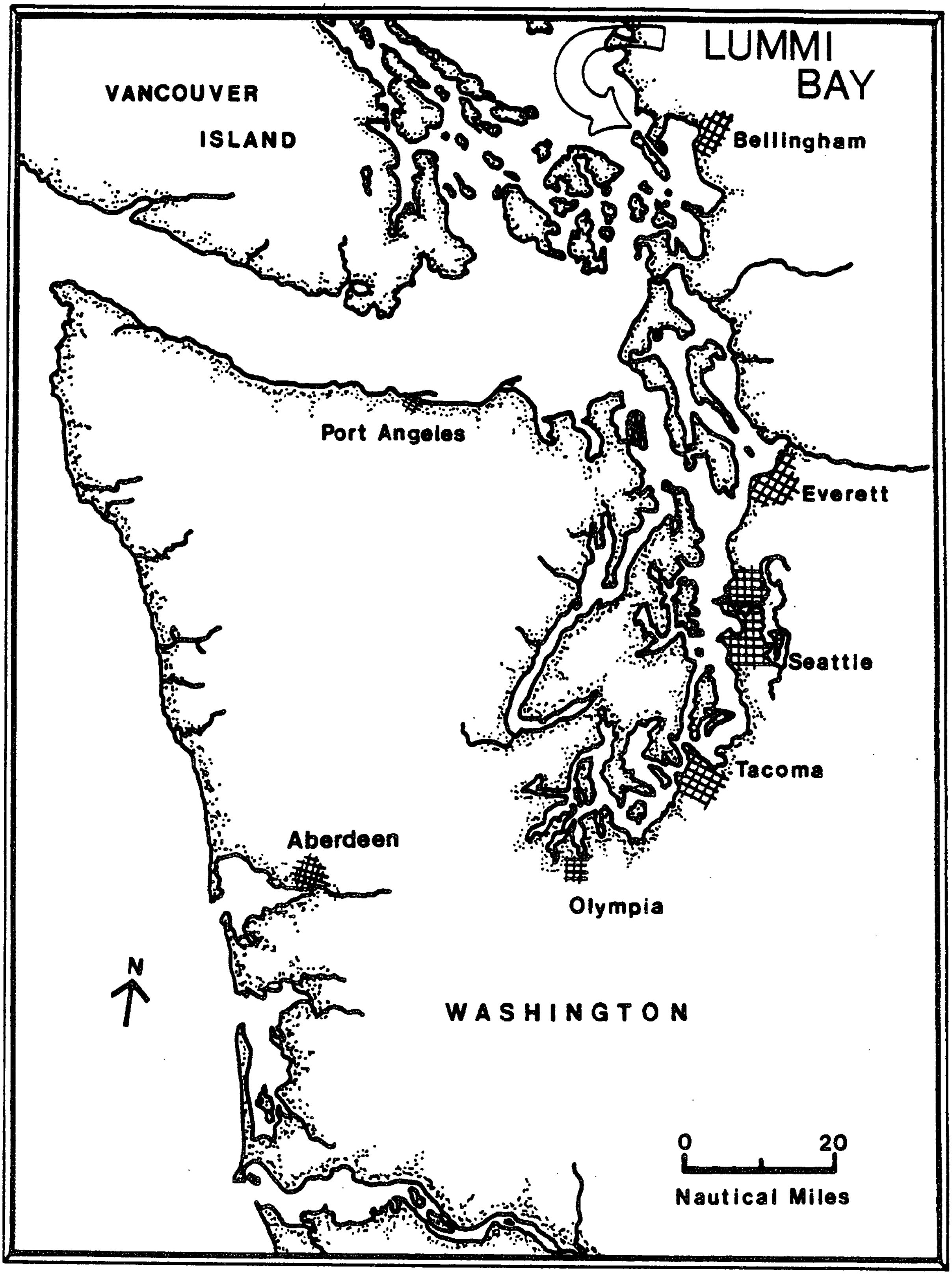

Figure 1. Map of western Washington State showing the location of Lummi Bay.

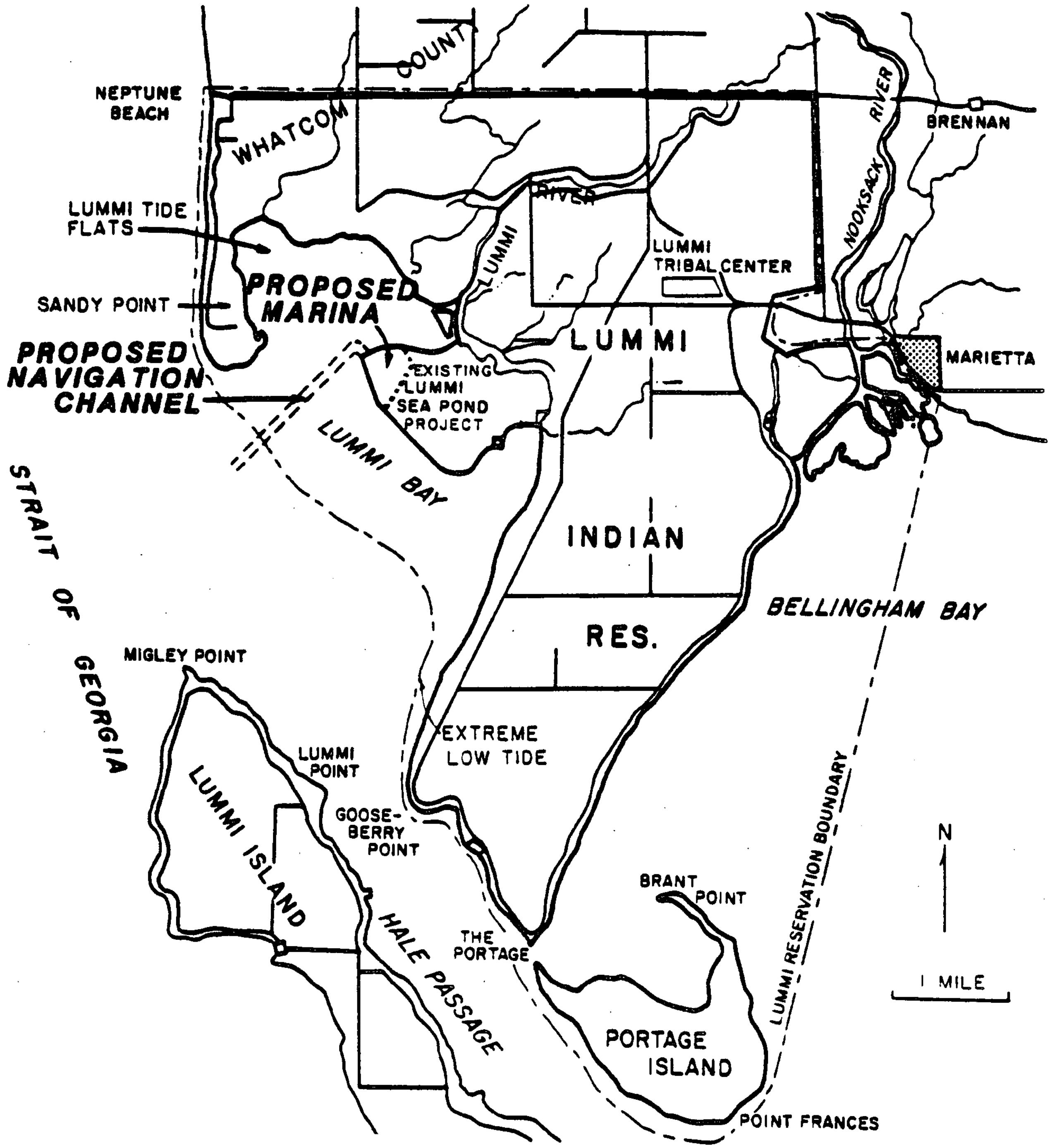

Figure 2. Project location map of the proposed Lummi Bay marina (from COE 1983).

provided funds and assistance to the School of Fisheries of the University of Washington to conduct a Dungeness crab habitat evaluation study of Lummi Bay, with special emphasis on the area of the Bay proposed for the new navigation channel. This study is a portion of a larger study of Dungeness crab habitat and population dynamics in north Puget Sound initiated in 1984 with funding support from the Washington Sea Grant Program and the Washington Department of Fisheries (Dinnel et al. 1985).

The specific objectives of the Lummi Bay Crab Habitat Study were as follows:

1) Estimate Dungeness crab abundances in Lummi Bay with an emphasis on juvenile crabs.

2) Determine distributions of life history stages by season, depth and habitat.

3) Determine settlement periods, growth rates and survival for young-of-the-year crab.

4) Assess potential impacts to Dungeness crab from dredging of a boat navigation channel through the Lummi Bay tide flats.

This document is the technical completion report for the Lummi Bay Crab Habitat Study specific to the marina project and the navigation channel dredging. Additional information regarding the overall north Puget Sound Dungeness Crab Study will be available at a later date.

MATERIALS AND METHODS

Sample Methods

Dungeness crab resources and habitat usage in Lummi Bay were assessed using three different sampling methodologies: 1) trawls made with a small plumb staff beam trawl; 2) commercial crab pots modified with small mesh Vexar screen to retain small crabs; and 3) intertidal quadrat sampling during periods of low tide.

Beam Trawls

Trawling was conducted with a 3 m beam trawl with an effective fishing width of 2.3 m (Fig. 3). This trawl was designed by Gunderson and Ellis (1986) for sampling demersal organisms and has been routinely used in Grays Harbor, Willapa Bay (Armstrong and Gunderson 1985; Gunderson et al. 1985) and North and Central Puget Sound for the last 2 to 3 years.

Intertidal (during high tide) and shallow subtidal (to 12 m depth below MLLW) trawls were conducted with a 7 m Boston Whaler equipped with a towing frame and winch. Each subtidal tow was 4 to 5 minutes in duration while intertidal tows were reduced to 2 to 2.5 minutes due to the large amounts of algae (especially *Ulva*) and eelgrass (*Zostrea marina*) caught in the trawl.

The contents of all trawls were sorted into several categories: shell, vegetation, rock, wood and debris, crabs (excluding kelp and decorator crabs, *Pugettia* sp. and *Hyas* sp.), and other fish and invertebrates. 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 and reproductive stage of mature females. Temperature and salinity data were collected monthly from December 1985 to October 1986 from surface and bottom waters at Stations 7 (intertidal), 8 (-3 m) and 9 (-12 m) (see Fig. 4).

Crab Pots

Commercial-style Dungeness crab pots were generally fished for 24 hr periods using fresh or frozen fish or clams for bait. Each crab pot, including the escape rings, was covered with small mesh (approximately 13 mm x 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 the slots between the trigger

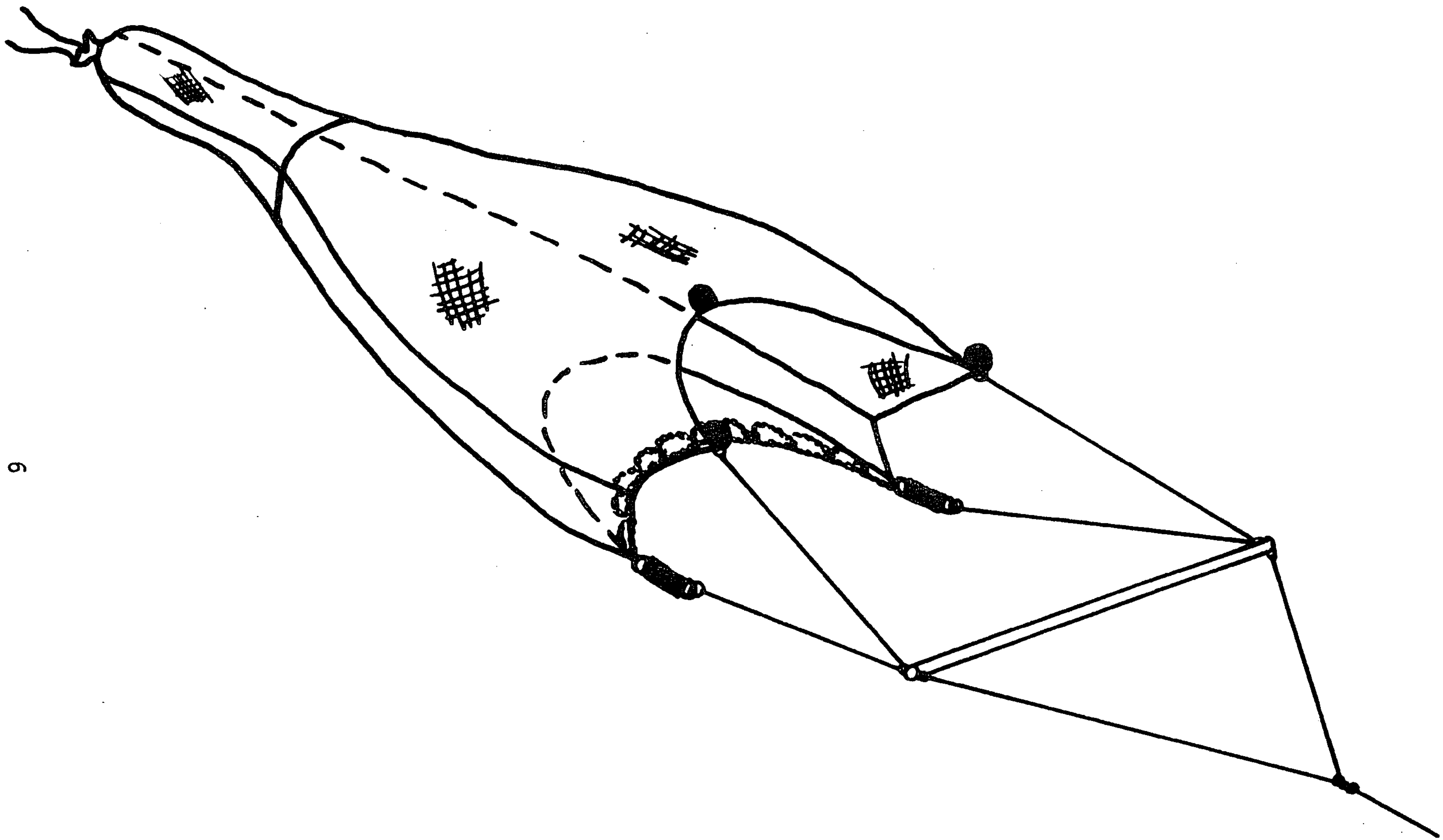

Figure 3. Diagram of the 3m beam trawl used to assess crab resources in Lummi Bay.

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.

Intertidal Quadrat Sampling

Intertidal samples for 0+ and 1+ age crabs were collected along transects by digging 0.25 m^2 samples to a depth of approximately 3 cm. Each sample was washed in 4-mm mesh nets or screens and sorted in the field. All crabs were identified, measured as above, sexed if greater than 20 mm carapace width, and returned to the beach. Notes were made of substrate type, plant cover type and percent (subjective estimates), and substrate and pool temperatures (at a depth of 1-2 cm) at each sample location.

Sample Sites

Beam Trawls

Nine beam trawl stations were established in June 1984 along three transects (Fig. 4), one each in the northern (Stations 1-3), middle (Stations 7-9), and southern (Stations 4-6) portions of the Bay, and were stratified by three depths: intertidal (Stations 1,4,7), 3 m below MLLW (Stations 2,5,8) and 12 m below MLLW (Stations 3,6,9). Four additional trawl stations were established in the intertidal channels in October 1984 to monitor the channel proposed to be dredged. Trawl Stations 10-12 were positioned in the "North" Channel (the proposed navigation channel) and Station 13 established in the "Middle" Channel to act as a "Control" station. Each station was trawled once per month through October 1985 (except twice during August 1984). Occasional bad weather limited sampling during a few months.

LUMMI BAY

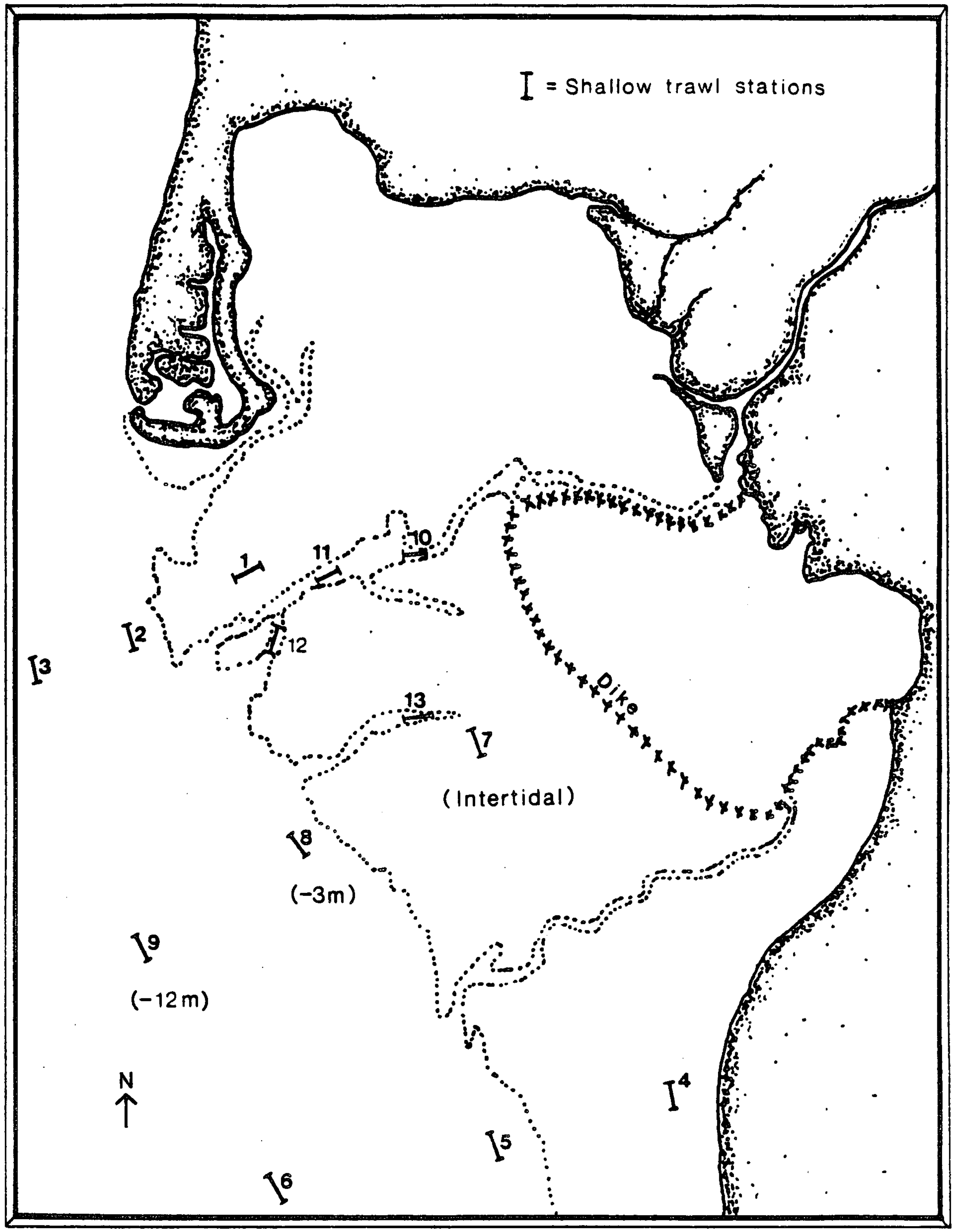

Figure 4. Locations of the beam trawl stations in Lummi Bay.

Crab Pots

The Vexar-modified crab pots were fished during most months from October 1984 through September 1985. Two crab pots were fished in the North Channel (Pot Stations 1 and 2), one pot fished offshore of the North Channel at a depth of 5 m below MLLW (Pot Station 3) and one pot fished in the middle "Control" channel (Pot Station 4; Fig. 5).

Intertidal Quadrat Samples

Three intertidal sampling transects were established in Lummi Bay (Fig. 5). Transect 1 ran parallel to the North Channel beginning at the foot of the northwest corner of the aquaculture pond dike and extended westward approximately 2000 m to the extreme low water line (Fig. 5). Transect 2 ran parallel to the Middle Channel from the foot of the dike about 1700 m westward to the low water line. Transect 3 in South Bay began on the upper beach at the foot of Cagey Road and extended westward approximately 400 m to the low water line. Each transect was generally sampled monthly although frequency depended on transect and season. Sampling on each transect was conducted at various intervals (e.g., 0, 100, 300, 500, 700 paces, etc.; 100 paces averaged 84.4 $\pm$ 1.6 m) out from the upper beach or dike and samples were selected haphazardly within each habitat type and percentage cover by tossing the 0.25 m^2 sampling quadrat onto those habitats and digging the material therein. The objective of this type of stratified sampling (stratified by distance from upper beach, type of habitat and percent plant cover) was to maximize the information obtained regarding use of different types of habitats by juvenile crab. For the stratified sampling program, an attempt was made to balance sampling effort at each distance on each transect when possible to facilitate within- and between-transect comparisons of crab densities and habitat usage (e.g., three samples each of 100%, 75%, 50%, 25% and 0% cover

LUMMI BAY

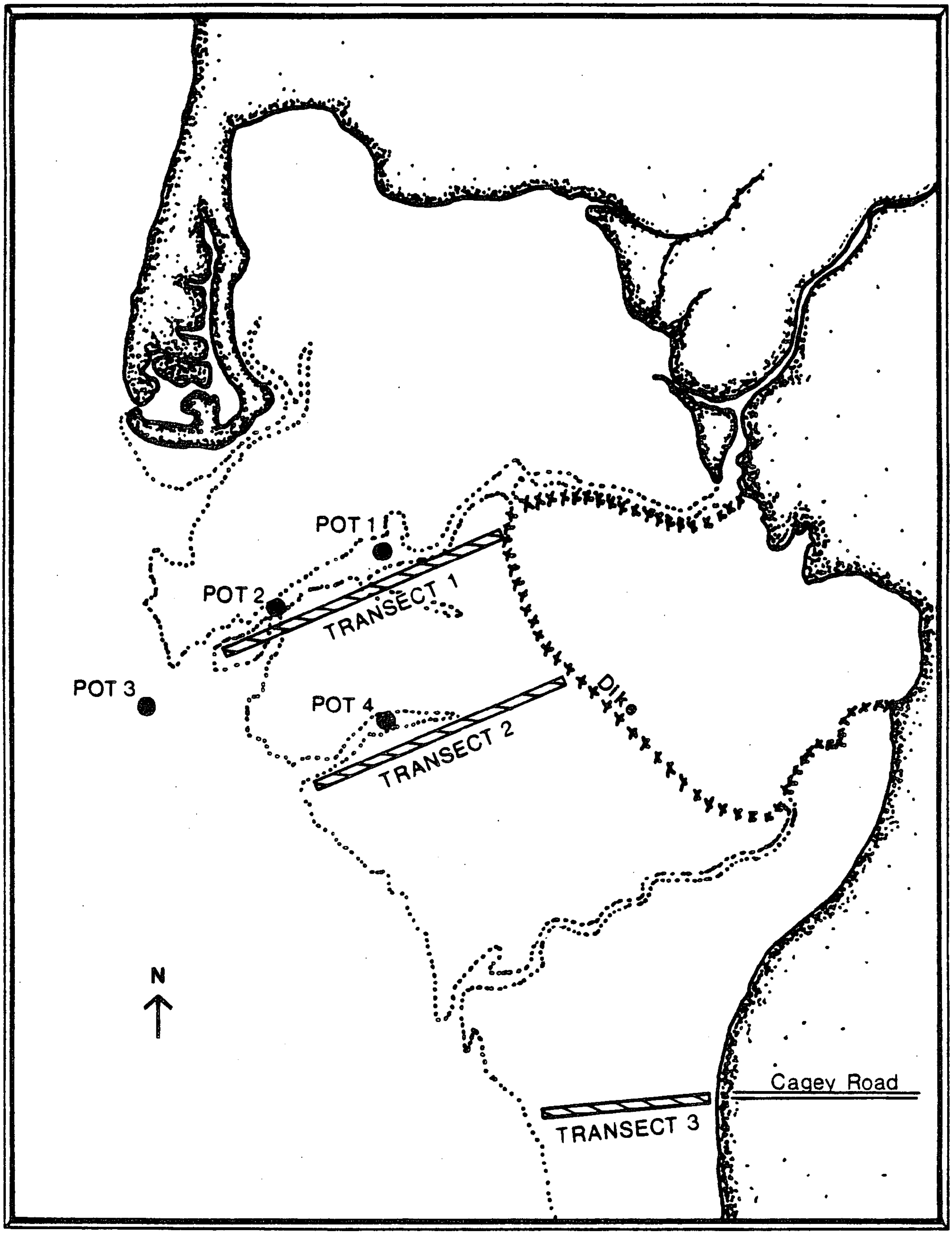

Figure 5. Locations of crab pot stations in the north and middle channels and the intertidal transects in north, middle and south Lummi Bay.

of the dominant plant(s) at each distance).

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 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 (m^2) 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:

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

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

$$Xt = \mathrm{Log}_{10}\ (\text{Abundance} + 1)$$

where Xt is the transformed variable (Elliott 1977).

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 time are probably not linear due to a variety of factors (i.e., number of crabs already in the pot, age of the bait, day vs. night, escapement of small crabs back out entrance channel "triggers", etc.)

Intertidal crab densities are reported as crabs/m^2 by multiplying the catches/0.25 m^2 by a factor of 4.

RESULTS

Beam Trawls

Abundances of Dungeness crab (number/hectare) calculated from the monthly beam trawls in Lummi Bay are summarized in Table 1 and presented graphically in Figure 6. The average overall trawl abundance of Dungeness crab in Lummi Bay was 320 $\pm$ 24 ($\pm$ 1 standard error) with a monthly high of 969 $\pm$ 414 (Sept. 1985) and a monthly low of 1 $\pm$ 1 (Feb. 1985) (Table 1, Fig. 6). Abundances of Dungeness crab were consistently higher during the summer-fall (July to Oct.) period of 1985 as compared to the same time period of 1984 for all stations combined (Fig. 6). Dungeness crab were very scarce in the beam trawl samples during winter at average abundances of only 1 to 15 crab/ha from January to March 1985.

Relative to depth, Dungeness crab catches were almost always highest along the subtidal "dropoff" contour at -3 m followed by intertidal, channel and, lastly, the -12 m contour (Fig. 6, Table 2). Geographically, there were no obvious differences in the calculated abundances of Dungeness crab between the North (Stations 1-3), Middle (Stations 7-9) and South (Stations 4-6) transects (Table 3; see Fig. 4 for station locations).

Seven species of demersal crabs (excluding kelp and decorator crabs) were caught in the trawls and of the total, Dungeness crab equalled 71.2% of the crab catch (Table 4). Of the Dungeness crab caught in the beam trawls, approximately 31% were males, 39% females and 30% of unknown sex (i.e., juveniles <20 mm CW) (Table 4). For shell condition, approximately 69% of the Dungeness crab had hard to very hard (i.e., yellow shells, often with encrusting barnacles) shells while the other 31% had recently molted

Table 1. Average abundances of Dungeness crab per hectare calculated from beam trawl catches in Lummi Bay from July 1984 to October 1985.

Cruise #	Date	n	Average Abundance Per Hectare	Standard Error
2	July 18-21, 1984	8	483	187
3	Aug 3-6	9	217	89
5	Aug 16-18	9	246	76
7	Oct 20-22	12	180	67
8	Nov 17-18	13	78	40
10	Dec 19	12	38	19
11	Jan 25-27, 1985	12	7	3
12	Feb 15-17	11	1	1
13	March 15-17	13	15	8
15	April 17-20	13	138	73
16	May 15-18	13	167	80
17	June 12-16	13	572	168
18	July 9-12	13	797	491
19	Aug 6-10	13	350	160
20	Sept 5-10	12	969	414
22	Oct 16	5	860	698
All Cruises Combined		11.3	320	24

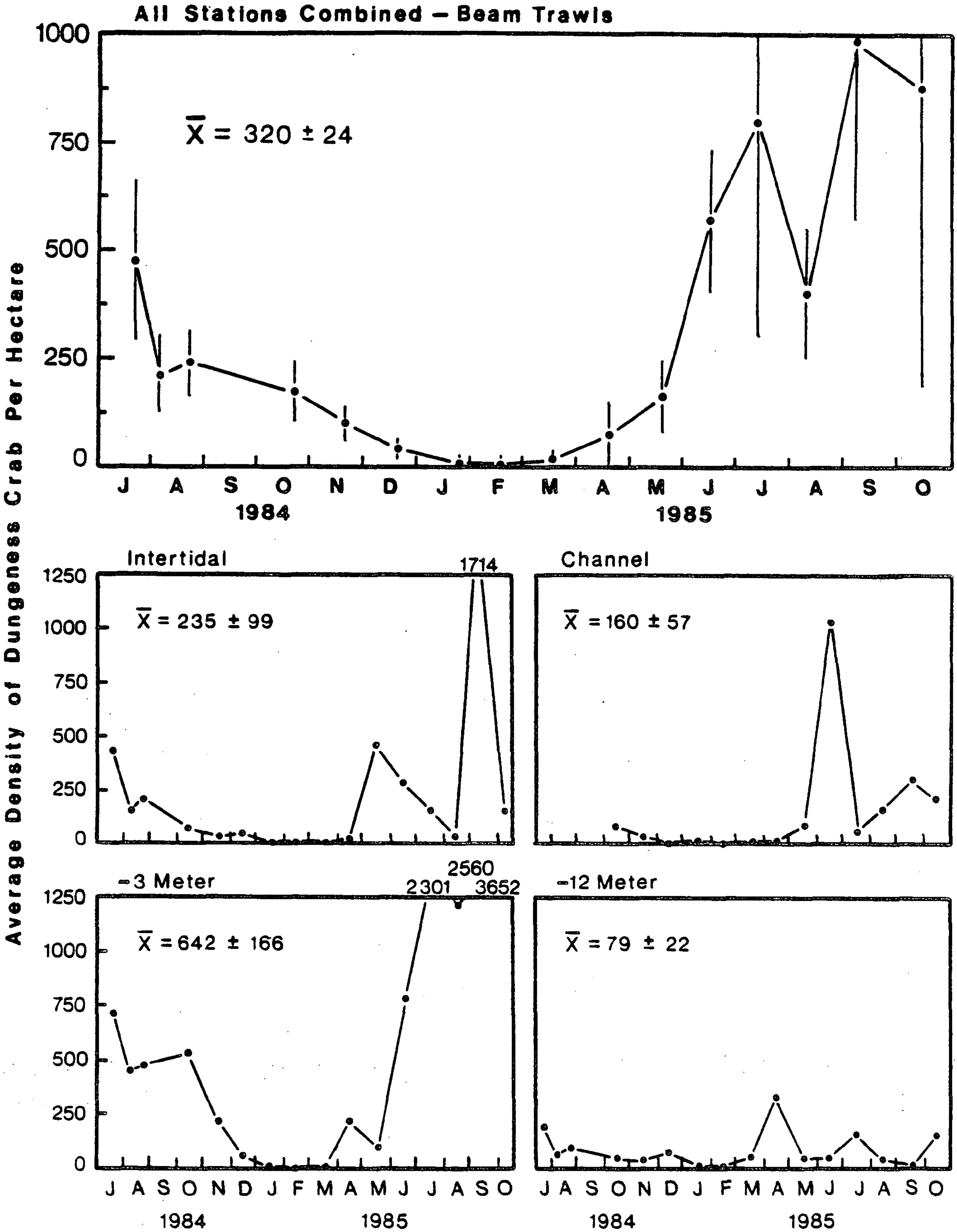

Figure 6. Average estimated abundances (± 1 standard error) of Dungeness crab calculated from beam trawl catches in Lummi Bay from July 1984 to October 1985 (see Fig. 4 for station locations).

Table 2. Average abundances per hectare of Dungeness crab in Lummi Bay by depth as calculated from beam trawl catches during 1984 and 1985.

Depth (meters below MLLW)	n	Average Abundance Per Hectare	Standard Error
0 (Intertidal)	46	235	99
1 (Channels)	43	160	57
3	45	642	166
12	42	79	22
All	176	320	24

Table 3. Average abundances per hectare of Dungeness crab in Lummi Bay by transect as calculated from beam trawl catches during 1984 and 1985.

Location	n	Average Abundance Per Hectare	Standard Error
North Transect (Stations 1-3)	44	269	67
Middle Transect (Stations 7-9)	45	390	160
South Transect (Stations 4-6)	42	320	116
Channel Stations (10-13)	43	160	57

and possessed soft or very soft shells (Table 4). Soft-shelled crabs were seasonal with the majority occurring from June through August in both 1984 and 1985. The majority of very hard shelled crabs (especially females) were found from April to July, prior to the summer molting and soft shell period. Very few gravid female Dungeness crab (only 2.4% of all females) were caught in the beam trawls (Table 4), and almost all were captured in March, April and May of 1985.

Average Dungeness crab size varied by season as well as by trawl depth with an overall average carapace width (CW) of 66 $\pm$ 46 mm ($\pm$1 standard deviation) for all samples (Fig. 7). The generally small average size of crabs caught during the summer months reflects the influx of young-of-the year (YOY) and the increased catchability of the 1+ year class at shallow stations. The large average crab sizes during the winter months reflects the capture of very few individuals, most being mature crab (Figs. 7 and 8).

Histograms of monthly Dungeness crab carapace width frequencies (Fig. 8) show that YOY crabs settled from approximately June through September 1984 with carapace widths of 5-15 mm. Relatively little growth took place prior to or during winter. The first substantial growth of the 1984 year class was not evident until about May 1985 and thereafter crabs reached an average CW of 70-80 mm by October 1985 as 1+ juveniles. The 1983 year class (1+ in 1984) was very evident in the April and May 1985 samples with carapace widths in the range of 100 to 130 mm. The abundances of these 2 year old crabs then decreased through June and July and dropped to almost zero after August 1985, suggesting a movement offshore to areas deeper than -12 m.

Table 4. Summary of beam trawl, crab pot and intertidal crab species composition and Dungeness crab sex, shell condition and state of reproduction.

	Percentage of Catch		
Characteristic	Beam trawls	Crab pots	Intertidal
Crab species:			
C. magister	71.2%	93.4%	89.8
C. productus	10.7	5.6	2.2
C. gracilis	8.1	0.2	0.8
C. oregonensis	6.0	0	0
Telmessus	2.4	0.8	2.2
Hemigrapsus	0.9	0	4.9
Lophopanopeus	0.7	0	0
Total count	3,121	882	716
Dungeness Crab Sex:			
Male	31.0	51.7	5.1
Female	38.9	48.2	4.2
Unknown (Juveniles <20.0 mm)	30.1	0.1	90.7
Total Count	2,221	824	643
Dungeness Crab Shell Condition (for crabs >100 mm):			
Very soft	1.3	0.4	NA[1]
Soft	29.3	4.5	
Hard	65.0	66.1	
Very hard	4.4	29.0	
Total Count	839	493	
State of Reproduction (Dungeness Females):			
Not gravid	97.6	100	NA
Gravid	2.4	0	
Total Count	246	226	

[1]NA = Not applicable since all but one Dungeness crab from the intertidal samples were juveniles <100 mm carapace width.

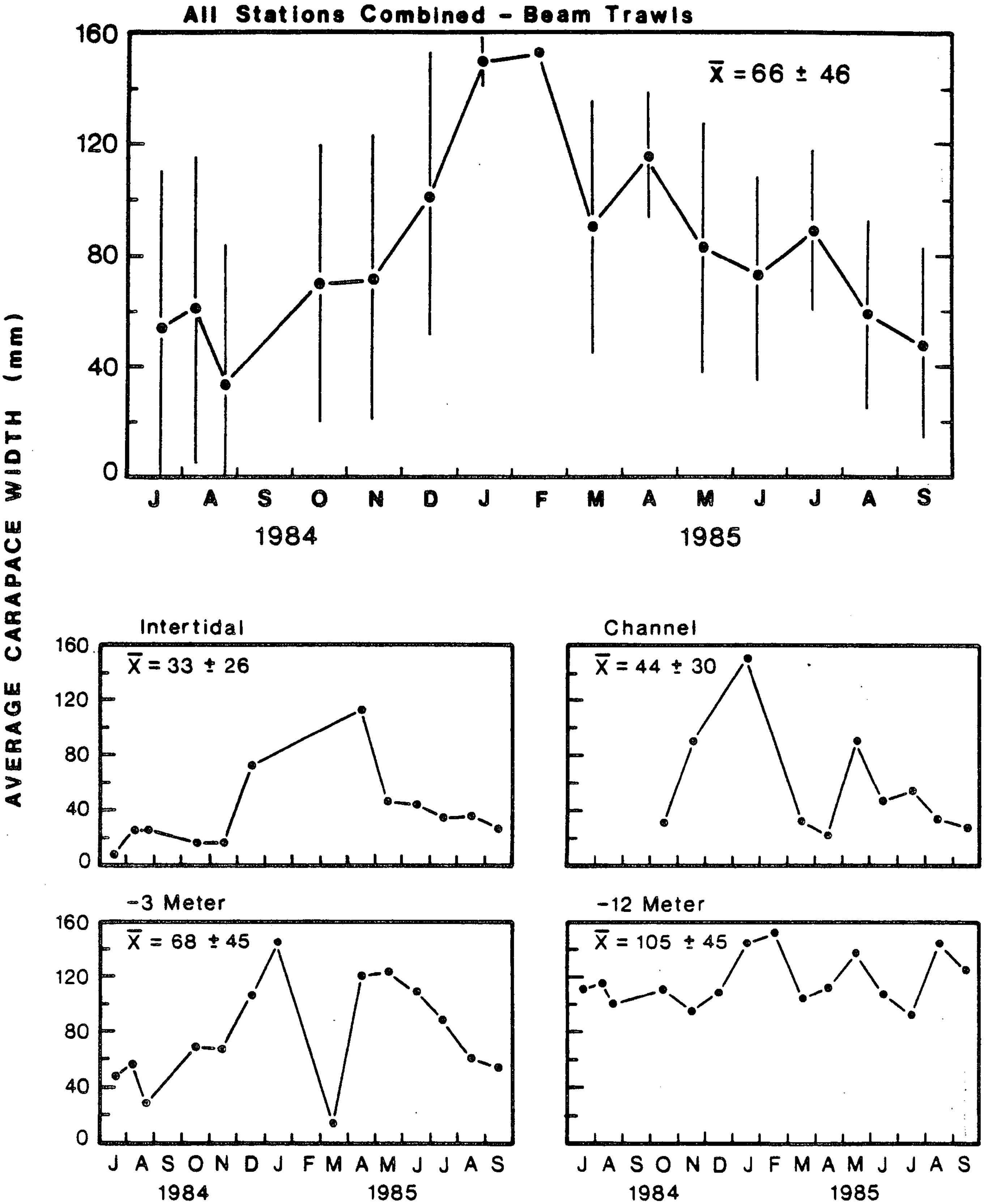

Figure 7. Average carapace widths (± 1 standard deviation) of Dungeness crab caught by beam trawl in Lummi Bay from July 1984 to September 1985.

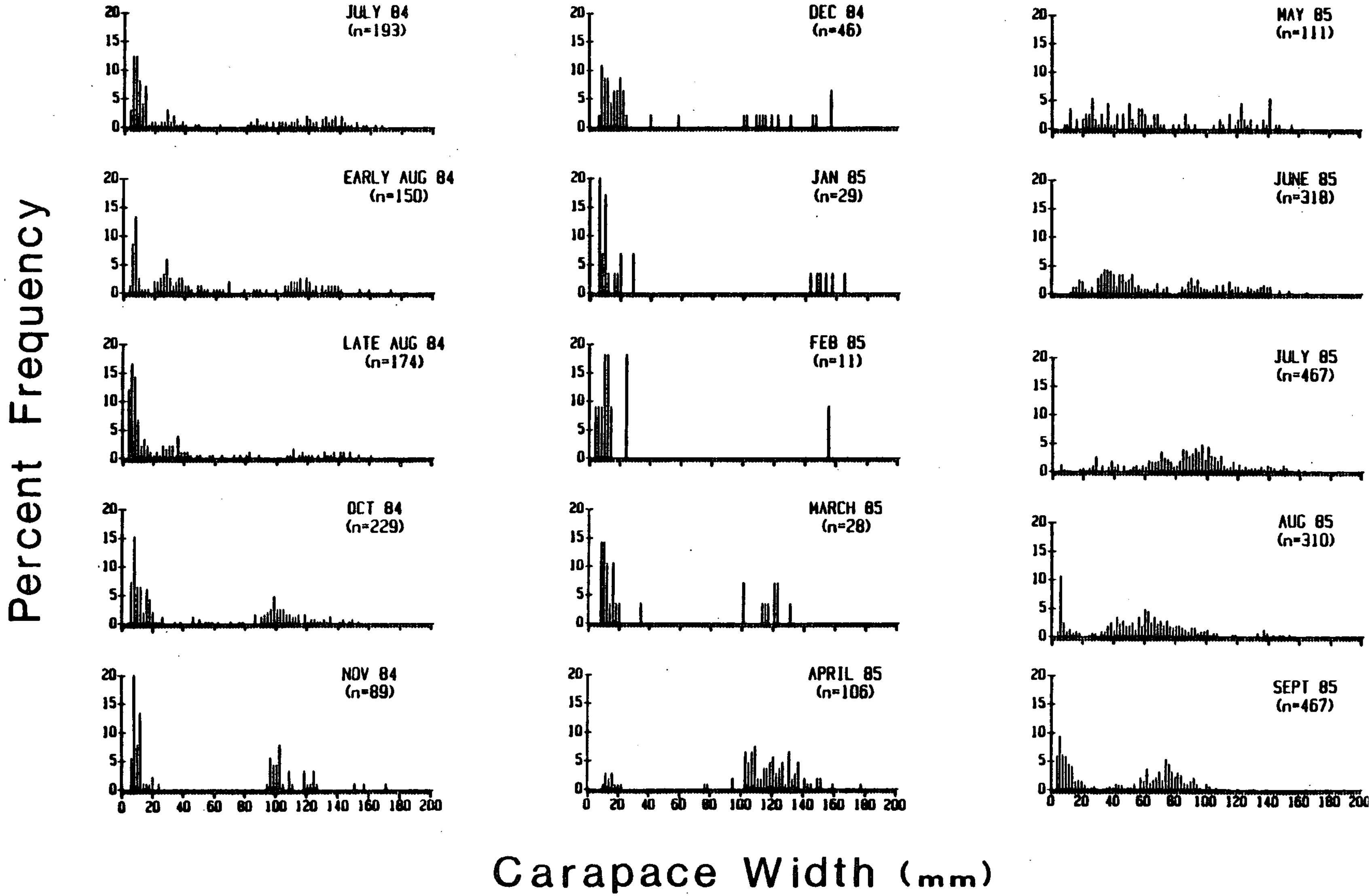

Figure 8. Size-frequency histograms of Dungeness crab caught in the beam trawl for each sample month, all stations combined.

The data presented above indicate that there was a gradual shift to deeper water as Dungeness crabs grew. Indeed, histograms (Fig. 9) of trawl-caught crab widths by depth substantiate this trend.

In June 1985, all 1+ crab (1984 year class) were caught intertidally or in the shallow channels cutting across the intertidal flats while 100% of 2+ crab (1983 year class) were caught at the -3 m stations. Older crab (1982 and older year classes) ranged between the -3 m and -12 m stations, probably moving to deeper waters by the following September.

As described above, the composition of Dungeness crab in the beam trawl catches was a function of both season and depth. Other factors which may affect the distribution (or catch) of Dungeness crab are substrate composition and/or epibenthic materials (which may provide cover or forage for fish, crab, and invertebrates), and speed of the trawl. The relationship of each of these factors to Dungeness crab abundances was analyzed by bivariate correlation analysis (SPSS Regression; Nie et al. 1975). The most signifcant Pearson correlation coefficient (r) was with trawl speed where r = -0.2251 (significance (p) = 0.001; Table 5) indicating a negative correlation between tow speed and crab catches. One reason for this negative correlation could be that the fastest tow speeds may not have allowed enough time for crabs buried in the substrate to emerge and be caught by the net. The slowest average speeds were at the intertidal, -3 m and -12 m stations where crab catches were usually the highest (Fig. 10, top). There was no significant correlation between trawl depth and Dungeness crab catches. However, as shown above, there was an obvious relationship between trawl depth and Dungeness crab age group.

There was no significant correlation between crab catches and total catch volume of substrate materials (Table 5), but there were significant correlations with several of the substrate components. There was a

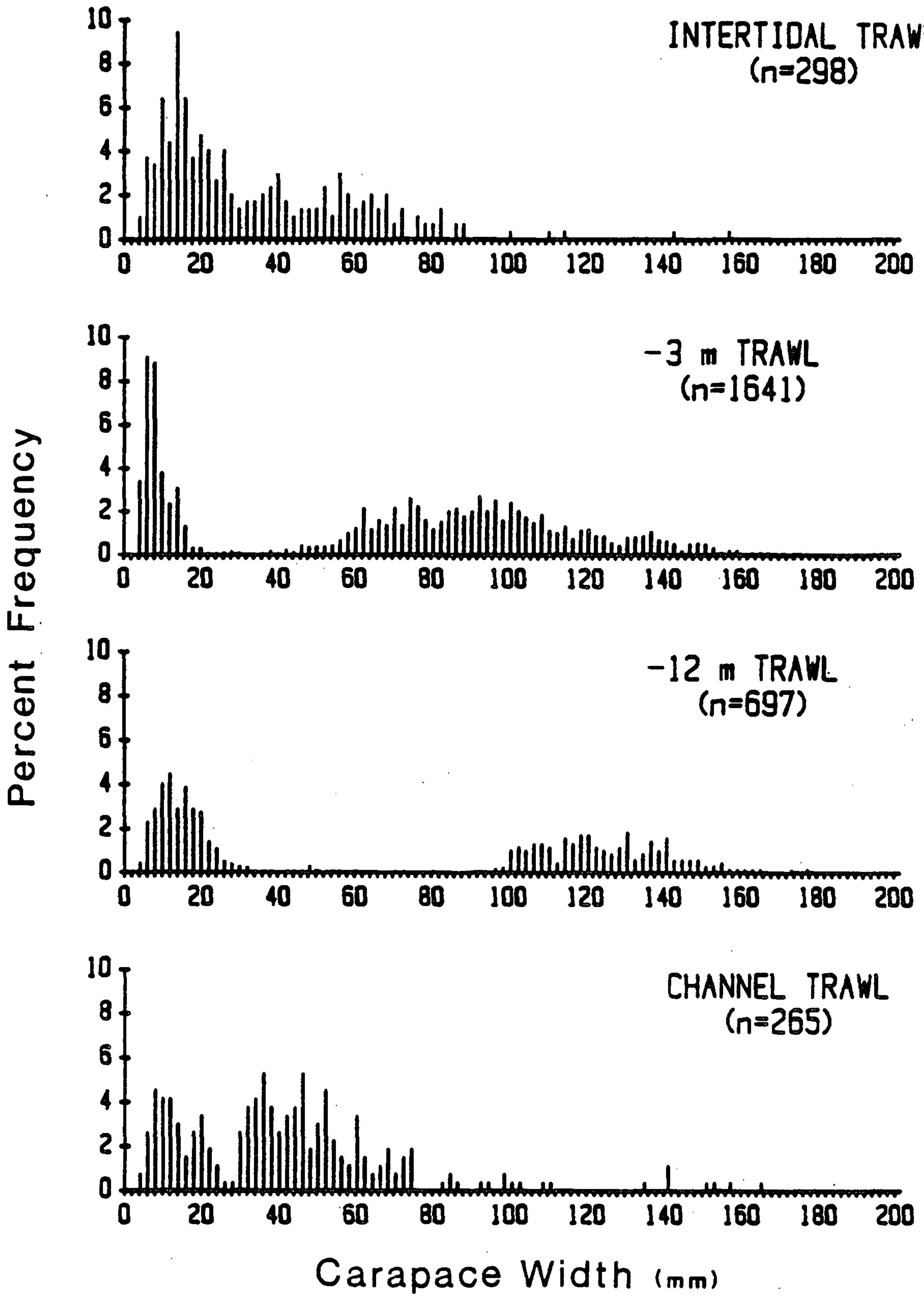

Figure 9. Size-frequency histograms of Dungeness crab caught in the beam trawls in four areas of Lummi Bay (stratified by depth), all sample months combined.

significant positive correlation of r = 0.1402 (p = 0.03, Table 5) with plant material (various algae, kelps, and eelgrass) while a significant negative correlation existed for rock (r = -0.1741, p = 0.01). Abundant plant material provides cover for juvenile crab (common in summer catches) in intertidal areas, and detrital algae and eelgrass were commonly caught at the -3 m stations where crab catches were highest on the average (642 crab/ha; Fig. 10, bottom; Fig. 7). Catches of rock (gravel and small cobble) had a significant negative correlation due (in part) to the fact that most rock was caught at Station 6 (a -12 m station) where Dungeness crab were rarely caught (Fig. 10, bottom). Indeed, Station 6 appeared to provide optimum habitat for red rock crab (C. productus) and purple crab (C. gracilis) in contrast to all other trawl stations in Lummi Bay which favored Dungeness crab.

Air and water temperatures and salinities at the trawl stations varied seasonally as would be expected. Water temperatures were lowest in December 1984 at about 5° to 6°C and highest in July 1985 at 16° to 18°C (Fig. 11). Intertidal water temperatures were almost always isothermal due to the shallow water depths (0 to 3 m) and high degree of wind and tidal-induced mixing. Bottom temperatures were slightly different at the -3 m and -12 m stations where warmest temperatures reached 16° and 13°C, respectively during the summer months. Salinities varied from lows of about 23 ‰ in July 1985 to highs of 33 ‰ in January 1985 (Fig. 12). Intertidally, there was a 1 to 2 ‰ difference in surface and bottom salinities during the winter when the near shore area was subjected to increased freshwater runoff, but essentially isohaline during the rest of the year. At the -3 m and -12 m stations, salinities were usually within 1 ‰ of each other for the bottom and surface waters with no consistent

Table 5. Pearson correlation coefficients (r) between beam-trawl derived Dungeness crab catches (Log_{10} transformation) and catch volumes, substrate materials, trawl depth and speed.

Factor	r	Significance of r
Catch volume	0.1069	0.07
Plant material	0.1402	0.03
Animal (fish and inverts)	-0.0865	0.12
Rock	-0.1741	0.01
Shell	-0.0995	0.09
Wood and debris	-0.0590	0.21
Trawl depth	-0.0922	0.10
Trawl speed	-0.2251	0.001

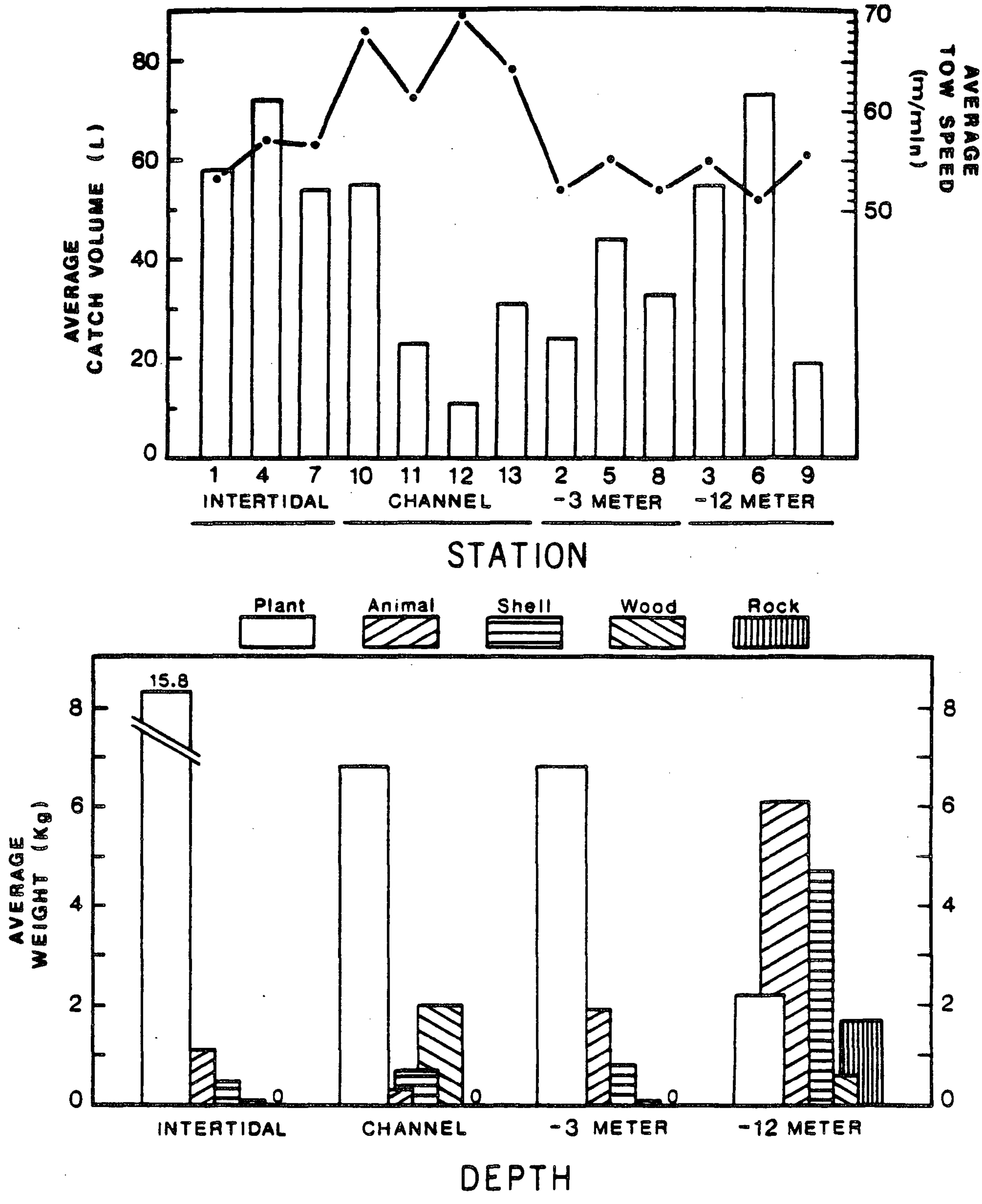

Figure 10. Top: Average beam trawl tow speed and volume of substrate material caught in the trawl at each Lummi Bay trawl station.

Bottom: Breakdown by category of substrate materials caught in the beam trawl for each set of stations stratified by depth.

pattern to the differences between them (Fig. 12). The one exception was during June of 1985 when a plume of low salinity (down to 23 ‰) water was detected (probably from the Fraser River in British Columbia).

Crab Pots

A total of 882 crabs were caught in crab pots set at the four sampling stations (see Fig. 5 for locations) in Lummi Bay from August 1984 to Sept. 1985 (Appendix Table 1). Dungeness crab accounted for 93.4% of the catch with the remainder being C. productus (5.6%), C. gracilis (0.2%) and Telmessus (0.8%) (Table 4). The Dungeness crab male/female ratio in the crab pot catches was essentially 1/1, 95% had shell conditions of hard or very hard and no gravid females were caught (Table 4). Only 5% of the Dungeness crab in the pots were soft or very soft vs. 31% in the beam trawls. This difference suggests that soft crabs were less active or more reclusive than hard crabs. The absence of gravid females in the pots is probably also indicative of a reclusive behavior during egg incubation or aggregation of females in other locations.

The seasonal catch of crabs in pots followed the general pattern of the beam trawls with highest numbers caught during summer and fall (June-Nov.) and least caught during winter (Dec.-March) (Fig. 13). The highest average crab catches (17.8 ± 4.5/pot) were from Station 1, that closest to the dike in the North Channel, although there were no statistically significant (t-test; p = 0.05) differences in catches between any of the North Channel stations (1-3) versus the Middle Channel station (4) (Fig. 13). The Middle Channel (control) station was closest in average catch to the North Channel Station 2, with 10.4 ± 3.1 vs. 12.3 ± 2.3 crabs/pot, respectively.

The average carapace width of all Dungeness crab caught in the crab pots was 108 ± 31 mm, with monthly averages ranging from a high of 127 mm

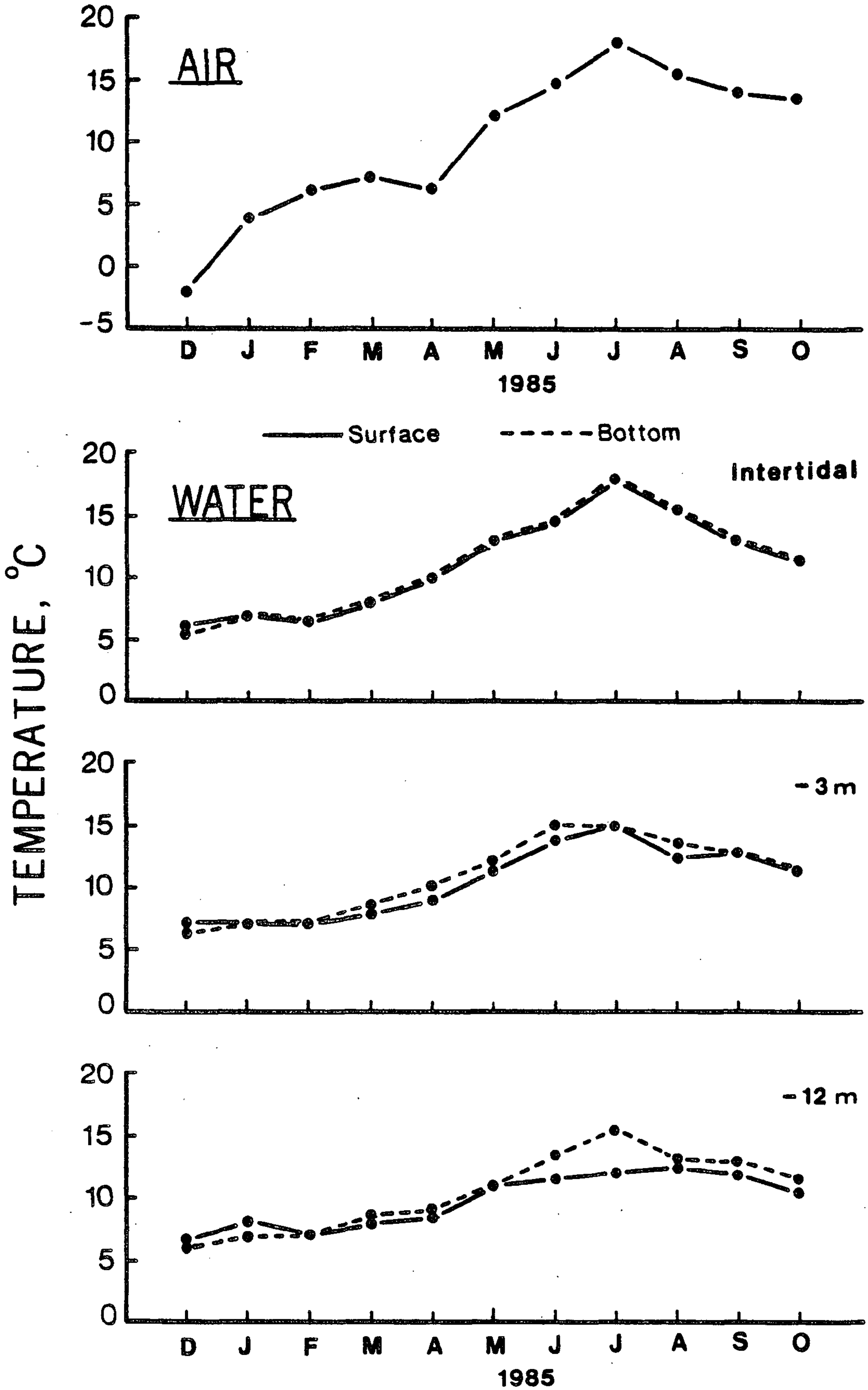

Figure 11. Air and water temperatures from trawl stations 7 (intertidal), 8 (-3 m) and 9 (- 12 m) in Lummi Bay from December, 1984 to October, 1985.

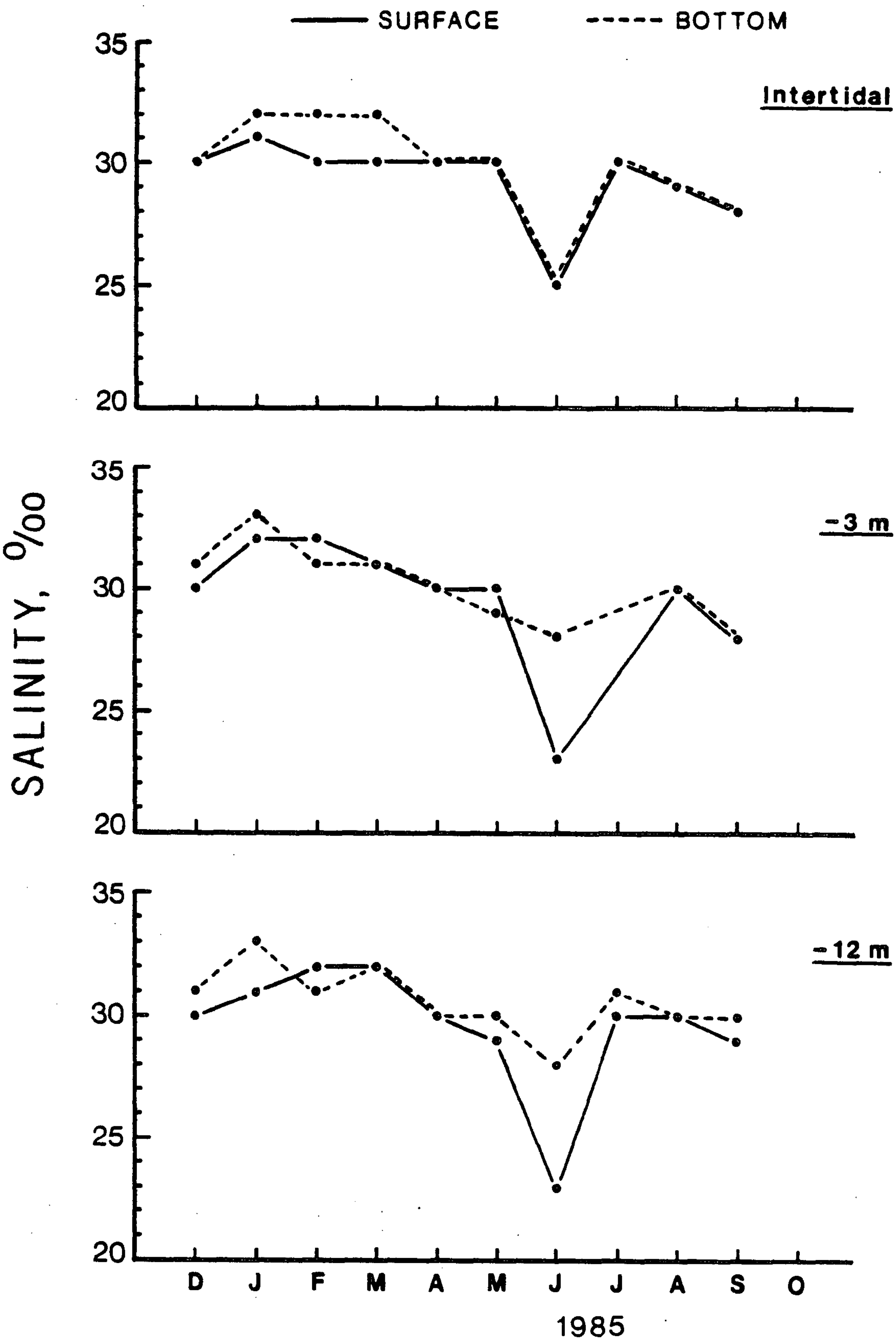

Figure 12. Surface and bottom water salinities from trawl stations 7 (intertidal), 8 (-3 m) and 9 (-12 m) in Lummi Bay from December 1984 to October 1985.

to a low of 74 mm (Fig. 14). This is in contrast to sizes of Dungeness crab caught by beam trawl which averaged between 33 to 44 mm CW. Rarely did Dungeness crab <50 mm in size enter the pots (or if they did enter, they were able to escape back out the crab pot entrance channel triggers). Most crabs caught in the pots were in the age groups 1+ to 2+ with few distinct patterns evident by month (Fig. 15). One distinct pattern that was evident was the influx of large crabs in the 120 to 150 mm size range during April and May. Approximately 90% of these crab were large, non-gravid females which then disappeared in June to be replaced almost exclusively by 2 year old crabs averaging about 70 to 80 mm (Fig. 15).

For the North Channel stations (1-3), there was an increase in the average size of Dungeness crab with distance away from (westward) the aquaculture pond dike (Fig. 16). There was no significant difference (t-test; $p = 0.05$) in average crab sizes between any of the North Channel stations versus the Middle Channel (control) station. However, the average size of Dungeness crab at the Middle Channel station was closest in agreement to North Channel Station 2 with average sizes of 112 ± 26 and 119 ± 27 mm, respectively.

Intertidal Quadrat Sampling

A total of 21 intertidal survey trips were conducted between July 1984 and October 1986. All three transects were not surveyed on each trip due to constraints of manpower and time. Surveys of Transect 3 were discontinued after June of 1985.

Five species of crab were caught in the intertidal quadrat samples of which 89.8% were Dungeness crab (in contrast to 93.4% in pots and 71.2% for the beam trawls; Table 4). Only 9.3% of the Dungeness crab sampled from the intertidal quadrats were large enough to be sexed (i.e., >20 mm CW) of

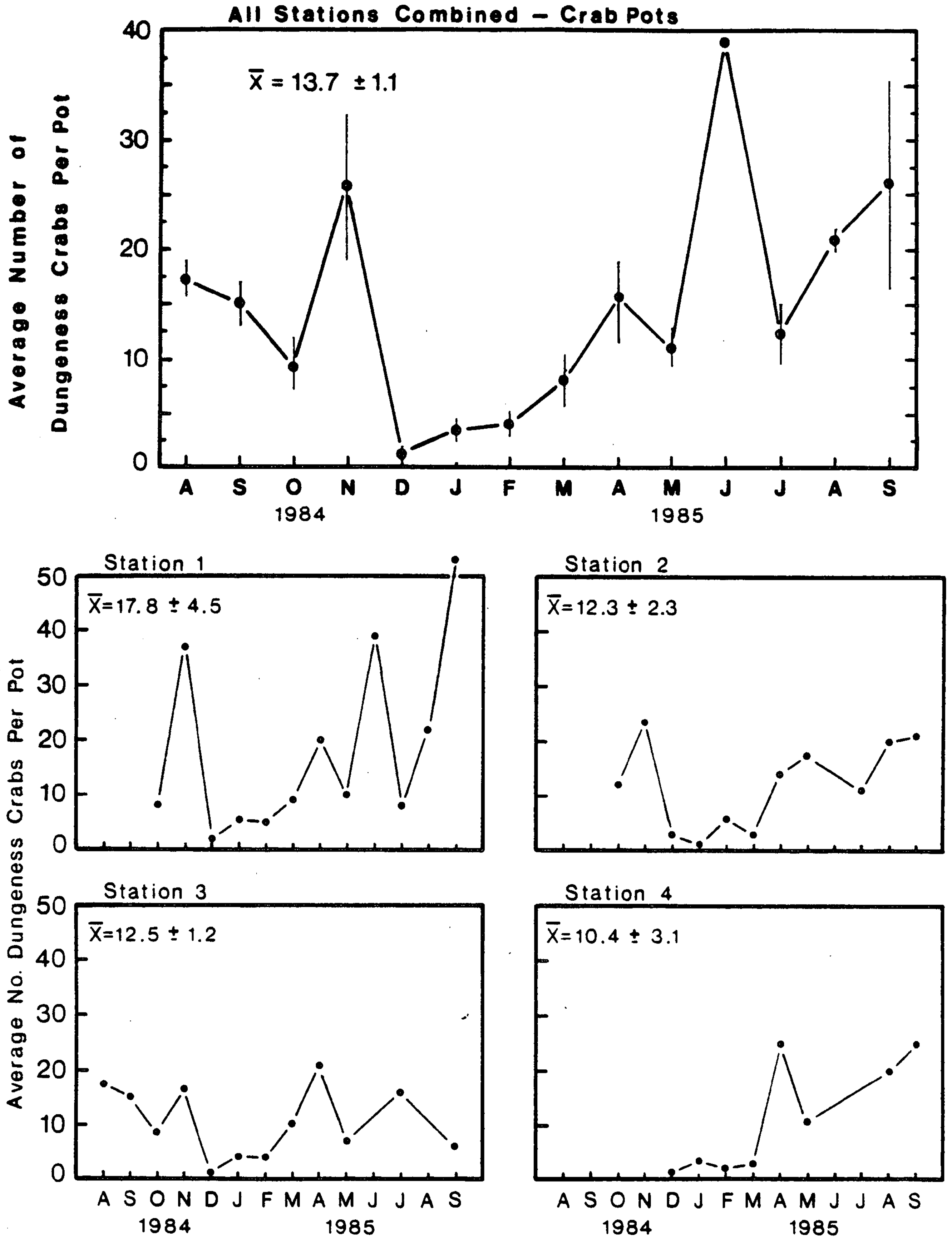

Figure 13. Average catches (± 1 standard error) of Dungeness crab in crab pots set at four stations in Lummi Bay from August 1984 to September 1985 (see Fig. 5 for station locations)

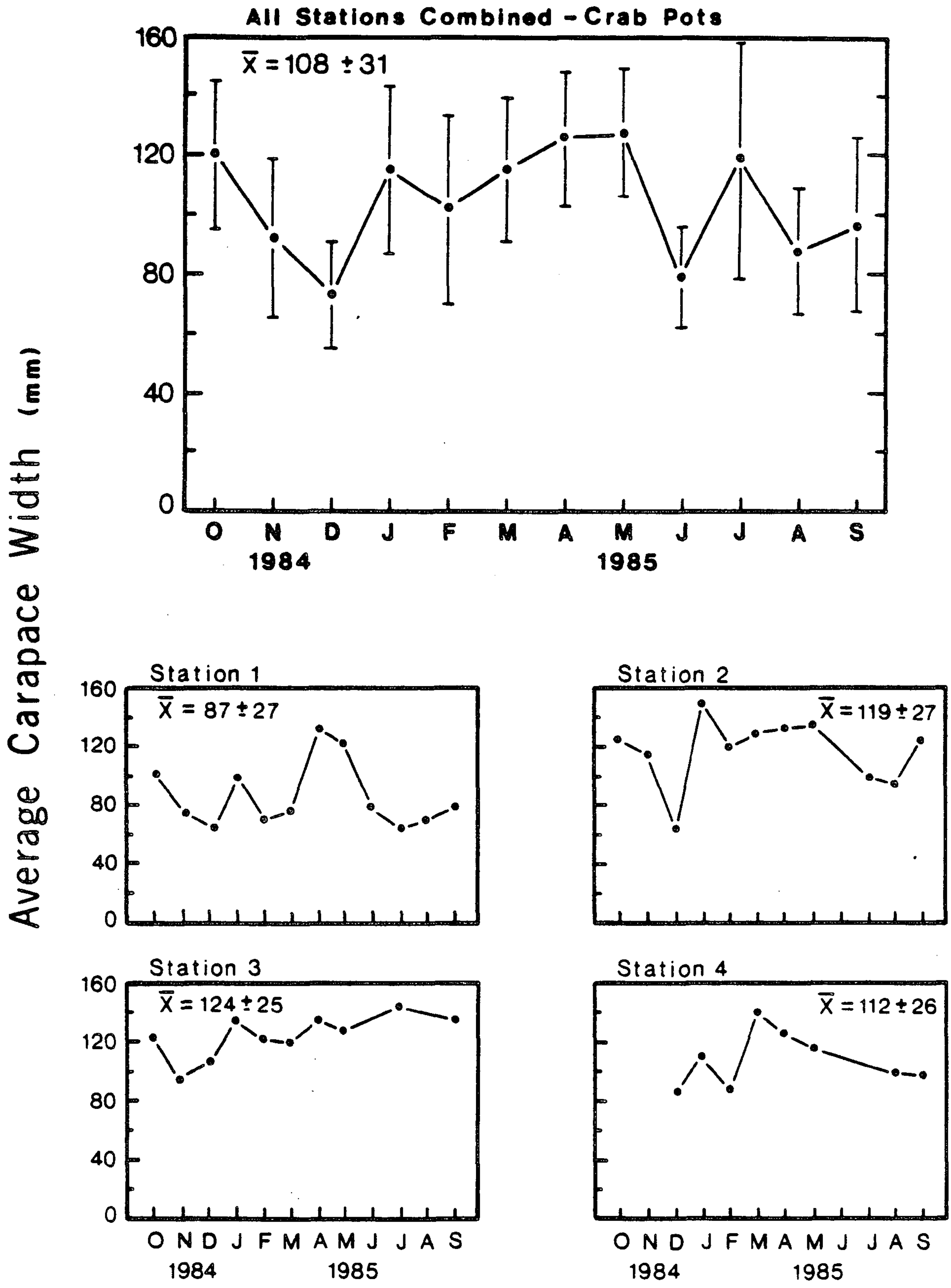

Figure 14. Average carapace widths (± 1 standard deviation) of Dungeness crab caught in crab pots in Lummi Bay from October 1984 to September 1985.

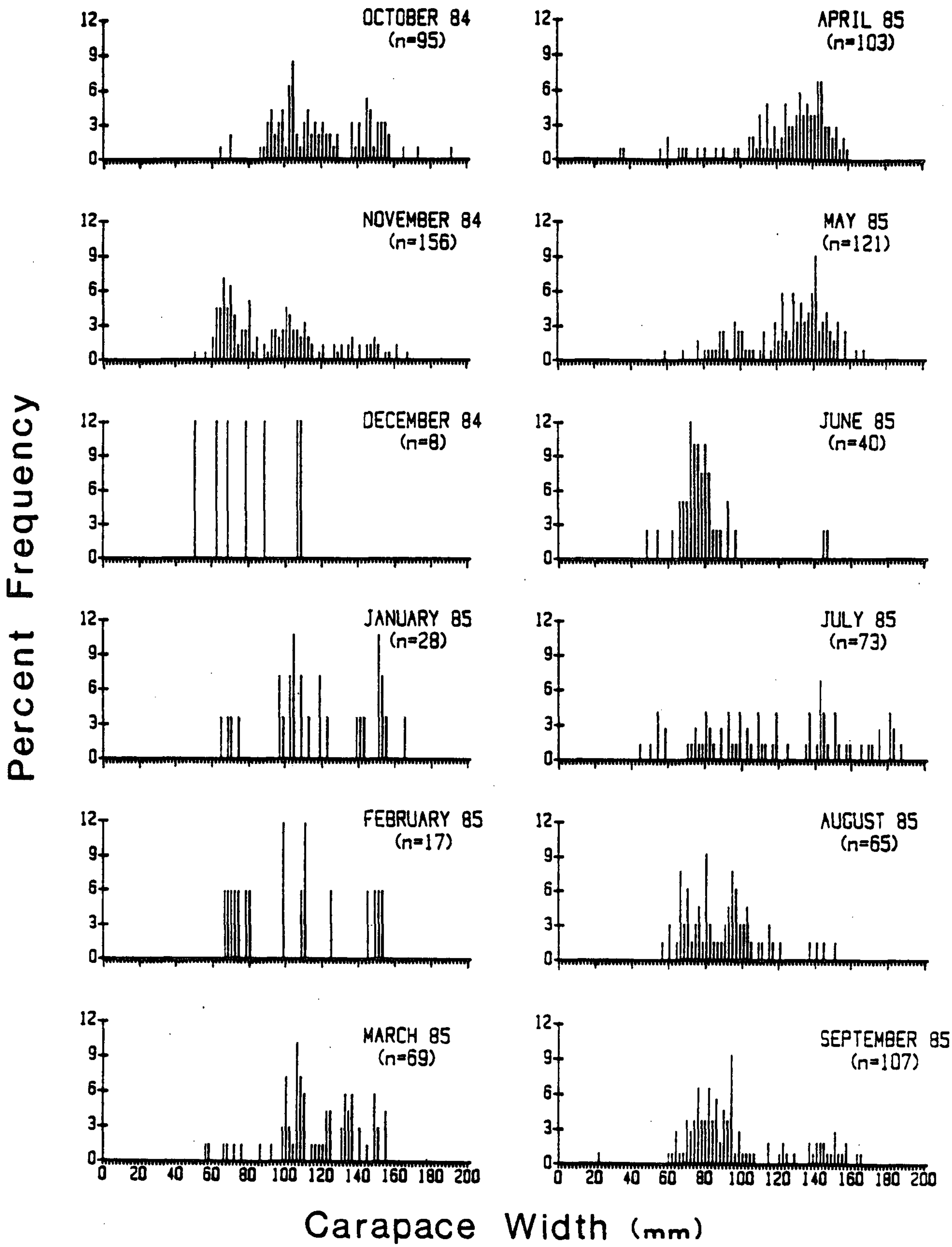

Figure 15. Size-frequency histograms of Dungeness crab caught in the Vexar-modified crab pots by sample month, all stations combined.

which the sex distribution was essentially even (Table 4). No gravid females were caught in the intertidal samples and only 1 of 643 Dungeness crab caught in the intertidal samples was >100 mm.

Intertidal abundances of Dungeness crab in Lummi Bay showed a seasonal cycle similar to that determined for both the beam trawls and the crab pots (Appendix Table 2). A rapid increase in crab density occurred through the months of July and August, and peaked in mid-August of both 1984 and 1985 (Fig. 17). These increases coincided with the periods of settlement and were, in fact, due to the abundances of newly metamorphosed first and second instar crabs. Following the period of highest settlement in August 1984, a general decline in density was observed, falling from a peak average of 8.8 crab/m^2 to less than 1/m^2 in June 1985.

During 1984, megalopae were observed in the intertidal samples from the first Lummi Bay sampling effort (July 12) until September 21. In 1985, the first megalopae appeared on July 1; however, none were observed after August 28, suggesting a shorter period of settlement for this year.

The occurrence of first instars coincided with that of the megalopae for both years and underscores the longer period of settlement observed in 1984 than in 1985. The 1985 settlement appeared greater in magnitude than 1984 with a high average density of 18.2 crab/m^2 in 1985 compared to 8.8 crab/m^2 for 1984 (Fig. 18). However, by October 1985, the average density had fallen to nearly the same value as for October 1984 (2.7/m^2 and 2.1/m^2, respectively).

Growth of 0+ crabs continued from the time of settlement until October, after which time little growth was seen until the following May. During this period of arrested growth (October through early April), substrate and water temperatures had fallen below 10°C. The 1984 year class resumed growth in about April 1985 (Fig. 19).

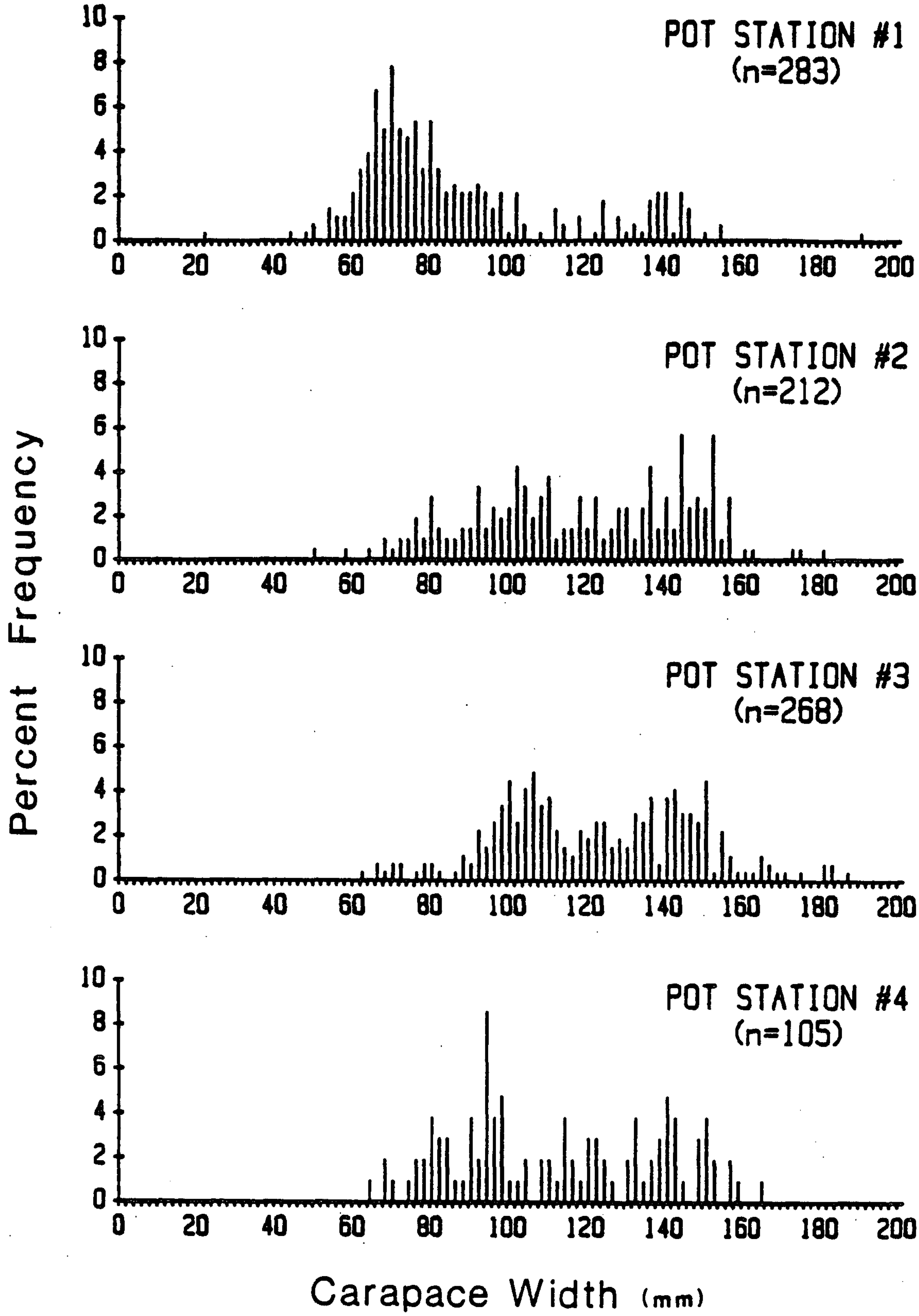

Figure 16. Size-frequency histograms of Dungeness crab caught in the Vexar-modified carb pots set at each pot station in Lummi Bay, all sample months combined (see Fig. 5 for station locations).

The virtual disappearance of the previous year class from the June 1985 intertidal samples coincided with their appearance at the channel and subtidal beam trawl stations (Fig. 8). The emmigration of this year class from the intertidal flats into the channels closely preceded recruitment of the 1985 year class (Fig. 19).

The annual pattern of crab abundance and timing of arrival and movement was similar on all three transects (Fig. 18 and Appendix Table 2). Statistical comparisons (t-test) of average crab densities and carapace widths (calculated using only survey trips on which both Transects 1 and 2 were sampled) showed no significant ($p = 0.05$) differences between the two transects for either parameter.

On Transect 1 the vertical (and consequently, horizontal) distribution of 0+ and 1+ crab followed a trend of increasing abundance with decreasing elevation in the intertidal zone. The lowest average density, 1.3 crab/m^2, occurred between +1.0 and +2.0 feet above MLLW while the highest, 4.3 crab/m^2, occurred between -1.0 and -2.0 feet below MLLW (Fig. 20). Densities above the MLLW mark were roughly half of those below this level.

Within Lummi Bay, 98.5% of the juvenile crabs sampled in the intertidal zone were associated with some form of plant cover. Crab densities varied according to the plant species, ranging from a low of 2.1 crab/m^2 for mixed _Zostera_ (i.e., a mixture of _Z. marina_ and _Z. japonica_) to 5.7/m^2 for _Ulva_ (Fig. 21 and Table 6). An ANOVA performed on the average crab densities grouped by plant species showed no significant ($p = 0.05$) difference between them. When all plant categories were grouped, there was significantly ($p = 0.05$) greater density compared to samples with no plant cover. The percent cover provided by the different plant species was generally positively correlated to crab density (Fig. 22), a trend best

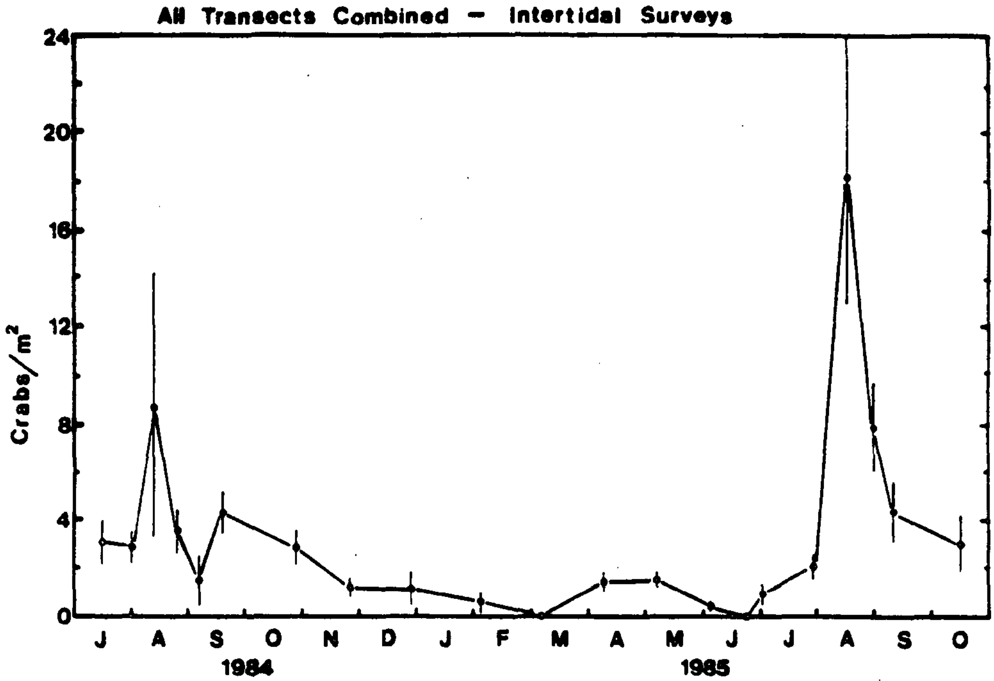

Figure 17. Average (± 1 standard error) densities of juvenile Dungeness crab from July 1984 to October 1985, all intertidal transects combined.

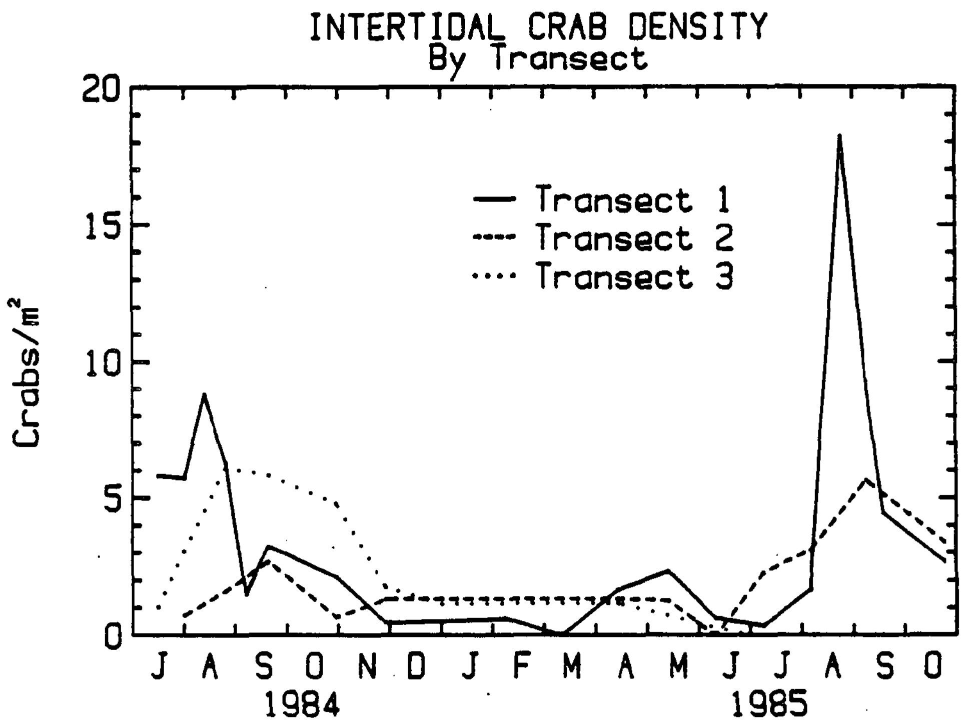

Figure 18. Average densities of juvenile Dungeness crab for intertidal transects 1, 2 and 3, July 1984 to October 1985 (see Fig. 5 for transect locations).

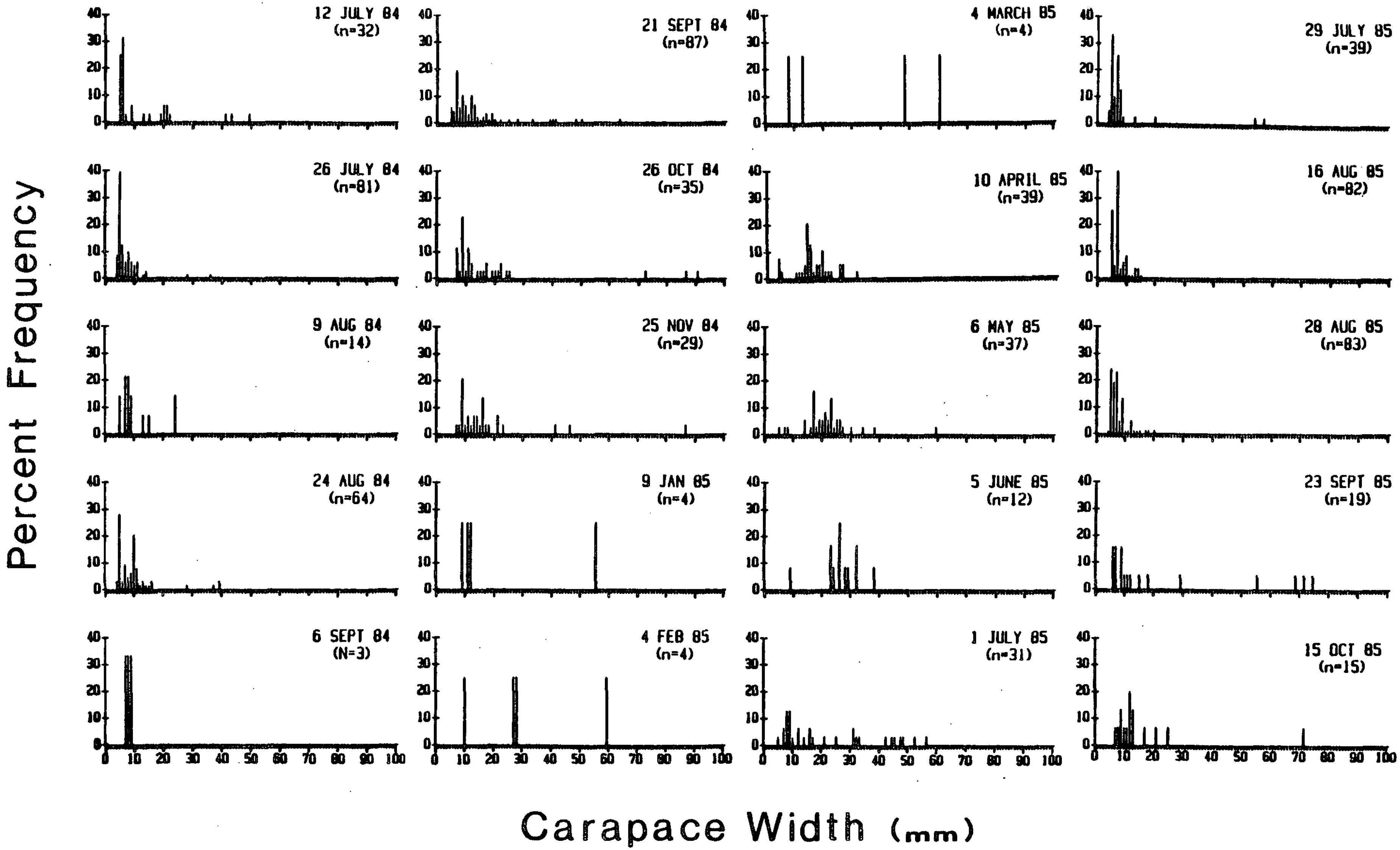

Figure 19. Size-frequency histograms of Dungeness crab caught in the intertidal quadrat samples along three transects in Lummi Bay, all transects and stations combined by month.

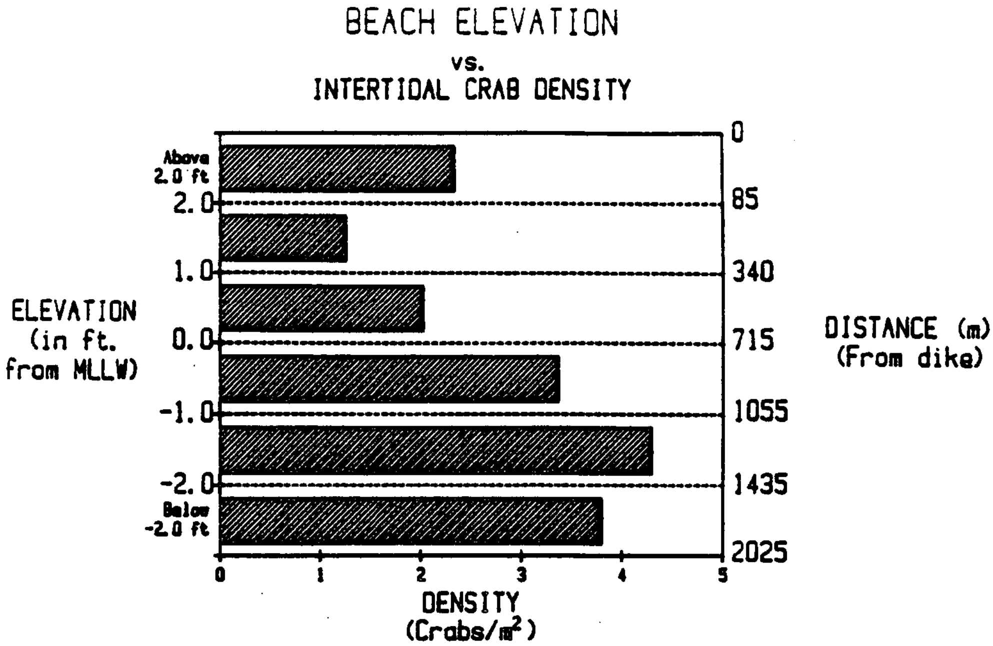

Figure 20. Average densities of 0+ and 1+ Dungeness crab by elevation on Transect 1, July 1984 to October 1985.

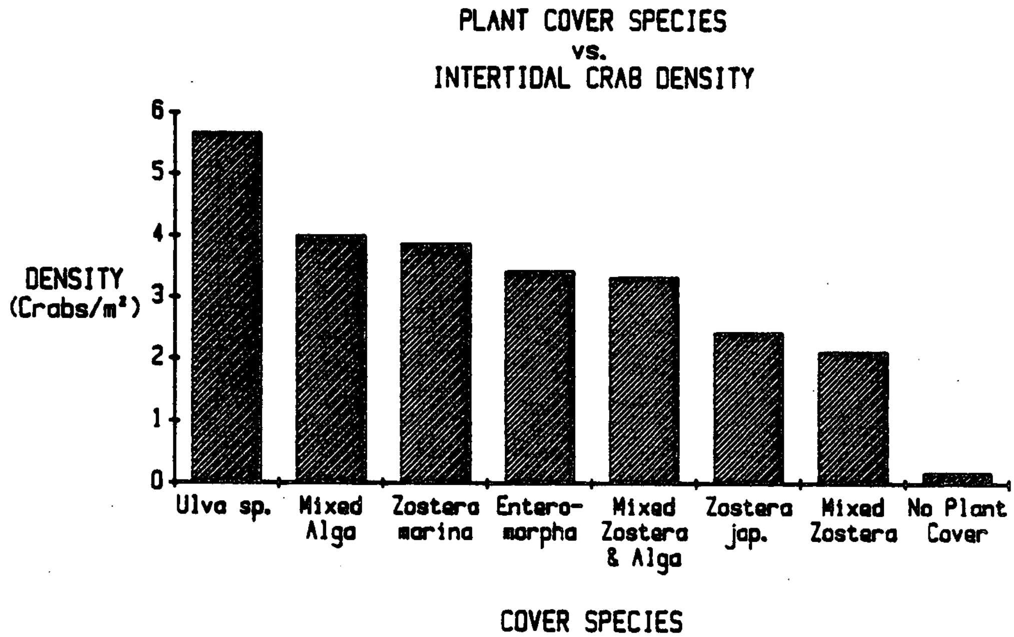

Figure 21. Average crab densities associated with different intertidal plant species, all transects combined.

Table 6. Distribution of intertidal sampling effort and catches of Dungeness crab by plant cover species, all transects and survey trips combined.

Plant cover species	Average crab density (Crab/m^2)	Sampling Effort		Crab Distribution	
		Number of samples	Percentage of samples	Number of crab	Percentage of crab
Zostera marina	3.9	347	36.6%	336	50.7%
Zostera japonica	2.4	123	13.0	75	11.3
Ulva sp.	5.7	38	4.0	54	8.1
Enteromorpha sp.	3.4	14	1.5	12	1.8
Mixed *Zostera*	2.1	15	1.6	8	1.2
Mixed Algae	4.0	9	0.9	9	1.4
Mixed *Zostera* & Algae	3.3	191	20.1	159	24.0
No plant cover	0.2	207	21.8	10	1.5
Other	0	5	0.5	0	0
TOTALS		949	100.0	663	100.0

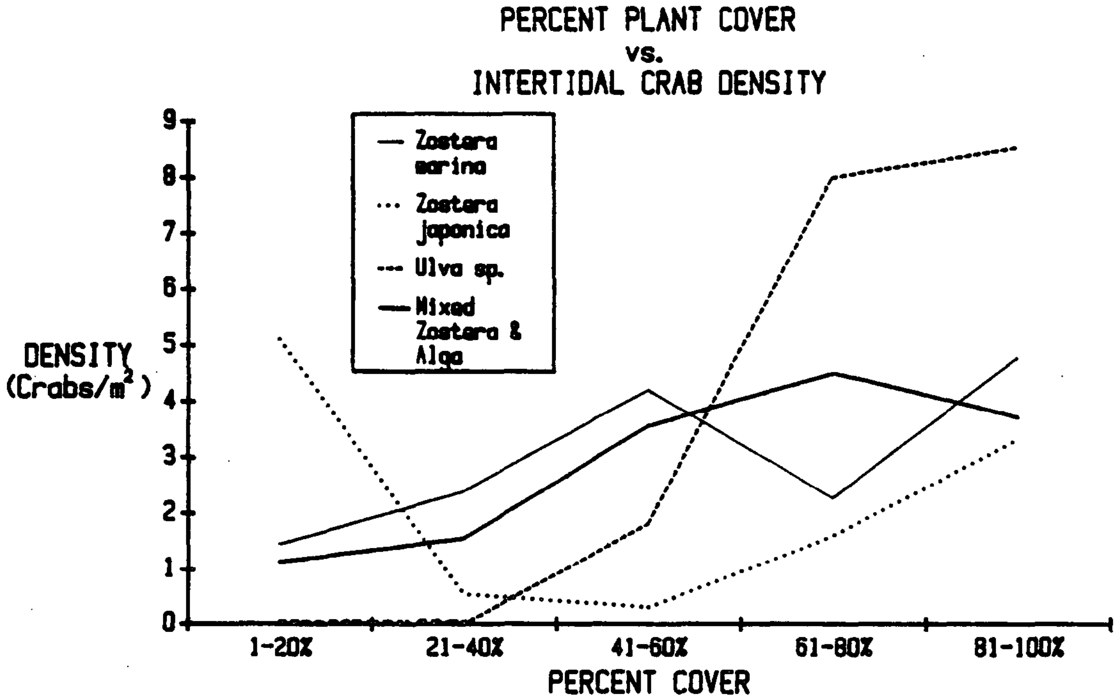

Figure 22. Average crab densities by percent plant cover for the four most abundant intertidal plant species. Averages are plotted for each 20% interval, all transects combined.

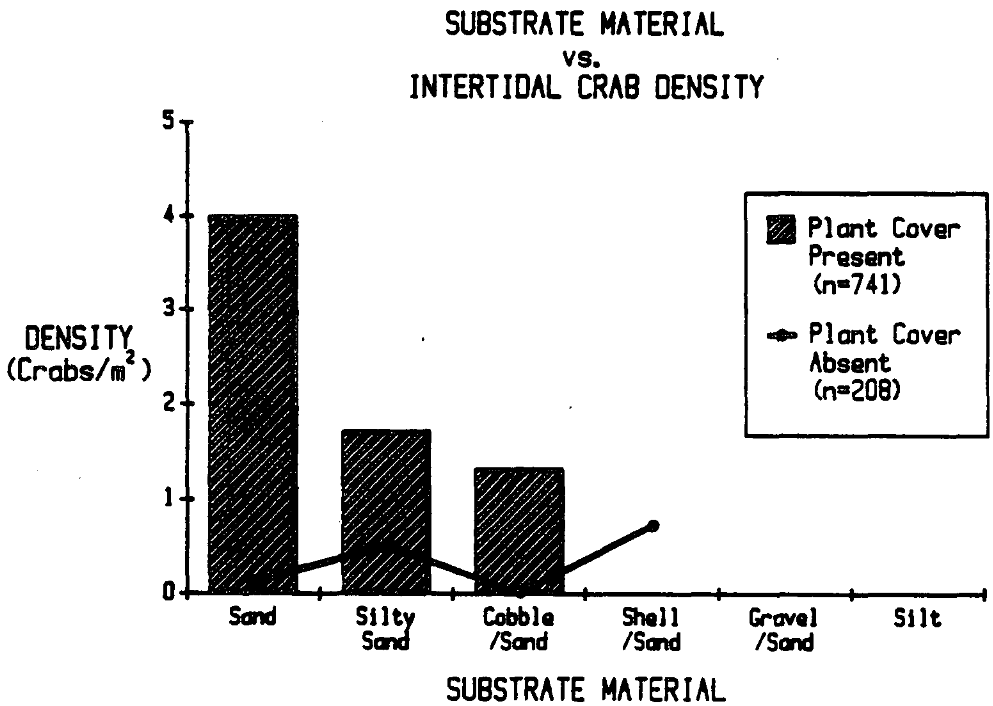

Figure 23. Average crab densities associated with different substrate materials, both with and without plant cover, all transects combined.

demonstrated for *Ulva*.

Average crab densities associated with substrate materials were quite different depending upon whether plant cover was present or not (Fig. 23). Crab densities were lower in the absence of plant cover, but the relatively uniform nature of the substrate within Lummi Bay made it difficult to discern any well defined preference for substrate materials in the absence of plant cover.

Temperatures were recorded for air, substrate, and water in standing pools and adjacent channels (Fig. 24). Little variation was observed between the different transects; however, seasonal fluctuations were high (e.g., average substrate temperatures ranged between a low of 0.1°C in February to a high of 22.2°C in August 1985). Salinity is shown for pools and channels within the intertidal region in Figure 25. The lower channel salinities presumably represent freshwater input from the Lummi River and other terrestrial sources.

DISCUSSION

It is evident from the data presented above that the population characteristics of Dungeness crab in Lummi Bay are complex and dynamic and that Lummi Bay provides important habitat for most of the post-larval life history stages of this species. General patterns of Dungeness crab distribution, seasonality, recruitment, survival, and growth have emerged from this study. Some of the most important findings can be summarized as follows:

1) Dungeness crab was the dominant crab species (excluding kelp crabs) in Lummi Bay and comprised 78% of all crabs sampled followed by *Cancer productus* (8%), *C. gracilis* (6%) and *Telmessus* (3%).

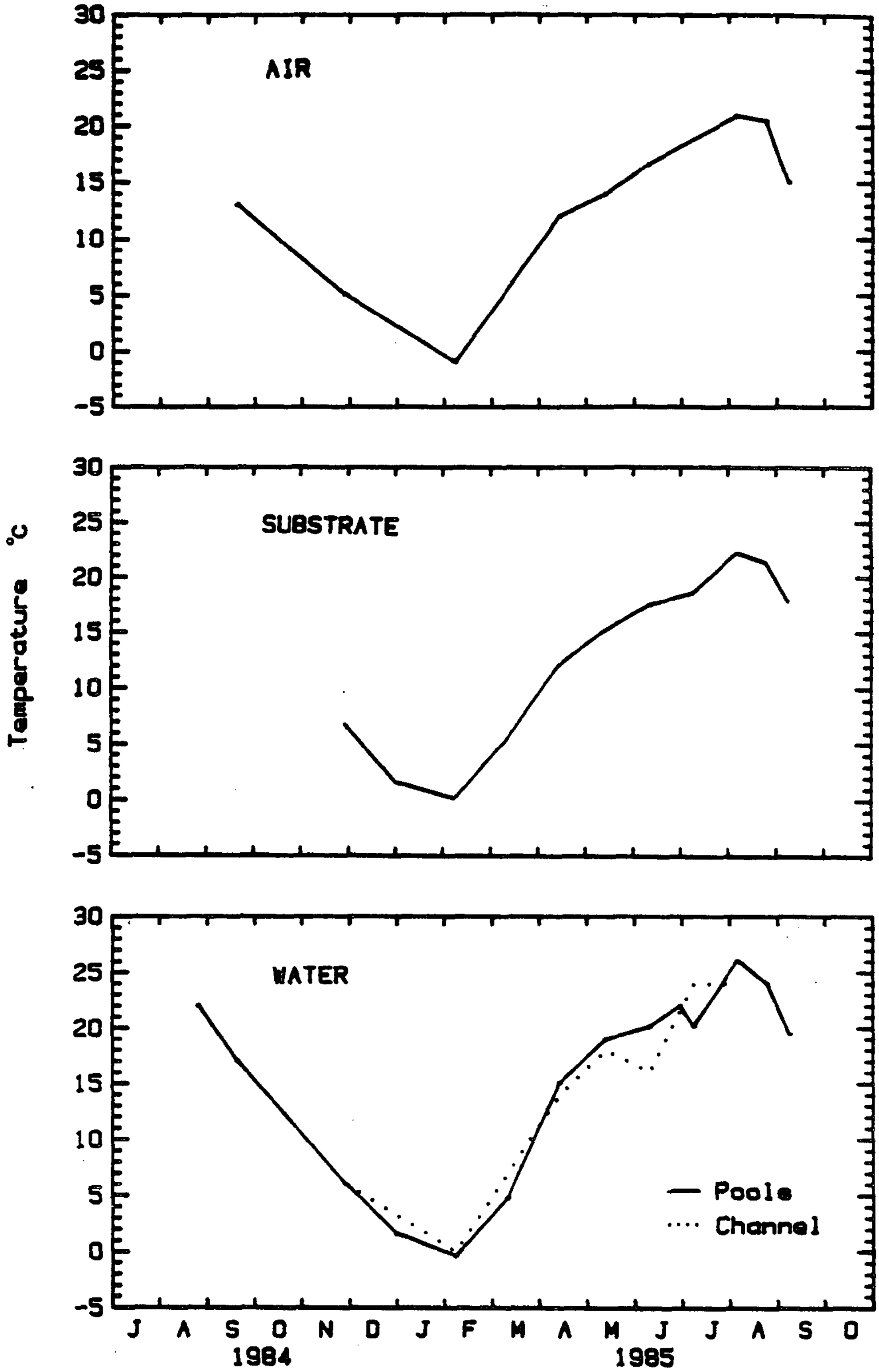

Figure 24. Average temperatures at low tide for the Lummi Bay intertidal region.

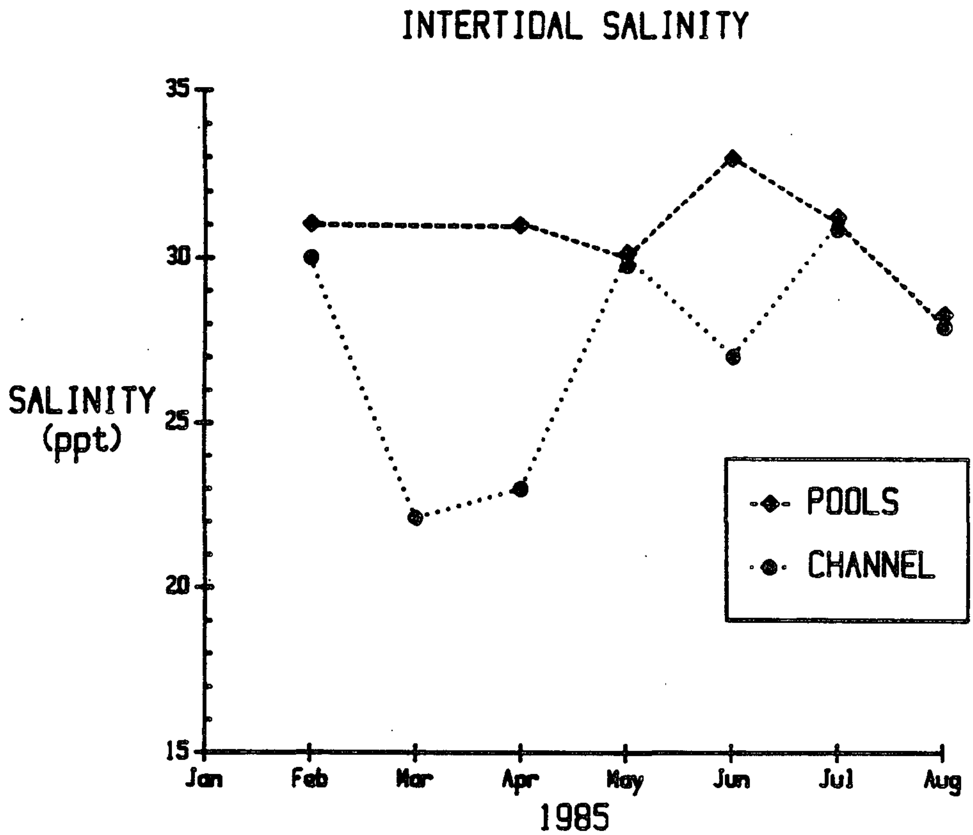

Figure 25. Average salinities at low tide for the Lummi Bay intertidal region.

2) Each of the three sampling methods catches crabs differently in regard to size class selectivity, catch efficiency and degree of quantification possible. The intertidal quadrat sampling was virtually 100% efficient, easy to quantify, but was limited to intertidal areas frequented by crab <1 year old. Beam trawls were possible in all areas, could be quantified reasonably well, but varied in capture efficiency from less than 1% for young-of-the-year (YOY) in eelgrass (Dinnel et al. 1985) or gravid females solidly buried in the substrate (Armstrong et al. 1987a) to almost 100% during the summer when crabs are active in sandy areas devoid of cover (Dinnel et al., in progress). Pots can be fished in areas difficult to trawl but do not catch small crab (<50 mm) and such data provide only relative measures of crab abundance.

3) Regardless of the sample method, a seasonality in crab abundance was evident with the highest catches during the summer months and the lowest during the winter. Intertidally, this pattern of seasonal abundance was due to the summer settlement of many post-larval crabs with few of these new recruits surviving until winter. Subtidally, the apparent low winter crab populations may be due to poor gear efficiency because of the relatively inactive and reclusive (i.e., buried in the substrate) nature of this species during the cold winter months.

4) Settlement of 0+ crab begins in about July of each year and continues until September. Mortality of the new recruits is high during this time, probably due to predation by a variety of fish, birds and invertebrates (including cannabalism). The YOY are highly associated with any type of cover where survival may be highest because of reduced predation.

5) One of the most interesting findings of this study is that Dungeness crab age group distribution is dependent on depth and that older animals often aggregate by sex. Generally, successful recruitment of 0+ crabs occurred in intertidal and shallow subtidal vegetated areas. The 0+ remain in the shallow areas for the first year, averaging only about 15-20 mm CW in the first winter. Growth resumes during the summer of the second year when they reach an average size of about 80 mm and move into channels and shallow subtidal areas along the intertidal "dropoff." During the summer of their third year, these crabs average about 100-130 mm in size and move out of the shallow water areas of Lummi Bay where they may form aggregations by sex as noted in several other areas of Puget Sound (Dinnel et al., in progress; Dinnel et al. 1986a). Larger crabs in their fourth year (or older) may then move back to shallow water where the males enter the pot fishery and the females may aggregate during the egg incubation period.

The stratification and movement of crabs by age group is outlined in detail by the size-frequency histograms in Figure 26. This figure shows a cycle of Dungeness crab abundances at four strata (intertidal, shallow channel, the -3 m "dropoff" area, and -12 m depth offshore) in Lummi Bay from July 1984 to October 1985. The arrows show that the 1984 year class moves out of the intertidal into the shallow channels in about June and thence into the "dropoff" (-3 m contour) area by July where they grow quickly to an average size of about 80 mm by October. At about the same time, the 1983 year class was found to move away from the -3 m "dropoff" area out to the -12 m offshore area (and probably beyond) so that intermixing of the year classes is

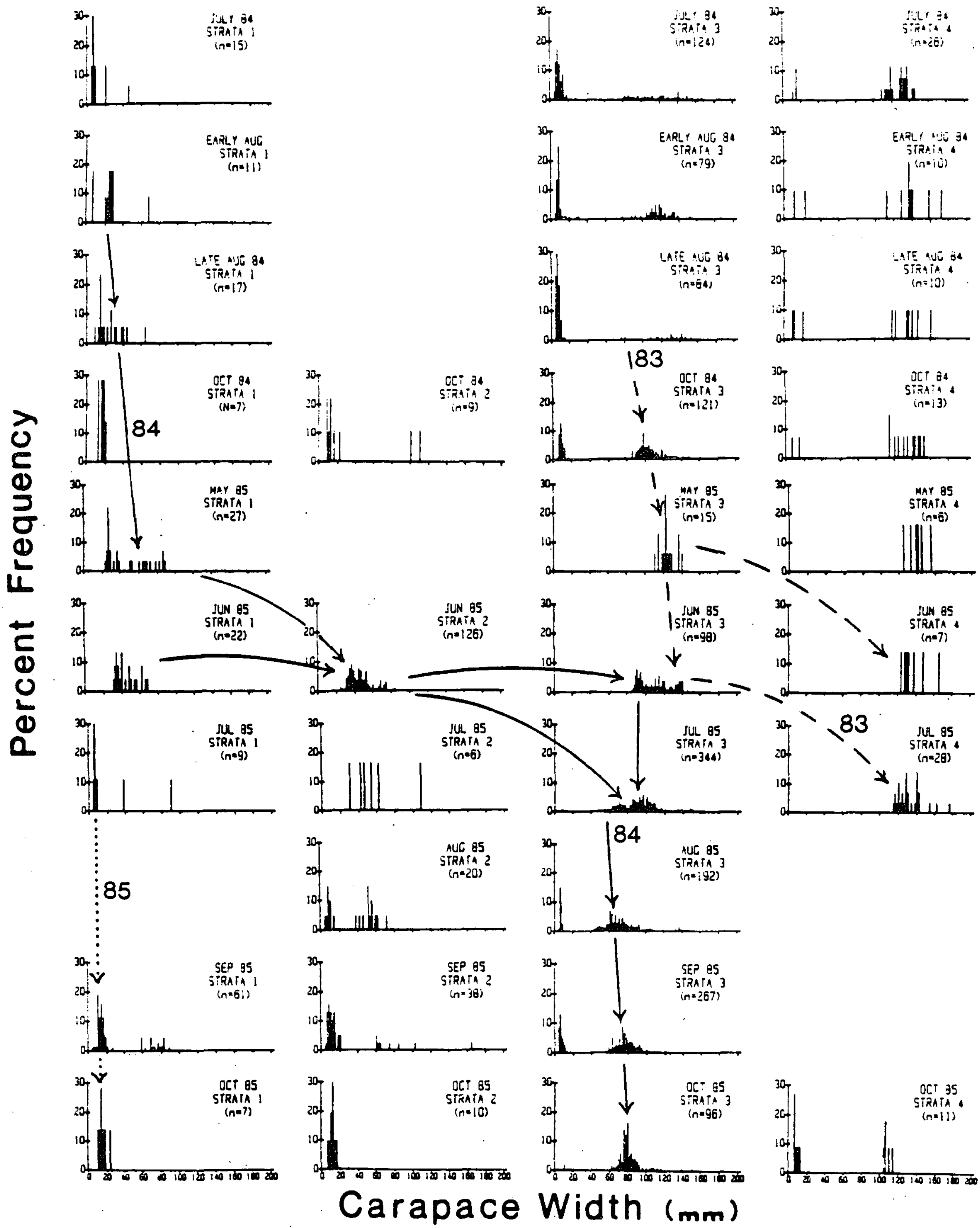

Figure 26. Size-frequency histograms of Dungeness crab caught in the beam trawl. Data for each sampling period is divided into four depth strata: 1 = intertidal; 2 = shallow channel; 3 = -3 m; and 4 = -12 m depths. Plots appear only where sufficient data were present. The arrows show the general movement of the 1983, 1984 and 1985 (as labeled) year classes during 1985.

minimized. Following the synchronized outward movements of the 1984 and 1985 year classes, the 1985 YOY metamorphose from megalopae and establish residency in their favored strata, the intertidal/shallow subtidal eelgrass zone where they grow to about 20 mm by November, essentially "hibernate" during the winter and begin the cycle anew in 1986.

6) The sex ratio of crabs caught in the crab pots fluctuated seasonally, exhibiting a greater number of males from July through October. During March, April and May, females dominated the catches (Fig. 27). This was attributable to mature, non-ovigerous females, >100 mm carapace width, which appeared first in March catches at the deepest station (3) and not until April and May at the channel stations. It appears that following egg hatching these females become active and begin foraging, making them susceptible to capture by pots. Their appearance first at the deeper station (3) and subsequently at the shallower channel stations (1, 2, & 4), suggests a preference (while ovigerous) for greater depths than what is available in the channels.

Potential Impacts of the Proposed Navigation Channel

The primary objective of this study was to define potential effects on Dungeness crab of dredging a navigation channel through the Lummi Bay tidal flats. The potential effects can be divided into short term and long term effects.

Short Term Effects

Short term effects can be defined as the crab entrained and killed by initial dredging of the navigation channel. Dredging of the navigation channel would impact about 14.2 ha and remove 493,000 cubic meters of material. Of this 14.2 ha, approximately 3.6 ha of eelgrass beds would be removed, the remaining acreage being unvegetated shallow channel areas (COE

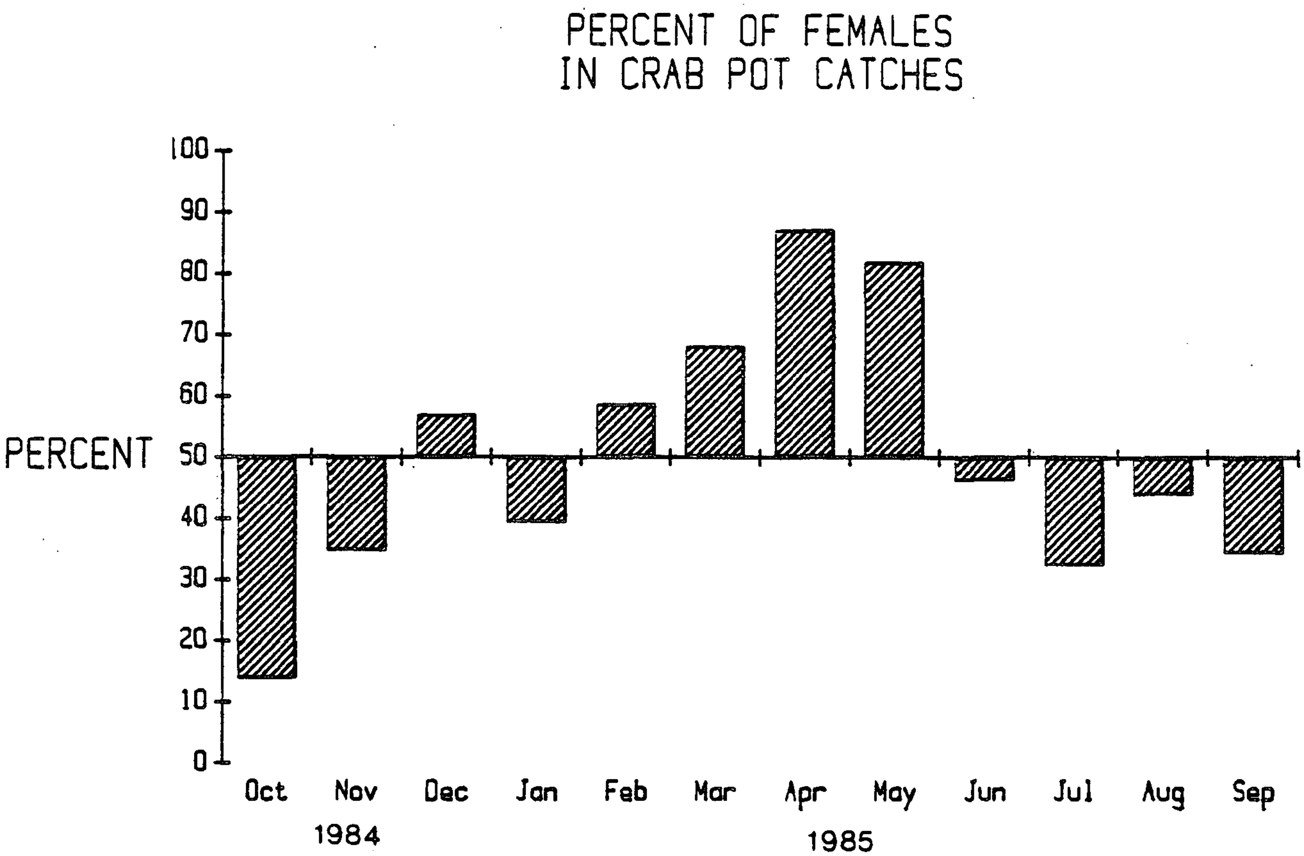

Figure 27. The percent of female Dungeness crab in monthly crab pot catches for Lummi Bay (Pot Stations 1 through 4 combined). Note the dominance of females in the March, April and May 1985 catches.

1983; Lummi Indian Fisheries 1984). Dredging is currently planned using a hydraulic dredge (with confined pipeline disposal) during the winter (December-March) to minimize impacts to other species (e.g., juvenile salmon and herring spawning). How, then, do these potential dredge-related impacts translate into crab mortality given the 1984-85 crab data presented above?

In the intertidal portion of the proposed navigation channel, Dungeness crab densities averaged about 1 crab/m^2 during the December to March period (intertidal quadrat samples; Fig. 18). During this same time, almost no crab were caught by beam trawl in the same area (Fig. 6). However, we suspect that the beam trawl efficiency was greatly reduced during this period due to inactivity and burial by the crabs in the substrate. Our rationale for this is based on our diver transect observations in other areas where crabs were uncovered during winter surveys by disturbing the bottom by hand which resulted in uncovering of buried lethargic crabs (Armstrong et al. 1987a). Hence, for purposes of this discussion, we will use the <u>average overall</u> beam trawl-derived crab density for the channels (160 crab/ha; Fig. 6) and the average winter densities (1.0 crab/m^2) found in the winter of 1984 intertidal surveys (Fig. 18).

Using the preceeding assumptions, the number of crab in the proposed dredge area can be calculated as follows:

1) [3.6 ha eelgrass] [crab density of 1/m^2] =
   36,000 crab (primarily 0+)
2) [10.6 ha of shallow channel] [160 crab/ha] =
   1,696 crab (primarily 1+ or older)

The total estimated number of crab in the proposed dredge area (based on winter 1984-85 surveys would be 36,000 + 1,696 = 37,696. These calculations show that by far the greatest number that could be affected is YOY crabs living in the eelgrass beds.

The calculations become less certain from this point on. The best crab entrainment/mortality data to date has been generated from studies in coastal estuaries such as Grays Harbor (Tegelberg and Arthur 1977; Stevens 1981; Armstrong et al. 1982), systems that are substantially different than the eelgrass flats of Lummi Bay. In Grays Harbor, Stevens (1981) and Armstrong et al. (1982) found that crab entrainment rates generally ranged from 0.13 to 0.65 crabs/cubic meters of material dredged by a pipeline suction dredge operating with a conventional cutterhead. Unfortunately, no estimates were given in these studies as to how many crab were actually present in the dredged area. Indeed, if we use the lowest value of 0.13 crabs/cubic meter and apply this value to the Lummi Bay Navigation Channel, we would calculate that 64,090 crab would be entrained - more than estimated to be present in the winter of 1984/85 based on the above calculations. From another dredge entrainment study in Grays Harbor, Dinnel et al. (1986b) estimated that a hopper dredge, operating with a draghead rather than a cutterhead, entrained only 15.9% of the Dungeness crab present in the area based on side-by-side beam trawl studies. However, this information is also of limited use because of differences in size of crab (average CW = 88 mm) and habitat (deeper channels, no vegetation) in that study compared to Lummi Bay. Hence, we are left with two methods of calculating what may happen in Lummi Bay. A "least impact" best case scenario indicates that 15.9% (or 5,994 crabs; based on Dinnel et al. 1986b) of the crabs present could be entrained and killed (assuming pipeline disposal behind a dike would kill 100%). A "worst impact" scenario suggests that essentially all of the estimated 37,696 crabs would be entrained and subsequently killed. There are two main reasons why a worst impact scenario might be realized:

1) Most of the crabs potentially affected in Lummi Bay will be young crab (0+ or 1+ age classes) which typically survive by hiding rather than fleeing to escape as older crab usually do. This "hiding reflex" will be characteristic of small crab in the area of the proposed channel where vegetation is present.

2) Temperatures during the proposed winter dredge period will be very low (typically 6-8°C). Low temperatures reduce activity in crabs and seem to induce a "semi-hibernation" mode which would make it very difficult for them to move away from a dredge suction head. This "hibernation" mode was quite evident during winter intertidal sampling. Small crabs dug from the substrate were quite torpid and moved only slightly compared to crabs dug out during warmer temperatures.

The calculations presented above are based on the density of crabs observed with the best, but potentially inefficient, sampling gear for buried crabs and only during the winter of 1984-85. Presently, we do not know how much interannual variability in recruitment, density and survival of Dungeness crab occurs in Lummi Bay or, in general, for the inland waters of Washington. Thus, these abundance estimates should be reassessed for the year when dredging takes place.

It was estimated above that somewhere between 5,994 and 37,696 crabs may be killed by the dredging activity proposed for Lummi Bay (assuming crab abundances similar to 1984 during the year of dredging). Most of these crabs would be of the 0+ and 1+ age groups, of which only a fraction would naturally survive to enter the fishery (or reproductive effort for the females). While natural mortality rates are poorly quantified for most age classes of Dungeness crab, two values do appear in the literature. Jow (1965) estimated a natural annual mortality rate of 0.15 based on tag returns. Gotshall (1978), also working with tag returns, estimated a natural annual mortality range of 0.005 to 0.183.

These rates, however, are not satisfactory for application to the present study since both Jow and Gotshall tagged only adult crabs (i.e., crabs >100 mm carapace width). Current work by Armstrong et al. (1987b), using several years of data from Grays Harbor, Washington, suggests that natural mortality of late 0+ and 1+ age crabs may be as high as 84% to 90%. Hence, the application of any natural mortality factor to the foregoing Lummi Bay crab impact analysis should proceed with caution and the understanding that a high degree of uncertainty is involved, especially since juvenile crab habitats in Puget Sound are substantially different from Grays Harbor.

One additional aspect of the life cycle which is poorly known makes short-term impacts difficult to predict. Very few gravid females were caught during this study. However, diving surveys used in conjunction with trawl surveys in a similar area of North Puget Sound have shown that high densities of gravid females can be present along the "dropoff" at depths of -2 to -6 m below MLLW (the subtidal eelgrass zone; Armstrong et al. 1987a). In this case the beam trawl was an ineffective tool for catching these females since they remained solidly bruied in the substrate, even when lightly disturbed. Presently, the distribution of mature females in and around Lummi Bay is unknown. A large number of mature females were found in the crab pots in the spring of 1985 and again in April 1986 beam trawls (Dinnel et al., in progress). This pattern suggests that the gravid females do utilize the nearshore area of Lummi Bay during the winter but are not caught in the sampling gear until they shed their eggs and begin moving around in the spring. Diver surveys are recommended for future assessment for gravid females.

Long Term Effects

Long term effects on crab populations are considered those caused by long term loss (or gain) of preferred or necessary habitats. COE (1983) predicts the loss of 3.6 ha of eelgrass habitat during initial dredging. However, eelgrass would be replanted over a portion of this area. Additionally, strong arguments have been presented (Hage 1984a, b) that stabilization of the North Channel by dredging would eliminate channel meandering which erodes portions of the adjacent eelgrass flats. Thus, the combination of mitigation as eelgrass transplants together with cessation of lateral erosion may increase the amount of eelgrass habitat present in Lummi Bay.

Regardless of gain or loss of eelgrass habitat, preliminary estimates can be generated for future crab losses (or gains) based on the 1984-85 crab data. Initial settlement of 0+ in 1984 and 1985 was as high as 8.8 and 18.2 crab/m^2, respectively. As noted above, these densities then declined to approximately 1 crab/m^2 during the winter and remained stable at this level until spring (recent sampling in 1986 suggests roughly the same pattern of settlement and survival). The issue of paramount importance regarding the value of eelgrass habitat in Lummi Bay is "how many crab does this habitat produce that eventually recruit to the commercial/sport fishery" (and how many females survive to reproductive age). Clearly, this value cannot be determined by the magnitude of initial settlement since most of the first or second instars do not survive. The value, then, might be determined by assessing the density of crab surviving to a size at which they are ready to migrate to a more suitable habitat. For 0+ Dungeness crab in Lummi Bay, migration appears to occur in June following the year of settlement as is evident by the disappearance of these young crabs from the intertidal samples (Fig. 18) and the increase of this age class in the May and June beam trawls (Fig. 8). Hence, the first good measure of a given year class success might be obtained by intertidal quadrat surveys during the first set of good daytime low tides (typically in April) before movement off the flats takes place.

Using this idea as a guide, the average density of the 1984 year class in April 1985 was about 1 crab/m^2 (same density as noted above for the December-March period since mortality was essentially zero during the winter; Fig. 18). We can gauge the value of eelgrass beds for this year class as equal to approximately 1 crab/m^2. Hence, the permanent loss (or gain) of 1 ha of eelgrass could be equivalent to the loss (or gain) of approximately 10,000 crab in each succeeding year (interannual variability in recruitment success or survival will change this estimate). Predicting crab recruitment to the fishery (or gravid females) is again another very uncertain step since no good measure is available for natural mortality rates for any age class of crabs in Puget Sound.

A second interactive aspect of the dredging modification of the North Channel concerns the change in depth of what is now a very shallow channel to a depth of about -4 m below MLLW. Evidence from the beam trawl sampling suggests that dredging may substantially improve the habitat for 1+ and 2+ age classes of crab. Figure 6 shows an average estimated abundance of crab in the shallow channels of 160 crab/ha while trawls at the -3 m depth contour produced crab catches equal to an average abundance of 642 crab/ha, a substantial increase over the shallow channels. Consequently, dredging of the aquaculture pond for the moorage basin (-3 to -4 m depth) should also improve this area for crabs.

RECOMMENDATIONS

Recommendations for future studies are divided below between general (those designed to understand the basic ecology of Dungeness crab and the fishery) and project-specific (those designed to monitor actual impacts of the proposed project).

General Recommendations

Almost two years of field data have been collected on Dungeness crab in Lummi Bay. Because of this, and because of the importance of crab resources in this area, we highly recommend continuation of long-term monitoring to refine the type of information presented above, determine ranges in year-to-year variability in the population dynamics of the various year classes, and further determine the importance of nearshore tidelands to recruitment of this valuable species. Specifically, we recommend:

1) Continuation of intertidal quadrat sampling for monitoring recruitment densities, survival and growth of future year classes. This should be done by establishing a permanent test plot (e.g., 100 m x 100 m in the area of the North Channel) and sampling randomly during the summer for estimates of settlement strength. This same plot should be sampled to determine overwintering survival once or twice in early spring (April) before the 0+ crabs move into channels.
2) Trawling should be continued during spring and summer at stations specifically selected to produce the best information on 1+ and 2+ age classes of crabs. This information, together with the intertidal data, can then be compared to subsequent commercial catches in Lummi

Bay to shed light on several important questions: e.g., is year class success controlled by density dependent factors and if so, at what age?; how important is Lummi Bay as a nursery area?; do juveniles raised in Lummi Bay return to the Lummi Bay fishery?, etc.

3) Three and four year old crabs apparently spend some time in deeper waters. These areas should be located, and the related habitat values for Dungeness crab described.

4) The location of gravid Dungeness crab females in or around Lummi Bay should be determined by diving surveys.

Project-Specific Recommendations

Specific recommendations for monitoring the impacts of channel dredging include:

1) Determine densities of crab present intertidally and in the channel subtidally prior to dredging.

2) Monitor the dredge spoils plume (assuming a pipeline disposal system) for crabs.

3) Quantify crab use of revegetated areas and of the newly dredged channel (and moorage basin) using the data presented in this report as a baseline and also comparing with the undredged middle (control) channel.

4) Determine presence or absence of gravid females in the outer navigation channel area prior to dredging.

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APPENDIX TABLES

Appendix Table 1. Average catches by month of four species of crab in Vexar-lined crab pots set at crabpot stations 1-4 in Lummi Bay during 1984 and 1985.

Month/Year	Sample Size(n)	Average Hours Fished	Average Number of Crabs			
			C. magister	*C. productus*	*C. gracilis*	*Telmessus*
Station #1 = Inner North Channel:						
Oct., 1984	2	23.5	8.0	0	0	0
Nov.	2	22.5	37.0	0	0	0
Dec.	1	68.0	2.0	0	0	0
Jan., 1985	2	23.0	5.5	0	0	0
Feb.	1	29.0	5.0	0	0	0
March	1	24.0	9.0	0	0	0
April	1	22.0	25.0	0	0	0
May	2	24.5	10.0	0	0	1.0
June	1	24.0	39.0	0	0	1.0
July	1	24.0	8.0	0	0	2.0
Aug.	1	4.0	22.0	0	0	0
Sept.	1	22.0	53.0	0	0	0
Station #2 = Outer North Channel:						
Oct., 1984	2	23.5	12.0	1.0	0	0
Nov.	2	22.5	23.5	0	0	0
Dec.	1	68.0	3.0	0	0	0
Jan., 1985	2	23.0	1.0	0	0	0
Feb.	1	29.0	6.0	0	0	0

Appendix Table 1. (Cont'd.)

Average catches by month of four species of crab in Vexar-lined pots set at crabpot stations 1-4 in Lummi Bay during 1984 and 1985.

Month/Year	Sample Size(n)	Average Hours Fished	Average Number of Crabs			
			C. magister	*C. productus*	*C. gracilis*	*Telmessus*
Station #2 = Outer North Channel:						
March	1	24.0	3.0	0	0	0
April	1	22.0	14.0	2.0	0	0
May	2	24.5	17.5	0.5	0	0
July	2	23.0	11.0	3.5	0	0
Aug.	1	4.0	20.0	3.0	0	0
Sept.	1	22.0	21.0	1.0	0	0
Station 3 = Offshore of North Channel (~5m Depth)						
Aug., 1984	27	12.4	17.3	3.3	0.1	0
Sept.	9	9.8	15.1	0.8	0.1	0
Oct.	5	14.8	8.6	0.8	0.2	0
Nov.	2	22.5	16.5	3.0	0	0
Dec.	1	68.0	1.0	1.0	0	0
Jan., 1985	2	23.0	4.0	0	0	0
Feb.	1	29.0	4.0	0	0	0
March	5	16.8	10.2	0.8	0	0
April	1	22.0	21.0	0	1.0	0
May	2	24.5	7.0	10.5	0	0
July	2	23.0	16.0	1.0	0	0
Sept.	1	22.0	6.0	1.0	0	0

Appendix Table 1. (Cont'd.) Average catches by month of four species of crab in Vexar-lined pots set at crabpot stations 1-4 in Lummi Bay during 1984 and 1985.

Month/Year	Sample Size(n)	Average Hours Fished	Average Number of Crabs			
			C. magister	*C. productus*	*C. gracilis*	*Telmessus*
Station 4 = Middle Channel:						
Dec., 1984	1	68.0	1.0	0	0	0
Jan., 1985	2	23.0	3.5	0	0	0
Feb.	1	29.0	2.0	0	0	0
March	1	24.0	3.0	0	0	0
April	1	22.0	25.0	1.0	0	0
May	2	24.5	10.5	0	0	0
Aug.	1	4.0	20.0	0	0	0
Sept.	1	22.0	25.0	0	0	0

Appendix Table 2. Average densities (crabs/m^2) of Dungeness crab from intertidal transect sampling in Lummi Bay from July 1984 to October 1985.

Sample Dates	Transect Number		
	1	2	3
July 12-14, 1984	5.8		1.0
July 27-30	5.7	7.4	3.1
Aug. 9-12	8.8		
Aug. 24-27	6.3	1.6	6.1
Sept. 6	1.5		
Sept. 21-24	3.2	2.7	5.8
Oct. 25-29	2.1	0.7	4.8
Nov. 23-28	0.5	1.3	1.7
Dec. 19-20			1.1
Feb. 3-6, 1985	0.6		
March 4-5	0.0		
April 7-10	1.7	1.3	1.2
May 6-9	2.3	1.3	
June 2-6	0.6	0.0	
June 21-22			0.0
June 30-July 3	0.4	2.3	
July 28-Aug. 1	1.7	3.1	
Aug. 14-17	18.2		
Aug. 26-28	9.3	5.7	
Sept. 22	4.4		
Oct. 15	2.7	3.4	