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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The impacts of widening and deepening the existing navigation channel in Grays Harbor on Dungeness crab, crangon shrimp and fish was investigated. The spartial and temporal distribution of these organisms was studied using an otter trawl and ring nets, and the uptake of organisms by dredges was estimated from samples collected on working hopper and pipeline dredges. Mean crab trawl catch per unit effort over the 14 month sampling period ranged from 7.56 crabs/100m^2 at South Reach to 1.19 crabs/100m^2 at South Channel; generally decreasing with increasing distance upriver from the harbor mouth and decreasing

20. ABSTRACT (Cont'd). salinity. Crabs were most abundant in summer and least abundant in winter. Diel migrations were evident and dependent upon tidal level, light and salinity. Annual mean crab density was greater in the channel than on the flats. Crabs generally changed their diet with age from one consisting of molluscs and crustaceans (especially crangon shrimp) to fish.

Tomcod, longfin smelt, staghorn sculpin and English sole were the most frequently caught fish species. South Reach consistently had the highest densities of fish and highest number of fish species.

Crangon franciscorum was the dominant species of crangonid shrimp in Grays Harbor and its population reached a high seasonal peak in the inner harbor from May through August. Abundances of all crangonid species varied at sites with season, tidal level and salinity. Total shrimp population estimates in Grays Harbor were 24.8 million in summer and 7.4 million in winter.

Crabs were entrained in hopper dredges at rates ranging from 0.035-0.502 crabs/cubic yard of dredged material. Entrainment rates generally corresponded with densities of crabs. Highest entrainment occurred during summer in the outer harbor. Impacts of the dredging project on crabs, shrimp and fish could be associated with entrainment, food loss and toxicants released from sediments. Scenarios are presented that predict impacts. Suggestions for reducing impacts are given.

COVER PHOTOGRAPH: A Dungeness crab from Grays Harbor. (Brad Stevens)

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Distribution and Abundance of Dungeness Crab and Crangon Shrimp, and Dredging-Related Mortality of Invertebrates and Fish in Grays Harbor, Washington

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and

U.S. Army Corps of Engineers

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DISCLAIMER

Data, interpretations, and conclusions in this report are those of the authors.

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1.0 GENERAL INTRODUCTION

David A. Armstrong, Bradley G. Stevens, and James Hoeman

1.1 Project Background

1.1.1 Dredging History of Grays Harbor: The port of Grays Harbor, with Aberdeen as its major city, has been an important center of the log shipping industry since the late 1800's. As this industry grew, shippers became aware of the increasing need to stabilize the navigation channel across the bar and through Grays Harbor. The first efforts at channel stabilization were the building of the south jetty in 1898-1902. The north jetty was constructed in 1907-1910, then raised and extended between 1910 and 1916. These efforts caused currents across the bar to increase, scouring the bar channel from its former depth of -4.0 m (-13 ft) below Mean Lower Low Water (MLLW) to -5.5 m (-18 ft) MLLW (USACE 1977).

The first dredging of Grays Harbor occurred in 1905, when the outer portion of the channel was dredged to -5.5 m (-18 ft) MLLW. This channel was later extended to Montesano and into the Hoquiam River. Maintenance dredging of these channels occurred regularly between 1910-1930. Between 1930 and 1955 various modifications were made to the channel, including deepening it to a maintained depth of -30 ft MLLW from Westport to Cosmopolis.

Between 1961 and 1974, hopper and pipeline dredging removed an average of 2.1 million cubic yards (cy) annually, of which about 50% was disposed of in the deeper waters of outer Grays Harbor and the rest placed in upland disposal sites. Increasing demands for improvements to navigation have resulted in greater amounts of sediment dredged from Grays Harbor in recent years, and concern about possible environmental problems associated with this dredging has also increased. For these reasons, the U.S. Army Corps of Engineers (USACE), the federal agency responsible for the maintenance of navigable waterways, entered into a contract with Washington State Department of Ecology to study the environmental effects associated with dredging and sediment disposal in Grays Harbor, Washington, in 1974-1975.

The resulting study examined the effects of dredging on water quality, hydrography, sediment geology, wetland vegetation and wildlife, and estuarine vegetation, invertebrates, and fish, including bioassays of dredge-disturbed water on oyster and salmon larvae. The resultant report, "Maintenance Dredging and the Environment of Grays Harbor, Washington," published in 1977, provided baseline information on many species in Grays Harbor and the possible impacts of dredging upon them.

1.1.2 Background of *Cancer magister* Studies: Of the species investigated during the Maintenance Dredging study, *Cancer magister* was considered to be one of the most important for several reasons including: 1) the value of the coastal and harbor crab fisheries (Section 1.3), and 2) the magnitude of the impact of dredging on *C. magister* (Section 8.3). It was apparent during the study that crabs were one of the most severely impacted animals since they were frequently in the dredged material. Efforts were made to determine the number of crabs entrained by dredges but, due to the short time covered by the research, these efforts were preliminary in nature (Tegelberg and Arthur 1977). Nonetheless, some estimates made showed very high entrainment rates for crabs on the order of 0.13 to 0.33 crabs per cubic yard entrained by the dredge BIDDLE in the Crossover and outer reaches (these are two separate estimates, not a confidence interval).

In response to their initial inability to establish reliable dredge entrainment rates for C. magister, Washington State Department of Fisheries (WDF) requested the USACE provide funds for another study which would attempt to refine sampling methods and provide more reliable figures. That study was conducted from October 1978 to May 1980 (Stevens 1981). During that study, sampling techniques were devised for four dredges operating in Grays Harbor. The techniques, detailed in Section 6.2, allowed consistent collection of C. magister from dredged material, and estimation of survival and mortality as a result of dredging. Furthermore, entrainment rates for clamshell and pipeline dredges were found to be lower than for hopper dredges. Recommendations were made specifying that clamshell dredges should be used whenever possible to lessen the impact of dredging on crabs.

As a part of the same study, crabs were trapped in pots at five locations along the navigation channel in order to determine if crab distribution and/or movements could be successfully monitored. These traps were found to be an unreliable indicator of crab abundance, as catches fluctuated greatly with tidal conditions. Nevertheless, some recommendations were made, based on the evidence gained, that were thought to help attenuate the impact of dredging on crabs.

Information gained from the 1978-1980 trap study (Stevens 1981), and from an abundance study conducted during the Maintenance Dredging Project (Tegelberg and Arthur 1977) showed that juvenile crabs were abundant in the inner harbor where adults were scarce, indicating that the harbor might be an important nursery and for juvenile crabs and fish. Also of interest were the questions of indirect impacts of dredging on crabs by reduction or alteration of benthic organisms which serve as food sources for crabs. Recommendations were made to the USACE for further crab research.

1.1.3 Origin of the Present Project: For over a decade there has been interest in a major modification of the Grays Harbor navigation channel. In 1975 this interest was renewed and actions taken toward securing federal appropriations. In 1980 the U.S. Congress voted to approve funds for deepening the harbor channel by 3 m (from 9.1 to 12.2 m) and widening it by 30-60 m. This Widening and Deepening (W&D) project was designed to remove 19.4 million cy of sediment from Grays Harbor, an amount equivalent to about 10 times the annual maintenance dredging, and to increase annual maintenance dredging to 2.5 million cy. Associated with the W&D project was the responsibility of the USACE to prepare an Environmental Impact Statement for the project. Early in 1979, the USACE had requested federal, state, and citizen groups to submit proposals for research in Grays Harbor. A proposal for further research on *Cancer magister* ecology and entrainment was prepared, involving the USACE as funding agency, WDF as contractor, and the College of Fisheries, University of Washington, as subcontractor and principal investigators.

This project, along with 18 other research programs, was funded in Spring 1980. Two other topics which were later included in the study were analyses of crab food habits and crangonid shrimp distribution. These latter studies began in June, 1980.

1.1.4 Outline of the Project: The objectives of the contract included the following topics, listed by section number:

2.0 Distribution and Relative Abundance of *Cancer magister*. A 14-month survey of crab populations in Grays Harbor by otter trawl and ring net trapping.

3.0 Diel Distribution and Abundance of *C. magister*. An attempt to define changes in crab population density through a 24-hr cycle, and the effects on density produced by tide level, light cycle, season, salinity, and subtidal elevation.

4.0 Food Habits and Prey of *Cancer magister*. Stomach analysis of crabs of different age groups from different locations to determine the nature of feeding habits and identify potential indirect impacts of dredging.

5.0 Distribution and Abundance of Benthic Fish. All species of fish collected by trawl concurrent with the crab survey were enumerated and measured, and their distribution and abundance studied from December 1980 to May 1981.

6.0 Entrainment and Mortality of *C. magister* by Dredges. This research was conducted to refine estimates of crab entrainment, especially regarding early instars during the recruitment period, and other species such as Crangon and benthic fish, in areas and time periods not sampled by the previous study (Stevens 1981).

7.0 Distribution and Abundance of Three Species of Crangonid Shrimp. Shrimp were collected by trawl concurrent with the crab survey, and their distribution analyzed. Potential dredging impacts were predicted.

8.0 Conclusions and Predictions. Data presented in each of the previous sections are reviewed, and possible direct and indirect impacts of channel dredging predicted. Suggestions are made by which potential impacts of dredging might be lessened or alleviated.

9.0 Suggestions for Future Research. More work is necessary to answer questions raised or remaining unresolved by the present study.

1.1.5 Physical Environment of Grays Harbor: Grays Harbor is located on the south-central coast of Washington, at approximately 47° N latitude, 124°W longitude. The harbor entrance lies 72 km (45 mi) N of the mouth of the Columbia River and 177 km (110 mi) S of Cape Flattery (Figs. 1.1, 2.1). The harbor is roughly triangular, with its apex near the city of Aberdeen, Washington. The base of this triangle opens to the Pacific Ocean by a narrow 2.5 km (1.5 mi) wide opening between Point Chehalis to the south and Point Brown to the north. The estuary occupies

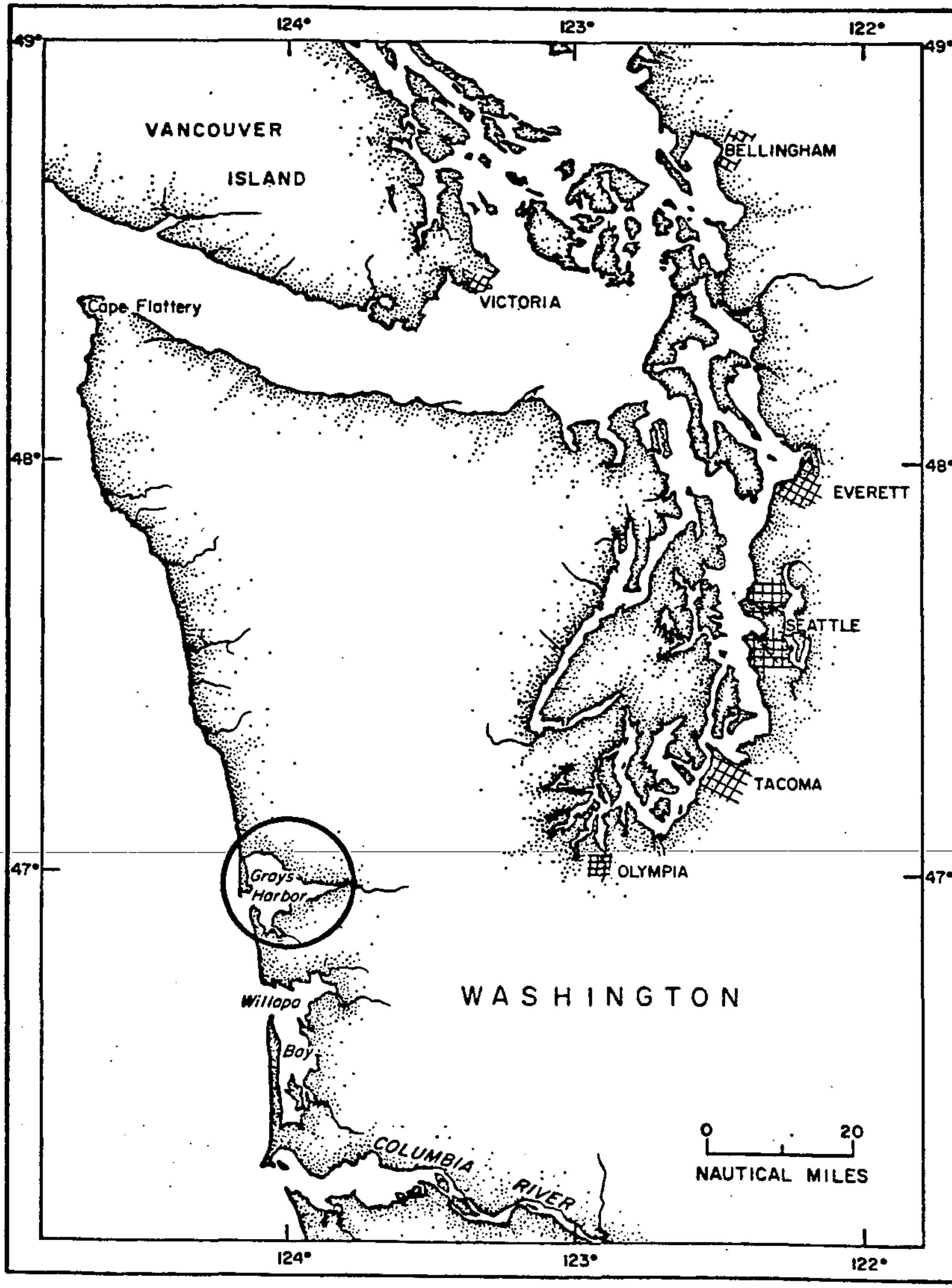


Fig. 1.1. Location of Grays Harbor.

a drowned portion of the Chehalis River mouth, extending 25.2 km (16 mi) east-west and 20 km (12.4 mi) north-south at its widest point. It covers an area of 223 km^2 (86 mi^2) at extreme high tide, and 99 km^2 (38 mi^2) at MLLW, exposing 124 km^2 (48 mi^2) of intertidal sand and mud flats. Water volume ranges from 10.5×10^8 m^3 (13.7×10^8 cy) at extreme high tide to 3.9×10^8 m^3 (5.1×10^8 cy) at MLLW. Most of the harbor is less than 5.5 m (18 ft) deep, but depths reach 80 ft near Point Chehalis (USACE 1977).

Grays Harbor receives 180-250 cm (70-100 in) of rainfall yearly, and has an annual average freshwater input of 10,500 cubic ft per sec (cfs) from six rivers. These are the Humptulips, Hoquiam, Wishkah, Johns, Elk, and Chehalis rivers, with the latter contributing 80% of annual river flow. Tides are of the unequal semidiurnal type, with maximum spring tide ranges of -0.64 to +3.8 m (-2.1 to +12.5 ft) at Aberdeen, and an annual mean range of 2.1 m (7 ft). The harbor is a type B salt wedge estuary where tidal flow exceeds river flow, and tidal flow at surface and bottom are about equal. It is also classified as a positive estuary where influx (precipitation plus runoff) exceeds evaporation, and net surface flow is seaward. Strong tides cause the salt wedge to vary in position, and to reverse the direction of river flow as far upstream as Montesano on incoming tides. Flushing of the harbor has been calculated to require as few as 6 days during winter, or as many as 42 days during periods of low river flow (Knott and Barrick 1977).

A horizontal salinity gradient is maintained from Grays Harbor mouth to Aberdeen, with differences of 15-25 ppt between those points. Vertical mixing is very strong, causing surface and bottom salinity differences of only 1-3 ppt in the outer harbor, and about 5 ppt in the upper reaches, but occasionally reaching 10 ppt at the latter. Water temperatures range from 3.3 to 21.1°C (38-70°F, USACE 1977). Marine sediments occur from the harbor mouth to about halfway to Aberdeen, well into the South Bay, and about halfway into the North Bay. Fluvial deposits are present near the river mouths, and a zone of mixed sediments occurs in an area between the fluvial and marine deposits (Knott and Barrick 1977).

The harbor includes 22 km^2 of salt marsh in a band around the edge, ranging in width from 20-400 m (65-1300 ft). About 45 km^2 (11,000 acres) of intertidal area are covered by eelgrass (mostly Zostera marina) which will be shown in Section 2.4 to be a major habitat for early instar crabs (USACE 1977).

1.2 Life History and General Biology of Cancer magister

Various aspects of C. magister biology have been reported by many authors. General reviews of life history have been published by Mackay (1942) and Cleaver (1949), among others and a schematic of life-history stages is given in Fig. 1.2. The species is reported to range from Unalaska, Alaska, at the NE end of the Aleutian Archipelago, to Magdalena Bay, Mexico, near the southern tip of Baja California, and usually occupies bays and coastal regions with sand or sandy mud bottoms (Schmidt 1921). Maximum depth range is reported by Cleaver (1949) to be 90 m, but was based on the catch of commercial fishermen, who rarely fished deeper waters, so this could be a conservative estimate.

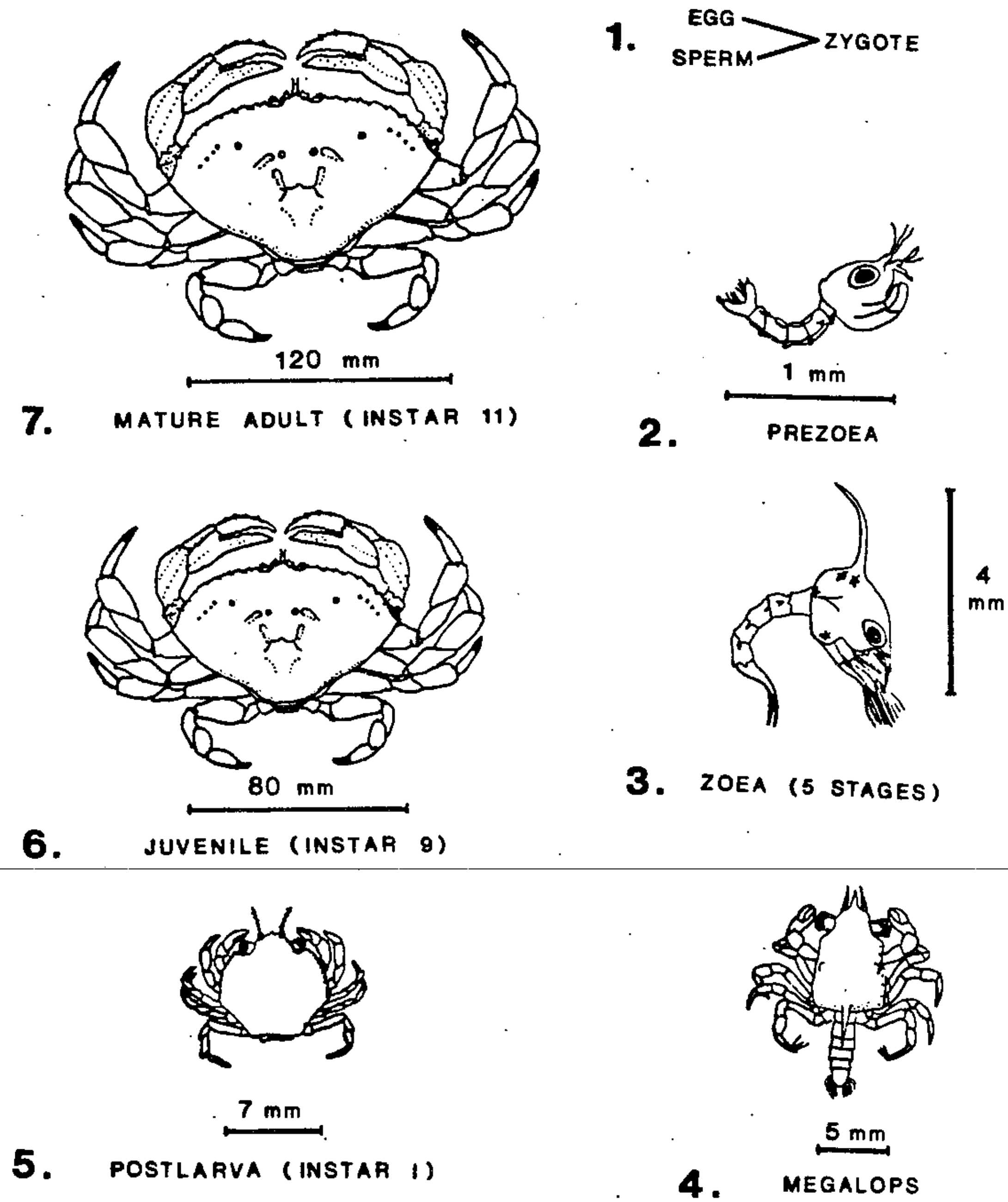


Fig. 1.2 Life history stages of Cancer magister. Sketches by Stevens, after various authors: prezoea (Buchanan and Milleman, 1969); Zoea and megalops (Poole, 1966); Postlarva, juvenile, adult (Mackay, 1942).

1.2.1 Reproduction: *Cancer magister* is dioecious. Mating usually occurs in the spring from March-July in California (Poole and Gotshall 1965), May-June in Washington (Cleaver 1949), and April-September in British Columbia (Mackay 1942; Butler 1956), following molt of the sexually mature female population. Male crabs can recognize premolt females, possibly due to pheromone release (Hartnoll 1969). A large male will embrace a smaller premolt female in a premating embrace for up to 7 days which may serve to protect the female from predation and insure mating success. About one hour after the female molts, copulation occurs by insertion of the male gonopods (modified first and second pleopods) into the female spermathecae, on the third thoracic segment beneath the reflexed abdomen, then followed by deposition of spermatophores (Snow and Nielsen 1966). Sperm are retained within the spermathecae until egg extrusion, which may occur September-October in California (Orcutt et al. 1976), October-December in Washington (Cleaver 1949), or September-February in British Columbia (Butler 1956). Viable sperm may remain in the spermathecae for many months (MacKay 1942), possibly through a molt (Orcutt et al. 1978). Fecundity may be as high as 2 million eggs per large female, although values are typically between a quarter and half a million eggs (Wild 1980).

1.2.2 Egg and Larval Development: Eggs are fertilized when extruded, and become attached to setae on pleopods beneath the abdominal flap. Egg maturation time varies with water temperature, but usually requires 2-3 months (Cleaver 1949, Orcutt et al. 1978; see Section 1.3.5.2 for discussion of temperature effects on development time and viability of eggs). Hatching time varies with yearly and geographic differences in seawater temperatures (as above) but generally occurs in January-February off the Oregon coast (Lough 1975). Various reports for British Columbia cite December-June (Mackay 1942), and late April (Butler 1956). Larvae hatch as pre-zoeae, but molt to Zoea I within an hour (Buchanan and Milleman 1969; Fig. 1.2). Larvae then pass through five zoeal stages and one megalops stage, requiring 130-160 days, before metamorphosis to first instar postlarvae (Poole 1966; Lough 1975). Larvae hatch within 5-16 km of shore, then drift progressively farther offshore, such that stage V zoeae are abundant 95-185 km offshore (Lough 1975; Tasto et al. 1977; Cal. Fish and Game 1981). Megalopae, however, soon appear abundantly within 1 km offshore, either by locomotion, prevailing currents (Lough 1975), or "hitch-hiking" by commensal attachment to the drifting hydroid Velella velella (Wickham 1979c). Inshore appearance and settlement occur from April in Oregon (Lough 1975), to September in British Columbia (Butler 1956).

Rates of larval mortality during pelagic development are unknown but thought to be very high. Lough (1975) discusses a mass mortality of zoeal stages of the 1971 year class and contrasts this group with the high densities of 1970 larvae. Possible causes of greatly reduced survival are anomalous water temperatures, food quality and quantity, predators or, more likely, the concommitant interplay of multiple environmental and biological effects. The success and survival of larvae to metamorphosis is thought by several authors to be the primary determinant of the magnitude of the commercial fishery (Peterson 1973; Wickham et al. 1976, McKelvey et al. 1980).

1.2.3 Juvenile Life and Growth: Metamorphosis occurs in or near bays and inlets, and early postlarvae move into shallow water habitats associated with eelgrass (*Zostera* spp.) or kelp (Butler 1956; Orcutt et al. 1975). Sheltered eelgrass habitats probably harbor the majority of a year class. Orcutt et al. (1977) estimated that 50-80% of a year class hatched off of Central California resides within San Francisco and San Pablo bays for varying periods of time as early juveniles. Juveniles spend a year or more within the bays, and eventually migrate to offshore areas at about the time of sexual maturity (Poole and Gotshall 1965; Orcutt et al. 1977). Some crabs may remain permanent residents of bays (Mayer 1973), or exhibit annual in and out migrations (evidence from Cleaver 1949; Tegelberg and Arthur 1977).

Growth requires molting, during which the hard exoskeleton is shed and a new one formed (for review of crustacean molting and growth *see* Barnes 1974, or Passano 1960). The new shell is very soft and allows the emergent crab to imbibe water and swell to its new, postmolt size, after which shell hardening occurs. Subsequently, feeding is resumed and water is gradually replaced by new tissue growth. Postlarvae pass through about 11 instars before attainment of sexual maturity, which occurs at about 2 years of age, and widths of 93-122 mm for males, and 100-105 mm for females (Butler 1960, 1961; Poole 1967). The ratio of premolt:post-molt carapace width is identical for males and females until this stage of life, at which it decreases for both sexes, but more so for females (Cleaver 1949; Butler 1961), probably reflecting proportionate increases in the amount of energy directed toward reproduction instead of growth.

Absolute growth rates depend on the definition of age 0, variously defined as time of hatching (Butler 1961) or as time of megalopal metamorphosis to postlarval instar 1. The latter method shall be used herein, and was probably the definition used by Orcutt et al. (1975), although they did not specify it as such. According to this definition, Orcutt et al. (1975) specified that some portion of crabs in San Francisco and San Pablo Bays reached a mean width of 100 mm at the end of their first year (after metamorphosis). Poole (1967) corroborated this finding and reported that 10% of the 1961 year-class were 10th instars at 94 mm, 1 year after metamorphosis; 40% were 9th instars at 82 mm. Such growth rates are accelerated relative to data for Oregon, Washington, and British Columbia. Cleaver (1949) showed that crabs captured inside Grays Harbor reached 35-55 mm 1 year after metamorphosis and about 110 mm after 2 years. Butler (1961) stated that crabs of Hecate Strait, British Columbia, reached 24-31 mm after 1 year and 97-120 mm after 2, but these data are difficult to interpret because of his use of hatching as the beginning of age 0, and the measurement technique employed by Canadian biologists, which includes the length of the spines. If metamorphosis in September is used as the beginning of age 0, widths attained were 42-56 mm at age 1, and about 112 mm at age 2, without spines (based on a spine length regression formula presented by Weymouth and Mackay 1936). This agrees more closely with Cleaver's data. The difference between data presented by these authors and that of Orcutt et al. (1975) could be due to temperature differences or to sampling error by the latter. At any rate, the issue of potentially increased growth rates of crabs in harbors is not yet resolved (<u>see</u> Section 2.4.5 for further discussion).

1.2.4 Adult Life: Male crabs are recruited to the commercial fishery at a width of 159 mm, which is usually attained about 3 1/2 years after metamorphosis. Estimates of mortality are usually made for this size group, because the commercial fishing industry provides a mechanism for widespread tag recoveries. Jow (1965) estimated seasonal natural mortality from tag returns at a rate of .15 per year. Gotshall (1978b) estimated natural mortality at 0.005 (1966-67) to 0.183 (1971-72). Bottsford and Wickham (1978) suggest 0.20 for crabs prior to sexual maturity, but the true mortality rate is probably much higher for early instars which have not yet attained a size refuge from predation by fish and conspecifics. Fishing mortality, i.e., the percentage of legal males caught each season, has been estimated at 80% by Cleaver (1949, for Washington 1947 season) and 84% by Jow (1965, for California 1962-63 season). Thus, the fishery shows a very heavy dependence upon a single year class. Maximum size of about 220 mm is attained in the 16th instar, at 5-6 years of age, but females rarely reach that size (Butler 1961). At age 4, molting decreases to once per year, but might be skipped by some animals. Maximum age attained is 6-8 years (MacKay 1942, Butler 1961).

Minor migratory movements occur among adult crabs. Most crabs reared in estuaries eventually leave them. During spring and summer many crabs reside in shallow inshore oceanic areas, possibly for mating purposes (Cleaver 1949, Butler 1957). During fall and early winter, many adults move offshore and southerly until the onset of the northerly-flowing Davidson current in spring. This time they move north and back inshore (Gotshall 1978c) and some return to estuaries (Cleaver 1949). These are broad generalizations, as many small subpopulations exhibit a reversed order of north/south movement (Gotshall 1978c). Nevertheless, the periodic offshore/inshore movement appears to be widespread among adult crabs. Crab populations in Similk Bay, Washington, showed cyclic annual migration around the perimeter of the bay. Range of movement varies greatly. Gotshall (1978c) reported that 20% of crabs tagged off northern California were recovered within about 2 km of their tagging location, while Waldron (1958) found an average migration distance of 13.4 km for crabs offshore and 6.7 km for those in bays of Oregon. Cleaver (1949) reported the recovery of a tagged crab which had migrated 150 km from Westport, Washington to Oregon, and Mayer (1973) reported the recovery of a crab from Westport which had been tagged in Similk Bay, having traveled a distance of 444 km in 191 days.

1.2.5 Behavior and Interspecific Interactions:

1.2.5.1 Feeding: Crab feeding behavior and prey items will be presented in greater detail in Section 4.0, but a brief review is presented here. Crabs often detect food tactilely, by mechanoreceptive hairs on the chelae and pereipods, as they probe the sediment, usually while they remain partially buried (Butler 1954). Food can also be detected by chemoreceptive organs (aesthetascs) on the antennules, which are sensitive to concentrations of clam extract as low as 10^{-10} g/l (Pearson et al. 1979). Once detected, a discrete series of feeding behaviors is stimulated, including searching, groping, grasping, shredding, and eating (Pearson et al. 1979).

Crabs are for the most part opportunistic feeders, eating a large variety of benthic infauna, particularly small clams and crustaceans, as well as some fish (Butler 1954, Mayer 1973, Gotshall 1977). Larvae are semi-filtration feeders, using natatory hairs of their maxillipeds to capture zooplankton and probably phytoplankton as well (Reed 1969; Lough 1975). Cannibalism by adult crabs on smaller juveniles is known to occur (Butler 1954; Gotshall 1977) and may play an important role in population dynamics (Bottsford and Wickham 1979, McKelvey et al. 1980).

1.2.5.2 Predation: Pelagic zoeae are probably preyed upon by many filter-feeding organisms and larger predatory zooplankton. Important predators of megalopae are coho and chinook salmon (*Oncorhynchus kisutch* and *O. tschawytscha*, respectively), but a large number of other species, including sturgeon, flounders, skate and sculpins prey on megalopae and early instars as well (Orcutt et al. 1977). Salmon predation on *C. magister* is widely documented and is thought by some authors to be a major source of mortality during pelagic development. MacKay (1942) reported up to 1500 megalopae in the stomachs of coho salmon, and it has been postulated that historic increases in Columbia River hatchery production of coho have escalated the predation rate on San Francisco area crab megalopae, in part accounting for the demise of that fishery (Cal. Fish and Game 1981). However, Botsford et al. (manuscript submitted) have found no statistical correlation between salmon catch and crab landings for northern California. Predation by fish on early benthic stages of *C. magister* seems correlated to crab abundance in the San Francisco/San Pablo Bay complex (Orcutt et al. 1977).

The least obvious but perhaps most effective predator of C. magister is Carcinonemertes errans, a species-specific nemertean worm which preys upon egg masses of female crabs (Wickham 1979, 1980). Wickham estimated that up to 98% of all available hosts in California waters carry C. errans, and predation may annually cause up to 50% egg mortality coast-wide. He suggests that such predation could exert a major influence on crab population cycles (see Section 1.3) and be a possible cause of the collapse of the central California crab fishery (Botsford and Wickham 1978). These worms have been seen among the egg masses of female crabs caught offshore of Westport, Washington.

1.2.5.3 Other behaviors: Crabs may temporarily burrow into the sediment for a variety of reasons. When buried, only the eyes and chemosensory antennules remain uncovered, and the chelae are drawn up to the maxillipeds forming a channel through which respiratory currents can pass (MacKay 1942). Burial may occur while mating, spawning, or feeding, or in order to avoid exposure to air (on tide flats) or low salinity waters. Very little research has been done on this behavior which could affect population estimates based on net-surveys (see Section 2.4).

Crabs may exhibit agonistic behaviors interspecifically and intra-specifically, but these have not been extensively studied.

1.3 Dungeness Crab Fisheries

1.3.1 Landings and Value: Dungeness crab contribute the second largest crustacean fishery, in pounds landed, on the western United States coast from California to Washington, surpassed only by pandalid shrimp. Ten-year averages of the three state landings from 1969-78 are 35.5 million lb shrimp (PMFC 1981) and 26.6 million lb crab (PFMC 1979; Fig. 1.3). However, Dungeness crab is the leading crustacean fishery in dollar value since ex-vessel prices have been 2-3 times higher than those paid for shrimp. In 1979, crab brought $.65-.80/lb with highs to $1.00-1.20/lb while shrimp sold for $.46/lb (PMFC 1981).

In Washington State, Dungeness crab is exceeded only by oysters as a shellfish industry in wholesale dollar value (Nosho et al. 1980), with total statewide values of $5.6 and $8.8 million, respectively, in 1978 (last year for available oyster data). Total Dungeness crab landings for the entire state (including north and south Puget Sound) in 1979 were 9.04 million lb (Nosho et al. 1980), and for coastal ports were 7.98 million lb (Pacific Packers 1981, PMFC 1981, see Fig. 1.4). Crab landings at Westport, Washington, totaled 66% of coastal poundage (3.48 x 10^6), and 72% of ex-vessel value (\$2.7 x 10^6, Nosho et al. 1980). Clearly, Westport in Grays Harbor is Washington State's most important receiving port for the coastal Dungeness crab fishery. In 1979 total fisheries products landed in Westport were valued at \$12.43 x 10^6 (second richest in the state after Bellingham at \$15.03 x 10^6) and of this, Dungeness crab comprised 21.7% (Nosho et al. 1980).

1.3.2 Trends in the Fishery: Cycles of High/Low Abundance: The most striking feature of landing data summarized for the last 30 years is a cyclic pattern of high-low abundance with periods of about 9-10 years (Fisg. 1.3, 1.4). Total landings for Washington, Oregon, and California (three-state totals) show peak years in 1957, 1969-70, and 1977 with

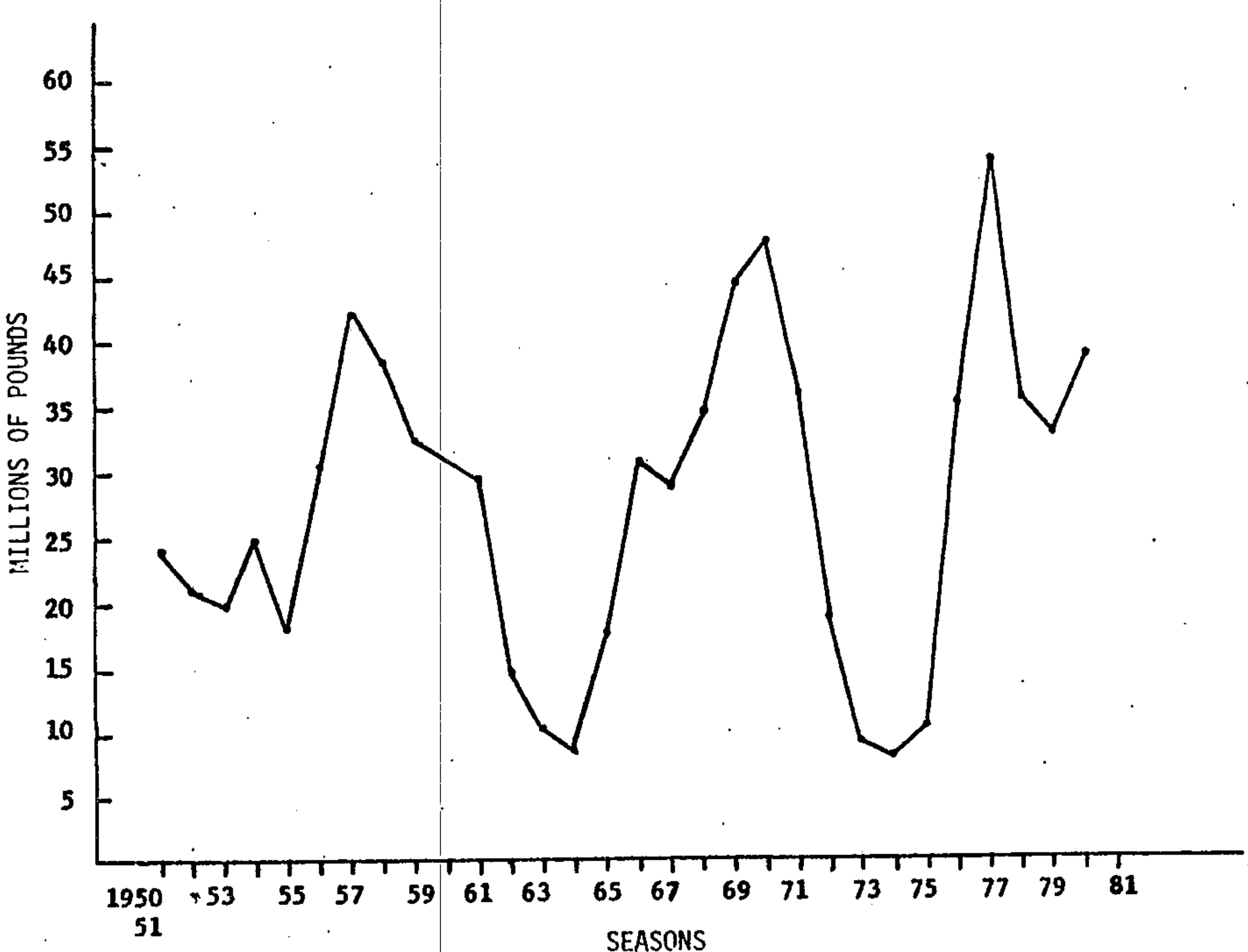


Fig. 1.3. Combined Dungeness crab landings for California, Oregon, and Washington. Data from PMFC (1979) and Pacific Packers Report (1981). Note the cyclic pattern of landings with a period of 9 - 10 years.

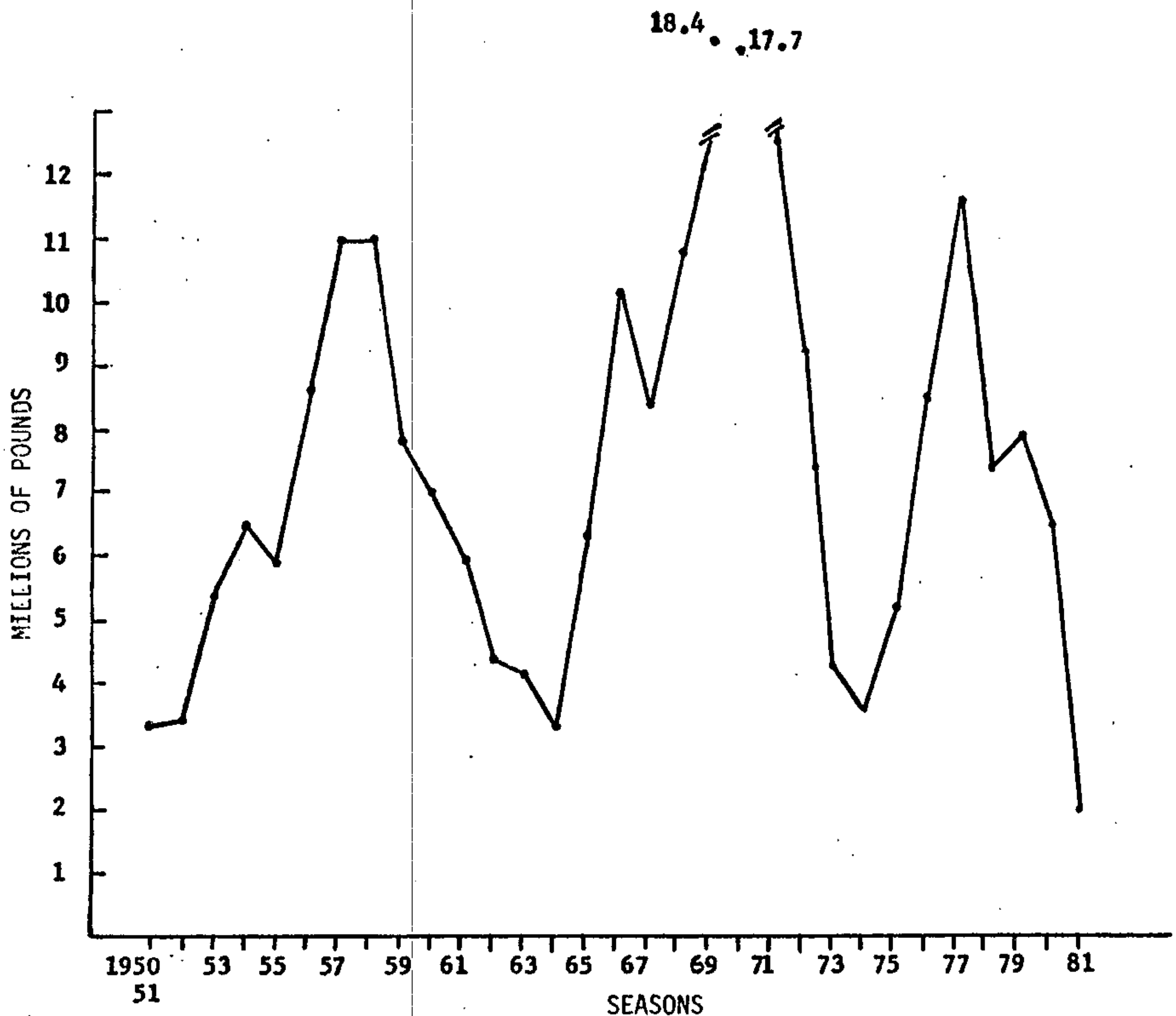


Fig. 1.4. Annual landings for Washington coast ports: Grays Harbor, Willapa Bay, and Columbia River (from PMFC, 1979). Data for 1981 is preliminary (Steve Barry, Washington Dept. Fisheries, personal communication).

landings of 42, 47, and 53 million lb, respectively (Fig. 1.3). Conversely, very poor landings centered around the years 1964, 1973-74, and possibly 1981 (Steve Barry, WDF, personal communication) with totals of 8.9 and 7.8 million lb for the two former periods, respectively. During the past 27 years landings have averaged 26.6 million lb for all three states.

Washington landing statistics closely track the fluctuations shown for three-state totals (Fig. 1.4), and have ranged from 3.2 million lb in 1951 to 18.4 million lb in 1969. Preliminary data for 1981 indicates the worst season to date for Washington, as only about 1.9 million lb (Fig. 1.4) have been landed at coast ports, and fishing effort through the rest of the season is expected to remain very low (Steve Barry, WDF, personal communication). Thus landing cycles and periodicity are important biological parameters to include in discussions of potential dredging impacts on crab populations (see Section 8.0).

1.3.3 San Francisco and Central California: Particular attention has been given the cycles of Dungeness crab landings in central and northern California. Between 1945 to 1960 mean annual crab landings at San Francisco (central California) were 4.8 million lb, and 1957 was the highest year at 8.9 million lb (Fig. 1.5). In 1960-61 the central California fishery declined in concert with landings along the entire coast, but the fishery has never recovered and annual catches have remained suppressed between 230,000 to 1 million lb (Orcutt et al. 1976, Fig. 1.5). Studies of possible reasons for this decline have been done by personnel of the California Department of Fish and Game (California 1981), and

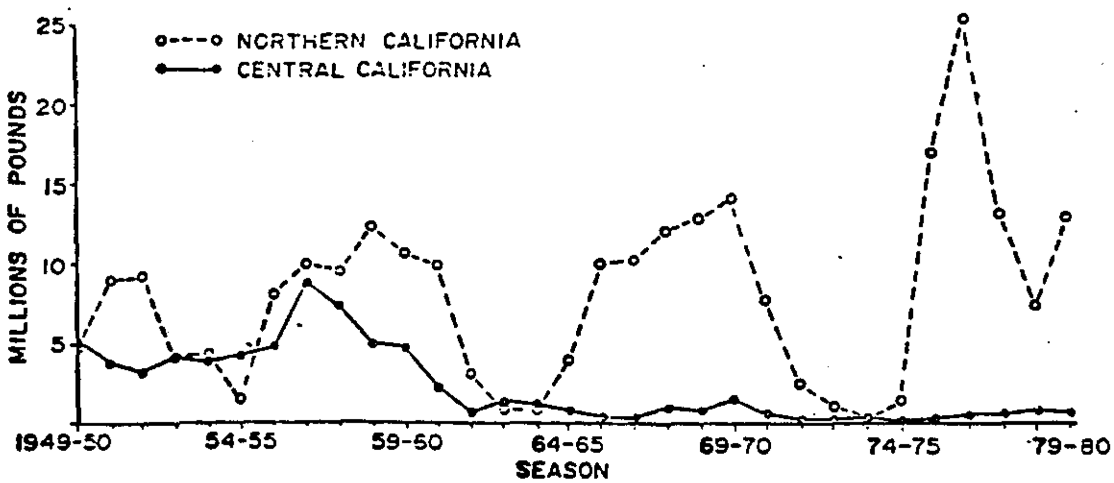


Fig. 1.5. Dungeness crab commercial fishery landings for northern and central California by season since 1949 (Cal. Fish and Game, 1981).

tentative hypotheses formulated from these studies are discussed in the following subsection. The plight of the San Francisco-based crab fishery is a relevant consideration in discussions of possible impacts to crabs off Washington stemming from dredging programs in Grays Harbor. San Francisco Bay has been extensively dredged and filled, is surrounded by some of the most concentrated industrialization in California, and annually receives tons of grease, oil, heavy metals, and pesticides from urban and agricultural drainage (Orcutt et al. 1975). In addition, slight changes in offshore oceanographic conditions (California 1981) have added to the list of hypotheses proposed as explanations for the demise of Dungeness crab around San Francisco. Because human alterations of San Francisco Bay and its water quality have probably contributed to impairment of the crab fishery, this region may serve as an important negative lesson in management of other coastal estuaries such as Grays Harbor (see Section 8.4 for discussion).

1.3.4 Northern California: A final point on cycles in the fishery relates to data for northern California crab landings that show increasing amplitude between high and low years (Fig. 1.6). Botsford and Wickham (1978) used age-specific, density-dependent models to reflect these cycles and concluded that Dungeness crab populations may be cycling in an unstable manner. They note selective fishing of only large males, and other perturbations such as egg predation, might cause increasingly high, followed by low, years of abundance, which could lead to a long-term decline of stocks as happened in central California. However, McKelvey et al. (1980) argue against this conclusion, stating that

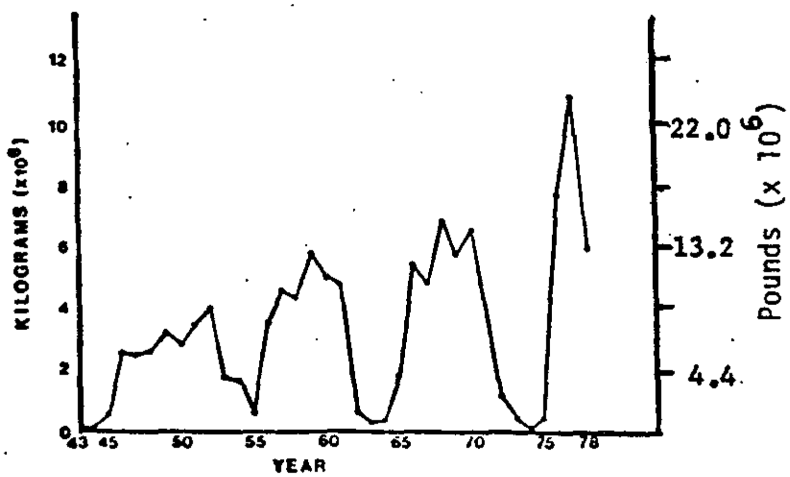


Fig. 1.6. Annual landings of Dungeness crab in northern California fishery, 1943-1978 (McKelvey et al. 1980).

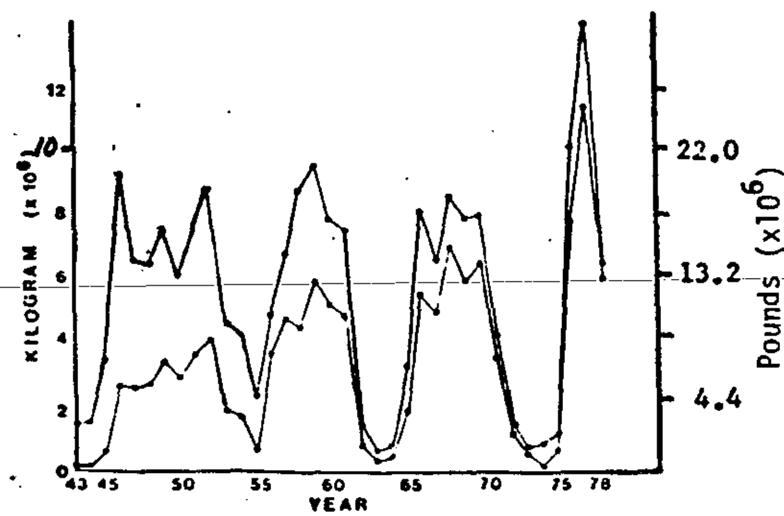


Fig. 1.7. Annual landings (lower line) and estimated initial harvestable biomass (upper line) of Dungeness crab in the northern California fishery, 1943-1978 (McKelvey et al. 1980).

landings (Fig. 1.6) are not necessarily an accurate gauge of year-class strength. Rather, they use data on fishing effort (range of 6,100 to 50,000 pots in 1974 and 1978, respectively), natural mortality rates, exploitation rates, landings, and catchability coefficients to estimate initial abundance of harvestable crab biomass (i.e., legal males). Their results (Fig. 1.7) show that while the amplitude of actual landings has increased, the levels of pre-season harvestable crabs predicted by their equations have remained relatively constant during the cycles. Rather than assuming that biological causes explain increasing amplitude of landing cycles, they believe the vagaries of fishing effort and exploitation rates are the reasons, and they therefore discount claims of increasing instability within the population made by Botsford and Wickham (1978).

1.3.5 Hypotheses for Cycles of Abundance

1.3.5.1 The Coast: Discussions of possible mechanisms driving abundance cycles that are reflected in commercial landings, include abiotic and biotic factors that influence production and/or survival of either eggs and larvae or benthic juvenile and adult stages.

1.3.5.1.1 Abiotic factors: 1. Peterson (1973) investigated correlations between upwelling indices along the west coast of the United States and annual catches of Dungeness crab. He found fairly good agreement between years of strong upwelling and good commercial landings 1 1/2 yr later in California-Oregon, and 1/2 yr later in Washington. He hypothesized from this result that nutrient availability increased with upwelling, which ultimately increased benthic food supplies for crab via greater phytoplankton/zooplankton productivity in the water column. After appropriate time lags, this material settles, is used by epibenthic and infaunal consumers and thereby creates a more plentiful food reserve for crab which reduces competition. Older year classes, 1/2 to 1 1/2 yr from entering the fishery, are the primary beneficiaries of strong upwelling years in Peterson's model.

2. Botsford and Wickham (1975) followed Peterson's lead and used different correlation procedures to study upwelling and crab catch relationships. From auto-correlation they concluded that crab landings are definitely cyclic but upwelling is not. While upwelling may contribute to crab abundance, as a noncyclic, abiotic factor it is probably not primarily responsible for year-class strength. Rather, Botsford and Wickham suggest that biotic, density-dependent interactions may drive the cycles.

3. Lough (1975) studied larval Dungeness crab population dynamics off Oregon in 1970-71, and reported a catastrophic reduction in larval abundance during 1971, suggesting a mass mortality had occurred. He considered several hypothesis to explain the failure of 1971 larvae, including below-normal water temperatures, reduced food availability, and greater offshore transport of larvae beyond shelf areas of probable recruitment back to the fishery. Lough does not conclude that any single factor was most responsible for larval mortality, only that larvae are very sensitive to environmental perturbations which need only be of relatively brief duration to severely affect the population.

1.3.5.1.2 Biotic factors: Many researchers point out that abiotic factors such as upwelling or anomalously low temperatures will not occur at regular intervals and cannot, therefore, account for the periodicity of crab abundance. Hypotheses of biological forces driving cycles include:

1. Density-dependent mechanisms based on compensatory influences such as competition for food between young and older crabs, and cannibalism; Botsford and Wickham (1978) applied mathematical models to the fishery and concluded that the extent of survival, or mortality, of early benthic young-of-the-year crabs (first few instars) largely explains later abundance reflected by commercial landings. During a year or two of very large adult populations (e.g. Figs. 1.2 and 1.3 show large populations in 1977), newly metamorphosed first instars will settle out from pelagic existence to face tremendous populations of adult and older juvenile crabs. Direct cannibalism (see Section 4.0) or competition for food will result in poor survival of that year class, and a poor fishery 3 to 4 years later (e.g., mortality of the 1977 year class should have been high, and in 1980-81 a decline in the fishery is the consequence - Fig. 1.4).

2. Larval and egg natality and subsequent survival to metamorphosis; McKelvey et al. (1980) use a complicated mathematical program to model 48 variants in an attempt to describe possible causes underlying cycles in crab landings and highlight most crucial life history stages. They conclude that survival of eggs and larval stages is most crucial for the species and can best account for cycles. Density-dependent

cannibalism of young-of-the-year by older crabs is excluded as an important variable (although they base this on the poor assumption that only mature crabs, 2-plus years old, prey on young-of-the-year).

3. Predation on crab eggs by a species of nemertean worm, Carcinonemertes errans, represents a significant source of mortality that might be linked to cycles of abundance. In a series of papers, Wickham (1978, 1979a, b, 1980) documents predation by this worm on Dungeness crab eggs, and resultant direct mortality as high as 55% of eggs borne by females off California. With mortality rates this high and predator densities up to 100,000 worms per female crab, Wickham suggests that C. errans may be the most significant predator of Dungeness crab. The interaction of worms and crabs would partially explain cycles of commercial landings and also the long-term suppression of the San Francisco fishery (Wickham 1979b).

It is likely that several or all of these hypotheses contribute to cycles of crab abundance along the coast. Such information on factors affecting crab survival is germane to questions of possible dredging impact in Grays Harbor on crab populations. If effects of dredging on estuarine populations are severe enough to influence the magnitude of natural cycles, then the program must be considered deleterious to C. magister. However, given the present amplitude of cycles and lack of definitive cause-and-effect relationships in the preceding hypotheses, it is virtually impossible to predict (other than in very qualitative terms) how dredging might alter survival and recruitment, both of which are already so dependent on other factors.

1.3.5.2 San Francisco, Central California: The severe decline in the Central California Dungeness crab fishery shown in Fig. 1.4 prompted the Department of Fish and Game to launch a comprehensive study of this problem in 1974. This and other investigations have led to several hypotheses to explain the protracted reduction of stocks.

1.3.5.2.1 Abiotic factors:

1. Oceanographic conditions off central California changed in the late 1950's and have persisted for at least 20 years with a detrimental effect on crab life cycles. Wild (1980) shows an increase in mean October-December (period of *C. magister* egg brooding) ocean temperatures off San Francisco from 13.2 to 14.1°C with several years exceeding 15°C. In laboratory studies of rates of egg development, time-to-hatch at elevated temperatures were 64 days at 16.7°C and 123 days at 9.4°C. However, there is a strong negative correlation between temperature and hatching success. At 10°C an average of 685,000 eggs per experimental female hatched while at 16.7°C an average of only 14,000 (2% of former) develop to hatching. These results are in accord with laboratory studies of Mayer (1973) who showed a significant increase in egg mortality of *C. magister* between 10°-15°C, and complete mortality at 20°C. Wild speculates that even a long-term increase of only 1°C toward higher temperatures is severely reducing the reproductive success of Dungeness crab of the central California coast. Neither author speculates as to the physiological links between elevated temperature and egg mortality, but energetic inbalances caused by excessive metabolic demands and increased incidences of disease are likely factors.

2. Pesticides and other pollutants have long been considered a likely stress affecting the San Francisco-based fishery. Toxicity of organic chemicals and metals, and tissue concentrations in wild crabs are discussed in Section 8.3.3. However, the study of pollutants done as one aspect of the California Fish and Game crab program (Orcutt et al. 1975, 1976, 1978) has given no evidence that pollutants are detrimentally affecting crab (California Fish and Game 1981). Tissue levels of the few measurable toxicants found are not greater in San Francisco crabs than in those from other, less polluted areas. Further, tissue levels of heavy metals in crabs killed during bioassays are often an order of magnitude greater than levels in feral crabs (Orcutt et al. 1978).

1.3.5.2.2 Biotic factors:

1. Disease of crab eggs may be more prevalent offshore and just north of San Francisco than farther north toward Eureka. In several papers Fisher (1976) and Fisher and Wickham (1976, 1977) describe epibiotic fouling of Dungeness crab eggs and attendent mortality due to suffocation and entangling at hatch. They found greater fouling and mortality of eggs collected from females in Drakes Bay (27.6%) just north of San Francisco than in samples from the Russian River (9.7%), considered a control area. In laboratory experiments, fouling and mortality of crab eggs increased if nutrients (nitrate and phosphate) were added to culture water, and from this observation they concluded that the wintertime northerly flow of nutrient-rich effluent from San Francisco Bay was enhancing epibiotic growth and reducing egg viability.

2. Nemertean egg predators of Dungeness crab have been at much higher population levels in the San Francisco region than elsewhere on the coast during the last 20 years. As discussed in subsection 1.3.5.1.2, Wickham (1979a, b) claims that Carcinonemertes errans is a major predator of C. magister and he has estimated annual egg mortality rates around San Francisco to be 45-63%. He hypothesizes a direct predator-prey balance between worms and crabs has suppressed crab to a low- point equilibrium that is reflected in the 20-year reduction in fishing stocks (Wickham 1979b). He further states that epibiotic fouling of eggs previously discussed, is only a secondary result of worm predation caused by release of yolk nutrients into the egg mass. This enhances bacterial growth on eggs and is greater near San Francisco because of more extensive worm predation.

3. Fish predators of Dungeness crab have increased during the past 20 years with resultant heavier annual mortality rates of crab (California Fish and Game 1981). Silver salmon (Oncorhynchus kisutch) production by Columbia River hatcheries has escalated tremendously since the early 1960's. Salmon are important predators on Dungeness megalopae (Orcutt et al. 1977), and the return of megalopae from offshore to nearshore waters coincides with the arrival of the hatchery-reared fish. Evidence of cause-and-effect impact is circumstantial but they (California Fish and Game 1981) believe this historic change in a predatory fish population might have significant consequences on crab recruitment around San Francisco.

1.4 Dredge Entrainment Studies other than Grays Harbor

Dredging of navigation channels and docking facilities in United States waters is a regular and escalating process that costs hundreds of millions of dollars each year and results in the removal of over 400 million cubic yards of sediment annually (Lee 1976). The responsibility for maintenance dredging falls to the U.S. Army Corps of Engineers (USACE) in U.S. waters and to the Public Works Department in Canada. Hydraulic dredges of the pipeline and hopper type are used most frequently but mechanical dredges like the clamshell, side-caster, dipper, and ladder are also in use.

Accumulation of sediment in estuarine channels from offshore currents and river transport renders many channels too shallow to routinely accommodate large ships. Economic considerations have lead to programs to widen and deepen channels and turning basins for use of coastal ports by deeper draft vessels. Such programs also require increased annual dredging to maintain larger channels, and these activities may affect resident biota in ways, as yet, poorly understood.

1.4.1 Dredging Impacts Other than Entrainment: The National Water Quality Act of 1969 required assessment of environmental impacts of dredging operations. USACE has prepared Environmental Impact Statements (EIS) for dredging and dredged material disposal operations since 1973 (Snyder 1976).

The possible environmental impacts of dredging are numerous but the focus of most research in the United States has been on the water quality aspects of depositing dredged material in estuarine waters. This form of disposal typically occurs when hopper barges are emptied subtidally. Pipeline dredges that usually deposit material onshore are also occasionally used to deposit dredged material in the water.

Attention to water quality that is altered by the resuspension of contaminants has increased because of the U.S. Environmental Protection Agency's (EPA) adoption of the "Jansen Criteria" for the disposal of dredged material. These criteria, proposed by the Federal Water Quality Administration (FWQA), specified maximum amounts of volatile solids, COD, Kjeldahl nitrogen, oil and grease, mercury, lead, and zinc in dredged material to be deposited offshore (Lee 1976). The risk of resuspension of the pollutants when the sediment is dischared into receiving waters increases with higher concentrations of pollutants in the dredged material. Water quality problems are more likely to occur where the dredged material is disposed rather than where the material enters the dredge. O'Neal and Sceva (1971) recommend that all dredged material exceeding EPA guidelines should be disposed on land, and the area of offshore disposal should be zoned to exclude spawning areas or productive parts of an estuary.

Most heavy metals, chlorinated hydrocarbons, pesticides, and oil and grease compounds tend to concentrate in bottom sediments (see Section 8.4.4 for further discussion). When these contaminants are resuspended in estuarine waters by deposition of dredged material, they are still not very water soluble and will be quickly adsorbed to suspended particles that settle to the bottom (Burks and Engler 1978). The bioavailability of these sediment-sorbed heavy metals and oil and grease compounds is relatively low even with high concentrations in the sediment (Kerich and DiSalvo 1978). However, the temporary problem of increased turbidity and suspended solids can be worse in freshwater or estuarine water with low dissolved oxygen (DO). For example, the transitory release of hydrogen sulfide (H_2S) by a dredge disposal operation in Canada was the suspected cause of a large fish kill (Howrston and Herlinveaux 1957).

Sediments dredged from the Duwamish River, Washington, and deposited in Puget Sound resulted in increased turbidity, the formation of a mound of dredged material, and the release of ammonia, phosphorous, manganese, and polychlorinated biphenyls (PCB) into the water column. There was a decrease in the number and abundance of benthic animal species in the disposal area after dumping, but this was probably related to physical burial rather than resuspension of contaminants (Wright 1978).

Westley et al. (1973) used field-water bioassays developed by Woelke (1968) with the embryos of Pacific oysters and Japanese littleneck clams to test potential toxicity of water at a pipeline disposal site in Budd Inlet near Olympia, Washington. He found that sediments dredged from Olympia Harbor (which exceeded the EPA guidelines of 6%

volatile solid content) did not resuspend enough toxicants to significantly increase delayed development or reduce survival of oyster and clam larvae. Bioassays with water taken during disposal of dredged material were compared to bioassays with water taken before and after disposal operations. Some increased abnormal development and mortality in all three bioassays was observed, but appeared to be due to toxicity from sources other than dredging activity, such as sewage discharge and associated phytoplankton blooms. Salmon held in live-boxes near the disposal site also failed to show any increased mortality due to dredging disposal operations. An increase in suspended solids and turbidity plus the stimulation of phytoplankton growth were noted near the pipeline discharge disposal site. Westley et al. (1973) indicated that fluctuations in phytoplankton abundance were the main cause for changes in ammonia, biological oxygen demand (BOD), DO, phosphates, suspended solids, and turbidity in Olympia Harbor waters, but dredging activity was only a small factor contributing to overall production of phytoplankton.

One immediate impact of dredging, apart from degradation of water quality, is the decreased biomass of sedentary plants and animals in dredged areas due to their physical removal by the dredge. Numerous researchers have documented the reduced biomass of flora and fauna in dredged areas (Taylor and Saloman 1968; Murawski 1969; Godcharles 1971; O'Conner 1972; Slotta et al. 1973), and discussed recovery time of the benthic community (Swartz et al. 1980). Recovery depends not only on what species have been removed but also on changes in sediment composition, current patterns, and the proximity of recolonizing populations

(Swartz et al. 1980). Taylor and Saloman (1968) report that some macrobenthic populations failed to recover to predredging levels after 10 years in Boca Ciega Bay, Florida, while McCauley et al. (1977) found infaunal density recovered after 28 days in Coos Bay, Oregon.

Biological factors that affect species recovery rates include general tolerance to stress caused by the changed environment (Boesch 1974) and opportunistic life styles such as immigration of mobile crustacean adults and the larval recruitment of pelagic polychaete and mollusc larvae (Oliver et al. 1977). The decrease in the availability of prey or shelter in the dredged area, or the lack of competition for space and food created by the removal of the previous benthic species might also influence the species composition of the recolonizing community. Many areas in navigation channels and around loading docks are dredged every year so that some species may not have time to recover completely. The species found there at any time have had to adapt to dredging removal from many previous operations. In Grays Harbor for instance, maintenance dredging has occurred for over 70 years so the impact of future dredging in the same areas must be measured against the historical impact which has already occurred.

Disposal of dredged material is a major problem confronting the USACE (Snyder 1976). When dredged material is dumped offshore the problems include: (1) resuspension of pollutants, (2) increased turbidity, and decreased light penetration that affects photosynthesis and causes respiratory stress to animals, (3) decreased DO due to the exposure of unoxidized sludges which increase the chemical oxygen demand (COD), (4) physical burial of organisms, (5) substrate change at the deposition site, and (6) the possible backwash of dredged material into estuaries if not deposited far enough offshore.

Burial of organisms has been studied by several researchers who conclude that relatively sedentary molluscs like oysters would suffer high mortality (Lunz 1942) while other invertebrates can dig out after being buried by more than 20 cm of material (Saila et al. 1972), or even as much as 3 ft of material (Westley et al. 1973). Laboratory burial experiments performed with heart cockles (Clinocardium nuttalli) (Chang and Levings 1978) indicated that 100% were able to dig out of a burial depth of 5 cm, but less than 50% were able to dig out of 10 cm sand in 24 hr. All Dungeness crabs (Cancer magister) were able to dig out of 10 cm or less.

Location of disposal sites for dredged material presents problems unique to several different areas currently used. Dredged material deposited offshore does not always stay in the boundaries prescribed for disposal, rather it can produce submarine mudflows that impact surrounding areas (O'Neal and Sceva 1971). Deposition of dredged material in intertidal areas has its own problems and potentials. Intertidal dumping raises the elevation of the mud flats which alters the habitat of the area. Intertidal deposition of dredged material in Grays Harbor, Washington was found to decrease populations of Corophium amphipods and therefore reduce the utilization of the area by shorebirds that feed heavily on Corophium (Albright and Smith 1976). They found the biggest decrease in abundance of benthic invertebrates occurred when the intertidal area was raised to 2.13 m above mean lower low water (MLLW).

Deposition of dredged material on land is the most common method employed by pipeline dredges. One problem with this disposal method is that the slurry discharged by a pipeline dredge is 80-85% water. The long "dewatering" process of the sediments makes the area unsuitable for other uses and quickly limits the volume of material that can be deposited at one time. Much research has focused on ways to "dewater" the substrate quickly or to find other uses for the dredged material containment areas. One such use investigated by the USACE in Texas (Quick et al. 1978) was to use such areas as aquaculture facilities for rearing penaeid shrimp (Penaeas setiferus). Ponds were dug out of the containment area while waiting for the sediments to "dewater" (a process that can take months to years). This pilot project was judged to be an economically and biologically feasible solution to the problems of putting these areas to other productive use.

1.4.2 Dredge Entrainment Impacts: The impact of mortality due to entrainment (the actual uptake of organisms) by dredges has been poorly studied in the United States. This is in part due to the focus of environmental research on questions of disposal sites and associated water quality problems. Canadians, however, have been studying entrainment of salmon fry by dredges since 1971 when juvenile salmon were observed in discharged material from a pipeline dredge operating in the lower Fraser

River (Dutta and Sookachoff 1975a). The first Canadian study to quantify pipeline dredge entrainment was conducted at a land disposal site near the north arm of the Fraser River (Braun 1974a). No salmon fry were found entrained even though the dredge (24" pipeline Sceptre Fraser) was operating during a period of major salmon fry outmigration, 20 March-16 April 1973. Sampling methodology may have contributed to poor entrainment results, which precluded calculations of entrainment mortality. However, mortality rates were measured by introducing known number of fry near the cutter head (Braun 1974b; Dutta and Sookachoff 1975a). More than 95% of salmon fry were buried in the discharge mass, and of those recovered only 4.5% were alive. However, within 96 hr 70% of these fish had died from external and internal injuries including internal hemorrhaging and impaction of silt in intestinal tracts. The immediate dredge-related mortality plus the delayed mortality was calculated to be 98.8%. Predation by sea gulls and the circuitous route of water drainage from a land disposal containment area adds even more to the expected mortality rate of organisms deposited in a diked-off land area. Tutty (1976) injected salmon fry into the suction head of a hopper dredge, and then recovered them by sampling some of the overflow ports with dip nets. He found that only one in 84 juvenile salmon reached the overflow port.

Histopathological examination of superficially undamaged salmon smolts after they had been entrained by a hopper dredge (Tutty and McBride 1976) revealed many reasons for delayed mortality including: internal lesions, debris in internal and external cavities, sand in organs, and extensive descaling of the skin. These side effects indicated that overall mortality due to entrainment by a hopper dredge was probably near 100%.

The Fraser River is British Columbia's largest contributor of salmon fry and smolts. These fish have been shown to suffer high entrainment rates by both pipeline and hopper dredges operating in the lower Fraser River (Dutta and Sookachoff 1975b), and consequently the Canadian government established dredging guidelines for this area (Boyd 1975). The salmon seemed to occupy the entire water mass where the river was narrow and did not have the swimming capability to avoid the suction of hydraulic dredges. The guidelines included three general restrictions: 1) Dredging was prohibited in certain areas regarded as ecologically valuable. These areas included places of high foodfish production and rearing areas for the juveniles of important commercial species; 2) some areas were subject to timing restrictions so that dredging could be delayed during peak abundances of fish in spawning areas, holding areas, and critical migration routes; 3) dredges were monitored if they dredged during the restricted time from March 15-June 1. When the monitoring indicates significant loss of fish then dredging must cease. Few crabs were encountered in dredge entrainment samples from the lower Fraser (Dutta and Sookachoff 1975b). But entrainment of Crangon shrimp, which may be an important food sources for many estuarine fish and crabs, was sometimes extremely high (estimated at 22 million for pipeline dredge DPW Fort Langley "312" during operation from 18 April to 29 May 1975).

2.0 DISTRIBUTION AND ABUNDANCE STUDIES OF CANCER MAGISTER IN GRAYS HARBOR

Bradley G. Stevens and David A. Armstrong

2.1 Introduction

The majority of life history research on *C. magister* has been oceanic. Few studies have targeted on estuaries as specific habitats. During his study of crab life history and migration, Cleaver (1949) tagged about 500 adult male crabs (size range 155-210 mm) inside Grays Harbor in each of 1947 and 1948, and over 3,000 in the ocean nearby. Most of these crabs were tagged in December-January and recovered soon after. Cleaver cited an increase in crab catches by the commercial fishery in Grays Harbor in March-April of each year, at which time many ocean-tagged crabs appeared. From this evidence he concluded that the ocean augmented the harbor fishery to a great degree but the harbor contributed very few legal crabs to the ocean fishery. Cleaver also estimated the number of adult males of this size range in Grays Harbor at 143-173 x 10^3 in 1947, and 63-92 x 10^3 in 1948.

Bodega Bay, north of San Francisco, has been sampled by several authors for the magnitude of Dungeness crab populations. This area is completely open to the ocean and not at all analogous to a bay such as Grays Harbor. Trawl data reported by Poole (1967) and Wickham et al. (1976) show that a very substantial population of young-of-the-year crab metamorphose to this coastal area (Wickham et al. 1976, cite an estimate of 20 million crabs from Poole's paper, 1967, although we can find no such reference).

Butler (1957) showed that a large proportion of sublegal males tagged in McIntyre Bay on Graham Island, British Columbia, migrated into Hecate Strait, thus contributing to the deepwater fishery. Previous studies had shown the importance of inshore areas to juvenile crabs, especially Naden Harbor, an enclosed harbor supporting a large area of eelgrass beds (Butler 1956).

In California, work on crab populations in coastal estuaries has shown extensive use of such habitat by young Dungeness crab. Gotshall (1960) conducted a trawl survey of crabs in Humboldt Bay, California, in 1966-1969, and found greater densities of crabs in the harbor than in nearby offshore areas. Especially abundant were juveniles of the incoming year class. Orcutt et al. (1975-1978), surveyed the _C. magister_ populations in San Francisco and San Pablo bays and the Gulf of the Farallones, finding that crab densities inside the bays were from 1 to 4 times as dense as offshore populations. They estimated that 50 to 80% of crabs eventually recruited to the offshore fishery in the Gulf spent their first year in the bay complex.

In Washington state, Tegelberg and Arthur (1977) surveyed the crab populations of Grays Harbor by ring net, beam trawl, and crab pots from December 1974 to October 1975. They found no pronounced seasonal variation of crab catches except at one station in the mouth of the Chehalis River, but they did indicate that a great number of juvenile crabs utilized the flats and sinks in the eastern end of the harbor, and concluded that Grays Harbor probably served as an important nursery area for juvenile _C. magister_. Stevens (1981) also surveyed the Grays Harbor crab population by crab pots in 1979-1980. He found some weak seasonal variation in catches in the same location as Tegelberg and Arthur (1977). However, by regression analysis he was able to show that much of the variation in crab catch by pot was attributable to tidal exchange, i.e., pots did not fish effectively during spring tides when strong currents prevailed. His data supported the conclusion of Tegelberg and Arthur (1977) that small crabs were abundant in the east end of the harbor, but pot catches were not able to define the extent of use of other areas of the harbor by juveniles, as the presence of large crabs appeared to inhibit the presence of small ones in pots.

Based on the previous Grays Harbor studies, we concluded that an otter trawl would more accurately reflect the true densities of all size classes of crabs in the harbor, and would be less subject to fluctuations in catch due to agonistic behavior of crabs. Stations were selected primarily to represent different sections of the navigation channel to be dredged, sites of subtidal dumping, a proposed experimental salt marsh establishment site (for dredged material disposal) and its control study area, as well as several other habitats present in the harbor. In this manner, the investigators hoped to detect any habitat preferences that might be shown by the various age groups.

The objectives of this study were to:

1) Document the spatial and temporal variations in relative abundance of C. magister. Crab densities were found to be significantly greater in those stations west of the crossover

channel (i.e., the outer harbor), and during the spring and summer for the entire harbor.

2) Examine the differential use of selected habitats by successive year classes of crabs. Early instars were found to be abundant on or near nudflats and eelgrass beds, one-year-old animals were more widely dispersed, and late juvenile/early adults were most abundant in the outer harbor.

3) Observe growth in width and biomass of juvenile crabs. Mean growth rates show that an average crab can grow from 7 to 45 mm in its first year of life in the Harbor, to 90 mm during its second, and to 130 mm in its third. Mass increases during this time from an average of 0.02 g to 4.2 g (an increase of 210 times) in the first year, to 30.0 g the second year (a seven-fold increase) to 85.2 g in the third year.

4) Evaluate the importance of Grays Harbor to coastal populations of C. magister. Although this could not be achieved in a quantitative manner, it was apparent that great numbers of early instars used the harbor as a nursery area, and many adults probably left the harbor in order to spawn.

5) Provide baseline estimates of crab density, based on the best information available, for comparison with dredging entrainment studies. Crab densities, as determined by trawl net, were reliable indicators of dredge entrainment (see Section 6.0).

6) Examine the potential for impact of channel dredging upon populations of C. magister in Grays Harbor. Data collected during this

study were used in Section 8.0 to estimate potential impacts of dredging on crabs.

2.2 Methods and Materials

Crab and fish collections were made by otter trawl according to a monthly sampling schedule at nine stations, and a quarterly diel schedule at two stations (see Section 3.0). Ring nets were used to collect crabs only, at three additional sites. These sites and schedules are discussed below.

2.2.1 Trawling Method: Animals were collected with a 4-seam semi-balloon otter trawl, built to the following specifications:

Head rope	4.9 m	Bridle	15.25 m	Body mesh	38 mm stretch
Foot rope	5.8 m	Legs	.91 m	Codend liner	6 mm stretch

Doors 30 x 61 cm

Most trawling was conducted from a 17-ft (5.2-m) Boston Whaler powered by a 70 hp outboard engine. A 22-ft (6.7-m) bay-type crab boat (the WISHKAH) owned by WDF was used for monthly trawls in October-December 1980, and a 30-ft (9.2-m) commercial crabber-gillnetter (the GYPSY GIRL) was used in February-March, 1981.

The net was lowered into the water from a slowly moving boat as the doors spread to their working width of 3.0 m (specification from manufacturer). As the bridle swivel entered the water, an anchored buoy was set to mark the transect starting position. The minimum warp (ratio of tow-line length:water depth) allowed was 4.0, but often as much as 6.0. The net was towed at a ground speed of 1-3 knots, into the prevailing current, until approximately 500 m had been traveled. The net was then retrieved by hand (by winch from the GYPSY GIRL), and another buoy set when the bridle emerged to denote the transect end point.

2.2.2 Quantification of Tows: After net recovery, the boat was repositioned next to the transect endpoint buoys (in turn), and compass bearings were recorded to nearby stationary objects, typically navigation buoys, range marks, or buildings. Later, positions of the transect endpoint buoys were triangulated on 7.5 minute USGS topographic maps. The distance and area traversed by the net could then be accurately calculated. The transect buoys were recovered for use on the next tow.

2.2.3 Water Sampling: Surface and bottom water samples were collected by a 4.0-l modified Van Dorn-type sampling bottle (E. L. Scott Instruments, Seattle, WA). Temperature was measured to the nearest 0.1°C. Water samples were placed in 2-dram vials for return to shore where salinity was determined to the nearest ppt later that day with a hand-held refractometer (American Optical No. 10419), used when both the instrument and water samples had reached room temperature (about 18°C). The instrument was calibrated to 0 ppt with tap water before each day's use.

2.2.4 Ring Net Operation: Ring nets were used in three locations where underwater snags prevented operation of the trawl. These nets consisted of two circular steel hoops; an inner one of 61-cm diameter covered with steel wire with a 50-mm mesh size, connected to an outer one of

76-cm diameter by flexible netting of similar mesh size. The entire net was covered with a flexible plastic lining of 12 mm mesh Dupont Carcover to retain sub-legal crabs.

Four nets, baited with rockfish carcasses, were set from the boat in shallow water. Each net was buoyed to the surface by a 20-m line. Nets were set flat on the bottom such that crabs could walk onto them. After 20 min, the nets were pulled up rapidly, assuming a basket shape and trapping the crabs.

2.2.5 Specimen Treatment: All crabs were measured to the nearest millimeter across the carapace between the notches just anterior to the tenth anterolateral spines ("carapace width"). They were then sexed and returned to the water or dissected and stomachs removed (Section 4.0). In May and June of 1980 and 1981 newly recruited early instars (7 to 32 mm) were occasionally collected in extremely large quantities. Several times these were sorted out and subsampled separately (Tows 17, 18, 44, 45, 71, 74, 76 and 79).

Fish (from trawls) were separated and preserved in 5-10% buffered formalin/seawater. From May through October, 1980, these were turned over to the Salmon/Baitfish Research Team (Simenstad et al.). After October 1980, fish were frozen and returned to the University where all were counted, and up to 15 of each species measured (total length) to the nearest millimeter by the Crab Research Team (see Section 5.0).

A number of crabs were frozen and transported to the University of Washington, in Seattle. There, they were opened at the epimeral line and dried to constant weight at 60°C (48-72 hr). Log_{10} of dry weight (g) was regressed against log_{10} carapace width (mm). Males and females were treated separately.

2.2.6 Sampling Schedule and Stations: "Regular" trawls were made at stations 1-9 biweekly from May through October 1980 (Fig. 2.1). Thereafter, these were made at intervals of 4-5 weeks through June 1981. Attempts were made to restrict trawling to within 1-2 hrs of slack low tide, so at least two days were required to complete each series of tows. Ringnetting occurred at stations 10-12 on a monthly basis, usually requiring a third day. This was also done on slack low tide, except on March 2, May 20, and June 29, 1980, when additional netting was carried out at high tide on the adjacent mud flat, at the approximate level of +4.0 ft (+1.22 m) MLLW.

2.2.6.1 Stations: (See Table 2.1 for location and depth.)

1. South Jetty. Paralleling the south jetty from western end to midpoint, about 50 m north of jetty. Sand bottom with occasional shells and small rocks. Abandoned in early 1981 due to rough water conditions.

2. Point Chehalis (Buoy 13). About 100 m south of buoy "13" at the eastern end of the entrance channel. This site was in use during the study period as a disposal site for material dredged by hopper and clamshell dredges. Hard sand bottom.

3. South Reach. Originally located about halfway between buoys "16" and "18," along the north edge of Whitcomb Flats, in 7-8 m of

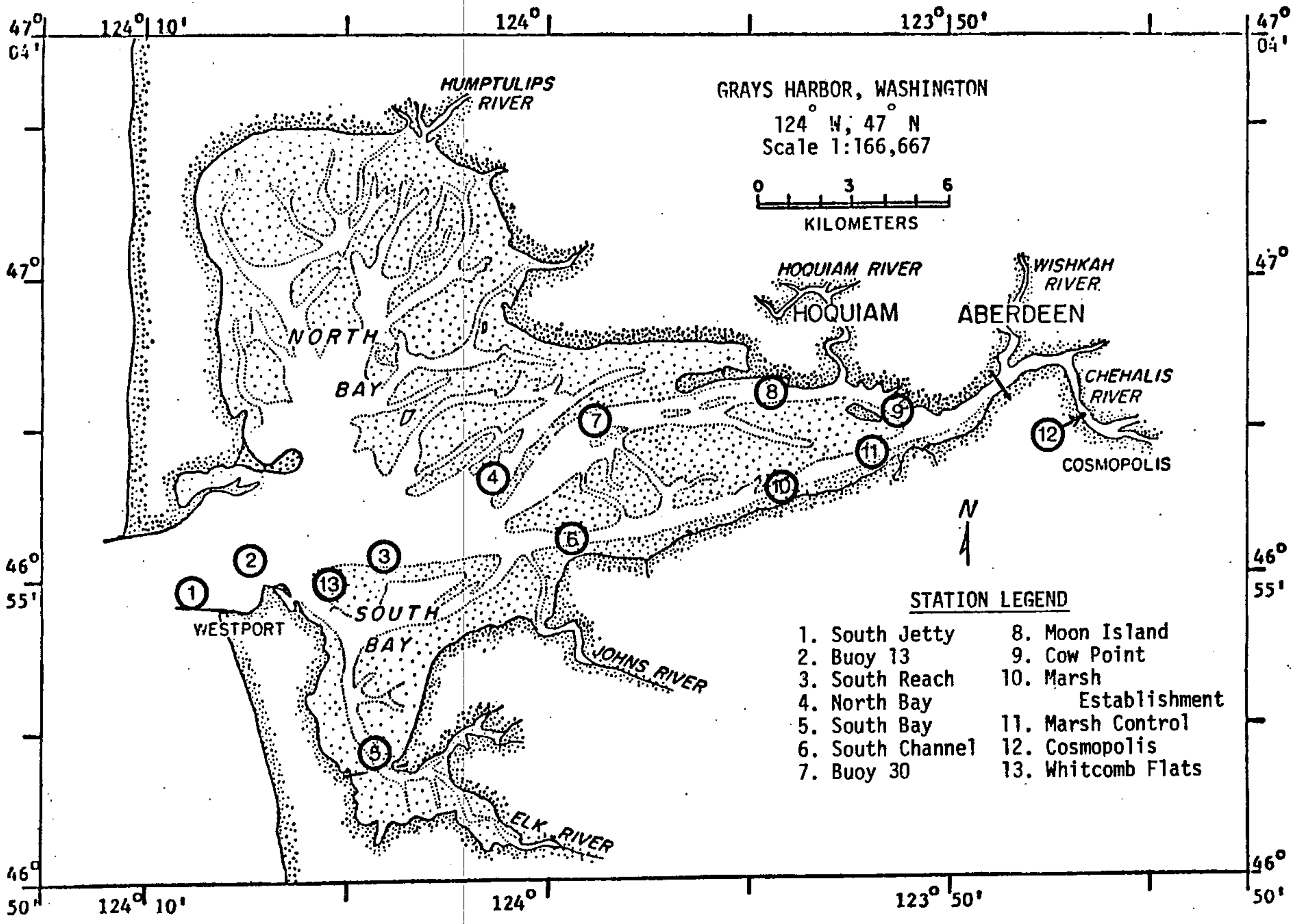


Fig. 2.1. Map of Grays Harbor, Washington.

water, this station was later moved westward, to a position from which better compass bearings could be obtained. From November 1980, through July 1981, it was located as described in Table 2.1, between buoys "17" and "18".

4. North Bay. This site was originally selected as representative of an eelgrass community. None was found there, but sampling was continued, as this site was the only representative of a shallow outer harbor habitat. Located in a narrow passage between sand bars in midharbor. Sand bottom.

5. South Bay. From 50 m north of Elk River Bridge to daymark "16". Selected to represent a tidal creek/river channel, this site has a sand-mud bottom, and is adjacent to extensive mud flats with eelgrass beds.

6. South Channel. Mixed sand-mud bottom with leafy debris, about 1.0 km east of Johns River channel.

7. Buoy 30. From about 50 m east of range mark "D" to 50 m north of buoy "32." Mixed mud-sand bottom.

8. Moon Island. Center of channel, with buoy 40 about midpoint. Bottom mostly mud.

9. Cow Point. Center of channel, from east end of Port of Grays Harbor Terminal No. 2 to dolphin 51. Mud bottom with numerous snags.

10. Site M (marsh). Selected for an experimental salt marsh establishment site. Nets set in center of adjacent section of south channel. Some sampling on mud flat, 4.0 ft (+1.22 m) level, soft mud.

11. Site MC (Marsh Control). Selected as a control site for site M. Nets set in midchannel, occasionally on adjacent mud flats (as noted).

12. Cosmopolis. Net set on a shallow shelf about 10 m from southwest shore, about 300 m north of launch ramp.

13. Whitcomb Flats. Site used for intertidal diel samples (see Section 3.1). About even with MLLW, mostly exposed on spring low tides. Hard sand bottom, covered only on high tides.

Table 2.1. Location and depth below MLLW of trawl/ring net stations.

		N. latitude			W. longitude			
No.	Name	deg	min	sec	deg	min	sec	Depth (m)
1.	South Jetty	46	54	30	125	9	0	15-18
2.	Pt. Chehalis (Buoy 13)	46	55	15	124	7	20	13-15
3.	South Reach	46	55	15	124	4	20	10-15
4.	North Bay	46	56	40	124	1	10	3-5
5.	South Bay	46	51	55	124	4	15	5-8
6.	South Channel	46	55	40	123	59	5	6-8
7.	Buoy 30	46	57	30	123	59	0	11-14
8.	Moon Island	46	58	10	123	55	20	10-15
9.	Cow Point	46	57	40	123	50	50	12
10.	Marsh Site (M)	46	56	20	123	54	15	3-4
11.	Marsh Control (MC)	46	57	12	123	51	15	3-4
12.	Cosmopolis	46	57	37	123	46	18	3-5
13.	Whitcomb flats	46	54	45	124	5	15	0-3

2.2.6.2 <u>Schedules</u>: Stations sampled on each date are given in Table 2-2, along with week numbers (for group comparison). During

May-November 1980, sites 3, 6, 8 and 9 were sampled biweekly, whereas sites 1 and 2 were alternated, as were sites 4 and 5. In December 1980, fog limited sampling to sites 3, 6, 8 and 9 only. In 1981, site 1 (South Jetty) was abandoned due to rough water conditions, but all other sites were sampled monthly, except when weather, time, or boat/net problems prevented completion of sampling. Ring netting was accomplished at sites 10, 11 and 12 monthly except in December 1980. No trawl or ring net samples were taken in January 1981 due to the unavailability of a boat.

Table 2.2. Dates and stations sampled by trawl and ring net within each weekly series.

		Trawls									Ring nets		
Week	Dates	1	2	3	4	5	6	7	8	9	10	11	12
	1980												
2	05/04-05/05		x	x		x	x	x	x	x			
4	05/13-05/17	x		x	x	x	x		x	x	x	x	x
6	06/03-06/06		x	x		x	x	x	x				
8	06/16-06/20	x		x	x		x		x	x	x	x	x
10	07/01-07/02		x	x		x	x	x	x	x			
12	07/15-07/17	x		x	x		x		x	x	x	x	x
14	07/30-07/31		x	x		x	x	x	x	x			
16	08/14-08/15	x		x	x		x	x	x	x	x	x	x
18	08/29-08/30		x	x		x	x		x	x			
20	09/12-09/14	x		x	x		x	x	x	x	x	x	x
24	10/12-10/14			x		x	x	x	x	x	x	x	x
26	10/27-10/28		x	x			x		x	x			
28	11/11-11/13	x		x		x	x	x	x	x	x	x	x
32	12/15-12/16			x			x		x	x			
	1981												
40	02/09-02/11		x	x	x	x	x	x	x	x	x	x	x
43	03/02										x	x	
44	03/11-03/13		x	x	x		x	x	x	x	x	x	x
50	04/21-04/23		x	x	x	x	x	x	x	x	x	x	x
54	05/20-05/23		x	x	x		x	x	x		x	x	x
60	06/29-07/03			x	x	x	x	x	x		x	x	x

2.2.7 Data Analyses: Generally, data was coded, keypunched, and stored on disk file at the University of Washington (CDC 6400). Raw crab data were stored as individual sex and width, along with week and tow number from which it was collected.

Width frequencies of all crabs caught during a given week were examined by probit analysis (Cassie 1954) and compared to frequency distribution graphs. From these analyses, upper and lower width limits were selected (arbitrarily non-overlapping) and used to define the size range of each year class group through time. Each crab was then assigned to an age group on the basis of width limit for each sampling week. Totals and average widths were hierarchically summarized by tow, age, and sex (SPSS BREAKDOWN procedure).

Environmental and tow data were kept on a separate file, including date, site, weather, water temperature and salinity, and effort, i.e., square meters covered by trawl, or number of ring nets used. Total numbers of crabs caught, and average widths were later added to this file (by tow number) within groups, e.g., total, males, females, and age groups 0 to 3.

For population abundance estimates, "effort" was defined as either the bottom surface area (m^2) covered by the trawl net, or the number of ring nets set for 20 minutes, depending upon which type of gear was used for a specific sample. "Catch" was defined as the total number of animals caught during a specific sample by either gear type. "Catch-per-unit-of-effort" (CPUE) was defined as the total catch (crabs) divided by the total units of effort used for any specific sample. Thus, ring net CPUE was expressed as the number of crabs caught per ring net. However, trawl net CPUE was normalized to a standard area of 100 m^2, and expressed as the number of crabs caught per 100 m^2. In the authors opinion, it was more meaningful to discuss 5.5 crabs per 100 m^2 than 0.055 crabs per m^2. The terms "catch-per-effort."CPUE, and "density" were used synonymously with respect to trawl data, implying a specific number of catchable animals collected per unit of area covered. The term "abundance" is used with reference to ring net CPUE and to means over large areas or time intervals. No corrections were made for gear efficiency, i.e., the proportion of crabs missed by the net, or other sources of error. In contrast, where the term "corrected density" is used, it implies an estimate of the actual number of crabs present in a given area, based on the observed catch-per-effort and considering the probable gear efficiency, where the latter value was based on the best information obtainable.

Catch per unit effort was regressed against bottom water salinity, temperature, and estimated Chehalis River flow by a stepwise multivariate procedure (SPSS REGRESSION) for all trawl samples. The same was done for all ring net samples using crabs per net as the unit of effort. The effects of season and area of the harbor on crab CPUE were examined by analysis of variance (SPSS ANOVA procedure). The sampling year was divided into two seasons: spring-summer (March-August) and fall- winter (September-February). The navigation channel was divided into two areas: sites 2, 3 and 4 were selected to represent the outer harbor (site 1 deleted due to lack of winter data points), and sites 7, 8 and 9 the inner harbor (essentially the north channel east of 124°W longitude to the U.S. 101 bridge at Aberdeen). A two-way ANOVA was performed with these two seasons and two station groups as the independent variables, and crabs/100 m^2 as the dependent variable.

2.2.8 Determination of Population Distribution Type: Because it was possible to make only one trawl at each site per month, and these were to be used for statistical analysis, a test was conducted to assess the variance of replicate tows, and to determine the type of distribution which the data fit most closely.

Using the GYPSY GIRL, ten short trawls were made within a 3.5 h span around slack high tide on 29 June, 1981. These tows were made in the central part of the outer harbor, about 1 km N of site 3, in 9-10 m of water. Transects generally ran parallel east-west, separated by about 25-50 meters. Simultaneous sets of 4 ring nets were made from the whaler, parallel to the trawl transects in areas not yet trawled over. All crabs and shrimp were counted, and crabs were saved for measuring after completion of all tows.

Data were converted to counts of crabs or shrimp per 100 m^2 (as before). A chi-square test for goodness of fit was performed as follows:

$$\chi^2 = \frac{s^2(n-1)}{\bar{x}}$$

and the statistic was compared to the upper and lower critical values for χ^2, at which $\alpha = 0.975$, or $\alpha = 0.025$ (Elliot 1977). This test, which generates a ratio of variance to the mean, was to determine whether the data distribution was random (x^2 within critical values), regular/ordered (x^2 less than lower critical value), or contagious/grouped (x^2 greater than upper critical value). The reader is referred to section 2.3.3 for results.

2.3 Results

2.3.1 Spatial Distribution of Crab Population: Catch per unit effort (CPUE) is expressed as crabs/100 m^2 for trawl samples, or as crabs/net for ring net samples. The station with the greatest average crab density over the 14-month sampling period (21.9 crabs/100 m^2) was site 1 (South Jetty), which also produced the largest single catch (1,284 crabs, or 81.1 crabs/100 m^2; Figs. 2.2 and 2.3). Excluding this latter sample, the average of five tows taken at site 1 from May-November 1980, was 10.1 crabs/100 m^2, still the highest average. South Reach (site 3) was the second most densely populated area, averaging 7.6 crabs/100 m^2, (Figs. 2.2 and 2.4). Following station 5 (South Bay, 6.5 crabs per 100 m^2), all other stations averaged less than 5 crabs/100 m^2, (Figs. 2.2 through 2.7), with catches declining almost directly with increasing distance from the jetties, and decreasing bottom salinity (Fig. 2.14). Notable exceptions were South Channel, with the lowest yearly average density of 1.2 crabs/100 m^2 (Fig. 2.6) and buoy 13 (site 2) with 2.9 crabs/100 m^2 (Fig. 2.4).

Catches at the ring net stations, though not directly comparable, showed a slightly different spatial trend (Fig. 2.8). Abundance was greater at site M, near the eastern (upstream) end of the South Channel than at site MC, near the middle and averaged 22.9 and 12.7 crabs per net, respectively, from June to October. No crabs were caught at site 12

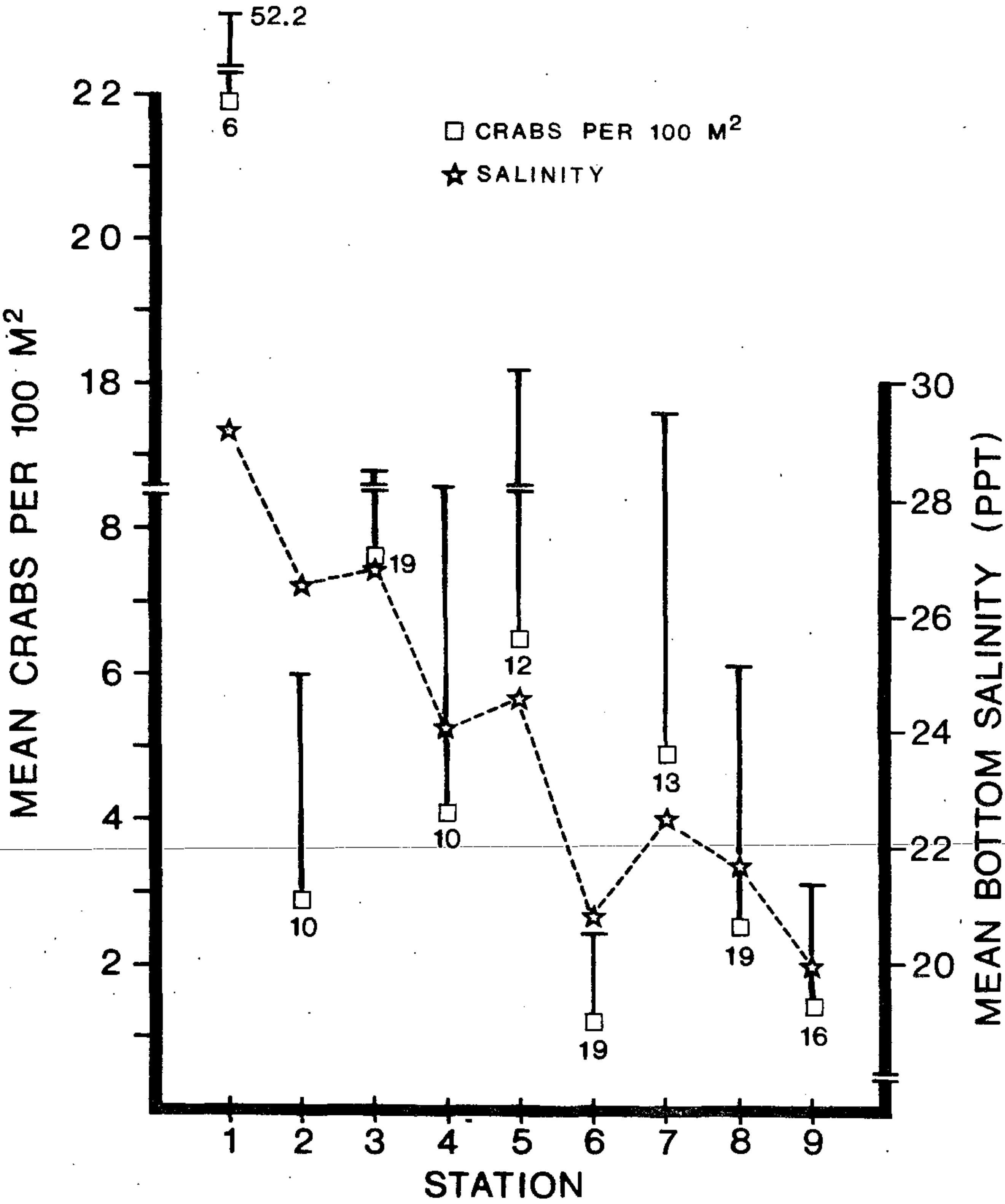


Fig. 2.2 Mean density of C. magister (crabs/100m^2) at nine stations, and mean low tide bottom salinity. Number of trawls shown below boxes, plus one standard deviation (vertical bar). Data from May 1980 to July 1981.

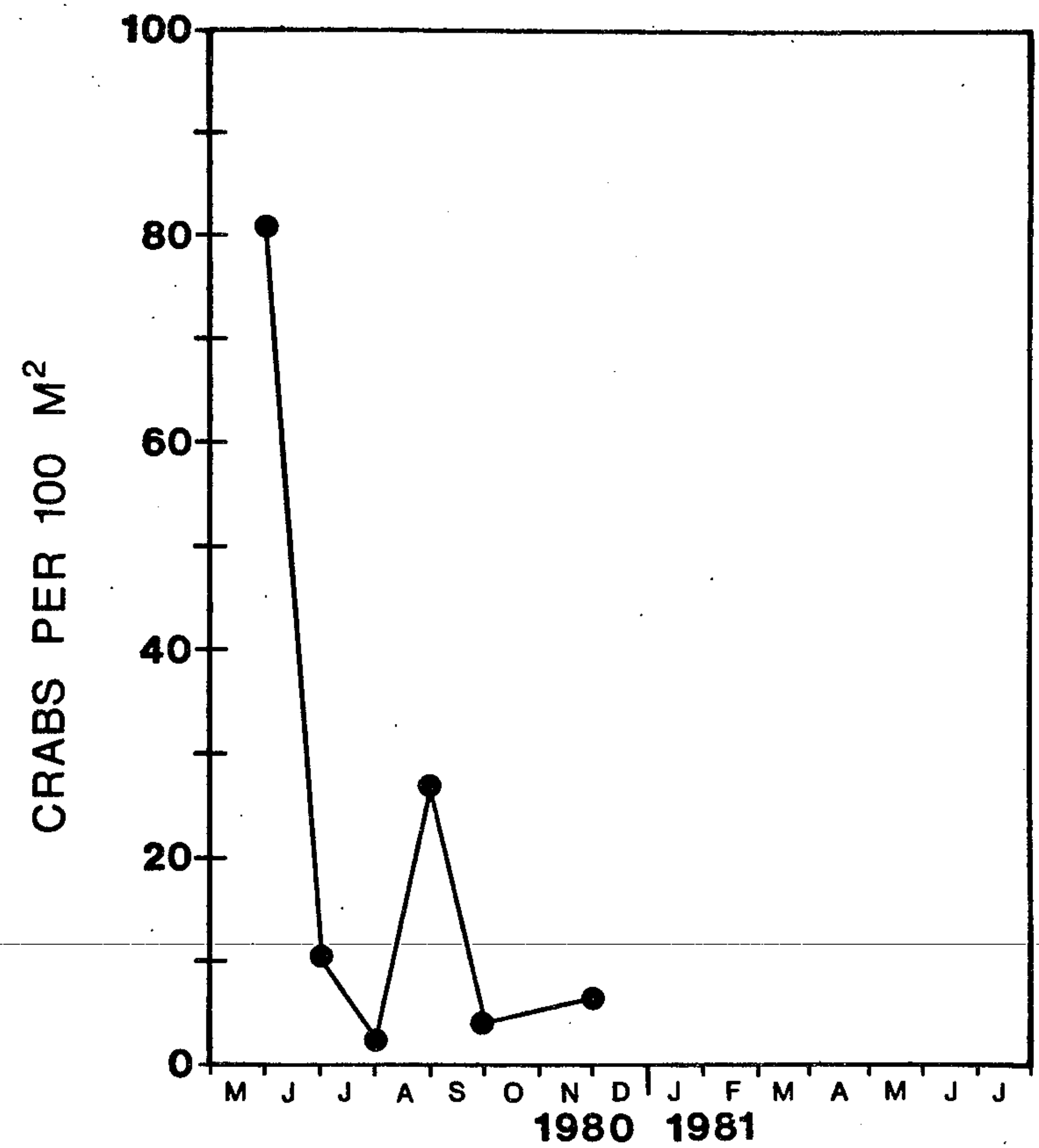


Fig. 2.3 Monthly density of C. magister at site 1 (South Jetty). Sampling was discontinued at this site in 1981 due to rough water conditions.

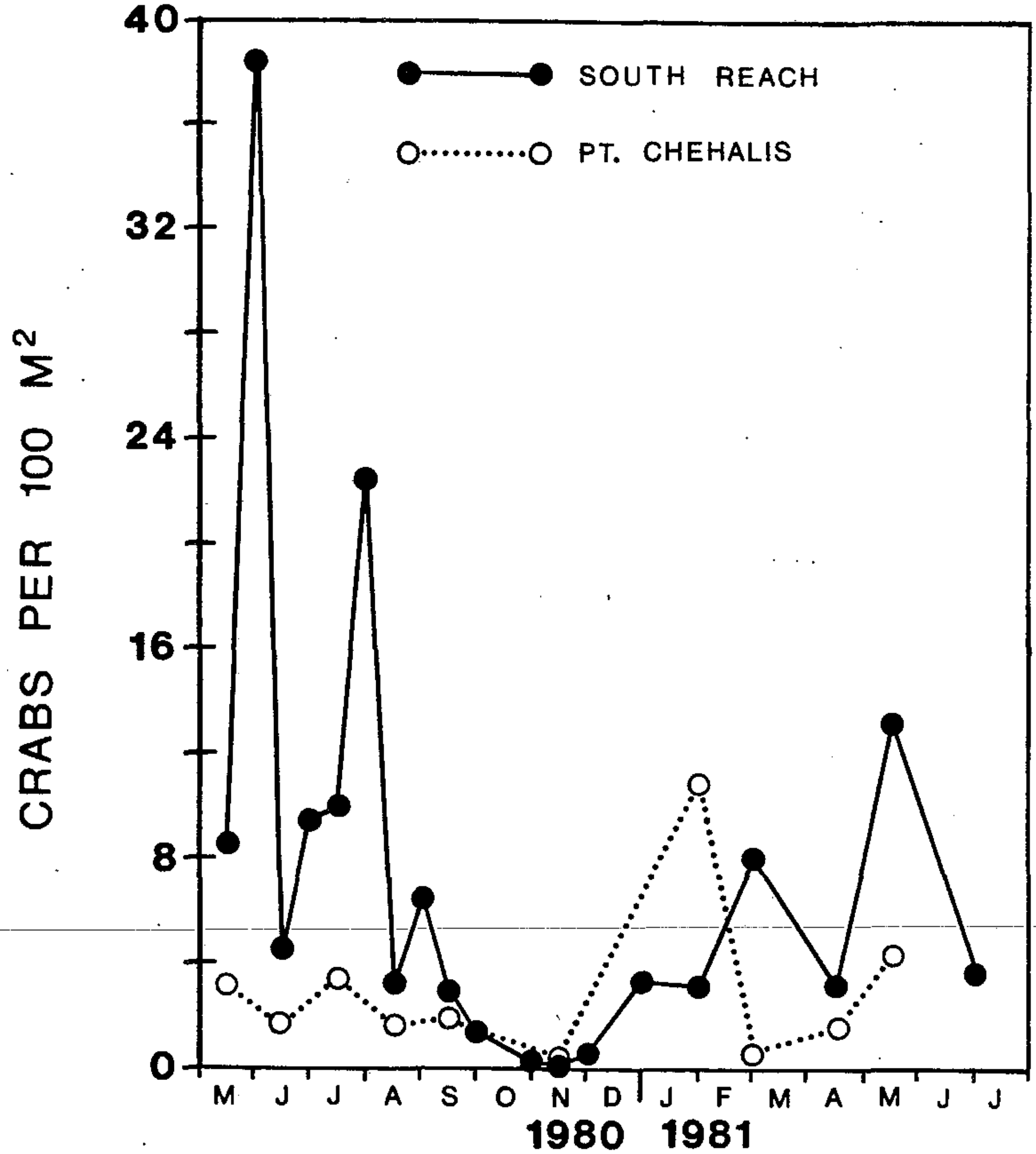


Fig. 2.4 Monthly density <u>C. magister</u> at site 2 (Pt. Chehalis) and site 3 (South Reach).

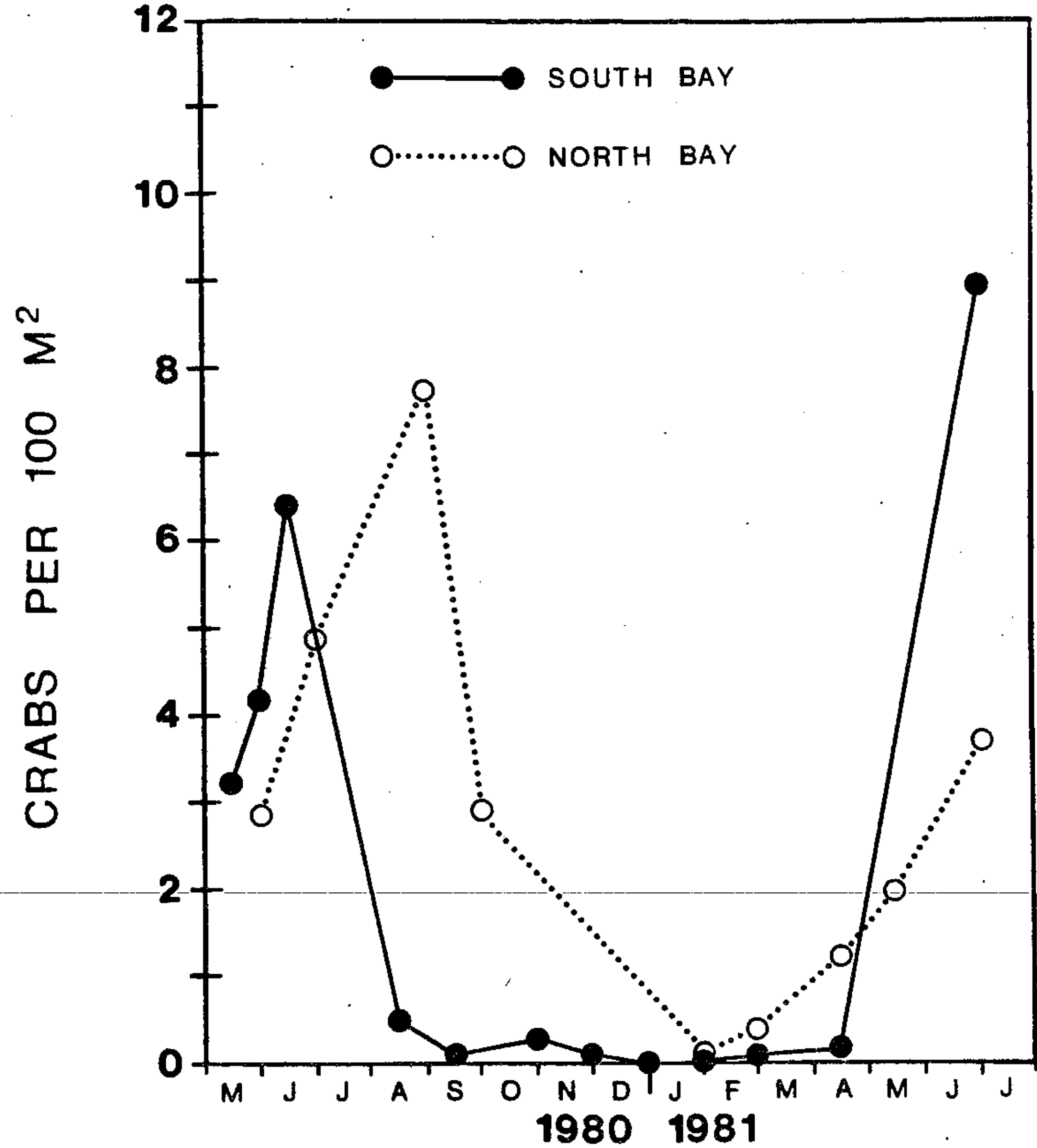


Fig. 2.5 Monthly density of C. magister at site 4 (North Bay) and site 5 (South Bay)

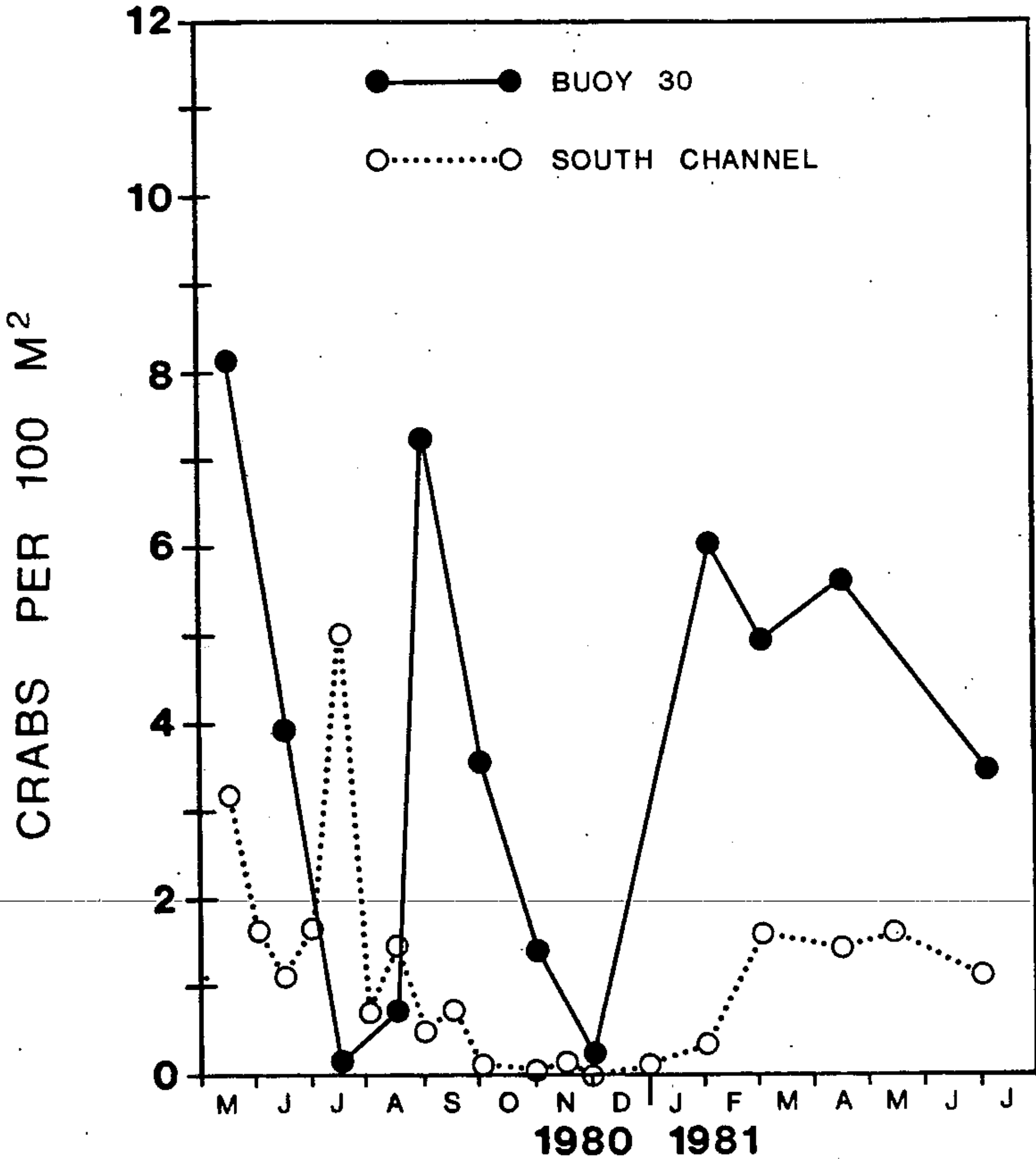


Fig. 2.6 Monthly density of C. magister at site 6 (South Channel) and site 7 (Buoy 30).

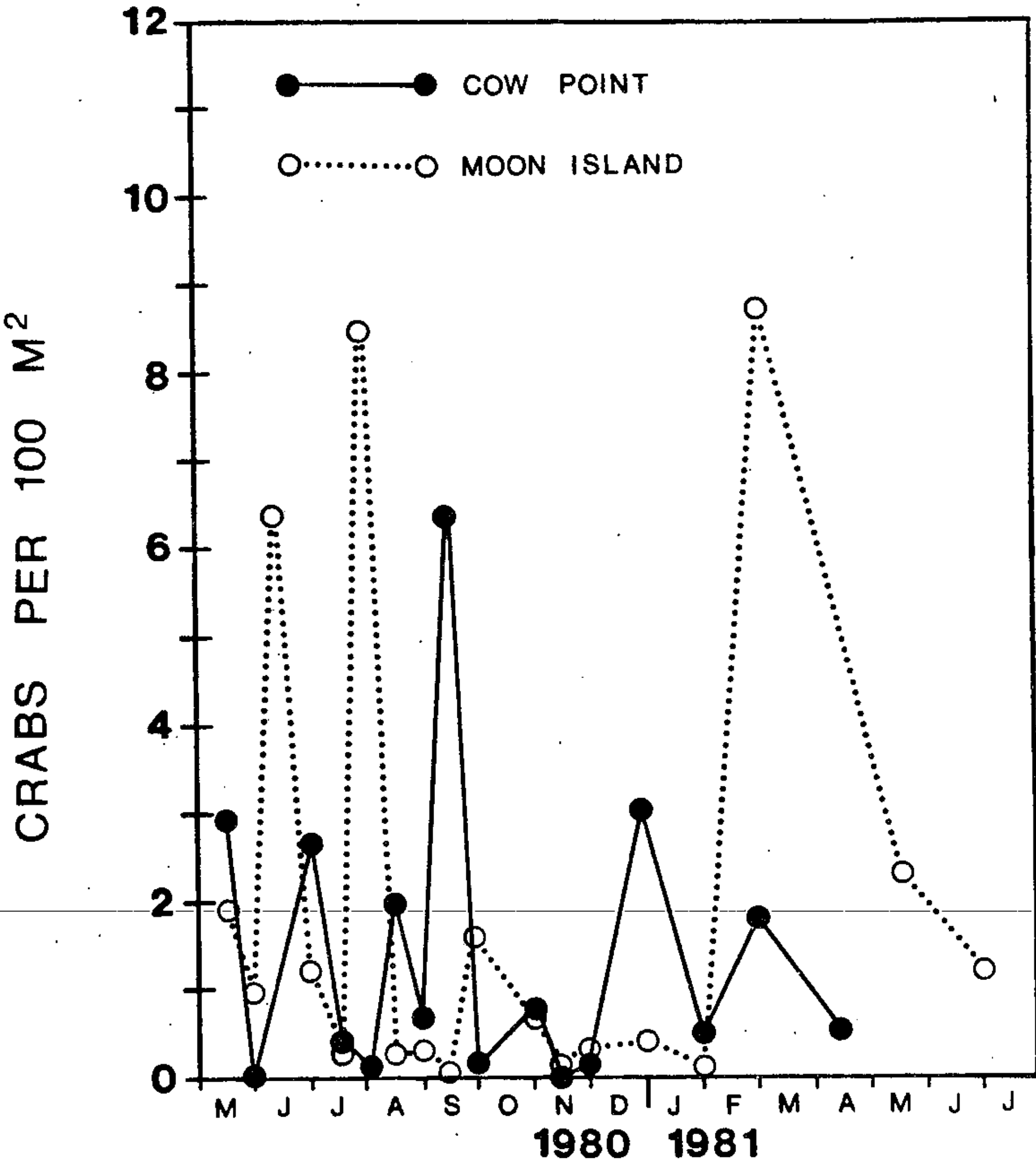


Fig. 2.7 Monthly density of C. magister at site 8 (Moon Island) and site 9 (Cow Point).

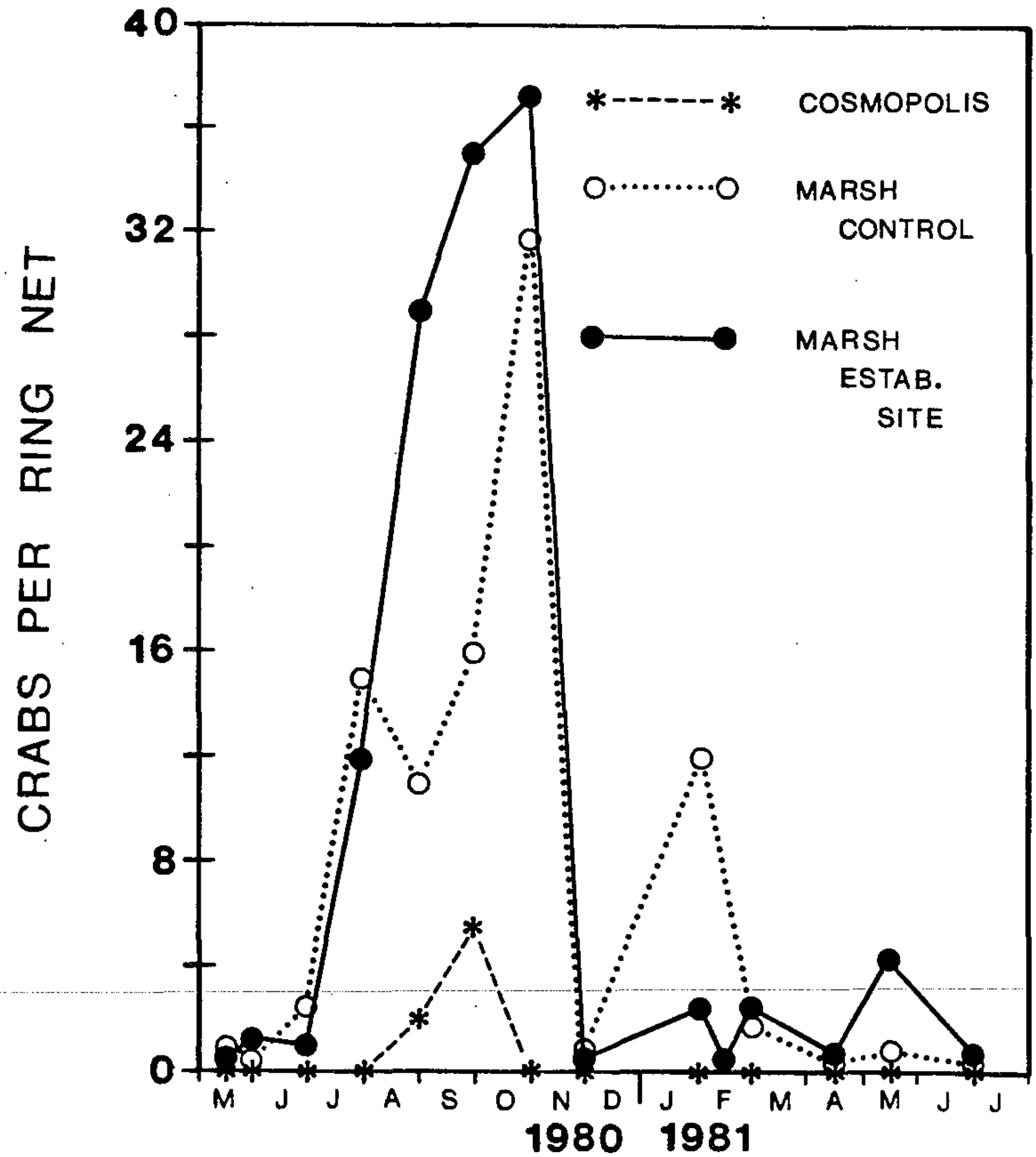


Fig. 2.8 Monthly density of C. magister at site 10 (MC, Marsh Control), 11 (M, Marsh Establishment Site), and 12 (Cosmopolis).

(Cosmopolis) except in August and September 1980 when the catches were 2.0 and 5.5 crabs/net, respectively.

2.3.2 Temporal Distribution of Crab Population: Crab densities at all stations were greater than 6.0 crabs/100 m^2 from May-August 1980 (Figs. 2.3 through 2.8). From September 1980, through January 1981, densities at all sites declined to less than 4.0 crabs/100 m^2. The lowest densities occurred in October and November 1980, none being greater than 2.0 crabs/100 m^2 except at the South Jetty (Fig. 2.3). Although monthly variation was high at each site, this general decline in crab catches during winter was widespread throughout the harbor, and more or less coincided with the commencement of winter rainfall in November 1980.

At the three ring net sites (10, 11, and 12) crab abundance increased dramatically from June (less than 4 crabs/net) through October 1980 (37 crabs/net at site M), then plummeted in November 1980 to a low of less than 1.0 crab/net at sites 10 and 11 (Fig. 2.8). No crabs were caught at Cosmopolis (site 12) except during August (2.0 crabs/net) and September 1980 (5.5 crabs/net), when the salinity reached 9 and 7 ppt, respectively. Salinity at site 12 was 1.0 ppt or less during all other months (Appendix Table A-12).

2.3.3 Analysis of Population Distribution Type: Of ten tows made on 29 June, 1981, tow no. 8 was rejected as inaccurate due to the low catch of crabs, and the fact that it ran across four previously trawled transects (Table 2.3). Afternoon fog caused difficulty in locating channel buoys for accurate determination of transect positions, so tows 9 and

Table 2.3. Data from population distribution test of 6/29/81

Tow no.	Area (m^2)	Shrimp Catch	Shrimp #/100 m^2	Crabs Catch	Crabs #/100 m^2	Ring-net Crabs Catch	Ring-net Crabs #/net
1	936	21	2.2	17	1.8	9	2.25
2	792	60	7.6	28	3.5	10	2.50
3	1440	9	0.6	11	0.8	6	1.50
4	1656	40	2.4	30	1.8	4	1.00
5	1800	157	8.7	40	2.2	16	4.00
6	2160	131	6.1	41	1.9	9	2.25
7	2376	105	4.4	14	0.6		
8	2808	10	0.4	1	0.04		
9	1080	46	4.3	44	4.1		
10	2304	113	4.9	91	3.9		
Tows 1-7		n	7		7		6
		$\bar{x}$	4.57		1.80		2.25
		s	3.02		0.96		1.02
Tows 1-7,9,10		n	9		9		
		$\bar{x}$	4.58		2.29		
		s	2.62		1.28		

Table 2.4. Calculations of test statistic (chi-square) for data distribution type.

Test statistic $= \chi^2 = \frac{s^2(n-1)}{\bar{x}}$

Species	Tows	χ^2	Critical Values lower	Critical Values upper	Result
Crab	1-7	3.07	1.237	14.999	H^o accepted
Crab	1-7,9,10	5.72	2.180	17.535	H^o accepted
Crab	Ring nets	2.31	0.831	12.832	H^o accepted
Shrimp	1-7	11.97	1.237	14.999	H^o accepted
Shrimp	1-7,9,10	11.99	2.180	17.535	H^o accepted

10 were made closer to the channel, along the lip of its northern edge near site 3. When all tows were plotted on the map it was seen that tows 9 and 10 wer far enough removed from 1-8 to be considered as a separate sampling area. Therefore data were combined in two ways for the chi-sqaure calculation:

1. Tows 1-7 only were used.
2. Tows 1-10 excluding 8 were used.

This method gave a mean and variance within a small area, or a larger area, respectively (Table 2.4).

For all combinations of tows for both crabs and shrimp, the values of X^2 fell between the critical values for a total α of 0.05 (two-tailed test). Therefore, we concluded that the sampled variables (crab counts per unit of effort) had more than a 95% probability of originating from a randomly distributed population, a type which most closely resembles the Poisson distribution model (Elliot 1977). Therefore, since the distribution was not "normal," a data transformation was necessary before the use of parametric statistical procedures which require the assumption of a normal distribution (ANOVA and regression). The transformation required was the square-root transformation, with the addition of a constant (1) to enable square roots of zero counts to be calculated (Snedecor and Cochran, 1967). The transformed variable (X_t) was computed as follows:

$$X_t = \sqrt{(X+1)}$$

where X represents a calculated crab abundance in terms of crabs per unit of effort (either a standard area such as 100 m^2, or a qualitative unit such as a ring net set).

Frequency distributions of trawl and ring net captured crabs are presented in Appendix B-3.

2.3.4 ANOVA of CPUE by Season and Area: Analysis of transformed catch-per-effort data showed a significant difference between the two seasons (p=0.002) and between the inner and outer harbor (p=0.018), as defined in seciton 2.2.7 (Table 2.5). Means and standard deviations of transformed data are presented in Table 2.5, along with reconverted means. The latter are derived from the geometric means of square-root transformed data as:

$$\bar{X}_r = (\bar{X}_t)^2 - 1 + 0.81$$

wherein $\bar{X}_r$ = the reconverted mean, and $\bar{X}_t$ = the mean of square-root transformed data. Subtraction of 1 completes the reconversion, and the addition of 0.81 (the residual mean square) is a rough correction for the discrepancy between the reconverted and algebraic means (Snedecor and Cochran 1967).

Thus, the mean catch per effort of crabs from the outer harbor, represented by sites 2, 3, and 4 (5.10 crabs/100 m^2) was significantly greater than the mean CPUE at inner harbor sites 7-9 (2.98 crabs/100 m^2), for both seasons. Also, crab catch per effort in both areas decreased significantly from a spring-summer mean of 4.78 crabs/100 m^2, to a fall-winter mean of 2.09 crabs/100 m^2 (Table 2.5). Interaction between seasons and areas was not significant (p = 0.48).

2.3.5 Crab Population Structure: Age is defined as the minimum number of years of life since metamorphosis from megalops larva to first

Table 2.5. Mean catch per effort of *C. magister* in areas and seasons compared by ANOVA. Values are crabs/100 m^2 transformed as described. Reconverted means shown in parentheses.

		Outer Harbor	Inner Harbor	Season Means	Probability of F-value
Spring-Summer	$\bar{X}$	2.52 (6.16)	1.96 (3.65)	2.23 (4.78)	
(March-Aug)	s.d.	1.12	0.86	1.03	
	N	29	32	61	
Fall-Winter	$\bar{X}$	1.66 (2.57)	1.41 (1.25)	1.51 (2.09)	
(Sep-Feb)	s.d.	.76	0.47	0.60	
	N	10	16	26	
Area means	$\bar{X}$	2.30 (5.10)	1.78 (2.98)		
	s.d.	1.10	.80		Seasons = 0.002
	N	39	48		Areas = 0.018

instar postlarva. Therefore, a crab which may have hatched from the egg in January 1980, and metamorphosed in May 1980, is defined as belonging to the 0 or 0+ age group until May 1981, at which time it entered the 1 or 1+ age group. Width frequency distributions for all crabs caught in the harbor are presented by sampling week in Appendix A. Cutoff values for the width frequency distribution of each age class were selected to be nonoverlapping. For example, width ranges selected by probit analysis for male crabs caught during the June diel sampling (1980) were 0-30, 30-70, 70-136, and 136+ mm for age groups 0+, 1+, 2+, and 3+, respectively (Table 2.6; also see Fig. 3.4-A).

The distribution of crabs within the harbor varied with age group. Animals in the 0+ age group were commonly found from site 2 (buoy 13) to site 8 (Moon Island), averaging 0.46 crabs/100 m^2, and representing 16.6% of total crabs caught in the harbor (Figs. 2.9 and 2.10) throughout the entire 14-month sampling period. The greatest mean density (1.60 crabs/100 m^2) of 0+ crabs occurred at site 5 (South Bay). No other site had a mean density above 0.5 crabs/100 m^2, of this age group. In May 1981, visual inspection of an exposed eelgrass bed/mudflat in the North Bay showed that first instar crabs were abundantly distributed on the mud flat in slight depressions at low tide, buried just beneath the surface and in burrows of _Callianassa_. Estimated densities were 5-10 crabs per square meter, based on non-random visual observations within an area of the North Bay mudflats measuring approximately 100 m^2. This density is 2 to 3 orders of magnitude greater than that calculated from trawl catches of this age group. Therefore, it is likely that this age group is grossly

Table 2.6. Upper limit of width range for each age group. Selection method was probit analysis (P) or interpolation (I).

Date	Method	Age of males 0+	1+	2+	Method	Age of females 0+	1+	2+
5/4/80	P	25	60	115	P	30	60	120
5/16/80	I	26	65	120	I	28	69	124
6/4/80	P	27	70	124	P	25	77	127
6/16/80	I	29	70	132	I	27	79	126
6/21/80	P	30	70	136	P	28	80	126
7/1/80	I	32	75	136	I	31	87	127
7/15/80	P	34	85	136	P	37	90	130
7/30/80	I	37	88	134	I	36	91	
8/14/80	P	40	92	132	P	36	92	
8/29/80	I	43	92		I	41	93	
9/12/80	I	45	94		I	45	94	
9/26/80	P	46	96		P	50	95	
10/13/80	P	46	105		P	50	96	
10/27/80	I	46	106		I	52	98	
11/12/80	P	46	107		P	54	100	
12/15/80	P	46	101		P	52	104	
1/17/81 1/	P	44	121		P	55	125	
2/9/81	I	44	121		P	54	126	
3/11/81	P	45	121		P	61	126	
4/4/81	P	47	120		P	56	133	
4/21/81	I	15	55		I	15	63	120
5/21/81	P	26	70	127	P	29	75	120
7/01/81	P	29	75		P	29	86	

1/ Data for January, 1981, from diel sampling (see Section 3.0).

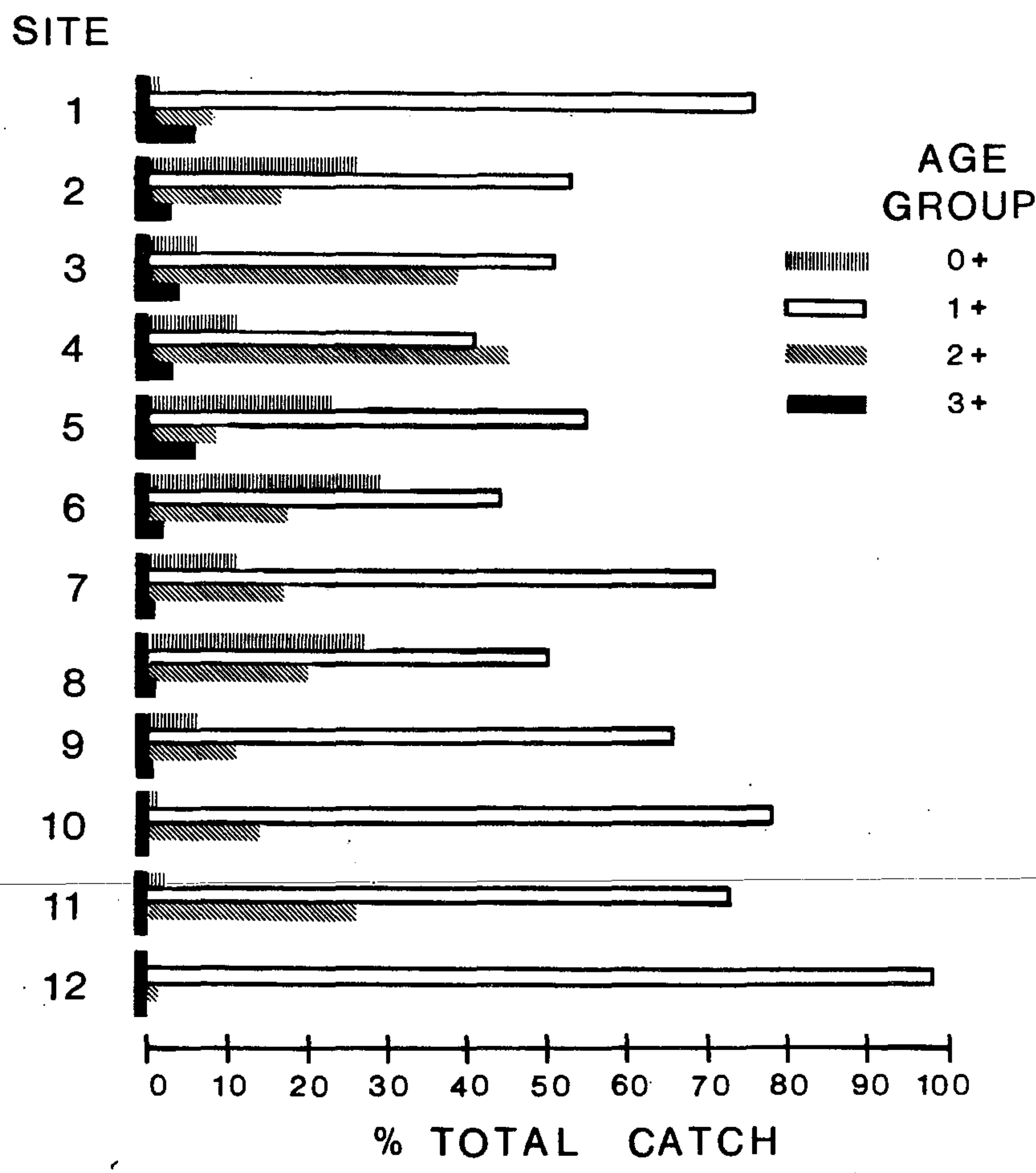


Fig. 2.9 Proportions of total crabs caught at each station represented by age groups 0-3. Values derived from the sum of all catches accumulated over 14 months for each station.

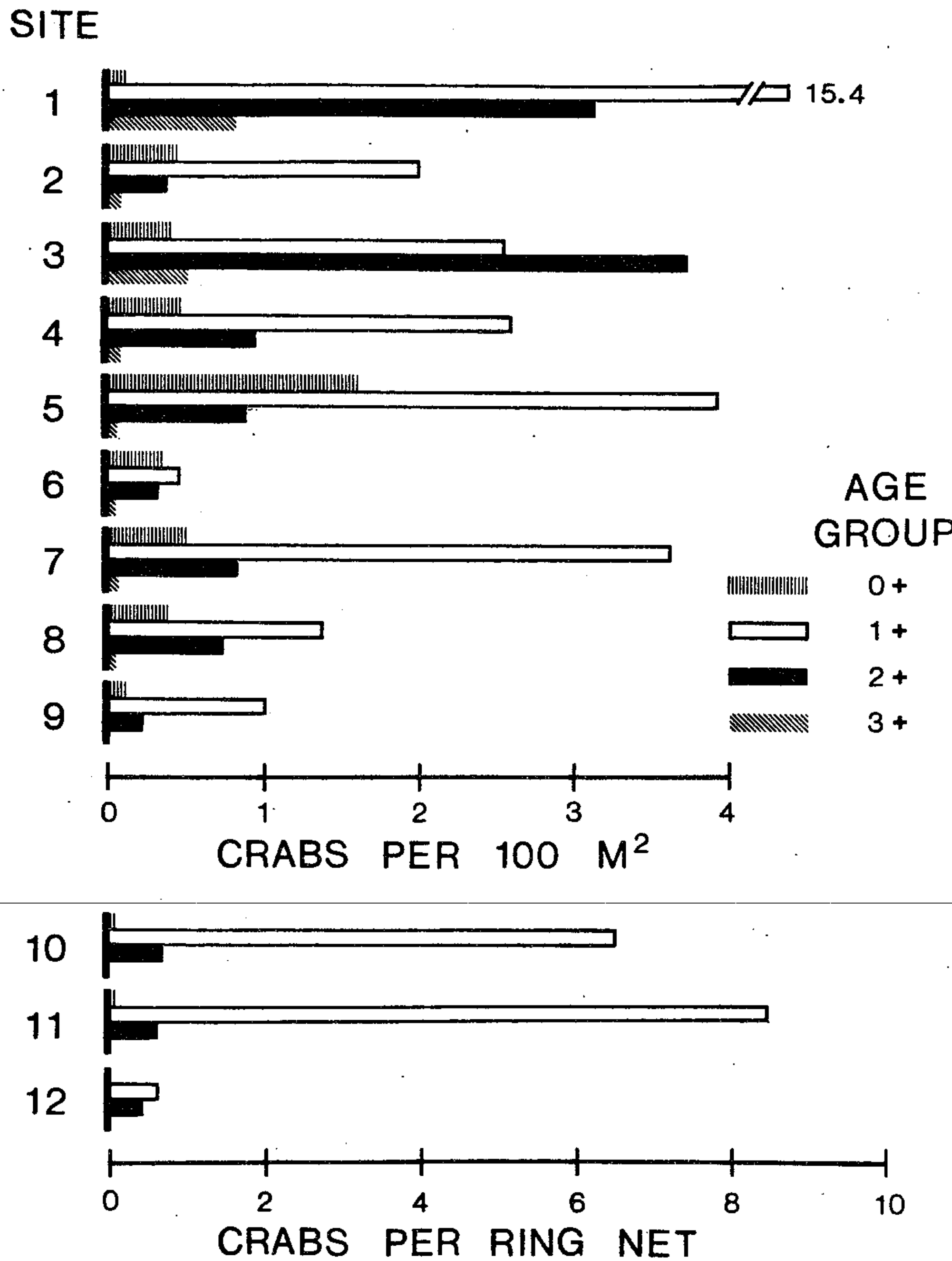


Fig. 2.10 Mean density of C. magister in age groups 0-3+ at each station. Data for all 14 months included.

under-represented in the trawl catch, especially at sites near mud flats, such as sites 4 through 8. Very few crabs of the 0+ group were caught at the South Jetty (site 1) and almost none at the ring net stations (10-12).

Whereas the annual mean catch of 0+ age group crabs was greatest at site 5 (South Bay), the figure of 1.60 crabs/100 m^2 does not convey the real usage of this important area by newly metamorphosed post-larvae. When catch per effort of this age group is shown on a weekly basis through the summer of 1980, it can be seen that abundances were relatively high during May-July, reaching almost 4.0 crabs/100 m^2 (Fig. 2.11). For comparison, data from South Reach and Moon Island are also shown. Both of those stations produced higher mean catches of 0+ age group crabs (about 0.4 crabs/100 m^2) than most other stations except South bay.

Animals in the 1+ age group were by far the most abundant at all sites except site 3, averaging 2.68 crabs/100 m^2 and 54.7% of all crabs, over the entire sampling period. Greatest abundances were encountered at site 1 (South Jetty), but this group was also abundant at sites 3, 4, 5, and 7 (Fig. 2.10), i.e., the outer harbor. This group was least abundant at site 6, causing that area to have a very even distribution of age groups 0-2 (Figs. 2.9 and 2.10). The 1+ age group was the largest proportion (73-78%) at the ring net sites (10-12).

The average density of the 2+ age group was 1.21 crabs per 100 m^2 (sites 1-9) comprising 21.3% of all crabs caught. Greatest abundances occurred at sites 3, South Reach, and 1, South Jetty (Fig. 2.11). This

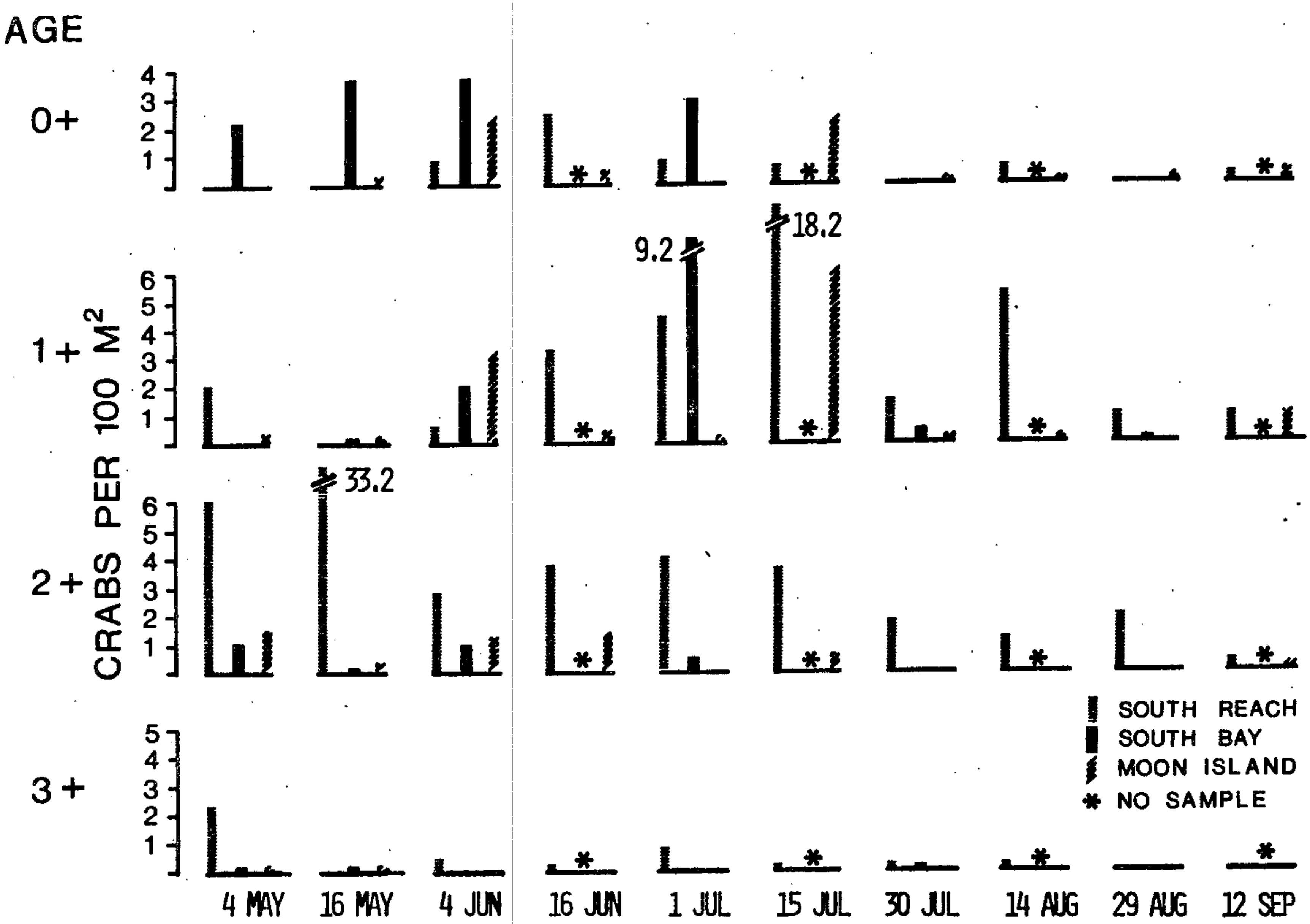


Fig. 2.11 Weekly catch per effort of C. magister at South Bay, South Reach, and Moon Island, by age group. Data for summer of 1980 only.

group was the most abundant at site 3, South Reach, making that site the only one where the 1+ age group did not predominate.

The 3+ age group was difficult to separate from the 2+ group because of the low number of these animals present in the trawls. However, they could be distinguished in May-August 1980. Of all samples taken during the project, they represented 3.0%, with an average density of 0.17 crabs/100 m^2. This group occurred primarily at sites 1-3, with greatest densities at site 1 (South Jetty).

2.3.6 Growth in Width: Crabs increased in width rapidly during May-October 1980 (Fig. 2.12). From then until March 1981, the 1+ and 2+ groups increased steadily at a slower rate, but the 0+ age group showed no increase in average width. Animals in the 3+ age group were distinguishable only during May-August 1980. Thereafter, they were so infrequent that any present were probably grouped in the 2+ group by the probit analysis.

2.3.7 Growth in Mass: Regression of $\log_{10}$ dry weight on $\log_{10}$ carapace width showed very similar A (y-intercept) and B (slope) values for 87 males (Fig. 2.13A) and 74 females (Fig. 2.13B), and strong correlation (r^2) for both sexes (Table 2.5). This is the first publication of weight/width regression data for *C. magister* known to us. During the first year after metamorphosis, first instar crabs at about 7.2 mm carapace width and a dry weight of 0.023 g would grow to about 50 mm and a weight of 5.66 g, nearly a 250-fold increase in the latter.

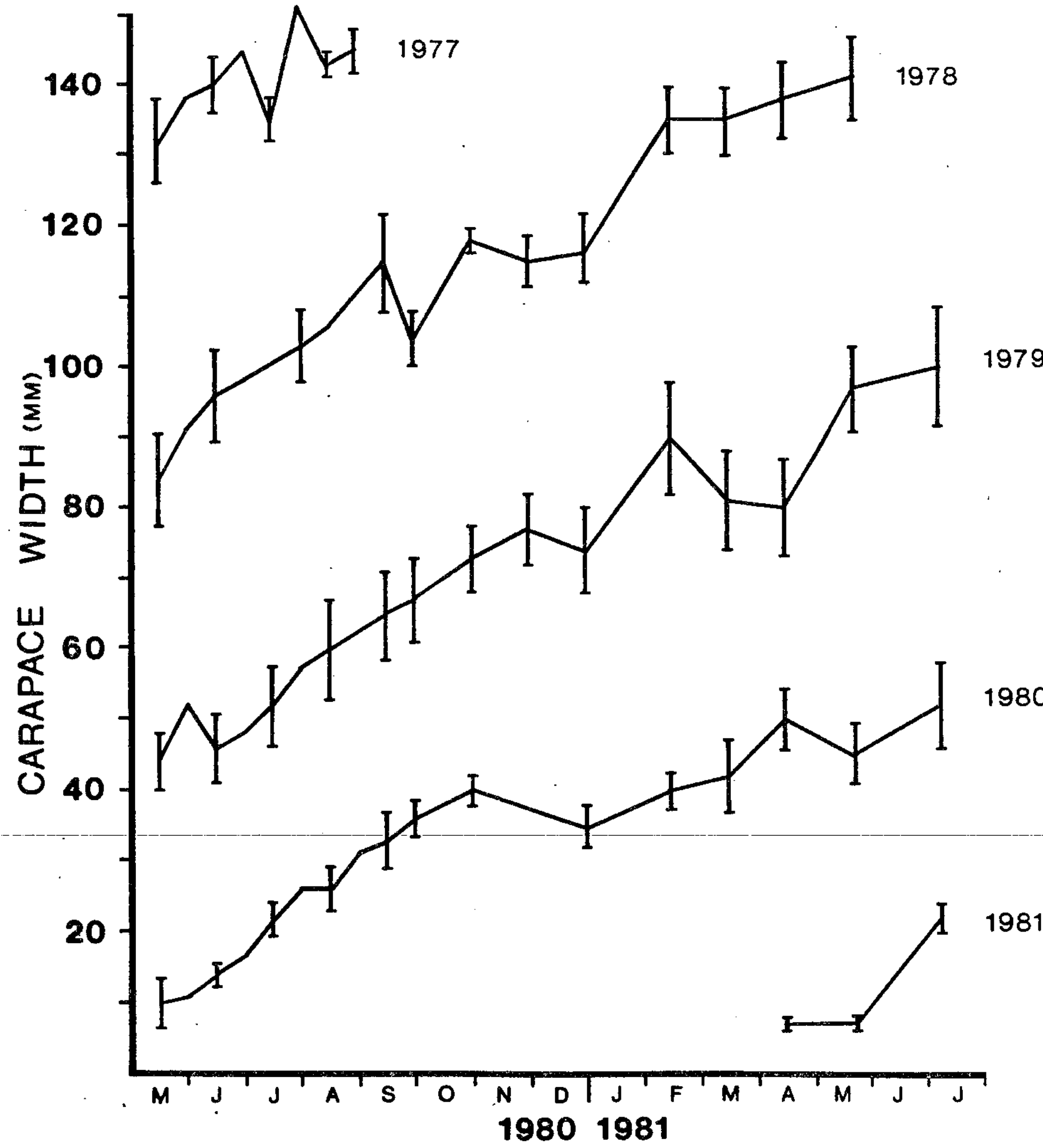


Fig. 2.12 Mean carapace width of C. magister at biweekly/monthly intervals, by year class. Vertical bars are ± 1.0 standard deviation at occasional intervals. The 1977 year class was not distinguishable after August 1980.

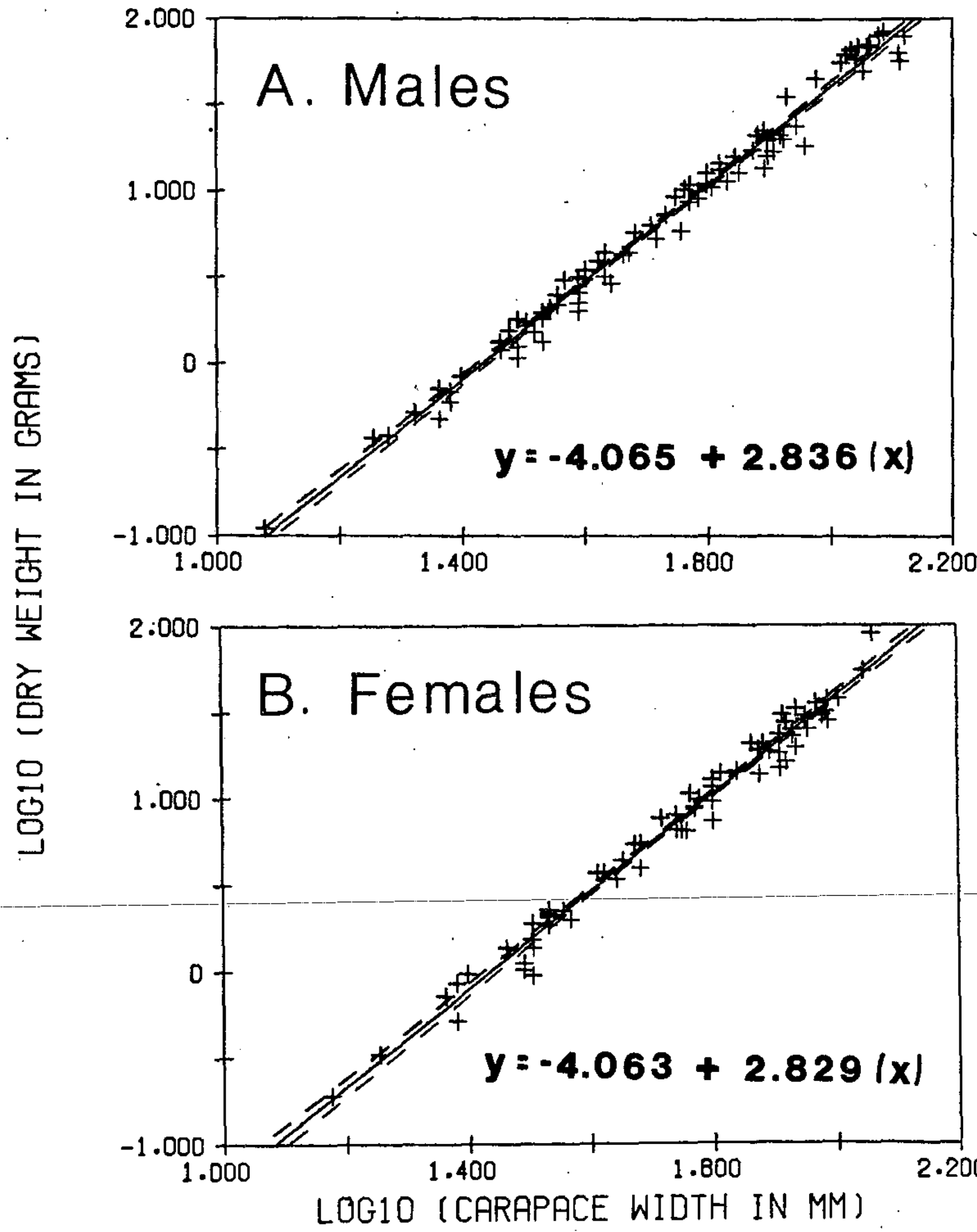


Fig. 2.13 Regression of $\log_{10}$ (grams dry weight) on $\log_{10}$ (carapace width, mm) for Cancer magister from Grays Harbor. A. Males, n=87. B. Females, n=74. Observations represented by "+" signs, regression line is solid, and dashed lines enclose 95% confidence interval for the mean.

Table 2.7. Regression equations for dry weight vs. carapace width of male and female *C. magister*. Y is $\log_{10}$ (dry weight in g), x is $\log_{10}$ (carapace width in mm).

Sex	Equation	p	r^2	Size range
Male	y = -4.065 + 2.836 (x)	0.001	0.986	12-132 mm
Female	y = -4.063 + 2.829 (x)	0.001	0.982	15-115 mm

2.3.8 Salinity and Temperature Data: A large number of salinity and temperature measurements were made, and are recorded in Appendix B for the use of future investigators. Mean and range of bottom salinity values at or near low tide are plotted for all stations (Fig. 2.14). Sampling sites showed three distinct types of bottom salinity range:

1. Sites 1-4, range 18-32 ppt. Outer harbor.
2. Sites 5-9, range 10-32 ppt. Upper reaches.
3. Sites 10-12, range 0-22 ppt. Riverine, shallow (less than 5 m).

Temporal changes in bottom temperature and salinity are plotted for sites 3 and 9 (South Reach and Moon Island) as selected examples (Figs. 2.15, 2.16; plots for remaining stations are included in Appendix B). Temperatures were more stable in the Outer Harbor but increased from about 7° to 14°C at South Reach from winter to summer, but rose from 5°C to 18°C at Cow Point during this same time (Figs. 2.15, 2.16).

In contradiction to Knott and Barrick (1975) who reported that mixing of water in Grays Harbor was so great that maximum differences in salinity from top to bottom were 3-5 ppt in the upper reaches, our data

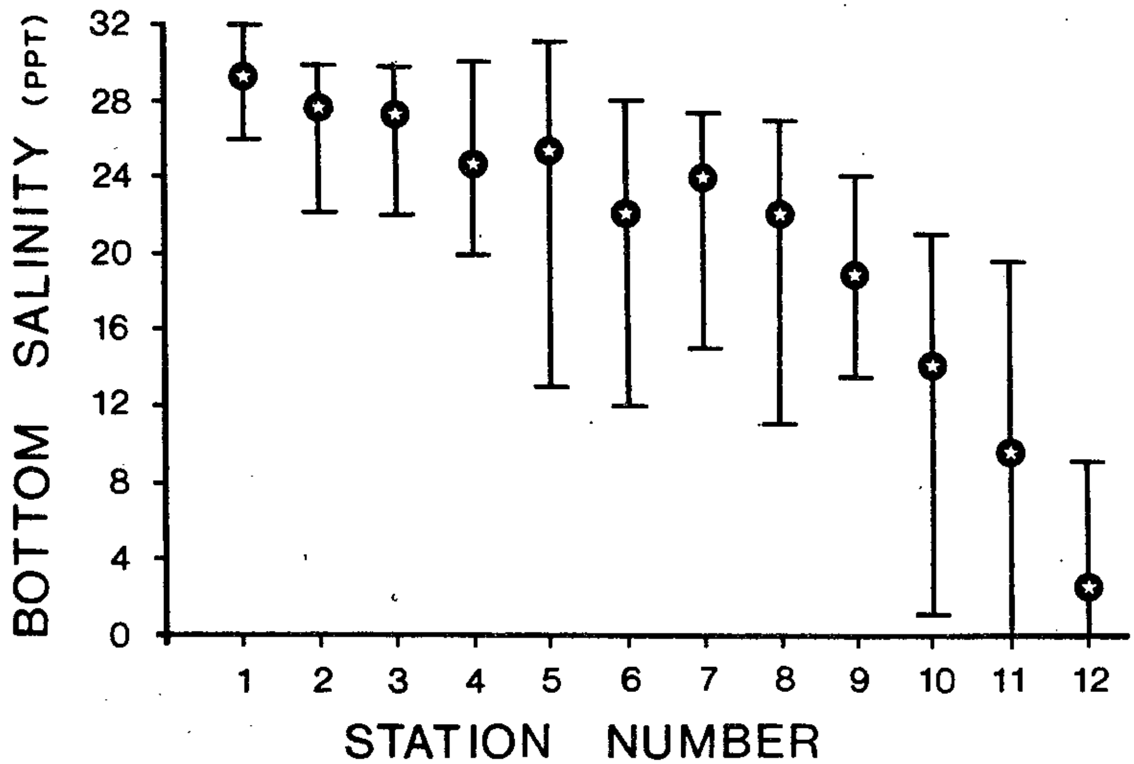


Fig. 2.14 Mean and range of bottom salinity at all crab sampling stations, 1980-1981. Most measurements made within 2 hrs of slack low tide. See Section 3.2.6.1 for exact location of sites; A pp. A for time of sampling.

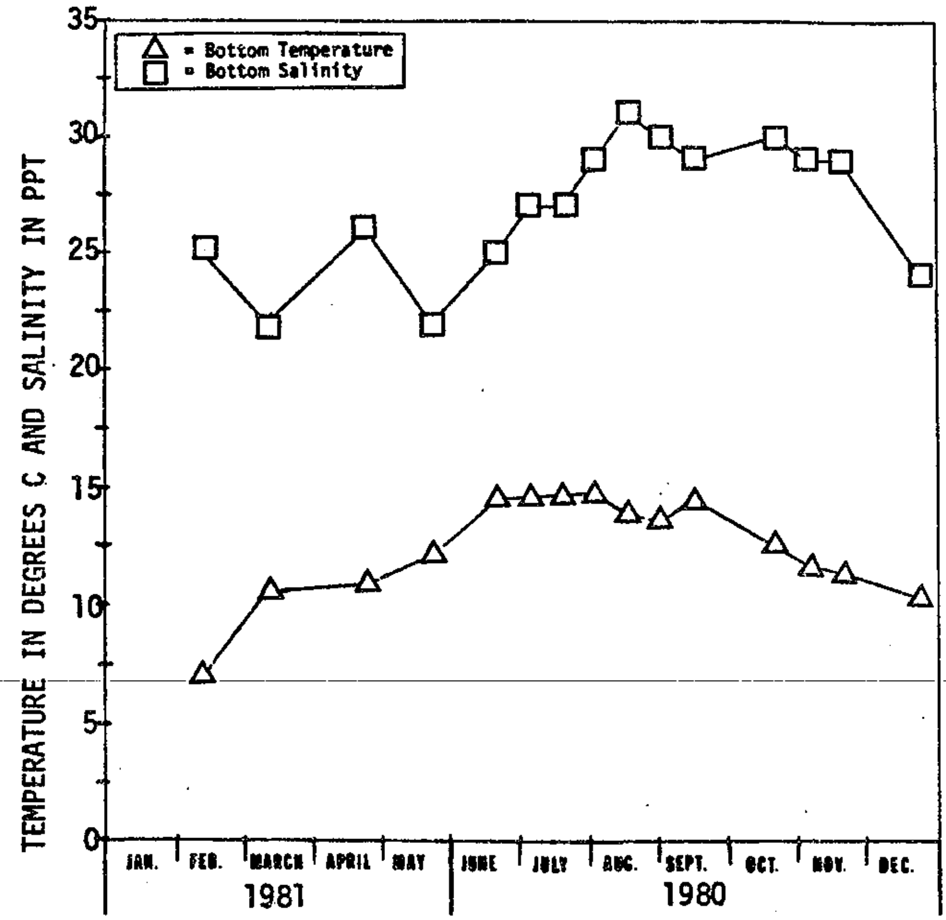


Fig. 2.15. Seasonal change in bottom temperature and bottom salinity at South Reach. Years are reversed to present a continuous seasonal progression.

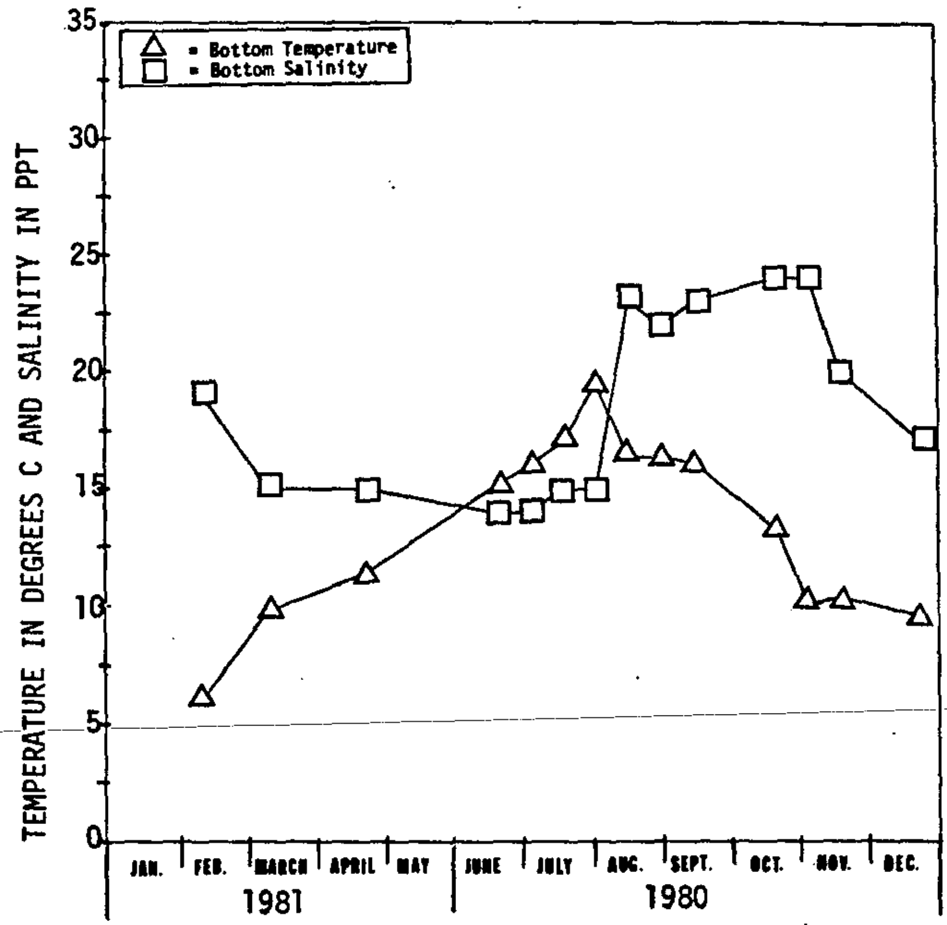


Fig.2.16. Seasonal change in bottom temperature and bottom salinity at Cow Point. Years are reversed to present a continuous seasonal progression.

show that much greater stratification may develop during winter rainfall, with top-to-bottom differences of as much as 14 ppt in the North Channel (Appendix B).

2.3.9 CPUE Regression Analysis: Regression of transformed crab catch per effort data from all regular trawls vs. salinity, temperature, and river flow was not significant for any of the independent variables, nor was there any significance shown when river flow was deleted from the analysis.

Regression of transformed ring net catch data (sites 10-12) vs. salinity, temperature, and river flow provided a significant result. However, the majority of significance was attributable to salinity, whereas temperature and river flow detracted from the result. Therefore, in another run, CPUE of ring net data was regressed against salinity alone, giving the resultant equation:

$$\sqrt{(\text{crabs/net}) + 1} = 0.136(S) + 0.726$$

or,

$$\text{crabs/net} = (0.136(S) + 0.726)^2 - 1.$$

The slope of the regression line was significantly greater than 0 (p less than 0.001) with $r^2 = 0.376$ (Fig. 2.17).

2.4 Discussion

2.4.1 Sources of Error: There is probably a great amount of spatial variability in crab population density within a given area and time in Grays Harbor (or any estuary). [Calculation of annual mean density at any site includes much temporal variation as well.] For some stations,

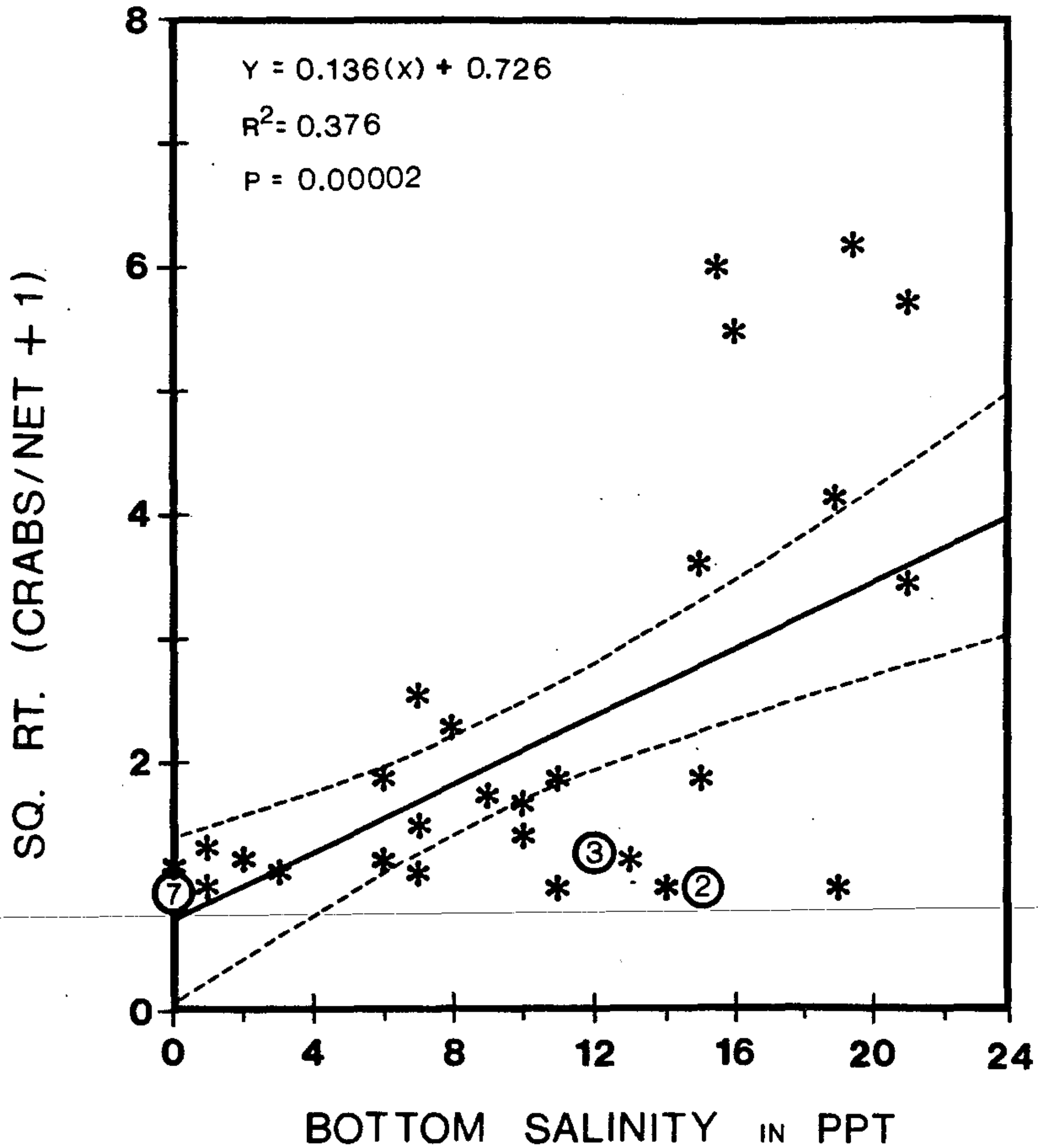


Fig. 2.17 Regression of transformed ring net CPUE on bottom salinity. Data from stations 10,11, and 12. Dashed lines are 95% confidence intervals, circled integers indicate number of overlapping data points.

the standard deviation about the mean annual CPUE was too great to be plotted within the confines of Fig. 2.2. Error may also be introduced during the process of triangulation. Compass bearings taken from a rocking boat were considered good if the accuracy was only ± 2 degrees. Triangulation error, defined as the difference between minimum and maximum estimates of transect length, was usually in the range of 5-20%, but occasionally as much as 50%. Certain stations, e.g., South Channel, gave consistently good estimates, usually with errors less than 5% and often as low as 1-2%.

The final calculated densities (crabs/100 m^2) presented in this report are meant only to be relative. They represent the catchable population under a given set of conditions, e.g., gear type and sampling design. These factors were held as constant as possible and therefore, the data should provide a reasonable estimate of relative crab density. Observations made by SCUBA divers have shown that true crab density may be up to 2.2 times as great as trawl-catchable density (Gotshall 1978). Therefore the trawl-based estimates given in this report represent minimum values.

It is likely that all size groups were not represented equally in the trawl catch. Crabs larger than 135 mm carapace width were scarce in the trawls. This may be the actual situation in Grays Harbor, but it may also be that increased size of crabs is associated with increased ability to outrun the net. However, personal observations made on our net show this to be unlikely, although escapement during net recovery is probably greater for large crabs. Abundances of recruits were very high during early summer of 1980. Although Fig. 2.9 shows that the 0+ age group was caught at the annual mean rate of 1.60 per 100 m^2 in South Bay, the density of this group estimated from individual trawls was as great as 3.7 crabs/100 m^2 (see Fig. 2.11). Tide flat observations (see Section 2.3.4) showed that true densities were much higher in those areas, as much as 5-10 early instars per square meter. Therefore it is likely that, where 0+ age group crabs were caught, the trawl catch may have represented only 1-5% of their true numbers. Crabs of this age group were virtually absent from trawls during the winter. They probably left the immediate vicinity of the sampling stations, but still may have remained within the harbor, as great portions of it were never investigated (most notably the North Bay area) for financial reasons.

The large number of crabs caught at South Jetty on 16 May 1980, may have been the result of podding behavior. This type of aggregative behavior has been documented to occur among juveniles of the King crab, *Paralithodes camschatica*, and is presumably a mechanism to increase protection from predators (Powell and Nickerson 1965). Although there are no published reports of this behavior by *C. magister*, it is a conceivable occurrence, and has been reported to biologists from time to time by SCUBA divers. Density estimates for a given area could be overestimated if they were extrapolated from a pod, i.e., a high concentration of individuals in a very small area. Our encounter may have represented a portion of a pod (1,284 crabs in this particular tow). Wickham et al. (1976) reported the catch of over 56,000 juvenile *C. magister* in a 20-min tow in Bodega Bay, California, with a net similar to ours (these are presumed to have been early instars, as no size range was given). Gotshall (1978) reported trawl catches up to 24,000 crabs per tow in the Pacific Ocean near Humboldt Bay. King crab pods may have 600 to 6,000 individuals (Powell and Nickerson 1965).

2.4.2 Unusual Stations: Analysis of variance showed that the seasonal difference between summer high densities and winter low densities was statistically significant. Regression analysis of ring net samples showed that salinity can account for some of the variance in catch per effort for ring net samples, but not necessarily for trawl samples. According to this evidence, crabs may have been more abundant in samples taken from high salinity areas. In this respect the buoy 13 site was an anomaly. Located between the two most densely populated stations (South Jetty and South Reach) and with relatively high salinity, this site produced very low catches (Fig. 2.2, 2.4). This site is also used as a disposal site for dredged material; studies conducted by the USACE have led to the conclusion that net sediment transport is seaward from the Point Chehalis station (Dave Schuldt, personal communication, 16 October 1981). During periods of channel dredging, barges may dump 500-1500 cubic yards of sediment, 2-5 times daily, at this site. It may be that barge dumping or high current scouring prevents the accumulation of food organisms and, consequently, crabs may not reside in the vicinity of this station but move on to more suitable habitat. However, other uninvestigated factors may also have contributed to low crab abundance at that site.

Ring netting at Cosmopolis occurred primarily in shallow water along shore. Nets could not be operated effectively in the channel center, about 20 m deep. During most of the summer, a salt wedge stabilizes in this area of the channel bottom (USACE 1977). Therefore, crabs may have been present in the channel bottom at times when they were not caught near shore, and may have been more abundant than indicated by nearshore sampling.

2.4.3 Comparison to Other Studies: Tegelberg and Arthur (1977), using primarily ring nets, showed a winter decline in crab abundance at Cow Point. Stevens (1981), using crab pots also detected this winter decline at Cow Point and in the North Channel near our Moon Island site. However, Tegelberg and Arthur detected no seasonal change in abundance at any other site, whereas Stevens showed a very slight decrease in crab pot catches during late summer in the outer harbor. Both of those reports are contradicted by the data presented herein, which show a statistically significant decline in trawl crab catch from summer to winter, over most of the channel length. Crab pots and ring nets may not have fish as consistently as the otter trawl did. Pots and ring nets are both subject to variations in catch due to minor changes in current, and ring nets are especially susceptible to operator error (Stevens 1981). The use of ring nets by Tegelberg and Arthur, and crab pots by Stevens, was probably responsible for the great monthly variability and the failure of these authors to detect strong seasonal changes in crab abundance.

The highest ring net catches reported by Tegelberg and Arthur (1977) occurred near Whitcomb Flats, at the approximate location of our South

Reach station, which produced our highest in-harbor trawl catches as well (exclusive of South Jetty). Tegelberg and Arthur also used a 1.8-m wide beam trawl for several months in early 1975, with total trawl catches at this site ranging from 0 to 27 crabs per 20-min tow. Our tows in the South Reach, while not regularly timed, could cover 500-1,000 m in 20 min, depending upon which boat was used. Tegelberg and Arthur, using a 6.1-m boat probably could have covered 1.0 km in their 20-min tows. This assumption may involve as much as 50-100% error, but is useful for comparison between studies. Converting their catch per tow to a catch per 100 m^2 gives crab densities of 0-1.5 crabs per 100 m^2 (Table 2.8). Our catches in the South Reach were 43-267 crabs per trawl during the same season of the year (in 1980), or 3.1-13.2 crabs per 100 m^2, quite an increase from the findings of Tegelberg and Arthur.

At a site near our Marsh Control site (MC, #10) Tegelberg and Arthur showed that catches by ring net were less than 10 crabs/net (20 min sets) for the period December 1974 - October 1975, with the greatest catch in December 1974 (20 crabs/net). Our annual mean catch of 7.1 crabs/net, with a standard deviation of 9.6, at site MC agrees closely with their data, but instead of being evenly distributed through the year, as shown by Tegelberg and Arthur, our catches were below 4 crabs/net for most of the year, but increased to 10-30 crabs/net during July - October 1980 in concert with general summer increases in crab populations detected by trawl at other stations.

Tegelberg and Arthur (1977) also claimed that the eastern mud flats and sinks lying between the North and South channels were heavily used by

Table 2.8. Comparison of crab catches and density in Grays Harbor, Washington, Humboldt Bay, California, and San Francisco-San Pablo Bay, California.

Bay	Month	Year	Transect Method	Transect Area (m^2)	Crabs/ $100m^2$	Source
San Francisco-San Pablo, California	Summer	1975	Trawl	*1500	0.9	Orcutt et al. (1975)
	May	1977	"	"	2.4	Ibid. (1977)
	June	1977	"	"	3.4	"
	Sept.	1977	"	"	1.7	"
	Sept.	1978	"	"	0.13	" (1978)
Humboldt Bay,	Aug.	1967	Trawl	2400	3.0	Gotshall (1978)
	April	1968	"	"	1.4	"
(Trawl)	Aug.	1968	"	"	12.8	"
	Oct.	1968	"	"	9.3	"
	Aug.	1967	SCUBA	140.3	5.2	"
	April	1968	"	"	0.0	"
	Aug.	1968	"	"	44.8	"
	Oct.	1968	"	"	2.8	"
Grays Harbor, Washington						
S. Reach		1975	Trawl	*1800	0-1.5	Tegelberg & Arthur (1977)
E. Flats		1975	"	*900	1.8	"
Grays Harbor,						
S. Reach	Dec.	1980	Trawl	1368	3.1	This report
	May	1981	"	2016	13.2	"
S. Channel	(Mean)	1980-81	"	Varied	1.2	"
Pacific Ocean, near Humboldt Bay	Oct.	1968	Trawl	**6667	0-94	Gotshall (1978)
	Nov.	1968	"	"	0-360	"

*Distance estimated as 50 m per min.

**Distance given. Area estimated as distance x trawl width, with the latter estimated as 2/3 headrope length.

small crabs, citing an average catch of 10.4 crabs/net for the period December 1974 - October 1975. This is also very similar to our Marsh Control site data, so it seems very likely that these eastern flats and sinks would show marked seasonal trends in abundance, as shown for the South Channel ring net sites in this report. Tegelberg and Arthur also used a beam trawl on these eastern mud flats, catching 83 crabs in five tows of 10 min duration each. Using the same assumptions as before concerning distance towed, these data represent a crab catch rate of about 1.84 crabs/100 m^2 (Table 2.8). This value is very close to the annual mean CPUE presented herein for the South Channel, Moon Island and Cow Point sites (Fig 2.2), but could not be considered as heavy usage compared to the outer harbor. It is most likely that use of these flats is extremely seasonal, like the South Channel ring net sites, being very high in summer and very low in winter.

Orcutt et al. (1975, 1976, 1977, 1978), employing a net of the same dimensions as ours, reported catches of <u>C. magister</u> in units of crabs/min of a 10-min tow. Assuming a 500-m transect (as above) and a net width of 3.0 m, then 150 m^2 were covered per minute of towing. At this rate, a catch of 1 crab/min equals approximately 0.67 crabs/100 m^2. Conversion of data from San Francisco-San Pablo Bay gives crab catches of 1.3 (1975), 2.5-5.0 (1977) and 0.2 crabs/100 m^2 (1978, Table 2.8). These values are within the range, but slightly lower than, values reported herein for outer Grays Harbor in 1980. However, the differences could be due to yearly or geographic variation as well as conversion errors.

Gotshall (1978), using an otter trawl with the same mouth diameter as ours, made monthly trawls over several measured 0.8-km transects in Humboldt Bay. Of 106 tows made during 1966-1969, the mean catch was 214 crabs/tow. Calculating the trawled area as 800 m x 3.0 m gives a trawl effort of 2,400 m^2, and an annual mean crab density of 8.9 crabs/100 m^2, a relatively high figure compared to Grays Harbor. Highest catches of crabs occurred during January during each year of that study, reaching 1,178 crabs/tow (49.1 crabs/100 m^2) in January, 1967, of which 73% were in the 0+ age group. Observation of underwater transects by SCUBA divers produced results contradicting the trawls--crabs were most abundant during August-September (as in Grays Harbor trawls), with observed densities averaging 10.8 crabs/100 m^2 for the periods August-September 1967, plus March-September 1968. Since the SCUBA and trawl transects made by Gotshall were measured they are more accurate than data presented by Orcutt et al. (1975-1978) or by Tegelberg and Arthur (1977), and therefore, more easily comparable to our results. Gotshall also made some 0.8-km trawls in the ocean near Humboldt Bay, using a net with a 12.5-m headrope. Calculating the trawl width as 2/3 of headrope length (a standard conversion, similar to our net) gives an estimated trawl width of 8.33 m and an estimated effort of 6,667 m^2 (Table 2.8). Catches of crabs in the ocean varied greatly, from 0 to 94 crabs/100 m^2 in October 1968, and 0 to 360 crabs/100 m^2 in November 1968. The mean catch of 0+ age crabs in November 1968 was 8.0 per 100 m^2 (range 0-640 crabs/100 m^2).

2.4.4 Habitat Preferences and Estuarine Life Cycle of *C. magister*: Megalopae were first encountered in Grays Harbor during April 1980. Experimental sampling with a 505-μm plankton net showed that megalopae were present at the South Bay site in densities as great as 191/1,000 m^3 (17 April) and 810/1,000 m^3 (22 April). These are at the low end of the range of densities encountered offshore of Oregon by Lough (1975) in 1970-71 (100-8000/1000 m^3).

Plankton tows made by the Fisheries Research Institute (FRI) (Simenstad et al. 1981) showed that C. magister were present in samples taken on 1 and 15 April 1980, in the Elk River channel, at Moon Island, and at the South Channel site, where they dominated the biomass of neritic zooplankton. During this period, we observed swarms of several thousand larvae swimming around the Westport marina, occupying a water volume of about 0.5 m depth by 10 m long by 2.0 m wide, with individuals spaced several centimeters apart. In contrast, during four years of intensive surveys, no megalopae were found inside the San Francisco-San Pablo Bay complex by the California Dep. Fish and Game (1981). It is likely that many megalopae metamorphosed to postlarvae within Grays Harbor during April 1980, as second instars were found in the first trawls made on 4 May 1980. By the second sampling period, 16 May 1980, first, second, and third instar animals were present (Appendix A). This appearance date is slightly earlier than the first appearance of postlarvae in San Pablo Bay during the years 1975-1978, which occurred in mid-May. The difference in timing could be due to geographic and/or yearly differences in oceanographic conditions.

Once settled in Grays Harbor, C. magister appears to undergo an ontogenetic change in habitat selection, i.e., centers of abundance change as crabs age. The highest densities of early instars were recorded in the South Bay in a channel draining extensive mud flats with eelgrass (Zostera marina) beds. Examination of the mud flats showed these crab stages to be abundantly distributed on and in the mud at low tide. Experimental trawls in 1.0 m of water over the mud flats produced higher catches of this year class than of any other. Therefore, eelgrass beds may be the preferred habitat of the first postlarval stages. Butler (1956) also found that the most abundant concentrations of early instars along the northern shore of Graham Island, Canada, were associated with the presence of Zostera in sheltered inlets.

Crabs in the 1+ age group, size range 50-90 mm, were the most abundant and most widely distributed group, although gear selectivity may have increased their proportion in the trawls somewhat. They appear to have developed the necessary osmoregulatory capability to survive in the salinities present as far upriver as Cow Point, and even Cosmopolis. By the time these animals reach the 2+ age group they are sexually mature (Poole 1967) and were abundant only in the outer harbor stations (1, 3, 4, 6 and 7). Many crabs probably migrate out of the harbor at this stage of life. This hypothesis is supported by 1) the low density of age 3+ crabs at stations east of South Reach, and 2) the total absence of gravid females from trawls taken in the harbor, although many trawls were made during the spawning season (October-January). Apparently, most mature females leave the harbor to spawn. According to Lough (1975), extrapolation from data of Reed (1969) indicates that early zoeae (20 days) could survive reasonably well (80%) in salinities and temperatures similar to those encountered in outer Grays Harbor (6.5-17.5°C, 21.5-35 ppt). Salinity and temperature tolerances of the developing eggs are unknown, but could be so sensitive that eggs may not survive inside Grays Harbor. This condition might motivate mature females to seek water offshore with the proper salinity and temperature combination to allow higher egg survival.

2.4.5 Growth Rates: During the first year of postlarval life, juvenile crabs have a very high relative growth rate. A first instar male (7 mm) of 0.02 g dry weight increases its dry biomass 210 times by the time it reaches the 6th or 7th instar (45 mm) weighing 4.2 g, one year later. Some reach 70 mm by this time, weighing 14.7 g, an increase of over 700-fold. Most of this growth takes place during the period May-October, and very little from then until the following spring. During its second year this crab may double in width, from 45 to 90 mm, and increase its dry biomass 7.15 times, from 4.2 to 30.0 g. During its third year, an increase from 90 to 130 mm represents a dry biomass increase of only 2.84 times. Calculation of dry biomass does not include the number of exuvia which are cast off during molting, which may occur 6-7 times during the first year. A vast amount of assimilated energy is lost by this route, perhaps 50% of the body mass at each molt for tanner crabs, Chionocetes bairdii (David Armstrong, unpublished data).

In contrast, Orcutt et al. (1975) stated that juvenile crabs spend only one year in San Pablo Bay, and that the growth rate in the harbor appeared to be twice that of ocean-caught crabs, such that bay animals may reach 100 mm by the end of their first year. High densities of C.

magister were present in San Pablo Bay in December 1977, but were very reduced by May 1978, suggesting that outmigration had occurred. It may be that, as in Grays Harbor, 0+ age group crabs are very scarce during winter, possibly moving into shallow extremities of the bay, or even out of the harbor. This would leave only older crabs in the channel by early spring, producing a single frequency mode near 100 mm, identical to the 1+ age group in Figs. 2.12, and 3.4D. Perhaps this mode was mistaken for the 0+ age group. Nevertheless, crab growth rates in estuaries could be higher than offshore. No reliable offshore data is available for comparison.

In water surrounding the Queen Charlotte Islands, Canada, C. magister hatching occurs in April, and metamorphosis in September, five months later than in Washington (Butler 1961). Postlarvae grow very slowly through the winter, and are only 20-25 mm carapace width by the following June. However, they grow very rapidly during the summer, reaching 45-60 mm (with spines, 42-56 mm without) by the end of the first year after metamorphosis. Slow growth in winter and rapid summer growth is repeated during their second year, at the end of which many crabs reach 120 mm. Canadian biologists include spines in their measurements, and conversion to spineless width (Weymouth and Mackay 1936) provides a more comparative 112 mm. Thus, even though Hecate Strait crabs hatch later and grow slower through their first 6-9 months than do Grays Harbor crabs, their accumulated growth after two years is very similar to Grays Harbor crabs. However, Butler's evidence is taken from small numbers of individuals captured during several trawls made each summer between 1950 and 1956, and is therefore somewhat hard to interpret, especially for crabs in their first 18 months.

2.5 Summary

1) An otter trawl net was used to collect specimens of *C. magister* from nine sites in Grays Harbor on a biweekly or monthly basis during the period May 1980 to July 1981. Two-hundred and fourteen tows were completed. Ring nets were used to sample three additional sites in which trawls were not usable.

2) Mean crab catch per effort over the 14 month sampling period ranged from 7.56 crab/100 m^2 at South Reach to 1.19 crabs/100 m^2 at South Channel, generally decreasing with increasing distance upriver from the harbor mouth, and decreasing salinity.

3) Crab catch per effort was high but fluctuated during summer 1980, decreased through the winter, then increased again in spring-summer of 1981. Ring net catches at upriver sites were low most of the year but increased dramatically during July-October 1980.

4) Analysis of variance showed that the mean catch per effort at three stations representing the outer harbor (5.10 crabs/100 m^2) was significantly greater ($P = 0.018$) than the mean of three stations representing the inner harbor (2.98 crab/100 m^2). Also, the mean for these six stations in March-August (4.78 crabs/100 m^2), was significantly greater ($p = 0.002$) than the mean for the period September-February (2.09 crabs/100 m^2).

5) Stepwise multiple regression of catch per effort on Chehalis River flow and bottom water salinity and temperature at low tide showed that only the ring net catches were significantly positively correlated only with bottom salinity. However, between-sample variance was too great to show a significant regression for the monthly trawl data on these factors. The conclusion is that salinity can contribute significantly to variance in crab CPUE data, and the distribution of crabs in the harbor, but other unknown factors are probably involved also.

6) Megalops larvae entered the harbor in April 1980, and began metamorphosis to postlarvae. Instars 1-3 were present by 16 May 1980. In June 1980, recruits comprised 35% of animals caught at South Reach. Animals of the 0+ age group were most abundant on mud flats with eelgrass beds and in nearby channels. Age 1+ crabs were the most abundant group at eight of the nine stations and were distributed throughout the harbor. Age 2+ animals were less abundant than the 1+ agroup, more abundant than the 0+ group, and found progressively closer to the harbor mouth. Age 3+ crabs were the least abundant group in trawl and ring net samples.

7) Crabs in Grays Harbor reached mean widths of 45, 90, and 135 mm at 1, 2 or 3 years after metamorphosis, respectively. Equations are presented for the regression of dry weight on carapace width for crabs from 12-132 mm. Mean increases in dry biomass were 210 times during the first year and 7.1 times during the second.

3.0 DIEL PATTERNS OF CRAB DISTRIBUTION AND ABUNDANCE

Bradley G. Stevens and David A. Armstrong

3.1 Introduction

Other studies have indicated that *Cancer magister* may follow certain cyclic diel behavior patterns. Gotshall (1978) indicated that trawl catches of crabs in Humboldt Bay, California, decreased during daylight, possibly due to increased visual detection of the net. He also found increased catches on outgoing tides, and hypothesized that crabs moved toward the channel centers at those times. In order to determine if *C. magister* in Grays Harbor express similar behavior patterns, a series of diel surveys was designed.

The objectives of this portion of the research program were to:

1) Determine the effects of light level (day vs. night) and tide level (high vs. low) on crab catch-per-unit-effort (as an index of population density changes),
2) determine the effects of season on (1),
3) determine if differences in crab catch-per-unit-effort occur between subtidal and intertidal areas, and how these elevation differences affect (1) and (2),
4) examine the potential for reducing dredge-induced crab mortality by alterations of dredging schedules to reflect diel changes in crab population density.

3.2 Materials and Methods

3.2.1 Location of Sampling Sites: Diel sampling occurred at two sites within Grays Harbor. These were a subtidal dredged channel bottom (site 3, South Reach, "channel") and an intertidal sand-mud flat (site 13, Whitcomb Flats, "flats"). Both were described in section 2.2.6.1 and Table 2.1. These sites were about 1 km apart, but still close enough to be considered adjacent within the context of Grays Harbor. They could be reached by boat within 15-30 min from the Westport marina.

3.2.2 Sampling Method: Crabs and shrimp were collected by trawl as previously described in sections 2.2.1-2.2.3. Lighted gillnet buoys were used to mark transect endpoints at night. During diel period 1, the Boston Whaler was used for daylight tows, and a 7.9-m (26-ft) converted Navy motor launch was used for night tows. The WISHKAH was used for all tows during diel period 2, and the GYPSY GIRL was used for all tows during diel periods 3 and 4.

3.2.3 Sampling Schedule: Channel trawls were made on each of 12 consecutive slack tides over a period of 3 days, for a total of 12 tows representing three replicates of each combination of light (day or night) and tide level (high or low; Table 3.1). Tows made at dusk or dawn were treated as night tows. Flats tows were made only at slack high tide over the same 3-day period, as this area was exposed during spring low tides, for a total of six tows representing three replicates of day or night trawls (Table 3.1).

Table 3.1. Tide and light combinations represented by diel survey trawls.

Combination	Number of replicates Channel	Flats	Total
Day, high tide	3	3	6
Day, low tide	3		3
Night, high tide	3	3	6
Night, low tide	3		3
Total	12	6	18

This pattern of trawls was conducted in each of 4 seasons:

Period 1. Summer. 21-24 June 1980.

Period 2. Autumn. 25-28 September 1980.

Period 3. Winter. 16-19 January 1981.

Period 4. Spring. 3-6 April 1981.

Exceptions to this schedule occurred when a net was lost during June 1980, so only 17 of 18 tows were completed. During April 1981, bad weather prevented two of the Whitcomb Flats tows, so 16 of 18 were completed.

3.2.4 Specimen Treatment: Crabs were sexed and measured as described in Section 2.2.5, and returned to the water, or dissected for stomachs (see Section 4.0).

3.2.5 Data Analysis: Catch per unit effort (CPUE), expressed as crabs per 100 m^2, was analyzed by 2-way or 3-way analysis of variance (ANOVA), after being transformed as previously described. Data from channel tows were tested for the effects of day vs. night, and high vs. low tide. All tows made at high tide (including flats tows) were tested for the effects of day vs. night, and flats vs. channel. Five comparisons were made; one for each season, and one for all data (all seasons) combined. The latter test was run as a 3-way ANOVA to include seasonal effects.

3.3 Results

Some patterns of change in crab density were found to be significant. Others showed consistent trends that were significant at probability levels below 95%.

3.3.1 Tide Effects

Mean crab densities (transformed data) from trawls made at low tide were greater than those made at high tide in June, September, and January, but the differences were significant only at probability levels less than 0.125 (Table 3.2). In April, a reversal of this trend occurred, with mean crab densities greater at high tide than at low tide (p=0.034). This reversal caused a significant interaction effect between tide and season (p=0.009, Table 3.3; Fig. 3.1), and may have been related to salinity (*see* Discussion).

3.3.2 Day/Night Effects

Day and night crab densities in the channel were significantly different in January 1981 (p=0.037; Table 3.2), but not in any other season. Also during January, there was a significant interaction between day/night effects and sampling site (p=0.003, Table 3.3). Daytime crab densities were greater in the channel than on the flats, but night trawls revealed greater crab densities on the flats than in the channel (high tide only, Fig 3.2). This type of interaction

Table 3.2 Means and significance levels for important ANOVA comparisons. All means reconverted from transformed data. Standard deviations were not convertable.

Type of Effect	Data group	Season	Prob. level	Factor	Crabs /100m[2]	N	S.N.K. test[1/]
Tide	Channel	June	0.115	Low	15.64	5	
				High	8.51	6	
		Sept	0.103	Low	7.19	6	
				High	3.21	6	
		Jan	0.125	Low	4.43	6	
				High	4.10	6	
		April	0.034	Low	3.77	6	
				High	8.22	6	
Day vs. Nite	Channel	Jan	0.037	Day	5.90	3	
				Nite	3.76	9	
Site	High tide	Jan	0.053	Flats	4.10	6	
				Channel	2.18	6	
		All	0.001	Flats	2.50	22	
				Channel	5.60	24	
Season	Channel	All	0.001	Jan	4.60	12	│
				Sept	4.83	12	│
				April	5.92	12	│
				June	11.14	11	
	High tide	All	0.002	Sept	2.23	12	│
				Jan	3.25	12	│ │
				April	4.64	10	│ │
				June	6.45	12	│

1/ For Student-Neuman-Keuls test, means in ascending order. Brackets indicate means lacking significant differences between them. See Table 3.4 for details.

Table 3.3 Means and significance levels of ANOVA interactive effects.

Type of Effect	Data group	Season	Prob. level	Factor 1/	Crabs /100m²	N
Tide X Season	Channel	All	0.009	(see Tide Effects, Table 3.2)		
Site X Day/night	High tide	Jan	0.003	C/D	5.89	3
				C/N	2.59	3
				F/D	0.64	3
				F/N	4.27	3
		All	0.043	C/D	6.25	12
				C/N	5.03	12
				F/D	1.73	11
				F/N	3.38	12
Site X Season	High tide	All	0.040	June/F	5.06	6
				/C	8.00	6
				Sept/F	1.67	6
				/C	2.86	6
				Jan /F	2.35	6
				/C	4.27	6
				April/F	1.01	6
				/C	8.17	6

1/ Factor Codes: C = Channel, F = Flats, D = Day, N = Night.

Table 3.4 Computations for Student-Neuman-Keuls test. See Table 3.2 for results.

Data Group	d.f. 1/	Resid. M.S.	N	$S_{\bar{X}}$	A 2/	Q 3/	D 4/
Season Effects, Channel	32	0.469	12	0.198	4	3.83	0.758
					3	3.47	0.687
					2	2.88	0.570
Season Effects, High tide	30	0.304	12	0.159	4	3.84	0.611
					3	3.48	0.553
					2	2.89	0.460

1/ Degrees of freedom for residual mean square (M.S.) are less than 44 due to presence of other effects, including interaction.

2/ A = number of means across which comparison was made.

3/ Q interpolated from Table A-15, Snedecor and Cochran (1967), for p = 0.05.

4/ D = least difference between means required for significance at p=0.05.

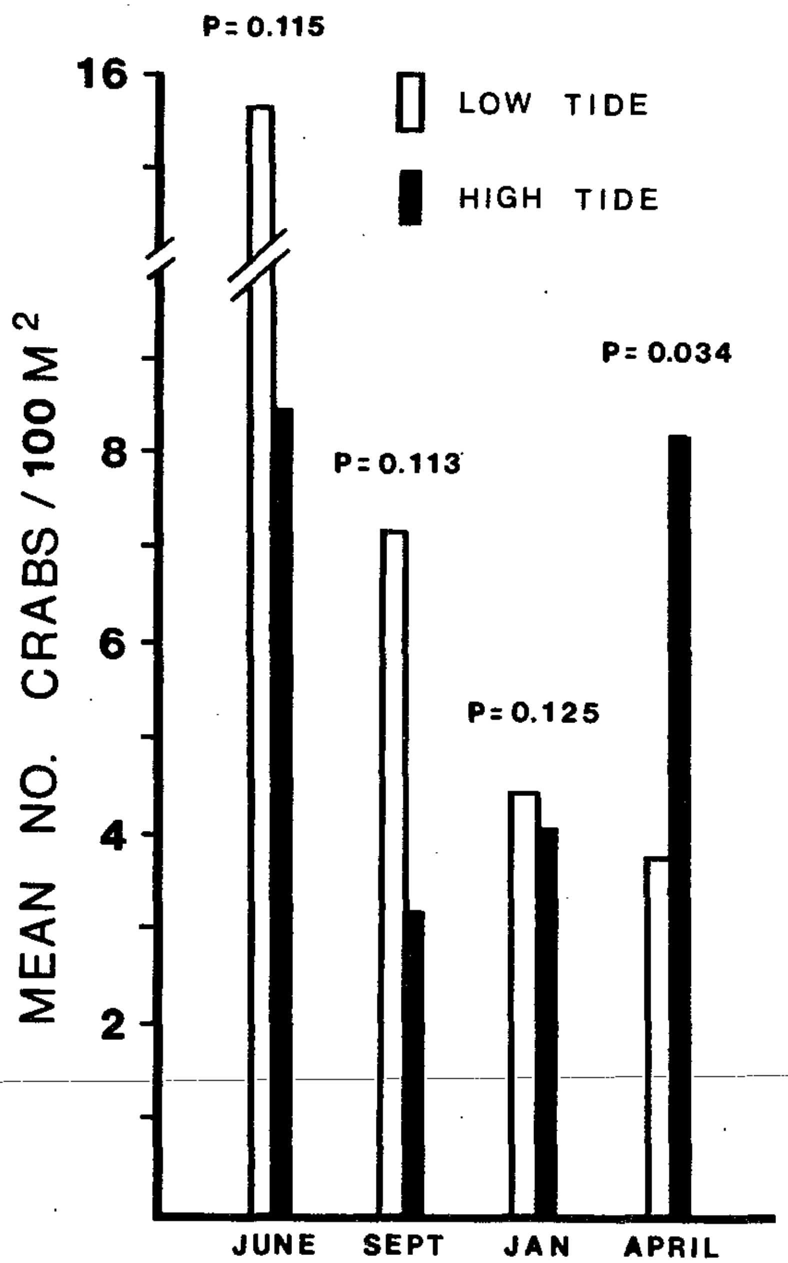


Fig. 3.1 Mean crab densities during channel tows showing interaction between tide level and season. All values are means of 6 tows except June low tide (N = 5). Probability of F-value for interaction = 0.009. Probabilities for paired comparisons (low vs. high tide) within each season shown above bars.

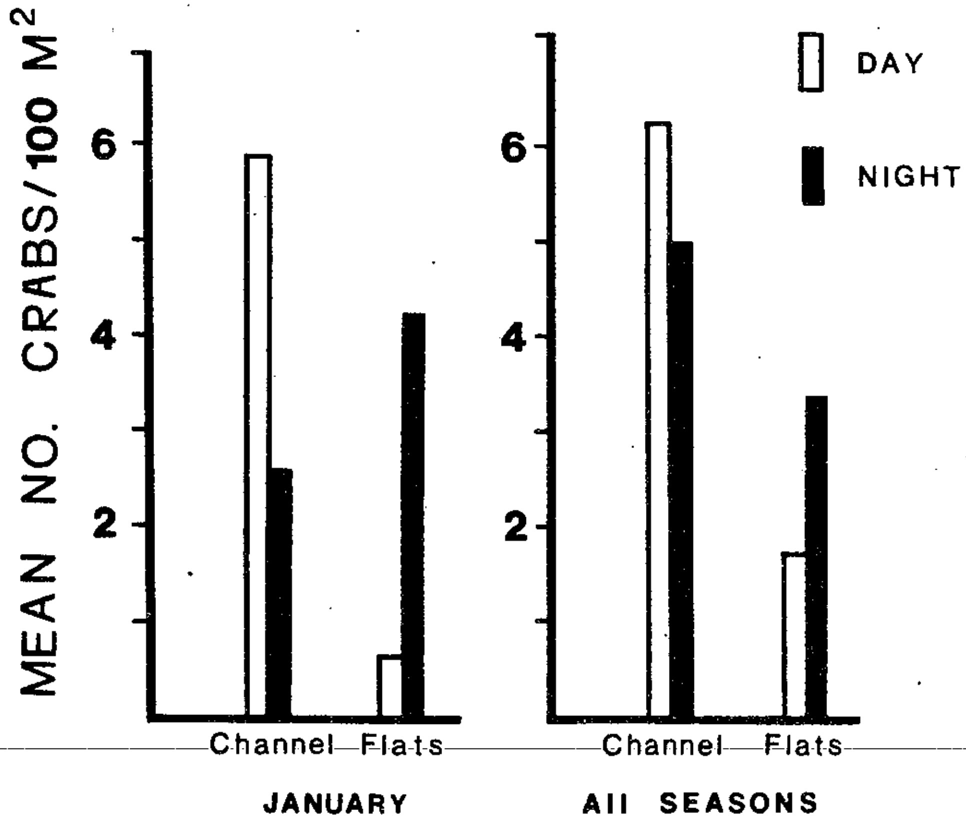


Fig. 3.2 Mean crab densities during high tide tows, showing interaction between site (channel vs flats) and day/night. Values for January are means of 3 tows; values for all seasons combined are means of 12 tows. Probabilities of F-value for interaction are p = 0.003 for January, p = 0.043 for all seasons combined.

was also significant in the 3-way ANOVA, when all seasons were included (p=0.043). A hypothesis is presented in the discussion.

3.3.3 Site Effects: Considering only high tide tows, crab density was significantly greater in the channel than on the flats at p=0.053 for January, and at p=0.001 when all seasons were included (Table 3.2).

3.3.4 Seasonal Effects: Seasonal mean crab densities were significantly different among channel tows (p=0.001) as well as for high tide tows (p=0.002; Table 3.2) Means were compared by a Student-Neuman-Keuls test for significant differences (Table 3.4). Results showed that mean channel crab densities for September, January, and April were not significantly different, but mean June crab density in the channel was significantly greater than all other seasons (p=0.05; Table 3.2, 3.4). High crab densities in June can be partly attributed to the abundance of 0+ age group crabs which had recently entered the harbor. Catch densities for this group were 5.7 to 20.0 crabs/100 m^2 in 6 of the 12 June channel tows, whereas the greatest catch density for this age group in any other season at this site was only 1.1 crabs/100 m^2.

Comparison of mean crab densities from high tide tows showed that the following pairs of seasonal means were not significantly different (p=0.05): September and January (least density), January and April (higher), and April and June (greatest density; Table 3.2).

A significant interaction occurred between season and site effects in the 3-way ANOVA (p=0.040). In June, September, and January, the ratio of flats to channel mean crab density values was about 0.80, whereas in April, this ratio was only 0.44, i.e., as crab density in the channel increased during spring 1981, crab density on the flats continued to decline (Fig. 3.3).

3.3.5 Population Structure: As described in section 2.2.7, size limits for age groups were selected by probit analysis and examination of width frequency diagrams.

3.3.5.1 Size Distribution by Season: In June 1980, all size classes were abundant, with recruits comprising 35%, and 1-year-old animals 44% of the total crabs collected (Figs. 3.4 and 3.5A). Catches during all other diel periods were almost totally composed of 1-year-old crabs. Two-year-olds composed 23% of the catch in June 1980, but a declining portion thereafter. Three-year-olds were distinguishable only during June 1980. The average width of 0-, 1-, and 2-year-old crabs increased from 19 to 40 mm, 51 to 73 mm, and 105 to 117 mm, respectively, during June to September 1980 (Fig. 3.6). Thereafter, 0-year crabs showed no increase in width until April, while 1- and 2-year-old crabs continued to grow throughout the remainder of the study.

3.3.5.2 Size Distribution by Site: Very slight differences in age structure of crab populations were apparent between the channel and flats sites. Over all 4 diel periods, proportions of 1-, 2- and 3-year old crabs were virtually identical (Fig. 3.5B). The only difference was in the abundance of 0-year animals, which composed 12.8% of the

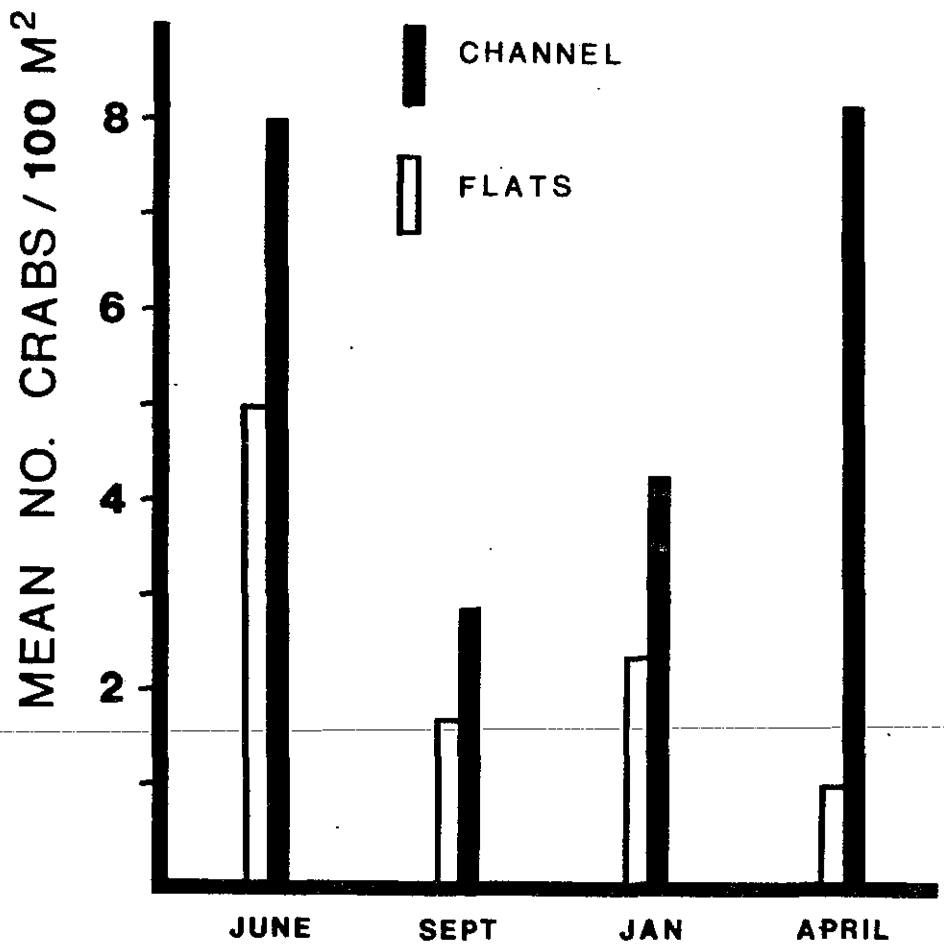


Fig. 3.3 Mean crab densities during high tide tows showing interaction between season and sampling sites. All values are means of 6 tows. Probability of F-value for interaction = 0.040.

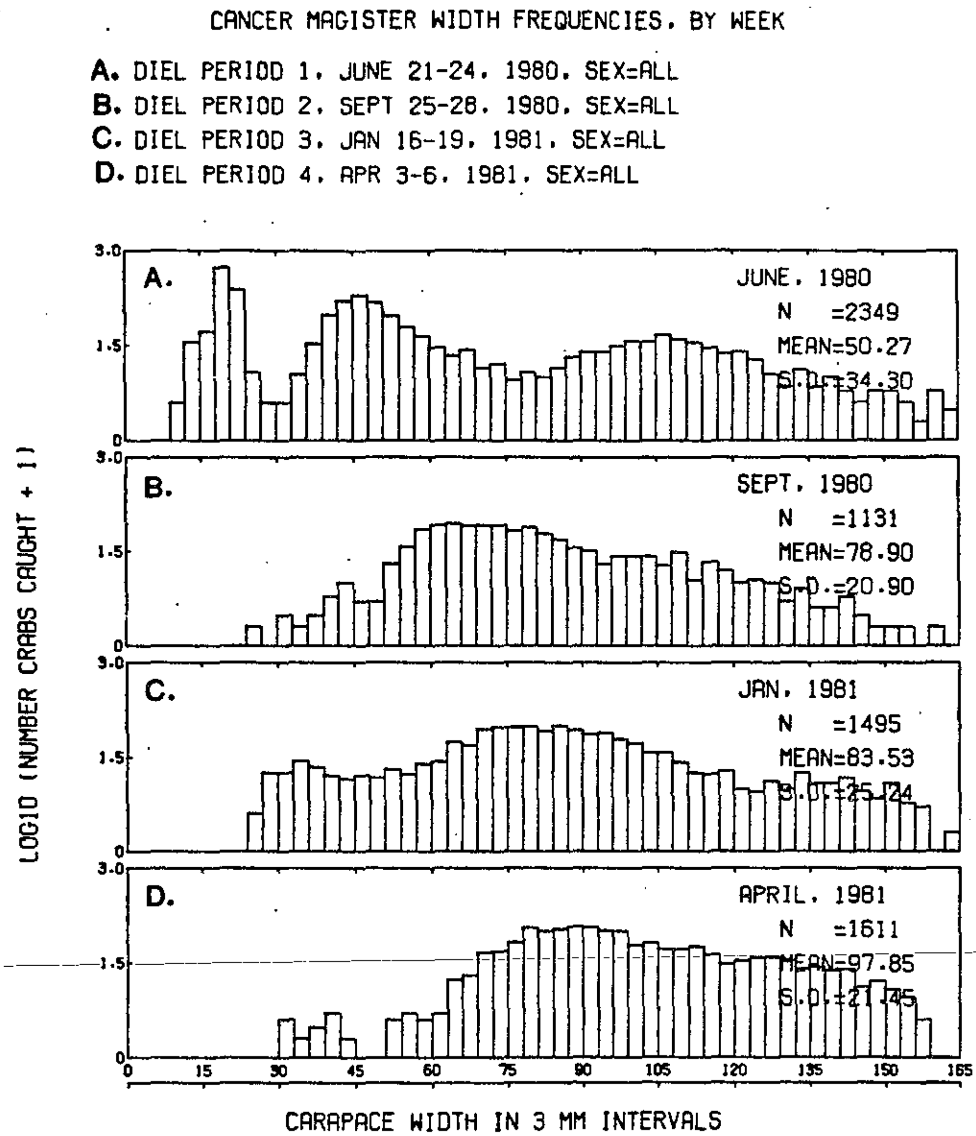


Fig. 3.4. Frequency distribution of all crabs caught during diel sampling periods 1-4: A. June, 1980; B. September, 1980; C. January, 1981; and D. April, 1981.

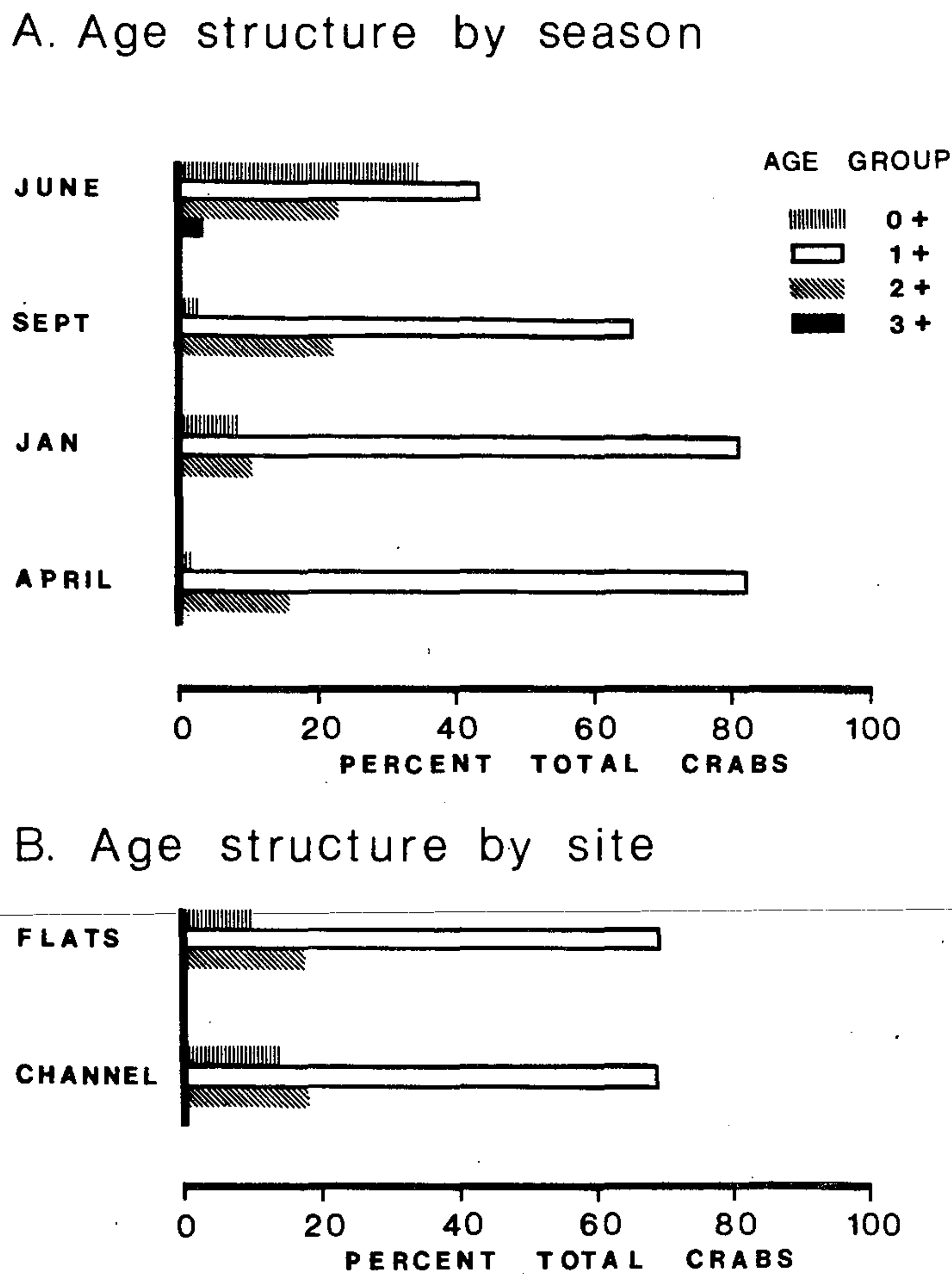


Fig. 3.5 Age structure of crab populations during diel sampling at South Reach and Whitcomb Flats: A. Age structure by season; B. Age structure by site.

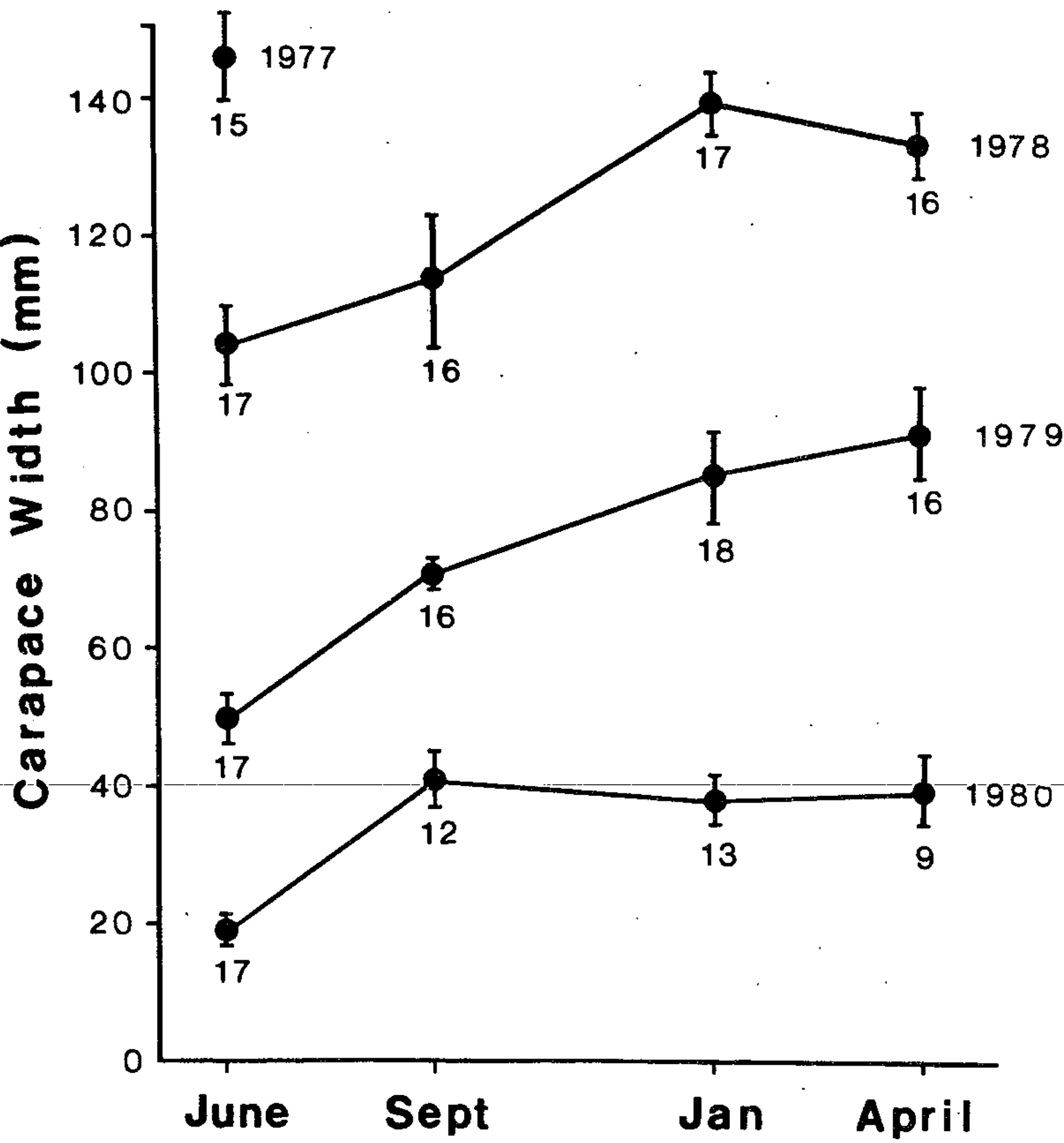


Fig. 3.6 Growth of crabs at diel sampling sites. Points are averages of mean widths for multiple tows, N shown below each point. Vertical bars are ± 1.0 standard deviation.

channel catches, but only 9.4% of crabs caught on the flats, i.e., there were about 27% fewer recruits on the sand flats than in the channel.

3.4 Discussion

3.4.1 Tide and Salinity Effects: There was a trend toward greater catches on low tides during the summer and autumn of 1980. This trend was statistically significant if a probability level of 0.125 was used. Given the great amount of daily variation between replicate tows made under similar conditions, a significance level greater than 0.05 may indicate biological importance for this phenomenon. This information supports the hypothesis of Gotshall (1978b) that crabs move down from intertidal areas into deeper channels during receding tides. However, this funneling effect may or may not result in increased catches of crabs by trawl, depending on other aspects of crab behavior such as burial.

In April 1981, the trend toward greater crab densities at low tide was reversed. This reversal may have been a consequence of lower bottom salinities encountered at low tide in that season (two readings were 11 and 16 ppt) than in all other seasons (minimum of 22-24 ppt). There is the possibility that our water sampler was not on bottom when triggered to close, as salinities of 11 and 16 ppt were extremely unusual for the South Reach site, but all measurements were made during a period of very high rainfall and river flow. If assumed to be accurate, then these low salinities at low tide might have stimulated self-burial by crab or movement away from the sampling site, toward the harbor mouth.

3.4.2 Light and Site Effects: Generally, crabs were less abundant on the flats than in the channel, probably because only a limited number of crabs could venture onto the flats and off again during the time that site was covered by water (6-9 hr per tide cycle). During the winter, however, channel densities were significantly greater during daylight than at night, but crab catches on the flats showed just the opposite trend, for greater catches at night than in daylight. Three hypotheses can be found to explain this phenomenon:

1. Visible detection of the net may play no role in escapement. Crab movements from channel to flats at night account for reduced daytime catches in the channel and increased night catches on the flats.

2. Light level plays no role in triggering crab movements. However, visibility in the channel bottom may be so poor as to prevent crabs from visibly detecting the net or escaping it, whereas visibility at high tide on the flats is very good (personal observation), thus leading to increased daytime escapement.

3. Combination of hypotheses 1 and 2. Poor visibility in the channel would not account for decreased catches there at night whereas nightly foraging movements would. Gotshall (1978b) estimated escapement at about 50% for daylight tows, from diver observations and day/night trawls. Our day:night catch ratio on the flats was 1:8 vs 1:2 of Gotshall. Therefore, a true difference in day/night abundance is indicated, and escapement may further

exaggerate this difference in the shallow clear water over Whitcomb Flats.

Preference of crabs for nighttime foraging could be due to either the nocturnal presence of certain food organisms (see Section 4.0 for discussion of feeding), or as a mechanism to avoid predation in shallow, clear water. Caillouet et al. (1968, 1970) found that increased catches of *Penaeus setiferus* and *P. aztecus* were associated with reduced water temperatures present during incoming or high tides and storm squalls. No temperature effect was found in our study.

3.4.3 Relevance to Dredging Activities: Darkness did not appear to reduce escapement of crabs from the trawl in the channel bottom, but may actually have induced crabs to leave the channels on foraging movements, especially during high tides. Therefore, if crab population densities in channel bottoms decrease during darkness and high tides, entrainment of crabs by dredges during those periods should also decrease. Similarly, return of crabs to channel bottoms during low tides would tend to increase their densities there, and subsequent entrainment by dredges as well.

One question that remains to be answered is that of crab burial. The exact conditions which stimulate burial are not known, but might be related to environmental change. Buried crabs would probably be entrained more easily than active crabs, but there is presently no method to predict burial behavior adequately.

3.5 Summary

1. Crabs were collected with an otter trawl during 12 consecutive slack tides, day and night, at two adjacent sites, a subtidal, dredged channel bottom and an intertidal sand-mud flat. This survey was conducted in June and September 1980, and in January and April 1981. Analyses of variance were performed on CPUE data.

2. During summer and autumn, there was a non-significant trend toward greater catches at low tide than at high tide, probably due to a funneling effect as crabs moved into the channels with the receding tide.

3. During April 1981, catches were reduced during low tides. Crabs may have buried themselves or left the area as a result of reduced low tide salinities resulting from heavy rainfall and high river flow in this season.

4. In January 1981, catches in the channel were significantly greater during daylight than at night, whereas the reverse situation occurred on the flats with greater catches there at night than in daylight. This may imply that foraging movements by crabs into intertidal areas were more likely to occur at night.

5. Annual mean crab density (four seasons averaged) was significantly greater in the channel than on the flats.

6. Crab population structure varied very little between the two sites. In summer, the population at both sites was more evenly divided among age groups, with recruits comprising a large proportion (35%). During the rest of the year, the population consisted primarily of one-year-old crabs.

7. Funneling of crabs into channels during low tides and reduced probability of making foraging trips during daylight could cause increased entrainment of crabs by dredges during the combination of daylight and low tides. Reduced salinities during periods of high river flow could further concentrate crabs into channels and induce burial behavior, both of which might result in further increases in crab entrainment by dredges.

4.0 FOOD HABITS AND PREY OF *CANCER MAGISTER*

Bradley G. Stevens, David A. Armstrong, and Robert Cusimano

4.1 Introduction

Analyses of gut contents represent an important component of general biological and life history studies for any animal species. Information on the variety and dominance of food and prey items, changes in feeding habits between life history stages and seasons, nutritional value of prey, gut clearance rates, and general energetic requirements of the predator species in question help to define trophic and community interactions and dependences.

In the case of Dungeness crab in Grays Harbor, the proposed Widening and Deepening project might impact crab populations in a variety of ways other than entrainment by dredges. One such impact could result from removal and long-term suppression of epibenthic and infaunal prey species used by *C. magister* during early growth in the estuary. Kaplan et al (1975) documented severe reductions in standing crop, population size, and species diversity of infaunal organisms after dredging operations around Long Island Sound. They reported that dry weight standing crop had recovered to only 3%-20% of pre-dredging values at most stations eleven months after the perturbation. Swartz et al.(1980) found an 80% reduction in density of invertebrates following dredging in Yaquina Bay, Oregon. They noted that initial indications of recovery were reversed after a second dredging, and once left undisturbed, the site required a full year for recovery. Grays Harbor widening and deepening projects will reduce infaunal food at the bottom and on the sides of the channel and will alter present communities along the channel as it is widened laterally. In a situation analogous to that reported by Swartz et al (1980), annual maintenance dredging will continue to disturb benthic communities. Questions that cannot be answered here, but perhaps addressed in a future synthesis of information from several projects, are what portion of preferred feeding grounds and resident infaunal prey of Dungeness crab will widening and deepening eliminate or reduce, and how the magnitude of impacts to food will curtail crab populations in the bay.

Feeding habits of Dungeness crab have been previously studied by qualitative observation of crab foraging behavior and actual gut analyses. MacKay (1942) reported that, in order of frequency of occurrence, crabs of unspecified size ate crustacea, molluscs, worms, and seaweeds. Butler (1954) examined 170 stomachs of large crabs from populations around the Queen Charlotte Islands and found more than 89% of animals consumed crustaceans, amphipods and mysids being most common. Molluscs were also important but fish had a very low frequency of occurrence. Tegelberg (1972) quantified frequency of prey items from stomachs of C. magister greater than 110 mm caught in Willapa Bay and offshore. While empty stomachs comprised 20%-60% of the samples, in those stomachs containing food small clams were most frequently consumed (50%-96%) followed by crustacea (25%-58%). Feder and Paul (1980) compared the contents of stomachs from large and small (<50 mm) specimens of C. magister in Cook Inlet, Alaska. Animals greater than 50 mm carapace width preyed primarily on small bivalves (67% of stomachs), barnacles (11%) and amphipods (6%). Bivalves were largely represented by Spisula polynyma and were young-of-the-year or just one year old. Dungeness crabs between 22-45 mm width contained predominately foraminifera (36%), polychaetes (28%), barnacles (28%), and small clams (25%). Gotshall (1977) examined over 200 stomachs of crabs 67-200 mm in width from the Eureka, California, area. He concluded that

C. magister is an opportunistic feeder, most frequently consuming clams (35%), fish (24%), isopods (17%), amphipods (16%), and razor clams (11%). Sampling along a depth transect he found changes in prey composition from an abundance of fish in stomachs collected in shallow waters (to 18 meters), to polychaetes and clams in deep waters (to 90 m). Bernard (1979) examined stomachs of commercial crabs from Hecate Straits, British Columbia, and reported that clams (primarily razor clams) and crustacea (the shrimp Crangon alaskensis) were the most important prey items; crabs less than 40 mm width fed almost exclusively on mollusca. Bernard's data show an increase in gut fullness in late afternoon, suggesting a diel pattern to foraging.

Cannibalism has been reported several times (Butler 1954; Tegelberg 1972; Gotshall 1977; D. Wickham, Bodega Marine Lab, pers. comm.). Frequency of occurrence have ranged from 7% (Gotshall 1977), to 50% (Tegelberg 1972). Such high levels of cannibalism have led some authors to suggest that intense intra-specific competition and predation between young and older year classes might, in part, account for cycles of abundance in the fishery (Botsford and Wickham 1978; see Section 1.3.5).

Generally, there has been little attention given to feeding habits of bay crabs, diel changes in foraging activity, and comparisions between large samples of distinctly different size categories. These points are included in the objectives of this section, which were:

1) Identify the prey species most commonly consumed by C. magister in Grays Harbor. These were several species of fish, crustaceans (especially Crangon spp) and small bivalves.

2) Determine if different prey species were consumed by crabs from different areas of the harbor. Inner harbor crabs consumed fewer bivalves but more crustaceans, especially barnacles.
3) Investigate the diel periodicity of feeding habits. We found that consumption of Crangon spp. increased dramatically at night on Whitcomb flats, displacing other species from the diet. There was little change in stomach fullness through a diel cycle.
4) Determine if differences existed in selection of prey species by various age groups of crabs. Bivalves were the most important prey of young crabs, but declined in importance as crustaceans, then fish, became important for older crabs.

4.2 Materials and Methods

4.2.1 Sample Collection: Most stomachs were removed from 341 crabs collected during diel trawling in June and September 1980, and January and April 1981. During those periods, stomachs were removed from crabs collected on each of four successive slack tides at the subtidal site (South Reach Channel) and each of two successive high slack tides at Whitcomb flats (intertidal). Crabs were available from day, night, and high and low tide periods. From each trawl, 5 or 6 crabs were selected within each of the width groups 0-60, 60-100, and >100 mm carapace width, for a total of 10-18 crabs per trawl. Often crabs in the smallest width group were not available.

Additional stomachs were taken from 69 crabs collected from sites 7 and 8 (Buoy 30 and Moon Island) during April and May 1981, and from Moon Island and South Bay during July 1981 (Table 4.1).

Crabs were measured and sexed, and stomachs removed as soon as possible after return to the dock. During diel sampling, many crabs remained in the net or a bucket for ½-2 hours before stomach removal, to allow completion of other sampling requirements. Upon removal, stomachs were placed in buffered 10% formalin-seawater in separate vials with labels. Specimens were later taken to the School of Fisheries, University of Washington, and after at least a week in formalin, were transferred to 50% isopropanol.

4.2.2 Stomach Examination Procedure: Stomachs were cut open and contents emptied into glass petri dishes for examination under a 10-70 power dissecting microscope. Contents were usually extremely shredded by the crab masticating process, requiring careful identification procedures.

Contents were identified to the lowest taxon possible, sorted into piles of individual prey species, and counted if possible. Visual estimates were made of the percent volume represented by each prey item. Comments about methods for particular prey categories follow.

Fish remains were most often noted by the presence of bones with attached flesh. However, species identifications were made by comparison of scales from within stomachs to a reference collection of scales removed from Grays Harbor fish species. Counts of greater than one fish per stomach were based on the presence of multiple heads or eye lenses.

Clam remains were usually very fragmented and identification was based on the umbo portions if present, which were also used for counts. Occasionally a large amount of clam parts would yield only one umbo, but was coded as 2 clams to indicate the examiners opinion that more than one individual was present. Counts are probably least accurate for this group.

Crustacean parts were usually readily identifiable to genus or species. Counts were single unless multiple parts (eyes, heads, chelae) were recovered.

Additional species which were apparently ingested inadvertently along with a prey item were not coded as crab stomach contents. These species included clams and copepods found inside fish guts within a crab stomach, and nematodes in association with fish remains. Sand was noted only if it exceeded 20% of the volume of a stomach contents.

When hard or heavy items such as bones, clamshells, or sand were found in association with wet tissue, the visual estimates of % volume for soft tissues were adjusted downward to reflect the probable % weight loss of each item after drying, when soft tissues would have only 10-25% of their wet volume. Fish flesh was thus estimated at 10% of its apparent volume, whereas crustacean parts were estimated at 25% of their apparent volume (because of the presence of carapace parts). This was sometimes an arbitrary procedure, but was necessary to avoid under-estimating weights of hard content.

Crabs were not weighed in the field. Therefore, dry weights were estimated by the width/weight regression formulae presented in Section 2.3.6. After examination, total stomach contents were dried to constant weight at 65^{o}C. Weights of individual prey items were calculated from estimates of % volume. This procedure was necessary because of the impracticality of sorting out all fragments of each prey species for weighing separately.

4.2.3 Data Analysis: Data were coded onto Fisheries Research Institute form S240.33A, for analysis by program GUTBUGS, a quantitative stomach analysis program developed by Charles Simenstad and Katie Swanson at the Fisheries Research Institute, University of Washington. The program is part of the computer library of Puget Sound MESA, NODC, NOAA, U.S. Dept. of Commerce, and is stored on the CDC 6400 system at the University of Washington.

Coded data for each predator (crab) included identification, numbers, and estimated dry biomass of each prey item. Within each sample (trawl) of 10-20 crabs, or subsample thereof, the program calculated for each prey item its percent frequency of occurrence (F.O. = % of stomachs containing this prey item), percent numerical occurrence (N.O. = % of total number of prey individuals in sample), and percent gravimetric occurrence (G.O. = % of total weight of all stomach contents in the entire sample). These values were then used to calculate an Index of Relative Importance (I.R.I.) for each prey category in a sample, as follows:

I.R.I. = (N.O. + G.O.) X F.O.

I.R.I. values were plotted as a rectangular area where the length consisted of N.O. + G.O., the width as F.O. (Fig. 4.1), and the area of the rectangle was equal to the I.R.I. value. A given sample would include a plotted area and I.R.I. value for each prey item, and, in turn, the % of the total I.R.I. values (areas) represented by each prey category was calculated.

Also calculated for each sample were the means and standard deviations of the following parameters:

Mean Width (predator, mm)

Mean Dry Weight (predator, grams)

Gut Content Ratio (% ratio of dry contents weight to dry weight of predator)

All calculations were made using only the adjusted sample size, i.e., excluding any empty stomachs, but the number and percent of the latter were also calculated.

4.2.4 Subsample Comparison: All stomachs from each trawl were first grouped together and analysed as a discrete sample. For all samples from a given site and season, e.g., South Reach summer, crabs were divided into 3 age class groups of carapace widths 0-60, 60-100, and >100 mm, then analysed as 3 discrete samples. For all stomachs gathered during diel sampling within a given season, all data were again sorted according to whether they represented night or day trawls, and analysed as two discrete samples. Crabs from high and low tides were also grouped, analysed separately, and compared.

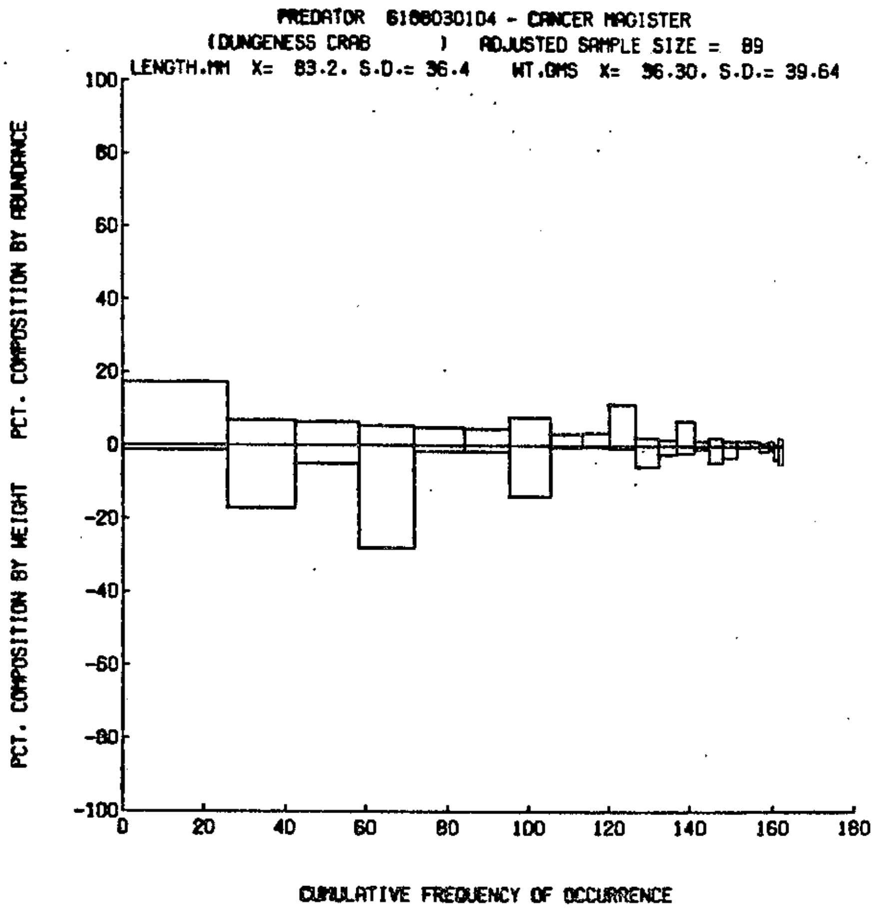
4.3 Results

4.3.1 Prey Items at Outer Harbor Stations: Complete I.R.I. tables and graphs for the diel stations (South Reach and Whitcomb Flats) are shown as Figs. 4.1-4.4. Note that the use of higher taxa such as Bivalvia represents only unidentified clams, and does not include those genera and species which were specifically identified. However, the major food types (fish, molluscs, and crustaceans) are summarized in Table 4.1. Boxes in the diagrams correspond, from left to right, with the sequence of species in the associated tables, from top to bottom.

In June 1980, the most important taxa (greatest % of total I.R.I.) were bivalves (22%), lingcod (21%), and Pacific sanddab (18%). Molluscs and crustaceans were almost equal in importance (Table 4.1, Fig. 4.1).

In September 1980, fish were still the most important group, but the use of molluscs increased greatly, as the use of crustaceans decreased (Table 4.1). The most important taxa were sandlance (>30%) and bivalves (21%).

In January 1981, fish were the dominant group eaten, followed by crustacea, including many Crangon, which were the most important taxa

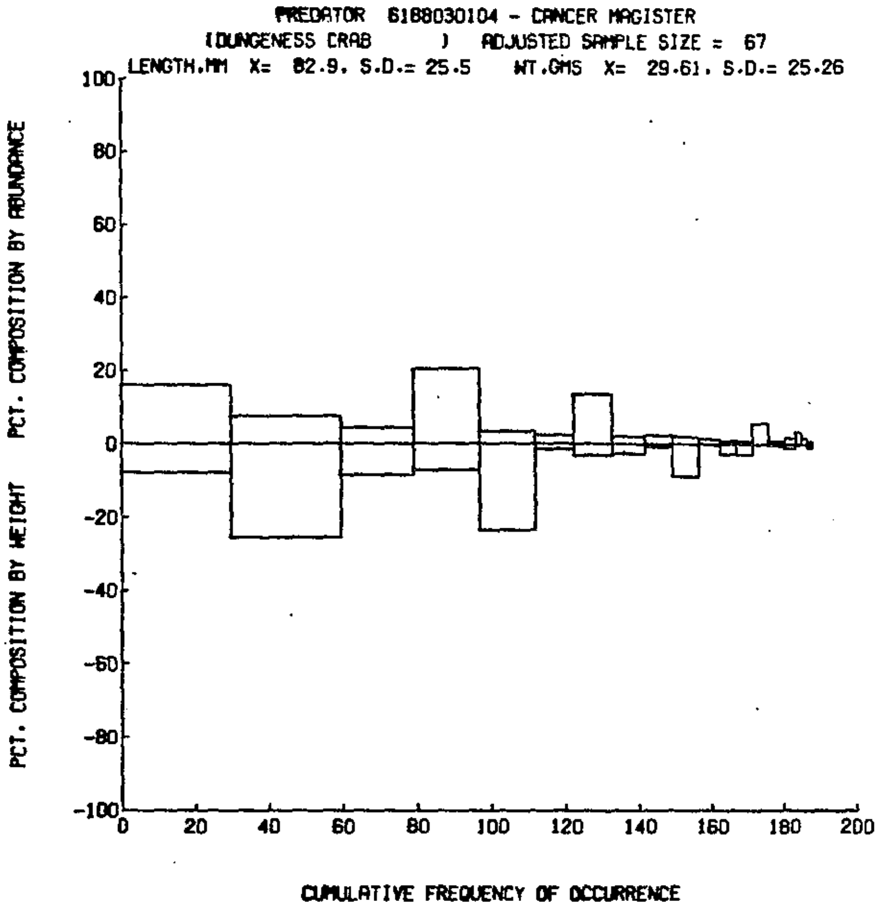


PREY ITEM	FREQ OCCUR	NUM. COMP.	GRAV. COMP.	PREY I.R.I.	PERCENT TOTAL IRI
BIVALVIA	25.84	17.35	1.17	478.6	21.73
CITHARICHTHYS SORDIDUS	16.85	6.85	17.05	402.9	18.29
CANCER MAGISTER	15.73	6.39	4.88	177.4	8.05
HEXAGRAMMIDAE	13.48	5.48	28.04	451.9	20.52
TELEOSTEI	12.36	5.02	1.69	82.9	3.77
CRUSTACEA	11.24	4.57	1.59	69.2	3.14
CRANGON SP.	10.11	7.76	13.79	218.0	9.90
DECAPODA	7.87	3.20	.44	28.6	1.30
TELLINIDAE	6.74	3.65	.26	26.4	1.20
MYSIDAE	6.74	11.42	.58	80.9	3.67
AMMODYTES HEXAPTERUS	5.62	2.28	5.54	44.0	2.00
CALLIANASSA CALIFORNIENSIS	4.49	1.83	2.29	18.5	.84
POLYCHAETA	4.49	6.85	1.97	39.6	1.80
CANCER SP.	3.37	1.37	.82	7.4	.34
CRANGON FRANCISCORUM ANGUSTIMA	3.37	2.28	4.37	22.4	1.02
CRANGON NIGRICAUDA	3.37	1.37	3.11	15.1	.69
UNIDENTIFIED	3.37	1.37	.22	5.3	.24
MYA SP.	2.25	1.37	.14	3.4	.15
LUMPENUS SAGITTA	2.25	.91	1.37	5.1	.23
OPHELIA SP.	1.12	1.37	.95	2.6	.12
PSETTICHTHYS MELANOSTICTUS	1.12	.46	3.51	4.5	.20
CRANGON STYLIROSTRIS	1.12	2.28	4.82	8.0	.36

PREY TAXA WITH FREQ. OCCUR. LESS THAN 5 AND NUMERICAL AND GRAVIMETRIC COMPOSITION BOTH LESS THAN 1 ARE EXCLUDED FROM THE TABLE AND PLOT (BUT NOT FROM CALCULATION OF DIVERSITY INDICES)

PERCENT DOMINANCE INDEX	.08	.14		.14
SHANNON-WEINER DIVERSITY	4.18	3.48		3.27
EVENNESS INDEX	.86	.72		.67

Fig. 4.1. Plot and table of I.R.I. values for prey of C. magister during diel sampling period 1 (June 1980). Crabs collected at South Reach channel and Whitcomb Flats. (See text Sec. 4.3.1)

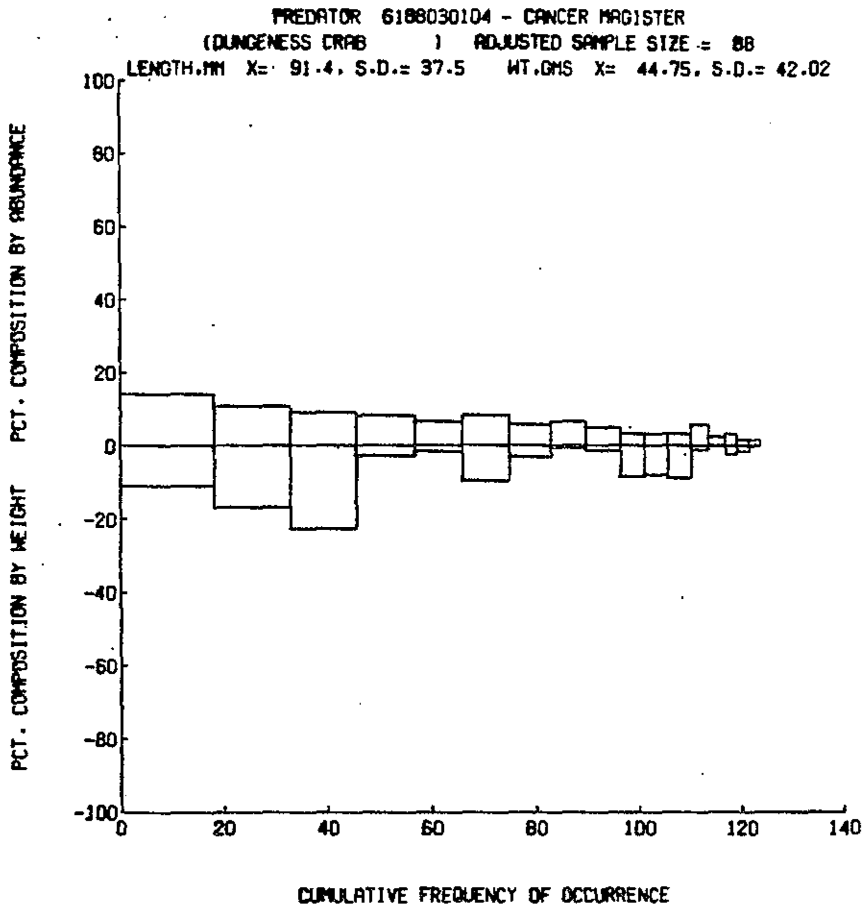


PREY ITEM	FREQ OCCUR	NUM. COMP.	GRAV. COMP.	PREY I.R.I.	PERCENT TOTAL IRI
BIVALVIA	29.85	16.10	7.82	713.8	21.47
AMMODYTES HEXAPTERUS	29.85	7.53	25.52	986.6	29.67
TELEOSTEI	19.40	4.45	8.38	249.1	7.49
CRYPTOMYA CALIFORNICA	17.91	20.55	7.10	495.2	14.89
CLUPEA HARENGUS PALLASI	14.93	3.42	23.52	402.1	12.09
CRUSTACEA	10.45	2.40	1.46	40.3	1.21
MYA SP.	10.45	13.70	3.14	175.9	5.29
CANCER SP.	8.96	2.05	2.61	41.8	1.26
MOLLUSCA	7.46	2.40	.72	23.3	.70
CALLIANASSA CALIFORNIENSIS	7.46	2.05	8.73	80.5	2.42
ENTEROMORPHA INTESTINALIS	5.97	1.37	.10	8.8	.26
PLEOCYEMATA-CARIDEA	4.48	1.03	2.55	16.0	.48
CYMATOGASTER AGGREGATTA	4.48	1.03	2.74	16.9	.51
COPEPODA	4.48	5.82	.00	26.1	.78
CITHARICHTHYS SORDIDUS	4.48	1.03	.34	6.1	.18
MACOMA SP.	2.99	1.71	1.05	8.2	.25
TELLINIDAE	1.49	3.42	.11	5.3	.16
CALANOIDA	1.49	1.71	.00	2.6	.08
CRANGON NIGRICAUDA	1.49	1.03	.79	2.7	.08

PREY TAXA WITH FREQ. OCCUR. LESS THAN 5 AND NUMERICAL AND GRAVIMETRIC COMPOSITION BOTH LESS THAN 1 ARE EXCLUDED FROM THE TABLE AND PLOT (BUT NOT FROM CALCULATION OF DIVERSITY INDICES)

PERCENT DOMINANCE INDEX	.10	.15		.18
SHANNON-WEINER DIVERSITY	3.93	3.30		2.91
EVENNESS INDEX	.78	.65		.59

Fig. 4.2. Plot and table of I.R.I. values for prey of *C. magister* during diel sampling period 2 (September 1980). Crabs collected at South Reach channel and Whitcomb Flats. (See text Sec. 4.3.1)

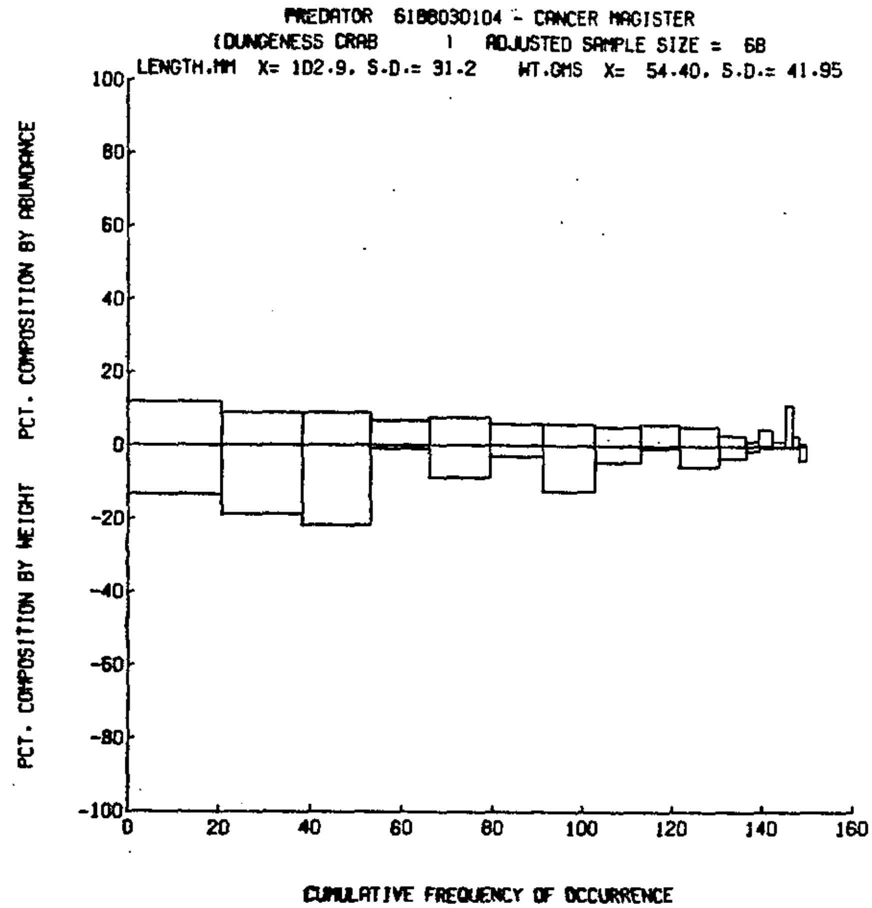


PREY ITEM	FREQ OCCUR	NUM. COMP.	GRAV. COMP.	PREY I.R.I.	PERCENT TOTAL IRI
CRANGON SP.	18.18	14.05	11.00	455.5	22.74
MICROGADUS PROXIMUS	14.77	10.74	16.88	408.1	20.37
SPIRINCHUS THALEICHTHYS	12.50	9.09	22.66	396.9	19.81
CRUSTACEA	11.36	8.26	2.81	125.9	6.28
DECAPODA	9.09	6.61	1.58	74.4	3.72
AMMODYTES HEXAPTERUS	9.09	8.26	9.57	162.1	8.09
TELEOSTEI	7.95	5.79	3.11	70.7	3.53
BIVALVIA	6.82	6.61	.68	49.7	2.48
CANCER MAGISTER	6.82	4.96	1.45	43.7	2.18
CLUPEA HARENGUS PALLASI	4.55	3.31	8.47	53.5	2.67
CALLIANASSA CALIFORNIENSIS	4.55	3.31	7.89	50.9	2.54
CITHARICHTHYS SORDIDUS	4.55	3.31	8.71	54.6	2.73
POLYCHAETA	3.41	5.79	1.06	23.3	1.17
UNIDENTIFIED	3.41	2.48	.08	8.7	.43
CRANGON FRANCISCORUM ANGUSTIMA	2.27	3.31	2.19	12.5	.62
PSETTICHTHYS MELANOSTICTUS	2.27	1.65	1.66	7.5	.38
CARDIIDAE	2.27	1.65	.07	3.9	.20

PREY TAXA WITH FREQ. OCCUR. LESS THAN 5 AND NUMERICAL AND GRAVIMETRIC COMPOSITION BOTH LESS THAN 1 ARE EXCLUDED FROM THE TABLE AND PLOT (BUT NOT FROM CALCULATION OF DIVERSITY INDICES)

	NUM.	GRAV.	PERCENT TOTAL IRI
PERCENT DOMINANCE INDEX	.08	.13	.15
SHANNON-WEINER DIVERSITY	3.90	3.34	3.18
EVENNESS INDEX	.93	.80	.76

Fig. 4.3. Plot and table of I.R.I. values for prey of C. magister during diel sampling period 3 (January 1981). Crabs collected at South Reach channel and Whitcomb Flats. (See text Sec. 4.3.1)



PREY ITEM	FREQ OCCUR	NUM. COMP.	GRAV. COMP.	PREY I.R.I.	PERCENT TOTAL IRI
CRANGON SP.	20.59	12.03	13.29	521.2	21.21
CALLIANASSA CALIFORNIENSIS	17.65	9.02	18.85	491.9	20.02
DECAPODA	14.71	9.02	21.78	453.0	18.43
CRUSTACEA	13.24	6.77	.94	102.0	4.15
CANCER MAGISTER	13.24	7.52	8.80	216.0	8.79
SPIRINCHUS THALEICHTHYS	11.76	6.02	2.93	105.2	4.28
MICROGADUS PROXIMUS	11.76	6.02	12.54	218.3	8.88
TELEOSTEI	10.29	5.26	4.47	100.2	4.08
BIVALVIA	8.82	6.02	.66	58.9	2.40
AMMODYTES HEXAPTERUS	8.82	5.26	5.54	95.4	3.88
PSETTICHTHYS MELANOSTICTUS	5.88	3.01	3.22	36.6	1.49
CRANGON FRANCISCORUM ANGUSTIMA	2.94	1.50	1.20	7.9	.32
MYSIDAE	2.94	4.51	.17	13.9	.56
UNIDENTIFIED	2.94	1.50	.04	4.5	.18
TELLINIDAE	1.47	11.28	.07	16.7	.68
AMPHIPODA	1.47	3.01	.14	4.6	.19
CYMATOGASTER AGGREGATTA	1.47	.75	3.74	6.6	.27

PREY TAXA WITH FREQ. OCCUR. LESS THAN 5 AND NUMERICAL AND GRAVIMETRIC COMPOSITION BOTH LESS THAN 1 ARE EXCLUDED FROM THE TABLE AND PLOT (BUT NOT FROM CALCULATION OF DIVERSITY INDICES)

PERCENT DOMINANCE INDEX	.07	.13	.14
SHANNON-WEINER DIVERSITY	3.92	3.26	3.18
EVENNESS INDEX	.92	.77	.75

Fig. 4.4. Plot and table of I.R.I. values for prey of C. magister during diel sampling period 4 (April 1981). Crabs collected at South Reach channel and Whitcomb Flats. (See text Sec. 4.3.1)

Table 4.1 Use of major food types by crabs in different seasons and locations.

Date	Sites	Tow No.	No. of crabs	Mean width (mm)	Gut content ratio	Percent of Total I.R.I.				
						Fish	Molluscs	Crust-acea	*Cancer magister*	*Crangon* spp
June 80	3, 13	69-74	89	83.2	0.50	45.0	23.1	29.3	8.4	12.0
Sept. 80	3, 13	94-98	67	82.9	1.33	49.9	42.8	6.2	1.3	0.6
Jan. 81	3, 13	134-139	88	91.4	0.56	57.6	2.7	38.1	2.2	23.4
April 81	3, 13	171-176	68	102.9	0.73	22.9	3.1	73.1	4.8	33.1
23 AP 81	Buoy 30	191	14	102.7	1.47	55.8	0.8	39.8	6.8	30.6
23 MY 81	"	196	12	62.6	1.42	24.4	8.9	66.4	60.5	4.3
23 MY 81	Moon I.	197	17	69.4	1.04	16.8	23.7	59.4	17.2	6.8
02 JL 81	"	201	14	60.9	0.91	16.1	21.1	62.8	17.7	22.3
03 JL 81	S. Bay	202	12	73.6	0.66	50.1	17.1	20.6	7.8	0.7

Table 4.2 Use of major food types by different size groups.

(A) Diel stations (South Reach, Whitcomb Flats)

Age (approx.)	Width (mm) Min.	Max.	Mean	No. of crabs	Gut content ratio (%) 1/	Percent of Total I.R.I. Fish	Molluscs	Crustacea	*Cancer magister*	*Crangon* spp
0+	0	60	39.7	107	1.56	10.6	61.6	24.1	5.9	0.5
1+	60	100	79.1	112	0.87	38.6	17.6	41.1	1.9	31.0
2+	100		126.2	122	0.62	52.5	6.3	40.2	4.9	10.7

(B) Upriver stations (S. Bay, Buoy 30, Moon Island)

Age (approx.)	Width (mm) Min.	Max.	Mean	No. of crabs	Gut content ratio (%) 1/	Percent of Total I.R.I. Fish	Molluscs	Crustacea	*Cancer magister*	*Crangon* spp
0+	0	60	47.4	29	0.95	1.2	33.3	65.5	34.4	4.5
1+	60	100	80.6	26	1.03	49.9	9.7	38.1	8.5	25.8
2+	100		117.7	14	1.54	47.4	2.6	46.5	26.9	13.6

1/ Gut content Ratio = 100 * (Dry wt. of stomach contents/Dry wt. of Crab).

(@ 20%) followed by tomcod and longfin smelt (@ 20% each). Molluscs were a very minor prey item.

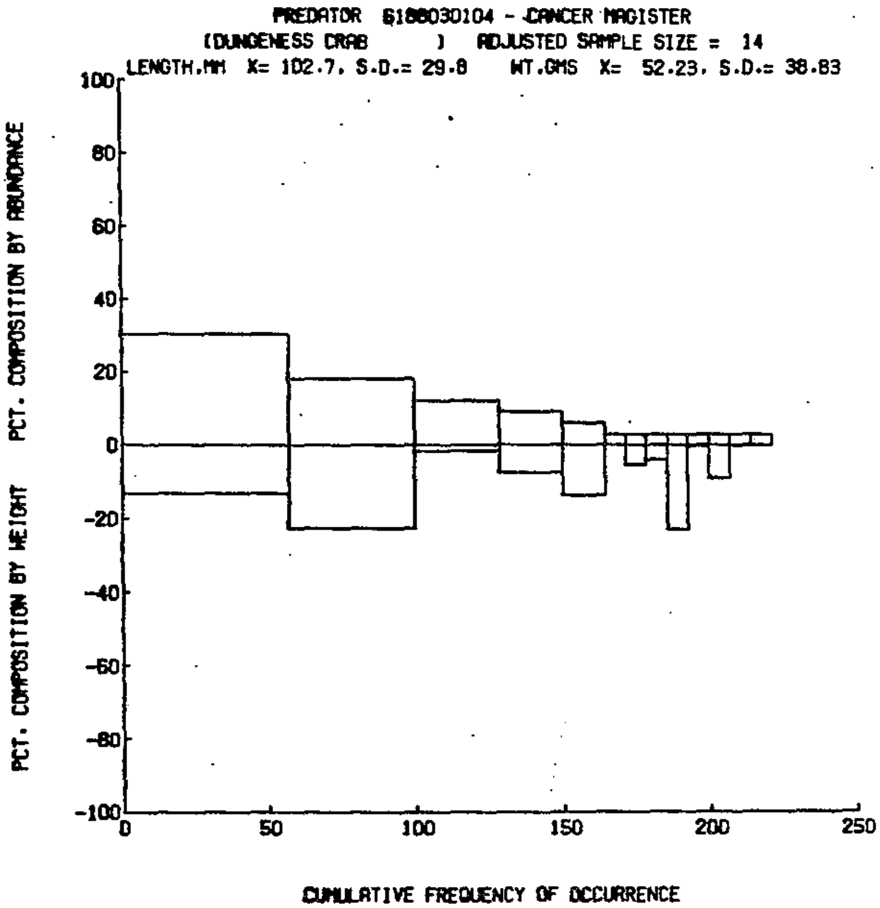
In April 1981, predation on crustacea was greatest, outweighing even the importance of fish. Molluscs were still very minor. Crangon and Callianassa were the most important taxa, each comprising about 20% of the I.R.I.

4.3.2 Prey Items at Inner Harbor Stations: At Buoy 30, the predominant prey species were fish in April 1981, but were crustaceans in May, as a large amount of cannibalism occurred in the latter month. Cancer magister was 66% of the total I.R.I., but was present in 11 of 12 stomachs examined (92%). Molluscs were relatively unimportant at this site (Table 4.1; Figs. 4.5, 4.6).

At Moon Island, crustaceans dominated the I.R.I., followed by molluscs. Fish were the least important at this site, a unique situation. Almost no change occurred in the predation on the major food groups from May to July at this site, including cannibalism, but the use of Crangon was greater in July. The most important taxon at this site during both months was Balanomorpha (barnacles; Figs. 4.7, 4.8).

At South Bay in July 1980, fish were the most important group, followed by crustacea and molluscs. The most important taxa were sand-sole and bivalvia (Table 4.1; Fig. 4.9).

4.3.3 Effect of Predator Size on Prey Selection: In order to detect the influence of location on size effects, all outer harbor data (diel samples) were separated from inner harbor data. Each group was

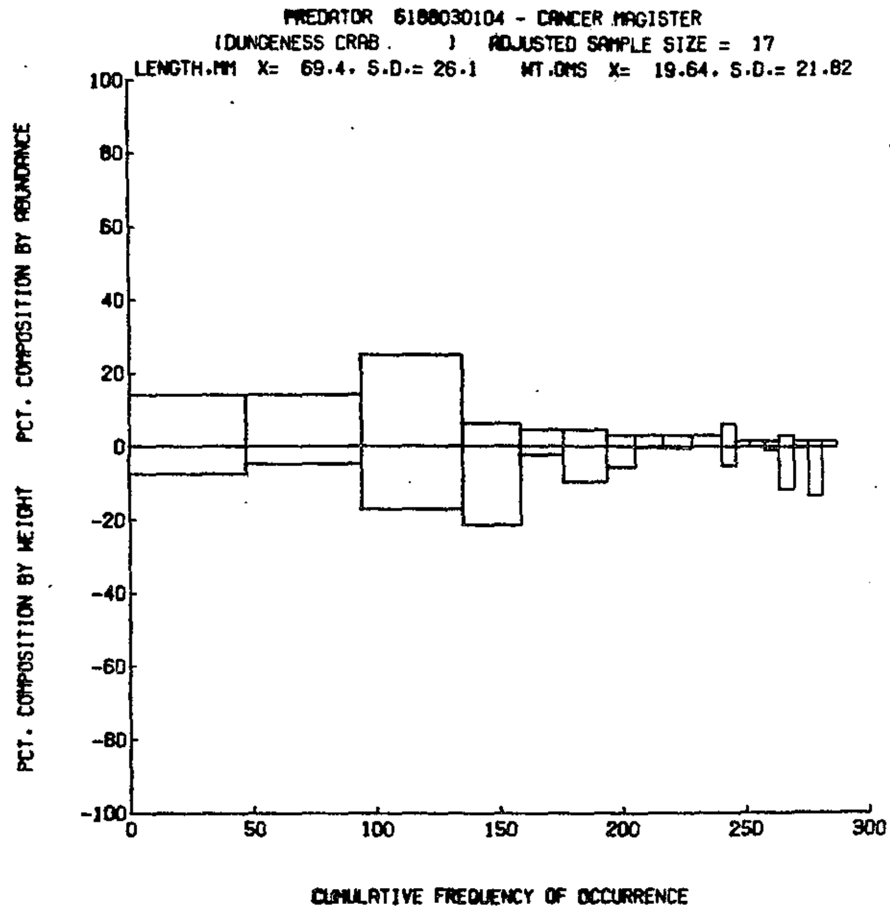


PREY ITEM	FREQ OCCUR	NUM. COMP.	GRAV. COMP.	PREY I.R.I.	PERCENT TOTAL IRI
TELEOSTEI	57.14	30.30	13.12	2481.3	43.29
CRANGON SP.	42.86	18.18	22.74	1754.0	30.60
CANCER MAGISTER	28.57	12.12	1.60	392.1	6.84
CYMATOGASTER AGGREGATTA	21.43	9.09	7.42	353.9	6.17
PSETTICHTHYS MELANOSTICTUS	14.29	6.06	13.61	281.0	4.90
POLYCHAETA	7.14	3.03	.01	21.7	.38
CALLIANASSIDAE	7.14	3.03	5.36	59.9	1.05
DECAPODA-BRACHYURA	7.14	3.03	4.00	50.2	.89
NEREIDAE	7.14	3.03	22.90	185.2	3.23
BIVALVIA	7.14	3.03	.30	23.8	.42
LEPTOCOTTUS ARMATUS	7.14	3.03	8.84	84.9	1.49
MACOMA SP.	7.14	3.03	.05	22.0	.38
EOGAMMARUS SP.	7.14	3.03	.05	22.0	.38

PREY TAXA WITH FREQ. OCCUR. LESS THAN 5 AND NUMERICAL AND GRAVIMETRIC COMPOSITION BOTH LESS THAN 1 ARE EXCLUDED FROM THE TABLE AND PLOT (BUT NOT FROM CALCULATION OF DIVERSITY INDICES)

PERCENT DOMINANCE INDEX	.16	.16			.29
SHANNON-WEINER DIVERSITY	3.12	2.88			2.28
EVENNESS INDEX	.84	.78			.61

Fig. 4.5. Plot and table of I.R.I. values for prey of C. magister collected at Buoy 30 on 23 April, 1981. (See text Sec. 4.3.1)

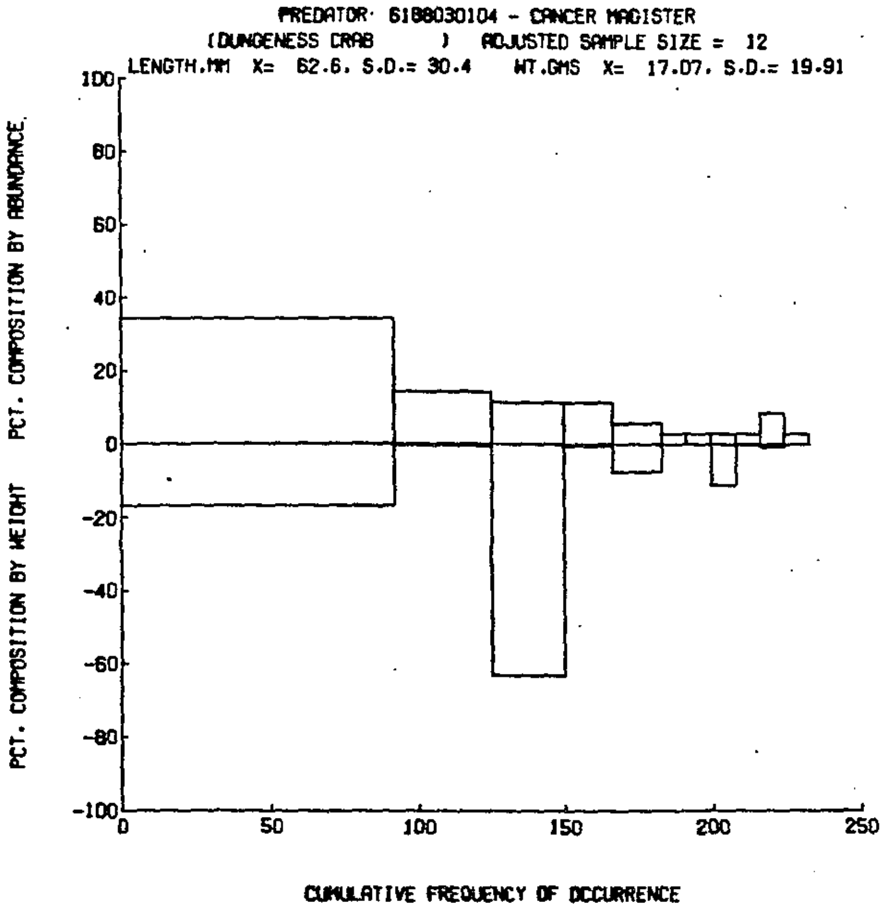


PREY ITEM	FREQ OCCUR	NUM. COMP.	GRAV. COMP.	PREY I.R.I.	PERCENT TOTAL IRI
BIVALVIA	47.06	14.06	7.39	1009.5	19.52
CANCER MAGISTER	47.06	14.06	4.83	889.1	17.19
BALANOMORPHA	41.18	25.00	17.06	1732.1	33.49
MICROGADUS PROXIMUS	23.53	6.25	21.42	651.9	12.59
MYA ARENARIA	17.65	4.69	2.36	124.4	2.40
CRANGON SP.	17.65	4.69	9.55	251.2	4.86
CRANGON FRANCISCORUM ANGUSTIMA	11.76	3.13	5.61	102.8	1.99
EOGAMMARUS SP.	11.76	3.13	.30	60.3	.79
TELEOSTEI	11.76	3.13	.45	42.1	.81
GAMMARIDAE	11.76	3.13	.01	36.8	.71
MACOMA SP.	5.88	6.25	5.11	66.8	1.29
CUMACEA	5.88	1.56	.00	9.2	.18
TELLINA SP.	5.88	1.56	.00	9.2	.18
TELLINIDAE	5.88	1.56	.84	14.1	.27
SPIRINCHUS THALEICHTHYS	5.88	3.13	11.60	86.6	1.67
DECAPODA	5.88	1.56	.19	10.3	.20
CYMATOGASTER AGGREGATTA	5.88	1.56	13.27	87.3	1.69
SAND	5.88	1.56	.00	9.2	.18

PREY TAXA WITH FREQ. OCCUR. LESS THAN 5 AND NUMERICAL AND GRAVIMETRIC COMPOSITION BOTH LESS THAN 1 ARE EXCLUDED FROM THE TABLE AND PLOT (BUT NOT FROM CALCULATION OF DIVERSITY INDICES)

PERCENT DOMINANCE INDEX	.12	.13	.20
SHANNON-WEINER DIVERSITY	3.55	3.19	2.79
EVENNESS INDEX	.85	.76	.67

Fig. 4.6. Plot and table of I.R.I. values for prey of C. magister collected at Buoy 30 on 23 May, 1981. (See text Sec. 4.3.1)

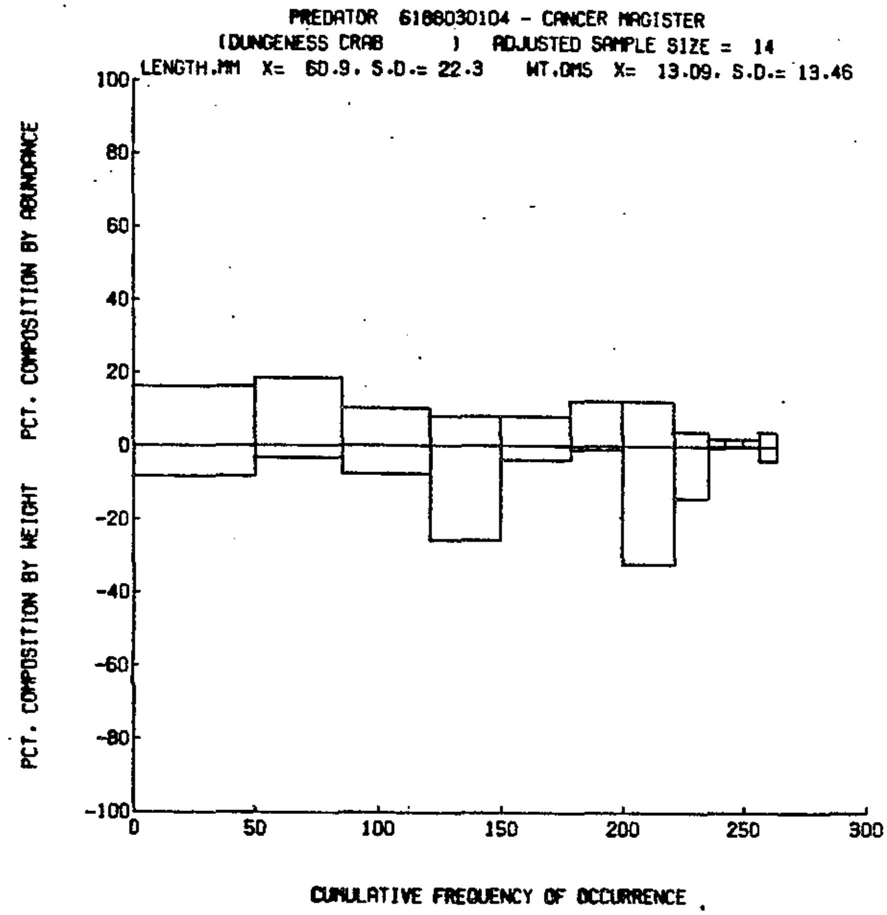


PREY ITEM	FREQ OCCUR	NUM. COMP.	GRAV. COMP.	PREY I.R.I.	PERCENT TOTAL IRI
CANCER MAGISTER	91.67	34.29	16.81	4683.8	60.48
BIVALVIA	33.33	14.29	.47	492.0	6.35
TELEOSTEI	25.00	11.43	63.12	1863.7	24.06
TELLINIDAE	16.67	11.43	.44	197.9	2.55
CRANGON SP.	16.67	5.71	7.44	219.3	2.83
EOGAMMARUS SP.	8.33	2.86	.00	23.8	.31
CHLOROPHYTA	8.33	2.86	.02	24.0	.31
CRANGON FRANCISCORUM ANGUSTIMA	8.33	2.86	11.07	116.1	1.50
CRUSTACEA	8.33	2.86	.07	24.4	.32
BALANOMORPHA	8.33	8.57	.52	75.8	.98
SPIRINCHUS THALEICHTHYS	8.33	2.86	.02	24.0	.31

PREY TAXA WITH FREQ. OCCUR. LESS THAN 5 AND NUMERICAL AND GRAVIMETRIC COMPOSITION BOTH LESS THAN 1 ARE EXCLUDED FROM THE TABLE AND PLOT (BUT NOT FROM CALCULATION OF DIVERSITY INDICES)

PERCENT DOMINANCE INDEX		.18	.44		.43
SHANNON-WEINER DIVERSITY		2.92	1.61		1.73
EVENNESS INDEX		.84	.46		.50

Fig. 4.7. Plot and table of I.R.I. values for prey of C. magister collected at Moon Island on 23 May, 1981. (See text Sec. 4.3.1)



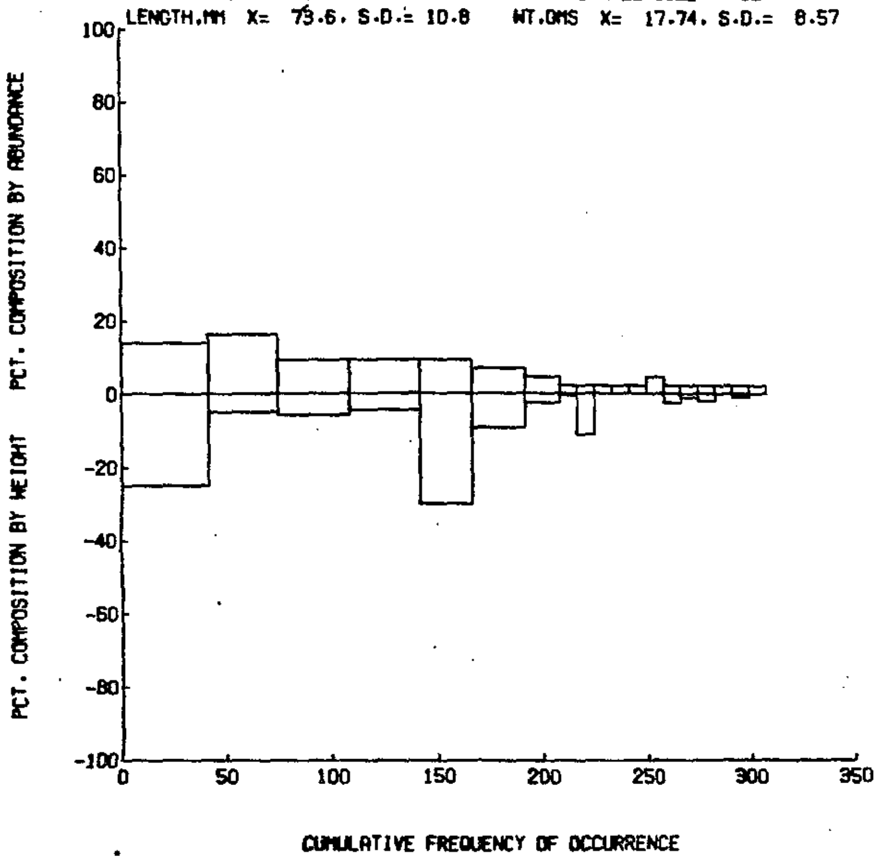
PREY ITEM	FREQ. OCCUR.	NUM. COMP.	GRAV. COMP.	PREY I.R.I.	PERCENT TOTAL IRI
BALANOMORPHA	50.00	36.33	8.19	1225.9	22.16
MYTIDAE	35.71	18.37	3.23	771.3	13.93
TELEOSTEI	35.71	10.20	7.56	634.9	11.45
CANCER MAGISTER	[illegible]	8.16	28.42	965.3	17.44
BIVALVIA	28.57	8.16	3.73	339.7	6.14
CRANGON SP.	21.43	12.24	1.03	284.5	5.14
CRANGON FRANCISCORUM ANGUSTIMA	21.43	12.24	32.18	952.0	17.20
SPIRINCHUS THALEICHTHYS	14.29	4.08	14.04	258.9	4.68
DECAPODA	7.14	2.04	.44	17.8	.32
CANCRIDEA	7.14	2.04	.09	15.2	.28
CRUSTACEA	7.14	2.04	.09	15.2	.28
MYA ARENARIA	7.14	4.08	3.70	56.1	1.01

PREY TAXA WITH FREQ. OCCUR. LESS THAN 5 AND NUMERICAL AND GRAVIMETRIC COMPOSITION BOTH LESS THAN 1 ARE EXCLUDED FROM THE TABLE AND PLOT (BUT NOT FROM CALCULATION OF DIVERSITY INDICES)

PERCENT DOMINANCE INDEX		.12	.21		.15
SHANNON-WEINER DIVERSITY		3.26	2.64		2.33
EVENNESS INDEX		.91	.74		.82

Fig. 4.8. Plot and table of I.R.I. values for prey of C. magister collected at Moon Island on 2 July, 1981. (See text Sec. 4.3.1)

PREDATOR 6188030104 - CANCER MAGISTER
(DUNGENESS CRAB) ADJUSTED SAMPLE SIZE = 12
LENGTH,MM X= 73.6, S.D.= 10.8 WT.GMS X= 17.74, S.D.= 8.57



PREY ITEM	FREQ OCCUR	NUM. COMP.	GRAV. COMP.	PREY I.R.I.	PERCENT TOTAL IRI
PSETTICHTHYS MELANOSTICTUS	41.67	33.95	25.07	1625.8	31.25
BIVALVIA	33.33	16.26	4.95	707.9	13.61
CRUSTACEA	33.33	9.30	5.75	501.7	9.64
ENTEROMORPHA SP.	33.33	9.30	4.69	489.8	9.44
CYMATOGASTER AGGREGATA	25.00	9.30	29.91	980.3	18.85
CANCER MAGISTER	25.00	6.98	9.23	405.1	7.79
MYSIDAE	16.67	4.65	2.41	117.7	2.26
POLYCHAETA	8.33	2.33	.49	23.5	.45
NEPHTYIDAE	8.33	2.33	11.71	112.8	2.17
LEPTOCHELIA DUBIA	8.33	2.33	.01	19.5	.37
GAMMARIDEA	8.33	2.33	.01	19.5	.37
COROPHIUM BREVIS	8.33	2.33	.01	19.5	.37
EOGAMMARUS SP.	8.33	4.65	.01	38.8	.75
CRANGON FRANCISCORUM ANGUSTIMANA	8.33	2.33	2.40	39.4	.76
CALLIANASSIDAE	8.33	2.33	1.04	28.0	.54
GASTROPODA	8.33	2.33	2.00	36.0	.69
ULVACEAE	8.33	2.33	.01	19.5	.37
CARDIIDAE	8.33	2.33	.99	27.7	.53
NO ORGANISMS FOUND	8.33	2.33	.01	19.5	.37

PREY TAXA WITH FREQ. OCCUR. LESS THAN 5 AND NUMERICAL AND GRAVIMETRIC COMPOSITION BOTH LESS THAN 1 ARE EXCLUDED FROM THE TABLE AND PLOT (BUT NOT FROM CALCULATION OF DIVERSITY INDICES)

		NUM. COMP.	GRAV. COMP.		PERCENT TOTAL IRI
PERCENT DOMINANCE INDEX		.09	.18		.18
SHANNON-WEINER DIVERSITY		3.85	2.90		2.96
EVENNESS INDEX		.91	.68		.70

Fig. 4.9. Plot and table of I.R.I. values for prey of C. magister collected at South Bay on 3 July, 1981. (See text Sec. 4.3.1)

then subdivided into 3 width ranges (Fig. 4.10).

In the outer harbor, small crabs (including twenty eight between 15 and 22 mm) ate mostly molluscs, followed by crustaceans, but not Crangon, and very few fish (Table 4.2). Intermediate crabs showed increased predation on fish and crustaceans, especially Crangon. Use of bivalves decreased by about 60%. Large crabs showed increased dependence upon fish, but no increase in use of crustaceans. Use of bivalves and Crangon decreased.

Inner harbor crabs showed the same trends, except that crustaceans were more important than molluscs for small crabs. Intermediate crabs showed decreased use of bivalves, high predation in Crangon, and increased fish predation. Large crabs were similar to small crabs except for less predation on Crangon by the latter.

Bivalves appear to be most important during the first year of life. Crangon was a major food source only during the second year of life, fish were the most important prey item except during the first year (Table 4.2).

Cannibalism was greatest among small crabs, least among intermediate crabs, and increased again among large crabs. However, the size of crabs preyed upon could not be determined.

4.3.4 Effects of Diel Cycle on Prey Selection at Channel Site: A generalized diel cycle (average of 4 seasonal diel sampling periods) is presented in Figure 4.11.

Light: The stomach fullness as represented by gut content ratio,

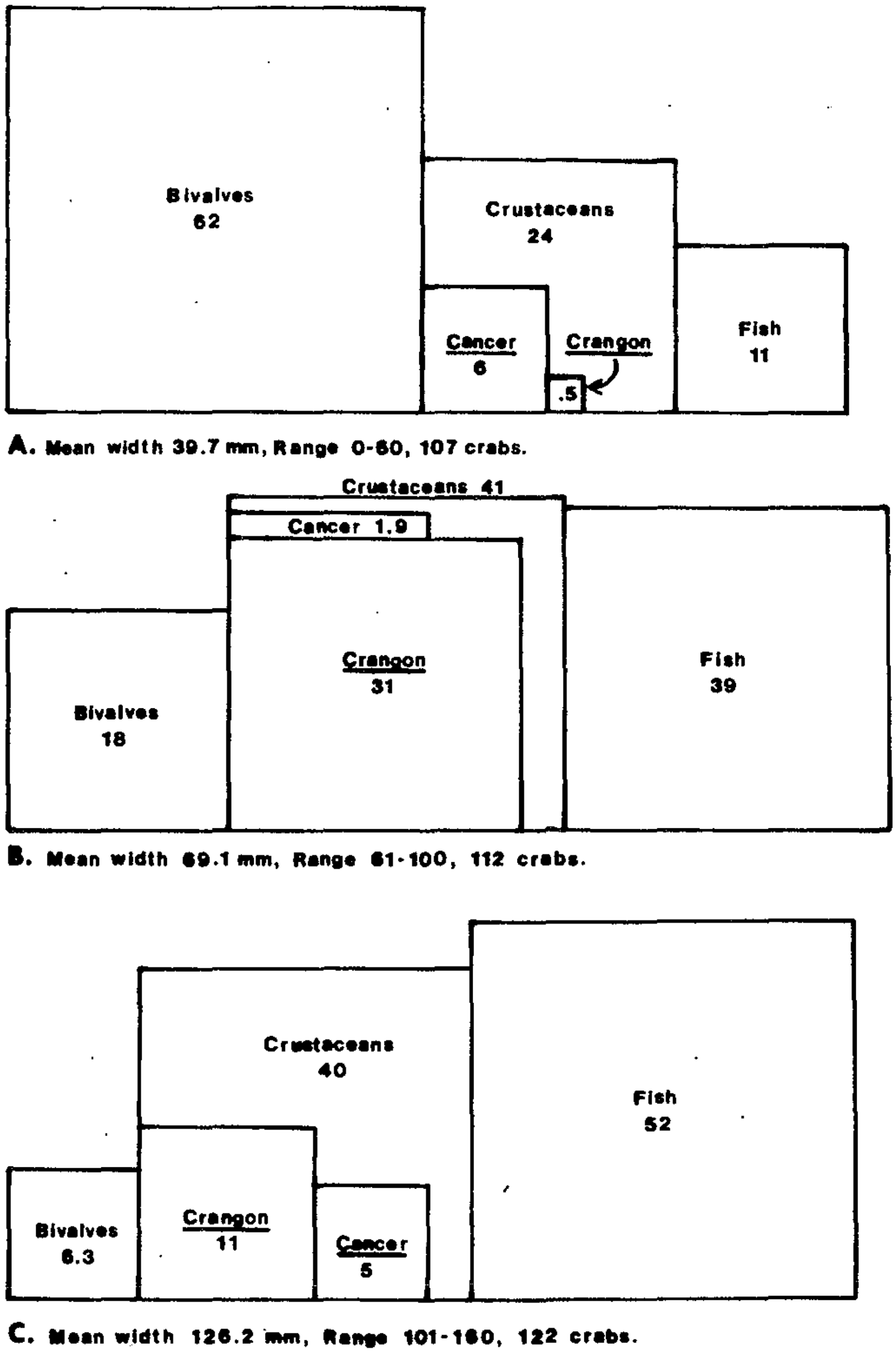


Fig. 4.10. Percent of the total I.R.I. values represented by major food types for three size ranges of C. magister. A, 0-60 mm width; B, 61-100 mm width; B, 101-160 mm width. Mean width and number of crabs shown below each diagram.

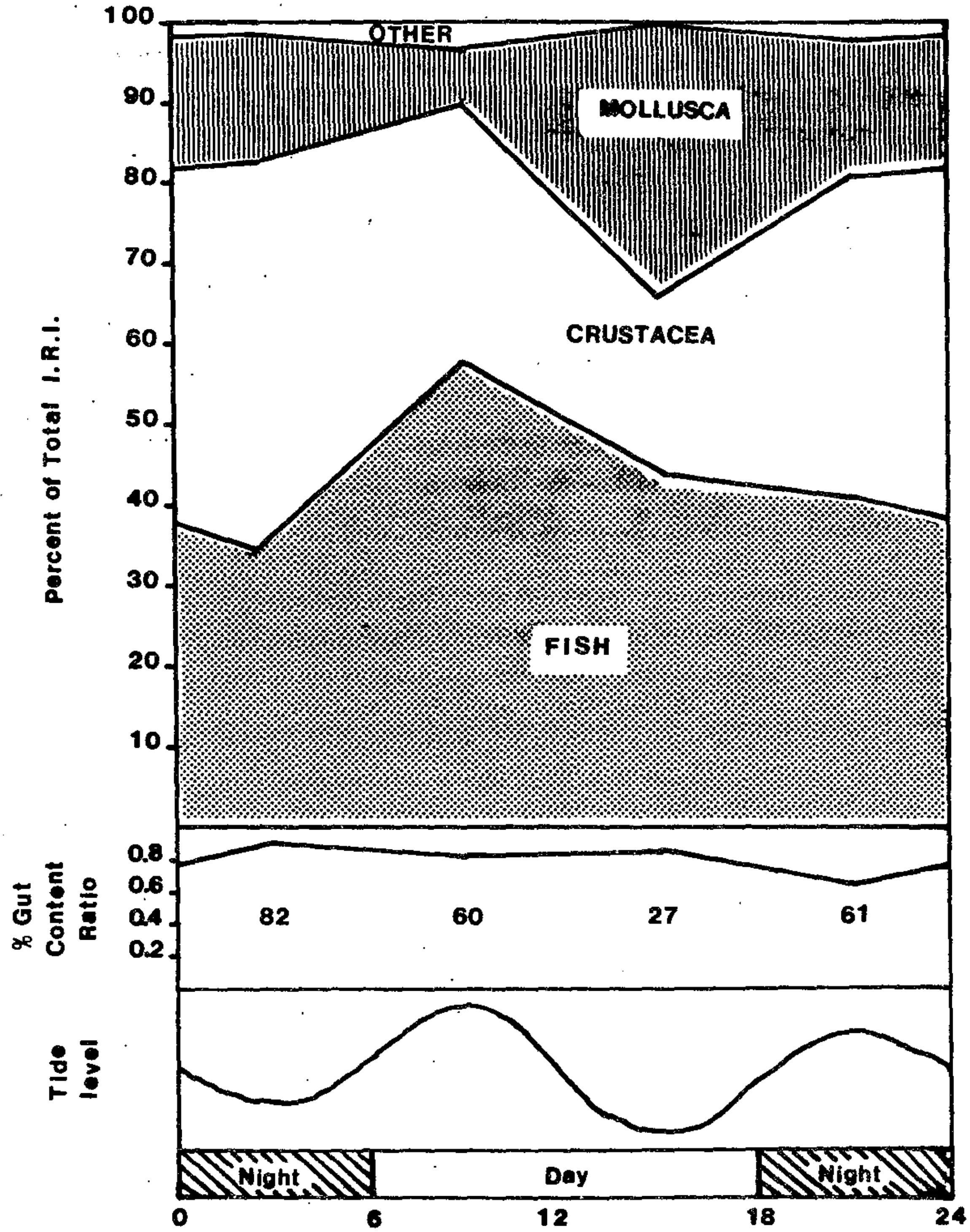


Fig. 4.11. Changes in the utilization of major food types by C. magister throughout a generalized diel cycle. Points are means for the number of crabs shown directly below gut content ratio.

showed no regular change from day to night. At night, predation on fish decreased, but predation on clams and crustaceans (mainly *Crangon*) increased.

Tide: From high to low tide, stomach fullness (gut content ratio) increased by 20% (from 0.75% to 0.90% dry body weight). Predation on fish decreased, and predation on bivalves increased greatly (70%). Use of crustaceans increased slightly.

General diel cycles: During early morning (dark) low tides, crustaceans and fish were most important but bivalves were also frequently consumed. By early day high tides, predation switched to mostly fish (Fig. 4.11). Afternoon low tides caused a great increase in use of bivalves. Evening (night) high tides caused an increase in the use of crustaceans (*Crangon*).

Time of day: Time of day appeared to have no consistent effect on feeding rate. During June 1980, and January 1981, gut content ratio delcined after noon (Fig. 4.12). However, during September 1980, and April 1981, gut content ratio increased after noon.

4.3.5 *Diel Cycle on Whitcomb Flats*: All tows over the flats were made at high tide, so no tidal effect was apparent. However, in contrast to the crabs caught in the channel, feeding rate increased by 19% on the flats at night (Table 4.3). At this time, cannibalism decreased, and predation on *Crangon* rose from 1.3 to 27.3% of the total I.R.I. Predation on fish and bivalves decreased only slightly.

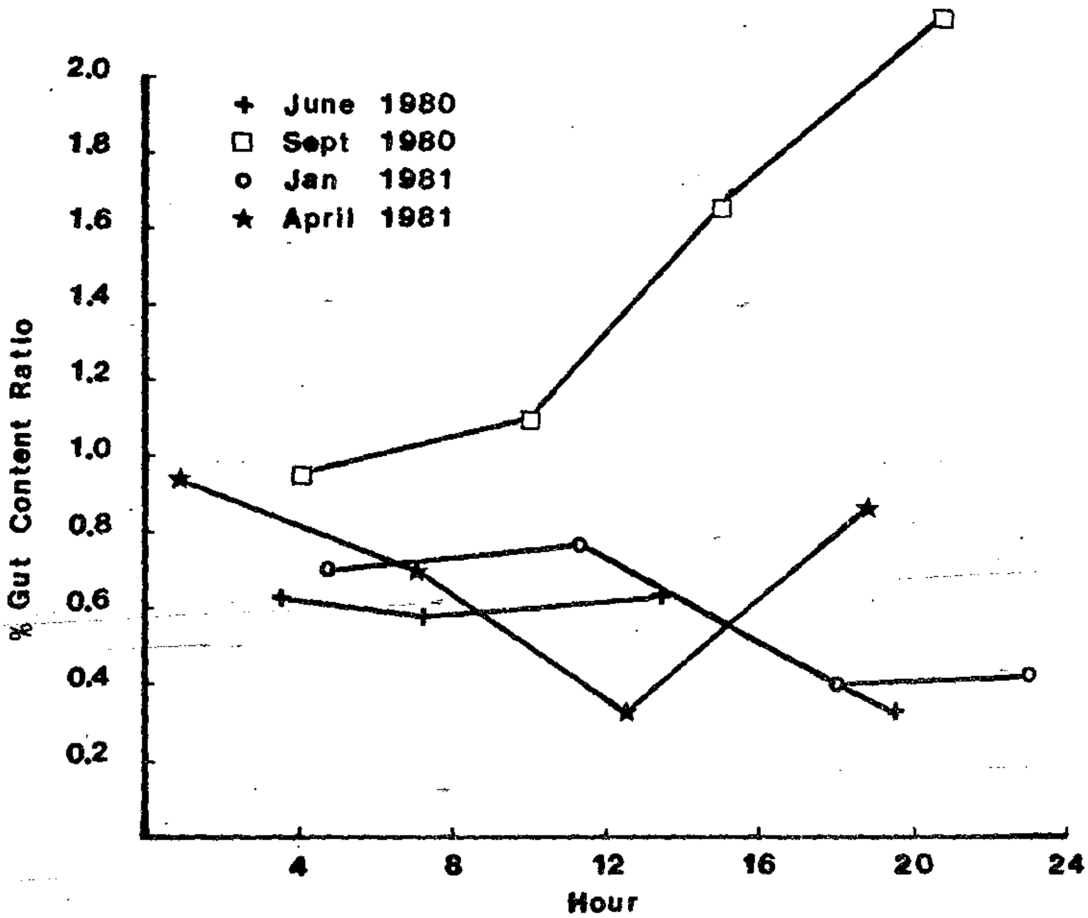


Fig. 4.12. Effect of time of day on gut content ratio for C. magister collected during diel sampling. Each point is a mean of 11-21 crabs.

Table 4.3 Diel use of major food groups on Whitcomb Flats

Tide	Light	No. of crabs	Gut content ratio (%)	Percent of Total I.R.I. Fish	Mollusc	Crust-acea	*Cancer magister*	*Crangon* spp
High	Day	28	0.57	47.9	13.8	30.3	9.6	1.3
High	Night	54	0.68	41.0	14.8	40.2	0.9	27.3

4.4 Discussion

4.4.1 Prey and Food Habits: Due to the large variety of sample types, locations, and timing, it is hard to generalize about food habits of *Cancer magister*. The most important food type (as percent of the total I.R.I.) for crabs in Grays Harbor were small fish, particularly sandlance (Ammodytes hexaptera), sanddab (Citharicthys sordidus), shiner perch (*Cymatogaster aggregatta*), and lingcod (*Ophiodon elongatus*). However, the most important single genus of prey was *Crangon* spp. Neither of these groups were highly important during the first year of life when small bivalves (*Cryptomya*, *Macoma*, and *Tellina* species) comprised the major prey category.

This ontogenetic switch in food preferences, i.e. changing with age, is probably a result of increasing body size. Elner and Hughes (1978) have shown that for a given sized crab, there is an optimum size of prey at which the ratio of energy content to handling time is at a maximum. This optimum prey size increases with crab size. Crabs less than 60 mm can easily handle small clams while their chelae and mouth parts are small (no large bivalves or univalves were present in the sampling areas, according to the benthic survey; P. Bouthillette, personal communication, May 1981). As crabs grow in size, growth of chelae and mouth parts would enable them to catch and handle shrimp and fish. When they mature, however, they either lose the agility to catch shrimp, or else optimal foraging strategy dictates that they prey on fish in order to secure greater food energy with less effort.

Predation on Crangon was so closely tied with changes in its density that shrimp abundance could almost be predicted solely by examination of crab stomachs. During winter and spring, predation was high at the South Reach and Whitcomb Flats sites reflecting the outward movement of these shrimp during winter (see Section 7.0). In late April predation was high at Buoy 30, and by July Crangon were abundant in stomachs from Moon Island. On Whitcomb Flats, predation on Crangon increased radically at night, reflecting the nightly increase in shrimp abundance over the flats. Increased nightly shrimp density and nightly predation by crabs were both most pronounced in January.

Outside of the major food types listed in Table 4.1 few other organisms were eaten. Polychaetes were rarely found in stomachs. Amphipods were occasional but not abundant. Cumaceans and isopods were even less frequently observed. Algae and sand were observed occasionally, but were probably the result of accidental ingestion. English sole scales were never found in stomachs, which was surprising considering that this species is abundant in Grays Harbor. Less than 1% of stomachs were empty; these were automatically deleted from I.R.I. tables and plots.

Mackay (1942) indicated that Cancer magister ate the following food groups, in order of importance: crustacea > mollusca > polychaeta > algae (Table 4.4). Butler (1954) showed that crabs of Hecate Strait

Table 4.4 Previous reports of *C. magister* gut contents.

Author	Location	No. of crabs	Frequency of Occurrence (%) Crustacea	Bivalves	Fish	Other species	Size range of crabs
Mackay (1942)	British Columbia		(1)*	(2)*		(3)*Polychaeta	n.d.
Butler (1954)	Hecate Strait	170	62	51	2		0-166 mm
Tegelberg (1972)	Washington Coast	264	34	65	33		All crabs over 110 mm
Mayer (1973)	Similk Bay, WA	50	(1)*	(2)*			n.d.
Gotshall (1977)	N. California	168	#	46	24		n.d.
	Humboldt Bay	40	38	62	87		n.d.
Bernard (1979)	Hecate Strait	202	#	#	#	*Crangon* 24% *Siliqua* 22% *Tellina* 20%	n.d.
Feder and Paul (1980)	Cook Inlet, AK	349	30	67	2	*Spisula* 48%	All over 50 mm
		64	#	25	0	Forams 36% Barnacles 28% Polychaeta 28%	Less than 50 mm

* A relative rank, shown in parentheses, was given by these authors.
\# Data not convertible to frequency of occurrence.
n.d. = no data given.

consumed crustaceans more frequently than molluscs, but both were very important. He found no sexual differences in food habits, but noted that "small" crabs (< 100 mm) consumed more clams than large crabs (57% vs 42% frequency), in agreement with our data (Table 4.4). Fish were not an important food item. Tegelberg (1972) reported that clams, especially the razor clam Siliqua patula, were the most abundant prey item, with fish and crustaceans each being eaten by about 1/3 of the crabs examined, all of which were over 110 mm width. Mayer (1973) showed that C. magister frequently preyed on other crustacea in Similk Bay, Washington, but his data were not convertible to frequency of occurrence. Gotshall (1977) showed that clams were more important than crustaceans, especially in crabs greater than 151 mm width, which preyed heavily on razor clams in offshore areas. In contrast to most previous reports, he showed fish to be the most frequent prey group for crabs less than 100 mm and for 40 crabs recovered from the shallow water of Humboldt Bay. This latter observation agrees with our study, except that our data shows almost no fish use by crabs less than 60 mm. Bernard (1979) showed that Crangon alaskensis was the most important prey species, followed by Siliqua patula, and Tellina carpenteri. He also showed that molluscs were most important to small crabs and crustaceans to larger crabs. Razor clams were important to large crabs. Feder and Paul (1980) found that large Cook Inlet crabs ate bivalves (especially Spisula polynyma) twice as frequently as crustacea, and rarely consumed fish. However, crabs less than 50 mm ate foraminifera, barnacles, polychaetes, and clams with almost equal frequency.

Common to our study and several of those cited above was the importance of small clams (less than 10 mm) to young crabs and, in other reports, the importance of larger bivalves (Siliqua, Clinocardium) to older crabs. However, only Gotshall (1977) supported our observations of the importance of fish, probably because his was the only other study which examined crabs from a shallow bay that serves as a nursery for abundant juvenile fish. Crustacea were found to be important in all studies, although seemingly used as a "secondary" prey category when other food types (i.e., bivalves or fish) were not readily available.

Bernard (1979) calculated a fullness index based on a ratio of gut content weight to carapace width, and claimed that larger crabs had a larger mean fullness index. This index is not comparable to ours because it is not constant, i.e., mass or volume of a crab stomach increases as the cube of length, whereas width increases linearly. Therefore, large crabs will always have a larger index, even if they ate the same percentage of their weight as did small crabs. Our use of gut content dry weight over crab dry weight is a much more stable index, as both parameters increase as the cube of width. Our data for outer harbor crabs show that the percentage of body weight eaten decreases with increasing size range, as does the relative growth rate (Section 2.4.5). Data from inner harbor crabs did not agree with this, however, but could be misleading since the sample size from this area was only 1/5 of that from the outer harbor. Bernard also claimed that gut fullness index increased during the day from 0800 to 1800 h, and that feeding was probably enhanced by greater visibility during daylight hours (no night samples were taken). We found this pattern present only in September, 1980, but feeding was even higher in the evening after dark. In all other seasons, feeding seemed to actually decrease during the daylight hours.

Cannibalism is a common phenomenon, having been reported by Mackay (1942), Butler (1954), Tegelberg (1972), Gotshall (1977), and this study. As in this report, most of the above authors cited its occurrence to be greatest during periods of recruitment of post-larvae. Curiously, both our inner and outer harbor collections showed that cannibalism was greatest among crabs less than 60 mm indicating intraspecific predation within an incoming year class, probably during molting processes. Among the 60-100 mm crabs, cannibalism was least frequent. Among crabs over 100 mm, cannibalism was again frequent, but not as great as among the early instars. However, the differences in cannabalism rate between year classes may not be significant.

Most authors concluded that crabs ate a representative selection of the benthos around them, that most feeding was opportunistic, and that little selection was evident. In our study we found that crab size dictated the proportionate use of the major food groups, and within these there was little selection. However, the use of *Crangon* might be greater than its relative proportion, and the use of polychaetes appeared to be much lower than their probable proportion among the benthos, as noted also for English sole earlier. Feder and Paul (1980) indicated that *Spisula* was frequently found in crab stomachs, but rare in benthic grabs from Cook Inlet. Therefore, there may be some selection for certain prey species, but this probably occurs more often where food is abundant, as in estuaries, than where food is more scarce, as offshore.

4.4.2 <u>Relationship of Diet to Channel Dredging</u>: Dredging of sandy bottom channel areas, especially the South Reach, Entrance, and Bar channels, is likely to remove most of the small bivalves which are preyed upon heavily by crabs less than 60 mm. This is especially true of *Cryptomya californica*, a commensal in *Callianassa* burrows. Small crustaceans and shrimp are also important to small crabs, and are likely to be removed by bottom dredging also. Therefore, use of dredged areas for foraging by crabs will be very limited until populations of small bivalves and crustaceans can recolonize these areas, if in fact, recolonization is possible in light of data given by Swartz et al (1980) and the magnitude of annual maintenance dredging.

Larger crabs would be less affected, as they are more dependent upon juvenile fish for food sources. Fish are less likely to be removed by dredging, as they are more mobile, and can escape from dredges as well as recolonize bottom areas much more rapidly (see Section 6.0).

Swartz et al (1980) showed that dredging in Yaquina Bay, Oregon, reduced the number of infaunal species by 48-55% and the number of individuals by 71-80%, relative to predredging values. Initially, recolonization occurred by the immigration of small mobile crustaceans (*Eogammarus*) and recruitment of polychaete larvae, neither of which was found to contribute much to the diet of *C. magister* in Grays Harbor. Changes in species composition were largely due to removal of fine sediments from the area. Species richness and sediment quality did not return to pre-dredging levels until one year after dredging. Periodic maintenance dredging, such as will be required for the entire length of the Grays Harbor channel, is likely to disallow the complete recovery of benthic communities affected, especially those alongside channels where widening will occur, and in the Bar and Entrance reaches which currently require no dredging. However, these reaches contain a very small proportion of fine sediments. These reaches were found during our study to have the highest density of crabs in the entire harbor (excluding Pt. Chehalis). It is possible that reduction of benthic species richness may directly induce reduction in the number of crabs which can be supported by those areas.

4.4.3 Sources of Error: When fish were present in stomachs, the flesh usually dominated the estimated volume of the stomach, i.e., the percent gravimetric occurrence of fish parts usually contributed highly to the I.R.I. In contrast, when clam or crustacean parts, especially crab parts, were present, they usually represented a large percent frequency of occurrence, but very little mass. In one sample from the Buoy 30 site, 11 of 12 stomachs contained crab parts, but these parts were mostly dactyls of chelae and walking legs, i.e., the most dense body parts, and requiring the greatest time to digest. Therefore, actual body mass eaten was underestimated for crabs, and clams similarly. These species could conceivably contribute a much greater proportion to the I.R.I. than estimated by undigested body parts.

Otoliths were extremely rare, appearing in only 2 or 3 of our crab stomachs. However, fish scales were present whenever other fish parts were. Usually these were abundant, and occasionally scales from more than one species were found. In such instances one type of scale would usually be present in large numbers and was concluded to be from the species eaten, and the other scales were scarce, possibly remnants from a previous meal, or accidentally swallowed while in the net. Even though many fish still had scales attached when recovered from stomachs, some of the scale evidence could be considered circumstantial. However, the presence of occasional fins, jaws, and gill arches always supported our scale identifications. Some fish could possibly have gone undetected due to the lack or paucity of scales, such as starry flounder, or staghorn sculpin. The latter was the most abundant and ubiquitous fish in the harbor, but only noted in one stomach, by the presence of a pectoral fin.

Feeding of crabs upon other occupants in the trawl net was noted occasionally. However, this was generally discounted as the source of food items because most crab stomachs were removed within 30-60 minutes of capture, and remains were usually well digested.

4.5 Summary

1) Stomach contents were examined from 341 crabs recovered during day, night, high and low tides of four seasons of diel sampling in the outer portion of Grays Harbor.

2) Stomach contents were examined from 69 crabs collected at other harbor sites.

3) Of these crabs, 136 less than 60 mm preyed mostly on molluscs and crustaceans, but very few fish or Crangon.

4) Crabs between 61 and 100 mm showed increased predation on fish and Crangon, and less use of bivalves.

5) Crabs larger than 100 mm width preyed mostly on fish, less on crustaceans, and very little on bivalves.

6) Some seasonal changes occurred in the proportions of the various food groups preyed upon. Lingcod were only common in June. Crangon spp were more frequent in stomachs from the outer harbor during winter and spring, but more frequent in stomachs from the inner harbor in summer.

7) At the intertidal site of Whitcomb Flats, predation upon Crangon was heavy at night but absent by day in accord with shrimp movements in this region.

8) Gut fullness, as evidenced by the gut content ratio, usually showed a decline during daylight, except in September 1980, when it increased steadily into late evening. During that sampling period the amount of food consumed was about double the average of other seasons in the outer harbor.

9) The amount of prey consumed at Buoy 30 and Moon Island, based on gut content ratios, was generally greater than at the South Reach.

10) Dredging will probably affect food sources of small crabs the greatest, as it is these crabs that prey most heavily upon the less mobile infauna such as small bivalves and crustaceans.

5.0 DISTRIBUTION AND ABUNDANCE OF BENTHIC FISH IN GRAYS HARBOR

James C. Hoeman

5.1 Introduction

The distribution of benthic fish in Grays Harbor was studied during the Maintenance Dredging project of 1974-75 (Bengston and Brown 1977). The authors collected 53 species of fish, the most numerous of which were juvenile English sole, staghorn sculpin, threespine stickleback, shiner perch, northern anchovy, Pacific herring and smelt. Many of these and other species were only found in abundance in shallow areas of the harbor, particularly the mud flats and eelgrass beds west of Moon Island. Most of these species were more abundant in summer than in winter, a result the authors associated with salinity changes in the harbor. By visual observation they detected no large numbers of fish in pipeline disposal enclosures, and suggested that entrainment was not a serious problem. However, they concluded that filling of shallow water habitats with dredged material was the most serious threat to the survival of these fishes. Bengston and Brown also confirmed that Grays Harbor served as an important nursery area for juveniles of many species of fish, some of great economic importance, including English sole and salmon.

Stevens (1981) found that small benthic fish were entrained easily by both hopper and pipeline dredges but at much lower rates than crabs. Clam-shell dredges were found to entrain very few crabs or fish. Staghorn sculpin, sandlance, sandsole and sanddab were the fish species most often entrained. Since these were now known to be impacted by dredging activities, and further entrainment studies were underway to more accurately determine entrainment rates (Section 6.0), USACE requested that fish species encountered during crab sampling in Grays Harbor be enumerated and measured.

The goals of this study were to:

1) determine the relative abundance of fish species captured by trawl,
2) detect any seasonal shifts in abundance,
3) determine average sizes of those species encountered, and
4) provide baseline information with which to compare dredge entrainment rates and predict potential dredging impacts.

5.2 Methods and Materials

5.2.1 Sample Collection: Fish were collected in the same trawls as crabs, as outlined in Section 2.2.1. However, fish were only kept from those sites of interest to the USACE, which were South Reach, South Channel, Moon Island, Cow Point, and either North Bay or Point Chehalis, whichever of the latter two was sampled in a given month.

5.2.2 Sampling Schedule and Specimen Treatment: Fish were collected on the same schedule as crab trawls (Table 2.2). Prior to November 1980, all fish were turned over to the Fisheries Research Institute (FRI) at the University of Washington for examination. Trawls were not made for the following months and stations due to bad weather or scheduling problems: December - Point Chehalis and North Bay; April - North Bay;

May - Cow Point and North Bay. From December 1980 through May 1981, fish were examined as follows.

Small catches were examined on board the boat. All were identified to species and counted, and up to 15 of each species were measured (total length) to the nearest millimeter. All were then returned to the water, though most did not survive. Large catches were sealed in large plastic bags and labeled. At the end of the day, these were placed in a freezer in Westport, WA. At the end of the sampling week, the frozen fish were returned to the School of Fisheries, University of Washington, where they were thawed, identified, counted, and measured.

5.2.3 Data Analyses: For each trawl from which fish were kept, the bottom surface area swept by the trawl was calculated as described in Section 2.2.2. Numbers of each species present were divided by area swept to estimate relative density of fish per 100 m^2. Mean total length, and standard deviation were calculated for each species.

5.3 Results

All fish measurements recorded during this study are presented in Appendix C. Appendix D is a list of all species encountered during trawling in Grays Harbor. Information on stomach contents of several fish in Grays Harbor is available in Section 7.3.4.

5.3.1 Species Composition and Seasonal Occurrence by Station

Cow Point: Cow Point samples from December 1980 through April 1981 included 13 different fish species (Table 5.1). Cow Point was not

Table 5.1. Fish caught at Cow Point in otter trawls, December 1980 - April 1981.

	December					February				
Species	Total number	Number measured	No./ $100 m^2$	Average length	Stand. dev.	Total number	Number measured	No./ $100 m^2$	Average length	Stand. dev.
Bay Pipefish	--	--	--	--	--	--	--	--	--	--
Blacktail Snailfish	--	--	--	--	--	--	--	--	--	--
Buffalo Sculpin	1	1	.051	108.00	0.0	--	--	--	--	--
English Sole	35	15	1.768	106.87	14.33	63	25	4.545	103.76	10.81
Longfin Smelt	46	15	2.323	110.87	17.87	144	27	10.390	111.00	13.14
Pacific Herring	3	3	.152	102.33	17.21	11	11	.794	91.27	8.83
Pacific Sanddab	--	--	--	--	--	--	--	--	--	--
Pacific Sandlance	--	--	--	--	--	--	--	--	--	--
Padded Sculpin	--	--	--	--	--	--	--	--	--	--
Prickly Sculpin	--	--	--	--	--	--	--	--	--	--
Redtail Surfperch	--	--	--	--	--	--	--	--	--	--
Saddleback Gunnel	--	--	--	--	--	--	--	--	--	--
Sand Sole	--	--	--	--	--	--	--	--	--	--
Shiner Perch	1	1	.051	121.00	0.0	--	--	--	--	--
Snake Prickleback	2	2	.101	169.50	45.96	6	6	.433	179.17	33.54
Staghorn Sculpin	14	14	.707	117.64	22.09	--	--	--	--	--
Starry Flounder	18	15	.909	126.07	20.75	2	2	.144	148.50	2.12
Three-spined Stickleback	3	3	.152	54.67	10.21	--	--	--	--	--
Tomcod	93	12	4.697	153.67	51.99	127	25	9.163	135.88	24.62

Table 5.1. Fish caught at Cow Point in otter trawls, December 1980 - April 1981 - continued.

	March					April				
Species	Total number	Number measured	No./100 m^2	Average length	Stand. dev.	Total number	Number measured	No./100 m^2	Average length	Stand. dev.
Bay Pipefish	--	--	--	--	--	--	--	--	--	--
Blacktail Snailfish	--	--	--	--	--	--	--	--	--	--
Buffalo Sculpin	--	--	--	--	--	1	1	.077	92.00	0.0
English Sole	52	26	3.359	106.35	11.54	23	23	1.775	104.91	9.18
Longfin Smelt	44	15	2.842	106.60	16.57	19	14	1.466	102.00	14.50
Pacific Herring	--	--	--	--	--	--	--	--	--	--
Pacific Sanddab	--	--	--	--	--	--	--	--	--	--
Pacific Sandlance	--	--	--	--	--	--	--	--	--	--
Padded Sculpin	--	--	--	--	--	--	--	--	--	--
Prickly Sculpin	6	6	.388	114.17	14.08	3	3	.231	110.67	16.86
Redtail Surfperch	--	--	--	--	--	--	--	--	--	--
Saddleback Gunnel	5	5	.323	126.20	8.87	--	--	--	--	--
Sand Sole	1	1	.065	112.00	0.0	--	--	--	--	--
Shiner Perch	--	--	--	--	--	1	1	.077	98.00	0.0
Snake Prickleback	15	14	.969	174.00	19.80	4	4	.309	184.25	10.01
Staghorn Sculpin	16	16	1.034	120.00	25.81	19	16	1.466	136.06	46.23
Starry Flounder	5	5	.323	119.40	37.17	4	4	.309	126.00	9.38
Three-spined Stickleback	--	--	--	--	--	--	--	--	--	--
Tomcod	51	15	3.295	125.27	17.18	22	15	1.689	130.40	48.72

sampled in May 1981. The most abundant species were English sole, longfin smelt, and tomcod. Moderately abundant species included staghorn sculpin, snake prickleback and starry flounder. Less abundant species included buffalo sculpin, sand sole, shiner perch, and three-spined stickleback.

Fish that occurred only in the spring but not in winter were sand sole, prickly sculpin, and saddleback gunnel. The peak catches of both longfin smelt and tomcod occurred in February. Three-spined stickleback were present only in the December sample.

Moon Island: Fish caught at Moon Island between December 1980 and May 1981 included 12 of the 13 species found at Cow Point (Table 5.2). Blacktail snailfish, a species not found at Cow Point, increased the total number of species found at Moon Island to 13. Prickly sculpin were found at Cow Point but not Moon Island.

English sole, longfin smelt, tomcod, and staghorn sculpin were the most abundant species in Moon Island samples. Moderately abundant fish included buffalo sculpin, shiner perch, snake prickleback and starry flounder. Less abundant fish included blacktail snailfish, saddleback gunnel, sand sole and three-spined stickleback.

The density of both longfin smelt and English sole increased from February to March then decreased in April. Saddleback gunnel, sand sole, and starry flounder did not appear in most winter trawls but were very abundant in December, then disappeared from subsequent trawls made February through May.

Table 5.2. Fish caught at Moon Island in otter trawls, December 1980 - May 1981.

Species	December					February				
	Total number	Number measured	No./100 m^2	Average length	Stand. dev.	Total number	Number measured	No./100 m^2	Average length	Stand. dev.
Bay Pipefish	--	--	--	--	--	--	--	--	--	--
Blacktail Snailfish	--	--	--	--	--	1	1	.042	92.00	0.0
Buffalo Sculpin	--	--	--	--	--	1	1	.042	87.00	0.0
English Sole	2	2	.136	103.00	1.41	23	23	.968	98.57	15.08
Longfin Smelt	44	15	2.981	114.13	24.20	27	27	1.136	125.37	11.20
Pacific Herring	5	5	.339	96.40	8.59	1	1	.042	224.00	0.0
Pacific Sanddab	--	--	--	--	--	--	--	--	--	--
Pacific Sandlance	--	--	--	--	--	--	--	--	--	--
Padded Sculpin	--	--	--	--	--	--	--	--	--	--
Prickly Sculpin	--	--	--	--	--	--	--	--	--	--
Redtail Surfperch	--	--	--	--	--	--	--	--	--	--
Saddleback Gunnel	--	--	--	--	--	--	--	--	--	--
Sand Sole	--	--	--	--	--	--	--	--	--	--
Shiner Perch	--	--	--	--	--	1	1	.042	74.00	0.0
Snake Prickleback	--	--	--	--	--	--	--	--	--	--
Staghorn Sculpin	1	1	.068	96.00	0.0	5	5	.210	112.60	12.58
Starry Flounder	--	--	--	--	--	--	--	--	--	--
Three-spined Stickleback	75	5	--	47.00	7.55	--	--	--	--	--
Tomcod	1	1	.068	102.00	0.0	16	16	.673	141.94	27.46

Table 5.2. Fish caught at Moon Island in otter trawls, December 1980 - May 1981 - continued.

Species	March					April				
	Total number	Number measured	No./100 m^2	Average length	Stand. dev.	Total number	Number measured	No./100 m^2	Average length	Stand. dev.
Bay Pipefish	--	--	--	--	--	--	--	--	--	--
Blacktail Snailfish	--	--	--	--	--	--	--	--	--	--
Buffalo Sculpin	4	4	.327	104.75	22.38	7	7	.278	99.14	22.48
English Sole	49	25	4.003	99.08	9.80	25	25	.992	99.92	8.37
Longfin Smelt	84	25	6.863	122.08	15.56	2	1	.079	116.00	0.0
Pacific Herring	--	--	--	--	--	--	--	--	--	--
Pacific Sanddab	--	--	--	--	--	--	--	--	--	--
Pacific Sandlance	--	--	--	--	--	--	--	--	--	--
Padded Sculpin	--	--	--	--	--	--	--	--	--	--
Prickly Sculpin	--	--	--	--	--	--	--	--	--	--
Redtail Surfperch	--	--	--	--	--	--	--	--	--	--
Saddleback Gunnel	4	4	.327	113.25	7.18	4	4	.159	117.00	6.48
Sand Sole	1	1	.082	87.00	0.0	--	--	--	--	--
Shiner Perch	1	1	.082	137.00	0.0	11	11	.437	119.64	10.78
Snake Prickleback	8	8	.654	170.25	12.46	7	7	.278	216.14	19.27
Staghorn Sculpin	23	15	1.879	120.60	40.34	18	15	.714	125.80	19.76
Starry Flounder	4	4	.327	39.00	14.65	19	15	.754	122.07	58.60
Three-spined Stickleback	--	--	--	--	--	--	--	--	--	--
Tomcod	122	25	9.967	137.84	24.36	57	15	2.262	141.00	14.83

Table 5.2. Fish caught at Moon Island in otter trawls, December 1980 - May 1981 - continued.

	May				
Species	Total number	Number measured	No./ 100 m^2	Average length	Stand. dev.
Bay Pipefish	--	--	--	--	--
Blacktail Snailfish	--	--	--	--	--
Buffalo Sculpin	1	1	.041	127.00	0.0
English Sole	20	20	.817	103.55	10.84
Longfin Smelt	12	9	.490	116.00	19.99
Pacific Herring	--	--	--	--	--
Pacific Sanddab	--	--	--	--	--
Pacific Sandlance	--	--	--	--	--
Padded Sculpin	--	--	--	--	--
Prickly Sculpin	--	--	--	--	--
Redtail Surfperch	--	--	--	--	--
Saddleback Gunnel	3	3	.123	96.33	10.07
Sand Sole	5	5	.204	91.60	12.70
Shiner Perch	--	--	--	--	--
Snake Prickleback	1	1	.041	267.00	0.0
Staghorn Sculpin	11	11	.449	139.09	13.64
Starry Flounder	5	5	.204	113.20	20.68
Three-spined Stickleback	--	--	--	--	--
Tomcod	61	15	2.492	146.27	48.84

South Channel: Samples from the South Channel contained 16 species of fish, three of which were not found at Cow Point or Moon Island (bay pipefish, redtail surfperch, and Pacific sanddab; Table 5.3). The most abundant species were English sole, longfin smelt, shiner perch, staghorn sculpin and tomcod. Less abundant species included bay pipefish, buffalo sculpin, Pacific herring, Pacific sanddab, prickly sculpin, redtail surf-perch, saddleback gunnel, sand sole, and snake prickleback.

Three-spined stickleback were very abundant in December and February, present in low numbers in March and April, and absent from samples in May. Longfin smelt and shiner perch both reached peak abundances in April.

South Reach: Samples from South Reach included 15 different species (Table 5.4). The most abundant species were English sole, longfin smelt, Pacific sanddab, sand sole, staghorn sculpin and tomcod. Less abundant species were bay pipefish, buffalo sculpin, padded sculpin, saddleback gunnel, shiner perch, snake prickleback, starry flounder and three-spined stickleback. The padded sculpin was found only in one sample from the South Reach.

Pacific herring were abundant in December and February, low in March and April, and absent from the May sample. Pacific sanddab were very abundant in December and February. Tomcod were very abundant in the March trawl. Longfin smelt were very abundant in the May trawl.

Point Chehalis (Buoy 13): Only nine species were present in samples from Point Chehalis, the lowest number at any station (Table 5.5). One

Table 5.3. Fish caught at South Channel in otter trawls, December 1980 - May 1981.

Species	December					February				
	Total number	Number measured	No./100 m^2	Average length	Stand. dev.	Total number	Number measured	No./100 m^2	Average length	Stand. dev.
Bay Pipefish	--	--	--	--	--	1	1	.051	164.00	0.0
Blacktail Snailfish	--	--	--	--	--	--	--	--	--	--
Buffalo Sculpin	--	--	--	--	--	1	1	.051	73.00	0.0
English Sole	1	1	.043	80.00	0.0	39	26	1.337	92.12	13.98
Longfin Smelt	4	4	.174	61.00	8.21	14	14	.720	85.79	25.73
Pacific Herring	1	1	.043	92.00	0.0	4	4	.206	82.50	5.00
Pacific Sanddab	--	--	--	--	--	3	3	.154	86.67	4.16
Pacific Sandlance	--	--	--	--	--	--	--	--	--	--
Padded Sculpin	--	--	--	--	--	--	--	--	--	--
Prickly Sculpin	--	--	--	--	--	--	--	--	--	--
Redtail Surfperch	--	--	--	--	--	--	--	--	--	--
Saddleback Gunnel	--	--	--	--	--	1	1	.051	113.00	0.0
Sand Sole	1	1	.043	78.00	0.0	3	3	.154	175.33	81.71
Shiner Perch	--	--	--	--	--	4	4	.206	76.00	4.24
Snake Prickleback	--	--	--	--	--	--	--	--	--	--
Staghorn Sculpin	2	2	.087	101.00	12.73	33	15	1.698	114.20	26.66
Starry Flounder	--	--	--	--	--	2	2	.103	119.50	2.12
Three-spined Stickleback	164	15	7.118	45.93	8.00	21	14	1.080	44.21	4.46
Tomcod	1	1	.043	97.00	0.0	41	25	2.109	126.40	26.01

Table 5.3. Fish caught at South Channel in otter trawls, December 1980 - May 1981 - continued.

Species	March					April				
	Total number	Number measured	No./100 m^2	Average length	Stand. dev.	Total number	Number measured	No./100 m^2	Average length	Stand. dev.
Bay Pipefish	2	2	.103	139.50	3.54	--	--	--	--	--
Blacktail Snailfish	--	--	--	--	--	--	--	--	--	--
Buffalo Sculpin	3	3	.154	75.67	10.02	1	1	.026	72.00	0.0
English Sole	66	25	3.395	97.20	12.95	39	25	1.022	108.92	15.95
Longfin Smelt	9	7	.463	98.57	16.79	123	15	3.223	95.20	18.04
Pacific Herring	1	1	.051	198.00	0.0	3	3	.079	100.33	.58
Pacific Sanddab	--	--	--	--	--	--	--	--	--	--
Pacific Sandlance	--	--	--	--	--	--	--	--	--	--
Padded Sculpin	--	--	--	--	--	--	--	--	--	--
Prickly Sculpin	--	--	--	--	--	2	2	.052	74.50	17.68
Redtail Surfperch	--	--	--	--	--	--	--	--	--	--
Saddleback Gunnel	2	2	.103	118.50	3.54	1	1	.026	137.00	0.0
Sand Sole	4	4	.206	62.25	13.67	--	--	--	--	--
Shiner Perch	7	7	.360	111.00	21.99	136	15	3.564	119.67	11.94
Snake Prickleback	1	1	.051	210.00	0.0	--	--	--	--	--
Staghorn Sculpin	14	14	.720	133.93	17.43	42	15	1.101	120.47	12.86
Starry Flounder	--	--	--	--	--	19	15	.498	134.93	24.03
Three-spined Stickleback	1	1	.051	50.00	0.0	3	3	.079	44.33	2.52
Tomcod	84	26	4.321	121.04	14.02	49	15	1.284	141.27	15.12

Table 5.3. Fish caught at South Channel in otter trawls, December 1980 - May 1981 - continued.

Species	May				
	Total number	Number measured	No./100 m^2	Average length	Stand. dev.
Bay Pipefish	--	--	--	--	--
Blacktail Snailfish	--	--	--	--	--
Buffalo Sculpin	--	--	--	--	--
English Sole	6	6	.490	90.67	18.97
Longfin Smelt	54	15	4.412	104.07	13.38
Pacific Herring	--	--	--	--	--
Pacific Sanddab	--	--	--	--	--
Pacific Sandlance	--	--	--	--	--
Padded Sculpin	--	--	--	--	--
Prickly Sculpin	--	--	--	--	--
Redtail Surfperch	3	3	.245	301.67	2.89
Saddleback Gunnel	--	--	--	--	--
Sand Sole	5	5	.408	82.40	23.48
Shiner Perch	81	14	6.618	110.21	13.62
Snake Pricklebach	8	8	.654	181.13	24.49
Staghorn Sculpin	14	14	1.144	141.00	17.80
Starry Flounder	8	8	.654	150.75	15.55
Three-spined Stickleback	--	--	--	--	--
Tomcod	14	14	1.144	155.07	12.68

Table 5.4. Fish caught at South Reach in otter trawls, December 1980 - May 1981.

Species	December					February				
	Total number	Number measured	No./100 m^2	Average length	Stand. dev.	Total number	Number measured	No./100 m^2	Average length	Stand. dev.
Bay Pipefish	--	--	--	--	--	--	--	--	--	--
Blacktail Snailfish	--	--	--	--	--	--	--	--	--	--
Buffalo Sculpin	--	--	--	--	--	10	10	.731	86.00	16.79
English Sole	51	13	2.673	81.54	11.54	65	25	4.751	85.72	17.55
Longfin Smelt	9	7	.472	104.71	25.63	9	9	.658	89.89	23.33
Pacific Herring	25	15	1.310	106.27	9.23	41	15	2.997	89.80	25.70
Pacific Sanddab	131	16	6.866	75.38	18.75	128	25	9.357	74.72	14.84
Pacific Sandlance	--	--	--	--	--	--	--	--	--	--
Padded Sculpin	--	--	--	--	--	1	1	.073	85.00	0.0
Prickly Sculpin	--	--	--	--	--	--	--	--	--	--
Redtail Surfperch	--	--	--	--	--	--	--	--	--	--
Saddleback Gunnel	1	1	.052	144.00	0.0	--	--	--	--	--
Sand Sole	7	7	.367	90.71	20.06	39	25	2.851	71.36	18.31
Shiner Perch	3	3	.157	83.33	4.16	1	1	.073	80.00	0.0
Snake Prickleback	--	--	--	--	--	--	--	--	--	--
Staghorn Sculpin	34	15	1.782	126.73	34.35	84	15	6.140	113.87	25.11
Starry Flounder	--	--	--	--	--	--	--	--	--	--
Three-spined Stickleback	5	5	.262	44.40	2.70	--	--	--	--	--
Tomcod	74	15	3.878	125.27	23.31	29	15	2.120	142.13	28.09

Table 5.4. Fish caught at South Reach in otter trawls, December 1980 - May 1981 - continued.

Species	March					April				
	Total number	Number measured	No./100 m^2	Average length	Stand. dev.	Total number	Number measured	No./100 m^2	Average length	Stand. dev.
Bay Pipefish	2	2	.139	193.50	33.23	--	--	--	--	--
Blacktail Snailfish	--	--	--	--	--	--	--	--	--	--
Buffalo Sculpin	--	--	--	--	--	1	1	.063	58.00	0.0
English Sole	15	15	1.042	94.67	29.21	87	25	1.578	93.56	15.93
Longfin Smelt	14	11	.972	81.55	17.78	8	6	.505	92.67	9.77
Pacific Herring	2	2	.139	109.50	10.61	1	1	.063	109.00	0.0
Pacific Sanddab	89	15	6.181	74.87	31.28	34	15	2.146	81.93	10.63
Pacific Sandlance	--	--	--	--	--	--	--	--	--	--
Padded Sculpin	--	--	--	--	--	--	--	--	--	--
Prickly Sculpin	--	--	--	--	--	--	--	--	--	--
Redtail Surfperch	--	--	--	--	--	--	--	--	--	--
Saddleback Gunnel	--	--	--	--	--	--	--	--	--	--
Sand Sole	47	16	3.264	77.44	18.53	18	15	1.136	84.93	7.14
Shiner Perch	--	--	--	--	--	7	6	.442	83.83	18.47
Snake Prickleback	--	--	--	--	--	1	1	.063	150.00	0.0
Staghorn Sculpin	32	15	2.222	113.27	22.78	10	9	.631	114.89	24.86
Starry Flounder	--	--	--	--	--	1	1	.063	132.00	0.0
Three-spined Stickleback	--	--	--	--	--	--	--	--	--	--
Tomcod	194	15	13.472	147.93	32.00	9	6	.568	130.83	21.15

Table 5.4. Fish caught at South Reach in otter trawls, December 1980 - May 1981 - continued.

Species	May				
	Total number	Number measured	No./100 m^2	Average length	Stand. dev.
Bay Pipefish	--	--	--	--	--
Blacktail Snailfish	--	--	--	--	--
Buffalo Sculpin	--	--	--	--	--
English Sole	38	26	1.885	95.96	23.38
Longfin Smelt	368	15	18.254	93.80	9.70
Pacific Herring	--	--	--	--	--
Pacific Sanddab	18	16	.893	115.00	0.0
Pacific Sandlance	--	--	--	--	--
Padded Sculpin	--	--	--	--	--
Prickly Sculpin	--	--	--	--	--
Reftail Surfperch	--	--	--	--	--
Saddleback Gunnel	1	1	.050	74.94	19.17
Sand Sole	2	2	.099	110.00	1.41
Shiner Perch	4	4	.198	106.00	23.42
Snake Prickleback	6	6	.298	183.67	35.91
Staghorn Sculpin	14	14	.694	127.79	23.08
Starry Flounder	1	1	.050	119.00	0.0
Three-spined Stickleback	--	--	--	--	--
Tomcod	35	15	1.736	152.40	11.21

Table 5.5. Fish caught at Point Chehalis in otter trawls, February 1981 - May 1981.

Species	February					March				
	Total number	Number measured	No./100 m^2	Average length	Stand. dev.	Total number	Number measured	No./100 m^2	Average length	Stand. dev.
Bay Pipefish	--	--	--	--	--	--	--	--	--	--
Blacktail Snailfish	--	--	--	--	--	--	--	--	--	--
Buffalo Sculpin	--	--	--	--	--	--	--	--	--	--
English Sole	--	--	--	--	--	2	2	.096	100.50	14.85
Longfin Smelt	--	--	--	--	--	7	7	.335	84.14	22.56
Pacific Herring	--	--	--	--	--	--	--	--	--	--
Pacific Sanddab	--	--	--	--	--	5	5	.239	97.00	14.40
Pacific Sandlance	3	0	.208	--	--	--	--	--	--	--
Padded Sculpin	--	--	--	--	--	--	--	--	--	--
Prickly Sculpin	--	--	--	--	--	--	--	--	--	--
Redtail Surfperch	--	--	--	--	--	--	--	--	--	--
Saddleback Gunnel	--	--	--	--	--	--	--	--	--	--
Sand Sole	--	--	--	--	--	4	4	.192	184.50	121.20
Shiner Perch	--	--	--	--	--	1	1	.048	126.00	0.0
Snake Prickleback	--	--	--	--	--	--	--	--	--	--
Staghorn Sculpin	--	--	--	--	--	4	4	.192	144.50	28.63
Starry Flounder	--	--	--	--	--	1	1	.048	136.00	0.0
Three-spined Stickleback	--	--	--	--	--	--	--	--	--	--
Tomcod	--	--	--	--	--	20	20	.958	167.15	33.10

Table 5.5. Fish caught at Point Chehalis in otter trawls, December 1980 - May 1981 - continued.

Species	April					May				
	Total number	Number measured	No./100 m^2	Average length	Stand. dev.	Total number	Number measured	No./100 m^2	Average length	Stand. dev.
Bay Pipefish	--	--	--	--	--	--	--	--	--	--
Blacktail Snailfish	--	--	--	--	--	--	--	--	--	--
Buffalo Sculpin	--	--	--	--	--	--	--	--	--	--
English Sole	1	1	.035	112.00	0.0	2	2	.146	99.50	3.54
Longfin Smelt	3	3	.104	86.00	6.0	--	--	--	--	--
Pacific Herring	--	--	--	--	--	--	--	--	--	--
Pacific Sanddab	2	2	.069	93.50	2.12	10	10	.731	122.40	28.76
Pacific Sandlance	--	--	--	--	--	--	--	--	--	--
Padded Sculpin	--	--	--	--	--	--	--	--	--	--
Prickly Sculpin	--	--	--	--	--	--	--	--	--	--
Redtail Surfperch	--	--	--	--	--	--	--	--	--	--
Saddleback Gunnel	--	--	--	--	--	--	--	--	--	--
Sand Sole	--	--	--	--	--	6	6	.439	95.83	28.39
Shiner Perch	6	5	.208	114.00	6.20	--	--	--	--	--
Snake Prickleback	--	--	--	--	--	--	--	--	--	--
Staghorn Sculpin	2	2	.069	141.00	7.07	--	--	--	--	--
Starry Flounder	--	--	--	--	--	--	--	--	--	--
Three-spined Stickleback	--	--	--	--	--	--	--	--	--	--
Tomcod	2	1	.069	132.00	0.0	--	--	--	--	--

species, Pacific sandlance, was present only at this station. Tomcod were abundant only in the March trawl; no other species were abundant in any month. Only three fish, all Pacific sandlance, were caught in the February trawl. In general, fewer fish were caught at this station than at any other station for which fish catches were recorded. Species of low abundance included Pacific sandlance, English sole, longfin smelt, Pacific sanddab, sand sole, shiner perch, staghorn sculpin and starry flounder.

North Bay: Ten species were present in samples from North Bay (Table 5.6). Longfin smelt were abundant in February. English sole and sand sole were both abundant in March. Less abundant species included bay pipefish, Pacific herring, Pacific sanddab, redtail surfperch, staghorn sculpin, three-spined stickleback and tomcod.

5.3.2 Size Distribution: The mean and standard deviations of the total lengths for fish species in trawls are recorded along with density estimates in Tables 5.1 through 5.6. Size and age classes might be discerned from the modal lengths of each species. Actual lengths for each measured fish are included in Appendix C, but modes were not analyzed.

5.3.3 Summary of Number of Fish and Fish Species: The number of fish caught in trawls was plotted (Figure 5.1) by site and date to summarize total fish densities, including all species. The number of fish species at each date and station were also summarized.

Table 5.6. Fish caught at North Bay in otter trawls, February 1981 - March 1981.

Species	February					March				
	Total number	Number measured	No./100 m^2	Average length	Stand. dev.	Total number	Number measured	No./100 m^2	Average length	Stand. dev.
Bay Pipefish	2	2	.116	120.00	11.31	--	--	--	--	--
Blacktail Snailfish	--	--	--	--	--	--	--	--	--	--
Buffalo Sculpin	--	--	--	--	--	--	--	--	--	--
English Sole	--	--	--	--	--	31	25	1.389	77.72	7.95
Longfin Smelt	25	25	1.447	65.20	23.71	--	--	--	--	--
Pacific Herring	5	5	.289	76.60	39.02	4	4	.179	92.25	2.63
Pacific Sanddab	2	2	.116	84.50	14.85	5	5	.224	81.00	3.54
Pacific Sandlance	--	--	--	--	--	--	--	--	--	--
Padded Sculpin	--	--	--	--	--	--	--	--	--	--
Prickly Sculpin	--	--	--	--	--	--	--	--	--	--
Redtail Surfperch	2	2	.116	161.50	33.23	--	--	--	--	--
Saddleback Gunnel	--	--	--	--	--	--	--	--	--	--
Sand Sole	2	2	.116	55.00	2.83	14	14	.627	99.64	61.51
Shiner Perch	--	--	--	--	--	--	--	--	--	--
Snake Prickleback	--	--	--	--	--	--	--	--	--	--
Staghorn Sculpin	2	2	.116	108.00	12.73	2	2	.090	112.50	9.19
Starry Flounder	--	--	--	--	--	--	--	--	--	--
Three-spined Stickleback	--	--	--	--	--	3	3	.134	40.67	.58
Tomcod	1	1	.058	108.00	0.0	1	1	.045	95.00	0.00

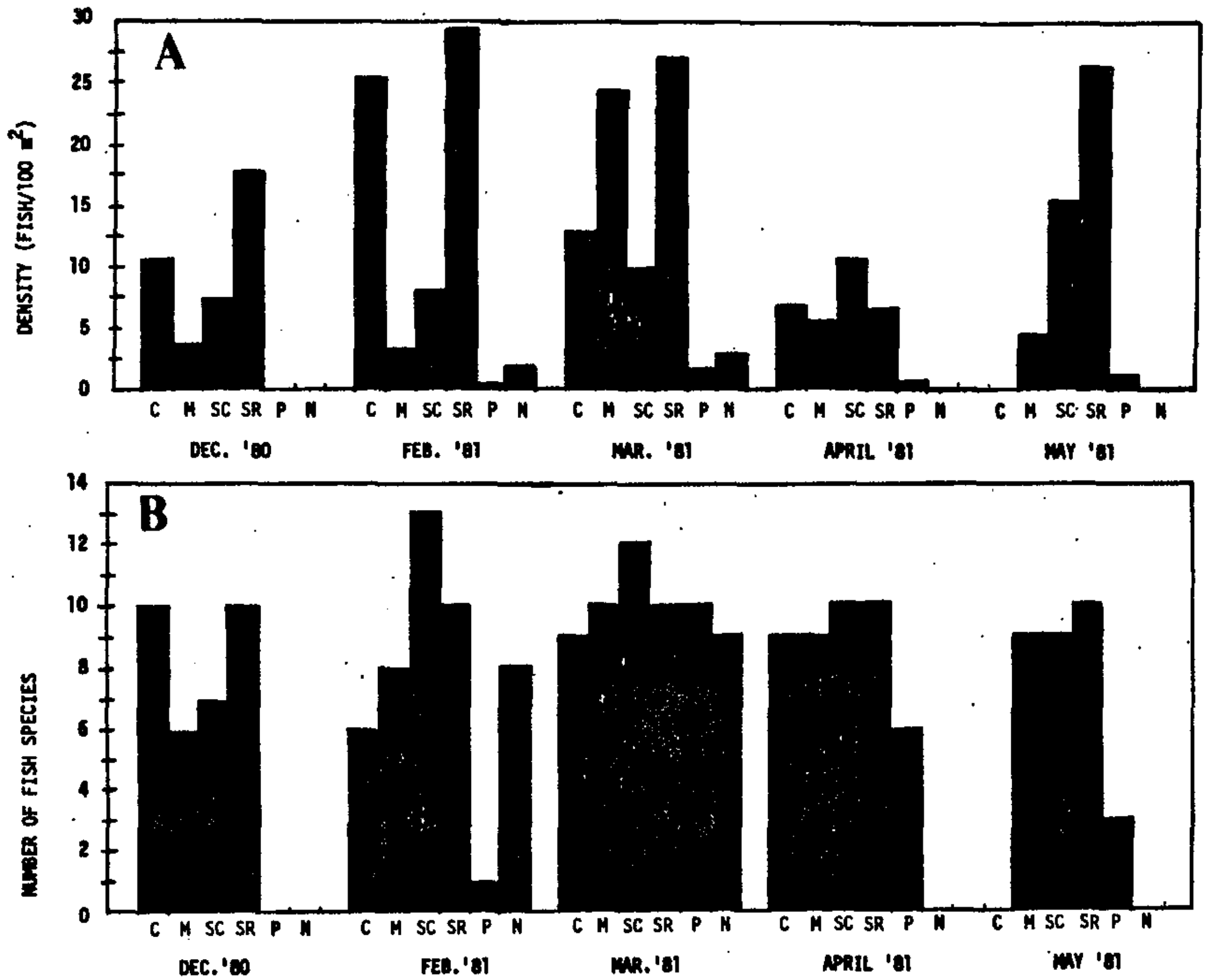


Figure 5.1. A. Density of all fish species taken by trawls from six stations in Grays Harbor, Washington.
B. Number of fish species at each station. The stations are as follows: C = Cow Point, M = Moon Island, SC = South Channel, SR = South Reach, P = Point Chehalis (Buoy 13), N = North Bay. Stations with no histogram bars represent missing data.

5.4 Discussion

5.4.1 Changes in Dominant Species Among Stations: Cow Point, Moon Island and South Reach were chosen as sampling stations because these areas of the navigation channel are currently maintained by annual dredging, and will be dredged to a greater depth if the channel is enlarged. The South Channel station was selected so that fish densities and fish species in this undredged channel could be compared with densities and species in the frequently dredged North Channel. Point Chehalis (buoy 13) is currently utilized as a subtidal disposal site.

North Bay and Point Chehalis were similar in that fewer fish species and individuals were caught at those stations than at stations of the inner harbor. At Point Chehalis, tomcod were the only species abundant, and then only in the March trawl. North Bay samples sometimes included abundant numbers of English sole, sand sole and longfin smelt. Low overall fish catches at Pt. Chehalis may reflect a decrease in sampling efficiency at this outer harbor station. Wave and current action might have lifted the net off-bottom more frequently here than at the relatively calmer inner harbor stations.

South Reach, South Channel, Moon Island, and Cow Point all showed the same dominant species in trawls made December through May. These were tomcod, longfin smelt, staghorn sculpin, and English sole. Shiner perch were abundant at South Reach but not at other locations. Part of the reason these fish dominate the samples may be because they are more susceptible to the gear than other fish in the area.

5.4.2 <u>Seasonal Distribution and the Possible Role of Salinity</u>: Salinity in the Grays Harbor Estuary usually decreases in the winter due to increased freshwater input from rivers (mainly the Chehalis River), then increases in the summer as river flows decline. The magnitude of the effect depends on the distance from the mouth of the Chehalis River and might also be affected by tide stage, amount of rainfall, and degree of oceanic upwelling.

Salinity changes may partially explain the seasonal distribution of fish in the harbor. Three-spined stickleback, for example, were caught in higher numbers in the winter and prickly sculpins were only caught in the early spring at the station closest to the the Chehalis River mouth, Cow Point. These fish may require or prefer the lower salinity conditions likely found in these areas in winter and early spring, and otherwise would be found only upriver.

Sand sole and shiner perch were examples of fish that were found in greater numbers at outer harbor stations or at inner harbor stations later in the summer. These fish may need higher salinities than other estuarine fish.

Many fish were more abundant in spring samples than winter samples, possibly due to a general inshore migration for most species in summer.

5.4.3 <u>Interpretation of Groundfish Data</u>: Fish caught in trawls from April through September 1980 were processed and recorded by Simenstad et al. (1981). Any interpretations about distribution and abundance for Grays Harbor bottomfish should include that data. Groundfish data in our report were meant to be a supplement to, and continuation of, work done by Simenstad et al.

5.5 Summary

1) Of the six stations from which fish were saved from December 1980 through May 1981, South Reach consistently had the highest densities of fish and highest number of fish species (Figs. 5.1).

2) Four species of fish were most frequently caught by trawls, throughout the harbor. These were tomcod, longfin smelt, staghorn scuplin and English sole.

3) Prickly sculpins and three-spined stickleback may move from freshwater to the inner harbor in winter and early spring since densities of these freshwater fish were increased in the winter at Cow Point.

4) Sand sole and shiner perch had greater densities in the outer harbor stations than in the inner harbor stations.

5) The bottomfish trawl data in this report (December 1980 - May 1981) should be included with similar trawl data (April 1980 - September 1980) reported in Simenstad et al. (1981) to interpret seasonal trends in bottomfish distribution and abundance.

6.0 DREDGE ENTRAINMENT STUDIES

James C. Hoeman and David A. Armstrong

6.1 Introduction

To our knowledge, only two previous studies of dredge entrainment have been done in the United States. Both of those studies, sponsored by the USACE, Seattle District, were on the impact of dredge entrainment on Dungeness crabs in Grays Harbor. Tegelberg and Arthur (1977) tried to monitor entrainment by the hopper dredge BIDDLE with the use of an airlift sampler. This sampler recovered 1% of the crabs artificially inserted into the hopper and was considered too inefficient and unreliable to use repeatably as a monitoring device. High crab entrainment rates were observed but it was difficult to accurately quantify the data by this sampling method.

Stevens (1981) sampled several different dredges by straining the discharged material with nets or steel baskets in order to calculate entrainment and mortality rates for each type of dredge used in Grays Harbor. Entrainment rates were calculated in terms of organisms entrained per cubic yard (cy) of sediment dredged so that these rates could be compared for different dredge types, seasons, and areas. Hopper and clamshell dredges were found to entrain 0.223 and 0.012 crabs/cy, respectively. Estimates of mortality caused by entrainment considered immediate injury, delayed mortality after disposal of sediments, and biases caused by sampling protocol. An overall estimate of 59% mortality of crabs entrained by a hopper dredge was given (see Section 6.5 for further discussion of that study).

6.1.1 Objectives of the Present Study: The port of Grays Harbor and the U.S. Army Corps of Engineers have proposed to widen and deepen the existing Grays Harbor navigation channel so that larger ships can utilize the harbor. The width would increase from 107 m (350 ft) to 122 m (400 ft) seaward of Aberdeen and from 61 m (200 ft) to 107 m (350 ft) near Aberdeen. In addition, two turning basins, one at Cow Point and another north of Cosmopolis, would be constructed. The depth would increase from 122 m (40 ft) to 13.7 m (45 ft) MLLW at the channel entrance and from an average of 10.7 m (35 ft) to 12.2 m (40 ft) from Westport to Cosmopolis (Loehr and Collins 1981). The proposal would involve initial removal of about 20 million cy of sediment and a 1.5 million cy increase in annual maintenance dredging.

The goals of the dredging entrainment study were to:

1) Obtain entrainment rates for *C. magister*, other invertebrates, and fish by hopper and pipeline dredges operating in two areas and seasons, specifically winter and summer;

2) Modify the basket-sampling system developed by Stevens (1981) to capture smaller crabs on hopper dredges, particularly young-of-the-year crabs below 35 mm carapace width which are abundant in Grays Harbor during spring and summer;

3) Calculate hopper dredge entrainment rates of *Crangon* shrimp, benthic fish species, and salmonid smolts;

4) Develop an improved method for sampling pipeline dredge discharge for salmon, benthic fish, shrimp, and crab entrainment;

5) Estimate the impacts of widening and deepening operations on the epibenthic macrofauna of Grays Harbor; and

6) Formulate recommendations designed to attenuate these impacts.

6.2 Materials and Methods

Pipeline dredges were sampled in two different seasons (summer and winter/spring) but in only one general location, the Port of Grays Harbor terminals in Aberdeen. In the summer of 1980, 351.34 cy of sediment were sampled from the pipeline dredge MALAMUTE. In a separate experiment 60.86 cy of pure water were sampled while the draghead was lifted off-bottom. A pipeline dredge will occasionally lift its drophead off-bottom and pump pure water in order to clear the discharge pipe of sediment. Since this will occur at times during normal dredging operations fish which spend more time in the upper water column might be more vulnerable to entrainment when the draghead is off-bottom. Specifically, the test was conducted to see if juvenile salmon might be entrained more frequently under these circumstances. In the winter and early spring of 1981, 934.96 cy of sediment were sampled from the pipeline dredge McCURDY.

The hopper-barge Manson #56 (SANDSUCKER) was sampled in four locations from May to September 1980. This dredge did not operate in any other season during the contract period. Another hopper dredge, the HARDING, did operate in Grays Harbor in the winter of 1980 but was impossible to sample with the present methods because the sediment was discharged from only two high-velocity central ports as compared to 21 lower velocity exit ports on the SANDSUCKER. The high velocity would have filled the sampling baskets too rapidly. Results from a previous study on the SANDSUCKER (Stevens 1981) did provide excellent data for a comparison between winter and summer Dungeness crab entrainment rates in what turned out to be the most critical entrainment area, the South Reach section of the Grays Harbor navigation channel. A total of 1,204.93 cy were sampled on the SANDSUCKER in the present study.

6.2.1 Hopper Dredge Description and Study Area: The SANDSUCKER had been modified since it was last sampled by Stevens (1981). Instead of having one intake arm, pump, and discharge pipe, it now has two independent dredging units (Fig. 6.1). The original discharge pipe and accompanying pump are 50.8 cm (20 in) in diameter. The pump impels dredged material from the suction head, through the movable intake arm then into the barge via 11 exit holes in a centrally located discharge pipe. The secondary discharge pipe and pump are 40.64 cm (16 in) in diameter. This pipe has 10 exit holes with splash plates located under each to direct dredged material to the center of the barge. Both pumps can work simultaneously so this modification reduced the required time to fill the barge from three hours to an hour and twenty minutes. The barge usually holds from 1300 to 1600 cy of dredged material.

The SANDSUCKER was pushed by a tug to the site to be dredged, then slowly propelled while the dredge was operating. Two passes were

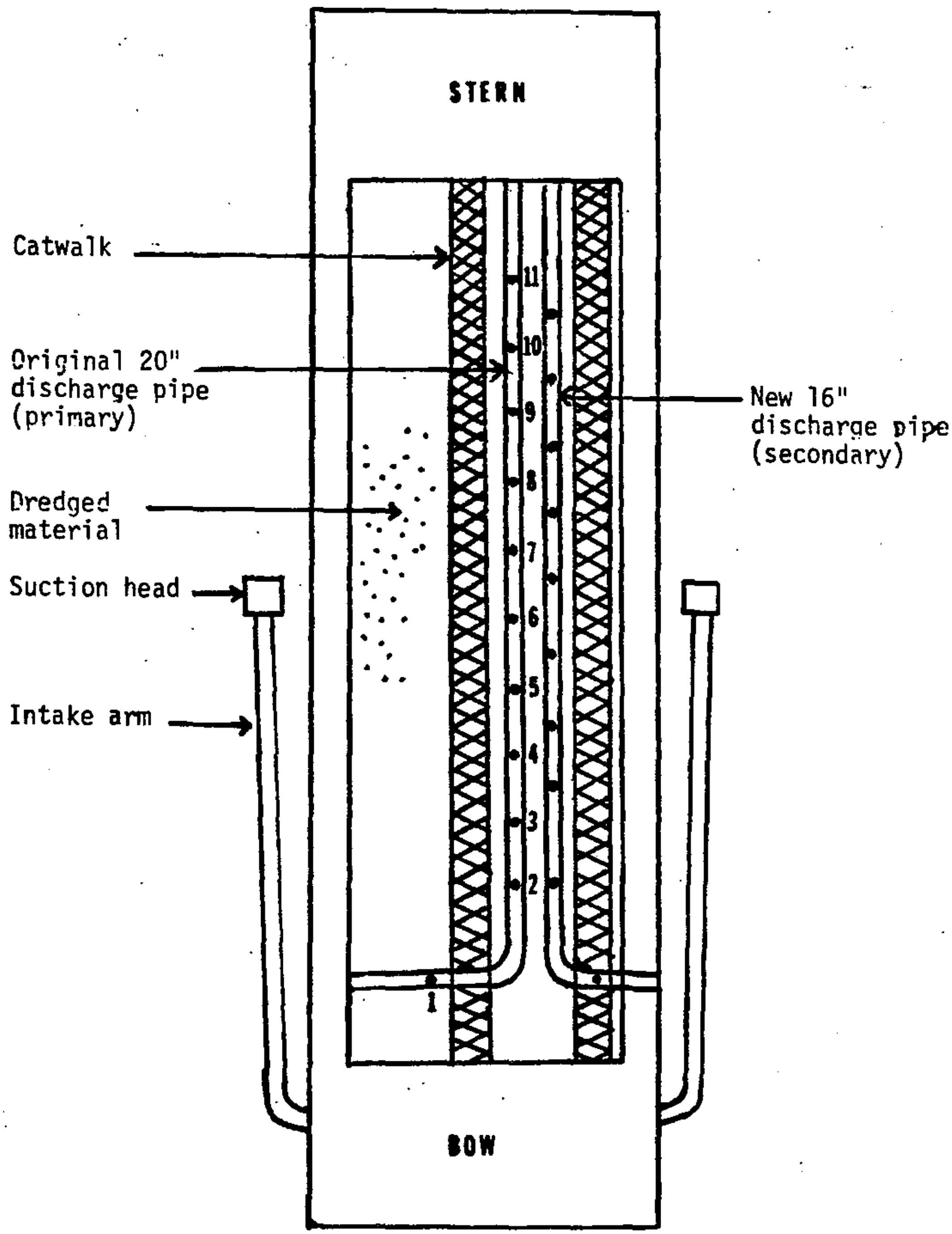


Fig. 6.1. Design of Manson barge #56 (SANDSUCKER) after Stevens (1981). Holes on the primary discharge pipe are numbered from bow to stern. Scale 1:300 (1" = 25').

typically made over the work area while both suction heads worked in vacuum cleaner fashion to remove sediment. Once the barge was full it was taken to an outer harbor site near buoy 13 where sediment was disposed. The time required to travel to the dump site depended on where dredging took place. The round trip required 1-1/2 hr from South Reach and 5 hr from Cow Point. The SANDSUCKER operated 24 hr a day with most time being spent going to and from the disposal area.

The study area included four sections of the Grays Harbor navigation channel (Fig. 6.2). The Crossover Channel was sampled between navigation buoys 25 and 30 on 29 and 30 May, 6 and 7 June, and 3 and 4 September 1980. South Reach was sampled between buoys 14 and 21 on 1, 2, 18 and 19 July 1981. North Channel was sampled between buoys 32 and 33 on 20, 21 and 22 August 1980. Cow Point was sampled between Port of Grays Harbor terminals T-2 and T-4 (Fig. 6.3) on 20 and 21 June 1980. Night sampling was attempted on 6 June 1980 in the Crossover Channel.

6.2.2 Sampling Methods and Gear Aboard the Hopper Dredge SANDSUCKER: Protocol and gear used to sample the discharge pipe aboard the SANDSUCKER were the same as described by Stevens (1981) except that the mesh size on the metal collapsible sampling baskets was reduced to increase sampling efficiency for young-of-the-year Dungeness crabs and outmigrating salmon fry and smolts. These baskets were 35.6 cm x 40.6 cm x 76.2 cm (14 in x 16 in wide, and 30 in deep). The outside mesh was diamond-shaped with lengths of 44 mm (1 3/4 in) on the long axis and 16 mm (5/8 in) on the short axis. A plastic liner of

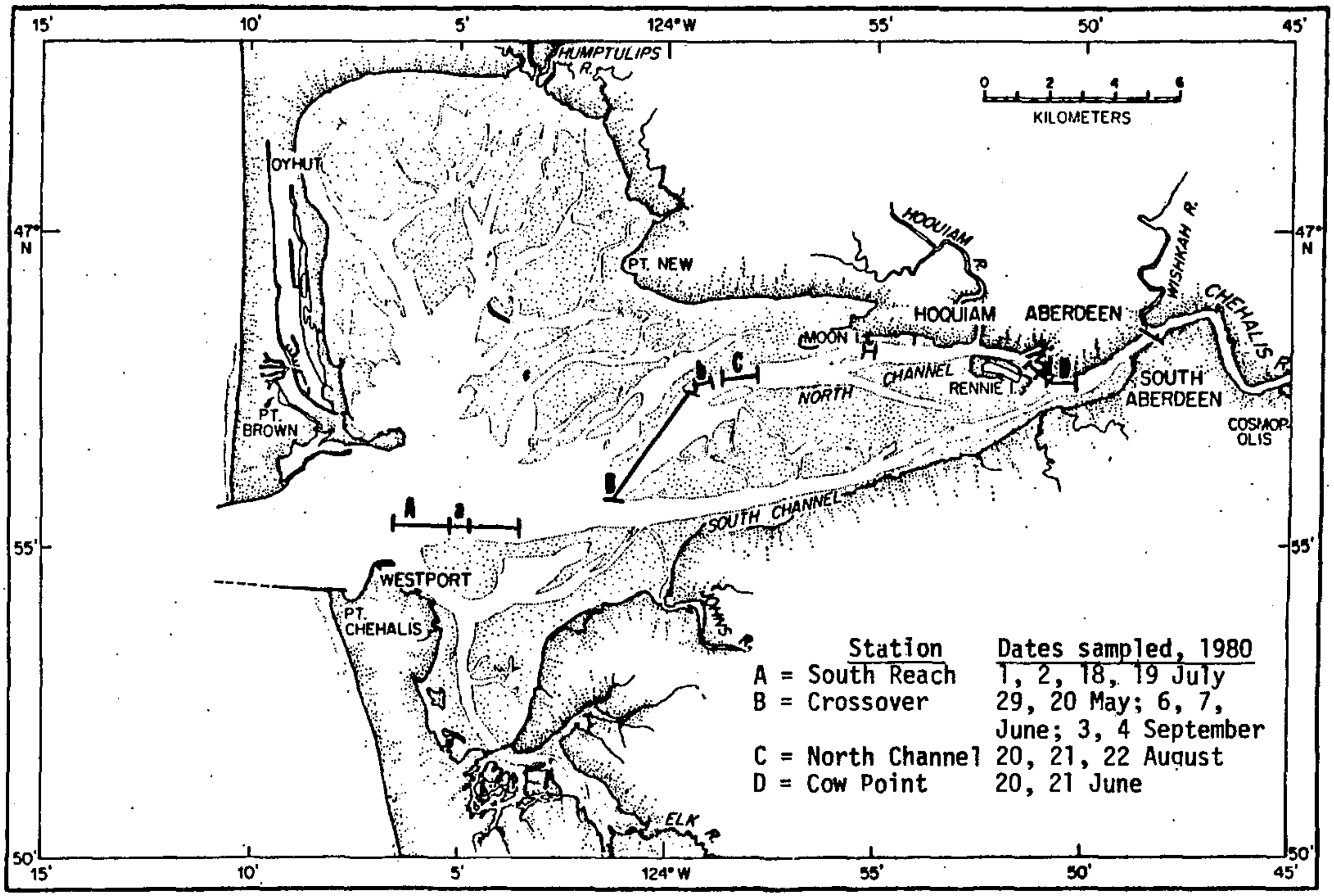


Fig. 6.2. Sampling locations for the hopper dredge #56 (SANDSUCKER) in Grays Harbor. Small letters represent trawl sites from which fish and crabs were compared to those caught at dredge sampling sites (corresponding large letters).

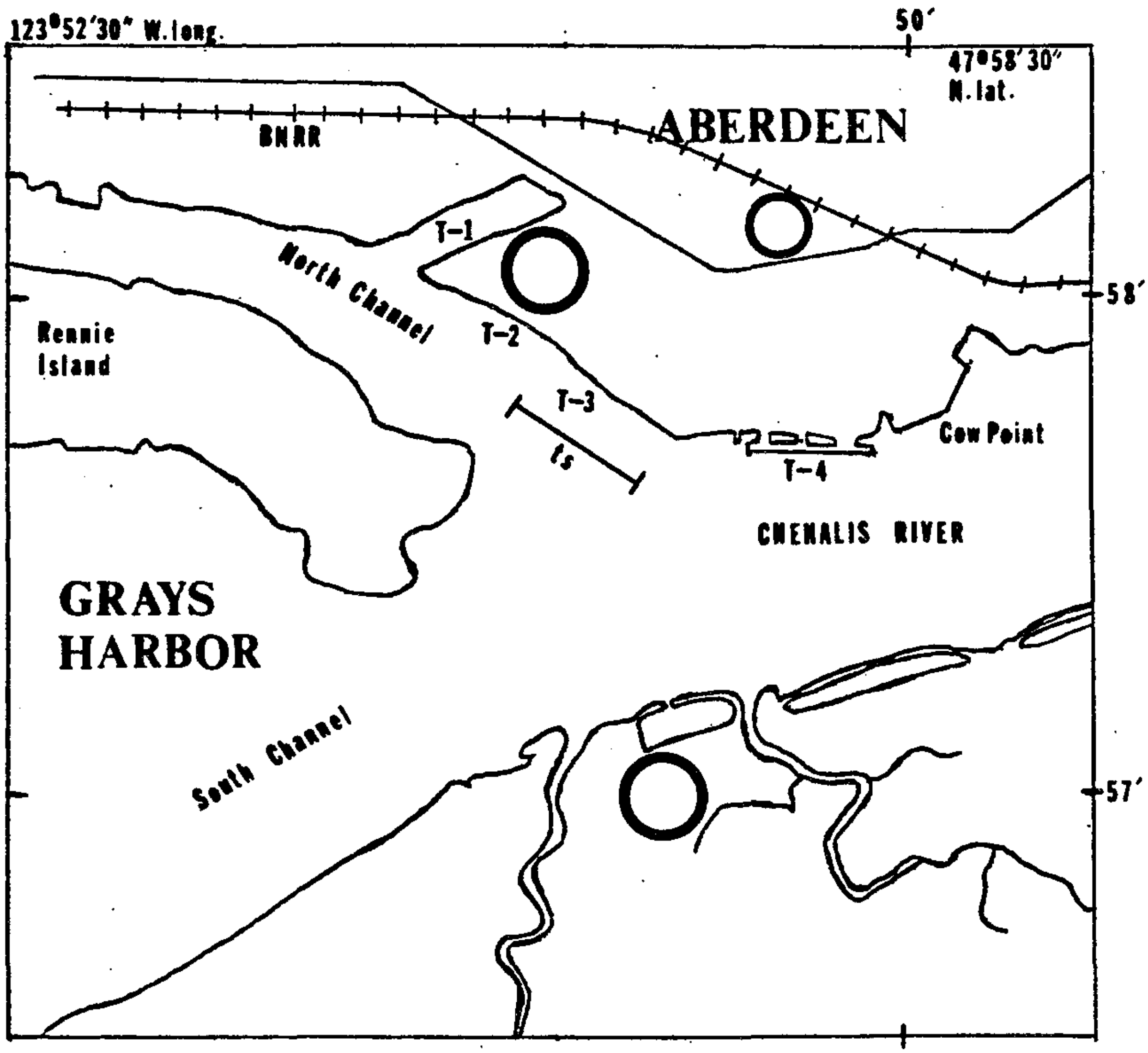


Fig. 6.3. Pipeline dredging and disposal sampling locations. T-1 through T-4 represent shipping terminals 1-4. Circles represent sites of dredged material disposal where actual sampling occurred. Fish and crabs taken from Cow Point trawl site (ts, 500 m) were compared to pipeline entrainment rates.

Dupont Vexar with 12.7 mm (1/2 in) mesh was attached to the inside of the baskets. This reduced the overall mesh size to something less than 12.7 mm due to the overlay of outside and inside mesh in many places.

The baskets were positioned under discharge exit holes of the primary discharge pipe with the aid of a block and tackle suspended from a davit. The davit was put into a standard welded onto the pipe above the exit hole. This davit was free to swing in the standard so that the basket could be hoisted over the pipe from the catwalk then swung into position under the exit hole. Once the basket was adjusted to a position where it would catch most of the flow it was held in place by the block and tackle, chains, and long metal hooks. Each sample run was timed to the nearest second with a stopwatch and from 10 sec to 15 min depending on how fast the baskets became clogged with debris. Splashing prevented the basket from catching 100% of the flow so a visual estimate was made of the percentage of flow exiting a hole that actually passed through the basket. These estimates were in 10% intervals and ranged from 30-80% of the flow at each hole. When the baskets were about half full they were hoisted back over the discharge pipe and onto the catwalk. The baskets were opened up and the contents sorted for organisms that had been entrained by the dredge. A water hose was often used to help separate mud from fish, crabs, and other invertebrates in the sample. Sampling was easiest in the South Reach because the sediment was mostly sand and flowed readily through the basket mesh. Cow Point was difficult to sample because mud balls would quickly clog the baskets. Some sections of the Crossover Channel were also difficult where broken shells and sand filled the basket quickly.

Only the primary discharge pipe could be sampled with hanging baskets because the splash plates on the secondary pipe prevented a vertically suspended basket from catching the flow. Although the secondary (unsampled) pump and discharge pipe was smaller in diameter than the primary (16 in compared to 20 in), the proportion of total discharge exiting each pipe was roughly equal. This smaller pump was able to pump as much sediment as the larger one because the pump itself was located on the drag arm, closer to the suction head while the 20-in pump was located below the deck (dredge operators, personal communication).

6.2.2.1 Sample Quantification: The percent of the total discharge exiting each hole sampled had to be estimated in order to quantify entrainment rates. To do this, it was first assumed that 50% of the total discharge exited through the primary discharge pipe (dredge personal judged the proportion of the total discharge in each pipe to be roughly equal and there was no way to quantify this to obtain a more accurate estimate). Next the pattern of sediment flow and discharge through the pipe was considered. The amount of material exiting the first hole was less than that discharged through the next few holes, apparently due to an elbow in the discharge pipe which slowed the velocity of the sand-water mixture past that point (Fig. 6.1). Hole number two was blocked off during all sampling time on the SANDSUCKER. The amount of sediment discharged through holes 3-11 decreased with distance along the pipe.

Almost no material was discharged through holes 10 and 11 when the sediment dredged was other than pure sand. Therefore a separate estimate was made for the percent of discharge exiting each hole depending on whether the sediment was pure sand (as in the South Reach) or a mixture of mud and sand (as was encountered in the other areas sampled). The percentage estimates of discharge rates used in the South Reach were similar to those reported by Stevens (1981), except that all discharge holes were opened and only a single discharge pipe used in his study. Estimates of the percent of total discharge exiting each hole are given in Table 6.1.

Table 6.1. Visual estimates of percent of the total discharge exiting the sampled (primary) discharge pipe on the SANDSUCKER, in areas of two different sediment types. The individual estimates for each hole were arbitrarily assigned to add up to 50% of the total discharge of dredged material which was assumed to exit this pipe.

Station	1	2	3	4	5	6	7	8	9	10	11
South Reach[1/]	2.5	0.0	7.5	7.0	6.5	6.0	5.5	4.5	4.0	3.4	3.0
Crossover, North Channel, Cow Point[2/]	2.5	0.0	10.0	9.0	8.0	7.0	6.0	5.0	1.5	1.0	0.0

[1/]Sediment was marine sand. Percents are based on the same visual estimates used by Stevens (1981), except that they are reduced by half since now there are two discharge pipes instead of one on the SANDSUCKER. In addition, hole number two was blocked off in this study but was open when this dredge was sampled by Stevens. To allow for this change a small percentage was added to holes following hole number two.

[2/]Sediment was mixed mud, sand, and wood debris. These visual estimates reflect the fact that softer sediment would fall through holes 3-8 quicker and almost never reach holes 9-11.

Because of differences in sedimentation rates, heavier material might be expected to drop from the first few holes and lighter material from the last few. Crabs or fish might be more likely to exit certain holes on the basis of their density or behavior during entrainment. Therefore several different holes along the length of the pipe were sampled in each operating area of the bay to obtain an unbiased estimate of total dredge entrainment. The holes usually sampled were numbers 3, 5, 7, and 9. The number of cubic yards sampled in any run could be calculated from the sediment pumping rate (determined by dredge operators), the sampling time in minutes, the percent of total material exiting at a particular hole (% discharge), and the percent of discharged material that entered the basket at each hole (% flow). Each run was converted to units of discharge minutes (Dm), where one Dm represented 100% of the total dredge discharge from one minute of dredging.

$$\text{Dm} = (\text{sample time}) \times (\%\ \text{flow}) \times (\%\ \text{discharge})$$

The number of organisms from all sample runs during a hopper load were summed then divided by the number of cubic yards sampled in that barge load to estimate the entrainment rate (organisms entrained per cubic yard of sediment dredged). It was necessary to use volume of sediment discharged as a basis for entrainment rates because the area dredged and the volume of water associated with the sediment were unknowns. Most animals entrained are present on the sediment surface but there was no way to tell when the suction head was sucking sediment from the top layer or when it was buried deeper in the substrate. However, entrainment rates (organisms/cubic yard) are sufficient to compare different dredges and to obtain useful estimates of the number of crabs that will be entrained by any given dredge operation. Barge loads (rather than sample runs or days-sampling in one area) were used as a replicate unit for statistical tests because the rate of sediment pumping could be most accurately gauged from the time required to fill the hopper to a level of known volume. Both the pumping time and the volume of dredged material varied with every load, and this information was provided by dredge operators. For example, if 80 min were required to fill a barge with 1,400 cy then the dredge was pumping at a rate of 17.5 cy/min for that load. If 10 crabs were found in 4 Dm of sampling time then the entrainment rate was (10 crabs)/((4 Dm) x (17.5 cy/min)) = 10 crabs/70 cy = 0.143 crabs per cubic yard.

6.2.2.2 Specimen Treatment: Crabs were sexed and measured to the nearest millimeter across the back of the carapace between the notches anterior to the tenth anterolateral spines (carapace width). Fish were identified and measured to the nearest millimeter in total length (tip of the snout to tip of the caudal fin). Sand shrimp (Crangon sp.) and Ghost shrimp (Callianassa californiensis) were counted but not measured.

Samples always contained bits and pieces of broken crabs, which were converted to number of whole crabs as follows: pieces were sorted into piles of similar kind, e.g., legs, claws, abdomens, or carapace sections. The number of original crabs was derived from each pile independently by different criteria. One crab was counted for each 8 legs, 2 claws, 1 abdomen, or carapace sections larger than 50% of the original. The largest number of crabs necessary to account for the parts in any one of these categories was deemed to be the number entrained in that sample. Crabs and fish were recorded as alive or dead when removed from the sampling baskets. A number of additional calculations were required to arrive at an overall mortality rate that considered both immediate and delayed mortality.

Stevens (1981) found differences in the ratio of dead to live crabs depending on whether they were collected in sampling baskets or on the surface of the discharge mass on the SANDSUCKER. More dead crabs were found in the basket, a result that implies crabs are crushed and killed by the high velocity discharge of rocks and other debris which would impact crabs in the basket but not on the surface of sediments in the hopper. Stevens found that 61% of crabs collected in baskets on the SANDSUCKER were dead while only 30% of the crabs collected by hand from the dredged material surface were dead. Both these estimates were biased in opposite directions; some mortality of crabs in baskets is caused by the trauma of high velocity discharge and crushing by debris, which gives and overestimate from baskets, while live crabs would be expected to work to the surface of sediments in the hopper and be hand collected more readily thant dead crabs or crab parts. Dredge-induced mortality was estimated as 45%, the mean of 30% and 61%. Therefore Stevens best estimate for sampling-induced mortality was 16%, i.e., the difference between mortality caused by the dredges and total mortality observed in baskets. Steven's estimate of 16% was used in this study.

Delayed mortality of crabs after disposal can result from injury and stress caused during entrainment. Stevens (1981) placed live crabs from sample baskets in a flow-through aquarium for 96 hr and estimated a delayed mortality of 19%. These results included a control for crabs exposed to the air for the length of time experienced by those entrained. In summary, the overall mortality rate for Dungeness crabs entrained in this study was computed by first reducing the number dead in the sample baskets by 16% (to account for sampling mortality), then increasing the rate by 19% (to account for delayed mortality). This estimate is still very qualitative because mortality is size dependent (small crabs better survive entrainment), and injured animals that survive entrainment and disposal are probably still more likely to be preyed upon. Further, retention of young-of-the-year, first through third instars, in sample baskets is probably very low because of the 12.7 mm mesh liner used. This observation may be particularly relevant in the outer harbor where sand sediments and small debris reduce clogging of baskets, and young-of-the-year are most abundant (<u>see</u> Section 2.3). Therefore, total estimates of entrainment and mortality of crabs by the hopper dredge are probably conservative.

An attempt was made to sample for live fish that might escape the barge through the water-overflow, used to drain excess water from the hydraulically pumped slurry. Fish surviving entrainment might be expected to find their way out of the barge via these ports while crabs would likely try to maintain their position near the sediment surface. A metal ring with a diameter of 85.1 cm (33.5 in) and covered with 12.7 mm

(0.5 in) mesh was lowered over one of the water-overflow ports but the ring became clogged with suspended sand so quickly it was nearly impossible to retrieve, and such sampling was abandoned.

6.2.3 Pipeline Dredge Description and Study Area: Pipeline dredges, unlike hopper dredges, are usually confined to nearshore areas and calm water. They are anchored to the bottom by four steel cables. Instead of discharging dredged material on a barge, it is piped to either a land disposal site or an open water disposal site. Therefore, the area a pipeline dredge can cover is limited by the length of pipe necessary to reach its disposal site. The intake arm of a pipeline dredge is actually a cutter-head with rotating blades which are driven into the sediment. Winches are required to position the dredge and swing the cutter head back and forth because the floating dredge has no other means of propulsion.

Two different pipeline dredges were sampled during this study. The MALAMUTE is a 41 cm (16 in) diameter dredge that was sampled while operating in the Cow Point area near Aberdeen from April to May of 1980. Sampling took place on 2 and 3 May at the Port of Grays Harbor terminal Number 4 (T-4) and again on 15 May when the dredge was operating at T-1 (Fig. 6.3). The disposal site on 2 and 3 May was on the north side of the harbor near the terminals. Sampling was scheduled for 16 and 17 May but the water level was too high in the land disposal contaminent area. The sampling techniques used required dry land below the discharge pipe to stand on.

The pipeline dredge McCURDY had a 66 cm (26 in) diameter pipe/pump and was operating at T-3 (a new terminal) during February and March 1981 (Fig. 6-3). It was sampled 20 and 21 February and 13 March at the discharge site on the south side of the harbor, and on 14 March at a discharge site north of the Port of Grays Harbor terminals. The sediment type from all pipeline samples was mostly soft mud and wood debris. On 14 March, however, the McCURDY was dredging into a previously undisturbed bank area and the sediment there was mostly rocks and cobble.

6.2.4 Sampling Methods and Gear for the Pipeline Dredges MALAMUTE and MCCURDY: The MALAMUTE had been sampled previously by Stevens (1981) in the Cow Point area and in the Westport Marina. The sampling techniques employed in that study used a U-shaped basket supported under the discharge pipe by a backhoe. The basket was strapped to the end of the extended shovel of the backhoe by chains. A different method used in this study consisted of a net placed at the perimeter of the discharge area through which effluent flowed. A net 15.24 m long (50 ft) and 1.83 m wide (6 ft) with a mesh size of 12.7 cm (0.5 in) was stretched across a channel of water flowing away from the discharge point. Fence posts and metal stakes were initially used to support the net but this method proved impractical because the net quickly became clogged with debris, and the high velocity current washed away the fence posts and stakes. Instead, the top of the net was held by hand by two people at the boundaries of the channel while the footrope was dropped and quickly stood upon to hold the net in place. If the channel was wide, a third person held the top and bottom of the net in the middle of the channel. In all samples the footrope was held as tightly as possible on the bottom of the channel, but flow around the sides of the net was sometimes uncontrollable. When the net became heavy with debris the footrope was picked up and joined with the top rope so that all debris and entrained organisms would be contained in the net which was now folded in half. The sample was brought to shore and sorted. Each sample period was timed to the nearest second with a stopwatch. The average rate of sediment pumping that day was obtained from dredge operators or contract reports.

6.2.4.1 Sample Quantification: The velocity of the sediment/water discharge from the pipe was so great that a semi-permanent plunge-basin was usually formed directly underneath the pipe. The pool of water in this basin was several feet deep, and a number of individual channels of water with suspended materials left it in different directions. Instead of attempting to sample the total discharge, the net was stretched over a single channel and the percent of the total discharge sampled was estimated visually. The possibility that entrained crabs and fish would remain buried in the plunge-basin was remote because no build-up of light material was evident in the basin when the dredge shut down, indicating that high discharge velocity allowed only heavy rocks to drop close to the pipe. Therefore, it was assumed that entrained organisms would be swept into the channels of water leading away from the pipe. These channels were sampled as close to the plunge-basin as possible to avoid loss of organisms due to burial before they reached the net.

Channels that represented less than 20% of the total discharge could be sampled most efficiently by this net method, however, one could argue that a disproportionate number of entrained organisms might be swept into the larger channels with greater current velocities.

The computation of entrainment rates was simpler for the pipeline than the hopper dredge since 1 Dm = (sample time in minutes) x (% of the total discharge sampled by the net). The number of cubic yards sampled could be obtained by multiplying the number of discharge-minute units sampled times the average rate of sediment pumping for that day. The sample replicates in this case were days sampled. Samples from both pipeline dredges in all port terminal areas (T-1, T-2, T-3, and T-4), were considered to be from the same location because of their close proximity.

6.2.4.2 Specimen Treatment and Mortality Estimation: Fish and crabs were measured as described for the hopper (see Section 6.2.2.2). The proportion of dead to live crabs and fish was recorded to estimate immediate mortalty for organisms entrained by the pipeline dredges. However, the total mortality rate was assumed to be 100% because of the difficulty in escaping the enclosed, landbased, disposal containment area. Some water did flow from the disposal site back into the harbor, but only after traveling a circuitous route past many waiting seagulls, which were observed preying on entrained fish.

6.2.5 Analysis of Dredge Entrainment Data: The variance and standard deviation about the mean for entrainment rates per barge load on the hopper dredge were computed for Dungeness crab and Crangon shrimp. One-way ANOVA tests were performed on the mean entrainment rates per load, or per day sampled, depending on which data was being compared. A check was made for significant differences between the hopper dredge in different areas in the same season, in the same area in different seasons, and between the hopper dredge and the pipeline dredge operating in the same area and season. The mean entrainment rate for Dungeness crabs was the dependent variable tested in all ANOVA tests. Pipeline mean entrainment rates were tested for significant differences between different seasons at one location, and between two different areas in one season. It was necessary to use data collected in a previous study (Stevens 1981) to make some of these comparisons.

Bimonthly and monthly trawl samples taken in the Grays Harbor navigation channel during the Dungeness crab distribution study (Section 2.0) provided data on the abundance and species composition of fish and crabs in the areas where dredges had been operating. The density of fish and crabs in the trawl samples was compared to the dredge entrainment rates in those areas at the time the dredge samples were taken to learn if crabs and fish were avoiding the dredge. The average sizes of crabs and fish entrained were also compared to the average sizes collected in the trawls to determine if the dredge was size selective. The materials and methods used in trawl sampling are described in Section 2.2 of this report.

6.3 Results

6.3.1 Species Composition of Organisms Entrained by the Hopper and Pipeline Dredges: Dungeness crab and crangonid shrimp were entrained in greater numbers throughout the harbor than any other organisms, so entrainment data for these crustaceans is presented in greater detail than data for fish and other invertebrates. Highest entrainment rates of Dungeness crabs were measured in the South Reach at .502 crabs/cy of dredged sediment (Table 6.2, adjusted sample size). Inner harbor stations resulted in entrainment rates of crab at least four times less than the rate observed at South Reach. The mean daily crab entrainment rate by pipeline dredges was .015 crabs/cy, with a standard deviation of .025 in summer at Cow Point and $\bar{x}$ = .02, S.D.= .03 in winter at Cow Point (Table 6.2).

Sand shrimp, *Crangon* sp., was the most abundant organism entrained by the dredges with rates as high as 3.404 shrimp/cy from the pipeline dredge operating at Cow Point and 3.375 shrimp/cy on the hopper dredge operating at Cow Point (Table 6.3). Ghost shrimp, *Callinassa californiensis*, were only observed in samples from the South Reach (Table 6.4). Bivalves, including the heart cockle, *Clinocardium nuttalii*, small unidentified clams, and clam siphons, were observed in some samples but never in great abundance.

Nine different species of fish were observed in samples from the South Reach, while the largest number of fish species at any other site was only four (Table 6.4). Fish of possible sport or commercial value

Table 6.2 Average rate of crab entrainment by hopper (summer, 1980) and pipeline (summer 1980 and winter/spring 1981) dredges in Grays Harbor.

Dredge Type/Area	Total CY	Entrainment Rates1/			
		Crabs/CY(unadjusted)(n)2/		Crabs/CY(adjusted)(n)	
Pipeline (summer)		X̄	S.D.	X̄	S.D.
Cow Point	357.12	.015(3)	.025	---	---
Pipeline (winter/spring)					
Cow Point	934.46	.020(4)	.030	---	---
Hopper					
Crossover Channel	196.89	.055(11)	.062	.075(8)	.061
Hopper					
North Channel	76.33	.085(5)	.060	.107(4)	.041
Hopper					
Crossover + North Channel	273.22	.064(16)	.061	.084(12)	.059
Hopper					
Cow Point	36.17	.078(4)	.064	.079(1)	---
Hopper					
Crossover + North Channel + Cow Point	309.39	.067(20)	.060	.085(13)	.053
Hopper					
South Reach	312.93	.518(10)	.254	.502(8)	.234

1/ Two entrainment rates are given for the hopper dredge. Certain estimates of entrainment were based on relatively small samples of dredged sediment. Samples of less than 10 CY frequently had no crabs entrained. Unadjusted entrainment values are based on all samples regardless of total yards involved. Adjusted rates are based only on those samples in excess of 10 CY.

2/ n: represents individual loads sampled for the hopper dredge, and individual sampling days for the pipeline.

Table 6.3 Average rate of shrimp entrainment by hopper (Summer, 1980) and pipeline (summer 1980 and winter/spring 1981) dredges in Grays Harbor.

Dredge Type/Area	Total CY	Entrainment Rates[1/]			
		Shrimp/CY(unadjusted)(n)[2/]		Shrimp/CY(adjusted)(n)	
		X̄	S.D.	X̄	S.D.
Pipeline (summer)					
Cow Point	357.12	3.404(3)	5.890	---	---
Pipeline (winter/spring)					
Cow Point	934.46	.001(4)	.002	---	---
Hopper					
Crossover Channel	196.89	.342(11)	.739	.124(8)	.092
Hopper					
North Channel	76.33	.063(5)	.088	.079(4)	.093
Hopper					
Crossover + North Channel	273.22	.252(16)	.589	.109(12)	.091
Hopper					
Cow Point	36.17	3.375(4)	1.058	2.344(1)	---
Hopper					
Crossover + North Channel + Cow Point	309.39	.877(20)	1.447	.280(13)	.626
Hopper					
South Reach	312.93	.260(10)	.117	.232(8)	.112

1/ Two entrainment rates are given for the hopper dredge. Certain estimates of entrainment were based on relatively small samples of dredged sediment. Samples of less than 10 CY frequently had no shrimp entrained. Unadjusted entrainment values are based on all samples regardless of total yards involved. Adjusted rates are based only on those samples in excess of 10 CY.

2/ n: represents individual loads sampled for the hopper dredge, and individual sampling days for the pipeline.

Table 6.4 Mean entrainment rates of ghost shrimp and fish by two types of dredge. All numbers are organisms/CY of sediment dredged.

	Pipeline				Hopper							
	(winter)[1/]		(summer)[2/]		(summer)[3/]							
	Cow Point n=3[4/]		Cow Point n=4		Crossover n=11		North Channel n=5		Cow Point n=4		South Reach n=10	
	$\overline{X}$	(S.D.)	$\overline{X}$	(S.D.)	$\overline{X}$	(S.D.)	$\overline{X}$	(S.D.)	$\overline{X}$	(S.D.)	$\overline{X}$	(S.D.)
Ghost shrimp *Callinassa californiensis*											.727	(1.270)
Staghorn sculpin *Leptocottus armatus*	.001	(.001)			.027	(.065)	.016	(.035)			.092	(.136)
Pacific sanddab *Citharicthys sordidus*					.003	(.009)					.076	(.073)
Pacific tomcod *Microgadus proximus*					.008	(.027)						
Snake prickleback *Lumpenus sagitta*					.008	(.026)			.135	(.068)		
Prickly sculpin *Cottus asper*	.004	(.009)							.020	(0.40)		
Starry flounder *Platichthys stellatus*	5/											
Saddleback gunnel *Pholis ornata*			.023	(.039)							.005	(.010)
Three-spined stickleback *Gasterosteus aculeatus*			.004	(.007)								
English sole *Parophrys vetulus*	.001	(.001)									.035	(.045)
Northern anchovy *Engraulis mordax*											.018	(.050)

Table 6.4 Mean entrainment rates of ghost shrimp and fish by two types of dredge. All numbers are organisms/CY of sediment dredged.

	Pipeline				Hopper							
	(winter)1/		(summer)2/		(summer)3/							
	Cow Point		Cow Point		Crossover		North Channel		Cow Point		South Reach	
	n=3 4/		n=4		n=11		n=5		n=4		n=10	
	$\overline{X}$	(S.D.)	$\overline{X}$	(S.D.)	$\overline{X}$	(S.D.)	$\overline{X}$	(S.D.)	$\overline{X}$	(S.D.)	$\overline{X}$	(S.D.)
Sand sole <u>Psettichthys melanostictus</u>											.003	(.009)
Speckled sanddab <u>Citharichthys stigmaeus</u>											.003	(.009)
Lingcod <u>Ophiodon elongatus</u>											.002	(.006)
Pacific sandfish <u>Trichodon trichodon</u>											.002	(.006)
Chum salmon <u>Oncorhynchus keta</u>	.008	(.016)										

1/ Winter sampling took place on Febuary 20 and 21 and March 13 and 14, 1981 at T-3.

2/ Summer sampling took place on May 2, 3, and 15, 1980 at T-1 and T-4.

3/ Summer sampling on the hopper dredge included 15 days and 30 large loads sampled between May 29 and September 4, 1981.

4/ The number of replicate samples (n) used as the basis for mean entrainment rates and standard deviations was days sampled for the pipeline and loads sampled for the hopper.

5/ This species was only present in entrainment from the dredging test conducted with the draghead raised off-bottom. See Table 6.5

entrained by the dredges included: chum salmon, lingcod, Pacific sanddab, speckled sanddab, sand sole, English sole, and starry flounder. All these species were entrained at relatively low rates (.001 to .135 fish/cy).

Entrainment rates by the pipeline dredge operating at Cow Point were low for all fish and crabs in both seasons sampled, summer 1980 and winter/spring 1980 (Tables 6.2-6.4).

The pipeline samples at T-1 included several sample runs during which the cutter head was lifted just off the bottom resulting in pure river water being pumped through the discharge pipe. These sample runs were conducted to simulate a "worst possible case" for fish entrainment. Both the pure water and normal dredging conditions at this site resulted in low fish entrainment rates (Table 6.5).

6.3.2 Variance, Standard Deviations, and Confidence Intervals for Entrainment Data: The entrainment rate (organisms/cy) was calculated for each load sampled on the hopper dredge and each day sampled on the pipeline dredge. The means and standard deviations of these rates were then computed (Table 6.2-6.4). The data in Table 6.6 is given to provide an example of how these calculations were obtained. The mean entrainment rates for all 10 loads sampled were averages to obtain a mean of .518 crabs/cy and a standard deviation of .254 crabs/cy (Table 6.2, unadjusted sample size column). Notice that the number of cy sampled was not the same for any load. Since very small sample sizes (our samples collected by baskets) may have been inadequate to represent

Table 6.5 Pipeline dredge entrainment rates under two conditions, normal dredging with draghead on the bottom versus draghead raised off the bottom and pumping pure water.1/

Organism	Draghead On-Bottom Entrainment Rate/CY	Draghead Off-Bottom Entrainment Rate/CY
Dungeness crab	.137	0
Crangon spp.	.690	3.379
3-Spined Stickleback	.016	0
Starry Flounder	.016	0
Saddleback Gunnel	0	.068

1/ Test occurred on May 15, 1980 while the pipeline dredge was operating at Cow Point (T-1). The on-bottom condition represented 29.3 cubic yards of sediment sampled while 60.82 cubic yards of water were sampled for the off-bottom condition.

Table 6.6 Example of raw data from the hopper dredge used to calculated mean crab entrainment rates and standard deviations at South Reach in summer of 1980.

Date	Load number	Number Crabs	CY Sampled	Rate Crabs/cy
7/1/80	1	6	15.73	.381
	2	9	15.08	.597
	3	14	39.20	.357
7/2/80	1	20	48.21	.415
	2	2	7.18	.279
7/18/80	1	8	8.98	.891
	2	21	31.45	.668
	3	35	36.21	.967
7/19/80	1	12	54.15	.222
	2	22	54.23	.406

entrainment for an entire barge load, a second mean entrainment rate and standard deviation was calculated which included only barge loads for which at least 10 cy was sampled by baskets (Tables 6.2 and 6.3). In this example of crab entrainment at South Reach the rates for 7/2/80 load #2 (.279) and 7/18/80 load #1 (.891) were dropped in the second calculation and the best entrainment rate estimate became .502 crab/scy with a standard deviation of .234 (Table 6.2, adjusted sample size column).

6.3.3 Mortality Estimates: The total number of crabs found in hopper dredge samples from all locations was 172. Of these, 136 were dead or moribund, and 36 were alive.

The unadjusted initial mortality rate, the number of dead crabs divided by the total number of crabs in the samples, was 79.1%.

Some mortalities were assumed to be caused by the sampling procedure. Stevens (1981) using identical methods estimated this sampling-caused mortality to be about 16% on the SANDSUCKER. The initial mortality rate was therefore adjusted by subtracting 16% from the total number of dead crabs. This reduced the initial mortality rate to 66.3%.

Delayed mortality, the proportion of live crabs that would have died as a result of injuries and stress caused by hopper dredge entrainment, was estimated to be 19% by Stevens (1981). This estimate was obtained by Stevens when he compared the mortality rate of live crabs taken from entrainment samples on the hopper barge PACIFIC to the mortality rate of non-entrained crabs when both were observed for three days in a flow-through seawater aquarium. Crabs that initially survived entrainment later exhibited a mortality rate 19% higher than the control group (crabs caught and exposed to the air the same length of time as the experimental crabs before placement in an aquarium). By accounting for 19% delayed mortality (decreasing the number of survivors by 19% and adding these to the crabs killed), a corrected overall mortality estimate of 73% was calculated for the hopper dredge. In this way corrections have been made for both sampling and delayed mortality.

Differential mortality rates for two size classes of crabs were calculated in the same manner. After adjusting for sampling and delayed mortality, 85.6% of crabs $\geq$50 mm that were entrained died, but only 45.9% of the crabs <50 mm were killed. The best overall mortality rate of 73.1% for all size classes was closer to the rate for larger crabs because 71.7% of the crabs encountered in hopper samples in the summer of 1980 were in the ≥50 mm category. All crabs in hopper samples whose numbers were estimated from crab parts and were unmeasurable were included in the mortality for crabs ≥50 mm because these were nearly always larger sized crabs.

The total number of fish of all species entrained on the hopper was 101; 38 of which were dead in the baskets. This yielded an unadjusted initial mortality rate of 37.6%. No attempt was made to estimate sampling-caused mortality or delayed mortality for fish because each species probably exhibited different rates and entrainment was low for each species.

Among the pipeline dredge samples, 8 Dungeness crabs were found, of which 4 were alive and 4 dead, for an unadjusted initial mortality rate of 50%. Of the 10 fish found in the pipeline samples 6 were dead; an unadjusted initial mortality rate of 60%. The best estimate of total mortality on the pipeline was 100% for both fish and crabs because they were deposited in a landfill area.

6.3.4 Size and Sex Distributions for Entrained Dungeness Crabs: The average carapace width for 38 live crabs in the hopper samples was 49.79 mm. Of these, 21 were male, 7 female, and 10 indeterminant because of small size or loss of the abdomen and gonopore region.

The average carapace width for 58 measurable dead crabs was 69.24 mm. Of these, 38 were male, 17 female, and 3 indeterminant. Most of the 78 unmeasurable crabs were larger crabs whose number were estimated from crab parts.

A t-test between the mean sizes of live crabs and measurable dead crabs revealed a significant difference between the means at the $\alpha = .05$ level. The statistic T = -4.69 when variance of the two samples was pooled, and -5.00 when separate variance estimates were used. The rejection value of the null hypothesis, that both means came from the same distribution, was $T > \pm 1.96$ for a two-tailed test.

The average size of 4 dead crabs from pipeline samples was 53.33 mm while the average size of 4 live crabs was 20.75 mm.

6.3.5 Analysis of Variance Comparisons between Mean Entrainment Rates found in Different Locations, Seasons, or on Different Dredge Types: The mean number of crabs entrained per barge load at the South Reach was 0.518 crabs/cy which was significantly different from entrainment rates of 0.063 and 0.082 crabs/cy at the two inner harbor locations of the Crossover Channel and Cow Point, respectively. The null hypothesis tested and rejected by one-way ANOVA was that all three areas had the same entrainment rates ($P < .001$; $F = 28.383$).

An expanded version of this first ANOVA with pertinent data points and statistics is given in Table 6.7. Subsequent ANOVA tests were done in the same way.

One-way analysis of variance comparisons were also made on a per day basis so that all pipeline data and all data taken by Stevens (1981) could be tested. Four ANOVA tests were performed to reveal differences in crab entrainment (Table 6.8).

Table 6.7 ANOVA of SANDSUCKER entrainment rates (crabs/100 cy/barge load sampled) in summer at 3 different locations.

	South Reach	Crossover Channel	Cow Point and North Channel
	38.100	10.200	0.0
	59.700	8.900	9.100
	35.700	0.0	16.800
	41.500	12.600	7.900
	27.900	0.0	8.800
	89.100	0.0	15.800
	66.800	0.0	7.900
	96.700	8.500	7.300
	22.200	17.200	0.0
	40.600	2.900	
Total	518.300	60.300	73.600
Mean	51.830	6.030	8.178

ANOVA Table

Source	Degrees of freedom	Sum of squares	Mean square	F-value	Probability level
Total	29	20,093.912	692,894		
Treatment	2	13,617.099	6,808.550	28.383	.001
Residual	27	6,476.813	239.822		

Table 6.8 ANOVA comparison between dredge types, seasons, or locations based on mean entrainment rates as crabs/100 cy/day sampled.

Independent variables contrasted	Independent variables controlled				F-value	Probability level
	Season	Location	Dredge	Mean		
Hopper vs Pipeline	Summer	Cow Point	---	H=9.800 P=1.467	6.784	0.040
Winter/spr. vs summer	---	Cow Point	Pipeline	W/S=2.000 S=1.467	0.310	0.745
Summer '80 vs winter '79[1]	---	South Reach	Hopper	S=49.000 W=22.183	6.0970	0.039
Aberdeen vs Westport[2]	---	Pipeline		A=1.771 W=18.125	13.670	0.003

[1]Includes data taken in winter of 1979 by Stevens (1981).

[2]Includes data taken in fall and winter by Stevens (1981) with data taken in winter/spring and summer during the present study.

The hopper dredge rates were compared to pipeline rates for both dredges operating in the summer near Cow Point. The hopper dredge entrained significantly more crabs at the 0.05 probability level ($F = 6.784$, $df = 1,6$).

Summer and winter/spring pipeline entrainment rates at Cow Point were not significantly different. The null hypothesis that these pipeline rates were equal was not rejected at $P = .05$ because the F test statistic $F_{.95\ (1,6)} = 5.99$ was greater than the observed F-value of 0.310. Pipeline dredges operating at Cow Point and Westport Marina entrained 0.018 and 0.181 crabs/cy, respectively, which is significantly different ($P < .05$; $F = 13.67$ at 1,14 d.f.). Season was not controlled in this particular comparison, which included data taken in the fall of 1979 at Westport Marina by Stevens (1981).

The mean entrainment rate per day sampled was significantly lower in winter of 1979 (0.222 crabs/cy) than summer (0.490 crabs/cy) of 1980, for the hopper dredge operating in South Reach ($P < .05$, $F = 6.097$ at 1,9 d.f.).

6.3.6 <u>Comparison between Dredge Entrainment Rates and Trawl-Estimated Density of Fish and Crabs in the Sampling Areas</u>: Information from the monthly and bimonthly trawl stations in the Grays Harbor navigation channel (<u>see</u> Section 2.0) was used to determine the densities of crab and fish populations in the area at the time the dredges were operating. These densities were contrasted to the entrainment rates for the hopper dredge (Table 6.9) and the pipeline dredges (Table 6.10).

Table 6.9 Comparison of hopper dredge entrainment rates with crab and fish densities determined by trawls in the same area during summer 1980.

Month	Area	Species	Dredge density (/100 cy)	Trawl density (/100 m²)	Dredge average size(mm)	Trawl average size(mm)
July	South Reach	Dungeness crab	50.2	15.5	61	65
		Crangon shrimp	23.2	10.9	--	--
		Buffalo sculpin	0.0	0.2	--	78
		English sole	3.5	6.7	78	81
		Kelp greenling	0.0	0.1	--	67
		Lingcod	0.2	0.3	132	127
		Longfin smelt	0.0	0.1*	--	92
		Northern anchovy	1.8	0.0	141	--
		Pacific sanddab	7.6	0.0	62	--
		Pacific sandfish	0.2	0.0	105	--
		Pile perch	0.0	0.1	--	146
		Redtail surfperch	0.0	0.1	--	204
		Saddleback gunnel	0.5	0.0	123	--
		Sand sole	0.3	0.2	104	139
		Shiner perch	0.0	3.7*	--	104
		Snake prickleback	0.0	0.2	--	119
		Speckled sanddab	0.3	6.3	73	68
		Staghorn sculpin	9.2	1.5*	113	102
		Starry flounder	0.0	0.3	--	154
		Tomcod	0.0	0.1*	--	85
June	Cow Point	Dungeness crab	7.9	2.7	44	76
		Crangon shrimp	234.4	284.5	--	--
		English sole	0.0	0.1	--	50
		Longfin smelt	0.0	0.5*	--	98
		Prickly sculpin	2.0	0.1	140	128
		Saddleback gunnel	0.0	0.1	--	134
		Snake prickleback	13.5	1.0	231	215
		Staghorn sculpin	0.0	0.3*	--	137
		Starry flounder	0.0	0.1	--	180
August	Moon Island (North Channel)	Dungeness crab	10.7	0.2	33	50
		Crangon shrimp	7.9	35.3	--	--
		English sole	0.0	0.2	--	91
		Longfin smelt	0.0	0.2*	--	89
		Pacific herring	0.0	0.7	--	78
		River lamprey	0.0	0.1	--	200
		Sand sole	0.0	0.1	--	117
		Shiner perch	0.0	0.1*	--	120
		Snake prickleback	0.0	0.1	--	133
		Staghorn sculpin	1.6	0.1*	124	137
		Starry flounder	0.0	0.1	--	159
		Tomcod	0.0	0.3*	--	127
May-Sept.[1]	Crossover Channel	Dungeness crab	7.5	8.1	24	57
		Crangon shrimp	124.8	--	--	--
		Buffalo sculpin	0.0	4.0	--	70
		English sole	0.0	6.0	--	110
		Longfin smelt	0.0	0.3*	--	93
		Padded sculpin	0.0	0.3	--	83
		Pacific sanddab	3.0	0.0	167	--
		Saddleback gunnel	0.0	0.3	--	108
		Shiner perch	0.0	0.1*	--	120
		Showy snailfish	0.0	0.3	--	111
		Snake prickleback	8.0	0.1	--	197
		Staghorn sculpin	2.7	1.2*	148	132
		Starry flounder	0.0	0.3	--	122
		Tomcod	8.0	0.1*	234	145

[1]Dredge data was from May, June, and September samples but the trawl data was only from May samples because fish data was unavailable from the crossover in June and September.

* The trawl density calculations for these species may have been underestimated. See text for explanation.

Table 6.10 Comparison of pipeline dredge entrainment rates with crab and fish densities determined by trawls in the same area during summer 1980.

Month	Area	Species	Dredge vs density (/100 cy)	Trawl density (/100 m²)	Dredge average size(mm)	vs Trawl average size(mm)
May	Cow Point	Dungeness crab	1.5	1.7	64	68
		Crangon shrimp	340.4	--	--	--
		Buffalo sculpin	0.0	0.1	--	116
		English sole	0.0	0.5	--	111
		Longfin smelt	0.0	1.6*	--	86
		Prickly sculpin	0.0	0.4	--	135
		Saddleback gunnel	2.3	0.4	41	124
		Snake prickleback	0.0	0.4	--	181
		Staghorn sculpin	0.0	0.3*	--	184
		Starry flounder	0.0	0.6	145	135
		Three-spined stickleback	0.4	0.1	55	61

* The trawl density calculations for these species may have been underestimated. See text for explanation.

Fish caught in trawls before October 1980 were delivered to the Salmon and Baitfish Project, FRI, Univ. of Washington, for recording and use of the data in their report. These data were also used to calculate fish density in the locations and during times that dredge entrainment samples were taken. Unfortunately, FRI did not know the fish data might be used in this way so they sometimes discarded fish of the most abundant species in larger tows without recording or estimating a total fish count for abundant species. Therefore, while total counts for Dungeness crab, shrimp, and less common fish species used in computation of the trawl density figures in Tables 6.9 and 6.10 are accurate, densities determined for four common fish species are of questionable accuracy and are probably underestimations in some cases. The four fish species most likely affected are tomcod, longfin smelt, shiner perch and staghorn sculpin. No fish data in any other part of this report is affected by this error.

In the South Reach, Dungeness crabs were abundant in the trawl samples and in the dredge entrainment samples during the month of July 1980. A t-test betwen the average width of crabs caught in the area by trawls (64.5 mm) and the average size entrained by the dredge (61.3 mm) showed no significant difference. The t-value was -0.79 (with separate variances estimated) and the value needed to reject the null hypothesis, that the means were from the same distribution, was $T > \pm 1.96$.

At inner harbor stations the rate of crab entrainment tended to decline with the density of crabs, as determined by the trawls.

The average sizes of fish entrained by the dredges were usually close to the average size for those species caught in the trawls. Some fish species were shown by trawls to be in the sampling area, but did not occur in the entrainment samples. Conversely, some fish species that occurred in entrainment samples were not present in trawl samples.

Crab recoveries from the pipeline dredge and trawl surveys were lower at Cow Point than from hopper dredge samples or trawls at any other site. The only exception to this was a low density of crabs determined by August trawls in the North Channel (near Moon Island).

6.3.7 Salmonid Entrainment: The only salmon specimen recovered from any entrainment samples was a 37 mm chum salmon fry, entrained by the pipeline dredge operating at Cow Point on 21 February 1981.

6.3.8 Night Sampling: Deck lighting that was of sufficient brightness to monitor dredge samples at night was such that it interfered with navigation of the SANDSUCKER by the tug operators, and was discontinued.

6.4 Discussion

6.4.1 Comparison of this Study with Data from Stevens (1981): Even though different sampling techniques were used, the pipeline crab entrainment rates at Cow Point were similar in both studies. The mean crab entrainment rate reported by Stevens (1981) using a basket to sample the pipeline dredge at Cow Point was .0025 crabs/cy, while the mean rate obtained during the present study using a net was .0177 crabs/cy. The null hypothesis that these means were the same was not rejected in a one-way

ANOVA (P >.05, F = 0.310). The net used in the present study was probably able to recover some small crabs and fish that might not have been retained in the larger-mesh basket used by Stevens (1981). With a basket, however, fewer assumptions had to be made about how far crabs would be carried by currents from the discharge pipe.

Part of the reason for lower hopper entrainment rates in the South Reach in winter (Stevens 1981) compared to summer rates found during the present study, could have been due to the reduced mesh size of the sampling baskets used during summer. The mesh used by Stevens was 44 mm on the long axis by 16 mm on the short axis while the mesh used in this study was something less than 12.7 mm. Some crabs in the size range between 12.7 and 44 mm may have escaped the larger mesh baskets, reducing the entrainment rate calculated by Stevens. In the summer samples 39% of the catch was <44 mm, however, a large proportion of these same crabs would have grown larger than 44 mm by winter, large enough to be retained by the larger mesh sampling baskets.

Nonetheless, the primary cause of increased summertime crab entrainment rates was undoubtedly the significant spring-summer increase in crab population density as determined by trawls (Section 2.3.3).

6.4.2 <u>Impact of Different Dredge Types on Benthic Invertebrate and Fish</u>: Near Cow Point, the pipeline did entrain significantly fewer crabs than the hopper dredge (1.5 vs 9.8 crabs/100 cy, respectively; Table 6.5). This dissimilarity may have been caused by a more efficient sampling method on the hopper, a slight difference in crab density associated with the slightly different areas dredged at Cow Point, or a real difference in the ability of crabs to avoid the different dredge types. The rotating cutter-head on the pipeline probably covered ground less quickly and caused more disturbance than the flat suction-head of the hopper dredge. This difference may have accounted for the apparently increased ability of crabs to avoid the pipeline's suction.

6.4.3 Impact of Dredging Dependent on Location: Pipeline dredges have been shown to have the capability of entraining large numbers of Dungeness crabs if the density of crabs in the area is high. Entrainment rates were high for a pipeline dredge operating in Westport Marina by Stevens (1981; 18.1 crabs/100 cy/day sampled). These rates were significantly greater than the rates determined for pipeline dredges operating at Cow Point (1.8 crabs/100 cy/day sampled; from data in both studies). This ten-fold difference in entrainment of crabs, depending on where the pipeline dredge was operating, indicates that the location of dredging is a factor of paramount importance in the assessment of the impact of a dredging operation. Furthermore, the density of crabs utilizing the area to be dredged at that time of year may be the best indication of how many animals will be entrained.

For the hopper dredge, at least four times as many crabs were entrained per cubic yard in the outer harbor area (South Reach) than at any inner harbor location (Table 6.2). The South Reach was the only location that represented uniform sandy substrate with little wood debris, and stable salinity and temperature regimes. The Crossover Channel, North Channel, and Cow Point sites exhibited lower, but approximately equal crab entrainment rates reflecting much lower densities of crabs in the inner harbor (see Section 2.0). Inner harbor sites represented areas with a variable substrate, from pure sand, mixed mud and sand, to pure mud; all with variable amounts of wood debris. These sites also exhibited a wider range and more frequent fluctuations in both temperature and salinity (see Section 2.0 and Appendix E). These factors probably contributed to the apparent lower numbers of crabs available to the hopper dredge at inner harbor stations in the summer months.

6.4.4 Seasonal Vulnerability of Species to Dredge Entrainment: Seasonal differences between summer and early spring entrainment by the pipeline dredge at Cow Point were not very great, probably due to the low density of crab populations there compared to other sites.

The chum salmon was recovered from the pipeline dredge at Cow Point in February, when a bank near the shore was being dredged for the first time. Outmigrating salmon fry and smolts are much more available to a dredge in the mouth of a river during their peak downstream migration, from February through May in the Chehalis River. Salmon entrainment did not appear to be a problem in the areas dredges were sampled in this study.

Winter crab entrainment rates for the hopper operating in the South Reach were significantly lower than in the summer. However, the decision to dredge this area in winter instead of summer might be less clearcut when one considers the size of the animal entrained. The significantly smaller size of crabs that survived initial entrainment in this study, and the significantly smaller size of the crabs that survived delayed mortality in the study by Stevens (1981), both indicate a lower overall dredging related mortality rate for small crabs. In addition, one might argue that the entrainment of a larger crab represents more of a loss to the resource because of the high natural mortality rate usually suffered by earlier life history stages. Not all of the crabs under 44 mm included in the summer entrainment rates (39% of the total) would have survived to reach winter sizes had they not encountered the dredge because of natural mortality. Also, when estimating the magnitude of the impact, the same number of crabs entrained when harbor populations are swelled with young instars would represent a smaller percentage of the total abundance of crabs in Grays Harbor than at any other time of year. In this study, a small crab had the same weight in calculated entrainment rates as a large crab.

More fish species and individuals were entrained in the summer by the hopper dredge at the South Reach (this study) than in the winter for that area in samples by Stevens (1981). Fish entrainment in any season was low relative to crab entrainment. Thus, fish entrainment probably represented less of a direct impact to commercial and sport fisheries resources.

6.4.5 Fish and Crab Avoidance of Dredges: The trawl data was compared to entrainment data to determine if certain species or smaller members of the same species were more vulnerable to dredge entrainment (Table 6.6). No simple formula exists to convert the density per 100 cy (entrainment data) to density per 100 m^2 (from other trawls) but the comparison between the two did yield interesting relative information.

The density of Dungeness crabs was low for both pipeline entrainment and trawl samples at Cow Point in May 1980 (Table 6.7). The average size entrained (64 mm) was close to the average size in the trawl samples (68 mm). If larger crabs were avoiding the pipeline dredge, they were also avoiding the trawls. Larger crabs were probably not in that area in any great number at that time of year so the possible superior ability of large crabs to avoid the dredge was not tested adequately there.

Only three fish species were found in the May pipeline entrainment samples at Cow Point while nine fish species were found in the trawls at that location and time. Some of these fish may have avoided pipeline entrainment, especially longfin smelt, which were the most abundant fish in the trawls even though they were absent from the dredge samples.

A t-test revealed no significant difference in mean carapace width between the measurable crabs entrained on the hopper in the South Reach and the average size of crabs caught in a trawl in that area. Therefore, it appears that large crabs have no better chance to avoid a hopper dredge than do small crabs. Crabs over 160 mm had been observed on the barge but many larger crabs were broken into parts in the basket samples.

Fish species that were sometimes numerous in the trawls but never present in the hopper dredge samples included: buffalo sculpin, longfin smelt, Pacific herring, starry flounder, and shiner perch. Some or all of these species may be actively avoiding the dredge.

Large fish did not seem to avoid the hopper dredge any more than small ones, as the average sizes were similar for both dredge and trawl samples. The largest fish in the hopper dredge entrainment samples was a 234 mm tomcod, indicating that fish can be entrained up to at least this size.

6.4.6 Comparison between Entrainment Studies in Grays Harbor and Entrainment Studies in the Fraser River, Canada: Salmon entrainment was very low in Grays Harbor, only one salmon was recorded in this study and that of Stevens (1981). Dungeness crab entrainment was often high, up to 18.1 crabs/100 cy on the pipeline in Westport marina (Stevens 1981), and up to 47.3 crabs/100 cy on the hopper in the South Reach during summer of this study. Few crabs were entrained in any of the Fraser River Estuary studies, but many salmon fry and smolts were entrained by both hopper and pipeline dredges (Dutta and Sookachoff 1975b). The probable reasons for this difference between salmon entrainment rates were 1) the location of the dredging, 2) the location in relation to the river mouth. Much of the dredging in the Fraser River Estuary was actually above the mouth of the Fraser River rather than in the harbor proper (Braun 1974a; Dutta and Sookachoff 1975b; Boyd 1975). If dredging were to be conducted further up the Chehalis River away from its mouth in Grays Harbor during February through May, more salmon and fewer crabs might be entrained.

6.4.7 Possible Sources of Error

1. Visual estimates of the percent sediment discharge introduced a certain variability and error to entrainment rates. These estimates could easily be off by 10-15% for each estimate.

2. Some unknown number of crabs and fish could have been buried or diverted around the net which sampled the pipeline discharge, especially as the net filled with debris, thus reducing flow through the net.

3. Mortality estimates included a sampling-caused mortality estimate that was little better than a guess and excluded delayed mortality due to increased vulnerability to predators. Also, mortality rates were very size dependent. The accuracy of mortality estimates could be improved by calculating overall mortality rates for different size classes of crabs and judging which of these classes might be vulnerable to the dredge at different seasons and locations.

4. The average size and density calculations determined by the otter trawls may not be the best representation of local species density. The otter trawl may select for smaller fish and crabs. Sometimes fish and crabs from only one trawl in an area were used to estimate species composition and density for over a month. From some trawl samples collected for FRI between June and October 1980, not all fish were saved for processing, so the total counts used in density calculations may have been wrong. Some samples included total counts and others only included 25 of each species, so there was no way to distinguish whether 25 represented a subsample or total count.

5. The entrainment samples, in some cases, may have been too small to procure the best estimates available with these methods, considering the variability in the distribution of animals, and changes in sediment type and dredge locations. The South Reach entrainment estimates were relatively good, however, because the sediment type was uniform and the standard deviation of the data was less than one-half the mean.

6.5 Summary

1. Entrainment of crabs and fish by dredges in Grays Harbor was estimated by sampling discharged material with steel baskets on a hopper dredge, and with a small-mesh barrier net for a pipeline dredge. Several different areas and seasons were sampled.

2. South Reach crab entrainment rates on the hopper barge SANDSUCKER in the summer of 1980 were far higher than other harbor stations, .502 crabs/cy.

3. All inner harbor crab entrainment rates by the SANDSUCKER were similar and at least four times lower than at South Reach, which represented the only outer harbor site.

4. Pipeline dredges entrained significantly fewer crabs than the hopper barge, when compared at the same location.

5. Pipeline crab entrainment rates were low in both summer and early spring near Cow Point.

6. Fish entrainment for both dredge types was low compared to Dungeness crab entrainment, and salmon entrainment was extremely low (one chum salmon fry from all samples).

7. The best estimate of total mortality rate for entrained Dungeness crabs was 73.1% on the hopper barge SANDSUCKER and 100% on the pipeline dredge.

8. The mean width of crabs that survived entrainment was significantly smaller than the mean width of those killed.

9. Large crabs appeared to have no advantage over smaller crabs in avoiding the hopper dredge, because the average sizes entrained were not significantly different from the average sizes of crabs caught by trawls in the area.

10. Whenever crab densities were high in any area, entrainment rates were also high and, conversely low densities resulted in low entrainment rates.

11. Winter crab entrainment rates were significantly lower than summer rates in the high-entrainment South Reach area.

12. Crangonid shrimp were entrained in the greatest numbers of all organisms sampled from the hopper and pipeline dredges at rates up to 3.37 and 3.40/cy, respectively.

7.0 DISTRIBUTION AND ABUNDANCE OF THREE SPECIES OF CRANGONID SHRIMP IN GRAYS HARBOR

James C. Hoeman and David A. Armstrong

7.1 Introduction

Sand shrimp, Crangon spp., are small grey shrimp that rarely exceed 70 mm (2 3/4") in total length. These shrimp are well adapted for benthic dwelling as evidenced by their abilities to bury in the sand and assume camouflage coloration to match the bottom substrate, yet they are also active swimmers and are caught in surface tows and with traps designed to catch animals that vertically migrate at night. Current research supports the theory that Crangon often bury in the sand during the day then move off-bottom at night to feed on organisms such as mysids (Kaestner 1970; Thomas and Jelley 1972; Schmitt 1921; Sitts and Knight 1979; Hopkins 1958).

The three crangonid species found in Grays Harbor are all exclusively Pacific Coast shrimp that range from Alaska to lower California and from intertidal depths to about 90 meters (Butler 1980). The bay crangon, Crangon franciscorum franciscorum, Stimpson 1856, is the primary estuarine shrimp of low salinity waters. The black-tailed or sand crangon, Crangon nigricauda, Holmes 1900, and the smooth crangon, Crangon stylirostris, Holmes 1900, are the other species found in Grays Harbor. The life histories of Crangon franciscorum and Crangon nigricauda have been extensively studied by Israel (1936) in San Francisco Bay, California. Since then Krygier and Horton (1975) studied their distribution, reproduction, and growth in Yaquina Bay, Oregon, and Siegfried (1980) looked at the seasonal abundance of Crangon franciscorum in the San Francisco-Sacramenta River Estuary of California. The only study on the feeding habits of any Pacific coast Crangon was done by Sitts and Knight (1979) on the Crangon franciscorum populations in the

Sacramento-San Joaquin Estuary in California. Sitts found *C. franciscorum* were often caught off the bottom at night and that a high incidence of mysid shrimp were present in their stomachs.

Historically, sand shrimp have been used for human consumption, bait for sport fishing, and as industrial fish meal and pet food. There is no active fishery for them in Grays Harbor but they are a potential resource. They can be easily obtained in large numbers by dip nets, beam trawls, push nets, shrimp fyke nets, and Chinese shrimp nets. All these methods have been employed to harvest sand shrimp in other parts of the world (Israel 1936; Haefner 1979). The major fishery for sand shrimp today is for *Crangon vulgaris* in European waters (Butler 1980), and in the United States, *Crangon septemspinosa* is commercailly fished on the East Coast (Haefner 1979). *C. franciscorum*, *C. nigricauda*, and *C. nigromaculata* were fished commercially in San Francisco Bay (Israel 1936). In Washington *C. nigracauda* and *C. communis* were harvested commercially in Puget Sound (Ricketts and Calvin 1948) in the 1930's and 1940's.

When sampling began in Grays Harbor it quickly became apparent that sand shrimp would be the most abundant organisms entrained by the dredges. This finding suggested that the removal of large numbers of sand shrimp by dredging activity might reduce the food supply for the animals that prey on these shrimp. High incidental catches of sand shrimp in the trawl gear (used to sample for Dungeness crabs) indicated that crangonid shrimp might be one of the dominant epibenthic organisms in Grays Harbor. The sampling sites, gear and schedule organized to study crab distribution were ideal for collecting information on Pacific Coast *Crangon* species which have not been extensively studied.

The goals of the crangonid shrimp study were as follows: (1) describe the seasonal distribution and relative abundance of the three species within the harbor, (2) correlate factors such as bottom salinity, bottom temperature, tides, and diel movement to distribution and abundance, (3) define the major predators on Crangon and the prey items of Crangon in Grays Harbor, (4) combine this information with observed entrainment rates for Crangon to predict possible impacts of dredging on shrimp populations and discuss possible ramifications on the Grays Harbor ecosystem.

7.2 Materials and Methods

7.2.1 Sampling Schedule, Sampling Gear and Specimen Treatment: The sampling schedule, techniques and gear for collecting shrimp were identical to those used to sample for Dungeness crabs (See Sections 2.2 and 3.2). All shrimp collected from tows made from June 1980 through May 1981 were taken from the net and frozen for sorting and counting in the lab. Total counts were made by counting every shrimp in each tow except in three cases where the numbers exceeded 3,000 individuals. In these three cases several sets of 100 shrimp were weighed. Then the total catch was weighed and the total number was estimated by multiplication. Total counts of shrimp per tow were divided by the area trawled (square meters) to obtain shrimp density estimates. These density estimates are, in fact, relative abundance estimates because no information exists on net avoidance, escapement, and general net efficiency.

For all tows 50 shrimp were randomly subsampled from the catch and placed in 10% Formalin for 24 hours then transferred to 70% ethanol. The procedure for selecting a random sample consisted of the following steps: (1) shrimp were placed in a large rectangular tray, (2) they were stirred to fill the tray to a uniform depth, (3) the shrimp were divided in half and one half was discarded, (4) the shrimp were stirred and divided any number of times until about 50 shrimp were left as the subsample. This subsample was then considered representative of the entire catch for that tow, and was used to determine species composition, carapace length, sex, presence of eggs and developmental stage. Information on species composition and total shrimp counts were used in this report to analyze seasonal distribution, diel movement, and relative abundance of the three species in Grays Harbor.

Information on diel movement and changes in abundance of shrimp was gathered during diel trawl surveys for crab described in Section 3.0. Trawls in the South Reach channel were done over three consecutive days in four seasons of the year, at all combinations of high-low tide and day-night. Trawls were also made over an area of Whitcomb Flats adjacent to the channel, but only at high tide (see Section 3.0 for more detail).

In an attempt to discover the major fish predators of sand shrimp in Grays Harbor, several fish were taken from each otter trawl and analyzed for stomach contents. Fish large enough to eat adult sand shrimp were chosen preferentially. The fish species were identified, measured, and shrimp counted from stomach contents. Freshly eaten shrimp were recorded separately from well digested shrimp so that the possibility of net-feeding could be monitored. The sample sizes were small for many fish species because the otter trawl did not consistently catch more than two species of larger fish. Other easily recognizable stomach contents were recorded for general information.

Stomachs from all three species of crangonid shrimp were also examined to study feeding habits. Only material from the cardiac stomach was examined because remains in the pyloric stomach were too thoroughly digested for identification. Stomach contents were placed in a watch glass then examined under a binocular dissecting microscope. Only the incidence of recognizable organisms was recorded. No attempt was made to key the prey items to species or to quantify the prey categories because such a small percent of the contents were recognizable.

7.2.2 Treatment of the Data: Seasonal densities of sand shrimp were plotted against the measured bottom temperatures and salinities for each collection. These plots were used to analyze the possible effect of temperature and salinity on the seasonal distribution of Crangon spp. within the harbor. Regression analyses were used to learn if there is a significant relationship between bottom temperature or bottom salinity and the density of each species within the harbor. Analysis of variance was employed to test if winter densities were significantly different from summer densities, and if inner harbor densities were different from outer harbor densities. Trawl catches from April through September were defined as summer densities. Cow Point, Moon Island, Crossover Channel, and South Channel were considered to be inner harbor stations because of their location and lower salinity ranges. South Reach, North Bay, Elk River (also called South Bay) and Point Chehalis (sometimes referred to as Buoy 13) were considered to be outer harbor stations for the purpose of comparisons.

Trawl sites used to estimate average seasonal densities in different areas of the harbor were identical to those used for crab population estimates (see Section 8.2), except that Point Chehalis trawls were used to estimate populations in Area 15 (see Fig. 8.1). There was no reason to suspect that shrimp densities in Area 15 would be any higher than they would in Area 2, as was the case for Dungeness crabs.

7.3 Results and Discussion

7.3.1 Seasonal Distribution of Crangonid Shrimp in Grays Harbor and the Influence of Location, Bottom Temperature and Bottom Salinity: Shrimp were found to be randomly distributed (Table 2.4); therefore, a Poisson distribution was used to model their distribution. This required transforming CPUE data to $\sqrt{(\text{density} + 1)}$ before performing analyses of variance (see Section 2.3.3 for details). A two way ANOVA revealed that mean shrimp density was significantly greater in summer (April-Sept.; 59.4 shrimp/100 m^2), with $F = 22.6$ and $p < 0.001$. Mean shrimp density was also significantly greater at inner harbor stations (South Channel, Moon Island, Cow Point, Buoy 32; 60.8 shrimp/100 m^2) than at outer harbor stations (South Reach, Pt. Chehalis, North Bay, Elk River; 23.1 shrimp/100 m^2), with $F = 23.5$, and $p < 0.001$. There was also a significant interaction between season (summer vs. winter) and location (inner vs. outer harbor) with $F = 13.1$, and $p < 0.001$. This interaction effect was due to the great increase in shrimp densities from winter to summer at inner harbor stations (23.3 to 103.2 shrimp/100 m^2) while outer harbor stations showed little change from winter (23.8 shrimp/100 m^2) to summer (22.0 shrimp/100 m^2).

Seasonal changes in temperatures and salinity have been previously discussed in Section 2.3.7 (see Appendix E for figures of bottom temperature and salinity at each station over 12 months). Again comparing data for Cow Point and South Reach as representative of inner and outer harbor regimes, bottom salinity at Cow Point was about 14-15 ^{o}/oo March through mid-August but increased to 25 ^{o}/oo in mid-summer into November. The effect of seasonal rains and Chehalis River discharge were more pronounced at Cow Point as evidenced by a seasonal salinity regime spanning 10 ^{o}/oo from about 14 to

$24^{o}/oo$ (Fig. 2.16). In contrast, bottom salinity at South Reach was never less than $20^{o}/oo$ and typically $25^{o}/oo$ during February through July, and approached $30^{o}/oo$ through late summer and fall (Fig. 2.15). Water temperature also spanned a wider range in the inner harbor where a low of 5.5°C was recorded at Cow Point in February and a high of 19°C in August (Fig. 2.16); a range of about 14°C. At South Reach bottom water temperature ranged from about 6°C in February to 15°C in June through September.

Crangon franciscorum was the dominant species at all inner harbor stations and showed sharp seasonal changes in abundance with greatest densities during spring and summer, May through August (Figs. 7.1-7.4). At Cow Point, density of C. franciscorum increased from less than 25 per 100 m^2 in March to nearly 400 per 100 m^2 in July. In August numbers declined to 75 per 100 m^2, and dropped further through fall and winter (Fig. 7.1). This pattern of high spring abundance of C. franciscorum was found at all four inner harbor stations (Figs. 7.1-7.4), and the greatest crangonid density in excess of 500 shrimp per 100 m^2 was recorded at Moon Island in late July (Fig. 7.2).

Although seasonal peaks of shrimp abundance at all four inner harbor stations occurred at the same time, from May through August, salinity did not seem to be the primary cause since it ranged between 13 ppt and 27 ppt at these stations. However, temperature increased about 6°C between March and June (Fig. 2.16 and Appendix E) and probably represents more favorable conditions of food and warmer temperature for faster growth and increase of populations. Regression analyses of shrimp density as a function of temperature and salinity generally showed non-significant results. Although 7 of 24 regressions were significant at the .05 level r^2 values were low (significance by virtue of very large sample size) and never exceeded 0.45. The density of C. franciscorum, for

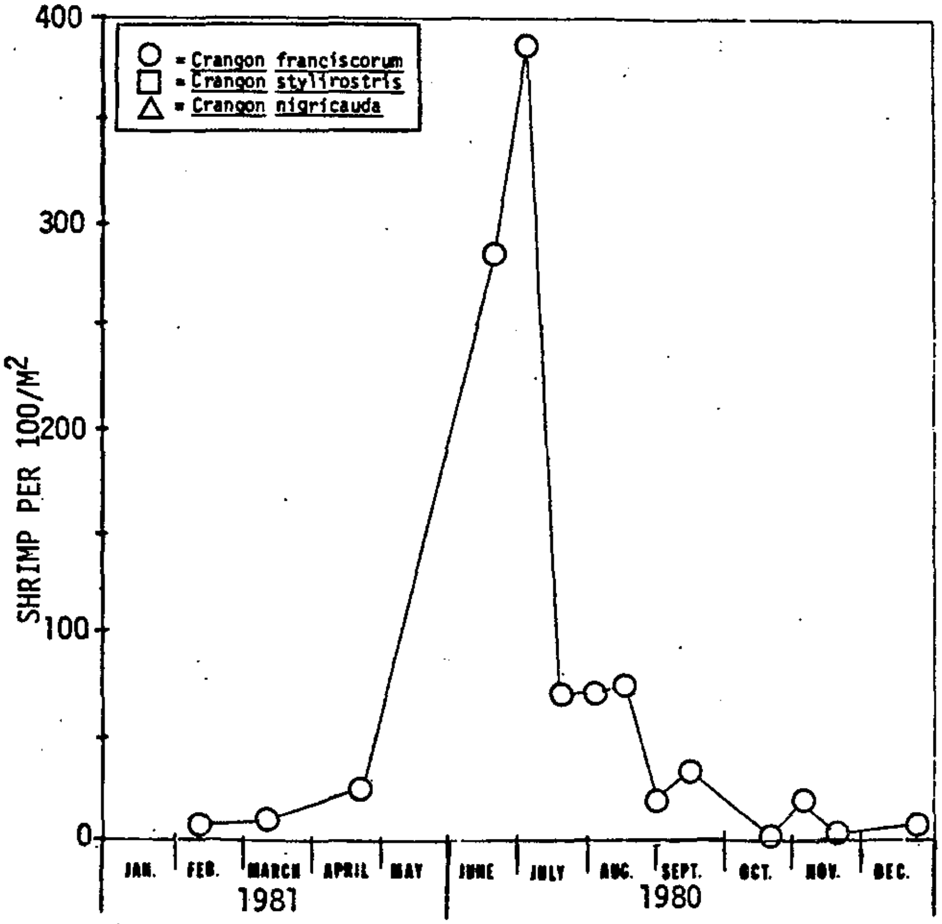


Fig. 7.1. Seasonal change in shrimp density at Cow Point.

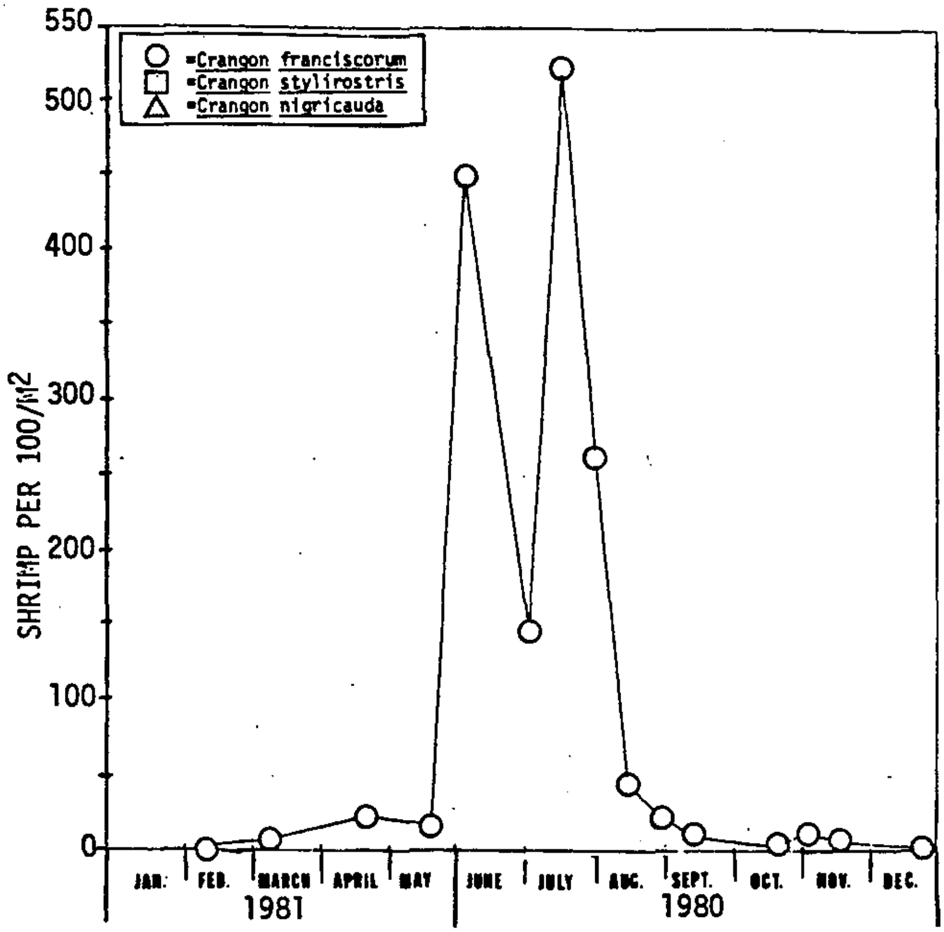


Fig. 7.2. Seasonal change in shrimp density at Moon Island.

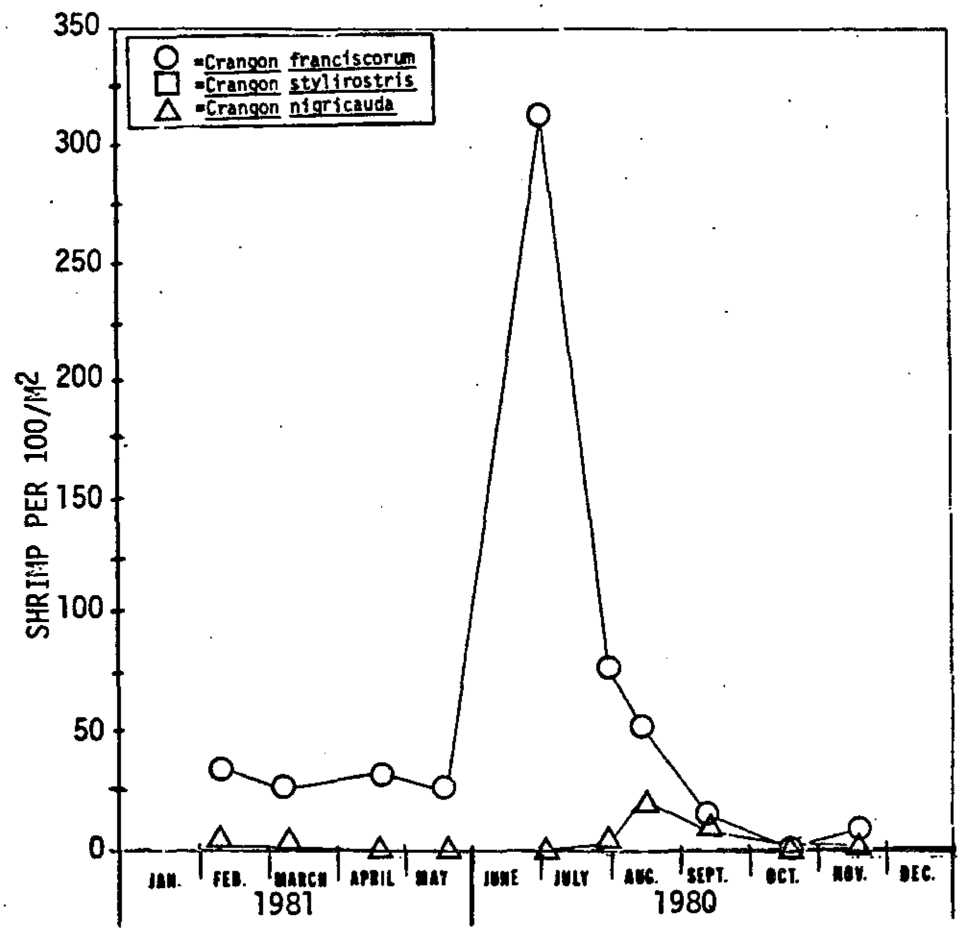


Fig. 7.3. Seasonal change in shrimp density at Crossover Channel (Bouy 30).

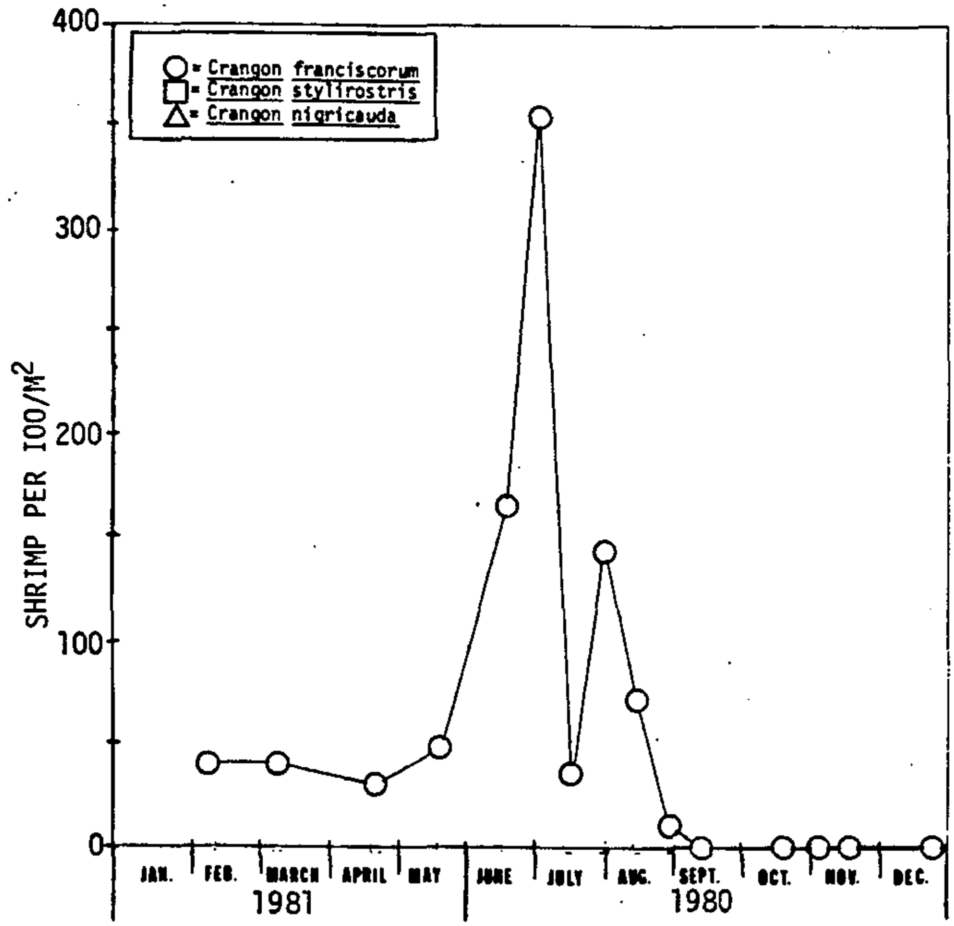


Fig. 7.4. Seasonal change in shrimp density at South Channel.

instance, did increase with an increase in bottom temperature, but since the r^2 value was very low (.21) most of the variability in the data was not explained by a straight line equation of density vs. bottom temperature.

Outer harbor stations always had significantly lower shrimp densities than those of the inner harbor (ANOVA, $p < .001$). Numbers of shrimp at South Reach, North Bay, Point Chehalis (Buoy 13), and Elk River rarely exceeded 30 per 100 m^2, and a highest value of 90 per 100 m^2 was recorded at Point Chehalis in June, 1980 (Figs. 7.5-7.8). The species composition of crangonid populations also changed in the outer harbor where C. nigricauda and C. stylirostris became more prevalent, although C. franciscorum still dominated at three of the four stations.

South Reach is considered the first outer harbor station progressing toward the jetties from the east. Here the average bottom salinity, measured at the times shrimp were collected, was 26.8 ppt compared to an average of 21.3 ppt for all inner harbor stations. This higher salinity (Fig. 2.15) may have been more favorable for C. stylirostris and C. nigricauda because all three species were present for much of the year, although C. franciscorum still predominated (Fig. 7.5). Densities of shrimp declined to usually less than 20 per 100 m^2 at this outer harbor station, compared to values of 100-500 per 100 m^2 at inner harbor sites (eg. compare Figs. 7.1 and 7.5). Two seasonal peaks were evident at the South Reach, one in early summer and one in winter but again the absolute numbers were lower than at the inner harbor stations. Ovigerous females of all three species comprised most of the catch at the South Reach and were found there is all four seasons, indicating an area of sympatric overlap in distribution.

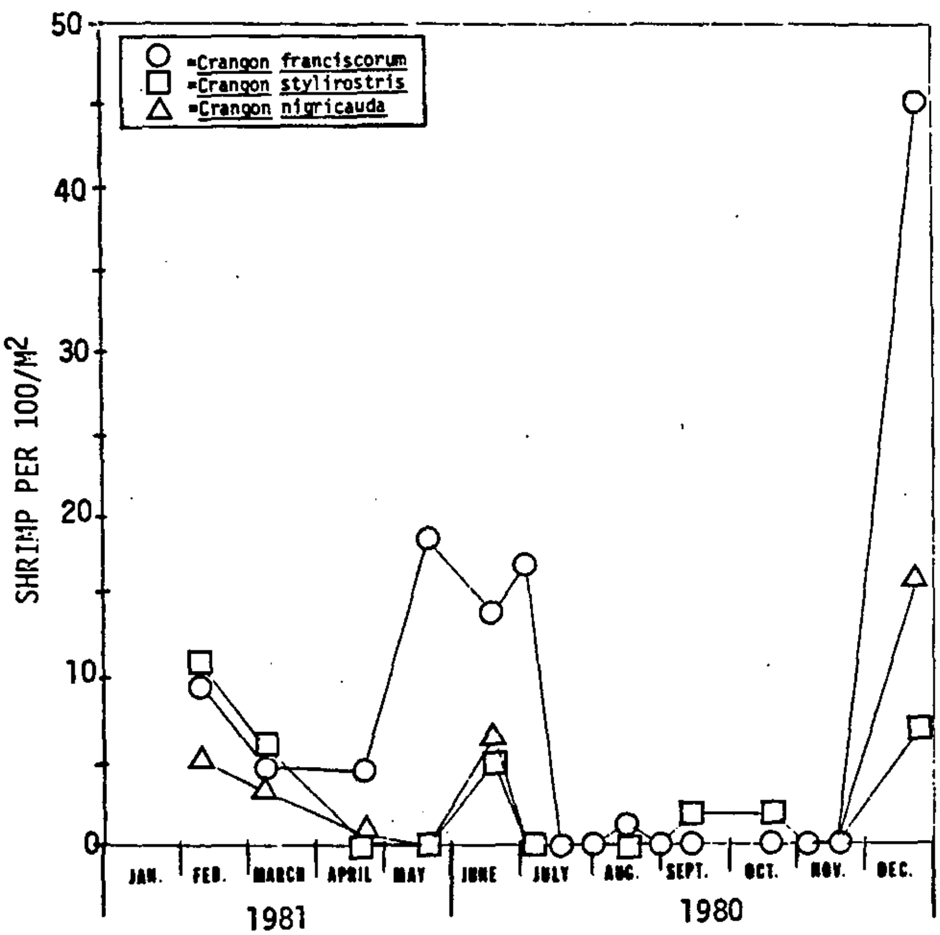


Fig. 7.5. Seasonal change in shrimp density at South Reach.

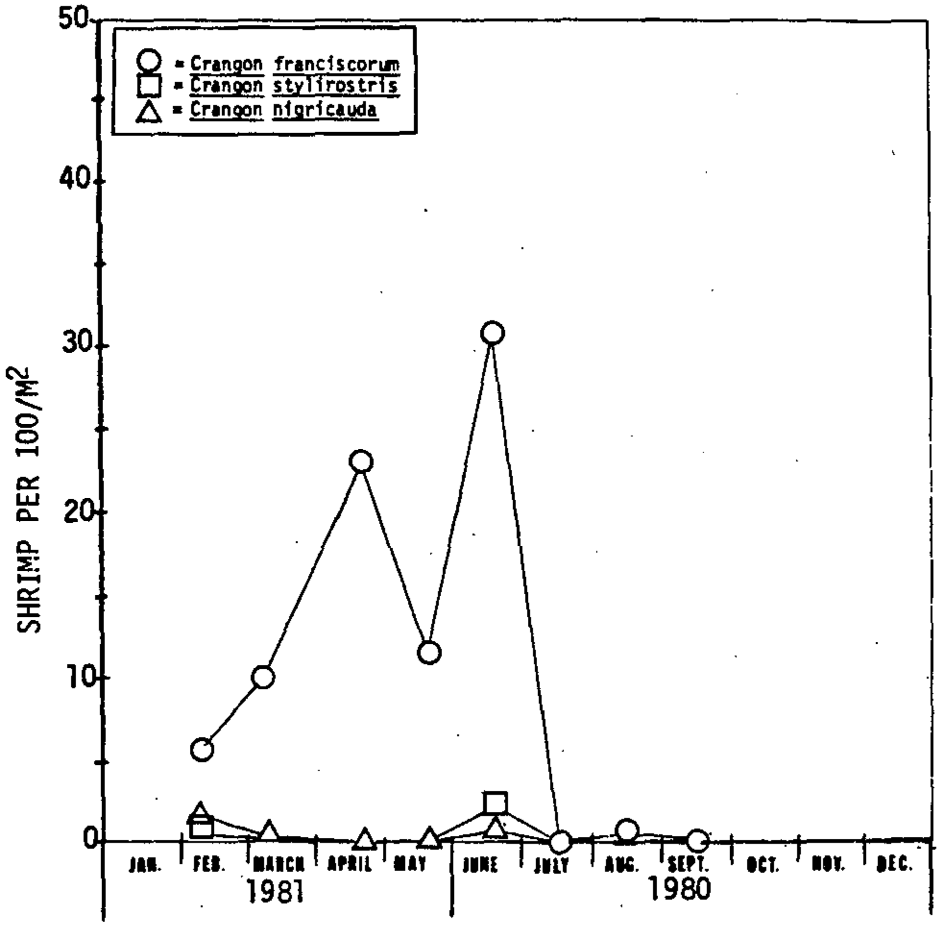


Fig. 7.6. Seasonal change in shrimp density at North Bay.

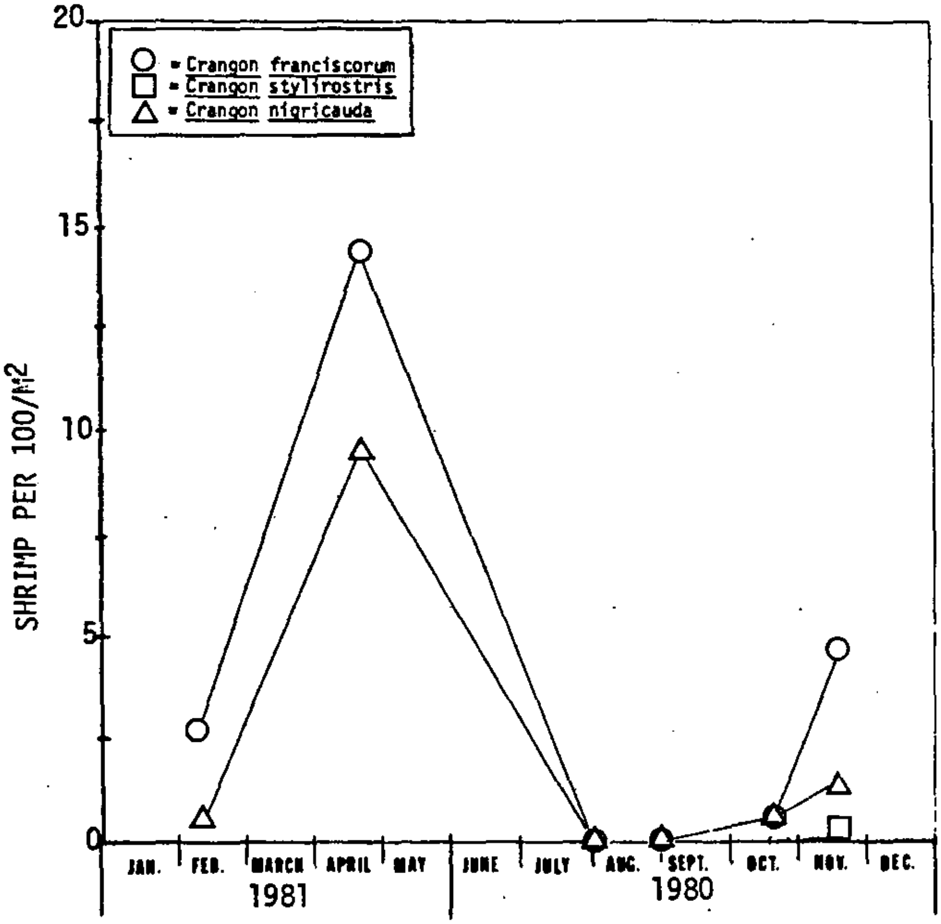


Fig. 7.7. Seasonal change in shrimp density at Elk River (South Bay).

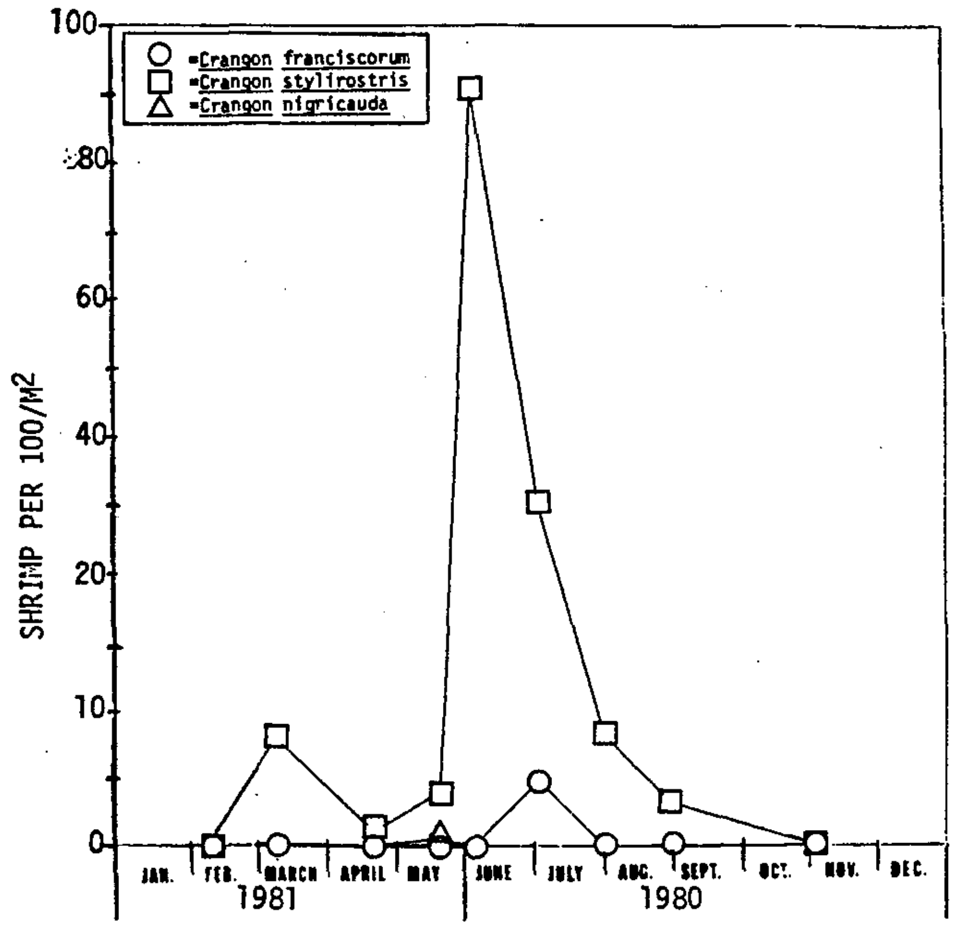


Fig. 7.8. Seasonal change in shrimp density at Point Chehalis (Bouy 13).

Point Chehalis was characterized by having the lowest average bottom temperature (11.5°C) and a fairly high average bottom salinity of 26.8 ppt (Appendix E). Crangon stylirostris was the most abundant shrimp at Point Chehalis, which probably represents the western edge of the range for C. franciscorum in Grays Harbor, and the beginning of the preferred habitat of C. stylirostris (Fig. 7.8). A peak seasonal abundance from May to August was consistent with the inner harbor, even though dominant species had changed.

7.3.2 Diel Movement and the Effects of Tides on Crangonid Shrimp Distribution: Analyses of day/night trawl data from Whitcomb Flats (All gathered at high tides) showed pronounced diel changes in shrimp abundance with much higher numbers caught at night than during day. In January and September C. stylirostris was the most abundant species on Whitcomb Flats. Day time densities ranged from 0.2 to 1.0 shrimp per 100 m^2 for three consecutive days, while night densities increased to 6-11 per 100 m^2. Such patterns of night time increase are seen in Figs. 7.9 and 7.12. C. nigricauda was also more abundant at night with densities often increasing 12 fold over day time densities (Fig. 7.9). Strong diel fluctuations in abundance were not consistently observed in April and June (Figs. 7.10, 7.11), although the highest three-day density estimates were from night trawls in both months. Higher night time densities of crangon on the flats was consistent with Dungeness crab foraging patterns and increased use of shrimp as prey (Section 3.0).

There are at least three possible explanations why more shrimp were caught at night: (1) Shrimp move onto the flats from deeper water at night but not during the day. In this case shrimp caught in trawls over the area would represent the density of shrimp in the area at the time. (2) Shrimp

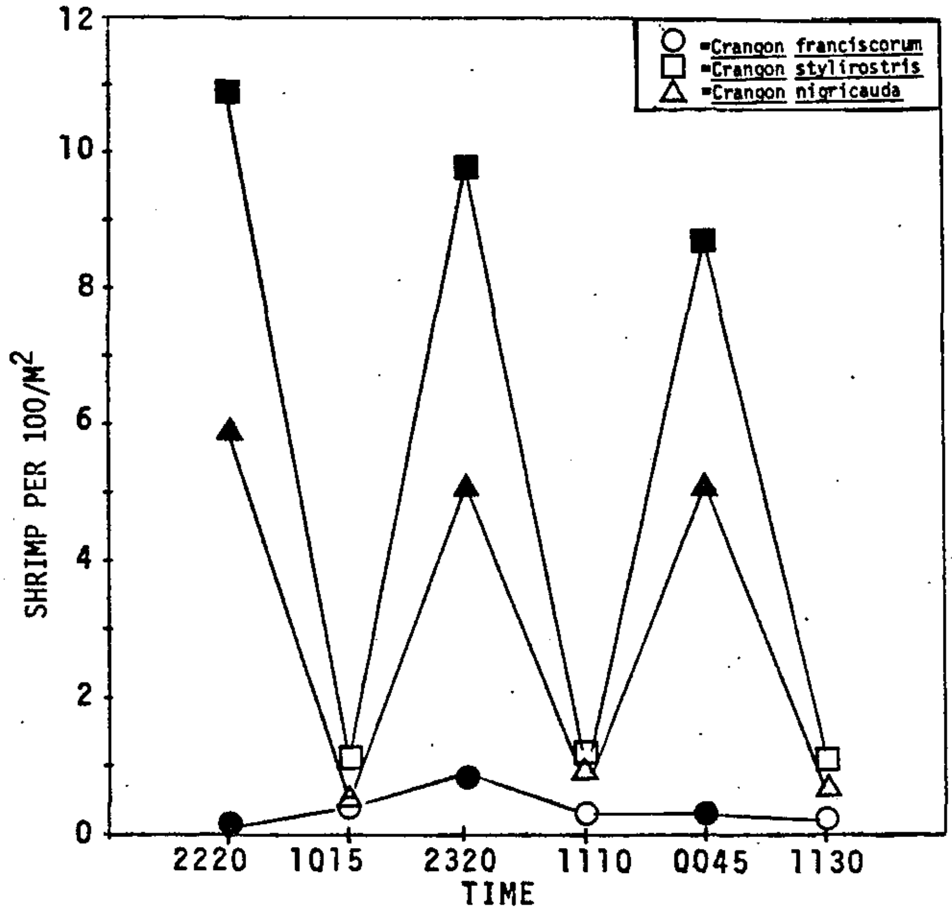


Fig. 7.9. Density of shrimp during the January 16-19, 1981, diel sampling period on Whitcomb Flats. Shrimp from night tows are closed circles,squares or triangles according to species. All tows were made at high tide.

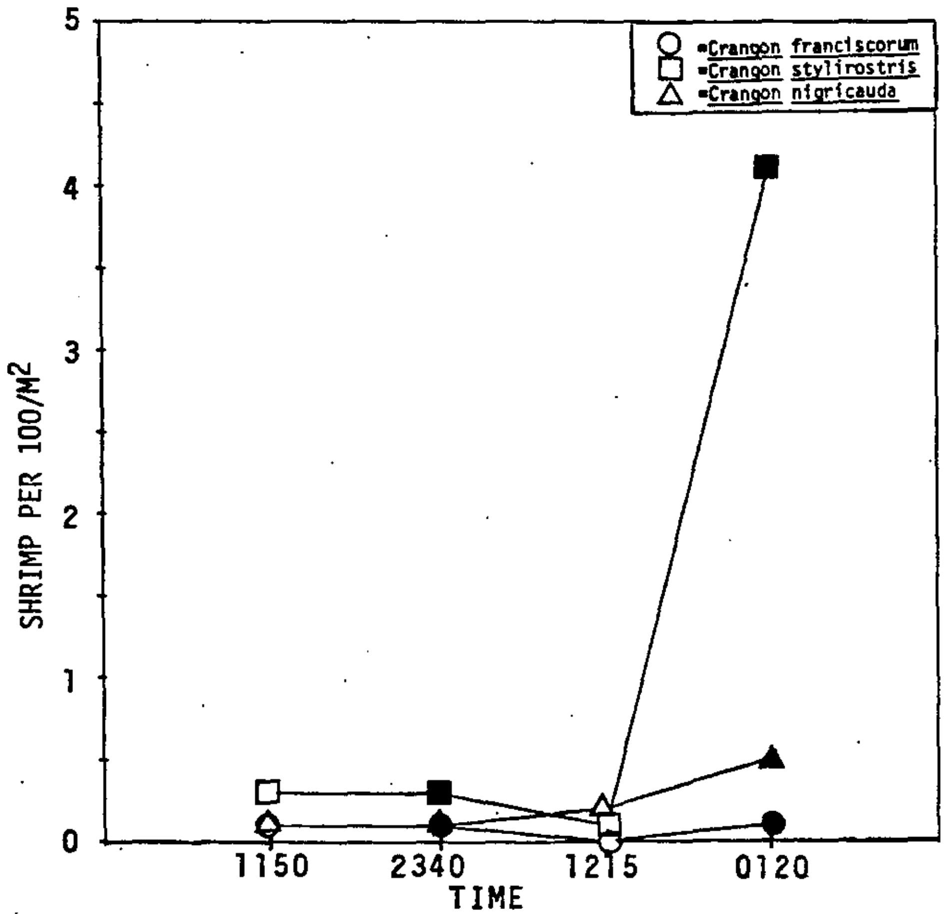


Fig. 7.10. Density of shrimp during the April 3-5, 1980, diel sampling period on Whitcomb Flats. Shrimp from night tows are closed circles, squares or triangles according to species. All tows were made at high tide.

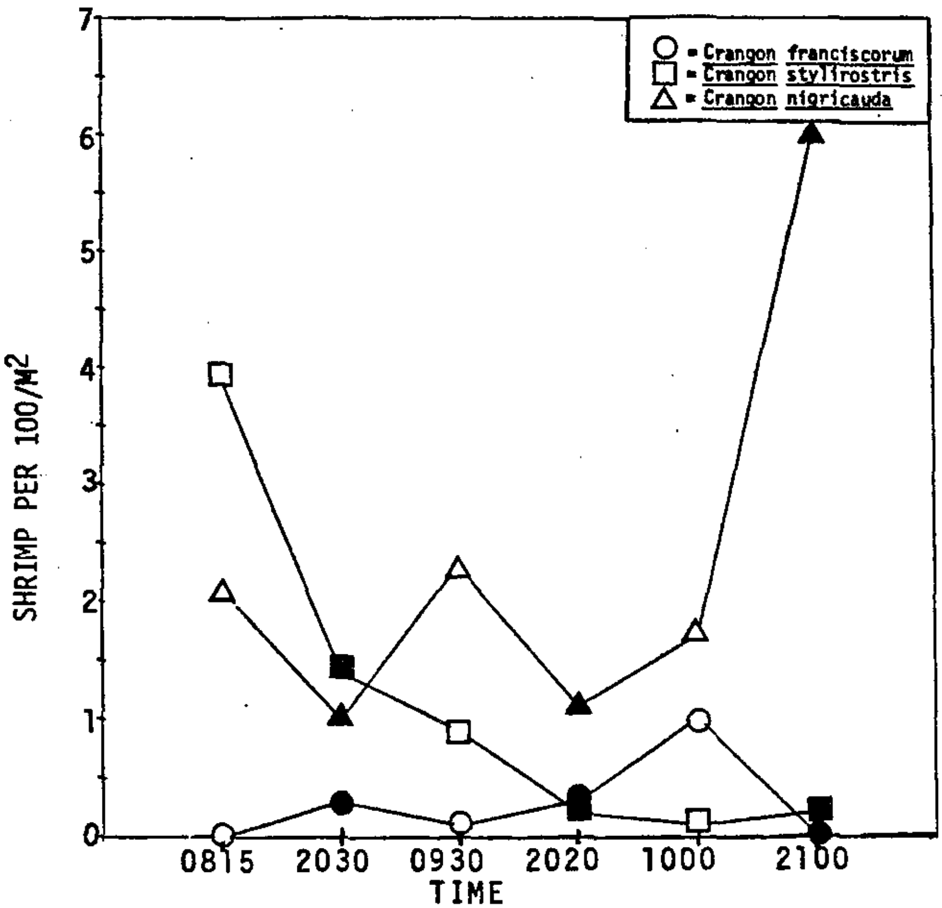


Fig. 7.11. Density of shrimp during the June 21-24, 1980, diel sampling period on Whitcomb Flats. Shrimp from night tows are closed circles, squares or triangles according to species. All tows were made at high tide.

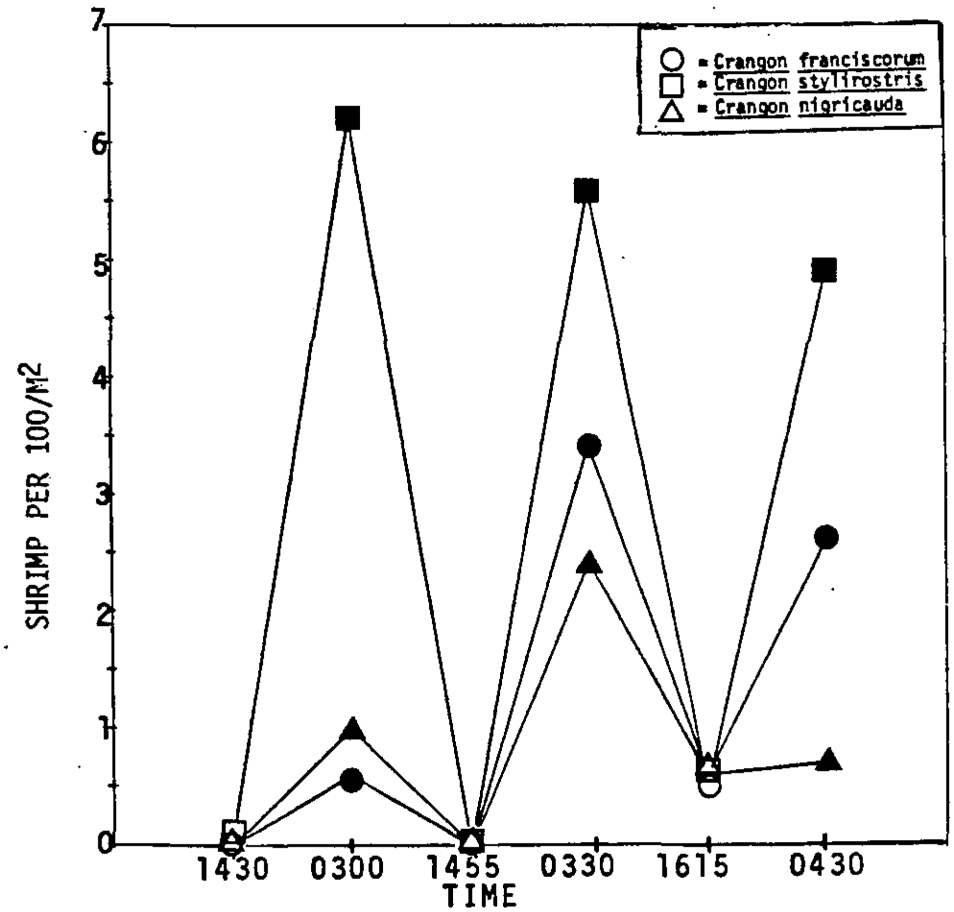


Fig. 7.12. Density of shrimp during the September 25-28, 1980, diel sampling period on Whitcomb Flats. Night tows are closed circles,squares or triangles according to species. All tows were made at high tide.

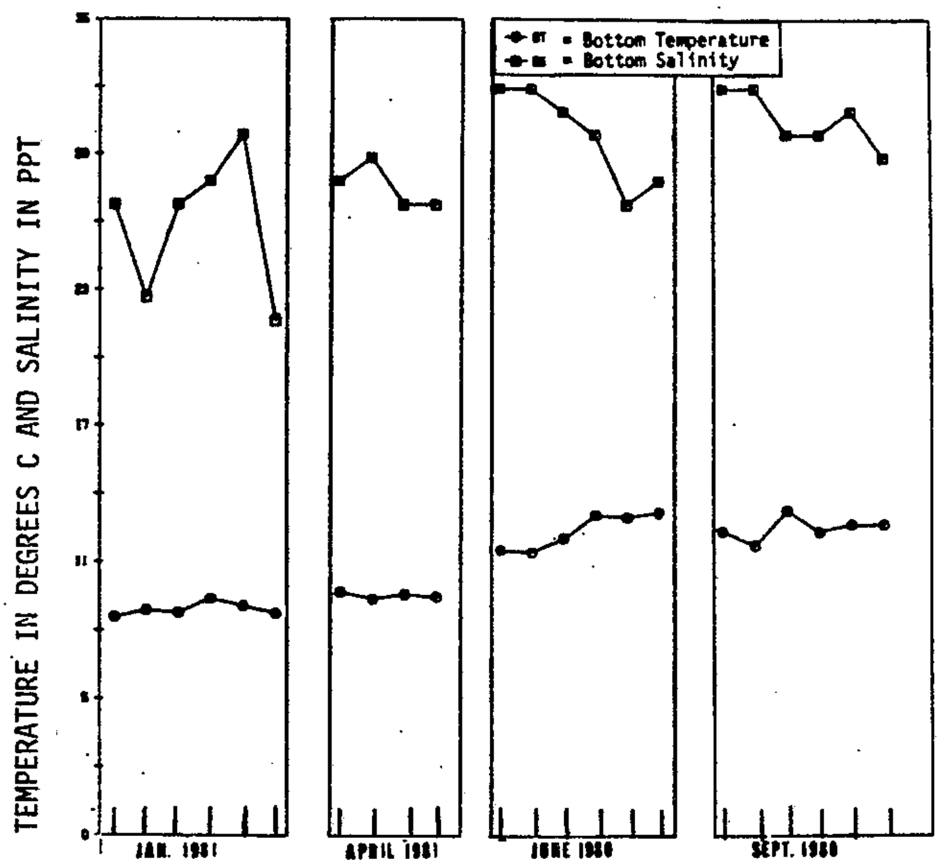


Fig. 7.13. Bottom temperatures and salinities recorded when shrimp were collected during the Whitcomb Flats diel sampling periods. Each hash mark represents measurements taken near a different tow. All tows within a season were about 12 hours apart.

were on the flats in the same densities both night and day but were active at night and buried during the day. In this case daytime trawls underestimated the shrimp densities present because more shrimp avoided the net by burial and/or reduced activity during the day. (3) Shrimp were better able to avoid capture by the net in the day, especially in shallow areas like Whitcomb Flats.

The second reason may not be so important in this case because a low tide occurred between every day and night tow which left the entire area above water. If as many shrimp were on the flats in the day as at night, then shrimp would have to move up onto the flats in the day, only to remain buried and inactive. It is more reasonable to speculate that shrimp, which are known to be night time feeders, move up on the flats at night to feed, but avoid the flats during daylight high tides when more vulnerable to predation.

Temperature and salinity changes over Whitcomb Flats did not seem to be causes of day/night differences in shrimp density. Temperature was virtually constant over three consecutive days of each month, and salinity fluctuated, at most, 6^{o}/oo but never was lower than about 23^{o}/oo (Fig. 7.13).

Diel changes in shrimp abundance in the South Reach Channel as a function of day/night or high/low tides were not as obvious as on Whitcomb Flats. Day or night did not seem to cause any discernable pattern of diel change in shrimp abundance, although during the three consecutive day study of any season, the greatest density recorded was usually at night.

Tidal cycles and accompanying changes in temperature and salinity might be more directly related to estimates of shrimp density at the South Reach than at Whitcomb Flats. Low tide was usually directly correlated with lower bottom temperatures and salinities and high tide with slightly higher temperatures and markedly higher salinities (Fig. 7.14). From high to low tide bottom salinity changed by as much as 16°/oo from 27°/oo to 11°/oo in April (Fig. 7.14) but temperature was relatively constant, changing by no more than 1°-2°C. Diel fluctuations in shrimp abundance in the South Channel was most evident in April and June (Figs. 7.16, 7.17), and most consistently correlated to high or low tide regardless of time of day. All three species were caught in greater numbers at low tide than at high tide, with changes in density exceeding 20 fold between many high/low tide observations (Fig. 7.16). Increases in low tide abundance probably reflects the concentrating effect of tidal recession, as shrimp leave flats and sand bars to aggregate in adjacent channels.

In contrast to regular monthly sampling at the South Reach station which indicated that C. franciscorum was still the dominant crangonid species at this distance from the mouth of Grays Harbor, C. stylirostris and C. nigricauda were often caught at this and the Whitcomb Flats station in high numbers during diel surveys. Apparently the distribution of all three crangonid species converges in the Whitcomb Flats-South Reach area. C. franciscorum is dominant throughout the inner harbor, and C. stylirostris toward the mouth of the harbor. This distribution pattern implies interesting differences in competitive ability, physiological tolerances, and larval recruitment between the species.

7.3.3 Estimates of Shrimp Populations in Grays Harbor and Projected Numbers to be Removed by Dredging: Information on species density at each station was transformed to fit a Poisson distribution so that mean densities and confidence intervals could be calculated for different areas of the bay in summer and winter. (See Section 8.2 for details). The bay was divided into fifteen areas enclosing each sampling station (Fig. 7.19), surface area

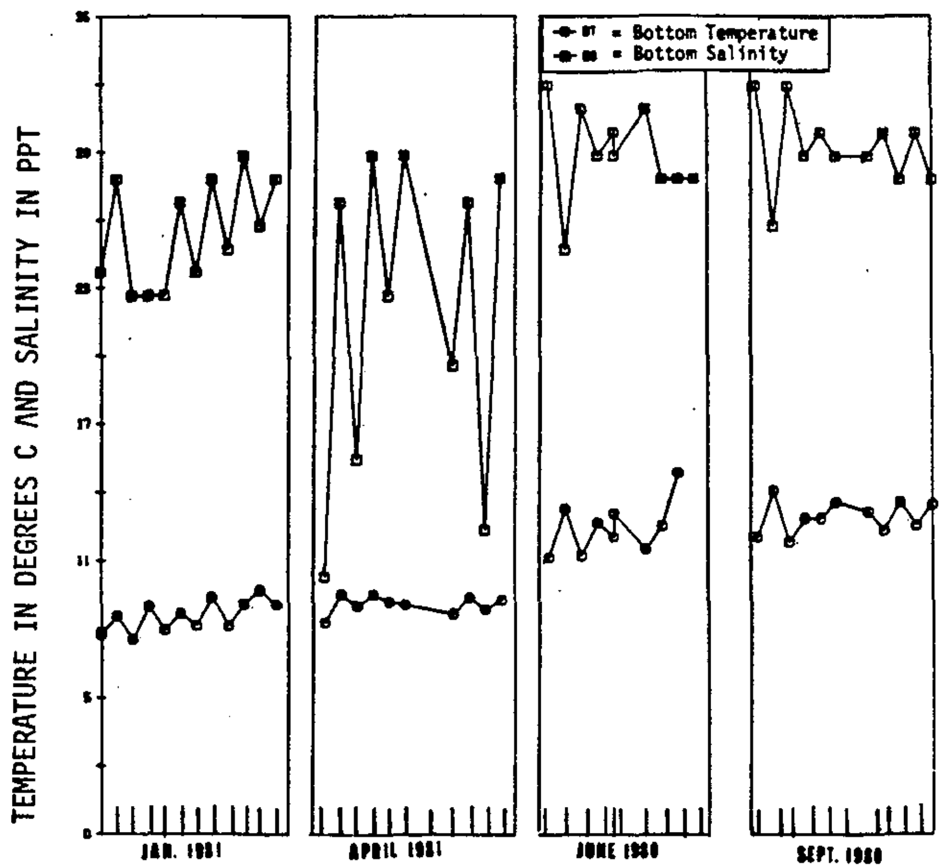


Fig. 7.14. Bottom temperatures and salinities recorded when shrimp were collected during the South Reach diel sampling periods. Each hash mark represents measurements taken near a different tow. All tows within a season were about 6 hours apart.

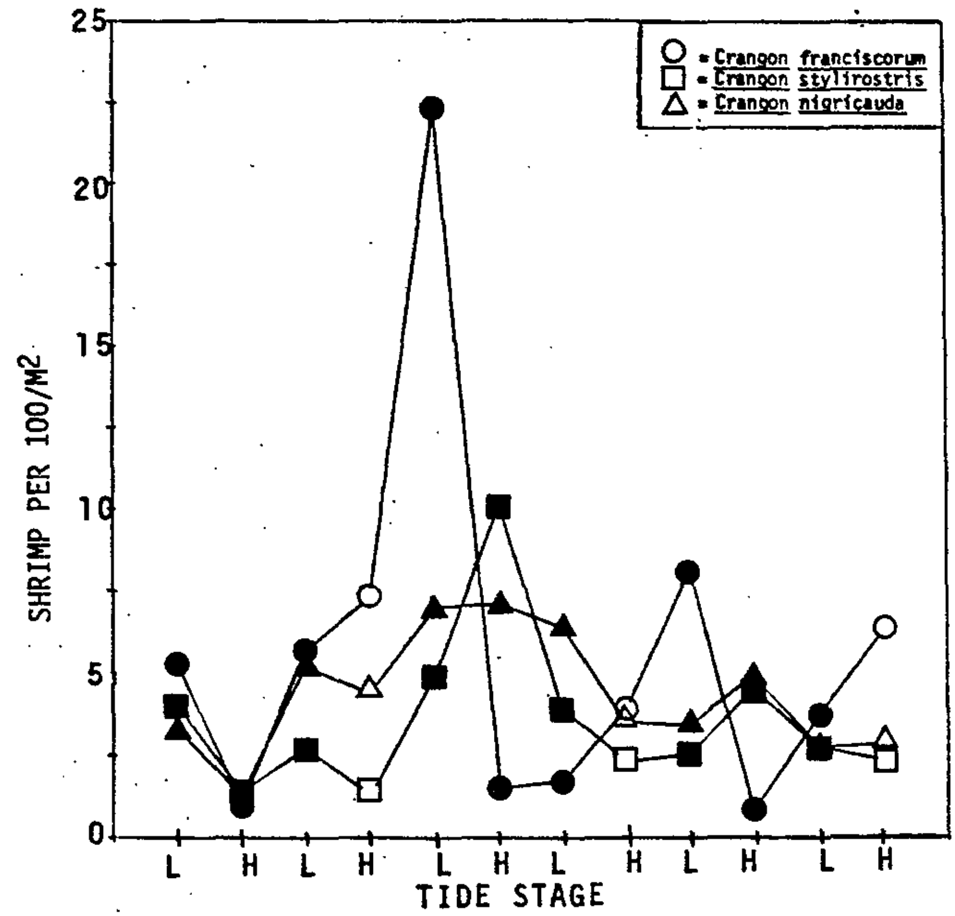


Fig. 7.15. Density of shrimp during the January 21-24,1981 diel sampling period at the South Reach. Nighttime tows are designated by darkened circles,squares and triangles. Low tide is indicated by L and high tide by H.

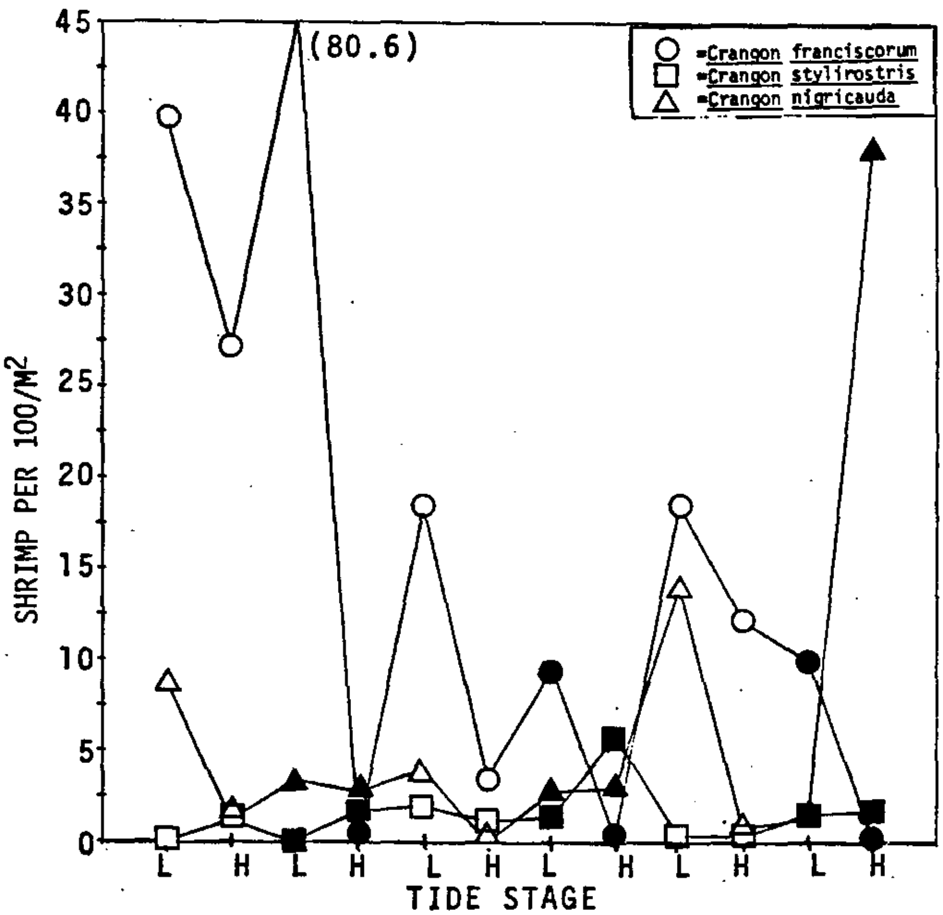


Fig. 7.16. Density of shrimp during the April 3-5,1980 diel sampling period at the South Reach. Nighttime tows are designated by darkened circles, squares and triangles. Low tide is indicated by L and high tide by H.

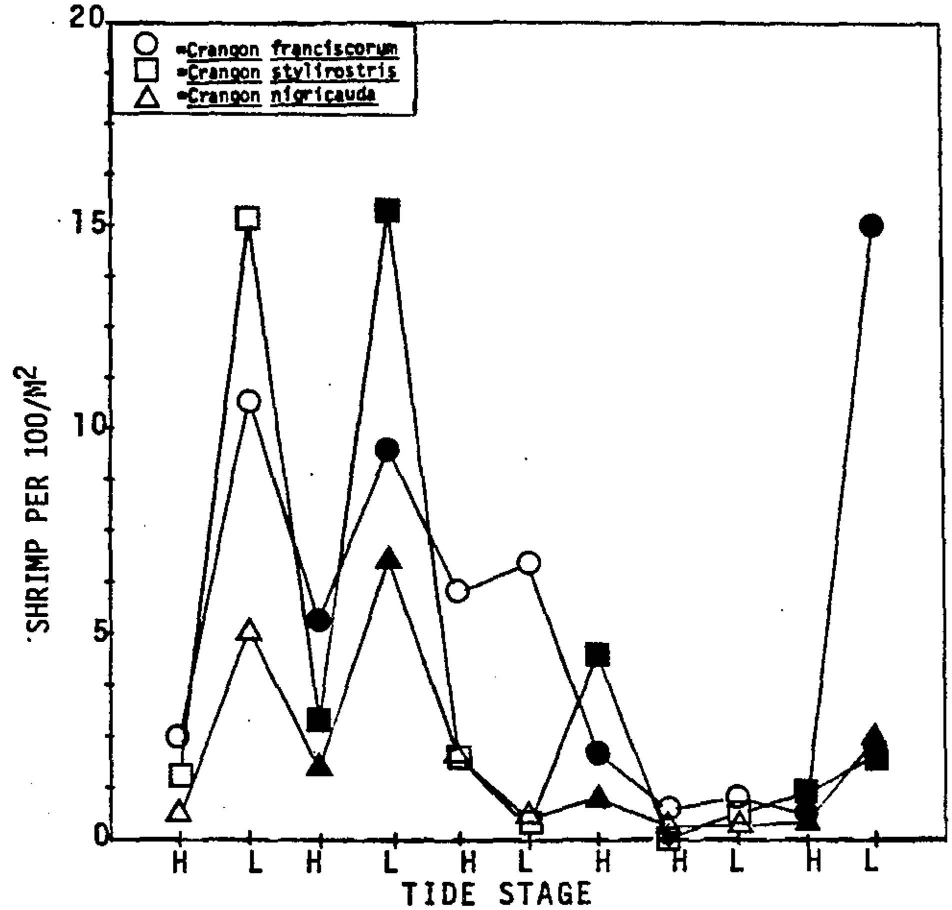


Fig. 7.17. Density of shrimp during the June 21-24,1980 diel sampling period at the South Reach. Nighttime tows are designated by darkened circles,squares and triangles. Low tide is indicated by L and high tide by H.

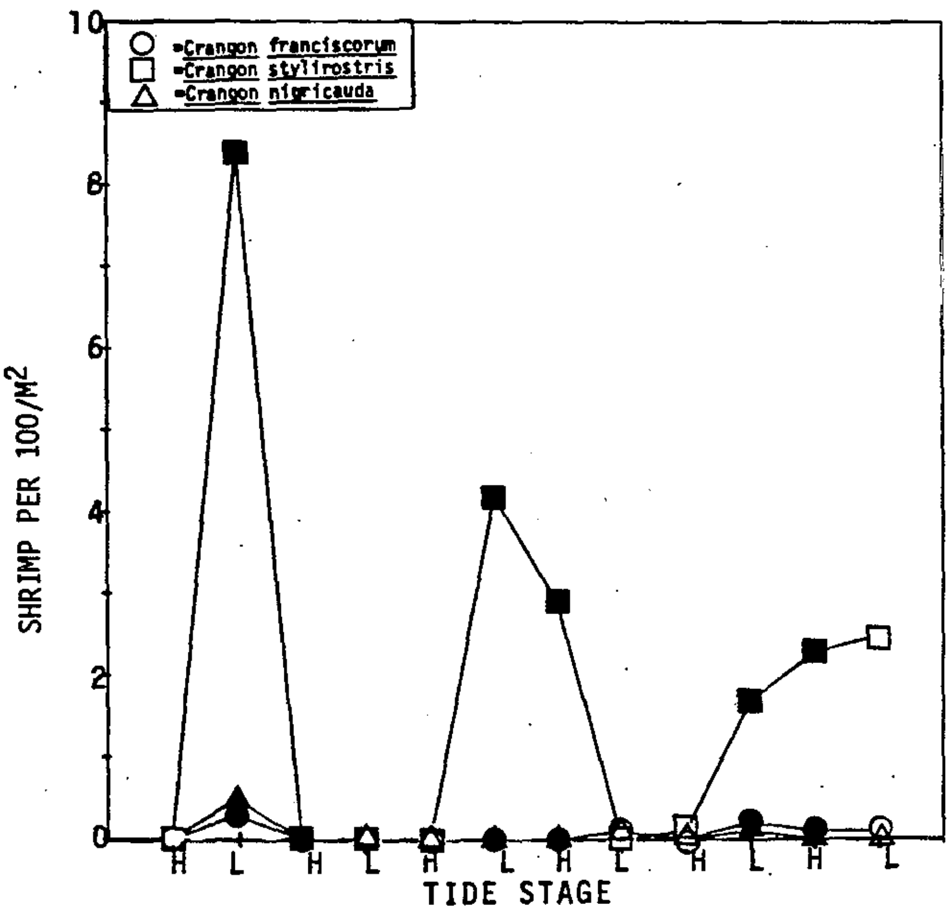


Fig. 7.18. Density of shrimp during the September 25-28, 1980 diel sampling period at the South Reach. Nighttime tows are designated by darkened circles,squares and triangles. Low tide is indicated by L and high tide by H.

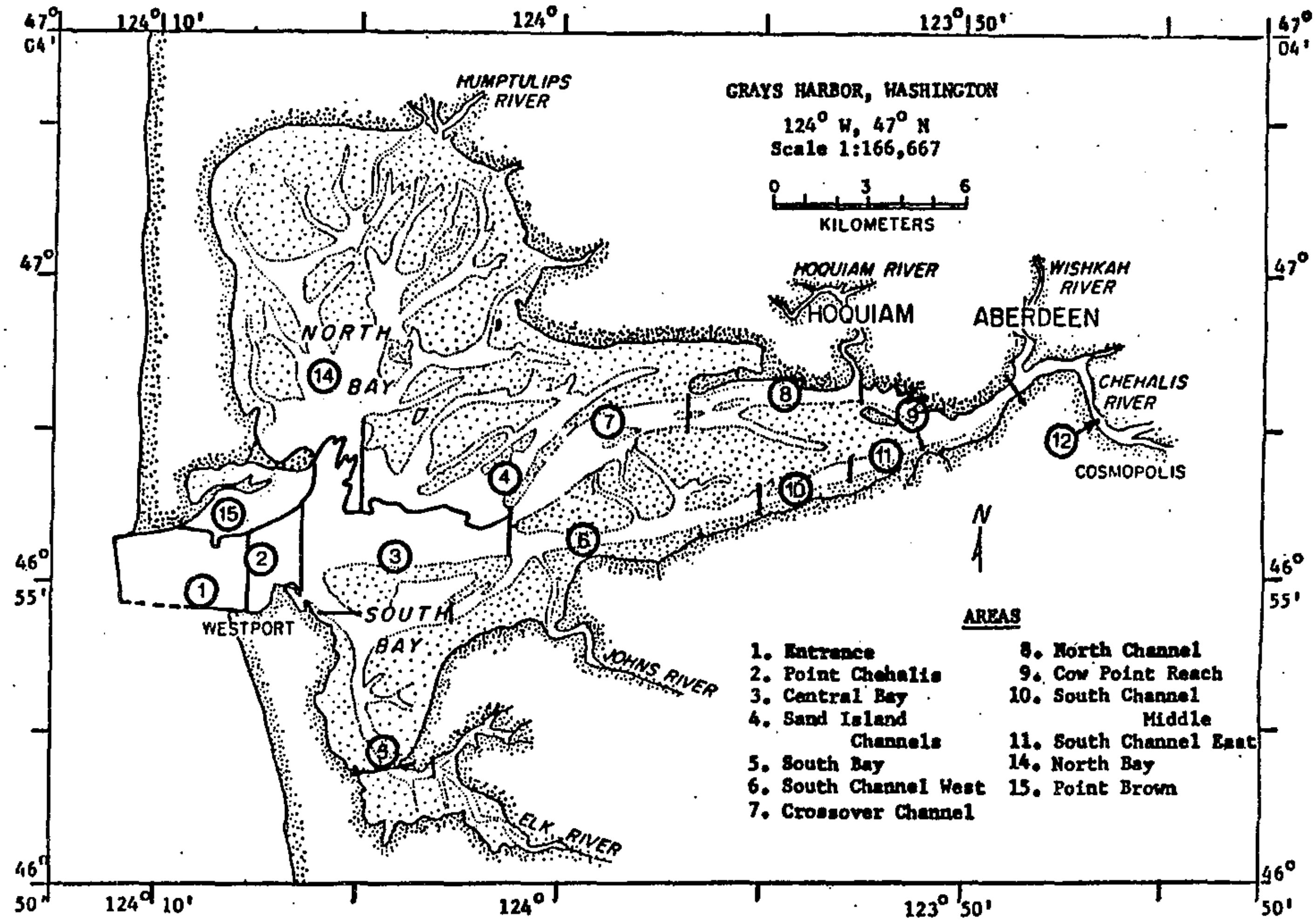


Figure 7.19. Areas of Grays Harbor used to estimate the crangonid shrimp population. Area numbers in this map correspond to trawl sites in Figure 2.1.

(excluding all intertidal lands; see Section 8.2 regarding each area) was calculated by planimetry (Table 7.19), and total shrimp within each area calculated from densities from trawl data.

Estimates of total shrimp are presented in Table 7.1 for two general seasons ("summer" = April-September; "winter" = October-March), and have not been corrected for assumptions regarding net efficiency. The total population of Crangon spp throughout the bay in winter was estimated at 7.4 million shrimp with greatest abundance in the Central Bay adjacent Whitcomb Flats and in the North Bay. In the summer period of April through September, population size had increased three fold to about 25 million shrimp reflecting recruitment of young-of-the-year to benthic populations.

Estimates of population size were used to assess the impact of dredge entrainment on shrimp populations. Data on entrainment rates (Section 6.3, Table 6.2) and the volume of sediment to be removed during widening and deepening were used to calculate total shrimp entrained in three areas of the bay by two types of dredges working under different scenarios (Table 7.2). In the first scenario, hopper dredges working throughout the bay year-round would entrain about 10.5 million shrimp (Table 7.2). However, in a second scenario a combination of pipeline and hopper dredges working in restricted areas and seasons would remove only about 1.9 million shrimp; about 6 fold less than entrained in the first scheme.

7.3.4 Sources of Error: In terms of absolute numbers, year-round dredging would remove over ten million shrimp from an unadjusted annual bay population of 23.4 million; nearly 50%. However, this contrast is misleading and must be qualified by several observations:

1. Trawl data used to calculate shrimp densities and, in turn, total population numbers by area leads to substantial underestimates of

Table 7.1 **Estimates of populations of *Crangon* spp. in Grays Harbor by area and season. Estimates are means derived from biweekly and monthly trawls in each area during the season indicated. Population estimates are not corrected for net efficiency and are likely underestimates of true population numbers. Minimum and maximum are lower and upper 95% confidence intervals. Values are shrimp X 10^3.**

Area		Summer (April - September)				Winter (October - March)			
No.	km^2	n (tows)	min	mean	max	n (tows)	min	mean	max
1	8.37	6	90	1,734	5,117	3	183	264	2,796
2	4.96	6	53	1,028	3,032	3	109	157	1,657
3	15.07	9	80	806	2,030	6	0	1,738	6,361
4	11.20	6	0	862	2,912	2	0	1,028	4,007
5	6.58	3	0	291	699	3	0	213	764
6	6.80	9	1,110	4,719	10,758	6	0	528	2,273
7	6.56	6	743	4,752	12,120	4	25	1,125	3,475
8	4.18	9	962	4,816	11,561	6	89	219	395
9	2.21	8	570	2,100	4,576	6	63	168	313
10	0.96	(9)2/	157	666	1,519	6	0	74	321
11	0.86	(9)2/	140	597	1,361	6	0	67	287
14 1/	26.53	(9)3/	0	1,609	11,953	5	0	1,648	6,288
15	4.14	(6)4/	44	858	2,531	3	91	131	1,383
Minimum			3,949				560		
Mean				24,838				7,360	
Maximum					70,169				30,320

1/ There was no data collected for shrimp at station 12, and station 13 was used for the diel survey in conjunction with station 3.

2/ Estimates for areas 10 and 11 based on mean and s.d. of Area 6.

3/ Mean and s.d. for Area 14 derived by combining data from Areas 4 and 5.

4/ Estimates for Area 15 based on mean and s.d. of Area 2.

Table 7.2 Estimated number of Crangon shrimp removed by proposed channel dredging.

Area No.	1			2			3				Totals
Channel Reaches	Outer Bar Entrance South Reach			Crossover North Channel Hoquiam			Cow Point Aberdeen S. Aberdeen				
Entrainment rates:	summer	S.D.	winter	summer	S.D.	winter	summer	S.D.	winter	S.D.	
(shrimp/cy) Hopper dredge	.232	(.112)	.548 2/	.109	(0.91)	.013 2/	2.344	(---)	.159 2/		
Pipeline dredge	---		---	---		---	3.404	(5.89)	.001	(.002)	
Sediment volume removed (cy):											
Enlargement	7,750,000			6,400,000			5,200,000				
Maintenance	1,000,000			1,500,000			26,000				
Scenarios of shrimp entrainment:											
1) Dredge 50% summer, 50% winter, hopper at all areas:											
Enlargement(shrimp)	3,022,500			390,400			7,107,800				10,520,700
Maintenance(shrimp)	390,000			91,500			32,500				514,000
2) Dredge area 1 summer only, area 2 winter only, area 3 winter pipeline only:											
Enlargement(shrimp)	1,780,000			83,200			5,200				1,868,400
Maintenance(shrimp)	232,000			19,500			26				251,526

1/ Entrainment rates and standard deviations from Table 6.4 in the adjusted sample size column.

2/ Winter entrainment rates estimated by multiplication of summer rate by winter/summer ratio of trawl catches in each area.

true population size. It is reasonable to assume that net efficiency is low, particularly in spring and summer months when very small young-of-the-year are prevalent in the bay. Shrimp densities for this reason could be underestimated by a factor of 10 or more (see Section 2.0 for discussion of crab estimates). In a similar vein, rates of entrainment of shrimp could also be underestimated since the 1/2 inch mesh size of baskets on the hopper dredge (Section 6.2.2) would not retain small animals except when clogged.

2. Estimates of shrimp population size are probably low because of net avoidance and because many Crangon spp. are known to bury in sand during the day and emerge at night to feed (Kaestner 1970). Since all trawls used to estimated shrimp populations were made during the day, the proportion of buried shrimp that were sampled may have been quite small.

3. A comparison of 10 million shrimp entrained to an annual mean population of 16 million assumes that all dredging for the widening and deepening program would be completed in a year. In fact, two to several years may be required to complete the project which will reduce annual entrainment to 10 million divided by the years involved.

4. The standard deviations for the means are large and reflect substantial variation in densities (Figs. 7.1-7.8), and hence estimates of total numbers of shrimp within each area. It is important to also realize that the mean population estimate for an area is the number of shrimp expected within the area month to month, i.e., it is a static estimate that in no way reflects or encompasses values for

production and mortality of the three crangonid species involved. A mean value of 25 million shrimp in the bay during summer months gives no information on numbers lost to predation and other categories of mortality, nor on recruitment of juveniles to the benthos and other measures of productivity.

5. Dredging will remove large quantities of sand shrimp but only from the strip of bay affected by channel modifications. Shrimp will continue to move in and out of the channel area while dredging takes place, but the major impact on shrimp populations will be localized. Areas untouched by the dredge are likely to continue to support large populations of <u>Crangon</u> shrimp. For the species that prey on sand shrimp, less food will be available to them in the dredged areas.

Considering these sources of error, an adjustment in the calculation of relative proportions of shrimp populations entrained must be made. Working from an annual mean population of 16 million shrimp it is assumed this is underestimated, on the average, by a factor of five because of gear inefficiency and because extensive sampling in large areas of the bay (North Bay, South Channel) was not done. The adjusted annual population of crangonids would be about 80 million animals. In the two entrainment scenarios, values of 10.5 and 1.9 million entrained animals are calculated, but it is assumed this would occur over two years resulting in an annual removal of as many as 5.25 million to as few as .95 million. The percents of the adjusted annual population estimate of 80 million removed in these high/low scenarios are 6.5% and 1.2%; relatively small fractions of the total population.

7.3.5 The Ecological Role of Crangon Shrimp in Grays Harbor: At least three fish species appear to be major predators on crangonid shrimp in Grays Harbor. Sixty-one percent of the 102 Pacific tomcod stomachs examined contained Crangon while one-third of the staghorn sculpin and sand sole stomachs contained Crangon. (One-fourth of the sand shrimp found in tomcod and staghorn sculpin stomachs were fresh and may represent net feeding by fish Table 7.3). Tomcod and staghorn sculpin were two of the five most abundant bottomfish species found in Grays Harbor (see Section 5.0), and therefore, crangonid shrimp probably represent a significant food source for a major portion of the estuarine fish community.

Other prey items found in the fish checked for Crangon shrimp were listed (Table 7.4) to provide general biological information. Of note was the presence of juvenile Dungeness crabs or megalopae in the stomachs of tomcod, staghorn sculpin, and longfin smelt. Stomachs from eighty lingcod caught in Grays Harbor contained mostly fish and no Crangon (Dan Grosse, School of Fisheries, U. of W., personal communication). The examination of stomach contents of salmon and English sole caught in Grays Harbor indicated these groups did not feed on Crangon (Charles Simenstad, FRI, U. of W., personal communication).

Other studies have shown that many fish species prey on crangonid shrimp. Among them are some fish which are present in Grays Harbor: Pacific sanddab, prickly sculpin, copper rockfish, Pacific cod, and big skate (Kravitz et al., 1976; Haertel and Osterbey, 1967; Prince and Gotshall, 1976; Rathbun, 1902;

Table 7.3 Summary of incidence of Crangon spp. in stomachs of fish collected in Grays Harbor, Washington between March 1980 and July 1981.

SPECIES	NUMBER EXAMINED[1/]	LENGTH(mm) $\overline{X}$	LENGTH(mm) ±S.D.	% OF FISH WITH CRANGON	AVE. NO. SHRIMP PER FISH	ESTIMATED[2/] % NET-FEEDING	% EMPTY STOMACHS
Buffalo Sculpin	10	125.3	16.2	0	0		30
Kelp Greenling	3	192.6	13.9	0	0		0
Longfin Smelt	7	130.1	22.8	0	0		57
Pacific Herring	6	183.2	41.9	0	0		83
Pacific Tomcod	102	174.0	24.3	61	1.0	18	12
Prickly Sculpin	8	119.3	18.9	0	0		0
Redtail Surfperch	3	285.0	30.4	0	0		0
Rock Greenling	1	330.0	—	0	0		0
Sand Sole	10	225.0	46.2	30	.5	0	20
Shiner Perch	19	131.0	13.9	0	0		74
Showy Snailfish	1	105.0	—	0	0		0
Snake Prickleback	9	200.0	51.2	0	0		22
Staghorn Sculpin	55	153.9	29.9	33	.55	27	11
Starry Flounder	11	191.3	48.7	0	0		36
Walleye Surfperch	1	130.0	—	0	0		0

1/ The majority of fish were taken in the months of March, July, and November from stations at South Reach, Moon Island, Cow Point and Crossover Channel.

2/ Percent net-feeding was obtained by dividing the number of fresh Crangon (with no signs of digestion) by the total number of Crangon identified from the stomach contents of that species. This fraction was probably eaten while the fish were in the net with the shrimp.

Table 7.4 Recognizable stomach contents of fish in order of importance, by biomass.

SPECIES	NUMBER EXAMINED	AVERAGE FULLNESS*	STOMACH CONTENTS
Buffalo Sculpin	10	1.7	fish, plants
Kelp Greenling	3	3.3	stout coastal shrimp (*Heptacarpus brevirostsis*), small unidentified crustacea, snails
Longfin Smelt	7	0.9	amphipods, Dungeness crab megalops
Pacific Herring	6	0.2	most stomachs empty, everything unrecognizable
Pacific Tomcod	102	3.0	*Crangon sp.* fish - including sand lance, ghost shrimp (*Callinassa californiensis*), unidentified crustacea, juvenile Dungeness crabs and megalopae, fish eggs, unidentified polychaetes.
Prickly Sculpin	8	1.8	unidentified crustacea, grammarid amphipods, insect pupae, *Corophium sp.*
Redtail Surfperch	3	2.7	fish - including three-spined-stickleback
Rock Greenling	1	4.0	fish eggs
Sand Sole	10	2.0	fish - including sand lance and Pacific herring *Crangon sp.*,
Shiner Perch	19	0.3	unidentified crustacea, small clams
Showy Snailfish	1	1.0	unidentified crustacea, small clams, unidentified worms
Snake Prickleback	9	1.7	plants, small clams, harpacticoids, nemotodes
Staghorn Sculpin	55	2.1	*Crangon sp.*, fish - including longfin smelt, Ghost shrimp, unidentified crustacea, amphipods, Mud shrimp (*Upogebia pugettensis*), juvenile Dungeness crab and megalopae, fish eggs.
Starry Flounder	11	1.0	unidentified crustacea, unidentified polychaetes
Walleye Surfperch	1	2.0	unidentified crustacea

* Each fish was given a stomach - fullness value from 1 to 4 where: 1 = 0 to 25%, 2 = 26-50%, 3 = 51-75%, 4 = 76-100%. The average fullness was the average of all these values for the fish examined.

Fitz 1956). In Europe, where Crangon have been studied more extensively, at least 19 fish species are known to prey on them including gadoids, flounders, plaice, whiting, pouting and brill (Tiews 1970; Butler 1980; Hartley 1940; van den Broek 1978).

Besides fish predators at least one species each of invertebrate, bird, and mammal probably feed heavily on the large populations of crangonids in Grays Harbor. Crangon shrimp were found to be a major food item for Dungeness crabs in Grays Harbor (See Section 4.0) ranking only after fish in terms of importance to their diet. Harbor seals are one of the most abundant mammals utilizing Grays Harbor. The diet of harbor seal pups before they switch to fish has been shown to consist almost entirely of crangonid shrimp on both the Atlantic and Pacific coast (Biggs 1973; Butler 1980). Grays Harbor supports large populations of ducks and shorebirds. The number of bird species that feed on sand shrimp is potentially quite large. Mallard ducks, which use the harbor in fall and winter months have been known to feed on Crangon (Green 1968) but they may not be the most important species of avian predator.

The prey organisms of sand shrimp in Grays Harbor were investigated by examining the stomach contetns of 212 shrimp from the South Reach and Whitcomb Flats diel collections (Table 7.5). A large incidence of polychaetes and their setae were noted in the stomachs (setae could be identified as polychaete because of their distinctly bent shape and the blade-like serrated edge toward one end of the setae). Other recognizable stomach contents included unidentified crustacean parts, small clams, ostracods, algae and diatoms (Table 7.5). Many of the stomachs contained unidentifiable digested material and sand. Of the 212 shrimp stomachs examined, 43.2% of them had some sand present while 22.7% of the stomachs contained mostly sand. No

Table 7.5 Percent incidence of recognizable prey in stomachs of Crangon spp. taken from Grays Harbor, Washington.

SPECIES	NUMBER EXAMINED 1/	CONTENTS: SMALL CLAMS	OSTRACODS	POLY-CHAETES	POLY-CHAETE SETAE	ALGAE	DIATOMS	UNIDEN-TIFIED CRUS-TACEA
Crangon franciscorum	55	5.5	1.8	3.6	15.4	0	0	14.5
Crangon nigricauda	79	19.0	5.1	0	3.2	0	2.5	12.7
Crangon stylirostris	78	7.7	1.3	1.3	1.9	1.3	0	11.5

1/ Shrimp are from diel collections made from June through September, 1980. Most were taken from Whitcomb Flats but 23 of the 212 shrimp examined were from South Reach.

conclusions could be reached on the degree of resource partitioning, time of feeding, or relative importance of various prey items to the diet of these sand shrimp species. Other studies have indicated they usually feed at night. Crangon vulgaris has demonstrated the ability to capture and eat prey in total darkness when observed by infrared light (Wienberg 1976).

In the only investigation of Pacific Coast Crangon feeding habits, Sitts and Knight (1979) found Crangon franciscorum in the Sacramento-San Joaquin Estuary of California to undergo nocturnal vertical migrations. This off-bottom movement presumably enabled them to feed in density layers on the mysid shrimp Neomysis mercedis, which were the primary food items found in C. franciscorum stomachs. Other prey items found were gammarid amphipods, copepods, insects, polychaetes, bivalves, larvae of the crab Rhithropanopeus harrisii, and larvae of a common caridean shrimp in that area, Palaemon macrodactylus.

Food items of the much studied European sand shrimp Crangon vulgaris include: polychaetes such as Nereis, amphipods including Corophium, mysids, small molluscs, gastropods, bivalves, algae, fish eggs, detritus and animal tissue (Tiews 1970; Lloyd and Younge 1947; Kaestner 1970).

Food items of Crangon septemspinosa from the Eastern Coast of the United States include: crustacean parts, copepods, polychaetes, amphipods, nematodes, ostracods, gastropods, mysids (especially Mysis mixta), bivalves including Gemma, plant material, fecal pellets, fish scales, invertebrate eggs, diatoms, thallose algae, dead blue crabs, Crangon larvae, and detritus (Wilcox and Jefferies 1974; Price 1962; Squires 1965; Sanders et al 1962).

There is some debate in the existing literature as to whether Crangon are primarily detritivores, carnivores, or omnivores. The high incidence of plants, sand, and fecal material in their stomachs has prompted the hypothesis that they are also occasional deposit feeders, engulfing inanimate objects such as sand for the associated microflora on the surface. This microflora would include colonies of bacteria, yeast, and protozoa that might have concentrations of certain needed nutrients (Odum 1971; Russel-Hunter 1970).

Lloyd and Younge (1947) classified *Crangon* as omnivores because of the large percentage of algae and plant material found in their stomachs. Dahn (1975) demonstrated that *Crangon vulgaris* chose living prey over dead and concluded these shrimp were primarily carnivores and secondarily detritivores. *Crangon* were classified as secondary consumers by Daiber (1959) because they fed on filter feeders like mysids which are nourished by salt marsh detritus. All this demonstrates that *Crangon* are very versatile feeders with the ability to eat a wide range of prey species and to capture prey both on the bottom and in the water column. By virtue of this versatility, the impact of dredging on the diet of crangonids will probably be minimal.

7.4 Summary

1) *Crangon franciscorum* is the dominant species of crangonid in Grays Harbor and its populations reach a high seasonal peak in the inner harbor from May through August.
2) *C. franciscorum*, *C. stylirostris* and *C. nigricauda* have overlapping distributions in the outer harbor but the densities of all three species combined are significantly less than for *C. franciscorum* in the inner harbor. Densities are as much as 25 times higher at inner harbor stations during peak abundance.
3) The distribution of *C. nigricauda* and *C. stylirostris* into the bay appeared to be limited by low bottom salinity and also some form of

competition with C. franciscorum.

4) Shrimp catches were much higher at night than in the day at Whitcomb Flats and were usually somewhat higher at low tide than at high tide at the South Reach.

5) Total shrimp population estimates in Grays Harbor were 24.8 million in the summer and 7.4 million in the winter. These calculations underestimate true populations because trawl nets used to make estimates are not 100% efficient.

6) Projected shrimp entrainment and removal by the proposed dredging project was estimated at a high of 10.5 million shrimp and this value was discussed relative to several sources of error. Percentages of the total adjusted shrimp population removed annually range from 1.2% to 6.5%.

7) The removal of Crangon by dredging means a reduction in food resources for animals such as the Dungeness crab which feed on these species.

8.0 SUMMARY OF CONCLUSIONS, PREDICTION OF POTENTIAL DREDGING IMPACTS, AND SUGGESTIONS FOR THEIR REDUCTION

Bradley G. Stevens, David A. Armstrong, James C. Hoeman

8.1 Summary of Conclusions Resulting from the Research Program

1) Fishery records for the Pacific coast show that the Dungeness crab, *Cancer magister*, supports the second largest crustacean fishery of the western United States, and the second most valuable shellfish industry in Washington. Large scale, long term, cyclical fluctuations in catch have made the magnitude of the fishery variable in the last 40 years. Further perturbations could have significant effects on this fluctuating fishery.

2) Surveys of trawl-catchable crab density made at nine stations in Grays Harbor over a 15 month period revealed the following:

a) Estimates of monthly and biweekly crab density showed a decline during fall and winter at all stations, followed by an increase in spring and summer. Analysis of variance for three inner harbor stations and three outer harbor stations showed that the spring-summer densities (March-August; 4.98 crabs/100 m^2) were significantly greater than the winter densities (September-February; 1.62 crabs/100 m^2). Part of the summer increase was due to the arrival of large numbers of early postlarval crabs, which appeared in trawl samples at most outer harbor stations, but may have been greatly underestimated, as shown by visual inspection of intertidal mud flats.

b) Annual mean crab densities were significantly greater at the three outer harbor sites (5.83 crabs/100 m^2) than at the three inner harbor sites (2.20 crabs/100 m^2).

c) Shallow brackish-water habitats of the inner harbor, represented by sites M and MC in the South Channel, supported very few crabs most of the year except July-October, when crab catches by ring nets increased ten-fold. This situation was probably also true for the mudflats in the east-central harbor, west of Rennie Island.

d) During summer, autumn, and winter, there was a consistent, but not statistically significant, trend towards greater crab densities in the channel bottom during low tide than at high tide, probably representing a funneling of crabs down off the tide flats into deeper water. This situation was reversed during a high flow period in April 1981, when reduced salinities at low tide may have stimulated crab burial behavior and avoidance of nets or movement to other areas.

e) Data from January 1981 indicated a significant nocturnal movement by crabs from the channels onto the tide flats, reducing channel densities and increasing intertidal densities significantly. An identical behavior pattern occurred among *Crangon* shrimp, the density of which increased ten-fold by night on the flats. This pattern reflects a predator-prey relationship supported by the observation that crab stomachs collected during this period showed an enormous increase in feeding upon *Crangon* at night on the flats.

3) Studies of the food habits of *C. magister* revealed the following:

a) *Crangon* spp. were the most important prey genus for crabs in Grays Harbor. Teleostei were the most important class of prey organisms.

b) At night, predation by crabs on *Crangon* spp. increased dramatically on intertidal flats. Stomach fullness changed very little through a diel cycle, indicating feeding activity continued during the day but categories of major prey changed at night.

c) Crabs less than 60 mm carapace width preyed most heavily upon small bivalves (1-5 mm) in the outer harbor, or small crustaceans (barnacles, amphipods) in the inner harbor. Crabs between 60 and 100 mm preyed heavily on other crustaceans and fish, and crabs over 100 mm preyed most heavily upon juvenile fish.

4) Studies of entrainment of crabs by hopper dredges gave these results:

a) Entrainment of crabs by the hopper-barge SANDSUCKER was at least four times greater at South Reach (outer harbor) than in the inner harbor during summer. In the inner harbor, pipeline dredges entrained approximately four times fewer crabs than hopper dredges, a statistically significant difference. At the South Reach, entrainment during the summer of 1980 was over twice as great as that during the winter of 1978-79 (also statistically significant; <u>see</u> Section 6.0 for rates).

b) The dredges were not size selective. Entrainment rates probably reflected local crab population densities and size ranges accurately. Crab mortality was estimated to be 73% for all crabs entrained by the SANDSUCKER, and large crabs >50 mm were a greater proportion of those killed than small crabs. Mortality from the pipeline dredge was estimated to be 100%.

5) Studies of shrimp population densities showed that:

a) Three species of <u>Crangon</u> shrimp were the most abundant trawl-catchable organism in the harbor. All stations showed peak densities of <u>Crangon</u> in May-August. At that time, densities were 300-500/100 m^2 at inner harbor stations (sites

6-9), and 15-100/100 m^2 at outer harbor stations (sites 1-4). Diel abundance of shrimp (3 species) was similar to that of C. magister in having high densities during low tide in the channel, and greatly increased density on the flats during night high tides.

b) Estimates of the trawl-catchable population size of Crangon spp. ranged from 11.7 million individuals in winter to 35.2 million in summer.

c) The most abundant species of shrimp was Crangon franciscorum at inner harbor stations. In the outer harbor, C. franciscorum populations are gradually merged with those of C. nigricauda and C. stylirostris, both of which are residents of higher salinity water than C. franciscorum.

d) Of those invertebrate species caught by sampling baskets crangonid shrimp are entrained by hopper dredges in the greatest numbers. Widening and deepening may entrain 10.7 million shrimp (see Section 7.0).

e) At least three species of fish, plus Cancer magister, depend upon Crangon spp. as a major food source. This source will be impacted by dredging.

8.2 Major Questions of Impact

The previous sections have presented evidence of the enormous numbers of crabs, shrimp, and juvenile bottomfish in Grays Harbor, and discussed the importance of these species to each other and their communities. With this information as background, questions can be formulated concerning the nature and extent of potential impacts of dredging on the epibenthic macrofauna of Grays Harbor. Some of the questions, grouped into categories of similarity, are:

1) What form(s) of direct impact occurs?
   Which life stages are most severely impacted?

2) What is the actual dredge-related mortality rate?
   Does it differ between species and life stages?

3) Will removal of food sources occur?
   How important are these sources?

   Will their removal affect predator population density or inter- and intra-specific competition for remaining food sources?

4) Will removal of crabs and/or their food sources affect the local and/or offshore fishery?
   If so, what will the extent of this effect be?

These questions are addressed in the remainder of section 8, although in some instances in an indirect or speculative manner.

8.3 Estimation of Grays Harbor Crab Population

Any prediction of entrainment and mortality of crabs in the estuary cannot be seen in perspective without an estimate of the total population in the estuary. With this estimate, mortality predictions can be viewed as a proportion of the total number of crabs in the harbor.

8.3.1 Basic Assumptions about Trawl Data: Certain basic assumptions must be specified in order to estimate the total crab population. These are:

1) The trawl net used in this study does not capture all animals in its path. During the summer months, densities and total numbers of the 0+ age group may have been greatly underestimated, due to net inefficiency as shown by visual examination of tidal flats. For other age groups, and for all crabs during other periods of the year, catchability was probably about 50% of the true population density, as indicated by Gotshall (1968), in Humboldt Bay, CA, an environment very similar to Grays Harbor.

2) Over a 24-hr cycle, catchability may change due to burial behavior, as indicated in Section 3. However, all monthly trawls were taken under conditions as similar as possible (daylight low tides). Therefore, we must assume that monthly/biweekly trawl catches represented a constant proportion of total crab density, i.e., catchability did not change between sampling periods due to burial behavior.

3) As a result of assumption 2, we concluded that monthly/biweekly changes in crab catch by trawl represented true changes in crab

population density. This assumption is based on the statistically significant density changes which occurred from summer to winter. Lower winter crab densities were assumed to be the result of such factors as high predation and mortality of early instars, and movement to areas of the bay not sampled or out of the bay entirely, but not due to any change in sampling efficiency as a result of long-term burial or greater net avoidance by crabs.

8.3.2 Area of Grays Harbor: In order to estimate the overall density and biomass of crabs in portions of the harbor, it was divided into sections roughly equivalent with habitats represented by each sampling site. Area numbers were assigned to correspond with sampling site numbers, and enclose the actual site. Boundaries were usually defined at the midpoints between sites. These areas were outlined on NOAA Chart #18502 (Grays Harbor, 1979 edition) and measured with a planimeter. Measurements were then converted to square kilometers. Sections were defined as follows (Fig. 8.1):

1) Entrance, 8.37 km^2. All area below the 18 ft depth contour, bounded on the west by a line drawn between the western tips of the submerged portions of the North and South Jetties, and on the east by the meridian at 124°08'W longitude.

2) Point Chehalis, 4.96 km^2. Bounded on the north by the 18' depth contour, on the south by the 0' depth contour, and lying between 124°08'00" and 124°06'30"W longitude.

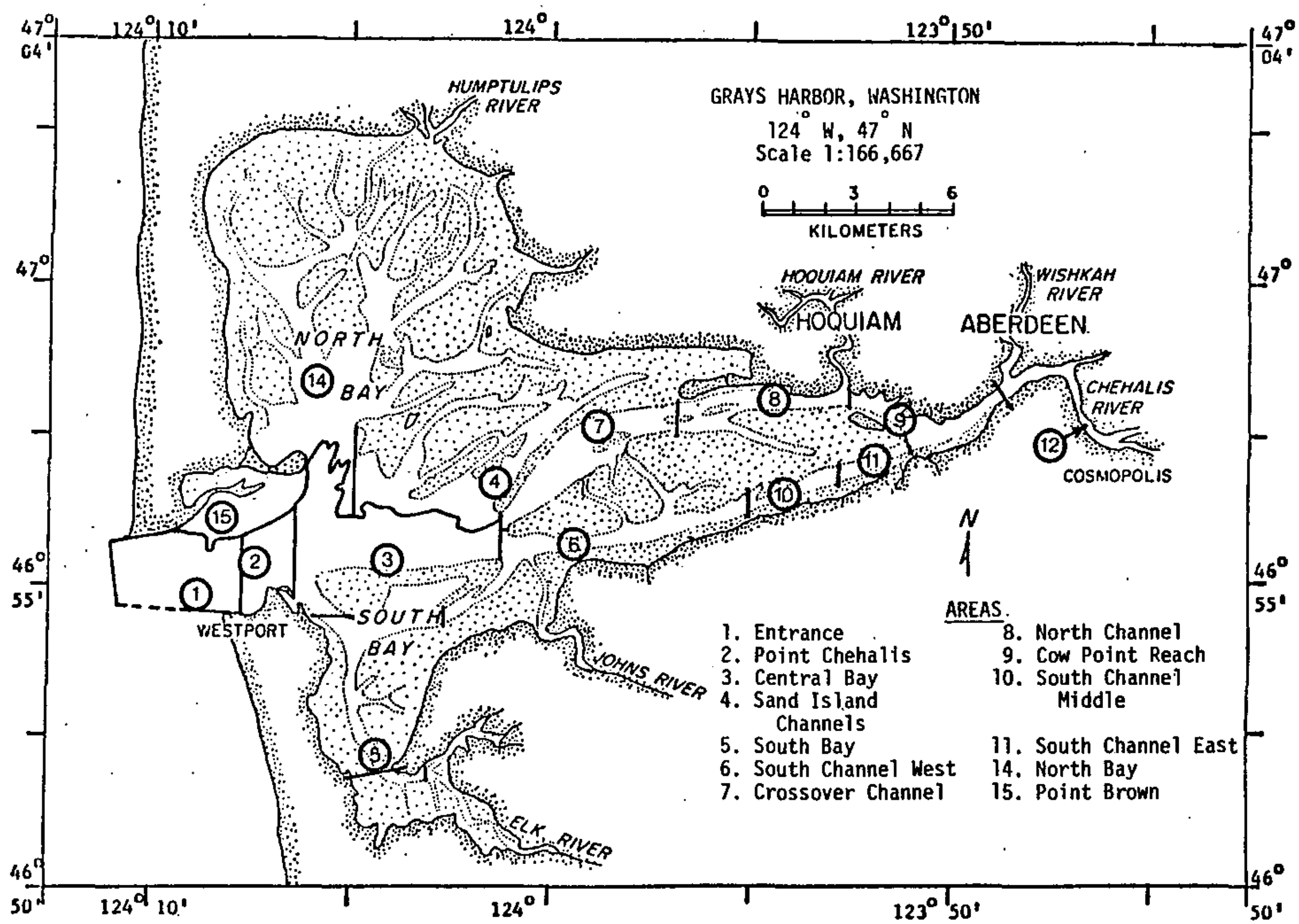


Fig. 8.1. Areas of Grays Harbor used to estimate the crab population.

3) Central Bay, 15.07 km^2. Bounded on the east and west by the meridians at 124°01'05" and 124°06'30"W longitude, respectively. Northern boundary formed by the 18 ft depth contour. Southern border followed the MLLW contour westward along the north shore of Whitcomb Flats, then turned southeast into the Elk River channel to W. longitude 124°05'30", across the river, then northwest along the south shore of this channel to 124°06'W longitude. The Westport Marina was also included in this area.

4) Sand Island Channels, 11.20 km^2. This area was bounded on the west by the meridian at 124°05'00"W longitude, on the south by the 18 ft depth contour east to 121°01'05" W longitude, north along this meridian to the MLLW contour at the sandbar along the western side of the Crossover Channel. Included in this section were all connected channels extending northward and bounded on the north by mud flats. Encloses the "North Bay" sampling station.

5) South Bay, 6.58 km^2. Including all area below MLLW in the Elk River Channel, from the mouth of Beardslee Slough to the border with area 3. A channel and shallow embayment extend N.E. from the main channel. The narrow portion of this secondary channel was bisected at 124°03'05", and those waters west of this line were included in area 5.

6) South Channel West, 6.80 km^2. All area below MLLW bounded on

the west by the border with area 3, on the north by mud flats, and including several channels across the flats to their northern openings, and bounded on the east by the meridian at 123°55'00". Bounded on the south by the mud flats, and including the Johns River Channel south to 46°54'28"N latitude (Coast Oyster Dock), and that portion of a small channel connecting South Channel to Elk River excluded from area 5.

7) Crossover Channel, 6.56 km^2. All area in the Crossover Channel below MLLW, west of the border with area 3 to 123°55'55" W longitude. Not including several channels running south across the mud flats to area 6. Encloses the Buoy 30 sampling site.

8) North Channel, 4.18 km^2. All area below MLLW and connected to the North Channel, lying between 123°52'30" and 123°55'55"W longitude, including the Middle Channel and the Hoquiam River mouth to the Burlington Northern Railroad Bridge. Encloses the Moon Island sampling station.

9) Cow Point Reach, 2.21 km^2. All area below MLLW, east of the border with area 8, and west of the U.S. 101 bridge at Aberdeen, excluding the South Channel.

10) South Channel Middle, 0.96 km^2. All area below MLLW in the South Channel between 123°52' and 123°55'W longitude. Encloses the Marsh Control station (site MC).

11) South Channel East, 0.86 km^2. All area below MLLW east of 123°52'W longitude, and west of a line drawn perpendicularly across the mouth of the South Channel where it joins the Cow Point reach. Encloses the experimental salt marsh establishment site (site M).

12) Numbers 12 and 13 were not used to designate Harbor sections in order to avoid confusion with trawl sampling sites 12 and 13.

14) North Bay, 26.53 km^2. All area below MLLW north of areas 3 and 4, including many blind channels and tidal creeks. No regular sampling occurred in this area.

15) Point Brown, 4.14 km^2. All area between MLLW and the 18' depth contour along the south shore of Pt. Brown, between the North Jetty and Damon Point. No regular sampling occurred in this area.

Although these areas include many steeply sloping channel banks, the area is calculated as if it were all within the same plane. The error introduced by this method is unknown, but probably small. Areas were calculated for the harbor at MLLW. No surface area above this contour was included. The total area estimated by this method is 98.42 km^2 (Table 8.1A), very close to the estimate of 99 km^2 given by USACE (1977).

Table 8.1A. Calculation of total population of *C. magister* in Grays Harbor. Minimum and maximum are lower and upper 95% confidence intervals. Values are crabs x 10^3.

Area		Spring (March - May)				Summer (June - August)				Winter (September - February)			
No.	km^2	n (tows)	min.	mean	max.	n (tows)	min.	mean	max.	n (tows)	min.	mean	max.
1	8.37	1	6,788	6,788	6,788	3	0	947	5,018	2	0	435	2,574
2	4.96	4	5	109	270	4	47	104	175	2	0	197	15,303
3	15.07	5	261	332	4,620	8	475	1,065	1,849	6	18	202	454
4	11.20	4	13	175	401	4	174	830	1,868	2	0	143	6,391
5	6.58	3	0	150	695	6	0	550	1,671	3	0	8	38
6	6.80	5	73	127	188	8	34	95	171	6	0	8	18
7	6.56	4	127	565	1,254	5	3	177	454	4	0	164	500
8	4.18	5	12	189	490	8	0	74	184	6	1	21	46
9	2.21	4	0	26	83	6	1	39	95	6	0	15	40
10	.96	1/	10	18	26	1/	5	13	24	1/	0	2	2
11	.86	1/	9	16	24	1/	4	12	22	1/	0	2	2
14	26.53	(7) 2/	16	509	1,876	(10) 2/	207	2,093	5,582	(5) 2/	0	186	7,646
15	4.14	3/	72	507	1,269	3/	130	293	508	3/	5	55	125
Minimum			7,386				1,080				24		
Mean				9,511				6,292				1,438	
Maximum					17,984				17,621				33,139

1/Estimates for Areas 10, 11 based on mean and s.d. of Area 6.
2/Mean and s.d. for Area 14 derived by combining data from Areas 4 and 5.
3/Estimate for Area 15 based on mean and s.d. of Area 3.

8.3.3 Calculation of Population Size of Crabs in Grays Harbor: Because of the significant change in crab population density from winter to summer, estimates were made by season. Spring included March-May 1981 and May 1980. Summer included June-August 1980 and July 1981. Winter included September 1980 through February 1981 because relatively few trawls were made in December and January, so more data points were required for averaging. Within these seasons, estimates of crabs per 100 m^2 were averaged for each station. In order to calculate confidence intervals, all crab density estimates were transformed as described in Section 2.3.3. Means, standard deviations and 95% confidence limits were calculated for seasonal crab density at each station, from the transformed values. These values were then reconverted to normal variables by squaring and subtracting one (Snedecor and Cochran 1967). The mean, minimum, and maximum density estimates were then multiplied by the total area represented by that station (sites 1-9). Areas 10 and 11, where ring nets were used in place of trawls, were calculated using the mean density values from area 6 (adjacent to 10). Area 14, the North Bay (not identical to our North Bay sampling site) was calculated from the average catch of South Bay (which it closely resembled in sediment character and salinity range) and our North Bay sampling site, defined as Sand Island Channels in this section, which was adjacent to it. Area 15, Pt. Brown, was calculated from the crab density of area 3, the Central Bay. This was done because area 2, the most adjacent area, represented the buoy 13 sampling site which was shown to have very low crab density, and Pt. Brown is heavily fished by the commercial in-harbor fleet, so was known to have a reasonably high crab density. Means, minima, and maxima for all these areas were then totaled, representing the entire harbor below MLLW from the western tip of the jetties to the U.S. 101 bridge at Aberdeen (Table 8.1-A).

These estimates were then examined and further modified. The spring estimate of crab population size for area 1 (6.8 million crabs) was greater than for the entire remainder of the harbor. This estimate was based on a single trawl sample in May 1980, which gave the highest catch of the entire study (81.1 crabs/100 m^2), and was, therefore, probably an unrealistic estimate for the mean of an entire season. Therefore, this estimate for area 1 was deleted from the total population estimate. In its place, a percentage of the number of crabs estimated for areas 2-15 were added to the total for those areas (Table 8.1B). This percentage was 9.3%, equivalent to the ratio of area 1 bottom surface area to the sum of surface areas for areas 2-15. The total estimate of trawl-catchable crabs was then multiplied by 2.0, to reflect an estimated net efficiency of only 50% (see Section 8.2.1). Confidence limits were treated in the same manner. The estimated total crab population for spring (March-May) was 6.10 million crabs, with 95% confidence limits of 1.31 to 24.5 million crabs. Confidence intervals were not symmetrical due to the squaring procedure required for data reconversion.

The estimate of crab population density in summer required more complex corrections. Of 4,975 crabs collected from all trawl samples

Table 8.1B. Correction of crab population estimate for inefficiency of net sampling.

1. Spring (March-May). (a) The estimated contribution of Area 1 was 71% of the seasonal total. Since this was based on a single tow, and was so much larger than any other catch, this number was excluded from the total population estimate for Spring, leaving 2.72×10^6 crabs.

   b) Because Area 1 represented 9.3% of the bottom surface of Areas 2-15, this amount of the adjusted total crabs were added back to the total:

   $$(2.79 \times 10^6) \times 0.093 + (2.79 \times 10^6) = 3.05 \times 10^6 \text{ crabs}$$

   c) This value was multiplied by 2.0, since trawl efficiency was estimated at 50% by Gotshall (1978a):

   $$(3.05 \times 10^6) \times 2.0 = 6.10 \times 10^6 \text{ crabs}$$

2. Summer (June-August).

   a) In summer 1980, 25% of 5000 crabs captured by trawl sampling at all stations were age 0+, less than 30 mm. Assuming these were underestimated at the rate of 12:1 for the period June-August, this portion of the population was:

   $$(6.30 \times 10^6) \times 0.25 \times 12 = 18.9 \times 10^6 \text{ crabs}$$

   b) Assume the remaining 75% were underestimated by 50% (as above):

   $$(6.30 \times 10^6) \times .75 \times 2.0 = 9.45 \times 10^6 \text{ crabs}$$

   c) The corrected sum:

   $$(18.9 \times 10^6) + (9.45 \times 10^6) = 28.4 \times 10^6 \text{ crabs}$$

3. Winter (September-February)

   a) Assume all crabs underestimated by 50%:

   $$(1.44 \times 10^6) \times 2.0 = 2.88 \times 10^6 \text{ crabs}$$

	Corrected Estimate (crabs X 10^6)		
Season	Spring	Summer	Winter
Minimum	1.31	4.86	0.048
Mean	6.10	28.4	2.88
Maximum	24.5	79.3	66.3

during June-August 1980, 25% were young of the year first to third instars. In late May 1981, examination of intertidal mudflats in the north bay showed that early instars were extremely abundant (see Section 2.3.5). Density of 0+ age group crabs on mudflats was estimated by non-random sampling to be >5 per m^2. If this estimate is conservatively reduced to 1 per m^2 for the entire subtidal area of the harbor, it is still 25 times greater than the highest density calculated from trawl samples for this age group (0.04 crabs/m^2; 4 June 1980; see Fig. 2.11). A still more conservative estimate may be made by assuming that only half of the available harbor bottom is utilized by early instars, thus their density can be estimated at 12 times that represented by trawl data. The corrected population estimate for this age group is then (6.30 million) x 0.25 x 12 = 18.9 million crabs (Table 8.1B). Older (1+ and 2+ years) crabs, comprising 75% of 6.30 million were probably underestimated by a factor of 2.0, as above. Thus their population was estimated as (6.30 million) x (0.75) x (2) = 9.45 million crabs. Maximum and minimum 95% confidence values were treated in a similar manner. The corrected mean population estimate for summer was 28.4 million crabs, the sum of the two values above. Confidence intervals ranged from 4.86 to 79.3 million crabs.

For the winter population estimate, it was assumed that all crabs were equally underestimated by a factor of 2.0, as above. Confidence intervals were treated in a similar manner. The corrected mean crab population estimate for winter was 2.88 million crabs, with a 95% confidence interval of 50,000 to 66.3 million crabs. The upper confidence limit was very high due to the low number of samples at site 2, requiring a high value of t (12.706 for = 0.05 and d.f. = 1). The large area of area 14 also contributed highly to this upper limit. The mean may also be underestimated, as crabs of the 0+ age group were very scarce in winter trawl samples. Those crabs may have been in parts of the harbor that were not sampled.

These calculations were made for that amount of harbor area covered at MLLW, since all of the tows were made at or near low tide. The summer estimate might have been even further increased if animals remaining on the tide flats at low tide were included.

8.3.4 Comparison to Other Studies: Cleaver (1949) estimated that 63 to 173 x 10^3 legal male crabs (those over 160 mm carapace width) were present in Grays Harbor during the winters of 1947 and 1948. Although very few crabs over 160 mm were caught in the present study, a large number of male crabs over 150 mm were caught. Considering the latter as representative of the legal size group, and using estimates only from the diel trawls made at South Reach and Whitcomb Flats in January and April 1981, 42 of 3,106 crabs, or 1.35% were above 150 mm. Most commercial fishing in the Harbor occurs no farther than the eastern end of the South Reach, so they are probably representative of the size frequency groups among which commercial fishing occurs and from which Cleaver's data originated. Of the possible 6.10 million crabs present in spring, 1981, 1.35% was 82,350 crabs, a number within the range of Cleaver's estimate made three decades prior.

Since Cleaver only made population estimates of adult male crabs in late winter and spring, he observed the migration of many crabs into Grays Harbor from the ocean and concluded that Grays Harbor made no great contribution to the offshore fishery. Our data also shows a springtime increase in crab population (from 2.9 to 6.1 million crabs), probably resulting from immigration and early recruitment. Following this summer increase in population size a large decline occurred in fall through winter as the population fell from an estimated 28.4 million or more to 2.9 million. This decrease may, in part, represent a re-distribution of crabs within the harbor, or a large scale emigration from the bay of young crab that entered the harbor as larvae (18.9 million of 28.4 million summer estimate), plus some natural mortality. Thus, in contradiction to Cleaver, who concluded that no ocean-caught adult crabs originated from the harbor, we find that Grays Harbor may contribute significantly to the offshore population. Orcutt et al. (1978) similarly estimated that the San Francisco-San Pablo Bay complex harbored 50-80% of the crabs that eventually entered the offshore fishery of the Farallone Gulf. Therefore, it is entirely probable that Grays Harbor, in concert with Willapa Bay, provides important nursery grounds for a large portion of juvenile crabs that eventually enter the valuable ocean-based Washington crab fishery.

It is difficult to estimate from our data the number of fishable crabs, i.e., legal males, contributed to the fishery 3.5-4.0 years hence, from populations of young-of-the-year recruited annually to the bay. Natural mortality would eliminate a large but unknown number within that time. Mortality rates for adults are estimated to be in the range of 0.15 to 0.20 (Botsford and Wickham 1978; McKelvey et al. 1980); mortality rates for juveniles are unknown but might be anywhere from 0.5 to 0.8.

8.4 Direct Impact of Dredging

For crabs, the direct impact of dredging is entrainment and subsequent mortality of a portion of those entrained. From empirically calculated entrainment rates, the expected number of crabs to be killed by widening and deepening the channel can be calculated. Two scenarios are considered in this subsection that estimate numbers of crabs killed either during year-round operations by hopper dredges, or during more restricted winter/spring operations with both pipeline and hopper dredges.

Trawl data from nine sampling stations in the navigation channel were grouped to compare and contrast three reaches or areas of the harbor that are distinguished by sediment quality and salinity range (Table 8.2A). Entrainment/mortality rates for Area 1 (outer reaches) were estimated from data collected in the South Reach. Winter data on entrainment rates was taken from Stevens (1981), and summer data from this report. Summer rates were determined for Area 2 from entrainment samples collected in the Crossover and Moon Island reaches, and for Area 3 from samples near the Port of Grays Harbor terminals in the Cow Point reach. Mortality rates as crabs killed/cy were determined by multiplying entrainment rates (Table 8.2A) by the percent killed of all crabs

Table 8.2 Estimation of crab entrainment and mortality caused by dredging during channel enlargement and maintenance of Grays Harbor.

8.2A Entrainment rates and quantities of sediment to be removed in three general areas of Grays Harbor.

AREA	1	2	3
Reaches of channel	Outer Bar Entrance S. Reach	North Channel Crossover Hoquiam	Cow Point Aberdeen S. Aberdeen
Salinity (ppt)	20-33	5-20	0-15
Sediment type	Marine sand	Mixed sand and mud	Fluvial mud and silt
Entrainment Rates: (crabs/cy)			
Hopper, winter	0.222 [1/]	0.037 [2/]	0.035 [2/]
Hopper, summer	0.502 [3/]	.084	0.079
Pipeline, winter/spring			0.015
Pipeline, summer			0.020
Volume of Sediment Removed			
Enlargement Project (cy)	7,750,000	6,400,000	5,200,000
Maintenance (cy)	1,000,000	1,500,000	26,000

1/ Winter hopper entrainment rate from Stevens (1981).

2/ Calculated from winter:summer ratio of entrainment at S. Reach (.442) times the summer entrainment rates observed at areas 2 or 3.

3/ Information on the derivation and standard deviations of all other entrainment rates presented in Table 6.3.

entrained by hopper dredges (as detailed in Section 6.3.3). Animals less than 50 mm carapace width comprised 28.3% of all crabs entrained and suffered a mortality of 45.9%, whereas larger crabs comprised 71.7% of the total, with a mortality of 85.6%. These percentages were used to determine total numbers of crabs in two size-classes killed during dredging operations considered in the following scenarios. Partitioning of entrainment and mortality between small and larger crabs reflects the appreciable increase in populations caused by summer recruitment of young instars to the benthos. By winter, survivors of an incoming year class have grown (Section 2.0) and so all bay crabs were assumed to be 50 mm or greater in width for winter scenarios. The value for percent killed used for calculation of total mortality in winter scenarios involving the hopper dredge was 73.1%, the overall mean rate (<u>see</u> Section 6.3.3 for derivation). All pipeline mortality was assumed to be 100% because of land-based discharge.

Total crabs entrained by area and season were determined by multiplying cubic yards of sediment to be removed from the area (data provided by USACE, see Table 8.2A) by the appropriate entrainment rate for dredge-type and season. This value of total entrained was the multiplied by percent killed to obtain total numbers killed in two scenarios of dredge activity (Tables 8.2B and C).

Two scenarios were prepared in order to estimate the potential impact of year-round dredging, and the impact of schedule alterations, and dredge substitutions as proposed herein (Section 8.6.2).

8.2B Scenario I. Dredge all three areas by hopper 50% summer, 50% winter. Consider size-selective mortality differences during summer recruitment of young-of-the-year. Values for entrainment and mortality X 10^3.

	AREA 1			AREA 2			AREA 3			Total Crabs	
	Summer		Winter[1/]	Summer		Winter	Summer		Winter		
	<50mm	≥50mm		<50	≥50		<50	≥50		All Crabs	Crabs <50mm
Enlargement											
Total Crabs Entrained[2/]	550.6	1,394	860	76	192	118	58	147	91	3,489	685
% Killed[3/]	45.9	85.6	73.1	45.9	85.6	73.1	45.9	85.6	73.1		
Total Killed	252	1,194	629	34	165	86	26	126	66	2,581	314
Maintenance											
Total Crabs Entrained	71	180	111	17.8	45	28	0.3	0.7	0.5	454	89
% Killed	45.9	85.6	73.1	45.9	85.6	73.1	45.9	85.6	73.1		
Total Killed	33	156	81	8.2	39	20	0.1	0.6	0.4	338	41

1/ Most crabs were considered to be in excess of 50 mm by winter and therefore no size-selective data are given.

2/ Numbers of crabs in two size-classes entrained during the summer were calculated for each area by multiplying one half the total volume to be removed (50% summer/winter effort) times the appropriate entrainment rate (Table 8.2A). The resultant number representing total crabs was multiplied by the proportion of crabs entrained <50mm or >50mm (28.3% and 71.7% respectively; see Section 6.3.3 for details) to obtain total entrained less than or greater than 50mm carapace width.

3/ See section 6.3.3 for derivation of percent killed in two size-classes.

8.2C. Scenario II. Dredge Areas 1 and 2 by hopper winter only, pipeline at Area 3 in winter/spring. All values for entrainment and mortality X 10^3.

	AREA 1	AREA 2	AREA 3	TOTAL CRABS
Enlargement				
Total Crabs Entrained 1/	1,720	236	78	2,035
% Killed	73	73	73	
Total Killed	1,257	173	57	1,487
Maintenance				
Total Crabs Entrained 1/	222	55	0.4	277
% Killed	73	73	73	
Total Killed	162	40	0.3	203

1/ Total entrained derived from entrainment rate times volume removed in Table 8.2A.

Scenario I. If dredging activities for channel enlargement and annual maintenance occur year-round, with approximately equal amounts dredged in winter and summer, total crabs entrained and subsequently killed are estimated to be 3.5 and 2.6 million crabs, respectively (Table 8.2B) for widening and deepening, and about 454,000 and 338,000 crabs, respectively, per year during subsequent maintenance dredging (Table 8.2B). Young-of-the-year less than 50 mm will constitute only about 12% of the total summer mortality; in part because of lower rates of entrainment and also lower percent killed than measured for larger crabs (Table 8.2B).

Scenario II. If dredging of reaches in Areas 1 and 2 is restricted to winter (September-February) and pipeline dredges are used in reaches Area 3, the potential total entrainment is estimated to be about 2.0 million crabs of which 1.5 million are killed during channel enlargement, and 277,000 crabs entrained per year during subsequent annual channel maintenance with a resultant mortality of 203,000 (Table 8.2C). The difference between these estimates indicates that crab mortality could be decreased by 1.1 million crabs (44%) during channel enlargement, and by 135,000 crabs (40%) during maintenance dredging, if dredging of the outer reaches is curtailed during summer months, and pipeline dredges are used in the inner reaches (Area 3) during winter. Use of clamshell dredges could reduce entrainment/

mortality even more, but the amount was not calculable for the inner harbor.

8.4.1 Underestimation of Dredge Entrainment and Mortality Rates: The difference in estimates of entrainment and mortality in the two scenarios is based on the observed increase in entrainment during summer compared to winter. The entrainment increase is probably due to the higher density of crab populations in summer. However, these populations may increase by about a factor of 10 from winter to summer (Section 8.2.3, Table 8.1B), whereas the dredging-related mortality increased only by a factor of 1.7 (Tables 8.2B and C). This fact, in concert with the paucity of crabs <25 mm carapace width in summertime dredge entrainment samples, indicates that the early instar crabs, which comprised 25% of summertime trawl samples, were not effectively collected by basket sampling techniques on the dredge. Therefore, dredging-induced mortality of this age group was probably greatly underestimated.

8.4.2 Relation of the Potential Mortality to Grays Harbor Crab Populations: The proportion of the Grays Harbor crab population which might be adversely affected by dredging could vary greatly depending on the types of dredges and the seasons in which they are used. Dredging operations that occur during both winter and summer would kill about 2.6 million crabs according to estimates (Table 8.2B). Adjusted estimates of summer crab populations in Grays Harbor are about 28 million crabs. Since widening and deepening is planned as a two-year program, mortality on an annual basis would be 1.3 million crabs which is 4.6% of the annual crab population. In contrast, a scenario that proposes most dredging in winter predicts 1.5 million animals killed (Table 8.2B) or 0.75 million per year. This mortality value is 26% of the estimated annual winter population of 2.88 million crabs (Table 8.1B). Although a higher relative percentage of the bay population is affected by dredging exclusively in winter, 1.1 million crabs fewer would be killed than the 2.6 million killed predicted for a combined summer/winter operation in the outer harbor (compare scenarios of Tables 8.2B and C).

Another important consideration is that crab entrainment rates will probably vary from year to year, just as they varied between seasons, due to cyclic changes in crab abundance. Therefore, the 8-10 year cyclic patterns of crab abundance must be considered in calculating dredge-related mortality and its relative impacts on the harbors and offshore populations. This is examined further in Section 8.6.

8.5 Indirect Impacts of Dredging

Aside from the direct impact of crab entrainment and subsequent mortality, there are numerous indirect impacts of dredging which bear on crab populations.

8.5.1 Removal of Food Sources: As shown in Section 4.0, crabs are dependent upon the juvenile fish, shrimp, and benthic invertebrates present in the harbor as food sources. When hopper dredging occurs in any area, all of these sources are removed. Recolonization of channel bottoms can require a few months to a year (Kaplan et al. 1975; Swartz et al. 1980). Although fish and shrimp are much more mobile than other crab prey species and could conceivably repopulate an area quickly, they also depend on the presence of benthic invertebrates for the motivation to do so. Therefore, any area dredged has been effectively subtracted for some period of time, from the total area of the harbor which can support epibenthic predators, until immigration from adjacent undisturbed areas or settlement and growth of larvae increase prey biomass to exploitable levels.

Disturbance and removal of infaunal and epibenthic invertebrates during a concerted widening and deepening program would certainly reduce standing stock in affected areas. Discontinuous but frequent dredging (e.g., maintenance of different reaches) could shift the community structures and reflect increases in opportunistic species some of which, like tellinid clams and certain amphipods, may still be acceptable prey for crabs. A decline in abundance of common species of amphipods and polychaetes following dredging may occur, but overall declines imply that type and quantity of prey items for crab could be significantly reduced in the area of the the expanded Grays Harbor shipping channel. To the extent that the area perturbed by dredging is part of C. magister's preferred feeding habitat, then intra- and interspecific competition involving crabs might increase. What is not known at this time is the relative epibenthic and infaunal biomass in the area proposed for widening and deepening relative to the rest of Grays Harbor. This area may comprise a very small percentage of feeding grounds for a ubiquitously foraging crab or a significant area if suitable foraging habitat is limited.

8.5.2 Alteration of Intraspecific Competition: Mean widths were very similar between crabs entrained by dredges and those caught in trawls (Section 6.0), indicating little difference in size specificity between these two "sampling methods." However, it has been shown that larger crabs are significantly more likely to sustain fatal injuries on passage through the dredging machinery (Stevens 1981, and this report). The result is that a dredge may take in crabs of all sizes but returns fewer live crabs of larger widths, thus decreasing their proportions in the crab population at large.

The biological ramifications of size-specific mortality of crabs caused by dredges are difficult to predict. If larger crabs entrained and killed are not replaced by immigrations from offshore, then competition between larger and young-of-the-year (0+) crabs could be reduced in the harbor. As noted by Botsford and Wickham (1978), reduced competition could be caused by either less interaction for food or by less direct cannibalism (see Section 4.0 for review of feeding habits). A general effect on populations of 0+ crabs might be increased survival and growth, but such a trend can in no way be gauged from this study.

8.5.3 Burial of Invertebrates by Sediment Disposal: The present practice of in-harbor disposal of dredged sediments probably causes burial of any benthic invertebrates which might be present at the dump site. During 1980-81, dumping at the buoy 13 site near Pt. Chehalis occurred fairly often, several times per day when dredges were active in Grays Harbor. Such frequent dumping could prevent complete recolonization of the area as long as the practice continues. Lack of invertebrate infaunal food sources could be one reason for low crab catches at that site (see Section 2.0).

Certain intertidal areas of Grays Harbor appear to be important habitats for young-of-the-year, first through about third instar crabs. High numbers were recorded in eelgrass beds (*Zostera* spp.) in the North Bay and at Elk River, and their numbers were seasonally high throughout the Outer Harbor around June (see Section 2.0, 3.0). Although not considered for the Widening and Deepening program, any plan to dispose of dredged sediment intertidally should address the suitability of various sites as preferred habitat for small 0+ age crabs. Intertidal disposal could bury or indirectly effect the productivity of eelgrass beds and associated diatoms and algae (Odum 1971). This production is utilized by the associated epiphytic and benthic communities and much of the nutrients are trapped and recycled thereby. High concentrations of juvenile fish, invertebrates, and early instar crabs reside in these areas (Bengston and Brown 1977; this report). Eelgrass beds should be considered preferred habitat of young crab and fish and so avoided as disposal sites in favor of other intertidal locations.

8.5.4 Toxicant Resuspension by Sediment Disposal: Another indirect effect of dredging activities may be exposure of fish and invertebrates to toxicants adsorbed to sediment particles or in interstitial water. Resuspension of sediment, exposure of deeper substrate layers and desorption of contaminants could generate toxic levels in very local areas or pose sublethal threats over larger regions. Several reports verify presence of contaminants such as heavy metals, petroleum hydrocarbons, pesticides, and PCB's that are often high in coastal estuaries such as San Francisco Bay (Willis 1970; Orcutt et al. 1976) and Grays Harbor (Smith et al. 1977; USACE 1980).

A detailed presentation of toxic substances found in coastal estuaries and bioassay studies of effects on Dungeness crab is given in Appendix F. Concerning Grays Harbor, the following summary about contaminated sediments can be made: 1) Concentrations of contaminants are higher in the inner than outer harbor, and are greatest in the inner harbor from Hoquiam Reach East to the ITT Rayonier stack; 2) concentrations are higher in sediments than overlying water; 3) subsurface (>20 cm) concentrations and numbers of compounds were sometimes equal to or somewhat greater than surface values at several stations tested (USACE 1980).

8.5.4.1 Dredge Impact: Chemical Toxicity: Predictions of potential toxicity of pollutants released by dredging operations to estuarine populations of *C. magister* must be based on tenuous links between laboratory bioassay information, data on field concentrations of pollutants, and knowledge of the crab's life history and ecology derived from this and other studies. Scenarios and arguments can be formulated and defended which range in predictions from minimal effects to severe impacts on this species. Smith et al. (1977) observed that the water quality in Grays Harbor was unquestionably degraded by the presence of pesticides at the time of their study (1975). This conclusion was reached because levels of several pesticides and metals found in Grays Harbor were often in excess of criteria for receiving waters established by the EPA

(1976, Table 8.3). Potentially unsafe concentrations were also reported by the USACE (1980) for Grays Harbor, again in the Cow Point-ITT Rayonier area.

It is misleading and inaccurate, however, to categorically conclude that disturbance of sediments during dredging will necessarily result in toxic exposures of resident estuarine organisms throughout extensive areas of the harbor. Toxicity by contaminants discussed thus far could stem from the following processes during and after dredging:

1) Disturbance of sediments could increase water concentrations of heavy metals, pesticides, hydrocarbons, and PCB's particularly by uncovering subsurface layers that sometimes contain high levels of these contaminants (USACE 1980). Desorption of contaminants bound to sediments might be enhanced somewhat by slightly acidic conditions temporarily in effect as lower, anoxic layers are exposed (Smith et al. 1977, show rather slight, transitory decreases in pH associated with dredging). Contaminants in the water column could pose a direct exposure threat to crabs and other invertebrates, perhaps magnified by synergistic interactions resulting from the diverse mixture of organics and metals released. However, any resultant toxicity may be acutely lethal only on a small local scale, as concentrations are quickly attenuated during mixing into surrounding water.

2) Disturbance of sediments would uncover subsurface layers with high contaminant concentrations. Residence on and burrowing in newly excavated areas would expose crabs, other invertebrates,

Table 8.X Quality criteria for receiving waters. Criteria specify concentrations of water constituents that are expected to be safe for resident aquatic life if not exceeded.

Constituent	Criteria[1] (μg/L) Marine	Freshwater	Special conditions
Ag	1.9	1.9	0.01 x 96 h LC_{50}, data from Table 8.1
Cd	5.0	0.4	
Cu	150		0.1 x 96 h LC_{50}, data from Armstrong et al. 76b
Hg	0.1	0.05	
Ni	100	100	
Pb	10		0.01 x 96 h LC_{50}, data from EPA 76
Se	10-200		0.01 x 96 h LC_{50}, data from Glickstein 78
Zn	10		0.01 x 96 h LC_{50}, data from EPA 76
Aldrin		0.003	
Chlordane	0.004		
DDT		0.001	
Endrin		0.004	
Heptachlor		0.001	
Lindane	0.004	0.01	
Methoxychlor[2]		0.03	
Polychlorinated Biphenyl		0.001	

[1]All criteria, unless cited otherwise, from EPA 1976, Quality Criteria for Water, 256 pp.

[2]Criteria for methoxychlor are too high. Armstrong et al. 1976 found 0.05 μg/L toxic to C. magister larvae. Using an application factor of 0.1, 0.005 μg/L would be a more reasonable criterion.

and fish to potentially toxic levels as contaminants leach to the overlying or interstitial water. Fowler et al. (1978) found that accumulation of PCB's by a nereid worm was minimal via water because of very low dissolved PCB concentrations. Rather, ingestion of sediments and/or contaminated food contributed 89-99% of measured body burdens in this polychaete. Cancer magister does not typically consume sediment although Crangon shrimp, on which crab feed, do (see Sections 4.0 and 7.0, respectively). Although it is not possible to predict the magnitude of effect caused by exposure to underlying contaminated sediments during dredging, infaunal food organisms and epibenthic crabs, shrimp, and fish will recolonize such areas and be exposed to contaminants present.

3) Disturbance of sediments could result in higher tissue concentrations of contaminants in deposit and filter-feeding epibenthic organisms and infauna. Consumption of such prey items by C. magister might increase body burdens to stressful, perhaps sublethal levels producing chronic disorders manifested in slower growth or reduced predator avoidance, as examples. However, it is difficult to say that body burdens of contaminants will even increase as a function of dredging and, if so, how such increases translate to toxic threats.

Comparative toxicity of contaminants to crustacea show water exposure is much more lethal than exposure via food. Epifanio (1971, 1972) found that crab larvae (Leptodius floridanus) were three to four orders of magnitude more susceptible to the insecticide dieldrin dissolved in water than contained in food. Likewise, Jennings and Rainbow (1979) found that cadmium uptake by the crab Carcinus maenas was about 10 times greater from water than food of comparable initial Cd levels. Thus, there may not be a general threat to Dungeness crabs posed by feeding on prey in the vicinity of dredging operations in Grays Harbor if, in fact, tissue levels of contaminants in prey remain low and feeding activity in the dredged channel is curtailed by lack of prey.

8.5.4.2 Dredge Impact: Changes in Other Water Quality Criteria: Smith et al. (1977) summarized possible changes in water quality parameters that might occur during dredging (see Appendix F for further discussion) and in general, changes in parameters such as pH, dissolved oxygen, hydrogen sulphide, and turbidity are transitory and normally non-stressful.

pH: Hydrogen ion concentrations can itself be toxic to aquatic crustacea but usually at levels lower than that found in Grays Harbor. Smith et al. (1977) rarely found pH to be less than 7.0 and more typically was 7.5-8.0. Therefore, pH per se is not expected to pose a threat to Dungeness crab. However, pH significantly affects the toxicity of heavy metals and hydrogen sulphide and could be an important factor if dredging releases these chemicals to the water in local areas.

Hydrogen Sulphide: The EPA criterion for hydrogen sulfide is 2 μg H_2S/l; at pH 7.5 this is about 5.0 μg/l total sulphide, and higher criteria of 10-50 g/l have been suggested. Smith et al. (1977) measured water quality before and after dumping of sediments from a hopper dredge near buoy 13 in Grays Harbor. Their analyses show a 1.3 to 4.0 fold increase in sulphides from baseline levels of 6-10 g/l to 13-44 g/l. Such concentrations could pose toxic threats to megalopae, young-of-the-year, and older juveniles of C. magister in and adjacent to dredged or disposal areas. Again, areas affected may be very local and concentrations of sulphide should be rapidly attenuated by oxidation.

Dissolved oxygen: No significant decrease of D.O. during disposal of dredged material at buoy 13 was found by Smith et al. (1977). They also found that D.O. was unchanged in the plume of the hopper dredge operating in the Hoquiam Reach. Pipeline operations also did not significantly change D.O. of overlying water. From these observations, it is concluded that Dungeness crab will not generally be stressed by changes in D.O. caused by dredging.

Turbidity: This water parameter was consistently elevated above the recommended criterion (10 Jackson Turbidity Units above background, EPA 1976) during previous studies in Grays Harbor (Smith et al. 1977). Baseline turbidity often approached this value but increased dramatically during disturbance of dredging or dumping. However, settling of sediments was rapid and turbidity often reached predisturbance levels in 1-2 hr. Continued respiration and branchial water movement by Dungeness crab caught in impacted areas of slurried sediment could cause loading of particulate material among branchial filaments, resulting in impeded oxygen transport and physical abrasion and damage to gills. To our knowledge, no studies of crab response and susceptibility to different levels of suspended sediments--strictly as an abrasive irritant--have been done.

8.5.4.3 Prediction of Most Probable Chemical Impact on Dungeness Crab: Area and Season: The preceding review has covered several categories of contaminants and possible impacts that could result if Dungeness crab are exposed to them. Gaps in available data and tenuous links between information and necessary assumptions have been acknowledged. While cautious predictions have been made for most individual categories of toxicity and stress (e.g., D.O., turbidity, sulfides) that could affect *C. magister*, there is a real potential for significant impact of synergistic effects of chemical contaminants in certain seasons and at particular locations within Grays Harbor.

A brief review of data presented in Section 2.3 on crab distribution and abundance shows greatest densities in the outer harbor to buoy 30 at the top of the Crossover Channel, and greatly reduced numbers in the inner harbor from Moon Island Reach through the Aberdeen Reach; also, crab abundance is low in the South Channel (ring net and trawl data). Therefore, numbers are relatively low in areas where sediment contamination is highest, i.e., the Hoquiam Reach (Smith et al. 1977; USACE 1980).

Grays Harbor is not used by *C. magister* for hatching and rearing of the five zoeal stages (most susceptible to toxicants, Armstrong et al. 1976b). However, megalopae enter the estuary from late March through mid-June with a peak during April. An apparent onshore migration after the fifth zoeal stage (Orcutt et al. 1975, 1977) results in millions of megalopae near shore and in the bay. By this time megalopae are near metamorphosis and cling to floating or stationary objects in the water column (e.g., 27% of 500 Velella velella sample in Grays Harbor 22 May 1981 had C. magister megalopae attached to them), or move to the bottom of the bay prior to molting (we also found megalopae on sand flats along the Humptulips River channel in North Bay on 22 May 1981). First instars are massed in the outer harbor from mid-April through mid-June, but are also very abundant in portions of North Bay (very little data from this area) and the Elk River drainage of South Bay (Fig. 2.11). In addition to entering as megalopae, crabs may metamorphose in shallow areas just offshore and migrate into Grays Harbor as first or second instars (Orcutt et al. 1977 speculate that significant numbers of crabs metamorphosing in the Gulf of the Farallons enter the San Francisco Bay complex; perhaps as much as 80% of a given year class hatched in this area will actually reside in the bay).

Disposal of dredge spoils in Grays Harbor presently occurs near buoy 13. Considering this location and the influx of larval and young-of-the-year crabs across the outer bar through the entrance channel in April-June, some degree of impact to Grays Harbor crab populations could result if dumping continues near buoy 13 during W & D operations. Disposal of contaminated sediments from the inner harbor several times per day over weeks to months during spring and early summer could expose megalopae and early instars to toxicants. Although exposure to toxicants may only occur on a local scale, the buoy 13 disposal site is strategically situated in front of the entrance channel, and some exposure of animals to contamined sediments and/or water should be expected as they move into or out of the estuary. Despite tidal cycles and flushing rates, contaminant levels in this area could exceed EPA criteria for several compounds and metals if persistent dumping--of the magnitude associated with W & D--continues near the entrance channel at buoy 13. The nature of sublethal effects could involve chemosensory impairment, behavioral changes, and changes in predator avoidance. Numbers of crabs affected cannot be predicted, rather it is important to note the potentially serious threat to crabs imposed if inner harbor sediments are disposed in the outer harbor during spring and summer dredging for the Widening and Deepening project.

8.6 A Synthesis of Potential Effects

Numerous examples of potential effects of dredging have been presented elsewhere in this report. Only if these are presented together as potential simultaneous impacts can the overall effects on the crab populations be visualized. Two scenarios are presented in this section. On one end, a worst case consisting of predicted detrimental effects, and on the other, a better caseincorporating measures designed to reduce crab mortality. Potential numbers of crabs affected by each case could be estimated only for entrainment effect; indirect effects could not be quantitatively assessed, but are discussed in a relative manner. Both scenarios assume that a widening and deepening (W&D) of the Grays Harbor ship channel would require at least two years of concentrated effort.

8.6.1 Worst Case Scenario: As in Scenario I of direct impacts (Section 8.4) dredging might be conducted throughout the year, resulting in a projected mortality of 2.6 million crabs from the W&D project, and 0.34 million crabs from subsequent annual maintenance dredging. Over 75% of crabs killed would be age 1+ or older, i.e., crabs which probably have a relatively high chance of surviving to adulthood, reproducing, and entering the commercial fishery.

In addition to crabs, populations of shrimp and juvenile fish were found to be extremely abundant in spring and summer; these constitute significant food sources for crabs and vice versa. Therefore, summer dredging activities have the potential for destruction of important food sources at a time when those sources are very densely concentrated, and heavily preyed upon by large summer crab populations estimated at 28 million animals. Partial destruction of these food sources could reduce the carrying capacity of the harbor by an unknown amount. Continuous dredging for the W&D project could effectively prevent recolonization of dredged bottom areas for a period of 2 years, thus decreasing the total area of productive harbor bottom surface area for that period of time.

If the present practice of dumping sediment near Point Chehalis were to continue through the W&D project, it could cause exposure of newly arriving megalops larvae and early instars to high silt loads and, possibly stressful toxicant concentrations in a localized area as crabs traverse the Entrance Reach dump site. Sensitive chemoreception might enable young crabs to detect dissolved toxicants transported from the buoy 13 disposal site to the ends of the jetties just outside Grays

Harbor. Detection of a potential perturbation could cause a significant number of young to avoid Grays Harbor and remain offshore, where, in competition with adults, survival may be reduced. For those recruits that continue into the harbor, abrasion of gill surfaces by suspended sediments, increased epibiotic fouling, and general sub-lethal toxicant effects could alter behavior, depress feeding, slow growth, and reduce predator avoidance. Considering both avoidance of the harbor and sub-lethal stress incurred by some animals entering the harbor, a significant proportion of an incoming year-class that normally enters Grays Harbor could be adversely affected. These effects would be in addition to those caused by reduced food sources and direct entrainment.

In addition to the timing of dredge scheduling within a given year, consideration must be given to the timing of a major dredging project (such as W&D) within the scope of long-term cyclical changes in crab population abundance (<u>see</u> Section 1.3). At some point in the population cycles of <u>C. magister</u> a very weak year class will be produced off Washington's coast. This event will not necessarily coincide with low adult populations, in fact, the converse seems to be true (McKelvey et al. 1980; Lough 1975). A combination of factors might curtail egg development and hatching success; anomalous weather, water temperatures, low food supplies and predation on eggs by nemertean worms could reduce larval survival (Lough 1975; Wickham 1979a and b); metamorphosis of first instars to confront strong adult and older juvenile populations could further decimate a new year-class through competition and cannibalism (Botsford and Wickham 1978). The effects of such inordinately high mortality would be felt by the commercial fishery some three years later; this season's low landings for Washington (Fig. 1.3) dramatize what was probably an extremely weak year-class(es) in 1977-78.

If the W&D proect was undertaken in a year of poor recruitment, a year class that may already be weak could be further decimated by the postulated direct and indirect effect of dredging.

8.6.2 A Better Case: In the previous scenarios the bleakest projections of dredging impacts to crab populations were considered from estimates of both quantitative direct impacts and qualitative indirect effects. On the other extreme, the impacts of dredging on crab populations could be considered slight by first assuming that many indirect perturbations (e.g., reduced food, toxicant stress, avoidance of the harbor) are minimal, and second, predicting when, during natural cycles of abundance, populations of juvenile crab are high and therefore less susceptible to mortality caused by dredging operations.

Based on data and hypotheses published by several authors concerning Dungeness crab (Botsford and Wickham 1978; McKelvey et al. 1980) there is, first, a regular cycle of high to low abundance in crab populations that is reflected in the commercial fishery (Figs. 1.3 and 1.4), and, second, an inverse relationship between the magnitude of adult and juvenile populations seems to exist (i.e., when adult populations are large survival of incoming juveniles is low). From these observations the following predictions of high or low juvenile and adult abundance can be made for this decade and used as a backdrop for discussions of desirable times to commence W&D operations. In 1981, and perhaps through 1982, when commercial crab catches are extremely low, indicating that adult population are depressed, strong year-classes of juveniles will be produced. Based on past trends in population cycles, 1985 through 1986 should be years of high adult crab abundance and good commercial fishing. Juvenile survival and numbers will be correspondingly low in the 1985-86 period and, consequently, adult populations and the fishery in 1988-89 will again be depressed. The 1988-90 year-classes should reflect high survival and recruitment of juvenle crabs to the benthos.

Since dredging predominantly affects young juvenile crabs within the harbor, dredging operations underway during years of high juvenile abundance would be expected to least impact the populations and, in turn, the fishery three to four years hence. During the 1980's two periods of high juvenile abundance should occur about 1981-1983 and again about 1988-1990, and are therefore considered best periods to complete dredging for the W&D project.

If the present practice of sediment disposal in the harbor mouth is discontinued, there would be no potential for harm to incoming larvae and early instars as a result of burial, physical abrasion, and exposure to contaminants. This is especially important for the period March-June, the time when recruitment of juveniles to the harbor occurs. After arrival of recruits in the harbor, growth is most rapid, and population density greatest, through the summer until September. Curtailment of dredging in the outer reaches (Entrance through Hoquiam reaches) could save 1.1 million crabs during a W&D project, and 135,000 crabs annually during subsequent maintenance dredging, if the crab population is similar to that of 1980-81. These mortality figures and potential savings will change as the population size and width frequency distribution changes.

Another result of a reduction in summer dredging activities would be reduced destruction of food sources. Though only a small percentage of harbor bottom may be actually affected, this area could be extremely productive for benthic and demersal organisms, especially during the summer months, and could support a large number of crabs. Although winter dredging might destroy established bottom communities, these might recolonize rapidly during spring and summer, whereas year-round dredging would probably eliminate the chance of larval recolonization of those areas dredged in spring/summer until the following year (except for species having bimodal spawning, perhaps in fall).

8.6.3 Inherent Errors in Scenario Prediction: The foregoing scenarios are intended to portray what might be the sequential impacts of dredging on crab populations. Unfortunately the arguments and predictions are open-ended because our data-base is incomplete in several crucial respects:

1) It is not known if high or low commercial landings of male crabs mirror concomitantly large or small populations of sexually mature females. Consequently it is not known with certainty from where in the cycles of commercial landings (Fig. 1.3) weak year-classes originate. Such an origin is important because the W&D project may begin during a low point in the cycle of natural abundance off

Washington (Fig. 1.4). We have assumed that strong year-classes will come from this trough in the landing curve because of reduced biological pressures on eggs, larvae, and young instars. If these assumptions are accurate, then large-scale dredging may commence at a time when high survival of larval and juvenile stages is expected, and impacts may, therefore, be less severe. However, if abundance of sexually mature females lags behind or proceeds that of males, and if the strength of a larval/juvenile year-class is somewhat linked to abundance of adult females (contrary to statements in McKelvey et al. 1980), then the commencement of W&D in either the mid or late 1980's may have more serious ramifications.

2) There is not a well-established ratio between sexually mature females in a population and numbers of males needed to ensure complete insemination. It is assumed that males are polygamous (although Butler, 1960, notes that evidence for such under natural conditions is virtually unobtained), and it is known from laboratory studies that a premating embrace (prior to female ecdysis) can last for a week (Snow and Neilsen 1966). Since females molt in a fairly discrete period in spring, each male may not breed more than a couple of females and, therefore, male:female ratios must be rather high to ensure a high percentage of breeding in the population. In the worst-case scenario, high natural mortality and dredge impacts result in inordinately low adult populations 2-3 years later. Since the fishery removes most of the legal males on an annual basis (Cleaver 1949, Jow 1965), sublegal, but sexually mature males

probably constitute an important segment of the breeding population (Butler 1969). Because females are not harvested, a weak year-class reaching sexual maturity might be preceded by one or two stronger year-classes of females that will, in fact, constitute much of the reproductive effort that year. If abundance of males has been reduced because of weak year-classes and fishing pressures, then breeding could be severely reduced at a time when populations should be increasing toward the high points of abundance cycles.

3) It is not known to what extent offshore populations (and ultimately the commercial fishery) are dependent on production and survival of estuarine populations. If W&D dredging in Grays Harbor somehow killed all Dungeness crabs in the harbor in a given year, would this represent a serious or trivial loss when considered as part of recruitment along the entire Washington coast? Orcutt et al. (1977) thought that 80% of crab populations offshore of San Francisco at some time used the bay, but this conclusion is arguable. Grays Harbor might, on the average, produce 80% of the local offshore fishery, or it might provide only a few percent. No data exist on the magnitude of first instar settlement and continued residence offshore to enable a comparison between coastal and bay populations of young-of-the-year.

So the benefits of scenario prediction are marginal. Dredging, if it coincides with adverse natural circumstances, could significantly impact crab populations along the Washington coast. Reduction of the bay crab population could affect the invertebrate communities of Gray Harbor.

On the other hand, dredging may be a relatively mild perturbation in light of natural mortality pressures, and may have little effect on the commercial fishery along the coast of this state. It seems wisest to hold the former consequence as more plausible, and formulate management strategies that do all possible to mitigate impacts.

8.7 Suggestions for Reducing Dredging-related Crab Mortality

8.7.1 Basic Considerations: The following are suggestions by which we believe dredging-induced crab mortalities could be significantly reduced. Having spent much time on the dredges, and after many conversations with dredge and USACE personnel, we are aware of certain economic and operational considerations affecting the dredges, which have been taken into account when formulating the following suggestions. The most important of these is that when operating in the harbor, dredges are usually in operation on a 24-hour basis (except Sundays). Therefore, in only one situation do we suggest interrupting this schedule.

These suggestions are meant to reduce crab mortality only, and do not reflect the possibilities of fish entrainment. Generally, bottom fish abundance changes proportionally with crab abundance, decreasing in winter and increasing in summer (Section 5.3), so these recommendations should help reduce mortality of such fish species as well, but were not designed specifically to do so. Although only one salmon fry was discovered in our samples, salmon can be entrained by hopper and pipeline dredges (see Section 6.0 for references), and their availability to the dredges increases in February-May, especially in the narrow portions of the Chehalis River upstream of Cow Point. Again, these recommendations are not made to reduce salmon entrainment, but that possibility should be considered by USACE.

8.7.2 Suggestions

1) Dredge Type

A) Use of clamshell dredges should be given first priority, especially west of the Hoquiam River. Use of this type dredge can reduce mortality by 95%.

B) East of the Hoquiam River, pipeline dredging was found to cause less crab mortality than hopper dredging. In this area pipeline dredging is the best alternative (after clamshell).

C) In all cases hopper dredges are the least desirable dredge-type. Where the use of hopper dredges cannot be avoided, the suggestions regarding seasonal scheduling which follow are especially important in that they can substantially reduce the impact.

2) Season

Crab density estimates derived from trawl data in this study contradict those of Stevens (1981) which were derived from crab pot data. The following statements supercede those of Stevens (1981) regarding seasonality:

A) Crab density, as estimated by trawl, and crab entrainment by dredges were both significantly greater in spring/summer than winter. Outer harbor crab densities were significantly greater than inner harbor crab densities. Therefore, reduction or cessation of dredging activities in the outer harbor during April-July (ideally March-August) could significantly reduce crab mortality. The dividing line between inner and outer harbor here is defined as the midpoint between the trawl sampling sites at buoy 30 and Moon Island (about $123^{\circ}57'30''$W longitude). Entrainment rates differed east and west of this point.

As presented in Section 8.4, application of scenario 2 (Table 8.2c) rather than scenario 1 (Table 8.2b) would produce a savings of 1.1 million crabs during channel enlargement and of 135,000 crabs during annual maintenance dredging. The great majority of crabs saved would be larger crabs (50 mm carapace width) which would have a much better chance of entering the fishery because of lower natural mortality than smaller crabs.

B) If curtailment of summertime dredging in the middle reaches is not economically feasible during the Widening and Deepening project, the following suggestion might be implemented: dredging of the outer reaches (Bar, Entrance, and South Reach) should cease April-July but dredging of the middle and inner reaches (Crossover, Moon Island, Hoquiam) might continue. This suggestion could still allow a savings of 0.98 million crabs during channel enlargment, and 108,000 crabs from maintenance dredging over dredging conducted on a year-round basis (Table 8.2b values for area 2, and 8.2c values for areas 1 and 3).

3) Diel Scheduling

If it is necessary to utilize hopper dredges in the outer harbor during the April-July period, then the following suggestions regarding diel scheduling should be followed:

A) Foraging movements by crab tends to decrease their numbers in the channel bottoms at night. If possible, nighttime dredging should be given priority to daytime dredging. This schedule could reduce entrainment by as much as 36% in the outer reaches (see Table 3.2; reconverted means).

B) Crab foraging movements tend to occur during high tides. Therefore, when possible, dredging at high tide should be given priority. This could reduce mortality by as much as 50% (average of June and September reductions; Table 3.2).

4) Dredged Material Disposal

It was not intended that this report deal with the topic of disposal of dredged material. However, our review of pertinent literature and observations during the course of this project have led to the formation of several conclusions on this subject. They are:

A) Intertidal disposal should be managed so as not to impact a significant habitat for juvenile crabs and fish species (see Section 2.3.5.).

B) In-water disposal of potentially toxic dredged material (such as found in the inner harbor) should be avoided (see Section 8.5 and Appendix F).

<u>Note</u>: Researchers (supported by USACE) are currently investigating sediment toxicity in Grays Harbor.

C) Sub-tidal, including off-shore, disposal sites should be selected which will minimize re-dredging and impact on benthic organisms and habitat (see Section 8.5).

5) <u>Structural Modifications</u>

No new recommendations are given herein. We support the suggestions of Stevens (1981) c9ncerning modifications that might reduce crab entrainment or mortality. Such modifications include:

A) Removal or alteration of splash plates.

B) Alteration of draghead shape or addition of water jets to repel crabs from the area immediately preceding it.

C) Addition of bright lights to the draghead to frighten crabs.

D) Investigation of the use of electrical fields or charges or sound to repel crabs from the area of the draghead.

These modifications would have to be tested prior to implementation, as there is no data presently available to show what effectiveness, if any, they might have.

8.6.3 Most Effective Recommendations

Realizing that full implementation of all the forgoing suggestions may not be possible, the following are believed by the authors to be the most efficient and reasonable of suggestions for the reduction of dredging-related crab mortality:

1) Clamshell dredges should be given first priority year-round for the entire harbor, and especially west of the Hoquiam River with sediment disposal offshore. This could reduce entrainment by a factor of 20 (Stevens 1981).

2) Any additional dredging of the outer harbor requiring the use of hopper dredges should be restricted to the period September-February, when entrainment rates were half of summer values, and crab populations were less dense. Hopper dredges should have modifications made to lessen entrainment and mortality. Sediment disposal should be offshore. Reductions in crab mortality from such scheduling were specified previously.

3) Pipeline and clamshell dredging could continue year-round east of the Hoquiam River with landbased or offshore disposal.

4) Summer scheduling of hopper dredges should be restricted or curtailed for maintenance dredging. However, major channel modifications, such as the Grays Harbor Widening and Deepening Project,

may require some summer dredging beyond the capacity of available clamshell dredges. In this situation, hopper dredging could be instituted on a 24-hr basis in the middle reaches (Crossover, Moon Island, Hoquiam). Summertime operation of hopper dredges in the outer reaches (Bar, Entrance, South Reach) should be entirely avoided if at all possible. However, if absolutely necessary, it should be allowed at first only between dusk and dawn. Any further extension of that schedule should exclude 4-6 hr around daylight low tides if feasible.

9.0 SUGGESTIONS FOR FUTURE RESEARCH

by

Bradley G. Stevens and David A. Armstrong

Following are some suggestions for future research which might be of interest to USACE, but would in any case provide information important to the understanding of _C. magister_ biology, ecology, and behavior, and useful for management and conservation of crab populations.

9.1 Inshore/Offshore Density Survey

The information presented in this report provides a basic understanding of relative distribution and abundance of crabs inside Grays Harbor, and allows some comparison to be made between dredging-related crab mortalities and potential crab numbers in the harbor. However, while the importance of the harbor populations to the offshore stocks and fishery can be speculated, no consistent evidence is available by which to compare actual densities, size distributions, and growth rates between the harbor and the ocean. Therefore, the following research is proposed to make such a comparison.

1) Measured trawls made at three offshore stations (possibly including a proposed/active offshore dumping site) would be compared to measured trawls at two stations within the harbor. Larger, more seaworthy craft would be required, such as a commercial trawler, and larger nets.

2) Each trawl should be replicated once or twice at each location, and the entire series repeated at least once in each season.

3) Numbers and width frequency of captured crabs would be compared between inshore and offshore stations. From this information, the relative importance of the estuary might be estimated.

9.2 Utilization of Shallow Water Habitats by Early Instar Crabs

Data gathered for the present report, as well as previously published literature, indicates the importance of eelgrass beds and associated mudflats as nursery grounds for early instar crabs (as well as fish and other invertebrates). In order to refine our estimates of total crab population, as basic information to the life history of *C. magister*, and for use in shoreline management, the seasonal density of early instar crabs in these habitats should be monitored as follows:

1) Areas of major eelgrass (*Zostera marina*) beds should be investigated. These are a) mud flats in the South Bay, b) mud flats between Campbell Slough and Humptulips River channels in the North Bay, c) mud flats north and west of Moon Island, and d) the east-central flats between North and South channels.

2) At each site, several transects could be laid out, as perpendicular lines to the MLLW depth contour, or as square grids at certain elevations.

3) At stratified or randomly selected plots of 1/4-1/2 m^2, all sediment to a depth of 15 cm would be removed, and early instar crabs counted.

4) This sampling would occur biweekly from early May through August.

9.3 Study of Crab Burial Behavior

One of the most obvious flaws in the present report is that there is very little concrete evidence regarding the water conditions that contribute to crab burial behavior, or how such behavior affects capture in trawls or entrainment by dredges. Thus, we have had to make some far-reaching assumptions. Burial behavior could be investigated in a two-part field/laboratory study which could provide useful information for help in interpreting our trawling results, in predicting the consequences of specific dredging schedules, and as important additions to the knowledge of *Cancer magister* biology. The research is outlined below:

1) Field Study. This portion of the project would be to determine if burial behavior changes around a diel cycle, and its effects on dredge/trawl avoidance by crabs.

A) An underwater enclosure would be constructed into which a known number of crabs could be inserted. The enclosure would prevent the escape of crabs, but would permit divers to observe them easily. The enclosure would be placed in an area subject to diel rhythms in tidal current direction and intensity, salinity, and light level.

B) SCUBA divers would count the ratio of buried to active crabs for a 1/2 hr period during each of eight points in a tidal cycle, i.e., every 3 hr over a 24-hr period. This could be repeated six to eight times.

C) Divers could observe a net or large object resembling a dredge draghead as it was dragged across the area, noting the different behaviors of active and buried crabs. This information could be used to estimate the potential capture rates of trawl/dredges during different diel periods.

2. Lab Study. If the field study detected different rates of burial through a diel cycle, laboratory observations could be used in attempts to elucidate the causative factors. Crabs could be placed in sand-bottomed aquaria and exposed to single or multiple conditions. Those of most interest would be current velocity and direction, and salinity and pressure changes.

9.4 Effects of Dredge Modifications

If dredges are physically modified as suggested in the recommendations of Stevens (1981) and this report, it would be useful to the USACE to determine the effectiveness of these modifications. This project would require sampling efforts essentially similar to those of Stevens (1981) and this report (Section 6.0), as follows:

1) Before modification, several dredge samples would be taken from a given area. Dredged sediment would be strained by basket, and crab entrainment estimated.
2) After modification, the same procedures would be used to estimate crab entrainment in a site as close to the "Before Treatment" site as possible.
3) Several modifications could be tested successively, or cumulatively.
4) This testing would be restricted to a small area of the harbor, and a short time span, in order to reduce natural variability in crab entrainment.

9.5 Improved Estimate of Grays Harbor Crab Population

Although the data presented in this report did allow some preliminary estimates of the crab population size to be made, such was not an original goal of the project, so the sampling design and data collected were not the most suitable for that purpose. A more accurate estimate of the harbor crab population would be extremely useful, especially in light of the wide confidence intervals generated by this study. Such an undertaking would be extremely expensive and labor intensive but would provide much needed information.

To determine the population size would require tagging of a large number of crabs, perhaps as many as 10% of the present estimated population, and recovery of 20-50% of those tagged. Such an undertaking is clearly not feasible, but a smaller number, perhaps 3,000 to 5,000 crabs, could possibly be tagged. Details of such a project would be complex, so are not presented here.

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The following appendices are available for review from
Seattle District, U.S. Army Corps of Engineers

APPENDIX A. GRAYS HARBOR STATION AND CRAB CATCH DATA

APPENDIX B. WIDTH FREQUENCY GRAPHS OF <u>CANCER MAGISTER</u> CAUGHT IN GRAYS HARBOR

APPENDIX C. TOTAL LENGTHS AND NUMBERS OF FISH CAUGHT IN TRAWLS

APPENDIX D. SPECIES LIST OF FISH OBSERVED IN GRAYS HARBOR, COMMON AND SCIENTIFIC NAMES

APPENDIX E. SEASONAL CHANGES IN BOTTOM TEMPERATURE AND SALINITY AT MONTHLY TRAWL STATIONS

APPENDIX F. POLLUTANT TOXICITY TO DUNGENESS CRAB