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ECOLOGY AND POPULATION DYNAMICS OF DUNGENESS CRAB, CANCER MAGISTER
IN SHIP HARBOR, ANACORTES, WASHINGTON

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Final Report to Leeward Development Company and
Washington State Department of Fisheries

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1.0 INTRODUCTION

1.1 Study Need

Dungeness crab, Cancer magister, is Washington State's most valuable crustacean fishery, and is situated primarily along the coast where a historic average of about 9-10 million pounds has been landed over the last thirty five years, although in the last five years this total has been closer to 3 million pounds (PMFC 1985). The commercial fishery in the inland waters of Puget Sound averages about 1.5 million pounds annually and is worth about \$1.50 per pound ex-vessel. In recent years the Puget Sound fishery has accounted for about one-third of Washington State's crab landings since populations have remained suppressed along the coast.

Washington State Department of Fisheries (WDF) is the agency responsible for management and protection of fisheries resources, including Dungeness crab. In recent years they have been asked to review and evaluate a number of proposals for projects within Puget Sound that would alter, in various ways, shorelines and shallow water habitat. With little biological information at their disposal, WDF has been restricted to a conservative view of project impact relative to fisheries resources, particularly in the case of Dungeness crab for which so little ecological and life history information exists throughout the species range in Puget Sound. Accordingly, a program was initiated in the summer of 1984 through the School of Fisheries, University of Washington under sponsorship of Washington Sea Grant and WDF to study: 1) timing and recruitment of young-of-the-year (YOY=0+) juvenile crab in Puget Sound; 2) their association with and dependence on particular types of habitat and substrate at

subtidal and intertidal locations; 3) growth rate and survival through the first two years following settlement and; 4) patterns of movements and shifts in abundance on a seasonal basis.

The intention of this program was to give a general backdrop of information to use for first order approximation of potential impacts occurring through various nearshore development projects. For example, depending on the types of habitat and cover within a proposed project site, an assessment could be made as to whether or not there was a high or low probability of finding juvenile stages of Dungeness crab in the area. Some research work would be required on-site to measure abundance of various life history stages and assess potential impacts of a specific project.

The first marina configurations at Ship Harbor required dredging approximately 8.1 hectares (ha) (20 acres) of intertidal and subtidal grounds. Subsequently, this was reduced to about 6.7 ha (16.5 acres) of which 1.4 ha (3.5 acres) was intertidal and 5.3 ha (13 acres) was subtidal. Much of the area to be dredged included dense, luxurious stands of eelgrass (Zostera marina) (Mangrove Systems 1986) which is viewed as an important resource both from the standpoint of primary production but also as habitat and refuge for various fish and invertebrates. Based on findings in coastal estuaries such as Grays Harbor, juvenile Dungeness crab occur in relatively high densities in certain habitats which include eelgrass, particularly within the intertidal and shallow subtidal zones (Armstrong et al. 1982; Stevens and Armstrong 1984; Armstrong and Gunderson 1985).

WDF was initially concerned that the marina project proposed for Ship Harbor would result in destruction and loss of habitat for juvenile Dungeness crab. Since transplant of eelgrass to adjacent areas was proposed as a form of mitigation for such habitat loss, WDF was also interested to learn the seasonal use of Ship Harbor by various life history

stages of Dungeness crab, both on and off the proposed marina site. The project, as originally conceived, dealt primarily with juvenile Dungeness crab at Ship Harbor in comparison to other nearby habitats in the Anacortes area. The original supposition that the area might support large populations of juvenile Dungeness crab did not prove true. Instead Ship Harbor is singularly unique for the high wintertime populations of ovigerous (egg bearing) females that use Ship Harbor for egg incubation and development. Based on this finding and the failure to locate similar populations of females in other areas around Anacortes, the decision was subsequently made to abandon the first marina configuration of a traditional rock breakwater, avoid dredging altogether and instead use floating breakwaters as boundaries for the marina.

1.2 Literature Review

Despite the historic importance of Dungeness crab as a commercial fishery in Puget Sound, relatively little work has been done on the species ecology and life history in inland waters. Most literature deals with crab populations along the open coast and in estuaries (e.g. Gotshall 1978; Stevens and Armstrong 1984; Armstrong and Gunderson 1985; Alaska Sea Grant 1985).

Most work on inland water populations of Dungeness crab has been done by Canadians on stocks located from Boundary Bay to the Queen Charlotte Islands. Early work on growth, size-at-instar and time between molts was done by MacKay and Weymouth (1935) and Weymouth and MacKay (1936) on samples of juvenile and adult crab taken from Boundary Bay just across the U.S.-Canadian border. Further analyses of age and growth as well as size and age at maturity and breeding patterns was provided by Butler (1960, 1961) on populations at the north end of Queen Charlotte Island. A cursory

study of distribution and abundance of early post-larval crab was also done by Butler (1956) again on populations settling along the northeastern coast of Queen Charlotte Island bordered by Dixon Entrance and Hecate Strait. He noted that small crab were most dense in eelgrass at certain locations and elsewhere in detached kelp or other macroalgae, and speculated that vegetation offers some form of protection. A cursory study of juvenile crab distribution and abundance at the Fraser River Delta by Breen (1985) also indicated use of eelgrass by early instars and, in general, dependence of small crab on some sort of shelter.

The only complete study of Dungeness crab populations in Puget Sound was done by Mayer (1973) on populations in Similk Bay, Washington. Although population abundance was calculated, as was size and fecundity of females, this study was based on use of pots as the only "fishing gear" which have been shown to be highly size selective by Hanken et al. (1985). Mayer's study dealt almost exclusively with adult male and female crab and in no sense provided information on small juveniles, their distribution and use of specific habitats.

Despite these investigations, the dilemma confronting WDF in assessing the potential impact of the proposed Ship Harbor marina was caused by a virtual lack of information on the ecology and population dynamics of early life history stages, particularly in regards to timing, density and pattern of settlement in different habitats. This report details the results of Dungeness crab studies performed on location at Ship Harbor from August 1984 to April 1986. A portion of the data presented here were provided by a more general study described by Dinneil et al. (1985) under sponsorship of a variety of federal, state and private entities. These data enable a broader comparison of the findings at Ship Harbor to crab

ecology elsewhere in North Puget Sound.

2.0 METHODS AND MATERIALS

2.1 Study Sites

Ship Harbor is located at approximately 48° 30' north latitude, 122° 41' west longitude along the south side of the Guemes Channel west of the city of Anacortes (Figure 1). Ship Harbor is characterized by a relatively shallow, broad intertidal and nearshore subtidal area that extends approximately 190 m from upper high tide to 3 m (10') depth (Fig. 2). The area of the harbor is approximately 29 ha (71 acres) shown as the combined shaded and stippled portion of Figure 2. Modified proposals for the marina required dredging over 6.7 ha in the nearshore area between transect lines B and C (Fig. 2). Of this total, about 1.4 ha (3.5 acres) was to be intertidal and 5.3 ha (13 acres) was to be subtidal. A dense bed of eelgrass found at Ship Harbor corresponds to the stippled area shown in Figure 2.

In order to compare the density and abundance of crab as well as their life history stage distribution at Ship Harbor to other populations within the region, a "control site" was selected in Padilla Bay just east of March Point (Fig. 1). This area was selected after consultation with WDF because it is known to contain populations of Dungeness crab, is heavily used by sports fisherman and also encompasses the same types and variety of substrate as found in Ship Harbor. Further, Padilla Bay is a National Estuarine Sanctuary, and the broader scope of the Sea Grant program underway in that area provided an opportunity to increase sampling effort and obtain a better time series of data against which to compare Ship Harbor results. The March Point study site was approximately 2 km on a side and included habitat that ranged from shallow intertidal and subtidal eelgrass beds to

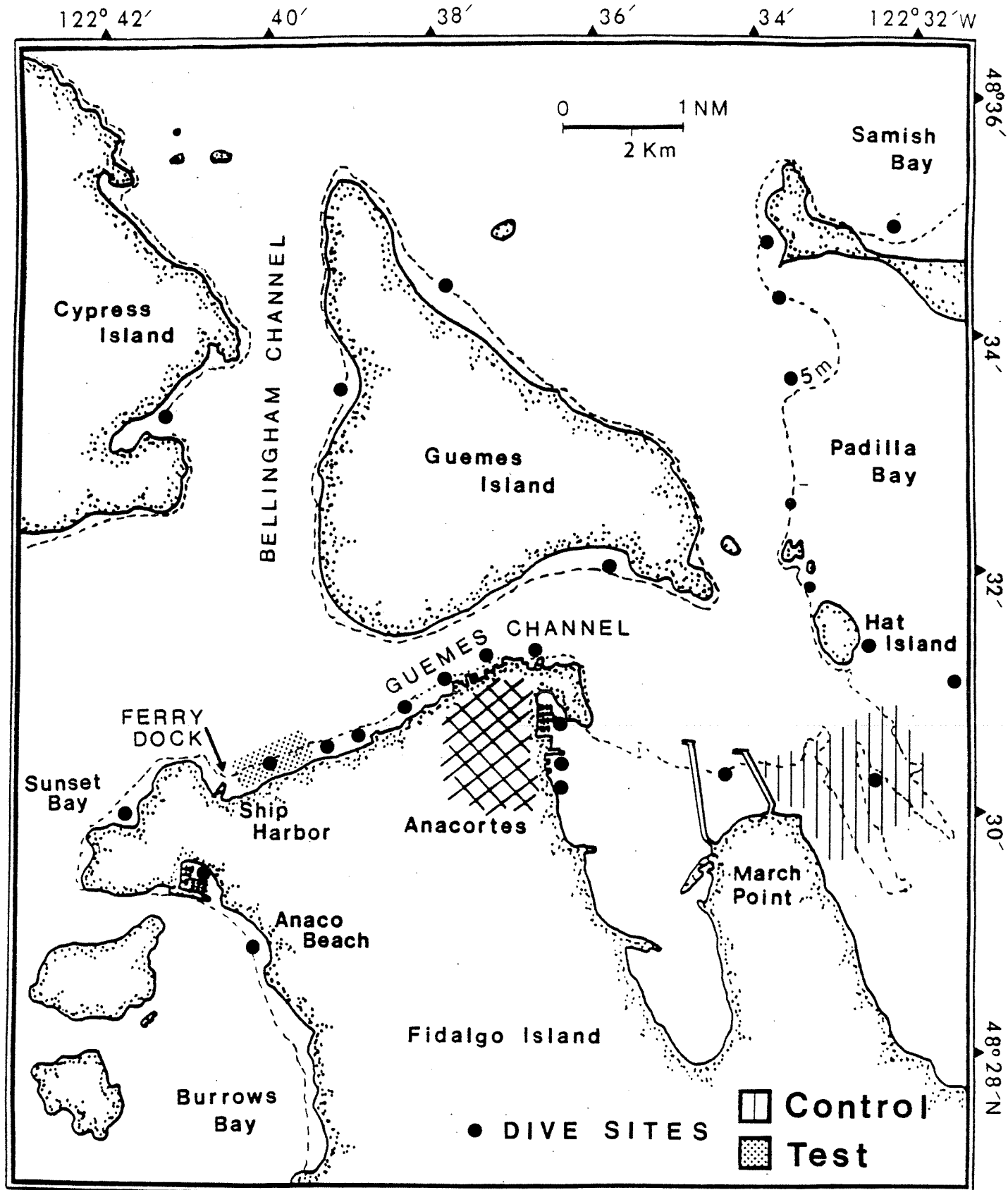


Figure 1. Area overview of test and control sites, Ship Harbor and March Point near Anacortes, Washington. Major depth contour at 5 m (16'). Dots indicate winter SCUBA dives to locate ovigerous females (see Figs. 2 and 3 for details within study sites).

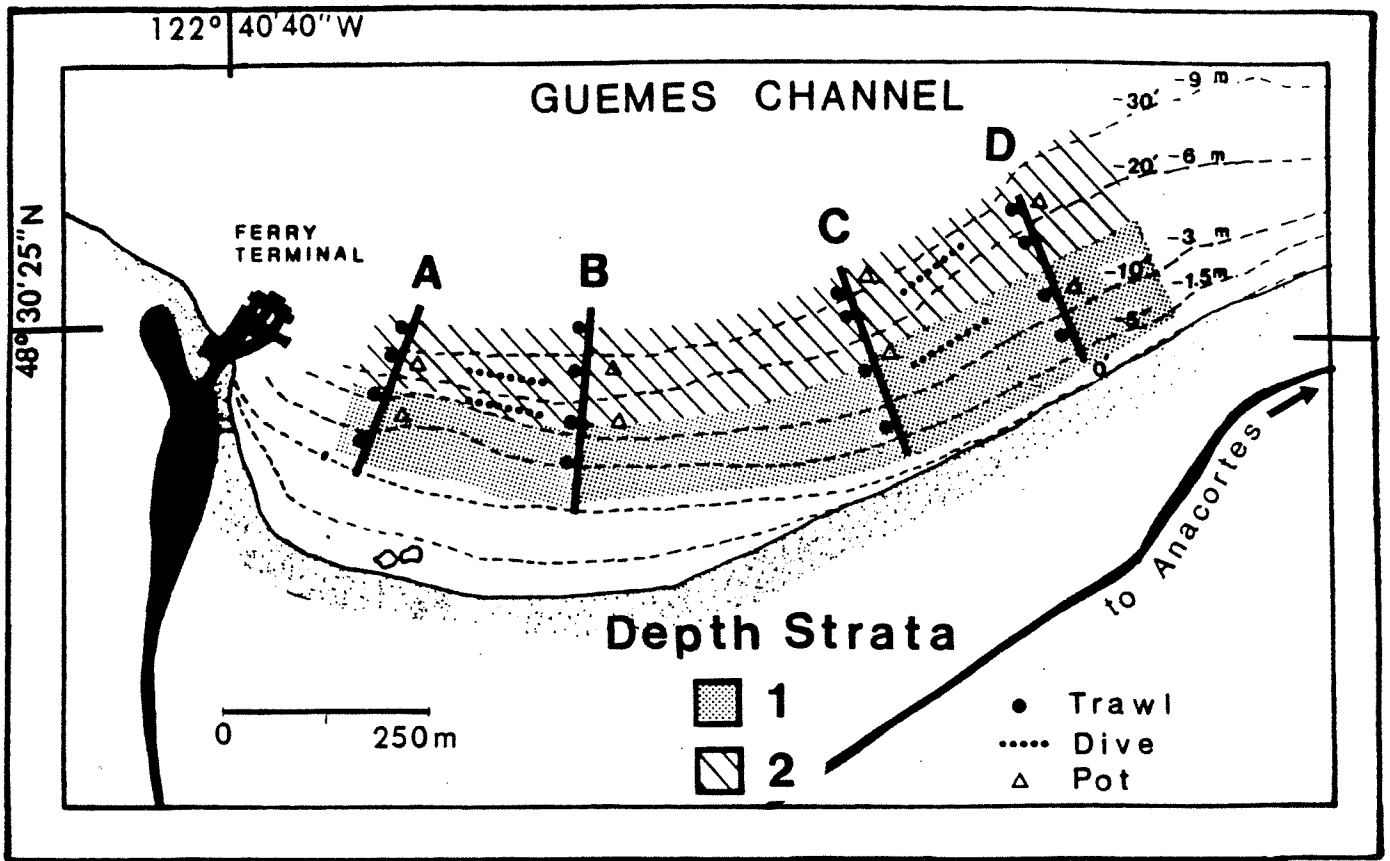


Figure 2. General sampling scheme used each trip at Ship Harbor. Four trawls per line, 2 pots per line and 2 dives between lines A-B and C-D. Depth contour lines are shown in feet and meters (see Table 1 for schedule of trips and extent of sampling). Stippled and hatched areas are two depth strata: Stratum 1 from -0.5 to -4.9 m (-1.5 to -16 ft) equal to 16.1 ha; Stratum 2 from -5.0 to about -10.0 m (-17 to -32 ft) equal to 12.6 ha.

deeper channels of shell and stick debris. The site was just east of the oil refinery and fuel piers located on March Point (Figs. 1 and 3).

2.2 Sample Gear

Four types of sampling were done at Ship Harbor and March Point during the 20 months of this study although all were not used each trip. Subtidal populations were sampled primarily with a three meter plumb staff beam trawl (Fig. 4) developed by Gunderson and Ellis (1986). The efficiency of this gear compared to more traditional otter trawl nets has been shown to be high and is standard survey gear for other crab studies located elsewhere in Puget Sound and along the Washington coast (e.g. Armstrong and Gunderson 1985). The apparatus is an improvement over an otter trawl net by virtue of much smaller mesh size, a tickler chain that precedes the net and helps to dislodge animals from the substrate and better conformation to bottom contours. The net was pulled from a 21' Boston Whaler and the distance towed was estimated from bouys placed at the beginning and end of trawls and measured with an optical range finder. This distance in meters times the effective fishing width of the net (2.3 m) was used to calculate the area swept and, in turn, the density of crab for each trawl.

SCUBA divers were used as a check on the efficiency of the net and added as a regular sampling routine for the winter of 1984 and 1985 because the behavior of large females to bury into the substrate put them beyond reach of the gear (see section 3.3.2). Two divers swam a weighted transect line of 40-60 m length, caught and measured all crabs in an effective survey width of about 3.5 m (because of visibility each diver was judged to be effective only within 1.7m of the transect line).

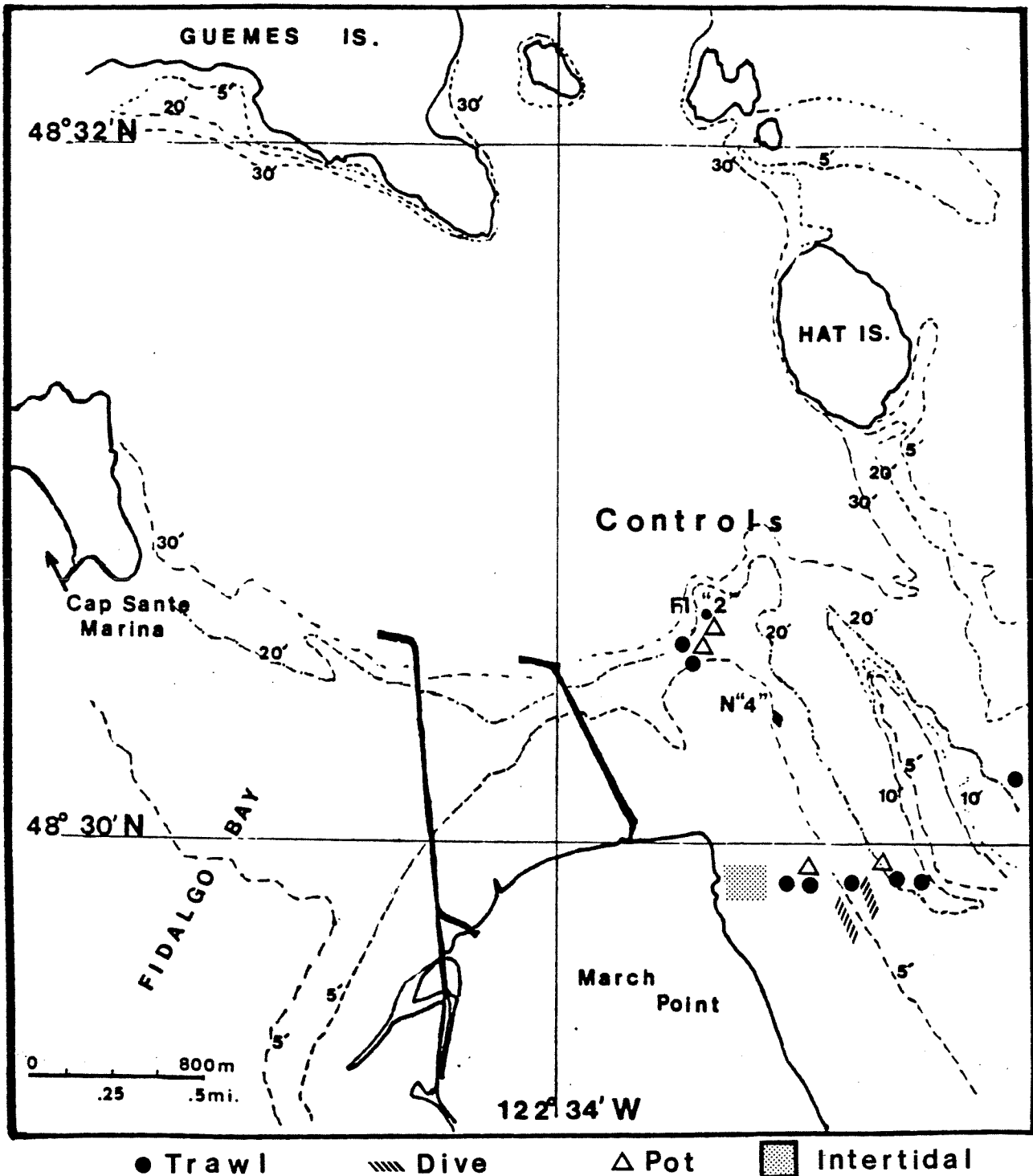


Figure 3. General sampling scheme used at March Point including beam trawls, crab pot sets, diver transects, and intertidal quadrats (see Table 1 for schedule of sampling trips).

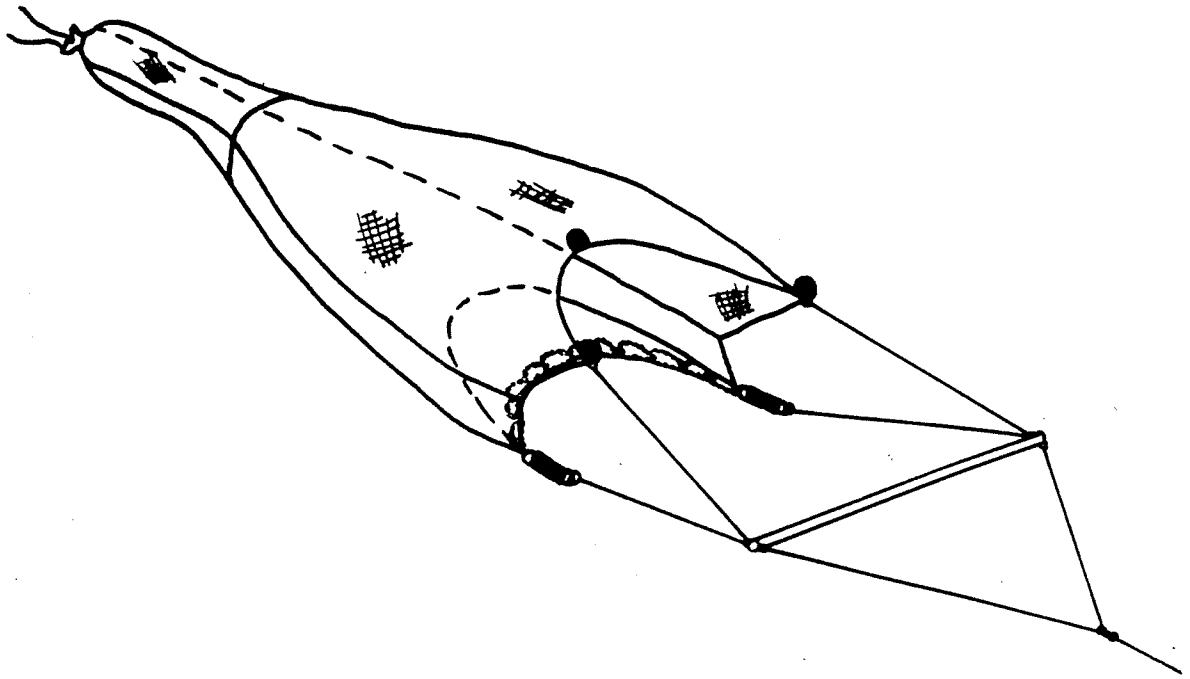


Figure 4. Three meter plumb staff beam trawl used to sample juvenile and adult crab at Ship Harbor and March Point (after Gunderson and Ellis, 1986).

Beginning with the third survey in December of 1984, crab pots were used as a further index of abundance in comparison between the two study sites. Pots were covered with reduced Vexar mesh and escape ports were closed in order to retain juveniles as well as adults. Each trip pots were generally set two times at both study sites for periods that were later categorized as "short" (<10 hr.) and "long" (> 10 hr.) which were also comparable to day and night samples. Free hanging fish bait was used and renewed each pot set. All crabs were sexed, measured and returned to the area of capture.

Because of evidence from Grays Harbor that juvenile crabs recruit to the intertidal (Stevens and Armstrong 1984; Armstrong and Gunderson 1985), limited intertidal sampling was conducted in Ship Harbor on four occasions and more frequently at March Point as part of the extended Sea Grant program. A series of quarter m² quadrant samples were excavated to about 5 cm depth, washed over a 3-4 mm mesh screen, and all crabs counted and recorded. Intertidal sites were selected to furnish a comparison of substrate with and without cover. Although the category of "cover" varied from eelgrass to macroalgae to cobble of variable proportions, a finer division of intertidal habitat than these two categories was not deemed effective or warranted for the purposes of comparing juvenile crab recruitment between Ship Harbor and March Point.

2.3 Sampling Protocol

A series of 11 sampling trips as required by WDF of the developer were made between August 1984 and January 1986 (Table 1). In addition, four trips were made between March and April 1986 as part of the extended Sea Grant program in north Puget Sound in order to gain a better time series of information on distribution and abundance of female crabs in late winter

Table 1. Number of samples taken per gear type, each survey trip from August 1984 to April 1986. Deletion of a gear in certain seasons (e.g. beam trawl winter) generally reflects changes in efficiency or preponderance of different life history stages. SH = Ship Harbor, MP = March Point.

Sampling Dates	Beam Trawls		Pot Lifts		Diver Transects		Intertidal	
	SH	MP	SH	MP	SH	MP	SH	MP
8/84	16	6					10	
11/84	16	6						
12/84	16	6	6	0	2	0		
3/85	10	7	0	3	3	3	17	
4/85								14
5/85	12	7	8	8	4	2		18
6/85	13	6	6	6	4	2	15	31
7/85	12	7	7	6	3	2		27
8/85*								38
9/85	17	6	8	8	0	0	18	17
11/85*								12
12/85	12	0	8	8	4	3		
12/85					8	0		
1/86					2	0		17
3/86*					1	0		
3/86*					1	0		
3/86*	2				4	0		
4/86*	2				5	0		
TOTAL	128	58	43	39	41	12	60	174
	186		82		53		234	

*Data incorporated from other N. Puget Sound sampling projects at March Point and Ship Harbor.

and early spring. Not all forms of sampling were done on each trip, primarily because of changes in the proportion of certain life history stages or activity and behavior of crab that negated efficiency or need for certain types of sampling in various seasons of the year.

Trawl samples were consistently collected through the first year and a half of the study. In Ship Harbor four transect lines were established (Fig. 2, labeled A to D) and usually 3 to 4 stations were collected per transect line in accord with depth increments. All crab were sexed and measured and in the case of mature females, information was taken concerning presence or absence of eggs and general state of development. As often as time allowed, other species caught by the trawl gear were counted and recorded in order to provide a qualitative estimate of the nearshore community of Ship Harbor, particularly in the eelgrass. During trips with diver surveys the number of trawl stations was reduced from sixteen to twelve because of the extra time required for dives and also because populations accessible to the trawl gear were usually much reduced during this period.

From three to four commercial crab pots were set each trip usually at two depth intervals and were fished for variable lengths of time in accord with beam trawl and diver activity in the area. Salmon heads were used for bait and were changed after each pot lift. The length of fishing usually coincided with shorter periods during daylight hours and longer periods overnight.

Diver surveys were conducted as previously described along weighted, measured transect lines usually in two areas of the harbor and at two depths per area (Fig. 2). The intention was to survey in an area within the boundaries of the proposed marina (between C and D line) and in an area outside the proposed marina (to the west between lines A and B).

Intertidal samples were taken at Ship Harbor on four occasions although not part of the designated study. Samples were collected from areas of cover or no cover from approximately -0.5 to about +1 m in front of transect line B (Fig. 2).

Sampling effort of all types except intertidal surveys was less intense at March Point, the control site. On most trips from six to seven trawls were conducted in two areas; five along a transect line labeled N4 at depths from approximately 2 to 10 m (6' to 32') below mean lower low water (MLLW). This range of depths covered habitats from shallow eelgrass areas just east of March Point to the main channel that occurs as an extension of the Swinomish Slough coming into Padilla Bay (Fig. 3). Two stations were sampled north of March Point near Flasher #2 (F1 2) at about 3 and 8 m (10' and 25') depth (Fig. 3). As shown in Table 1, trawl samples were collected at March Point in accord with the schedule followed at Ship Harbor. Crab pots were set at March Point both near N4 and F1 2 at shallow (about 3 m) and deep (10 m) locations. Diver transects were sampled on five trips at March Point as shown in Figure 3; again, usually in eelgrass and also at a slightly deeper depth beyond eelgrass beds. More extensive collections of intertidal samples were made at March Point on eight occasions from April 1985 through January 1986 (Table 1). Samples were collected on the northeast side of the point from an area of mixed eelgrass, shell and open habitat.

2.4 Data Analyses

The primary objective of this research was to study changes in abundance and distribution of Dungeness crab at Ship Harbor in contrast to other locations in the Anacortes area. Analyses of variance (ANOVA) on log transformed data were done to determine if there were significant differences

between density of crabs (no./ha) as a function of: 1) location (Ship Harbor vs. March Point); 2) habitat within location (synonymous with shallow stations within eelgrass and deeper stations beyond areas of eelgrass) and; 3) sex.

Data on crabs caught in pots were converted to a catch rate as crabs/hour and also compared by ANOVA after log transformation. Time of year, location, soak time and sex were independent variables used in the ANOVA. Soak time was comparable to daylight periods less than 10 hr or greater than 10 hr overnight. Differences in size of crab sampled over time was studied with ANOVA as a function of time of year, location, soak time and sex. If analyses of variance indicated that significant differences occurred among the independent variables, multiple comparisons were run with a Student-Newman-Keuls (SNK) test to identify portions of the data that varied significantly.

Because of the relatively small size of Ship Harbor compared to other areas around Anacortes where Dungeness crab occur, it was felt that measures of density per se would not be an accurate representation of crab abundance at Ship Harbor compared to March Point and Padilla Bay. Accordingly, population estimates were made from the observations of densities obtained each trip. To do this, representative areas were defined around the stations of each study site used to survey crab density and were digitized on a computer to obtain total area within the study site. Habitat within each study site was grouped into two categories: 1) shallow eelgrass beds that extended from MLLW (0 m) to about 5 m (16 ft) and; 2) 5 m to about 9.5 m depth. Deeper stations tended to occur on open substrate with occasional areas of shell, stick and leaf litter or several species of macroalgae at low density. Accordingly, two strata within each study site were defined and also digitized on a computer to provide a basis

for statistical contrast of both crab density and population abundance in shallow and deeper water locations (Figs. 2 and 5 for Ship Harbor and March Point, respectively). The total subtidal area of Ship Harbor digitized for calculation of population abundance equalled 28.7 ha (71 acres; 1 ha = 2.47 acres) and Stratum 1 (nearshore) and Stratum 2 equalled 16.1 ha and 12.6 ha, respectively (Fig. 2).

The representative control area off March Point digitized on a computer equalled 32 ha (800 acres) and was also divided into a shallow Stratum 1 (160 ha) and a deeper Stratum 2 (163 ha; Fig. 5). Although 11 times larger than the digitized area of Ship Harbor, the area off March Point used for calculation of abundance was considered conservative since it represents only about 20% of the subtidal of Padilla Bay. In addition, there are extensive shallow subtidal areas in Fidalgo Bay to the west of March Point and Samish Bay to the north of Padilla Bay (see Fig. 1) and in numerous other locations in the greater Anacortes area. Population abundance was calculated for each survey trip based on weighted mean density of crabs within each stratum by the BIOMASS program at the National Marine Fisheries Service, Seattle, Washington.

Population estimates were also calculated from crab densities obtained during diver surveys at times of the year when it became apparent that the efficiency of the trawl gear was too low for accurate estimates. Particularly for mature female crabs it became necessary in the winter of each survey year to use densities from diver surveys to estimate female abundance at Ship Harbor as done with the standard beam trawl data at other times.

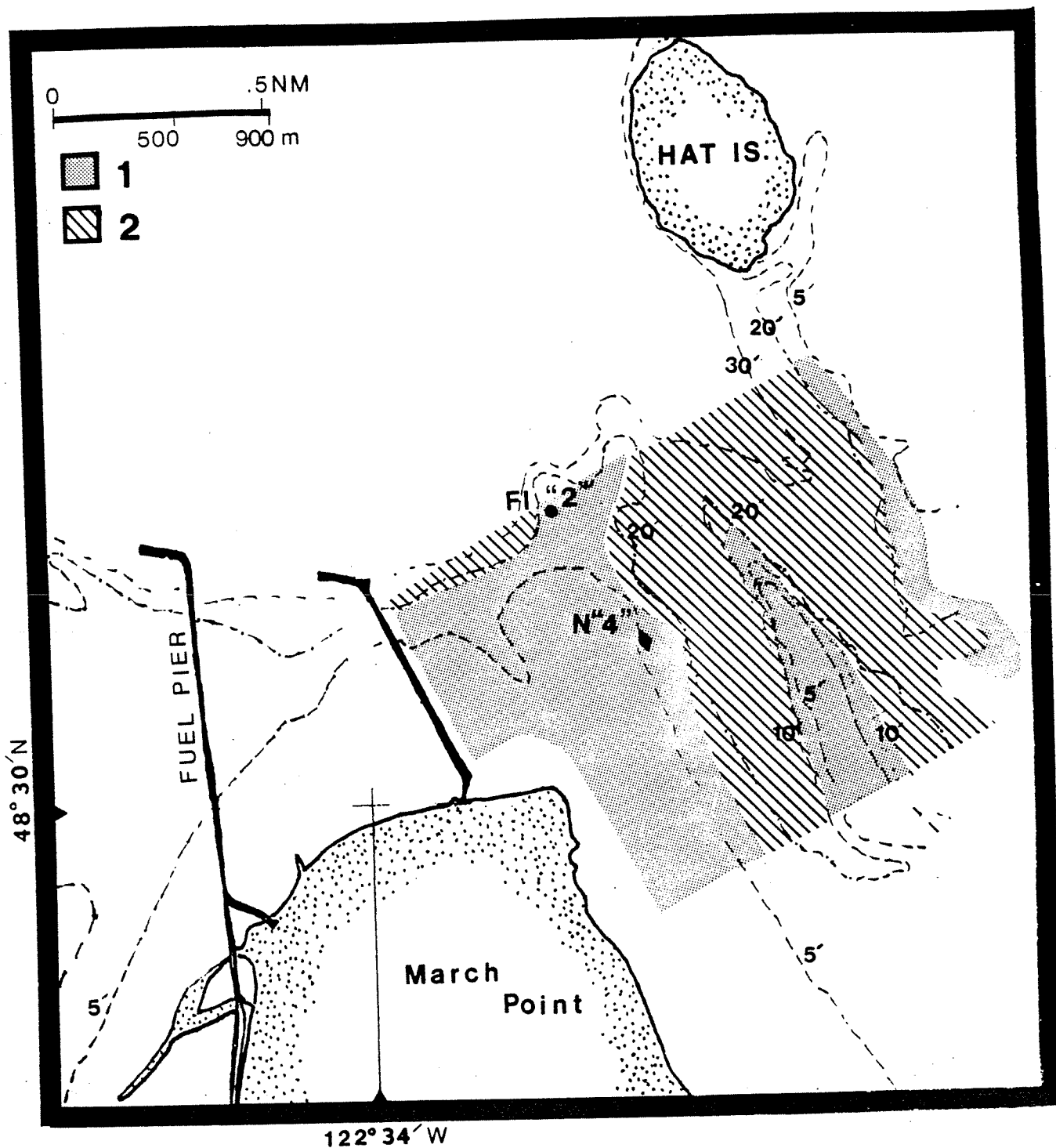


Figure 5. Depth strata at the control site March Point. Stratum 1 \leq 4.9 m (16 ft). Stratum 2 = 5.0 to 9.1 m (17 to 30 ft). Area of stratum 1 = 160 ha, stratum 2 = 163 ha. Flasher ("2") and Nun ("4") buoys are marked. Depth contours appear in feet.

3.0 RESULTS

3.1 Water Conditions and Habitat

Water temperatures ranged from a low of about 5°C in winter of 1984 to highs around 14° to 15°C in the summer of each year (Fig. 6). Surface and bottom water temperatures were almost identical between Ship Harbor and March Point, particularly bottom water temperatures that ranged from 5° to 12°C. Surface temperatures at Ship Harbor were about 2°C colder than those at March Point in the summer months (12° and 14°C, respectively in July 1985; Fig. 6). Air temperatures ranged from about -5°C in November 1985 to summer highs of about 25°C in both 1984 and 1985. The severely cold weather in November and December of 1985 froze standing water in the intertidal of Ship Harbor. Salinity was not measured at Ship Harbor during the study, however a series of measurements at March Point showed that bottom water salinity rarely declined below 29 ‰ and was generally about 30 ‰ over most seasons (Fig. 7). Surface salinity fluctuated more than bottom salinity and declined from a value around 32 ‰ in the fall and winter to about 27 ‰ in the spring. A low value of 22 ‰ in Padilla Bay was recorded in March 1986 (Fig. 7).

3.1.1 Ship Harbor

Based on diver surveys and materials caught by the beam trawl, a composite cross-sectional representation was constructed of the benthos at Ship Harbor from MLLW to about 10 m depth (Fig. 8). The broad intertidal area of Ship Harbor grades from medium to fine sand to a band of sand and small gravel (about 1-2 cm diameter) at about +0.5 m, then to sand that extends a couple of hundred meters from 0 to 3 m depth (Fig. 8). At about 220 m offshore there is a relatively steep decline in depth from 4 m to 12 m and in this area the substrate changes to a mixture of sand and mud.

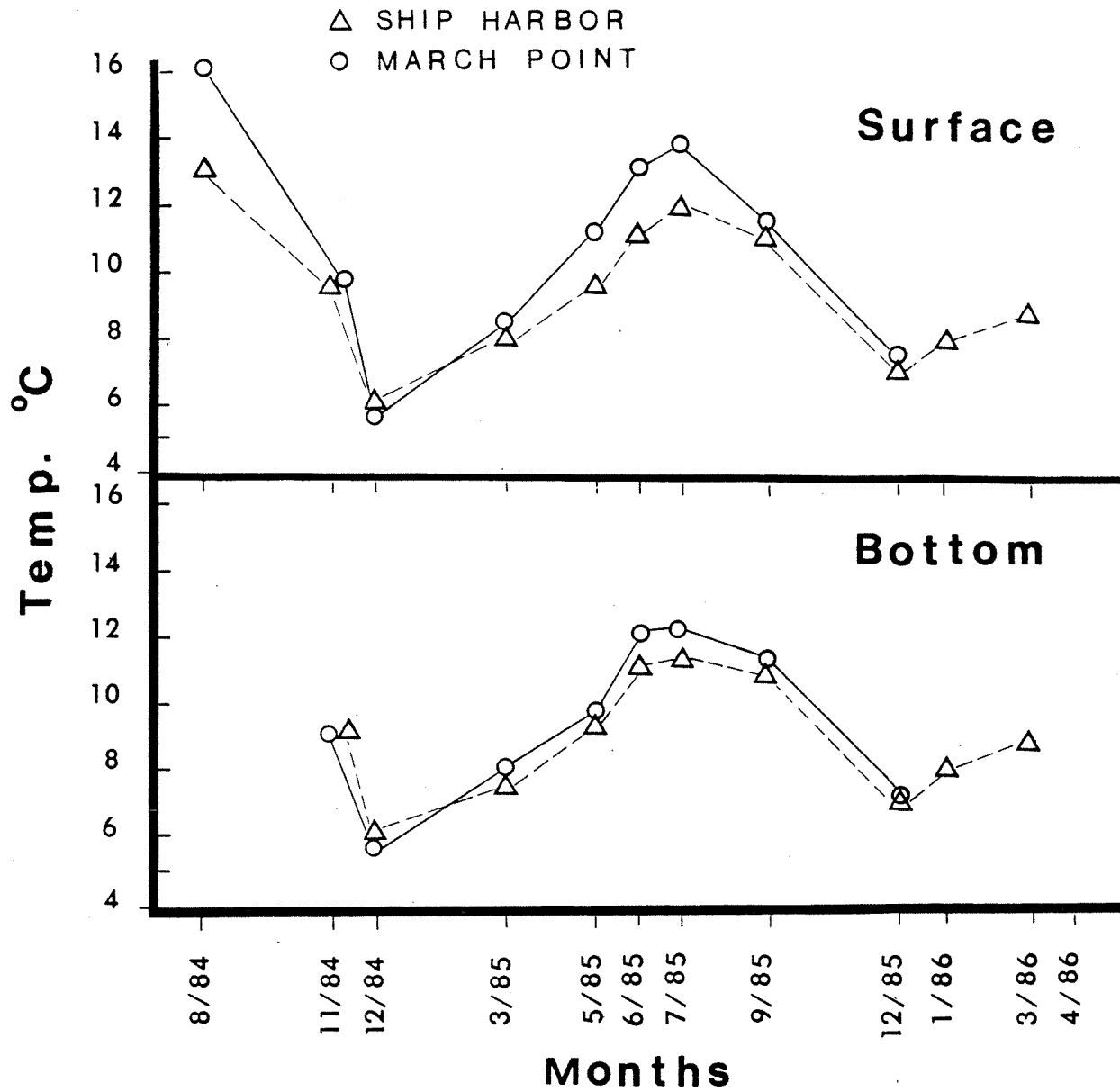


Figure 6. Surface and bottom water temperatures at Ship Harbor and March Point.

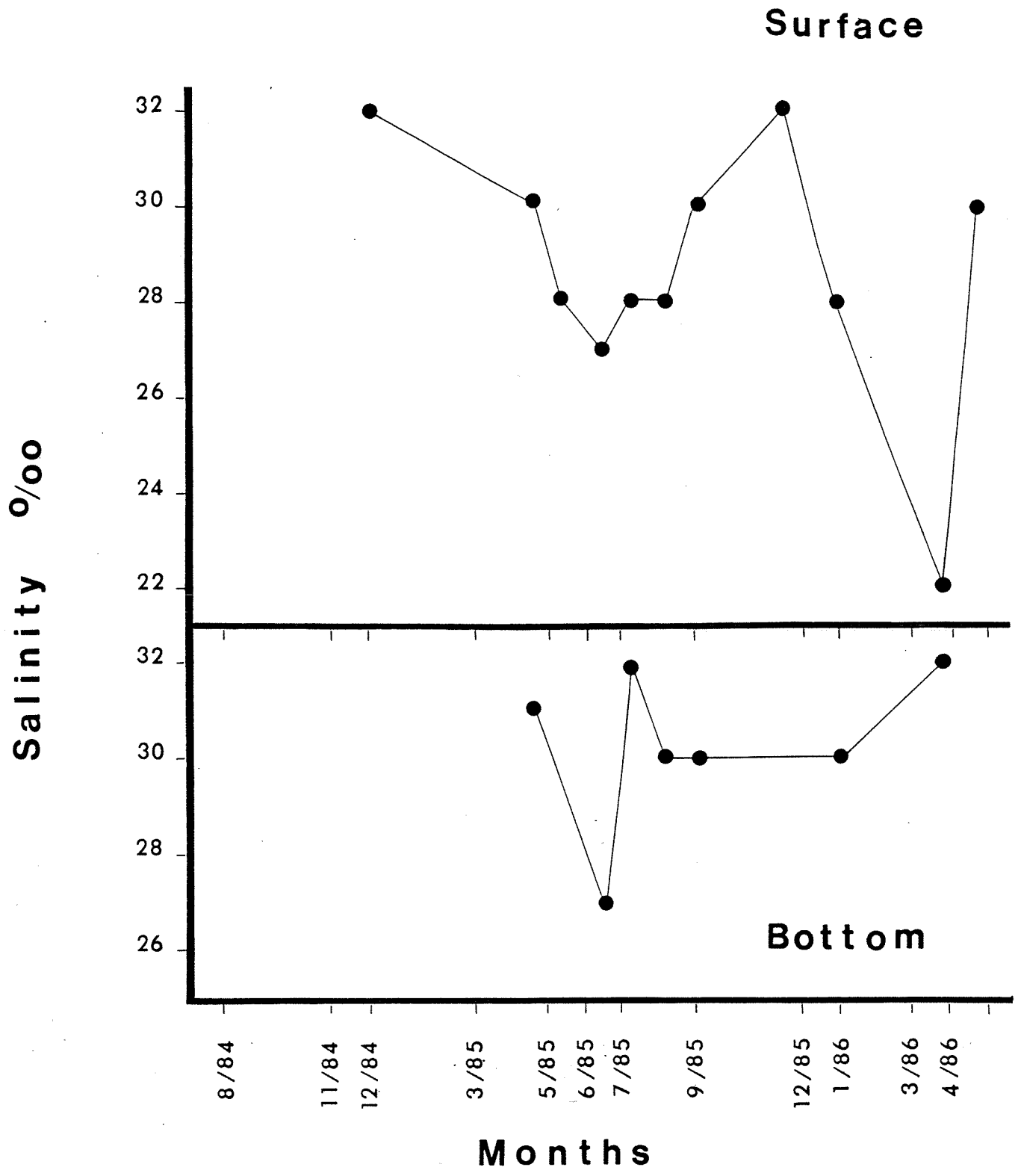


Figure 7. Surface and bottom water salinity at March Point.

BEACH CONTOUR AND SUBSTRATE

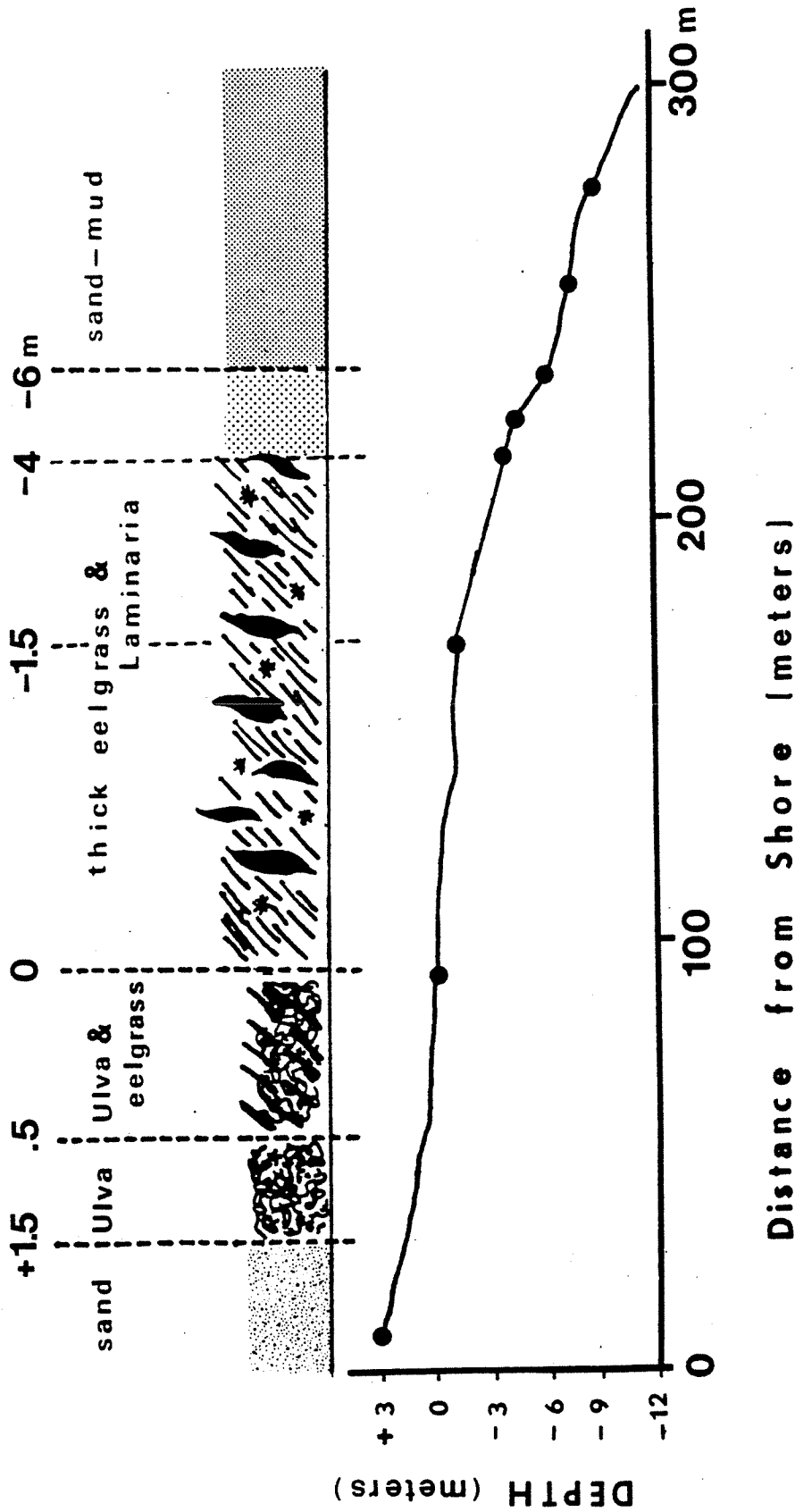


Figure 8. Cross sectional composite of substrate and depth at Ship Harbor (based on SCUBA dives and material in beam trawls). Ulva in the intertidal is drift; macroalgae and eelgrass are thickest in late spring and summer, decrease substantially in fall and winter.

Nearshore there is dense cover of macroalgae, particularly Ulva sp. in the spring and summer that washes in with high tide. From +0.5 m to about 0 m depth there is a mixture of Ulva and eelgrass (Zostera japonica) that is rather sparse in coverage. Particularly at the west end of Ship Harbor near transect line A (see Fig. 2) there is a tendency for drift algae to accumulate due to a pronounced gyre in Ship Harbor caused by deflection of currents by headlands to the west beyond the ferry terminal. From 0.5 m to about 4 m depth (1.5' to 13') there is a very thick cover of eelgrass (Z. marina) that is most dense toward the west end of Ship Harbor from transect line A to C. The eelgrass zone continues to the east and is essentially represented by the stippled portion of Figure 2. Also, to the east there is an increasing mixture of various macroalgae, predominately Laminaria spp. Thick eelgrass coverage ends at about 4 m (12' to 14') depth and is not replaced by any prominent cover. An open mud/sand bottom continues from about 4 to 10 m with occasional shell and stick debris but in general little cover (Fig. 8).

Substrate composition at March Point is generally similar and is comprised primarily of mud/sand bottoms from the intertidal through the shallow subtidal on down into deeper channels. There are extensive eelgrass beds from the intertidal to about 4 m depth (stippled area Fig. 5 shows approximate location of eelgrass at the March Point study site). Trawls in the major channels to depths of about 10 m (30' to 32') typically contained a mixture of shell, stick and leaf material, and on occasion, detrital eelgrass.

3.2 Crab Populations: Beam Trawl

3.2.1 Size and age of crab

All age classes of crab from 0+ to 4+ were caught at both Ship Harbor and March Point through this study although the proportion of various age

classes changed substantially over seasons (Figs. 9,10). The range of sizes varied from first instars at 5 to 7 mm carapace width (CW) to as high as 180 mm (legal males). In general, the time series of size frequency data were not good enough at either location to study growth rate with any reliability, and assignment of age at size is tentative at this time (better definition will come with completion of the Sea Grant study). 0+ crab were the most consistently apparent age group in the data and, for portions of the series, growth can be discerned as can increase in size of a year class from age 0+ to 1+ (Fig. 10).

Ship Harbor: The dominant age class at Ship Harbor in August 1984 was 0+ crab with a mode at about 20 mm CW (Fig. 9). Given this body size (equivalent to about 4th to 5th instar), the 1984 year class apparently settled a month or two earlier in June and July. The 1984 year class was still the dominant age class in November 1984 and little apparent growth had occurred since August. The data collected over winter on size frequency was generally spotty since relatively few crab were captured. In June 1985 the new year class recruited and 0+ animals were dominant in Ship Harbor over a size range of about 14 to 18 mm CW (Fig. 9). This age group had apparently doubled in size by September of that year and ranged from about 15 to 30 mm CW (Fig. 9). For most of the study period large numbers of older crab, as determined by beam trawl, did not reside in Ship Harbor but when present were primarily 1+ and 2+ age groups. In September and December of 1985 strong populations of 1+ that ranged in size from about 70 to 110 mm CW and 2+ from 110 to about 140 mm CW were present in Ship Harbor. In December of 1985 most of the resident population was a mixture of 1+ and 2+ crab and most were larger than the size of theoretical sexual maturity (100-110 mm CW).

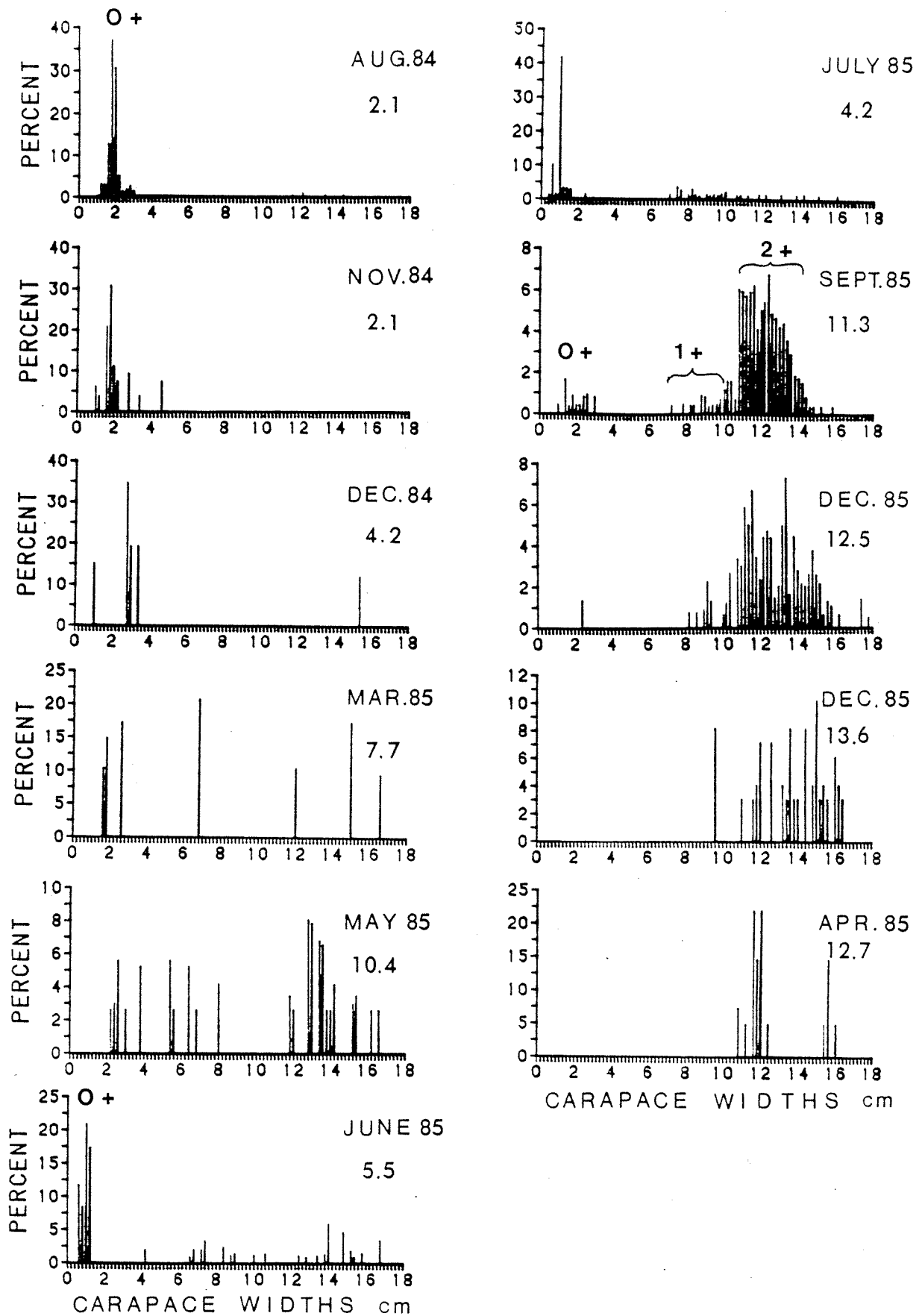


Figure 9. Size frequency histograms for crab caught by beam trawl at Ship Harbor. Data are grouped by 2 mm intervals and are based on expanded population estimates rather than actual numbers per trip. Number below each trip date is mean size of the entire population. Age classes are indicated for selected months.

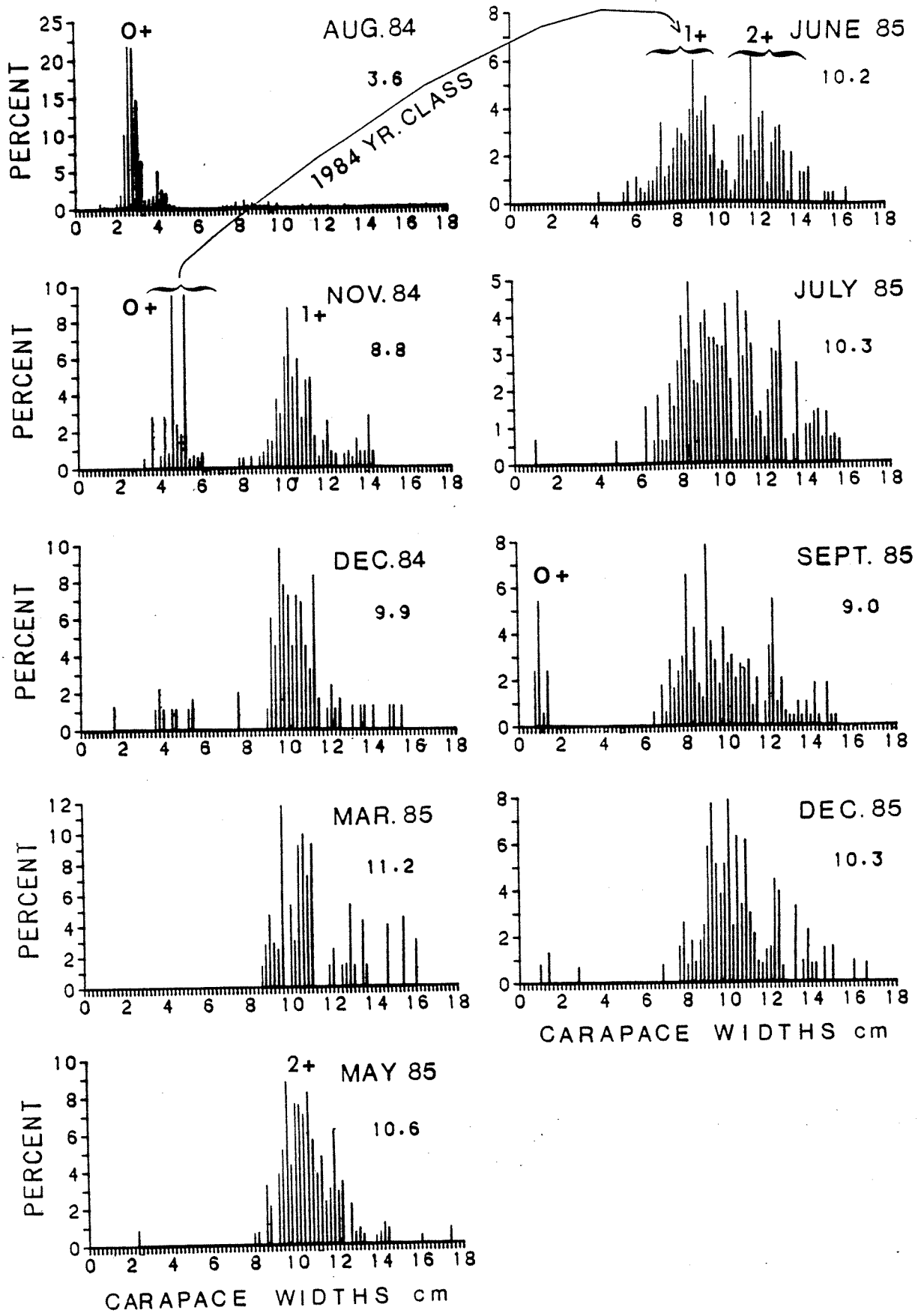


Figure 10. Size frequency histograms for crab caught by beam trawl at March Point. Data are grouped by 2 mm intervals and are based on expanded population estimates for the study site. Age classes are indicated for selected months.

March Point: A somewhat different pattern of age class composition and time of settlement occurred at March Point. In August of 1984 0+ crab were the dominant age group as at Ship Harbor, but were substantially larger and ranged between 20 to 30 mm CW (Fig. 10). By November 1984 this age group had increased in size to a range of about 40 to 60 mm CW, but thereafter through winter and early spring were not a major portion of the size frequency composition at March Point. However, in June 1985 a large population of crab between 60 and 100 mm CW was present at March Point and judged to be the 1984 year class, then in a 1+ age group (Fig. 10). Substantial recruitment of the 1985 year class at March Point was not apparent until September and then, in contrast to the previous year, crab were smaller than 0+ at Ship Harbor. During most of the year the largest portions of the subtidal population at March Point were composed of 1+ and 2+ crab (Fig. 10).

Crab caught by beam trawl at March Point were significantly larger than those at Ship Harbor ($F=67.9$; $df=1,2416$; $P<0.01$) and the mean size of crab increased significantly through time at both locations (Figs. 9,10,11). There was no significant difference between the mean size of male and female crab caught with beam trawl at either Ship Harbor or March Point during the study.

3.2.2. Sex ratio

On most sampling trips there were substantially more males than females caught at both Ship Harbor and March Point (Table 2). From two to five times fewer females were taken with the beam trawl and, although there was no definite trend, the ratio seemed to be skewed toward males both in the winter through early summer of 1984/1985 at March Point and in the fall and winter of both 1984 and 1985 at Ship Harbor (Table 2).

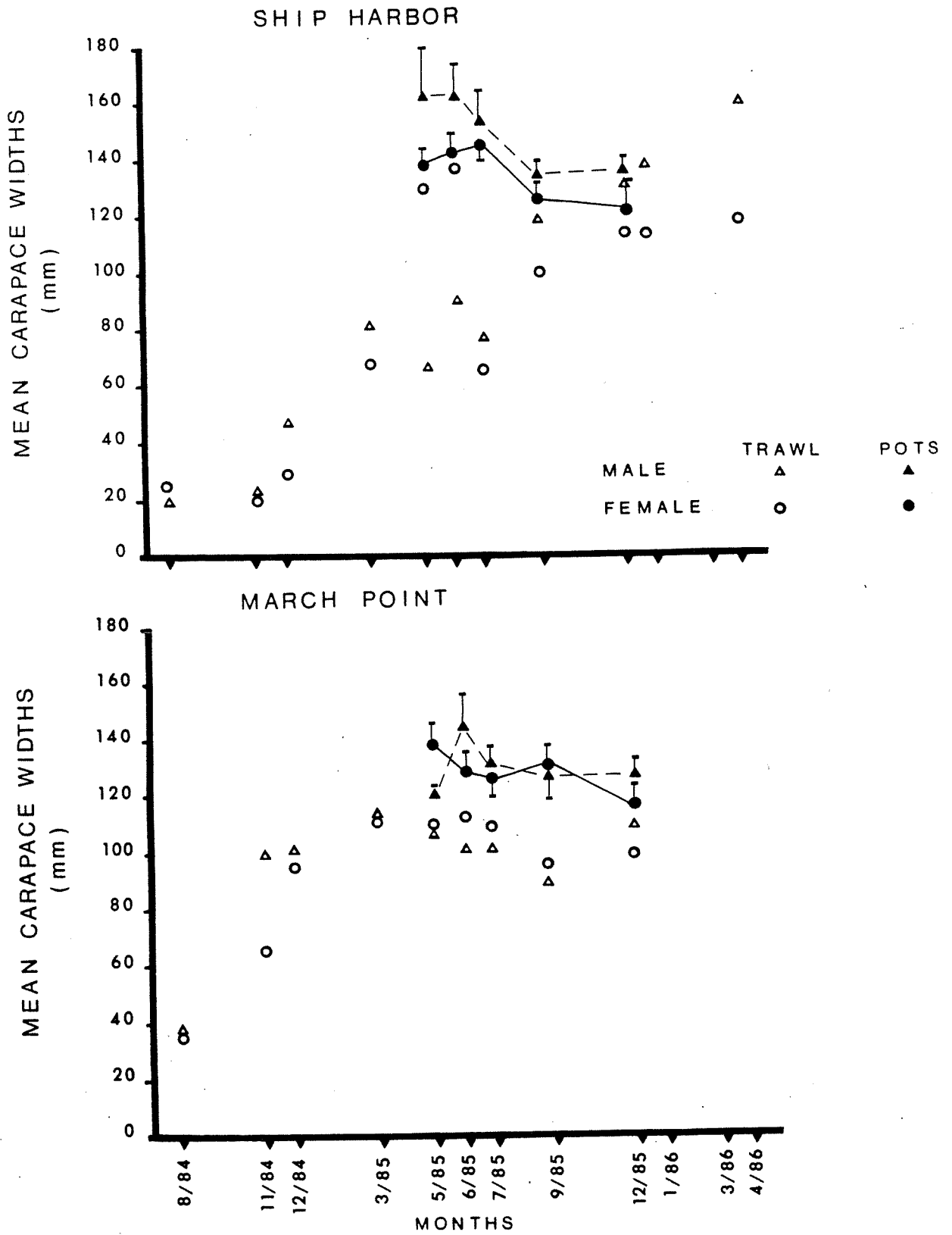


Figure 11. Mean size of male and female Dungeness crab caught at Ship Harbor and March Point with beam trawl and pots. Error bars represent ± 2 SEM for pot data (only a single tail is shown for visual clarity).

Table 2. Sex ratio of Dungeness crab caught at Ship Harbor and March Point by beam trawl (BT) and pots (P), 8/84 through 12/85. All age classes of crab are included except very small instars (<15 mm CW) caught in summer and not identified to sex (see Table 1 for sampling schedule).

Sample Date	Gear	SHIP HARBOR						MARCH POINT					
		n		RATIO		POTS		n		RATIO		POTS	
		M	F	M	F	M	F	M	F	M	F	M	F
8/84	BT P	114	104	1	0.9			362	324	1	0.9		
11/84	BT P	10	5	1	0.5			98	23	1	0.2		
12/84	BT P	5	1	1	0.2			59	11	1	0.2		
3/85	BT P	5	2	1	0.4			50	10	1	0.2		
5/85	BT P	14 3	18 28	1	1.3	1	9.3	146 145	12 31	1	0.1	1	0.2
6/85	BT P	21 10	12 8	1	0.6	1	0.8	163 28	38 53	1	0.2	1	1.9
7/85	BT P	27 16	14 32	1	0.5	1	2.0	93 68	41 70	1	0.4	1	1.0
9/85	BT P	218 92	53 28	1	0.2	1	0.3	97 62	36 52	1	0.4	1	0.8
12/85	BT P	103 64	36 5	1	0.3	1	0.1	67 101	60 24	1	0.9	1	0.2

3.2.3 Density

There was a significant difference between Ship Harbor and March Point in mean density (no./ha) of crab caught by beam trawl (Table 3). Although variability between stations within a sample site was high, significant differences occurred between the two locations during the first five sample trips from August 1984 through May 1985 when average densities at March Point were from 7 to 19 times greater than at Ship Harbor (Table 4). Although there was no significant difference in mean density of crab between transect lines within a study location, there was a highly significant difference between the combined transect densities of Ship Harbor (about 200 crab/ha) versus March Point (about 1,000 crab/ha) (Table 5; $F=18.47$; $df=5,68$; $P<0.01$).

Ship Harbor: There was a general pattern of cyclic density of crab populations in Ship Harbor that declined from a high value of over 500 crab/ha in August 1984 to less than 100/ha from November through May of the following year (Fig. 12). Populations began to increase in June 1985 and reached a second peak of over 400 crab/ha in December.

March Point: As previously noted, crab density was significantly higher at March Point for the first half of the study through May 1985. The highest average density throughout the entire study was recorded in August 1984 at March Point with a value over 6,000/ha, comprised almost entirely of 0+ crab of the 1984 year class (Fig. 12). Thereafter crab densities at March Point were more typically between 400 to 700/ha and were very comparable to (not significantly different from) densities at Ship Harbor from June through December 1985 (Fig. 12).

Stratum: Because of a major difference in habitat as a function of depth within each study site (eelgrass shallow, no eelgrass deeper) sample stations were grouped within each location according to depth ≤ 5 m (16')

Table 3. Analysis of variance of log transformed numbers of crab per hectare caught with beam trawl as a function of location (Ship Harbor vs. March Point) and trip from 9/84 through 12/85. P* = a significant difference.

Source of Variation	Degrees Freedom	Sum of Squares	Mean Square	F Ratio	P
Trip (T)	8	24.20	3.02	4.03	0.000*
Location (L)	1	53.51	53.51	71.34	0.000*
T x L	8	10.71	1.34	1.79	0.083
ERROR	163	121.98	0.75		

Table 4. Comparison of mean crab density (number/ha) at Ship Harbor and March Point from 8/84 through 12/85. Also given are +/- 1 SEM and data on analysis of variance of crab density between locations: df (degrees of freedom), F ratio and the probability (P* = significant difference).

Trip Date	SH		MP		Significance		
	\bar{X}	SEM	\bar{X}	SEM	df	F	P
8/84	538	173	6451	2231	1,20	107.9	0.004*
11/84	44	14.8	685	185	1,20	18.43	0.000*
12/84	21	8.8	396	107	1,20	27.29	0.000*
3/85	23	5.6	174	36	1,15	14.95	0.002*
5/85	90	34.4	559	188	1,17	9.8	0.007*
6/85	181	91	699	229	1,16	4.42	0.052
7/85	213	89	393	122	1,17	4.36	0.052
9/85	343	195	384	126	1,21	1.35	0.258
12/85	420	106	370	38	1,17	1.02	0.327

Table 5. Comparison of mean number of crab/ha along each transect line of Ship Harbor (A,B,C,D) and March Point (F12, N4). All trawls for each transect line have been combined for all trips 8/84 through 12/85.

Location	Transect*	n	Mean	+1SD	±1SEM
Ship Harbor	A	27	259	534	103
	B	30	154	314	57
	C	28	168	269	51
	D	26	201	664	130
March Point	F12	18	1291	3869	912
	N4	32	971	1507	266

*No significant difference (ANOVA) between transect line within a location, but a highly significant difference in transect density between locations ($F= 18.47$; $df= 5,68$; $p<0.01$).

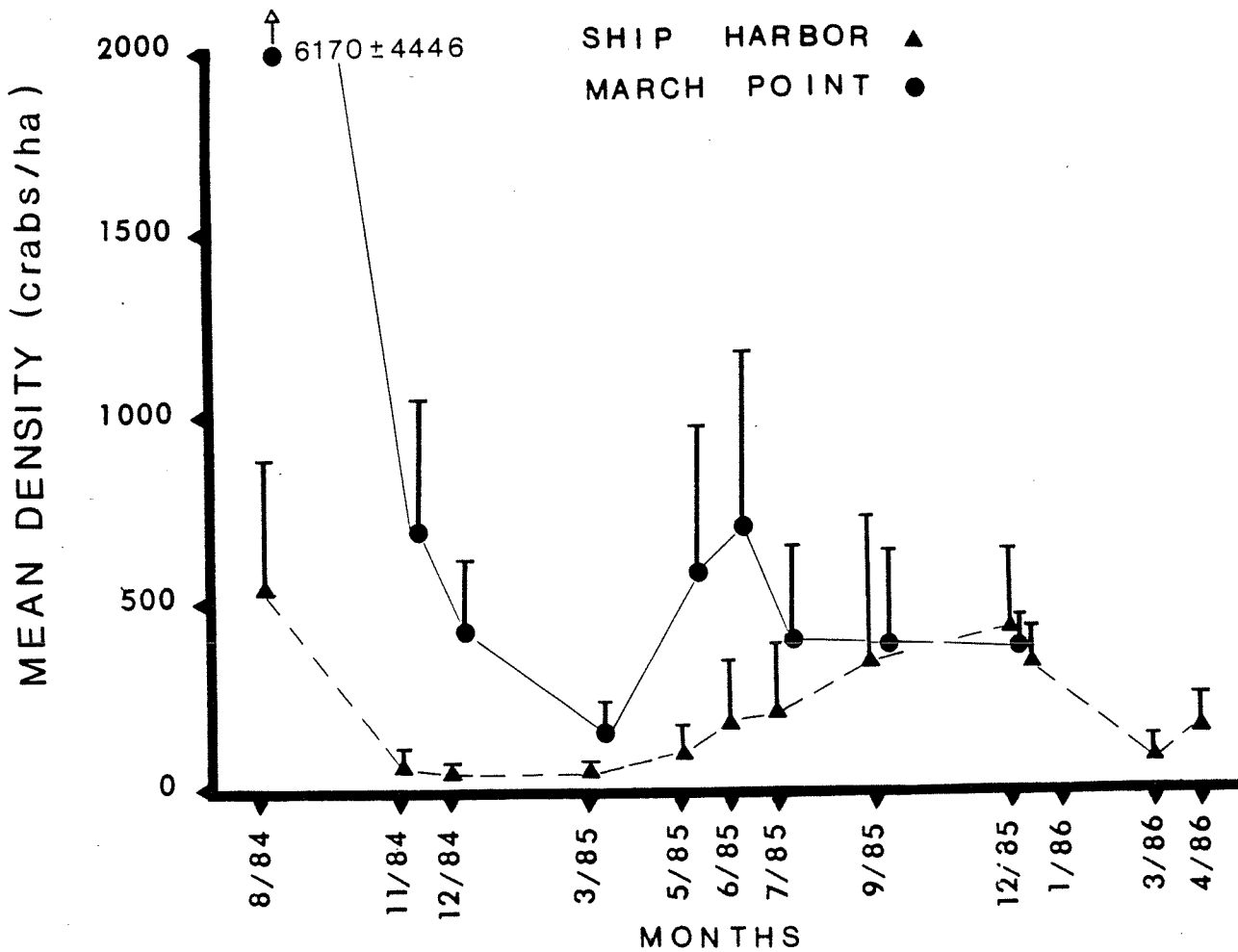


Figure 12. Mean density (number/hectare) of crab caught by beam trawl at Ship Harbor and March Point. Error bar is +/- 2 SEM but for clarity only the upper error is pictured.

and from 5.1 to 9.1 m (17' to 30') and crab density compared. There was no significant difference in density of crab at Ship Harbor between shallow and deep stations (Table 6), but there were significantly more crab off March Point at deeper than at shallow stations where mean densities through the entire study period were about 1,550 and 690, respectively (Table 6).

3.2.4 Population abundance

The densities of crab at individual stations computed as no./ha were expanded to a population estimate for each trip by extrapolating to the total area of each study site (see Section 2.4). Since there was no significant difference between strata (depth intervals) at Ship Harbor and the relationship was only slightly significant at March Point, all stations for each trip were used to calculate a total population estimate.

Ship Harbor: Within the nearly 29 hectares of the Ship Harbor study site total crab populations determined by beam trawl ranged from a high of nearly 18,000 crab in August 1984 to low values of about 500 crab in the winter of 1984-85 (Fig. 13). Following winter, populations began to increase in the spring from 2,300 in May to over 10,000 in September 1985 (Fig. 13). Again, in the winter and early spring of 1985-86 there was a significant decline in the population level to about 1,200 crabs in March 1986. Based on the sex ratios previously reported (Table 2), the majority of the Ship Harbor population determined by beam trawl was comprised of males which were often two to five times more abundant than females.

March Point: The estimated population at the March Point study site was consistently greater than that at Ship Harbor both because of higher crab densities during the first half of the study but, more importantly, the substantially greater area of the study site (323 hectares). The total crab population at March Point determined by beam trawl ranged from a high

Table 6. Comparison of mean crab density at Ship Harbor and March Point as a function of depth (\leq or $>$ 5m). All stations sampled from transect lines within each location have been combined for all trips (see Figs. 2 and 5 for strata areas).

STRATUM	Ship Harbor*				March Point*			
	n	\bar{x}	$\pm 1SD$	$\pm 1SE$	n	\bar{x}	$\pm 1SD$	$\pm 1SE$
Shallow (1)	57	165	273	36	27	693	1195	230
Deep (2)	54	224	602	82	23	1548	3567	744

* No significant difference (ANOVA) between shallow and deep stations at Ship Harbor; significant difference at March Point ($F=5.49$; $df=1,19$; $P<0.05$).

value of slightly more than two million to a low of about 58,000 crab (Fig. 14). The value of two million in August 1984 was due almost entirely to a couple of very large trawl samples and high densities of small 0+ (see Fig. 10). More typically, the long term population level at March Point ranged between about 60,000 to 230,000 crab. A pattern of abundance somewhat similar to Ship Harbor was observed as populations declined in winter and early spring and increased in the summer. Males were also more abundant than females at March Point as indicated by the sex ratios of Table 2 and the population trends of animals >100 mm CW shown in Figure 14. Total females >100 mm CW (theoretically sexually mature) were relatively consistent and ranged between 10,000 to 20,000 crab (Fig. 14).

Another measure of the relatively greater population of crab at March Point can be based on a comparison of the long term average populations relative to the area of each study site. Discounting the very high population levels from each site in August 1984, the grand population means of all trips were 151,000 (+/- 60,000; 1 SD) crab at March Point, and 4,100 (+/- 3,500) at Ship Harbor which was a population about 37 times smaller. However, a comparison of the relative areas, the 29 ha of the Ship Harbor site to the 323 ha of the March Point site, reveals a sampling area 11 times smaller at Ship Harbor. Thus a crab density about 3 times higher on average exists at March Point than at Ship Harbor, a fact partially responsible for the substantially higher population levels at March Point.

3.3 Crab Populations: Diver Surveys

Divers were initially used to check the efficiency of the net with the thought that small juvenile stages might not be consistently accessible to the gear in dense eelgrass. Divers, however, never found evidence of high juvenile densities in excess of those determined with the beam trawl.

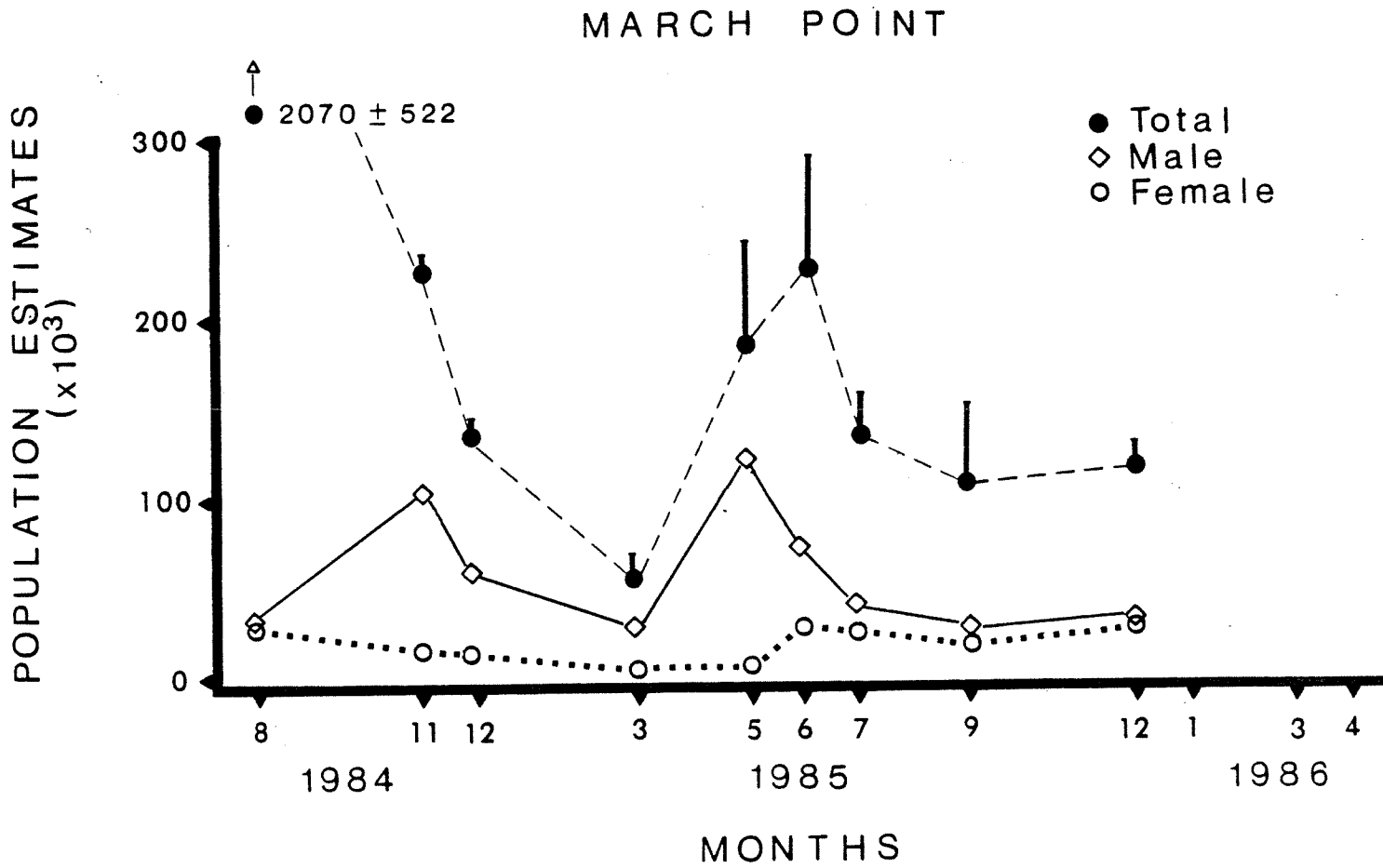


Figure 14. Total crab population estimates based on beam trawls at March Point. Also given are population estimates for males and females >100 mm CW. Error bars are +/- 2 SEM.

Divers did find, however, that both male and female crab in shallow water during the winter were often buried into the substrate and subsequently less vulnerable to the gear. Males were buried just to their eyestalks and antennae and remained fairly active throughout the wintertime. Females more often buried several centimeters deep with no visible means of contact with the overlying water column. The finding of greatest significance during the diver surveys was the high proportion of the females found buried that were ovigerous (egg bearing).

3.3.1. Ship Harbor

The size of crab caught by divers at Ship Harbor was comparable to the size range of older and larger crabs caught by beam trawl (Fig. 15). In December and March 1985 divers caught crabs in the 110 to about 180 mm CW size range which were for the most part, 2+ and 3+ age groups. Even in the spring and summer divers almost never took crabs smaller than 80 mm CW which indicates that in neither 1984 nor 1985 were 0+ crab abundant in the subtidal.

Since the distance and width of the diver transect could be measured accurately, the number of crab caught could be equated to area swept and converted to density. In the winter and early spring of both 1984/85 and 1985/86, divers measured consistently higher densities of crab than determined with the beam trawl (Fig. 16). In December 1984 divers estimated a mean density of over 500 crab/ha at a time when the beam trawl estimate was less than 100/ha. In late December 1985 through March 1986 diver estimates of crab averaged about 1,400/ha while the beam trawl estimates were around 300/ha (Fig. 16).

Expanded to a population estimate, diver surveys indicated a resident population of between 5,000 and 10,000 crab in Ship Harbor from late winter 1984 to early spring 1985 (Fig. 13). During the same winter period in

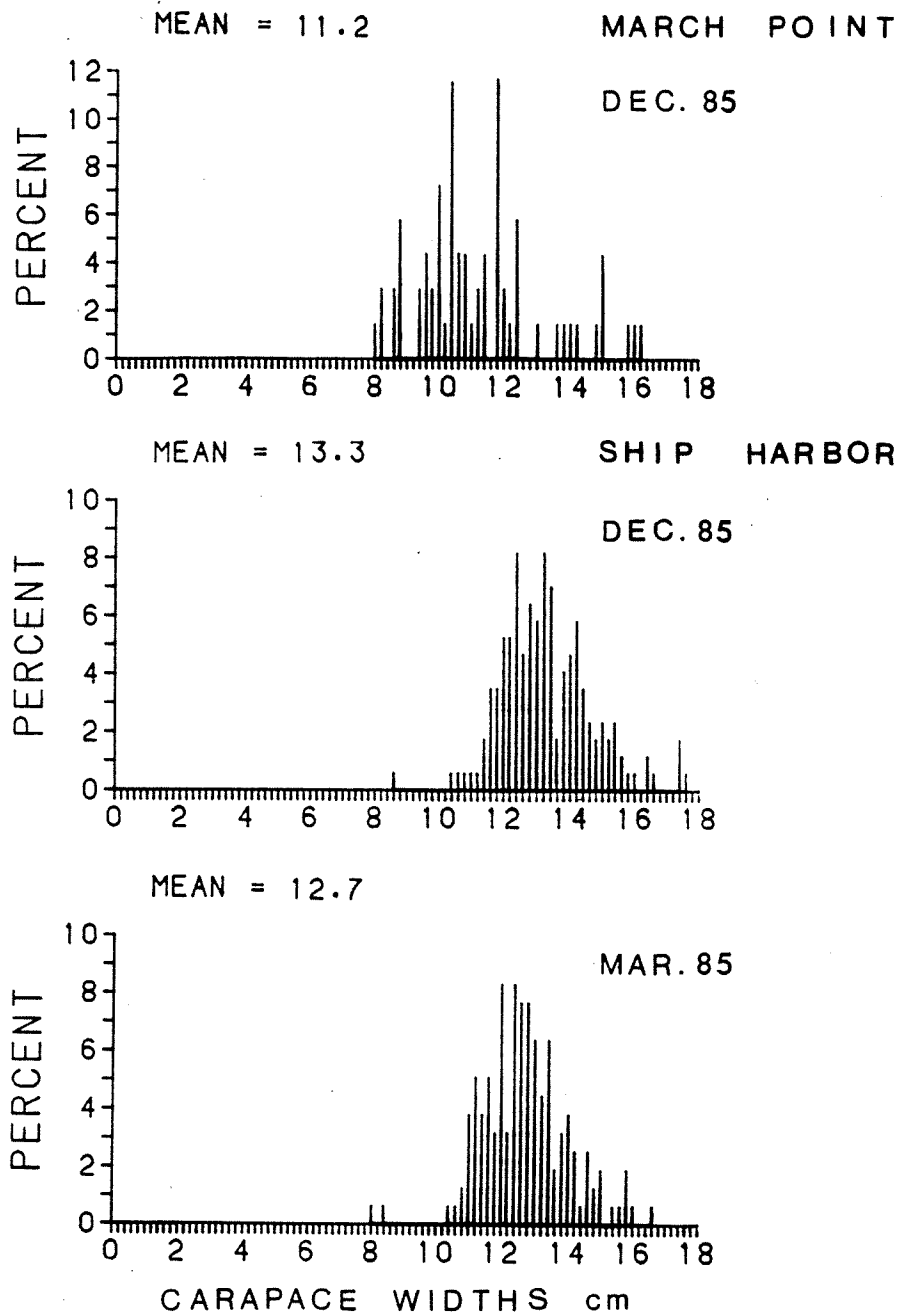


Figure 15. Exemplary size frequency histograms of crab caught by divers at Ship Harbor and March Point. The majority of crab caught at Ship Harbor were female and, in winter, from 50% to 90% were ovigerous; no ovigerous crab were taken at March Point.

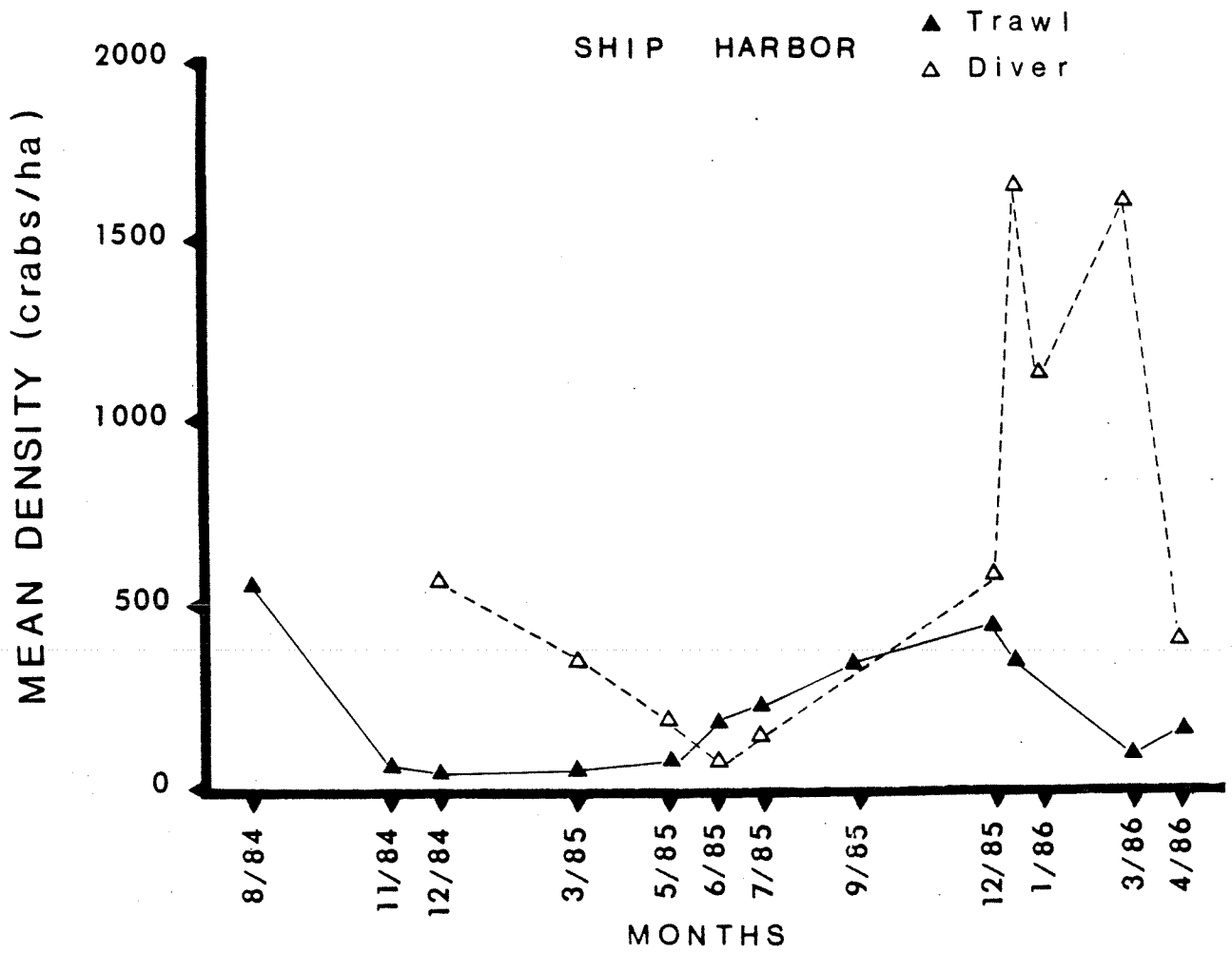


Figure 16. Comparison of total crab density at Ship Harbor determined by beam trawl and diver survey.

1985/1986 the diver population estimate ranged from about 20,000 to 25,000 crab and declined to 11,500 by April 1986. In comparing population estimates derived by the two methods, we selected diver estimates as more accurate when means for both techniques differed by more than ± 2 standard errors of the mean (± 2 SEM). A composite seasonal trend in population abundance determined by the two methods is indicated in Figure 13 by the solid curved line in which diver estimates are considered more accurate in the winter time and beam trawl estimates equally or more accurate in the spring through summer. Throughout time, populations were usually between 5,000 to 10,000 crab and in the winter of 1985/86 exceeded 25,000 crab at the study site on occasion.

3.3.2 Ovigerous females

The diver surveys in winter and spring were particularly significant because they revealed a large resident population when that computed by beam trawl had apparently declined. These dives also indicated a major shift in the life history stages comprising the winter population; most importantly, it was comprised of a high percentage of ovigerous female crab (Fig. 17). Divers always caught more female than male crab at Ship Harbor; and particularly in the winter and early spring of 1985/1986 they were generally from two to three times more abundant than males (Fig. 18). The majority of females taken by divers were buried several centimeters in the substrate and carried egg masses. Each sampling trip the percent of ovigers was almost always greater than 50% and typically was between 60% and 90% (Fig. 18). During December of both 1984 and 1985 almost all females carried newly extruded eggs characterized by a deep orange color. Eggs took several months to mature and by March of 1985 and 1986 the greatest proportion of ovigerous females caught at Ship Harbor carried old

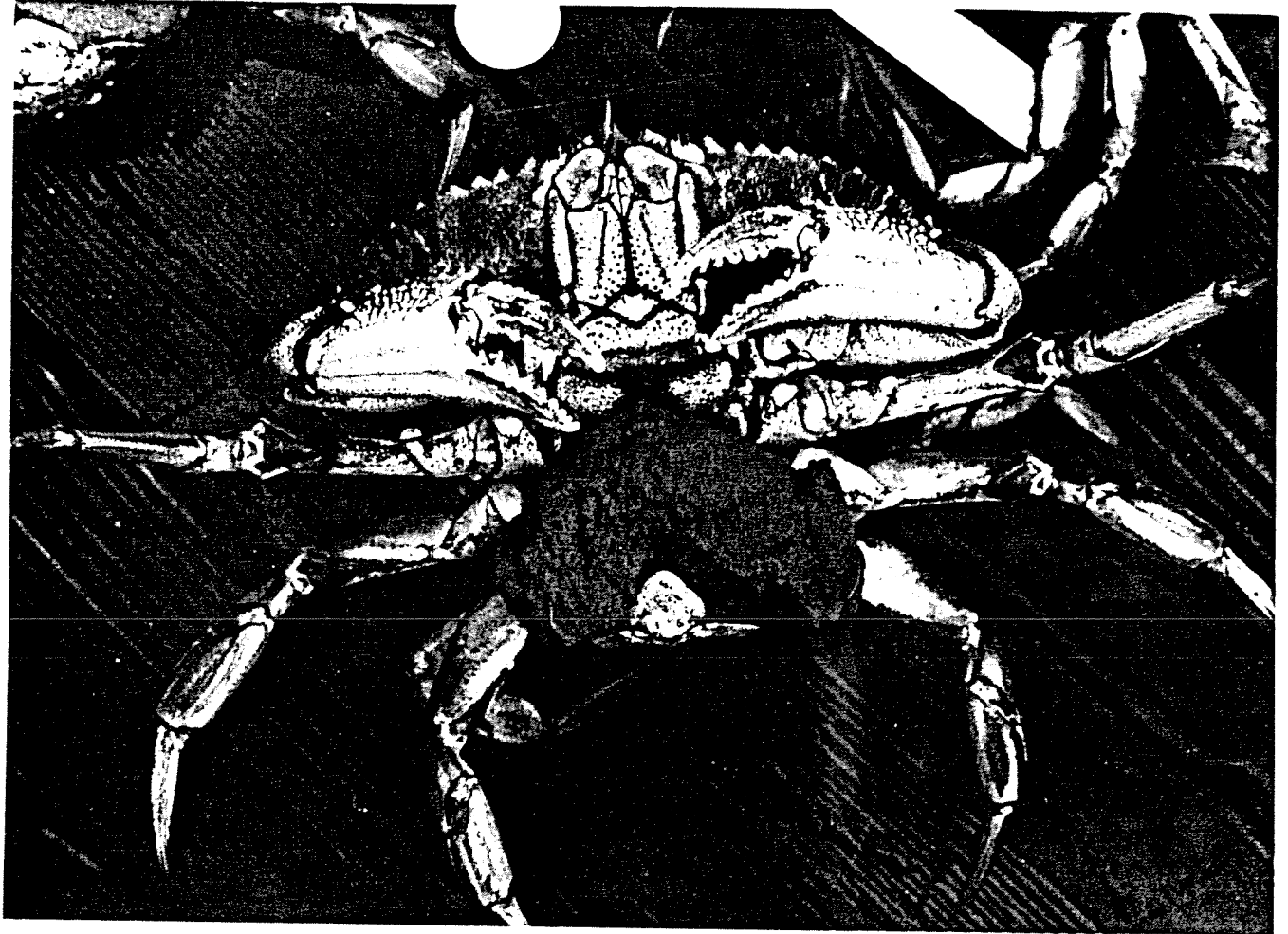


Figure 17. Example of an ovigerous female crab taken by divers at Ship Harbor in winter. All such females were buried several centimeters in the substrate and therefore not accessible to trawl gear. No ovigerous females were found at March Point.

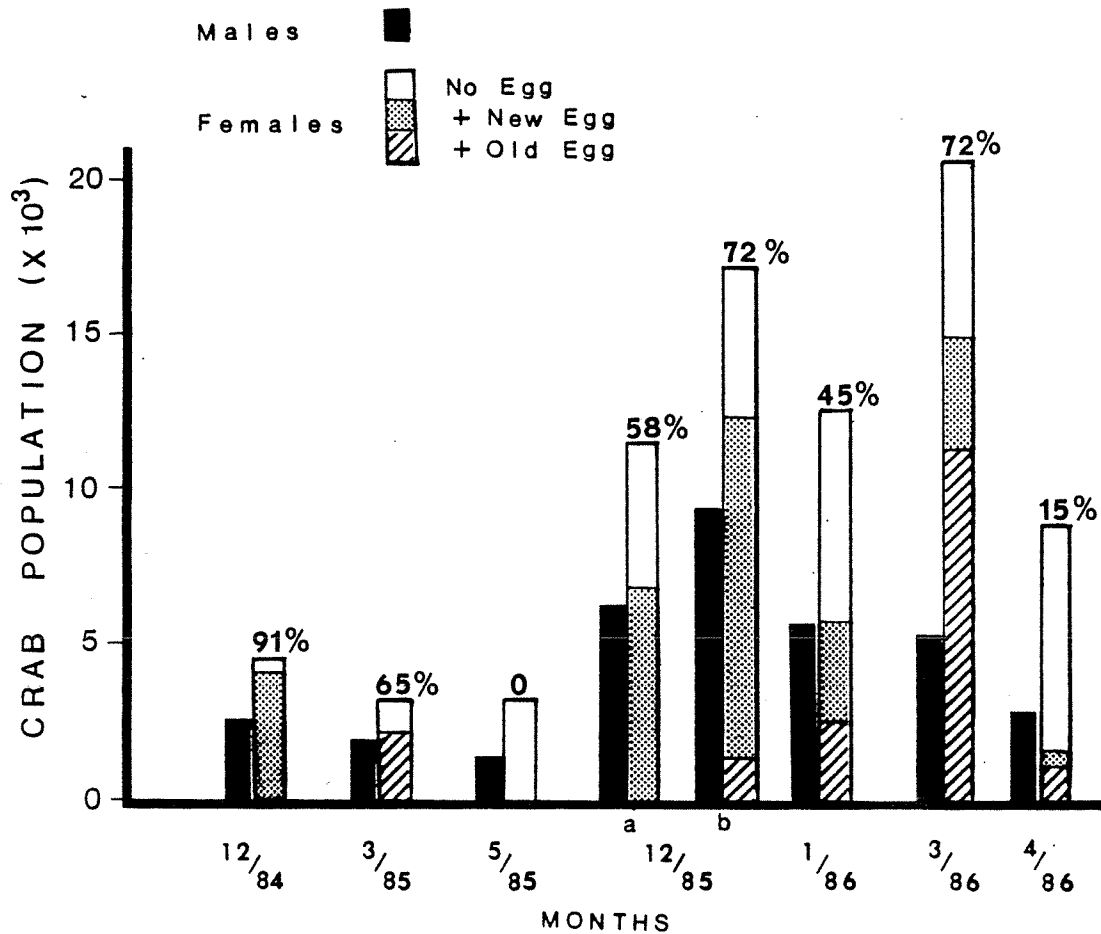


Figure 18. Population estimates of male and female crab at Ship Harbor based on diver estimates. Estimates for females are shown for those carrying no eggs and eggs that are either newly extruded or old (darker and/or eyed embryos). Data for June and July are not shown since beam trawl estimates are considered more accurate. Shown are percentages of females carrying eggs.

eggs (dark brown, eyed embryos) and some had already hatched. In April only 15% of the female population was ovigerous and by May none could be found (Fig. 18).

Almost all ovigerous females captured by divers were buried in relatively shallow water between 1 m to 3 m depth in open areas of the eelgrass zone and at highest densities around transect line C (refer to Fig. 2). The mean size of females carrying eggs was generally larger than that of females without and differed by as much as 5 to 9 mm CW (Table 7).

Because of the high density of ovigerous females at Ship Harbor and the consistent failure to locate females at the control site off March Point (see following section), diver survey was extended to a much larger area in December 1985 and January 1986 to include the entire south side of Guemes Channel, all of Padilla Bay, areas around Cypress and Guemes Island, and west of Ship Harbor around the point to Anaco Beach (see Fig. 1; Tables 8 and 9). Despite the extent and intensity of this survey, ovigerous females were only consistently found along the south side of Guemes Channel continuing east from Ship Harbor. Densities ranged from 230 to nearly 2,000 females/ha along the south side of the channel from Ship Harbor to Boomers Landing at Anacortes (Tables 8,9). No ovigerous females were located at any other sampling site throughout Padilla Bay, south Samish Bay, west of Ship Harbor to Anaco Beach, around Guemes Island, or within the Cap Sante and Skyline marinas. The only exception was a small population of ovigerous females found on the east side of Cypress Island at a density of about 290/ha (Table 9).

3.3.3 March Point

A more limited diver survey of crab populations was made at March Point (Table 1) in order to again check the efficiency of the beam trawl. Population estimates of crab based on diver transects were never greater

Table 7. Size of female Dungeness crab taken by divers at Ship Harbor with and without egg masses.

Trip	FEMALES NO EGGS				FEMALES WITH EGGS					
	n	\bar{X}	+1SD	+2SEM	Range	n	\bar{X}	+1SD	+2SEM	Range
12/84	-					10	139.0	5.5	3.5	126-147
3/85	-*					11	137.4	10.8	6.5	116-151
5/85	5	130	7.4	6.6	119-135	0				
12/85 (1)	8	122	9.5	6.7	110-127	11	129	13.7	8.3	112-145
12/85 (2)	25	122	20.0	8.0	108-139	57	131	11.5	3.0	104-155
1/86	11	129	9.6	5.8	108-142	10	134.5	10.2	6.5	120-156
3/86	35	125	10.0	3.4	104-140	108	127.3	11.7	2.1	109-158
4/86	58	120	8.2	2.2	100-145	10	128	10.3	6.5	121-156

*Eggs of remaining females had hatched (empty egg cases); n = 6, \bar{x} = 130 mm, $\pm 2SEM$ = 5.1

Table 8. Summary of crab density determined by divers (plus two trawls) at Ship Harbor and other adjacent areas, December 27-29, 1985. All values are based on catches of two divers who swam a marked line of 40 m and covered 132m². All depths are in feet below MLLW (0.0' tide). Of particular importance are values for female crab with and without eggs. Multiply crab density as no/100m² by 100 to get no./ha.

Location	Transect No.	Depth (ft.)	Total Crab				Density (No./100m ²)					
			Total	Male	Female >100mm	Female >100mm + eggs	Total	Male	Female >100mm	Female >100mm + eggs		
SHIP HARBOR	B-line	5	12	4	8	8	0	9.1	3.0	6.1	0	
	"	7	25	9	16	16	9(56)	18.9	6.8	12.1	6.3	
	"	10	50	16	34	34	31(91)	37.9	12.2	25.7	23.5	
	"	15				0	0				0	
	C-line	5	35	10	25	25	23(92)	26.5	7.6	18.9	17.4	
	"	7	7	5	2	2	2(100)	5.3	3.8	1.5	1.5	
	"	15	11	5	6	6	5(83)	8.3	3.8	4.5	3.8	
	B/C	12	14	12	2	2	0	2.7	2.4	0.3	0	
	C/D	7	14	14	0	0	0	3.7	3.7	0	0	
	D-line	5	19	3	16	16	9(56)	14.4	2.3	12.1	6.8	
East of SHIP Harbor	"	10	12	8	4	4	1(25)	9.1	6.1	3.0	0.8	
	E-line	6	28	3	25	25	17(68)	21.2	2.3	18.9	12.9	
	"	8-22	No female with egg beyond EG									
	F-line	7	14	10	4	4	3(75)	10.6	7.6	3.0	2.3	
	"	6-22	Some female to 10' in EG, none deeper in light EG and algae									
	G-line	9	19	15	4	4	4(100)	14.4	11.4	3.0	3.0	
	"	7-22	Some female to 10' in medium EG, butter clam shell and cobble, no female deeper than 12'									
	H-line	7	34	8	26	26	26(100)	25.7	6.1	19.7	19.7	
	I-line	8	0								0	
	Sunset Bay Washington Park	*	5-10	4	2	2						0
Anaco Beach, South Skyline Marina	*	3-20	0, no crab, medium EG, algae, gravel									0
PADILLA BAY	No. 1	12	0				0					0
	2	10	5	5	0		0	3.8	3.8			0
	3*	10	No females, many juvenile males									0
	4*	10	0				0					0
	5	10	0				0					0
	6	10	4	3	1	1	0	3.0	2.3	0.7	0	0
South Guemes Is.		12*	6	5	1							0

*Qualitative (no measured distance) transects swam by divers to verify absence of females, usually beyond eelgrass, or to look for any ovigerous females before setting marked transect lines.

Table 9. Extended diver survey to locate ovigerous female crab in January 1986. Refer to Fig. 1 for general locations. Multiply female density as no/100m² by 100 for no/ha.

Dive Location	Transect Dive No.	Depth	Area covered (m ²)	Total Crab			Density (No./100m ²)					
				Total	Male	Female	Total	Male	Female			
<u>SHIP HARBOR</u>	B/C	10	102	13	5	8	1 (12)	12.7	4.9	7.8	1.0	
<u>SUNSET BAY</u>	C	10	102	17	4	13	9 (69)	16.7	3.9	12.7	12.7	
		5-10	140	0								
<u>E. CYPRESS IS.</u>	1	5	102	8	4	4	3 (75)	7.8	3.9	3.9	2.9	
	2	5	102	10	7	3	2	9.8	6.9	2.0	0	
	3	5-25	*				6					
		*all females with eggs in EG, 5 to 10 ft depth										
<u>GUEMES IS.</u>												
West side		5-20	102	0			0				0	
Northeast side		3-25	*	*a few <u>C. magister</u> , no female with eggs								
<u>PADILLA BAY</u>												
March Pt. oil dock	1	7-30	*	*several small <u>C. magister</u> , no females with eggs								0
S. Hat Is., east of oil docks	2	5-15	*	*two small <u>C. magister</u> , no females with eggs								0
Bayview Channel	3	2-20	*	*six juvenile <u>C. magister</u> , no female								0
Between Saddlebag and Samish Is.	4	8-20	*	*several juvenile <u>C. magister</u>								0
S. side Pt. Williams	5	2-15	*	*two <u>C. magister</u>								0
S. Samish Is.	6	5-15	*	*two <u>C. magister</u>								0
Samish Bay, north Pt. Williams		0-25	202	20	13	7	1 (14)	9.9	6.4		0.5	
<u>Marinas</u>												
<u>SKYLINE</u>												
1	5-10	152	2	1	1	1	1	1.3	0.7		0.7	
2	5-15	101	20	11	9	6	0	19.8	10.9	8.9	0	
3	5-15	202	10	7	3	3	0	5.0	3.5	1.5	0	
West of Guemes Is ferry terminal		5-20	*	8 males, no female								0
Wynan's Boomers Landing area		5-10	152	21	13	8	7	2 (28)	13.8	8.5	4.6	1.3
Cap Sante		3-15	101	one male, no female								0
Anacortes, south of Cap Sante		8-15	202	7	5	2	1	0	3.4	2.5	0.5	0
Between Cap Sante and Anacortes marinas		5-15	152	30	25	5	0	19.7	16.4		0	

than those determined by beam trawl in both winter and spring and so population estimates determined for March Point were never adjusted by the diver survey. Divers also never located ovigerous females at March Point although they found a number of females buried into the substrate during winter and spring.

3.4 Crab Population: Pots

Data on crab pots was used as a relative index of abundance between Ship Harbor and March Point but was not used for calculations of density or population size. A rate of crab caught per hour was calculated and used to determine differences between locations and length of fishing time (soak time) which was essentially equivalent to day or night. Soak time was divided into intervals (≤ 10 hr or > 10 hr) which, given other operational needs and logistics, equated to periods of daylight or overnight, respectively. There was a highly significant difference in the rate of catch between Ship Harbor and March Point and between day and night at each location (Table 10). The rate of catch was significantly higher during the day which generally represented soak times from four to eight hours. At March Point the rate of catch was from two to nearly ten times greater (4 to 9 crab/hr) than at Ship Harbor (0.5 to 3/hr) (Fig. 19). Overnight the rate of catch was substantially less at both locations with no consistent pattern evident (Fig. 19).

An initial comparison of the size of crab caught by pot and beam trawl (ANOVA) indicated highly significant differences between trips and location, so data were then analyzed separately for Ship Harbor and March Point. Within each location there were differences in size of crab caught each trip and by beam trawl or pot, but not between sexes caught by the same type of gear (Table 11; Fig. 11). A multiple comparison (SNK; ANOVA

Table 10 . Analysis of variance of log transformed data on crab caught per hour in pots as a function of location (Ship Harbor and March Point), soak time, and five trips from 5/85 through 12/85.

Source of Variation	Degrees Freedom	Sum of Squares	Mean Square	F Ratio	P
Trip	4	0.129	0.032	0.78	0.542
Soak Time (Day/Night)	1	2.472	2.472	60.29	0.000
Location	1	1.803	1.803	43.97	0.000
Error	56	2.323	0.041		

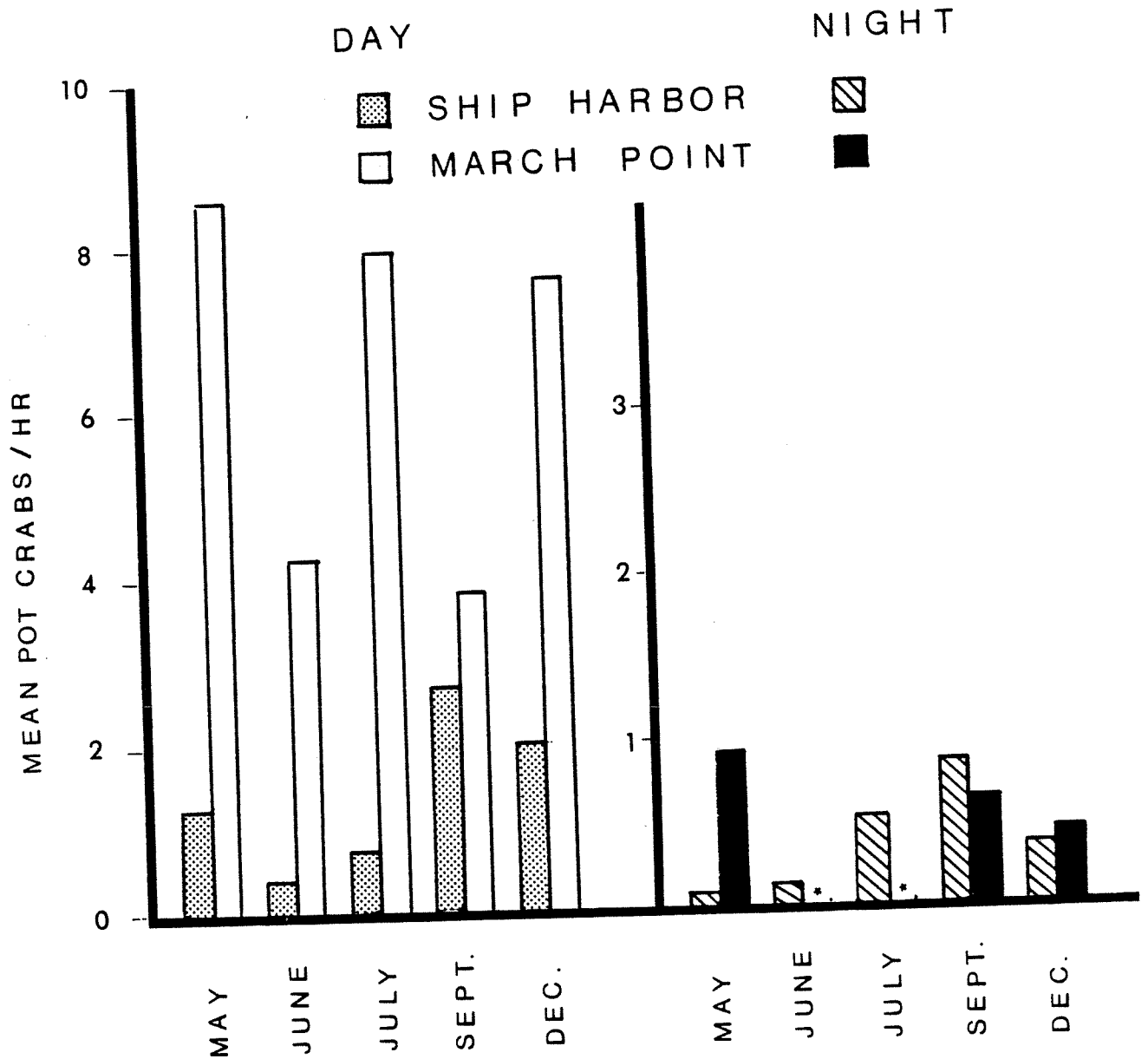


Figure 19. The rate of crabs caught per hour in pots covered with small mesh and escape ports closed at Ship Harbor and March Point. Day and night categories equate to periods \leq or >10 hrs soak time. An asterisk (*) indicates no samples were taken. No ovigerous females were ever caught in pots at either location.

Table 11. Analyses of variance of size of male and female Dungeness crab caught at Ship Harbor and March Point by pot and beam trawl between March through December 1985. Since an initial ANOVA showed a highly significant difference in size of crab between location, they were analyzed separately.

Source of Variation	df	SS	MS	F	P
<u>SHIP HARBOR</u>					
Trip	4	17,686	4,421	7.32	0.000
Gear	1	107,365	107,365	177.81	0.000
Sex	1	40	40	0.07	0.797
Error	782	472,198	603		
<u>MARCH POINT</u>					
Trip	5	15,845	3,169	7.79	0.000
Gear	1	115,724	115,724	284.37	0.000
Sex	1	611	611	1.50	0.221
Error	1,468	597,412	407		

each trip) showed that males caught by pot were significantly larger than caught by beam trawl at both locations on almost every sampling trip (Table 12). On average males were 65 mm CW larger (range 14 to 100 mm CW difference) in pots than beam trawl at Ship Harbor, and 25 mm CW larger (13 to 43 mm CW difference) at March Point (Table 12). Females at Ship Harbor were only significantly larger in pots on two of five trips, but at March Point were significantly larger every trip at an average difference of 21 mm CW (range 16 to 33 mm CW) compared to those caught by beam trawl (Table 12).

No ovigerous females were ever taken by pot at either location throughout the entire study.

3.5 Intertidal

A limited series of intertidal samples was collected at Ship Harbor, but a longer series at March Point as part of a more expanded study provided a basis of contrast. Intertidal densities of 0+ crab were comparable at both locations and ranged from about 1 to over 40/m² (Fig. 20). In March and April of 1985 intertidal density at both locations was about 5/m² and declined to about 1/m² between May and July 1985. Beginning some time in July recruitment of the 1985 year class occurred and densities increased significantly to over 30/m² at March Point and in September there were about 8/m² at Ship Harbor. After high recruitment at March Point in late summer, there was an appreciable decline through the fall so that by November, density was about 6/m² (Fig. 20). The mean size of crab in the intertidal reflects recruitment patterns and probably movement from the intertidal as crabs grew. Beginning in March 1985 the mean size of crab at both March Point and Ship Harbor increased from about 15 mm CW to over 30 mm during a period when the density declined. Between June and July there

Table 12. Comparison of size of male and female Dungeness crab caught at Ship Harbor and March Point by beam trawl and pot. There was no significant difference between male and female crab caught by the same type of gear (Table 11), but ** indicates highly significant difference between gear by sex. \bar{x} = average difference in size for only those trips that were significant.

Trip Date	MEAN SIZE (mm CW)						
	MALE			FEMALE			
	Pots	BT	P	Pots	BT	P	
<u>SHIP HARBOR</u>							
3/85							
5/85	162	62	100	**	138	129	9
6/85	161	93	68	**	142	137	5
7/85	152	74	78	**	145	70	75
9/85	132	118	14	**	126	100	26
12/85	133	130	<u>3</u>		122	115	<u>7</u>
			$\bar{x}=65$				$\bar{x}=50$
<u>MARCH POINT</u>							
3/85	126	112	14	**	130	112	18
5/85	120	107	13	**	138	115	23
6/85	144	101	43	**	128	112	16
7/85	131	100	31	**	128	110	18
9/85	127	93	34	**	130	97	33
12/85	125	109	<u>16</u>	**	116	98	<u>18</u>
			$\bar{x}=25$				$\bar{x}=21$

¹Pots were not used in Ship Harbor on this date.

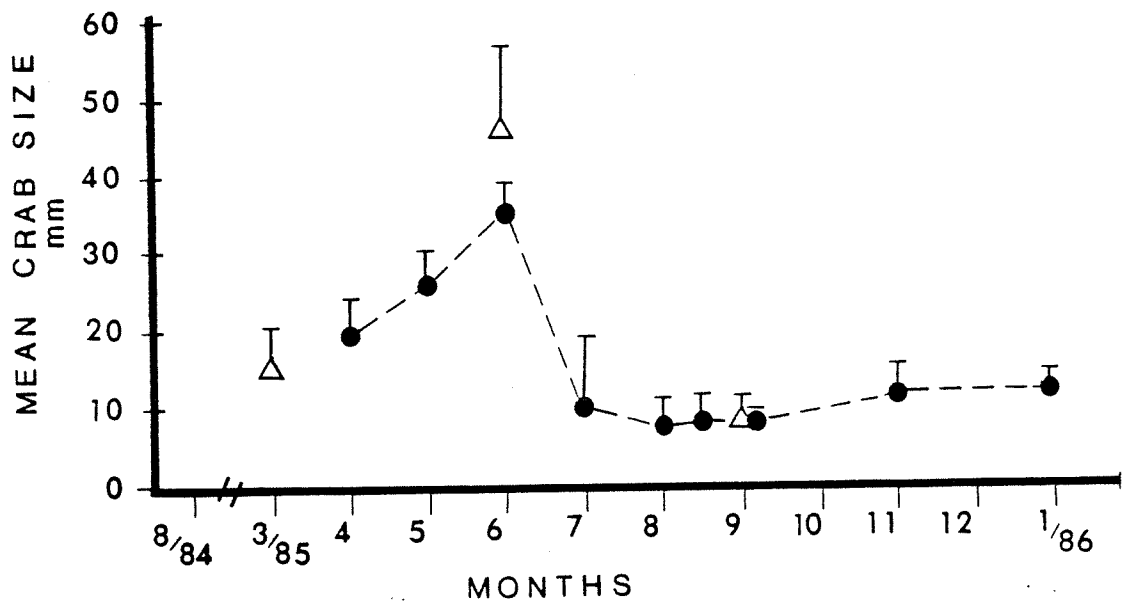
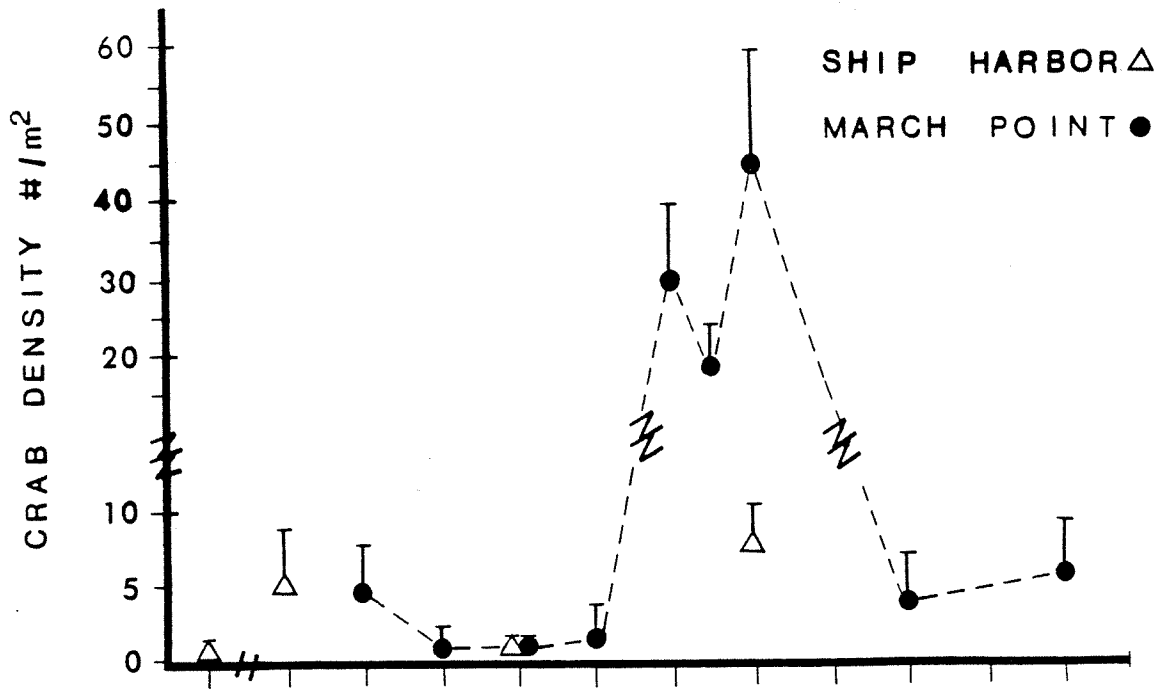


Figure 20. Mean density and size of 0+ Dungeness crab in the intertidal of Ship Harbor and March Point.

was a significant decrease in mean size of crab to about 10 mm which coincides with recruitment of the 1985 year class. Mean size remained between 8-10 mm CW through summer to winter of that year (Fig. 20).

3.6 Other Species

Although the primary effort of this study was to investigate ecology and population dynamics of Dungeness crab in small embayments of Puget Sound, data were also recorded on relative numbers of other invertebrates and fish caught by the trawl gear. Qualitative estimates of relative abundance of other species are given in Table 13 from August 1984 which was typical of months in the spring and summer. At Ship Harbor common fish were English sole (Parophrys vetulus), shiner perch (Cymatogaster aggregata), snake prickleback (Lumpenus sagitta), tube snout (Aulorhynchus flavidus), and tadpole sculpin (Psychrolutes paradoxus). Other Crustacea were common at Ship Harbor, most notably the decorator crab (Oregonia gracilis) at depths greater than 6 m, the lyre crab (Hyas lyratus) also at deeper depths, the kelp crab (Pugettia gracilis), crangon shrimp (Crangon spp.), and juveniles of the coonstripe shrimp (Pandalus danae). Appearance of juvenile shrimp was highly seasonal, with few evident in late fall through winter, but high numbers present in the dense eelgrass during spring and summer. A similar composition of species was found in trawls collected at March Point.

4.0 DISCUSSION

Compared to the open coast, the variety and extent of habitat in Puget Sound that could support Dungeness crab is seemingly much more complex and varied. The convoluted coastlines of myriad islands and numerous bays, abrupt changes in depth from intertidal to 100 m over short lineal

Table 13. Species list of animals caught by beam trawl at Ship Harbor, August 1984. A qualitative indication of abundance by depth interval is also given: (0) = not present; (-) = uncommon; (+) = moderately common; (++) = very common.

Common	SPECIES	Generic	Depth Interval Below MLLM (0-0)			
			3-10 ft 0.9-3.0 m	11-20 ft 3.3-6.1 m	21-30 ft 6.4-9.1 m	>30 ft >9.1 m
FISH						
English sole	<i>Parophrys vetulus</i>		-	+	++	++
Rock sole	<i>Lepidopsetta bilineata</i>		0	0	0	0
Starry flounder	<i>Platichthys stellatus</i>		0	-	0	0
Sand sole	<i>Psettichthys melanostictus</i>		0	-	0	-
Speckled sanddab	<i>Citharichthys stigmæus</i>		0	0	0	-
Rex sole	<i>Glyptocephalus zachirus</i>		0	0	0	-
Butter sole	<i>Isopsetta isolepis</i>		0	-	0	0
Sturgeon poacher	<i>Agonus acipenserinus</i>		0	0	-	-
Tubenose poacher	<i>Pallasina barbata</i>		+	0	0	0
Shiner seaperch	<i>Cymatogaster aggregata</i>		-	0	0	0
Striped seaperch	<i>Embiotoca lateralis</i>		0	-	++	++
Tomcod	<i>Microgadus proximus</i>		+	++	+	+
Snake prickleback	<i>Lumpenus sagitta</i>		-	-	0	0
Saddleback gunnel	<i>Pholis ornata</i>		0	-	0	+
Penpoint gunnel	<i>Apodichthys flavidus</i>		0	-	++	0
Unid. eelpout	<i>Lycodes sp.</i>		+	+	0	0
Tubesnout	<i>Aulorhynchus flavidus</i>		0	0	0	0
Bay goby	<i>Lepidogobius lepidus</i>		0	0	-	+
Midshipman	<i>Porichthys notatus</i>		0	0	0	-
Greenling	<i>Hexagrammos sp.</i>		0	0	0	-
Big skate	<i>Raja binoculata</i>		0	0	+	-
Staghorn sculpin	<i>Leptocottus armatus</i>		+	+	-	0
Tadpole sculpin	<i>Psychrolutes paradoxus</i>		-	-	0	0
Great sculpin	<i>Myoxocephalus polyacanthocephalus</i>		-	0	0	0
Silverspotted sculpin	<i>Blepsius cirrhosis</i>		-	-	0	0
Buffalo sculpin	<i>Enophrys bison</i>		0	-	0	0
CRUSTACEA						
Decorator crab	<i>Oregonia gracilis</i>		+	-	+	+
Lyre crab	<i>Hyas lyratus</i>		0	0	++	++
Kelp crab	<i>Pugettia producta</i>		-	+	0	0
Graceful kelp crab	<i>Pugettia gracilis</i>		-	-	0	0
Bristle crab	<i>Telemessus cheiragonus</i>		-	-	-	-
Graceful Cancer crab	<i>Cancer gracilis</i>		0	0	+	+
Hermit crabs	<i>Pagurus sp.</i>		0	0	+	-
Hairy Cancer crab	<i>Cancer oregonensis</i>		0	0	++	++
Crangon shrimp	<i>Crangon sp.</i>		0	0	0	0
Coon stripe shrimp	<i>Pandalus danae</i>		++	++	0	0
Red crab	<i>Cancer productus</i>		0	-	0	0
ECHINODERMATA						
Sea cucumber	<i>Parastichopus californicus</i>		0	0	0	0
Pink starfish	<i>Pisaster brevispinus</i>		0	0	-	0
MOLLUSCA						
Cockle	<i>Clinocardium nuttalli</i>		0	0	-	0

distances, intertidal that grades from rock to cobble to sand and includes many epibenthic covers such as eelgrass, macroalgae, shell and stick debris as well as vast stretches of shallow subtidal benthos all provide intricate habitat for life history stages of Cancer magister. Yet very little is known about the ecology and population dynamics of this species in Puget Sound and almost all information that is available relates to growth rates (molt frequency), size at instar and size at sexual maturity (Butler 1960,1961). Very little work has been done on population dynamics and habitat needs of this species, particularly small juveniles and ovigerous females. Butler (1956) provided limited information on occurrence of newly settled instars in eelgrass and macroalgae which suggested the need of cover as protection for small crab. Dinnel et al. (1985) provided preliminary information from an ongoing study of crab recruitment and habitat needs that substantiates the observation of higher density of juveniles in habitats that provide shelter, assumably from various species of predators. Breen (1985, unpublished manuscript) provided data on density of newly settled Dungeness crab within several habitats including shell and eelgrass and showed that, compared to open substrate, this species seems to survive better in areas that afford protection.

Despite the historic importance of the commercial fishery in Puget Sound, virtually no studies of adult populations of either sex have been done. Mayer (1973) investigated adult crab populations in Similk Bay just south of Padilla Bay but used crab pots as the primary means to sample populations. Although a tagging study was conducted in order to calculate population size, the great bias of crab pots in terms of life history stages caught, makes the data of limited utility except for notation of seasonal life history events such as molting, egg extrusion, movement, etc. The present study at Ship Harbor and March Point near Anacortes,

Washington, is the first detailed research on distribution and abundance and habitat requirements of all life history stages of Dungeness crab in inland waters. This study relied on use of several types of sampling methodology that reflected change in occurrence and behavior of various life history stages. The goal was to learn as much as possible about all benthic stages of the crab from settlement at first instar through sexual maturity (all pelagic larval stages were excluded in this program). Much of what has been observed in this study has already been expanded and may be interpreted differently in the future based on the larger scale program sponsored by Washington Sea Grant (Dinneil et al. 1985).

The issue that precipitated this program was one of potential impact caused by development of a proposed marina at Ship Harbor. Because WDF has so little ecological information on the species in inland waters with which to make judgements and assess potential impact, on-site research was deemed necessary for this proposed development. At the conclusion of this study it appears that, in most respects, there is little difference in overall ecology, occurrence of life history stages and their relative densities at Ship Harbor compared to the control site at March Point in Padilla Bay. The overwhelming feature of great significance that distinguishes the Ship Harbor population from that observed off March Point is, however, the occurrence in winter and early spring of a large population of mature, ovigerous female Dungeness crab that apparently use Ship Harbor as an overwinter area for egg incubation and hatch. Since so few female crab were found at numerous other locations in the greater Anacortes area, the potential of project impact on the species as the marina was first configured was deemed greater than if just juveniles and/or mature but non-reproducing crabs had been present at Ship Harbor.

Mature females and reproduction is viewed as a critical stage and sensitive biological event in the life history of this species; a perspective reflected in the management plan for the fishery that excludes commercial exploitation of females. A question of importance that still remains unanswered at the conclusion of this study is what relative importance do the females at Ship Harbor have in the overall reproductive effort of Dungeness crab in North Puget Sound. The fraction of total mature females in North Puget Sound which are present at Ship Harbor and that reproduce in a given year will probably never be known, and even crude estimates can certainly not be made without more extensive studies of distribution. However, the fact that females were found in high density at Ship Harbor but in very few other locations over an extended area is considered significant, and reason to be cautious about potential impacts of the proposed marina on habitat and future residence of females at Ship Harbor.

4.1 Female Reproduction

The occurrence of ovigerous female crabs was the singular unique feature of this species' presence at Ship Harbor compared to March Point.

4.1.1 Characteristics of the population

Timing of arrival: Female crab must move into Ship Harbor and extrude egg masses some time in mid-November to early December. Dives in November 1984 indicated no ovigerous female crab were present at Ship Harbor, yet by the dive on December 7th, 90% of the females caught were ovigerous (Fig. 18). Again in early December 1985 the majority of females caught by divers were ovigerous with new clutches of eggs that had undergone little cellular division, indicating recent extrusion. By January, 1986 the egg masses of about half the females caught were rated as "old" by virtue of a darker

color and, in some cases, eyed embryos. In March of both 1985 and 1986 most females carried "old" eggs and in the former year a number of females were caught with empty egg cases indicating that hatching began in March of that year. By April, 1986 only about 15% of the large females caught by divers at Ship Harbor still carried eggs.

Females spend approximately three to four months at Ship Harbor during egg incubation and development, and most of the population has hatched eggs by late March through mid-April each year. This ovigerous period is in accord with that reported by Mayer (1973) who caught most ovigerous females in pots between the months of December through March. Interestingly, Mayer did catch some ovigerous females in pots during his study while none were caught at Ship Harbor using this sampling technique.

Extent of the population at Ship Harbor: Virtually all of the ovigerous female population at Ship Harbor was located in the eelgrass zone from about 0.5 to 4 m depth (Fig. 2, stippled area). Densities were higher in the eastern portion of the study area toward transect lines C and D, than toward the west at lines A and B. The size of the estimated population varied considerably between the winters of 1984/85 and 1985/86 (Fig. 18). Approximately 5,000 ovigerous females were estimated in Ship Harbor in December 1984, but the number was nearly doubled in December 1985, and in March 1986 the highest estimate of nearly 15,000 females was calculated (Fig. 18). Interannual variability in the abundance of ovigerous females at Ship Harbor probably exceeds a factor of two to three over a longer period as has been seen in the cycles of legal males reflected in commercial landings (Botsford and Wickham 1978). It is probably not so much the magnitude of variation in the population of female crab at Ship Harbor or any other location that is the primary concern in assessing impact at this state of knowledge, but rather the consistency with

which a given life history stage uses a particular habitat in a given location. Given the presence of ovigerous females two years in a row at Ship Harbor, we are inclined to assume this species utilizes the region annually for egg incubation.

Burial behavior: The presence of ovigerous female crab at Ship Harbor was not an unexpected result of this study, but the fact that they were buried into the substrate and relatively quiescent was unexpected. In light of our previous experience along the open coast where ovigerous females can be obtained in commercial crab pots during winter and Mayer's (1973) similar experience in Similk Bay, we expected to catch egg-bearing females in our trawl gear but, in fact, never captured a single ovigerous female by either pot or trawl during the entire study. Females at Ship Harbor were buried several centimeters into the substrate (from carapace to surface) in sediments that were, in locations, apparently anoxic. Many females recovered by divers had blackened carapaces, abdominal flaps, and dactyls of walking legs, indicating reduced conditions in the sediments. It is interesting to speculate on the physiology of developing eggs and embryos that are carried by females buried in the substrate with no apparent means to circulate overlying water to and from the egg mass. Oxygen transfer and ammonia removal would seem difficult and slow in this situation and, consequently, pose a threat to the eggs.

A question that bears on the fate of egg masses buried in the sediment is just how often the female emerges and moves about on the surface. We have no data that pertains to this question but were told of an interesting experiment by Mr. Bruce Higgins (marine biological consultant, Seattle, Washington; personal communication) who observed buried ovigerous female Dungeness crab in the eelgrass north of Mukilteo during dives in 1980.

Once he became familiar with the characteristic depression in the substrate that typifies a female crab which has buried itself, Mr. Higgins conducted an experiment in which poker chips were placed on 12 such depressions during SCUBA dives and oriented with a mark toward magnetic north. Seven days later divers found that half the chips were disturbed and crabs had left, but six chips were still in place with the mark toward magnetic north and female crabs were still buried beneath. This preliminary observation indicates that a single female can remain buried for an extended period of time and suggests a sort of torpor during initial egg development.

The reasons for burial and type of habitat in which it routinely occurs are not clear. It may be that females with newly extruded bright orange egg masses are more vulnerable to predation and that burial substantially reduces this form of mortality. Possibly as the egg mass matures female crab become more active, bury less frequently or for shorter durations and finally do not bury at all as eggs near hatch. During deep water surveys of crab populations in Port Gardner in February, 1986 Dinnel et al. (1986) caught large numbers of ovigerous females with the same beam trawl gear used in Ship Harbor. However, all ovigerous crabs caught in February carried matured eyed egg masses and some had already hatched (the timing of egg extrusion, development and hatch in Port Gardner seem to be about one to two months earlier than found in Ship Harbor that same year). Much more research will have to be conducted to learn whether burial is a feature that is relatively typical of ovigerous female Dungeness crab and whether it is a behavior most characteristic of early incubation.

The type of habitat that ovigerous females select for residency during egg incubation and in which they might bury is not at all clear based on this study. As indicated, few female crab were found in many other survey

locations around the greater Anacortes area, although shallow water eelgrass - habitat seemingly similar to that at Ship Harbor - was common in much of Padilla Bay, Samish Bay, around Guemes and Cypress Islands, and west of Ship Harbor as well. In addition to ovigerous females at Ship Harbor we have had reports of and have observed females buried on the north side of Mukilteo and at Golden Gardens in Seattle. The only feature these locations share in common other than shallow water eelgrass is that the beach runs east/west, faces north and has some sort of headland protection on the south side. This may indicate that female crab select habitat that will be relatively sheltered from direct winds of southwest prevailing storms during the winter when eggs are incubated. In this vein it is interesting that at Ship Harbor most of the buried female crab were located near and east of transect line C which is sheltered by a prominent hill on the beach, whereas transect lines A and B at which ovigerous female crab were uncommon occurred in front of an extensive area of flat marsh and sand.

Size of mature females: The mean size of ovigerous females taken in the winter of 1984/85 (about 138 mm CW) was somewhat greater than the size in 1985/86 (about 130 mm CW; Table 7). It is interesting to consider the reproductive age of these females and the extent to which the reproductive population is composed of primiparous (first time spawners) or multiparous (spawned more than once) females. Butler (1960) indicates that female Dungeness crab attain sexual maturity between 100 and 110 mm CW, followed by molt and egg extrusion. In a sample of 31 mating pairs of Dungeness crab found around Ship Harbor and March Point and elsewhere in Puget Sound (Mission Beach, Tulalip Bay) females averaged 110 mm CW (+/- 8.7 mm= 1SD). Given pre-/postmolt size information on females provided by Butler (1960) and Hanken et al. (1985), a premolt female at 110 mm that is grasped by a

male will be about 130 mm CW after molting when she is bred and later extrudes an egg mass. Thus the majority of ovigerous females at Ship Harbor during 1985/86 were primiparous and it is likely that a large percentage of the 1984/85 population was also. It is interesting to consider whether the preponderance of primiparous females at Ship Harbor indicates selection of that type of habitat by first year spawners (larger, older females might brood eggs at depth), and/or a low proportion of multiparous females in the general population.

4.1.2 Comparison of ovigerous females at Ship Harbor to other populations

An important perspective to have of the Ship Harbor ovigerous population is their proportion relative to other spawning populations in the general area. Despite numerous dives made during the winter of 1985/86, ovigerous female Dungeness crab were essentially found only along the south side of Guemes Channel continuing east from Ship Harbor (Fig. 1; Tables 8 and 9). East of Ship Harbor divers found buried female crab along the beach adjacent to the old Schooner drydock facilities and at intermediate locations as far east as the Guemes ferry terminal on the Anacortes side and at Boomers Landing. During dives in late December and January 1985/86 divers found an average of 784 ovigerous females/ha (extrapolated from Tables 8 and 9 listed as Transect lines E,F,G,H and Boomers Landing). On nautical charts the area over which females were found along the south side of Guemes Channel equals approximately 57 ha x 784 females/ha is a total of about 45,000 ovigerous females in the winter of 1985/86. This number is approximately three to four times greater than the 10,000 to 15,000 estimated at Ship Harbor during this same time.

Most importantly, ovigerous female crab were not found at the other dive sites with the exception of the small number on the east side of Cypress Island and one individual each in Samish Bay and the Skyline Marina

(Table 9). Relative to the entire area surveyed around the greater Anacortes region, the population at Ship Harbor appears to account for a major portion of this spawning stock in the area during winter. As a cautionary note, it must be observed that the absence of females elsewhere, particularly throughout Padilla and in south Samish Bay, cannot be taken as a routine annual occurrence. In conversations with local crabbers, sport fishermen and divers we were told that ovigerous females have been found and caught along the oil docks off March Point adjacent to our own trawl stations, and in winter of 1984 we caught a fairly large number (about 50) of ovigerous females at the south end of Samish Bay (Fig. 1).

Based on the results of work in Port Gardner (Dinnet et al. 1986), ovigerous female Dungeness crab may also occur at depth (such distribution might also occur in Guemes Channel and particularly toward the east end near Hat Island). In Port Gardner in February 1986 at depths around 80 m, Dinnet et al. (1986) found densities of ovigerous female crab ranging from approximately 50 to 500/ha with an average of about 200/ha. This value is comparable to but somewhat lower than measured at Ship Harbor where divers in the winter of 1984/85 found about 320 females/ha, and at the peak of abundance in winter 1985/86 found about 600/ha (Fig. 16).

The only other study of adult crab populations in Puget Sound was that of Mayer (1973) who estimated a total population of about 14,000 crab in Similk Bay based on crab pot studies and tag returns. However, this number cannot be used for any basis of comparison since pots are such an inaccurate gear to measure population structure and abundance, particularly for certain life history stages, and no breakdown of his data was given according to sex.

4.2 Young-of-the-Year Juveniles

Young-of-the-year, 0+ juvenile Dungeness crab apparently metamorphosed and settled to the benthos as early as May and June but as late as September in 1984 and 1985. The schedule is somewhat earlier than that given by MacKay and Weymouth (1935) for Boundary Bay but is consistent on the later end of the time range. Unpublished evidence of Dinneil, McMillan and Armstrong (from the expanded Sea Grant Program) indicates that two periods of settlement might be common in North Puget Sound; one that occurs in May and June and is consistent in time with the major settlement along the open coast (Stevens and Armstrong 1984; Armstrong and Gunderson 1985), and one that occurs toward the end of summer in late August and early September that is consistent with other observations for inland populations (MacKay and Weymouth 1935; Butler 1956). Differential time of settlement, separated by as much as three months, suggests that distinctly different spawning stocks might occur in the Pacific Northwest.

0+ crab were the most abundant life history stage present at both Ship Harbor and March Point in August 1984, but through the winter and spring of 1984/85 decreased substantially in the subtidal and did not occur in significant numbers again until recruitment in June 1985 at Ship Harbor and September 1985 at March Point (Figs. 9 and 10). Although growth rate could not be followed with any degree of accuracy, it was striking that 0+ crab off March Point in August 1984 were approximately 10 mm CW larger than those at Ship Harbor and, based on the data of MacKay and Weymouth, would have been approximately 6th to 7th instars off March Point and 5th to 6th instars at Ship Harbor. This difference in size may have been due to earlier settlement at March Point and/or a faster growth rate by virtue of slightly warmer bottom water temperatures there compared to Ship Harbor.

Intertidal density of 0+ crab was significantly greater than determined by beam trawl in the subtidal (compare Fig. 12 that shows total crab abundance in the subtidal and Fig. 20 that shows intertidal 0+ only). Density of 0+ crab in the intertidal of March Point reached a peak of 40 crab/m² and more typically ranged between 2 to 5 crab/m² over most of the year (Fig. 20). Such values convert to about 20,000 to 50,000/ha which are densities one to two orders of magnitude greater than total crab densities in the subtidal (e.g. Fig. 12). Such discrepancies in relative abundance of newly recruited 0+ in the intertidal and older juvenile and adult populations in the subtidal are routine (Stevens and Armstrong 1984; Armstrong and Gunderson 1985; Dinneil et al. 1985).

0+ that recruit to the intertidal in the summer of a given year apparently find more adequate refuge from predators, grow in the intertidal through summer and portion of fall, over winter, and move off intertidal flats to the subtidal in the spring of the following year (Fig. 20). In comparing the two locations there was no difference in density of 0+ crab in the intertidal between Ship Harbor and March Point. Indeed, densities at these locations were comparable to intertidal population densities reported by Armstrong and Gunderson (1985) for vast areas of the intertidal of Grays Harbor where 0+ density is highest in shell debris, and ranges from 2 to 5 crab/m² through much of the summer.

To the extent that we could trace a year class in the beam trawl size frequency data, it appeared that 0+ which had settled off March Point were as large as 25 to 40 mm CW in August, 40 to 60 mm in November, and the following June (as 1+ crab) ranged between 65 to 100 mm CW (Fig. 10).

4.3 Older-Juvenile and Adult Populations

4.3.1 Reliability of estimates

The beam trawl is considered much more accurate sampling gear than the otter trawl formerly used for these types of benthic crab surveys (Stevens and Armstrong 1984; Armstrong and Gunderson 1985). The accuracy and efficiency of the gear is, however, predicated on certain aspects of behavior of the crab and requires that animals are active and on top of the substrate or still responsive to disturbance (by the tickler chain) if slightly buried. Ovigerous females in the winter cannot be sampled with the beam trawl and so another technique, divers, was required. The efficiency of the trawl gear in capture of very small 0+ crab in relatively dense vegetation such as eelgrass and macroalgae was also questioned. The diver surveys through the summer indicated no greater density of this stage than determined by the beam trawl. Nonetheless, the net tends to accumulate large amounts of eelgrass or macroalgae on the footrope and tickler chain where this vegetation is dense, which must reduce the efficiency of capture. Thus population estimates should always be viewed as conservative when determined by these means.

Crab pots are of only limited utility in providing an index of relative abundance of populations between two locales. The gear is obviously biased toward larger crabs (Table 12) as has been previously shown by Diamond and Hanken (1985). Pots used in our study were covered with smaller mesh and the escape ports closed which substantially increases the size of smaller crab caught, but is still biased compared to non-selective gear (Diamond and Hanken 1985). We converted our crab pot data to crab caught/hr in order to compare relative density between the two locations. The rate of capture was significantly greater during the day than at night and was higher at March Point than at Ship Harbor (Fig. 19).

From two to eight times more crab were caught per hour at March Point which is consistent with higher densities of crab in that area, determined by beam trawl, although data from pots cannot be used to calculate either density or population size.

In terms of the response of crabs to pots, it was surprising to see that the rate of capture during the day (shorter soak times) was much higher than at night (longer soak times; Fig. 19). Given evidence of apparently greater activity of crab during dark (Stevens et al. 1984) we expected higher rates of capture overnight at both locations. Longer soak times may have reduced the apparent rate of capture overnight (there may not be a linear increase of crabs within a pot over time if, for instance, bait is consumed or loses its scent) but virtually never were the total numbers of crabs per pot fished overnight as large as those obtained in just a couple of hours of fishing during the day. Diamond and Hanken (1985) showed a significant loss of crab <125 mm CW from commercial pots of standard mesh that had closed escape ports. Non-selective traps with mesh comparable to our covered pots but with narrower widths per trigger at the entrance tunnel, retained 100% of crab down to 100 mm and less. We suspect our covered, closed port pots behaved somewhere in between. Escapement overnight may represent some portion of the difference between day and night rates of capture, but the higher rate during the former is probably real.

4.3.2 Relative density

The dominant age group other than 0+ within Ship Harbor seemed to be 2+ and 3+ animals through most of the study period (Fig. 9 Beam Trawl; Fig. 15 Divers). Seasonal density of older age groups indicated greatest use of Ship Harbor during spring and summer although the measured densities of

less than 50 to about 500 crab/ha are not high compared to other systems. In Grays Harbor, Washington, subtidal crab density typically ranges from 1,000 to 5,000/ha and at settlement of 0+ may exceed tens of thousands per hectare on occasion (Armstrong and Gunderson 1985; Armstrong unpublished data). Densities of older juveniles at March Point were several-fold higher than in Ship Harbor during the first portion of this study, but comparable through the spring and summer of 1985 (Fig. 12). 1+ and 2+ juveniles were common off March Point throughout the year, and particularly 1+ crab were evident in the spring and summer of 1985 (Fig. 10).

The expanded population estimates for each system are, however, the major difference between locations. The largest winter populations estimated from diver surveys at Ship Harbor ranged between 20,000 to 25,000 crabs composed primarily of larger females, but at March Point winter populations ranged between 120,000 and 140,000 crabs composed primarily of one and two year-old males (compare Figs. 13, 14, and Table 2). During the spring and summer, population estimates from Ship Harbor based on beam trawl data were a maximum of about 10,000 crab but at March Point exceeded 200,000 crab in 1985 (Fig. 14). As noted previously, the population estimate off March Point is very conservative since the area selected for this study is only about 20% of the subtidal of Padilla Bay and local populations of juvenile crab also occur in Fidalgo Bay, Samish Bay, and along shorelines of all the local islands. Thus the Ship Harbor population was routinely 10 to 50 times less than that at the March Point study site and, in fact, is probably orders of magnitude less than crab populations throughout the greater Anacortes area.

4.3.3 Distribution by habitat

The definitions of "habitat" used in this study were: 1) shallow water areas of relatively dense cover comprised primarily of eelgrass and to a lesser extent macroalgae and; 2) deeper areas beyond eelgrass zones with occasional plant debris, stick, and shell. Thus, presence or absence of cover and depth were the two variables of "habitat" used for contrast of distribution within study sites. A third category could be considered all intertidal habitats which were, however, occupied primarily by 0+ crab and is an issue separate from the subtidal populations of older crabs.

The only life history category that occupied shallow eelgrass habitat in significantly greater numbers than deeper, more open habitat were mature ovigerous females in the winter at Ship Harbor. Otherwise there was no significant difference in mean density of total crab between the two strata at Ship Harbor throughout this study. Off March Point there were significantly greater numbers of crab in the deeper areas (primarily in some of the major channels of Padilla Bay) than in the shallow eelgrass habitats. This difference could be partially an artifact based on reduced efficiency of the trawl gear in dense eelgrass, but at both March Point and Ship Harbor divers in the spring and summer never captured crab at higher densities than determined by the beam trawl. Crab that are one and two years old may not require nearly the degree of protection from predators afforded by eelgrass as do small 0+, and thus for the older crab food supply and location may be more important. Infauna and epibenthic prey may be less abundant within dense eelgrass beds than in more open, deeper water areas which, in turn, affects the relative density of crab at March Point but is not the case at Ship Harbor.

4.4 Overall Importance of Ship Harbor to Dungeness Crab

Based on this investigation from summer of 1984 through spring of 1986 there is little in the overall life history and ecology of Dungeness crab that is unique to Ship Harbor compared to the control study site off March Point. Both sites are occupied by the same life history stages at comparable densities, but Ship Harbor supports significantly lower populations through most of the year. Intertidal recruitment and survival of 0+ young-of-the-year is comparable between the two systems, and a much greater expanse of such intertidal habitat throughout Padilla Bay and other locations reduces the apparent importance of Ship Harbor for early settlement and survival of significant portions of the 0+ age class. The single unique and important feature of crab population dynamics at Ship Harbor is the over winter use of the area by ovigerous female crabs during development of their egg masses.

The only population of ovigerous females found throughout the greater Anacortes area was along the southern side of Guemes Channel from Ship Harbor east approximately 5 km (Fig. 1). In the winter of 1985/86 Ship Harbor contained approximately 15,000 ovigerous female crab. Based on a cursory survey of crabs elsewhere along the channel approximately 45,000 additional ovigerous females occurred over the rest of the 5 km of nearshore habitat. Thus Ship Harbor accounted for about 25% of the ovigerous female population along the south side of Guemes Channel that year. Throughout this range females were located almost exclusively in shallow water areas of dense eelgrass and were very uncommon in open areas at depths exceeding 4 m.

Whatever the attraction of females to eelgrass beds in this area, dense vegetation of this sort seems important to the species and also holds dense populations of many other invertebrates and fish (Table 13). The

combined attributes of high rates of primary production, shelter for juveniles of many species, input to detrital energy stores and profound affect on local currents, sedimentation rates and sediment chemistry make eelgrass an important issue in any assessment of project development.

4.5 Revised Marina Plan

The original plan for the marina called for dredging a substantial portion of the shallow subtidal and intertidal of Ship Harbor in order to accommodate the boat basin. The area to be dredged was reduced from an initial estimate of 8.1 ha (20 acres) to 6.7 ha (16.5 acres). Of the 6.7 ha to be dredged, approximately 5.3 ha (13 acres) was to be subtidal and exclusively within the eelgrass zone. The extent of eelgrass in the Ship Harbor study site (stippled region of Fig. 2) equals about 16 ha (39 acres) and the original proposal would have, therefore, destroyed about one-third of the shallow water eelgrass habitat in the immediate Ship Harbor area. In terms of ovigerous female crab, the project impact could have been worse than that. Most of the female crab were located in the eastern portion of the harbor around transect lines C and D (Fig. 2) and numbers were substantially less to the west near transect lines A and B. The western end of the original marina was to begin midway between lines B and C and extend east beyond transect line C. In fact, most of the proposed subtidal dredging would have occurred in the area of highest overwinter female density and so the impact to critical female habitat would probably be much higher than 30%.

Confronted by various degrees of concern and opposition from state and federal agencies as well as private citizens, the developer elected to abandon the traditional rock breakwater for marina construction and avoid entirely the need to dredge nearshore shallow water areas. The most recent

version of the marina calls for use of floating breakwaters located farther offshore in deeper water and does not permit construction of boat slips inside the 3 m isobath (about 10'). This proposal eliminates direct impact to female crab and no longer necessitates eelgrass transplant mitigation for the express purpose of providing crab habitat lost to dredging. However, shading, possible changes in current regimes and other unforeseen impacts to eelgrass should be monitored to learn if this resource is diminished within the boat basin after construction. If extent and density of eelgrass decreases there may be a concurrent loss of female habitat as well.

From another perspective, there may be benefits to the Ship Harbor crab population from construction of a marina. Juvenile (1+, 2+) crabs are abundant in most of the marinas surveyed (Figs. 8 and 9), including the Cap Sante and Skyline Marinas around Anacortes and in other systems such as the marina at Westport, Grays Harbor. The presence of numerous pilings, storm barriers on the east and west side of the marina and causeways may attract crab into the area, both for shelter and additional food in the form of fish and invertebrate communities that colonize the new facility. Again, it seems very important to study the affects of the program on the extent and density of eelgrass, the response of ovigerous female crabs in the area and long term trends and use of the new facility by young and old juvenile stages.

5.0 SUMMARY

1. Crab populations at the site of a proposed marina at Ship Harbor and a control site off March Point around Anacortes were studied from August 1984 through April 1986.

2. The ecology, distribution and abundance of various life history stages were studied with beam trawl, pots and diver surveys in the subtidal as well as quadrat sampling in the intertidal.
3. 0+ juvenile crabs recruited to the benthos of both systems in June through September of both years and their density was greatest in the intertidal.
4. Subtidal populations were dominated by 1+ and 2+ crabs that were no more densely distributed in shallow water eelgrass habitat than in deeper, open areas.
5. Density of total crab was greater at March Point than Ship Harbor through the first half of the study, but beginning in June 1985 density was comparable at both locations and averaged about 400 crab/ha.
6. Estimated populations were much greater at March Point than at Ship Harbor because of the large difference in area (about 320 and 29 hectares, respectively). The population at Ship Harbor was approximately 20 to 50 times less than that at March Point and the latter estimates are conservative because the March Point study site was only a small fraction in the total area within Padilla Bay and adjacent areas.
7. Ovigerous female Dungeness crab were only found at Ship Harbor and along the adjacent south side of the Guemes Channel in winter but never at March Point and most other locations. Females were never sampled by the beam trawl or crab pots and diver surveys were necessary to estimate population abundance.
8. Approximately 15,000 ovigerous females were estimated at Ship Harbor in the winter of 1985/86, about 25% of the total ovigerous population distributed along the south side of the Guemes Channel.

9. Females were located almost exclusively in shallow water eelgrass beds between 1 to 3 m depth.
10. In the revised marina plan a floating breakwater will be used which eliminates the need for dredging shallow subtidal and intertidal habitat. This change should substantially reduce the potential impact of the project to ovigerous populations of crab. To the extent that the project might still impact portions of the eelgrass beds, both this cover and crab response and population size should be monitored during and following construction.
11. The completed marina could possibly benefit older 1+ and 2+ juvenile crab by provision of additional habitat and food.
12. Recruitment of 0+ crab to the intertidal should not be affected by the project and, overall, the numbers at Ship Harbor are not significant compared to 0+ density and distribution over much more extensive intertidal habitat in the proximity.

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