Outer Continental Shelf Environmental Assessment Program

Final Reports of Principal Investigators

Volume 67 **July 1990**

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
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Anchorage, Alaska

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Outer Continental Shelf Environmental Assessment Program

Final Reports of Principal Investigators

VOLUME 67 JULY 1990

CONTENTS

DISTRIBUTION, ABUNDANCE, AND BIOLOGY OF BLUE KING AND KOREAN HAIR CRABS AROUND THE PRIBILOF ISLANDS

by

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We thank the captain and crew of the RV Miller Freeman for all their efforts during the three cruises in May and August 1983 and April 1984. Commander Michael Fleming suggested use of sidescan sonar on this project and we appreciate his interest and help throughout. Paul Dinnel and Rae Baxter provided valuable field assistance. Murray Hayes of the Northwest and Alaska Fisheries Center authorized use of computer time and program accessibility at the National Marine Fisheries Service, Seattle, Washington, which greatly facilitated data analyses. Carla Norwood typed this document, and Dr. Paul Dinnel was instrumental in completion of the final report. Lyman Thorsteinson, Paul Becker, and Laurie Jarvela of NOAA, Ocean Assessments Division, Anchorage, Alaska, provided editorial assistance. We especially thank Lyman Thorsteinson for his patience and understanding.

ABSTRACT

A series of three research cruises in 1983/1984 were used to characterize nearshore distribution and abundance as well as population dynamics and general ecology of blue king crab (Paralithodes platypus) and Korean hair crab (Erimacrus isenbeckii). Because of proposed oil lease sales in the vicinity of the Pribilof Islands (St. George Basin), biological information on the species was deemed necessary in order to predict and possibly mitigate against any potential impact arising from any future oil mishaps. The survey approach was based on use of side scan sonar and groundtruthing techniques to map the general distribution of several major sediment types (sand, gravel, cobble, rock and shell debris) around the Pribilof Islands and to direct sampling effort to specific categories of substrate. Over 130 benthic trawls and dredges were done per cruise and extensive series of zooplankton samples were also taken.

Blue king crab spawn in mid-spring although multiperous females are on a biennial reproductive cycle and each individual spawns every two years. Larvae are abundant nearshore of St. Paul Island in the late spring through mid-summer and metamorphose and settle to the benthos about August and early September. Survival of small juvenile stages is apparently highest when animals settle to substrates that provide some degree of refuge from numerous species of predators in the area. Best refuge appears to be shell debris, composed primarily of four species of bivalve as well as neptunid gastropod shell, and secondarily small cobble covered with epiphitic growth.

First instar juveniles are small, about 3 mm carapace length (CL) and the rate of growth (frequency of molt) is exceedingly slow the first year since juveniles in the following spring are still only 5 mm to 8 mm CL.

The patterns of high density of juveniles up to about 30 mm CL corresponded very closely to cobble and shell habitat around St. Paul Island, particularly to the east of St. Paul and St. George Islands. Females move onshore in mid-spring to hatch eggs, perhaps in order to enhance retention of larvae near the islands, and males join them at this time to breed those females that subsequently molt. Despite hundreds of trawls in the vicinity of the Pribilof Islands, no blue king crab between 30 mm to 80 mm CL were found, which suggests occasional year class failure, possibly due to adverse transport of larvae away from the islands so that juveniles that settle are unable to find refuge habitat.

Distribution and general ecology of Korean hair crab closely follows that of blue king crab. Notably different in 1983/1984 was the low abundance of females compared to males, but very similar was the high proportion of small juveniles nearshore particularly around St. Paul Island on shell/cobble substrates.

From such patterns of nearshore distribution and close association with substrate types of limited distribution in the vicinity, there is a good possibility that major oil spills inundating the Pribilof Islands and contaminating the benthos to a depth of about 60 m could seriously affect both blue king crab and Korean hair crab populations.

TABLE OF CONTENTS

TABLE OF CONTENTS (continued)

TABLE OF CONTENTS (continued)

TABLE OF CONTENTS (continued)

LIST OF FIGURES

LIST OF FIGURES (continued)

LIST OF FIGURES (continued)

LIST OF FIGURES (continued)

LIST OF FIGURES (continued)

LIST OF FIGURES (continued)

LIST OF TABLES

LIST OF ABBREVIATIONS AND SYMBOLS

ADF&G	Alaska Department of Fish and Game
ANOVA	Analysis of Variance
BKC	Blue King Crab, Paralithodes platypus
BT	Beam Trawl
CG	Cluster Group
CL	Carapace Length
CPUE	Catch Per Unit of Effort
CTD	Conductivity, Temperature, Density
EI	Egg Index
GSI	Gonosomatic Index
Ho	Null Hypothesis
KHC	Korean Hair Crab, Erimacrus isenbeckii
N,n	Sample size
NAS	North Aleutian Shelf
NM	Nautical Mile
NMFS	National Marine Fisheries Service
No	Number
NOAA	National Oceanic and Atmospheric Administration
OCSEAP	Outer Continental Shelf Environmental Assessment Program
%	Percent
/oo	Parts-per-thousand (salinity)
RKC	Red King Crab, Paralithodes camtschatica
RD	Rock Dredge
SC	Shell Condition
SCUBA	Self-Contained Underwater Breathing Apparatus
SD	Standard Deviation
SE	Standard Error
SEBS	Southeastern Bering Sea
SG	St. George Island
SH	Shellhash
SP	St. Paul Island
SSS	Side Scan Sonar
SST	Sea Surface Temperature
ST	Substrate Type
Str	Stratum or Strata
UW	University of Washington
WSF	Water Soluble Fraction (for petroleum)
X	Average
Z	Zoeal Stage

Metric Units

°C	Degrees Centigrade
Cm	Centimeter
g	Grams
ha	Hectares (=10,000m)
Kg	Kilogram
KHz	KiloHertz
l	Liters
m	Meters
ml	Mililiters
mm	Milimeters
um	Micrometers

1. INTRODUCTION

1.1 Research Objectives

Oil exploration and development on leases sold in the St. George Basin pose a potential threat to animal resources over much of the southeastern Bering Sea (SEBS). Among animal groups thought to be vulnerable to oil mishaps in this region are several species of commercial crab that have, until recent years, constituted some of the richest crustacean fisheries in U.S. waters (Otto 1981, 1986; Armstrong et al. 1983). Participants in previous OCSEAP workshops have identified both red king crab (*Paralithodes camtschatica*) and blue king crab (*P. platypus*) as particularly susceptible to oil pollution because the nearshore geographic range and habitat requirements of certain life history stages are more likely to be impacted in oil spill scenarios than those for offshore, broadly distributed species such as Tanner crab (*Chionoecetes* spp.) (Curl and Manen 1982; Armstrong et al. 1984).

Despite their commercial importance and a fairly extensive literature dealing with the genus *Paralithodes*, many aspects of population dynamics of specific life history stages, their distribution, and timing of major biological events (e.g., molting, seasonal growth, reproduction) were or are still unstudied for blue and red king crab. For this reason OCSEAP initiated a series of studies on red king crab in the southeastern Bering Sea that covered larval population dynamics (Armstrong et al. 1983), juvenile feeding habits (Pearson et al. 1984), and nearshore larval and juvenile ecology (McMurray et al. 1984). Blue king crab, however, had been little studied apart from annual groundfish data gathered by the National Marine Fisheries Service (NMFS). Because of the increased importance of the blue king crab fishery as that for red king crab declined beginning in 1981 (Otto 1986; Otto et al. 1983; Hayes 1983), and because of the very insular distribution of blue king crab about the Pribilof Islands, workshop participants perceived a potential oil threat to this population from activity in the St. George Basin (Curl and Manen 1982), which prompted OCSEAP to fund the present study.

In addition to blue king crab, the Korean hair crab, Erimacrus isenbeckii, seems to be abundant around the Pribilof Islands (e.g., Otto et al. 1983, groundfish survey), and constitutes a limited fishery directed toward the Japanese market (see Section 1.3.4). Even less information on life history and population dynamics is available for this crab than for blue king crab ana, thus, Erimacrus was included in a nearshore study of distribution and population dynamics.

The principal research objectives during three cruises of this program were as follows:

1. Determine the distribution and abundance of all life history stages of blue king crab and Korean hair crab in the Pribilof Island region of the SEBS. This objective was guided by the following questions:
   a) Central to this study is whether adult and juvenile crab tend to segregate and, if so, is it a feature of different habitat preferences.
   b) If female crabs are less abundant offshore of the Pribilofs as noted by Otto et al. (1982, 1983), are they more common nearshore over cobble bottom or are their numbers intrinsically low.
   c) If females are common nearshore, is there a seasonal shift in adult male-female distribution that indicates near-offshore migration for breeding.

d) Are there seasonal shifts in subadult populations from near- to offshore habitat; if so, is the shift correlated to adult movements.

e) Is the majority of the population, both juvenile and adult, centered about St. Paul rather than St. George Island as indicated by NMFS surveys.

2. Investigate juvenile distribution in particular and quantify abundance relative to adult female and larval populations. Characterize substrate on which crabs are most abundant.

3. Characterize the benthic community in which blue king crab are found: use information on sediment type, depth, and dominant fish and invertebrate species to characterize the habitat in which juvenile, adult male, and female crabs are found.

4. Classify and map major substrate types around the Pribilofs and correlate juvenile Erimacrus and blue king crab distribution to particular materials.

5. Reproductive Biology

   a) Study timing of the gametogenic cycle as partial evidence for annual or biennial spawning cycle.

   b) Determining general periods of egg extrusion and hatching, and developmental time of embryos.

   c) Use data on larval stages in months of May, August, and April as evidence of uni- or bimodal annual hatch.

6. Molt Frequency and Growth

   a) Define the season(s) of molt for juvenile and adult crabs based on shell condition indices (NMFS 1979) since ecdysis is a period of increased sensitivity to perturbations that might result from an oil spill.

b) Attempt to gain information on growth-per-molt among younger crabs as done by NMFS for older animals (increase of 10.6% of carapace length given by Otto et al. 1982) to determine growth rate and age to sexual maturity. This is to increase the accuracy of impact predictions if certain benthic age/size classes are disproportionately destroyed because of habitat preferences.

c) Use length-frequency analyses to define young-of-the-year (0+), 1+ and 2+ juveniles based on size ranges. Attempt to determine the extent of growth (instar numbers and molt frequency) during summer in contrast to winter.

7. Larval Biology

a) Measure timing of occurrence and spatial density of larvae about the Pribilof Islands.

b) Determine time of peak hatch and correlate to information on benthic female shell and egg condition; as noted, look for evidence of bimodal hatch.

c) Look for evidence of transport of larvae away from or retention near the Pribilofs to assess possible age class losses in terms of metamorphosis nearshore (suitable substrate?) or offshore (suboptimal substrate?)

d) Define area of greatest larval abundance in relation to benthic populations of females.

e) Study possible vertical stratification of larvae and associated diel changes to assess the vulnerability of larvae to hypothetical surface oil spills.

f) Calculate frequency of occurrence of zoeal and megalops stages to indicate the rate of molting within the larval population. Since molting increases susceptibility to pollutants, the rapidity with which it occurs is important life history information relative to the longevity of an oil spill.

8. Interpret all data on timing of crab life history events, substrate preferences, distribution and abundance relative to possible oil spill impacts.

1.2 Description of Study Area

The Pribilof Islands lie between 56° and 57°N, and 169°20' to 170°20'W at the northwest end of the St. George Basin, about 400 km northwest of Unimak Pass. The southern island, St. George, is about 60 km west of the northern boundary of oil lease sale areas in the St. George Basin, and St. Paul Island is another 60 km north of St. George Island (Fig. 1.1). The Pribilof Islands lie relatively near the shelf break in about 80 m of water on a broad shelf that extends more than 750 km from upper Bristol Bay to the east.

Physical Oceanography: Extensive analyses of currents and major frontal systems have been conducted to the southeast of the Pribilof Islands and reported in several reviews (Favorite et al. 1976; Kinder and Schumacher 1981a,b; Schumacher and Reed 1983), but little such work has been done in the immediate vicinity of the Pribilofs. The shelf proper has been divided into three major areas (domains) based on characteristics of water masses: the coastal domain separated from the middle shelf domain by a frontal system (inner front) at about the 50 m isobath; the middle shelf distinct from the outer shelf domain and demarcated by another front (middle front) along the 100 m isobath; and the shelf break front at 200 m

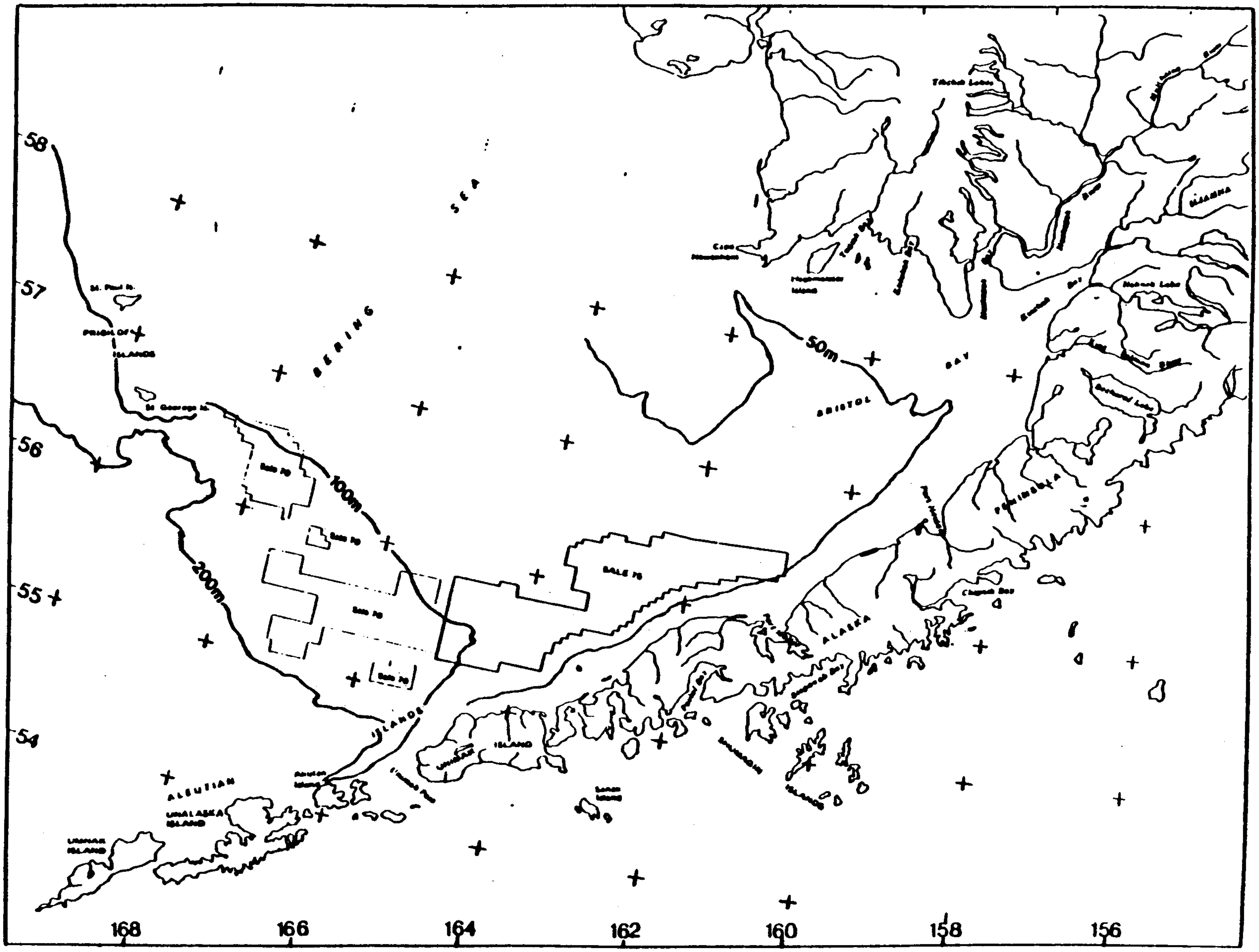


Figure 1.1 Map of the southeastern Bering Sea showing the Pribilof Islands, isobaths, and St. George oil leases.

separates the outer shelf from the oceanic domain (Kinder and Schumacher 1981a; Fig. 1.2). Water column structure is distinctly different between the three shelf domains, particularly in spring and summer when the coastal domain in shallow water is well mixed, the middle domain becomes a two-layered system marked by very cold bottom water, and the outer shelf domain is a three-layer system influenced by the intrusion of oceanic water up onto the shelf.

Although located in depths characteristic of the middle shelf domain (50-100 m), Schumacher (1982) describes water around St. George Island as a transition from a two-layered to a well mixed column and, in general, the features and properties of frontal systems are ill-defined.

Wind: The most frequent direction of airflow in the winter is from the northeast at speeds typically greater than occur in summer (Schumacher 1982). Based in part on wind direction, the resultant trajectories of oil predicted by simulation models of Liu and Leendertse (1981) are to the northwest and, in the case of hypothetical oil spills in northern St. George Basin, would reach the Pribilof Islands. Winter winds have a pronounced effect on both sea surface temperature and ice cover (Niebauer 1983; Overland and Pease 1982). In summer, mean winds are from the south and simulated trajectories of surface oil movement at this time are to the east although at a slower rate than in winter (see review of these data by Schumacher 1982). Despite the speed and force of winds over the SEBS, their effect is primarily on mixing, ice transport and current pulses, but not on mean current direction and speed (Schumacher and Reed 1983).

Currents: Kinder and Schumacher (1981b) presented a shelf circulation scheme (primarily surface and from summer data) that shows very weak mean flow (1 cm/sec) over the middle shelf proper, but relatively strong flows of 1-10 cm/sec to the northwest in the vicinity of the Pribilof Islands

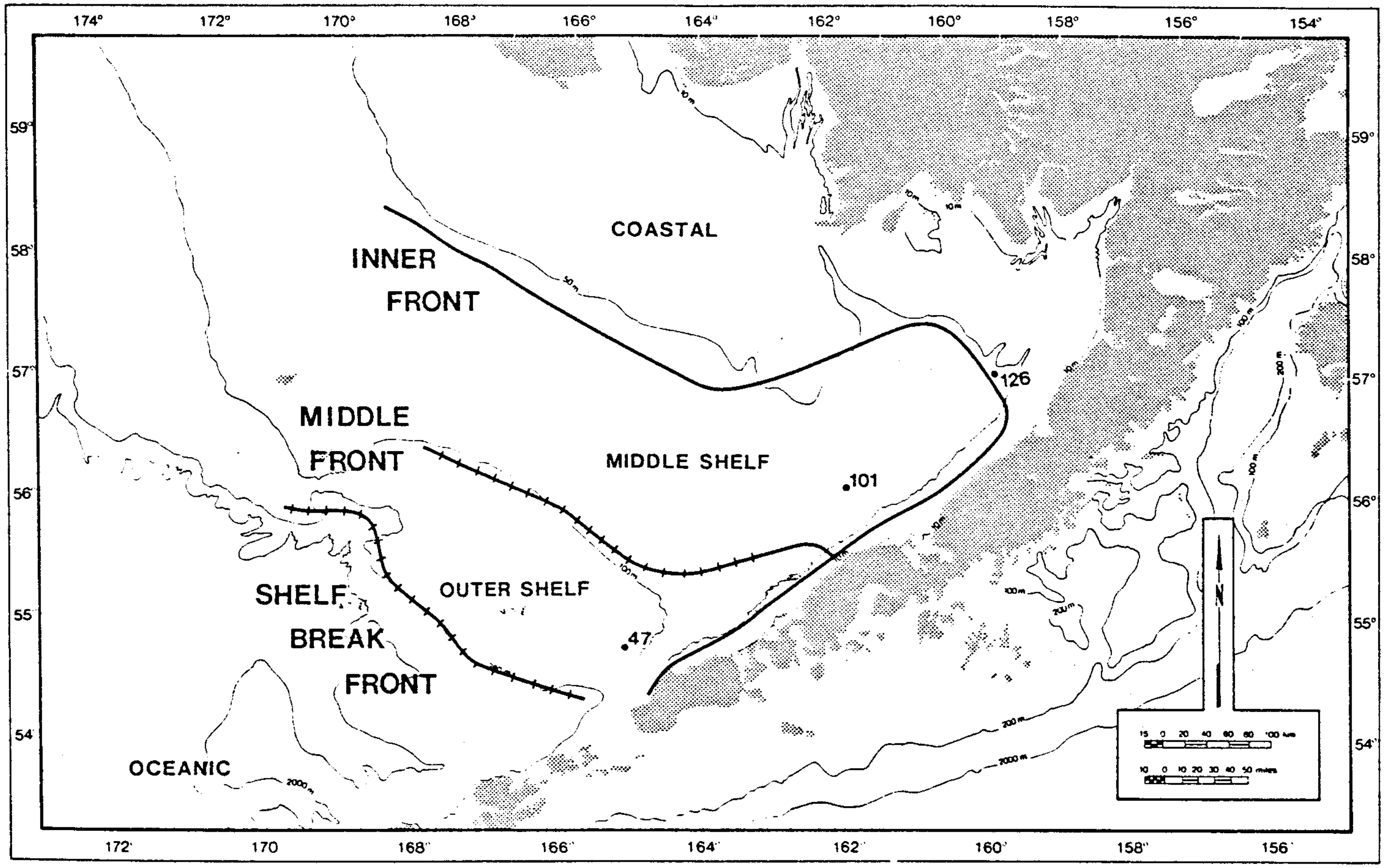


Figure 1.2 Approximate boundaries separating the three shelf (coastal, middle, outer) and the oceanic hydrographic domains. The boundaries are three fronts: inner, middle, and shelf break. These fronts roughly coincide with the 50 m isobath, the 100 m isobath, and the 200 m isobath (shelf break) (from Kinder and Schumacher, 1981).

over the outer shelf domain (Fig. 1.3). Over deeper waters to the west, eddies may be common and affect a change in direction of currents for periods of weeks or months (Kinder and Coachman 1977; Kinder et al. 1980). Such events, if occasionally occurring in the vicinity of the Pribilof Islands, may constitute a critical mechanism for larval retention. However, knowledge of current direction and speed, and variability of both is limited for this region. To the west, along-shelf flow is strong as is cross-shelf flow, all influenced to some extent by the Bering Slope Current (Schumacher and Reed 1983). To the east, mean currents over the middle shelf are weak although, as Kinder and Schumacher (1981b) suggest, substantial flow onto the shelf to replace the westward flow of coastal domain water (Fig. 1.3) may occur across the middle shelf between the Pribilofs and the inner front.

Ice: As an indication of weather patterns and circulation, sea surface temperatures (Niebauer 1981, 1983) and the dynamics of biota (Alexander and Niebauer 1981; Niebauer et al. 1981), ice is an important influence of variable magnitude. Niebauer (1981) depicts the limit of southern ice extent over the SEBS shelf which, on occasion, will reach and encompass the Pribilof Islands (e.g., 1976 and 1984). In other years such as 1979, ice may remain several hundred kilometers north. Such extremes in ice cover reflect year-to-year temperature variations. Mean annual sea surface temperatures (SST) recorded near the Pribilof Islands were 2.5°C in 1976 and 5.5°C in 1978 (Niebauer 1981). Surface and bottom water temperatures may have pronounced effects on biological/physiological events such as rates of egg development, time of hatch, survival and growth of larvae.

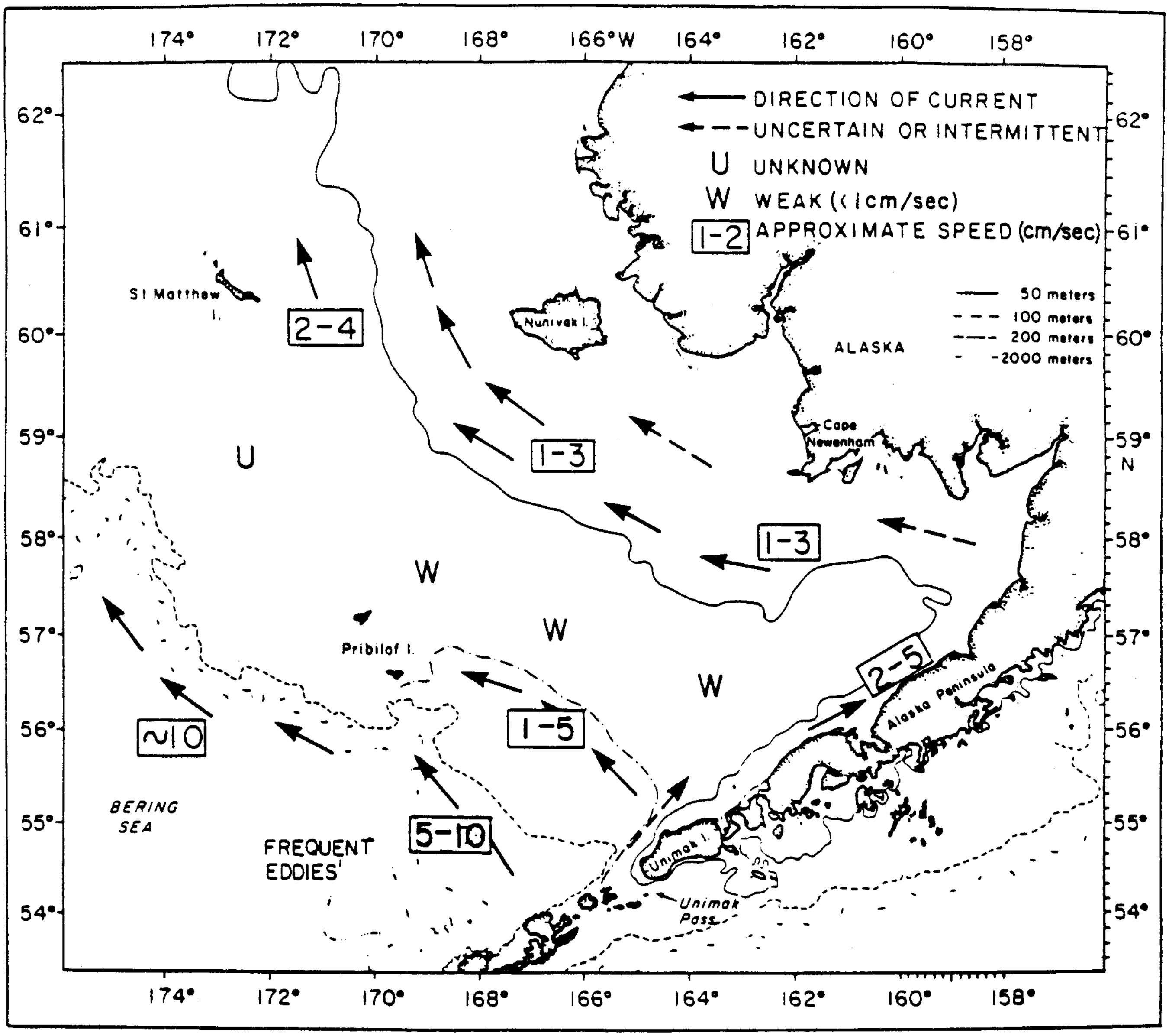


Figure 1.3 Current directions and net speed over the southeastern Bering Sea shelf (from Kinder and Schumacher 1981a).

1.3 Life History and General Biology of Blue King Crab and Korean Hair Crab

1.3.1 Distribution and Abundance of Juveniles and Adults

Blue King Crab

This is the most insular species of crab in the SEBS (Fig. 1.4), with major populations (and fisheries) centered at the Pribilof and St. Matthew Islands (Otto et al. 1982), and other populations at Kodiak Island in the Gulf of Alaska (Somerton and MacIntosh 1982). There was relative constancy in the location of benthic juveniles and adults around the Pribilof Islands in recent years (Otto et al. 1980, 1981, 1982), where greatest abundance was to the east and north of St. Paul Island, with few animals caught west near the shelfbreak or around St. George Island (Fig. 1.5 shows an example of female distribution). This pattern of distribution is generally true of pelagic larvae, although occurrence between and to the east of St. Paul and St. George islands has been reported by Armstrong et al. (1981; Fig. 1.6). The complete absence of blue king crab over most of the SEBS shelf (where red king crab, P. camtschatica are abundant) suggests either inextricable dependence on the benthic habitat associated with the islands (e.g., predator refuge), and/or restriction by virtue of some sort of competitive, agonistic interaction with other species. Confinement of the species to small areas around islands makes that portion of the SEBS population around the Pribilof Islands extremely vulnerable to possible oil spills originating in the northern St. George Basin lease sale.

The depth range of main aggregations of blue king crab is about 45 to 75 m on a mud-sand bottom, although gravel and rocky substrate is found immediately adjacent to both Pribilof Islands (Figs. 1.7 and 1.8; M. Hayes, NMFS, Seattle, personal communication, 1/5/83). Otto et al. (1982) note that estimates of female and juvenile blue king crab around both the

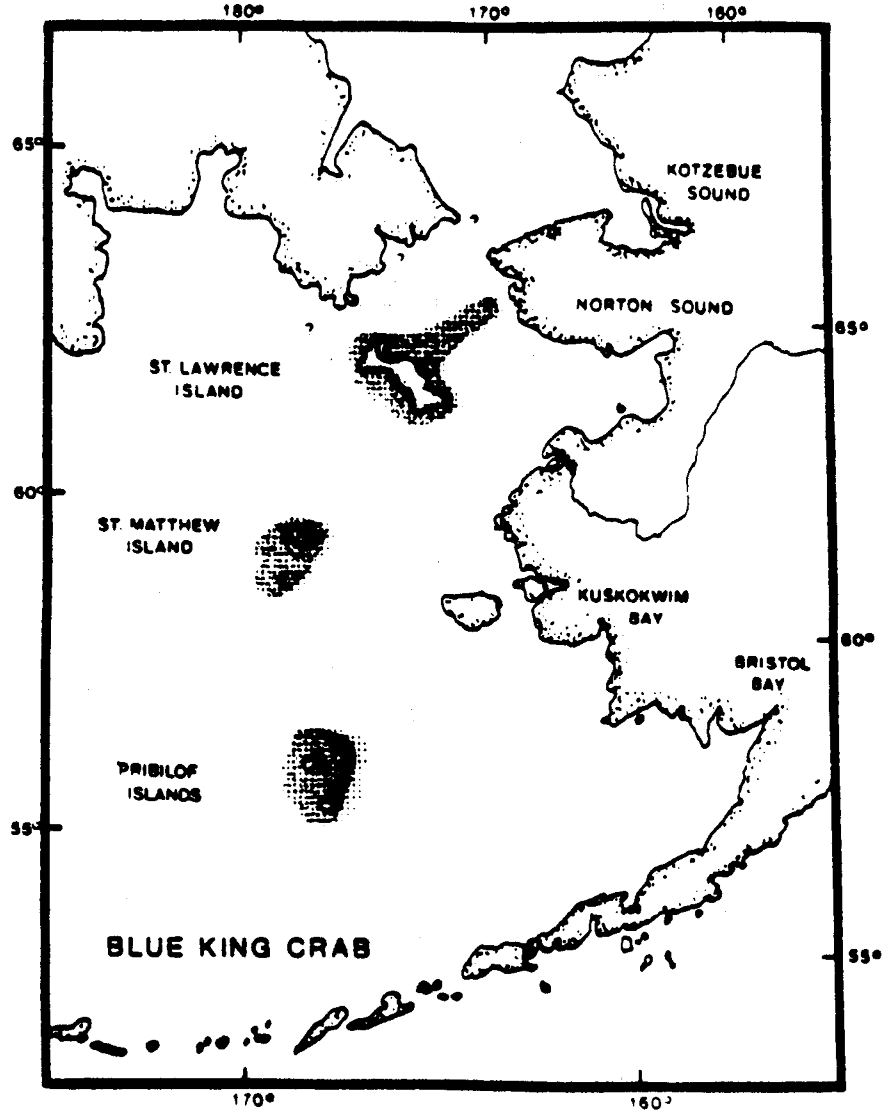


Figure 1.4 Distribution of blue king crab (Paralithodes platypus) in the eastern Bering Sea. Darkly shaded portions indicate areas of consistent abundance (from Otto 1981).

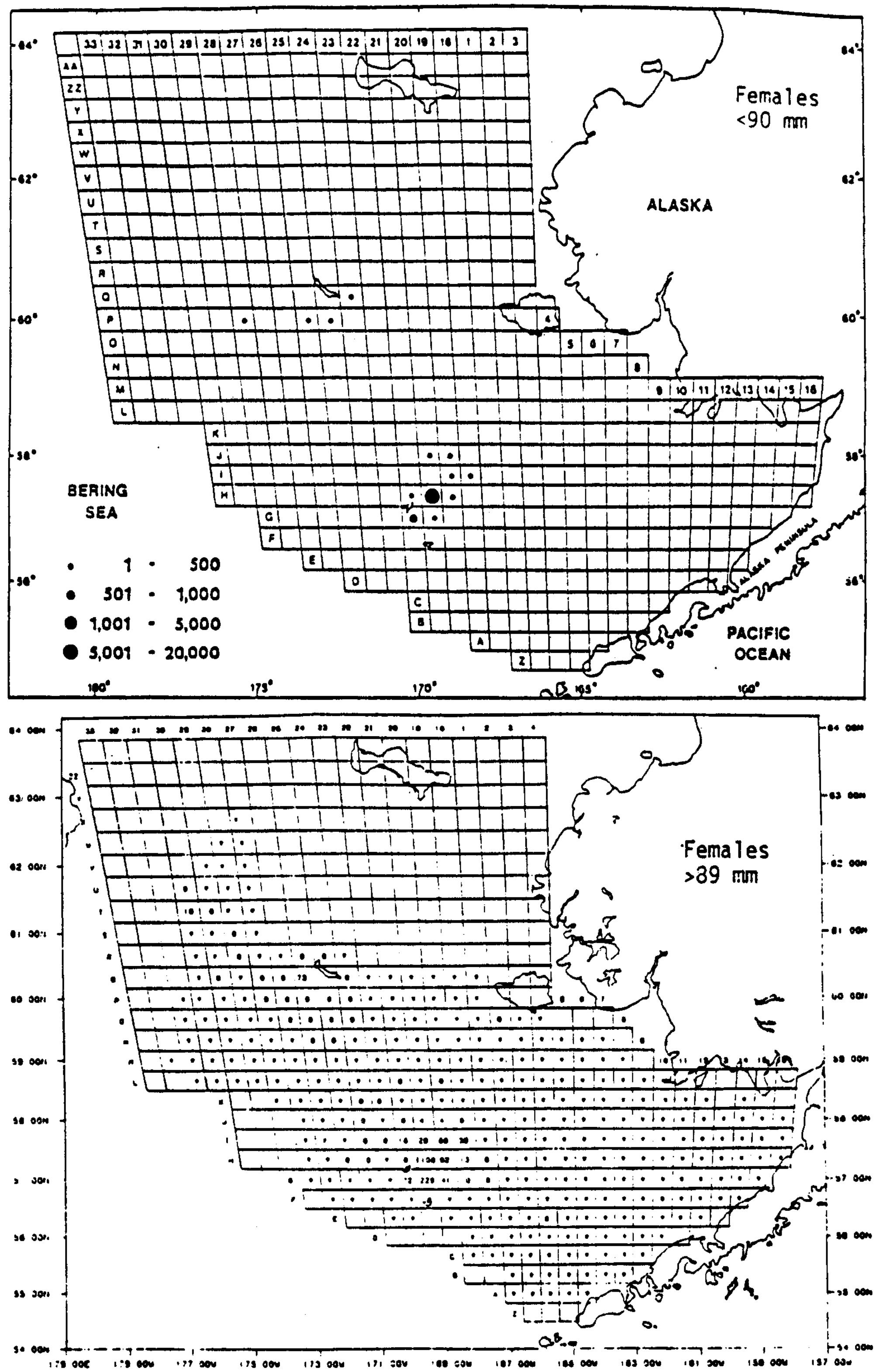


Figure 1.5 Distribution and abundance (numbers per mile²) of female blue king crab less than 90 mm carapace length in the eastern Bering Sea during May-July 1981 (above) and females greater than 89 mm in 1982 (below) (from Otto et al. 1981, 1982).

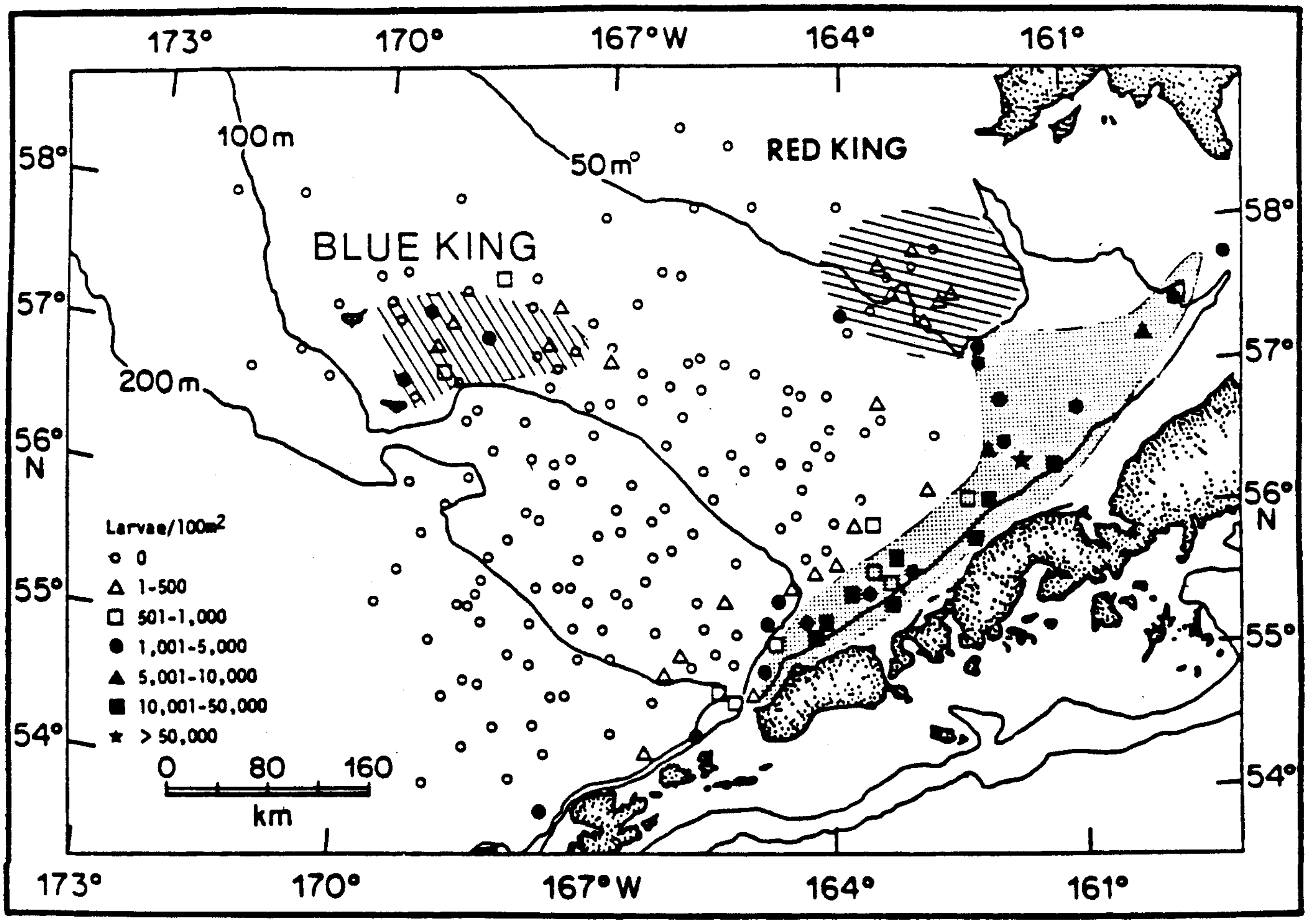


Figure 1.6 Larval king crab distribution in the southeastern Bering Sea. Data summarized from 1976 to 1981. Blue king crab larvae only at the Pribilofs (Armstrong et al. 1981). Shading highlights major aggregations of larvae.

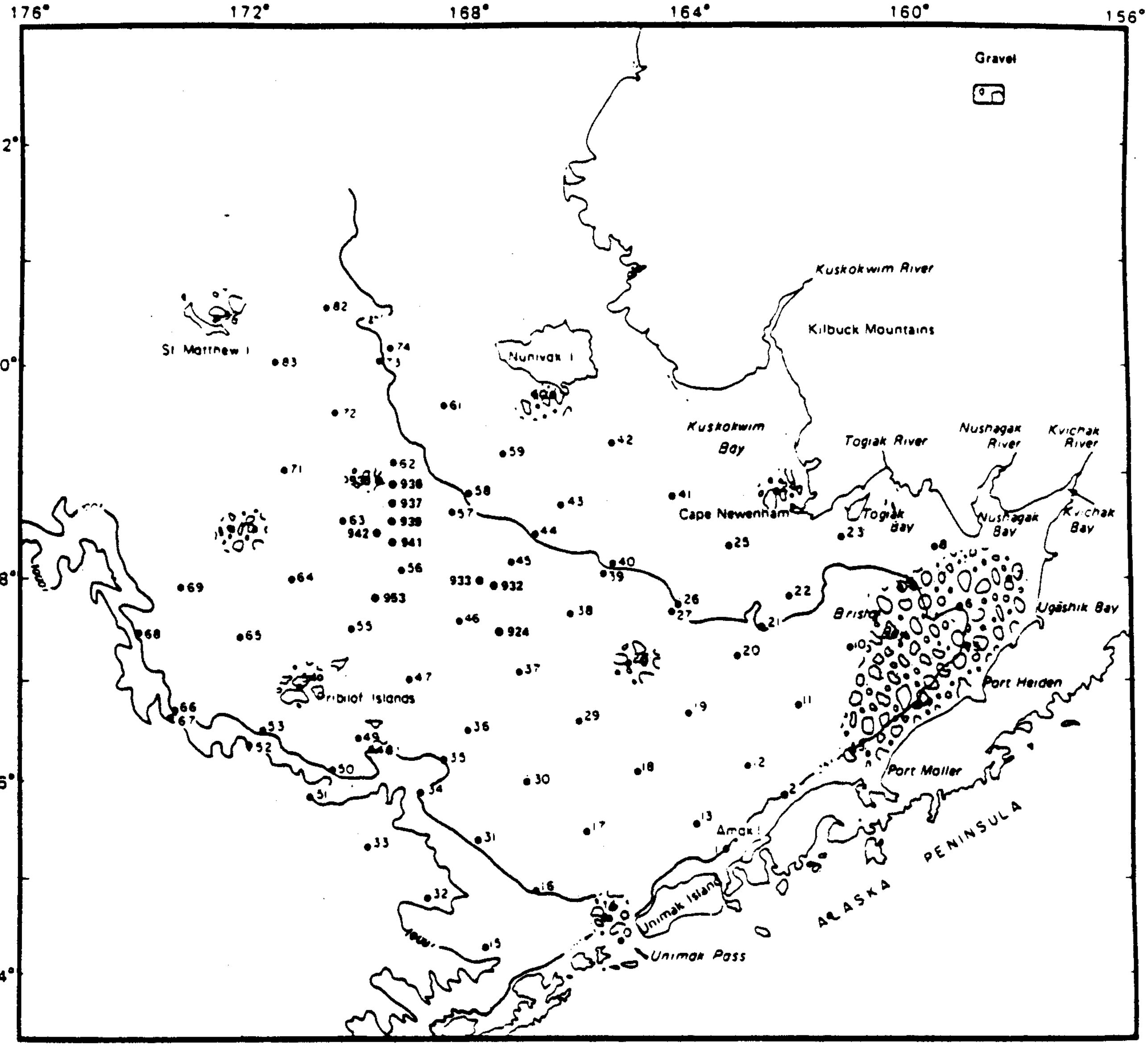


Figure 1.7 Distribution of gravel in the southeastern Bering Sea (McDonald et al. 1981).

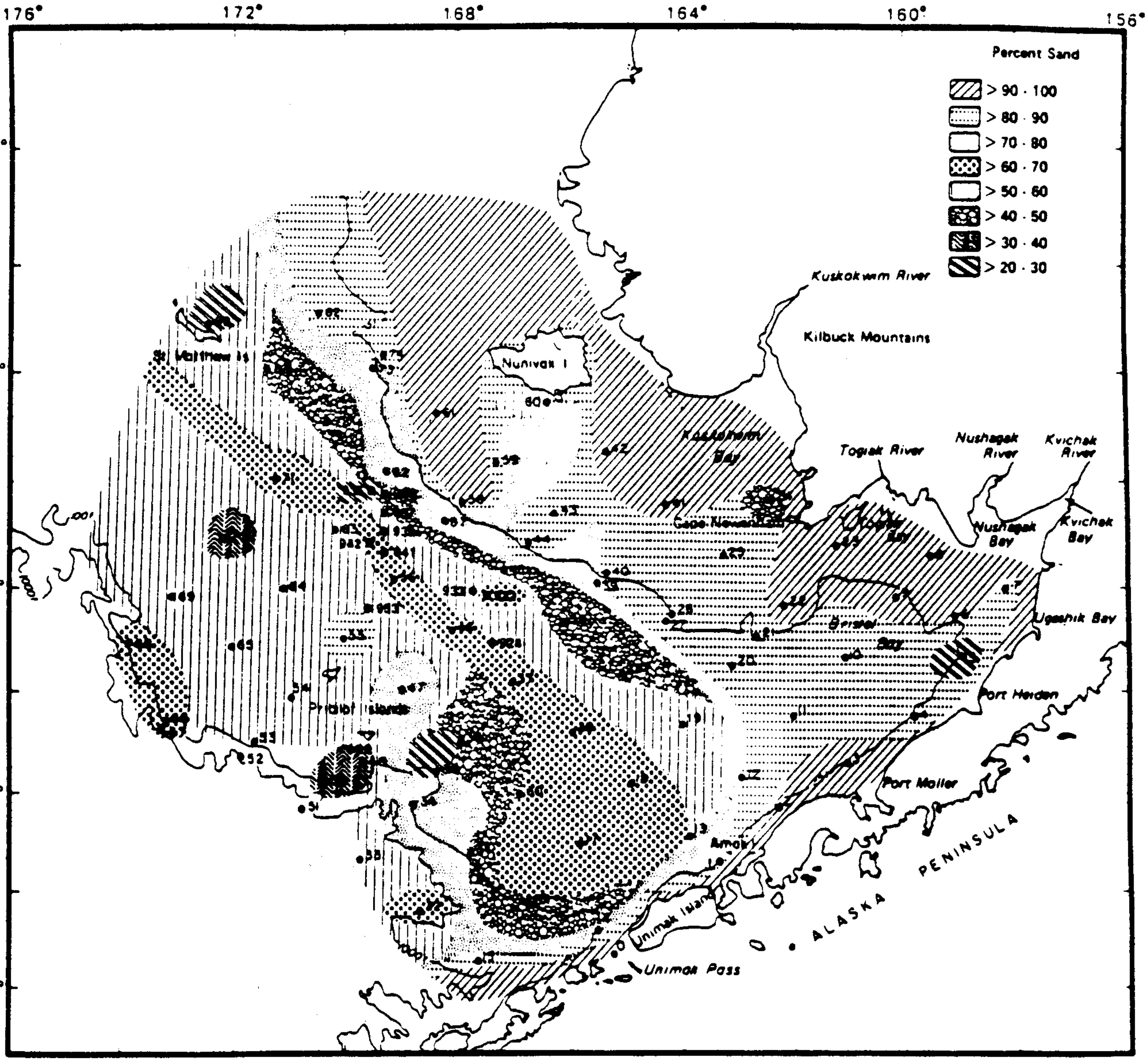


Figure 1.8 Distribution of sand in the southeastern Bering Sea (McDonald et al. 1981).

Pribilof and St. Matthew Islands are low because the species may be distributed over rocky, untrawlable bottom that NMFS does not survey. These observations suggest that spawning and successful recruitment of first instar juveniles may depend on nearshore, cobble-rocky substrate; later as older and larger animals, populations disperse farther offshore although still in a small area on the scale of the SEBS *in toto*.

Densities of blue king crab have been reported to range from less than 100 to several thousand per square nautical mile (NM^2; NMFS units in annual reports; see Fig. 1.5). Estimates of total abundance (population size) made by NMFS indicate less fluctuation in this population than found for red king crab, but populations have still decreased in recent years (Otto et al. 1981, 1982). Legal males (>134 mm carapace length, CL) have declined from an estimated abundance of 9.4 million in 1977 to 2.2 million in 1982. Sexually mature females were calculated to be 35.5 million animals in 1978 and 8.6 million in 1982 (Fig. 1.9). Otto et al. (1982) conclude that stocks will remain low for several years.

There is relatively little biological information published on blue king crab although Somerton and MacIntosh (1982, 1986) have summarized work from the Bering Sea and Kodiak Island. Animals are thought to grow at a rate comparable to red king crab (Somerton and MacIntosh 1982; Powell and Nickerson 1965; Weber 1967) and reach sexual maturity at about 96 mm and 108 mm CL for females and males, respectively, when they are about 6-7 years old. However, recent analyses of length-frequency data indicate that blue king crab may be longer lived and slower growing than red king crab, so that age-at-size may not be extractable from data on the latter (Somerton and MacIntosh 1986).

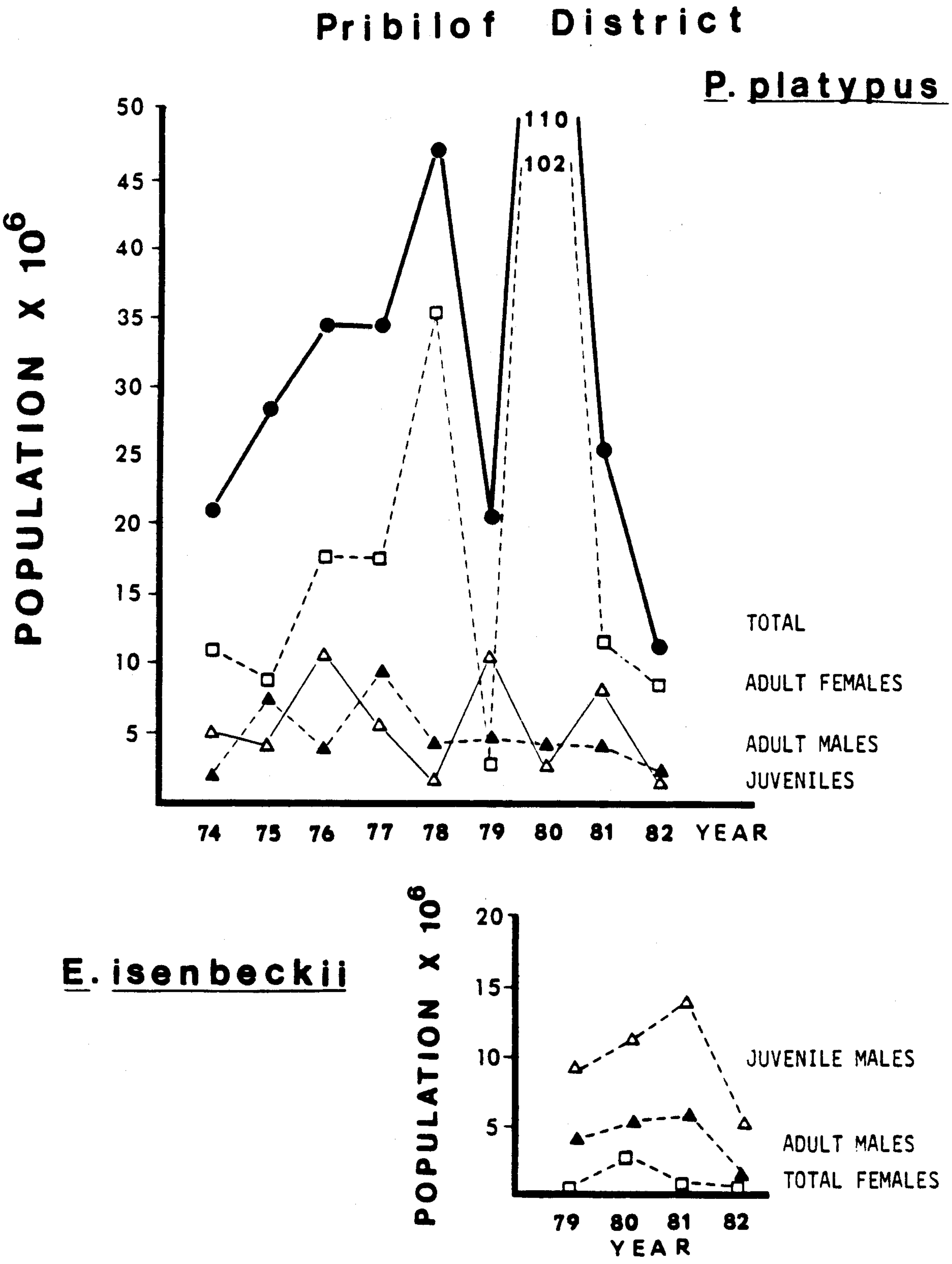


Figure 1.9 Estimates of annual abundance of Paralithodes platypus (above) and Erimacrus isenbeckii (below) over several NMFS survey years (modified from Otto et al. 1982).

Korean Hair Crab: *Erimacrus isenbeckii* has been a target-species of the NMFS annual groundfish survey since 1979 when a small fishery for this crab developed. Although widely distributed over the SEBS, there are two main aggregations; one about the Pribilof Islands and the second in shallow waters along the Alaskan Peninsula from Izembek Lagoon to Port Moller (Figs. 1.10 and 1.11; Otto et al. 1982). Jewett and Feder (1981) caught *E. isenbeckii* in about 28% of trawls made over the SEBS shelf in 1975 and 1976, and calculated that the species was about 1.5% of total epifaunal biomass.

Survey data on the species are intriguing because abundance estimates for males are always greatly in excess of those for females (Otto et al. 1980, 1981). For instance, total male abundance from 1979-1981 ranged from 12 to 18 million crabs while females were calculated to be 0.3 to 2.3 million animals. Populations of this species (as with blue and red king crab) also declined drastically by 1982 when abundance of males and females dropped to 6.3 and 0.1 million, respectively (Otto et al. 1982). Sexually mature crabs (>64 mm CL) were most common north of Port Moller in 1982, and virtually none were caught at the Pribilof Islands (Fig. 1.12).

1.3.2 Reproduction

Blue King Crab: Authors of previous studies of the reproductive cycle in *Paralithodes platypus* generally concluded that it differs from that of its better-known relative, *P. camtschatica* (Sasakawa 1973, 1975a; MacIntosh et al. 1979; Somerton and MacIntosh 1985), however, the timing of reproductive events, duration of embryonic development and interpretation of the cycle have remained in question. Female *P. camtschatica* produce mature ovaries and extrude eggs annually; females molt, mate and extrude a new clutch of eggs in the spring shortly after eggs from the previous year hatch

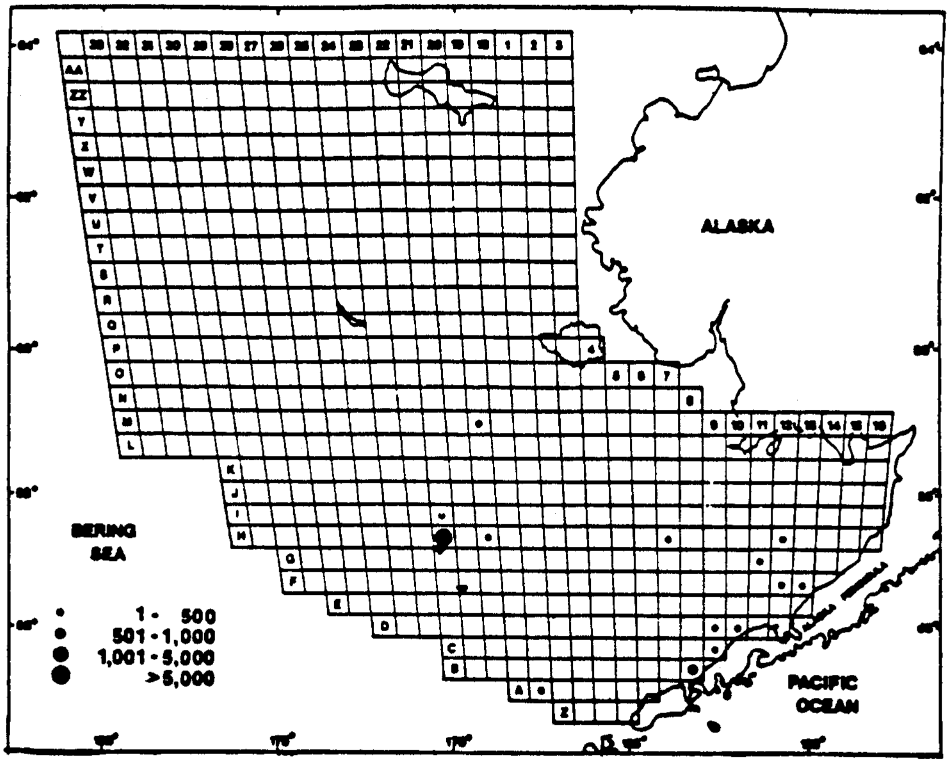


Figure 1.10 Distribution of female Erimacrus isenbeckii in the eastern Bering Sea during May-July 1980. Numbers per NM² (Otto et al. 1980).

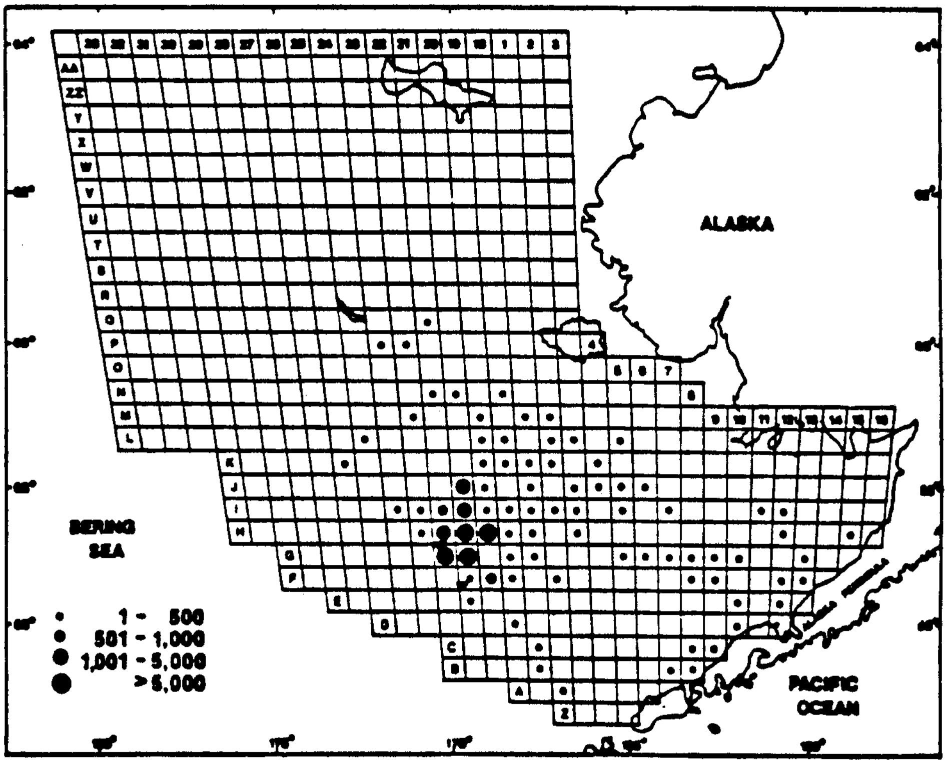


Figure 1.11 Distribution of male Erimacrus isenbeckii in the eastern Bering Sea during May-July 1980 (Otto et al. 1980).

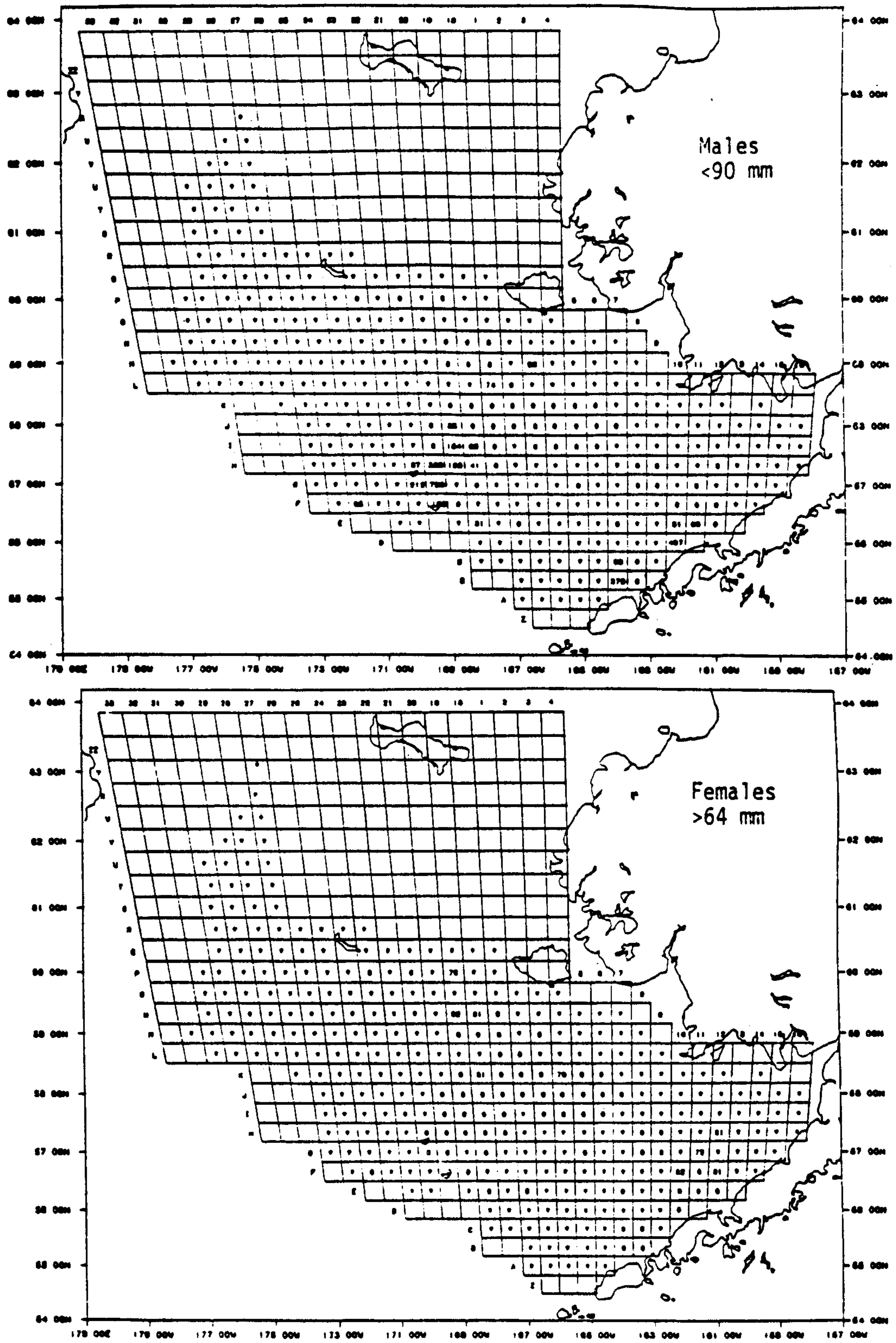


Figure 1.12 Distribution and relative abundance (no./mile^2) of male Korean hair crab less than 90 mm carapace length in the eastern Bering Sea during May-July 1982 (above) and females greater than 64 mm (below) (Otto et al. 1982).

(Marukawa 1933; Wallace et al. 1949). However, substantial interannual variation in the percentage of ovigerous female P. platypus within the mature population has been reported (Otto et al. 1979; MacIntosh et al. 1979; Somerton and MacIntosh 1985) and consequently, a two year reproductive cycle has been postulated for this species. Sasakawa (1973, 1975a) inferred from tagging experiments in the western Bering Sea that the reproductive cycle consisted of a 19 month ovigerous period (duration of embryonic development) followed by a five month period between hatch of old eggs and extrusion of new ones. Somerton and MacIntosh (1985), in studies of blue king crab at the Pribilof Islands, concluded that females were ovigerous for 14-15 months, and that biennial reproduction was due to a two year ovarian cycle that reflects longer life (than the red king crab) and a savings of energy and reduction of risk at molting. Otto et al. (1979) reported that most crab in the 101-110 mm CL interval (first time spawners or primiparous females) reproduce annually, but that a radical biennial decrease in the number of ovigerous females starts at 111-115 mm CL.

Female blue king crab in the Pribilof Island region attain sexual maturity at about 96 mm CL, and males at about 108 mm (Somerton and MacIntosh 1982, 1985). Fecundity ranges from 50,000 to 200,000 eggs per female (Somerton and MacIntosh 1982); Sasakawa (1975b) reported an average value of 120,000 for the western Bering Sea. Eggs are somewhat oval in shape and average 0.98 mm by 1.18 mm in length (Sasakawa, 1975b).

Korean Hair Crab: Reproduction of the Korean hair crab Erimacrus isenbeckii in Japanese waters has been described by Sakurai et al. (1972). Females are believed to mature at about 45 mm CL and although males are mature at 40 to 50 mm they may not mate successfully until they are about 70 mm in length. Mating apparently takes place several months prior to egg extrusion although at this point the ova are immature. The female molts while being grasped and her gonopores are apparently plugged after mating by a secretion from the male, possibly to prevent subsequent copulation. Mating occurs over a seven month period from August to February; the first four months involve older females in deep water and the latter period primiparous females in shallower areas. Yoshida(1941) suggests that female Erimacrus in Korean waters may molt every other year in order to acquire energy for egg masses. Fecundity ranges from 40,000 to 50,000 eggs but may be as high as 160,000; eggs are round and 0.8 to 0.9 mm in diameter.

The present study attempted to define the reproductive cycle of these two species in the Pribilof Island region through the examination of four factors: 1) shell condition (newly molted vs. old shell; presence or absence of empty egg cases); 2) proportion of ovary weight to body weight (gonosomatic index or GSI; 3) egg development and; 4) ovarian development (histological examination of ova).

1.3.3 Larval Biology, Distribution and Timing

Blue King Crab: Distribution and abundance of larval stages are poorly studied and only a few observations from the Pribilof Islands are available (Armstrong et al. 1981; Armstrong et al. 1985). Larval densities seem to be an order of magnitude less than high values recorded for red king crab (Fig. 1.6), and larvae have only been found to the east of the Pribilof Islands; however the observations are meager in time and space and not at all conclusive.

Limited data suggest that larvae hatch around the Pribilof Islands about mid-April (Armstrong et al. 1981) and development rates may be similar to red king crab. By June most larvae are third and fourth stage zoeae, and in July 1981 only megalops larvae were caught off St. George Island (Armstrong et al. 1983). This implies that metamorphosis to benthic juveniles could occur in late July or early August in some years.

Korean Hair Crab: Larvae of *E. isenbeckii* were not frequently encountered among hundreds of zooplankton samples studied by Armstrong et al. (1983), but when found were most common north of Unimak Island in the vicinity of Amak Island and rare near the Pribilofs (Fig. 1.13). During summer OCSEAP cruises in 1982, Armstrong found fair numbers of Korean hair crab larvae nearshore from western Unimak Island to Izembek Lagoon (unpublished data). Larvae are present in the Bering Sea by April (Armstrong et al. 1981) and pass through five zoeal and a megalops stage (Kurata 1963; Makarov 1966; Takeuchi 1969).

1.3.4 Fisheries

Blue King Crab: Most of the U.S. Bering Sea fishery for blue king crab is centered off St. Paul (Fig. 1.14) and St. Matthew Islands. Landings have increased from about 2.4 million lbs in 1975 to 10.8 million lbs in 1980 (Otto 1981, Pacific Packers Report 1981). In 1981 landings from the Pribilof district decreased 20% and dropped further in 1982 (INPFC 1982; Otto et al. 1982), reflecting the reduction predicted by the annual resource assessment surveys of NMFS. Landings in 1983 in the Pribilof district (Registration Area Q) were only 4.4 million lbs, and CPUE (number of crabs per pot) has declined from 26 in 1973 to only 5 in 1983 (Alaska Dept. of Fish & Game 1983). It is significant that for the first time in the fisheries, landings of blue king crab surpassed those for red king crab in the SEBS during 1982-1983 (ADF&G 1983).

Korean Hair Crab: Commercial landings of *Erimacrus* come primarily from the Pribilof Islands and were 600,000, 2.4 million and 930,000 lbs in 1980, 1981, and 1982, respectively (Otto et al. 1982; ADF&G, 1983). This is obviously a limited fishery that, to date, is directed toward Japanese

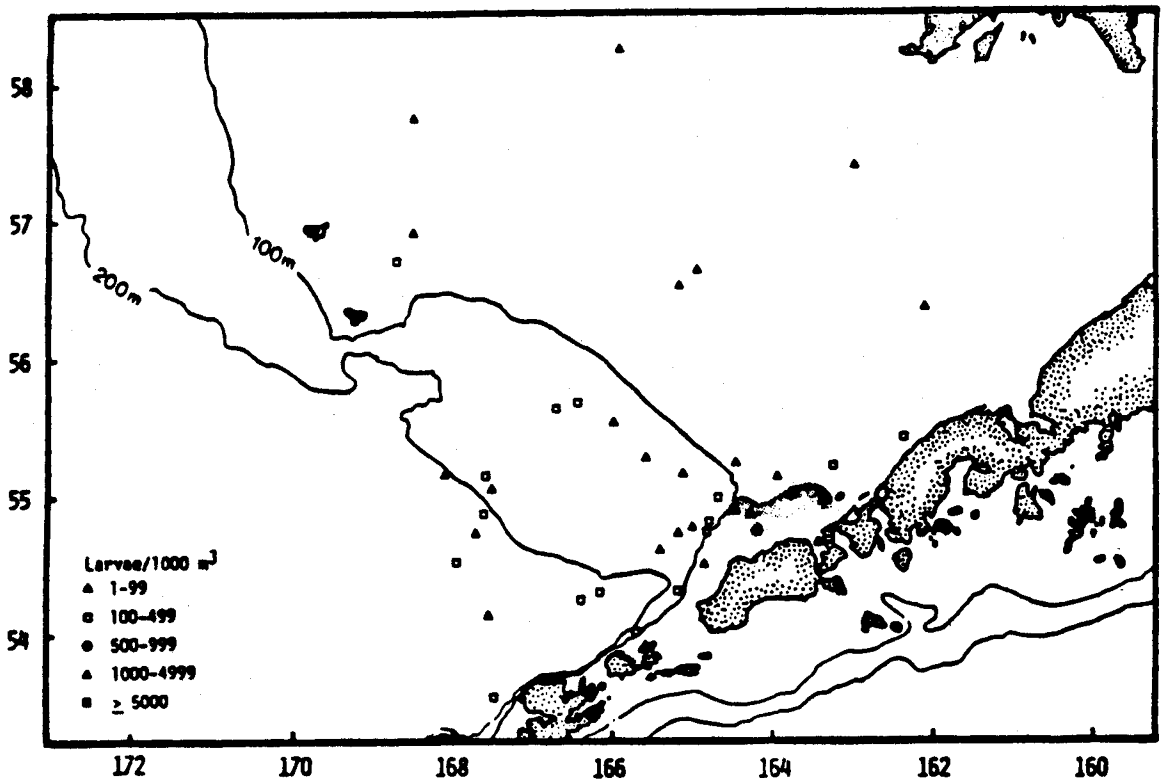


Figure 1.13 Locations and density of Erimacrus isenbeckii larvae collected in the southeastern Bering Sea from 1976 to 1980. Densities of larvae were corrected for the upper 60 m (Armstrong et al. 1981).

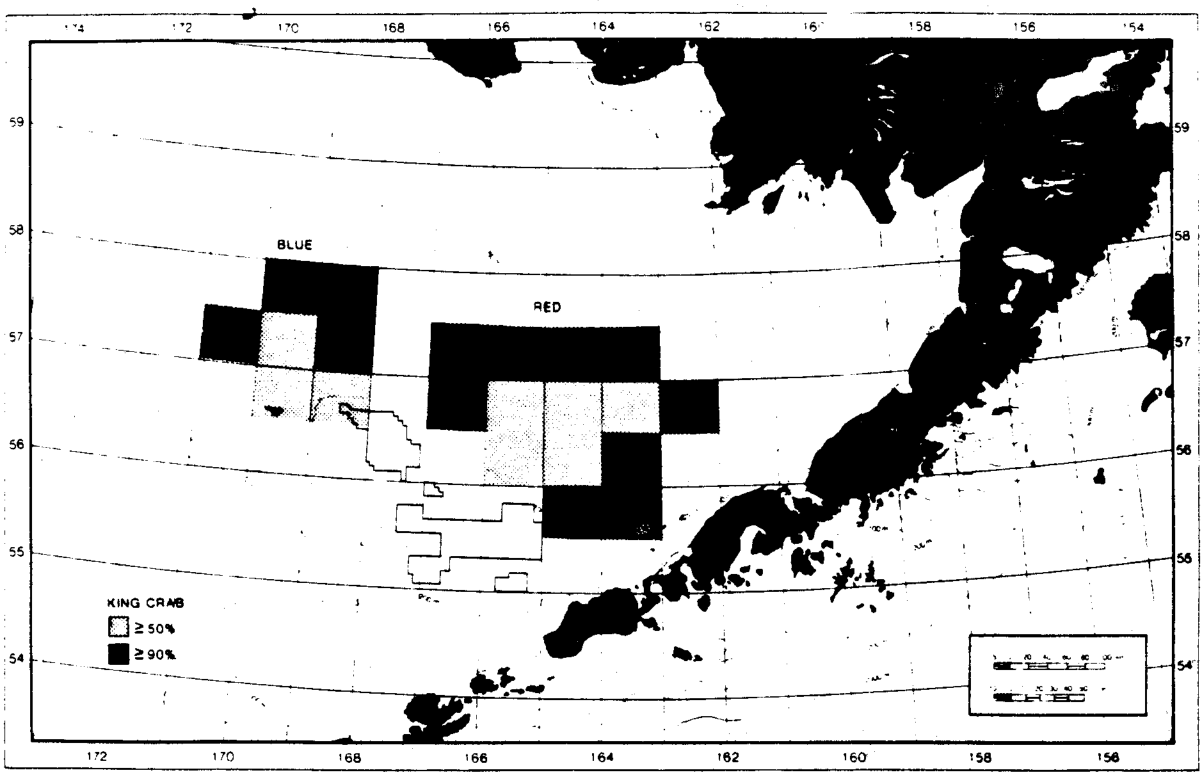


Figure 1.14 Major king crab catch areas relative to St. George Basin lease area (Otto 1981 in Curl and Manen 1982). Light shading represents ADF&G statistical areas from which 50% or more of commercial landings come. Dark shading represents 90% or more of commercial landings.

markets where it is sold as "kegani." The small size (about 2 lb per crab) and low value ($.55/lb in 1982) make this a fishery of only marginal appeal to American fishermen (ADF&G 1983).

1.4 Organization of this Report

Because of the number of topics studied during this research program and the need to provide details on methods and approaches to describe results of the objectives listed in Section 1.1, a different approach that we have used in past reports has been selected in this instance. Rather than proceed with a traditional methods and materials, results, and discussion format, we have decided to treat major topics in a more self-contained manner by combining methods and materials, results, and a short discussion that are pertinent to each major topic (e.g., Substrates, Blue King Crab Distribution and Abundance, Reproductive Biology). After a presentation of major biological results for the two species of crabs, a summary of the life history and general ecology is given that is then followed by an assessment of potential oil impacts.

2. SURVEY DESIGN AND SUBSTRATE ANALYSES

Although our initial sampling design for this program was one based on our sense of species biology and distribution, it became quickly apparent during the first cruise in May 1983 that the scale of distribution of crab and relative density was strongly influenced by substrate composition and location. Within that first cruise the survey plan was modified to allocate more effort nearshore of St. Paul Island in an area believed to be rocky based on evidence from Van Veen and Shipek grabs. A more important step was taken toward directed sampling effort on several general categories of substrate during the second cruise. Side scan sonar (SSS) was used to map substrates that were characterized according to broad definitions such as sand, gravel, cobble, rock or shell. Although a great deal of effort was expended on specific sediment analyses of many samples, the level of detail given by such analyses (phi size) was not useful in characterizing habitat in which juvenile and adult blue king crab and Korean hair crab are distributed. This section details the survey design used and modified through the three cruises, discusses the approach taken to map general substrates, and presents results from side scan sonar investigations. This information became important for characterization of communities (to the extent we were able to do so) and particularly important for definition of critical habitat required by blue king crab and to a lesser extent Korean hair crab.

2.1 Survey Design and Substrate Analyses

2.1.1 Location and Timing of Sampling Effort

Three cruises, each with approximately two and a half weeks of sampling time, were made during the term of this project. The first cruise covered the period May 9-30, 1983; the second cruise was from 19 August to 7 September 1983, and the final cruise ran from 11 April to 4 May 1984. Sampling approaches were modified for each cruise depending upon the experience of the previous cruise.

During the first cruise, stations were systematically arranged on transect lines radiating from St. Paul and St. George Islands (Fig. 2.1). Approximately 70% of the sampling effort was planned to be north of 57°N Lat and 60% of the effort shoreward of 60 m isobath. Additional stations were added in regions of high juvenile abundance and on certain substrates such as gravel.

Because it was difficult to determine the extent of various bottom types using just the Simrad sonars, and Van Veen and Shipek grab samplers, a side scan sonar (SSS) was used on the second cruise. The farthest offshore staitons of the first cruise were deleted from the second cruise because of exceedingly low abundance of juvenile crab, and substantially more effort was put into mapping nearshore habitats which had high densities of juvenile crab. Three survey grids were established around St. Paul Island (Figs. 2.2 and 2.3). The grids consisted of 36 cells of which 18 were randomly selected as stations. Because of the extent of nearshore habitat and limit on time, grids were not set up around St. George Island where densities of both crab species were low.

During April 1984, SSS was again employed to map areas to the southeast of both islands to fill in gaps from the previous cruise. In general, the August stations were revisited at this time (Fig. 2.4). Also, more emphasis was placed on sampling to the northeast of St. Paul Island for adult crab, but this operation as well as additional SSS to the north of St. Paul Island were hampered by sea ice. It was hoped that the timing of this cruise would catch the onset of larval hatch and provide adult

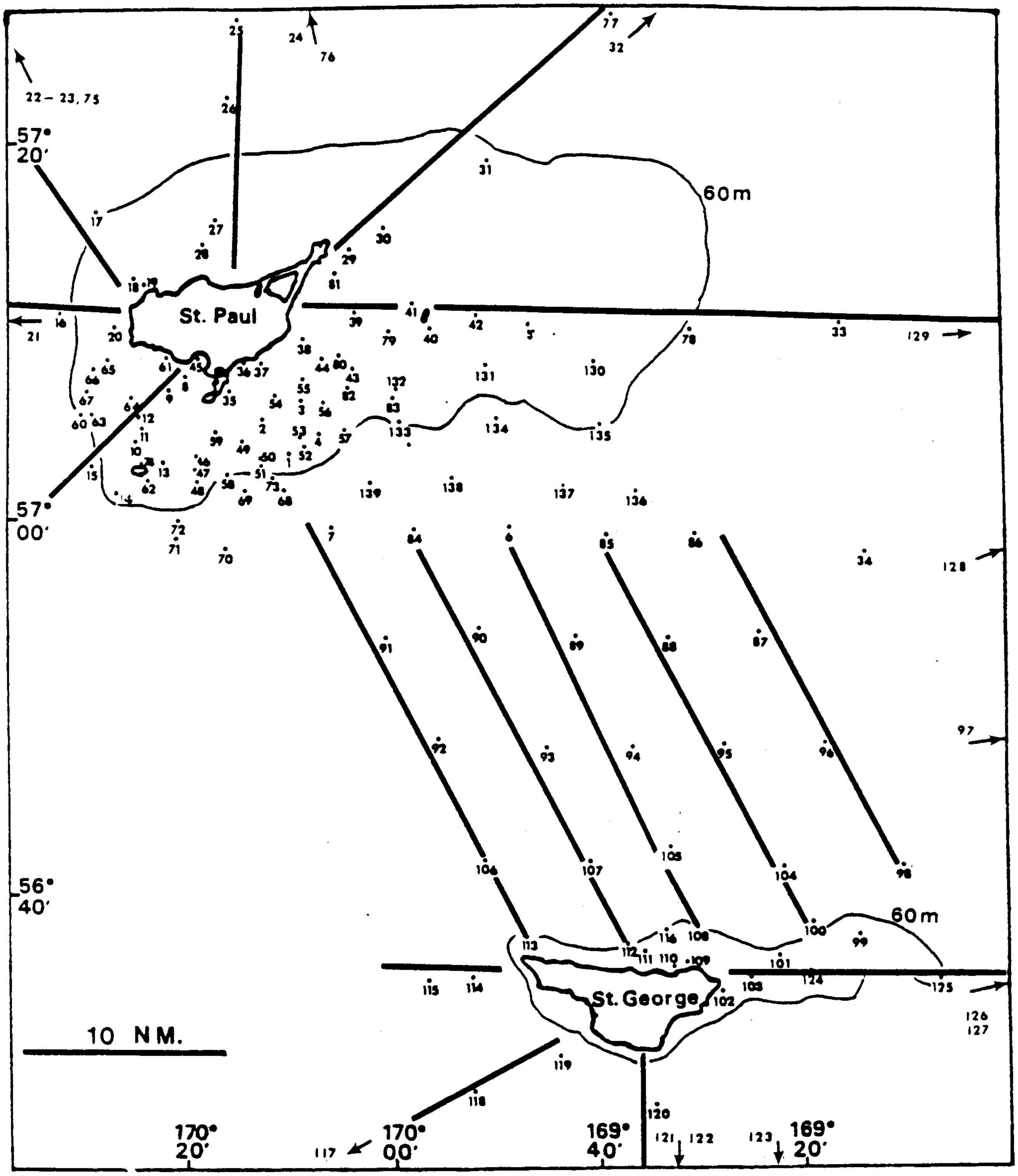


Figure 2.1 Station locations for zooplankton and benthic samples, May 1983. Stations were located up to 40 NM offshore of both islands as indicated. The original transect array emanated as spokes from the islands with coverage between the islands extended westward toward the 80-m isobath. Additional stations were added in areas of high juvenile abundance.

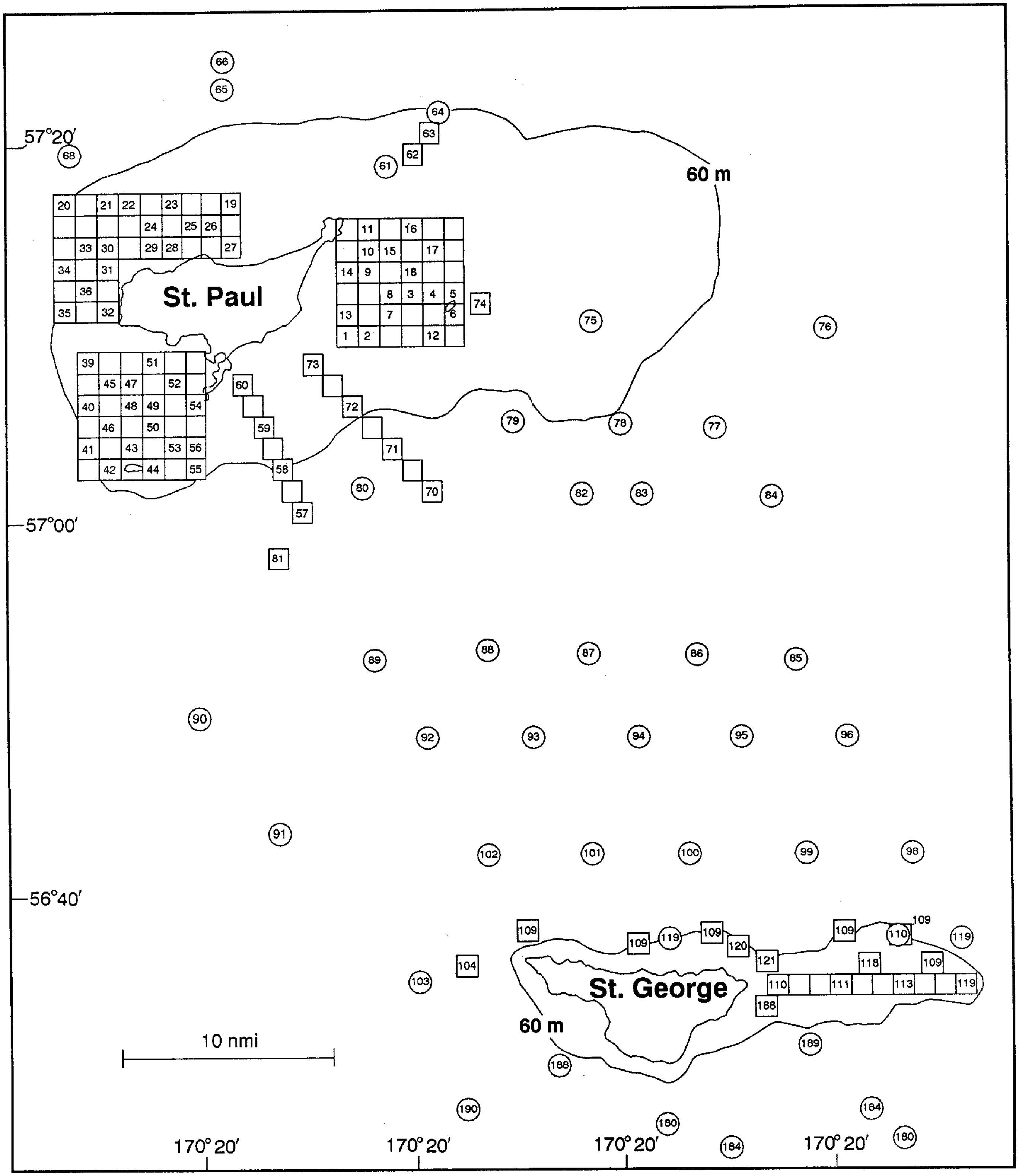


Figure 2.2 Side scan sonar (SSS) grid and regular stations, August 1983. Depicted as squares are grids in which random number selection was used to locate SSS stations around St. Paul and isolated SSS stations elsewhere. Circles show the location of stations where no SSS was used.

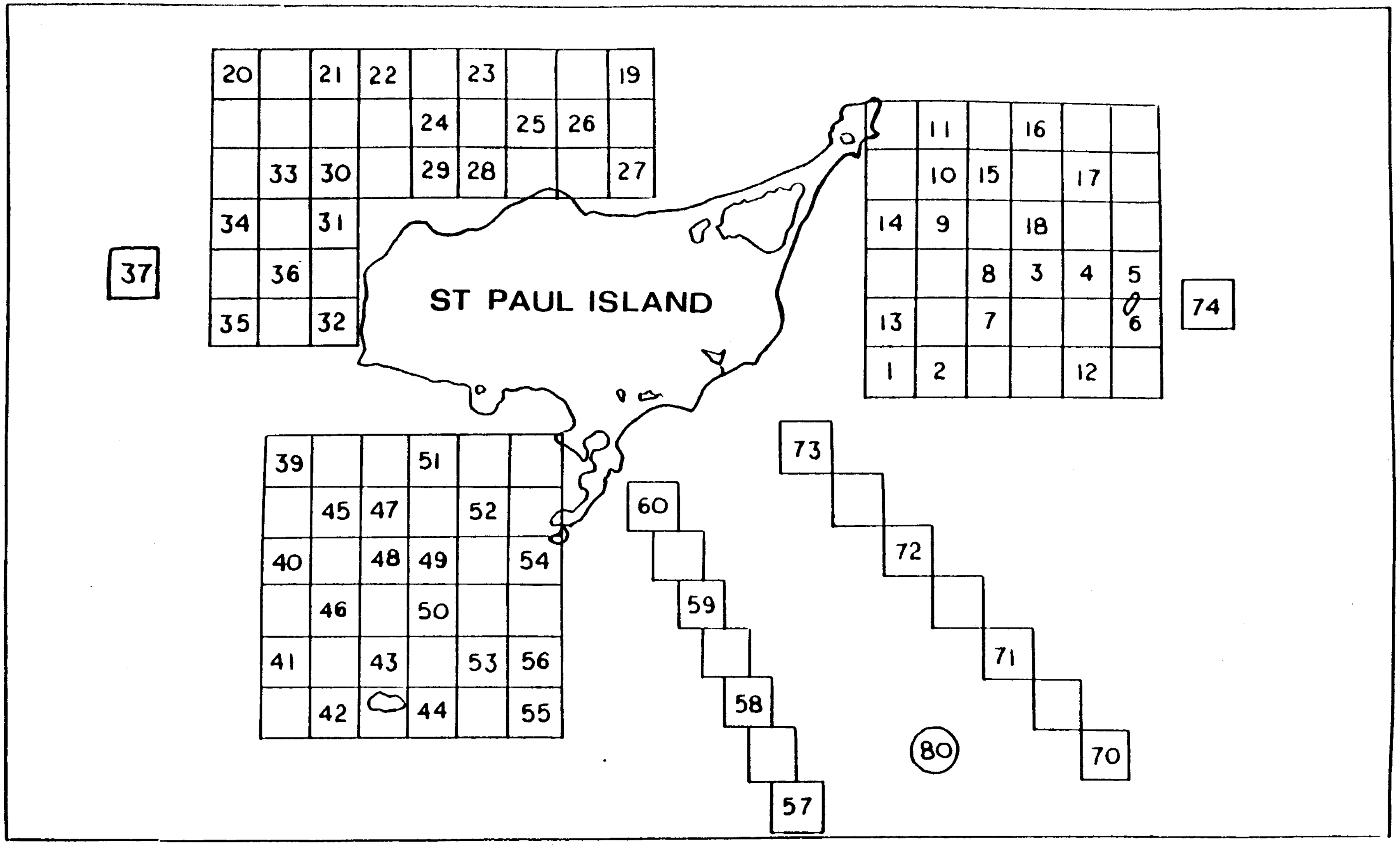


Figure 2.3 St. Paul side scan sonar grids, August 1983. Each square is 1 NM on a side and was selected by a random number process. The side scan sonar survey was conducted for a complete mile in a variable direction dictated by currents and winds. The bottom width covered during each survey varied from 75 m to 150 m on port and starboard of the ship.

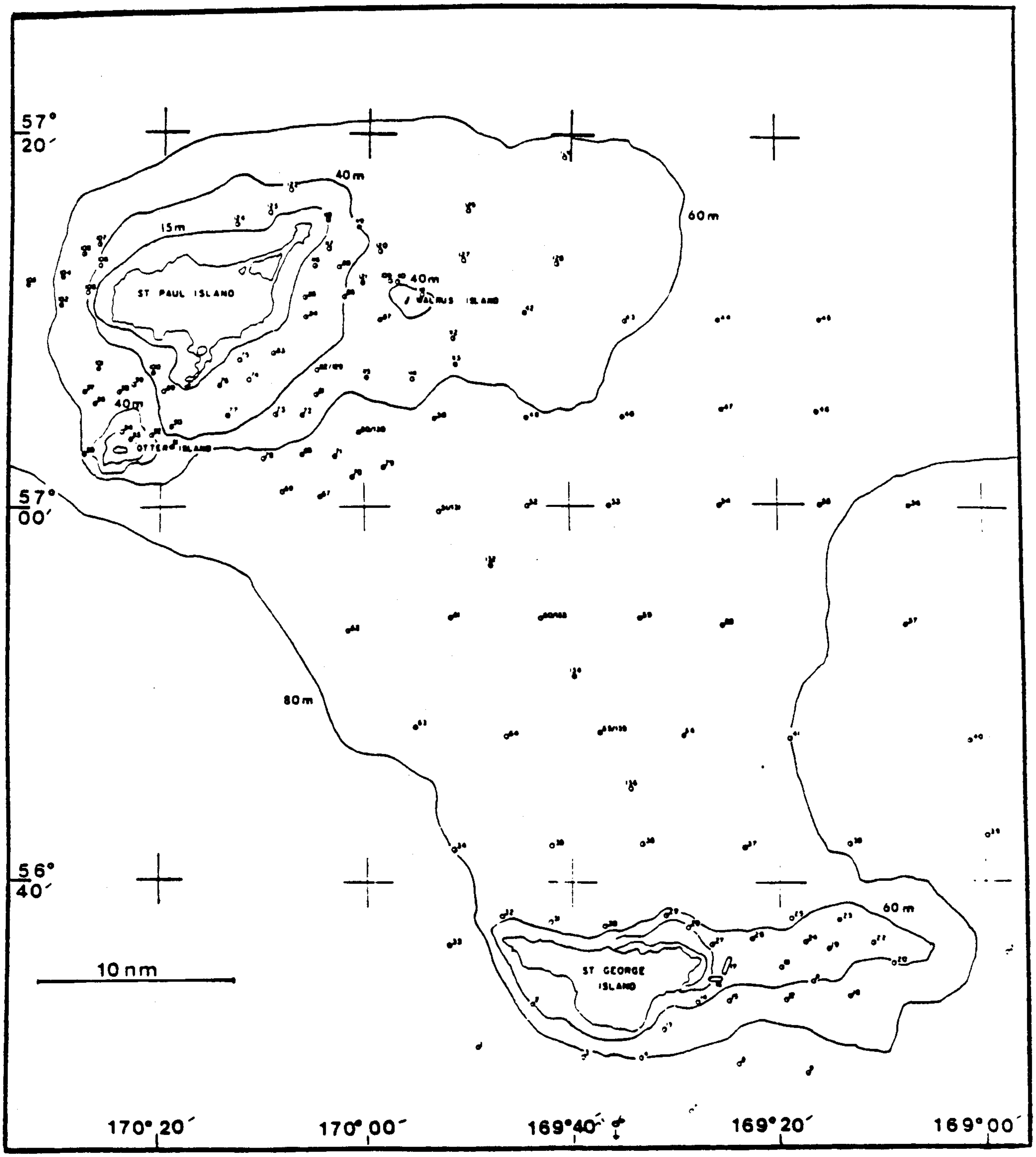


Figure 2.4 April 1984 station locations.

animals in a variety of reproductive states.

2.1.2 Side Scan Sonar

During the first cruise in May 1983, a Shipek and a Van Veen grab were used to take sediment samples for later analyses and to give information on substrate characteristics and to help in the choice of sampling gear. However, the disadvantages of such a limited probe along with increasing knowledge of the association between blue king crab (study target species) and certain substrate types made clear the need for a better assessment of bottom composition.

A SSS was included in the second cruise as standard survey gear. The purpose of this equipment was to identify and assess the extent of different habitats and, therefore, distribution patterns of characteristic communities. Other benefits derived from the SSS and resultant substrate maps were the more effective use of the sampling gear and improved estimates of total populations of crabs based on the area of propitious substrates. Basically, a SSS unit consists of 3 components: a transducer, customarily called the "fish", a line that serves as transmission and tow cable, and a dual channel recorder. The fish consists of a hydrodynamically shaped body containing two sets of transducers that scan the sea bottom on both sides.

The SSS used on the August 1983 cruise included a Klein Associates Inc. towfish model 422 S-0015 and a Hydroscan recorder model 521. With an output frequency of 500 kHz and a horizontal beam width of 0.2 degrees, this is considered a very high resolution unit. The transverse resolution (Rt) is defined as the minimum distance between two objects parallel to the line of travel that will be recorded as separate objects. It depends on the beam width and the distance scanned (D) according to the formula

Rt = sin * D where * is the beam width (0.2 degrees) and D is the distance scanned. For example, if the range is set at 75 m, the transverse resolution is:

$$Rt = (\sin 0.2)\ (75) = 0.26 \text{ m.}$$

The vertical resolution or range resolution (Rr) is defined as the minimum distance between two objects perpendicular to the line of travel that will be recorded on the paper as separate objects and depends on the range scale and the writing width of the recorder. Assuming a minimum paper spacing of 1 mm to plot two objects separately, the resolution will be 1/203 of the range scale since the writing width was 20.3 cm for each side. Again, with a setting of 75 m for the range scale, Rr = 75/203 = 0.37 m.

These resolution limits presented a problem in the interpretation of the sonographs. Although big objects like large cobble, boulders and rock shelves were clearly distinguishable, most of the time we had to rely on grab samples and substrate retained in the net to discern the sandy bottoms from gravel and shellhash. A Van Veen grab was used for this purpose which proved considerably more satisfactory than the Shipek grab used during the first cruise.

A one mile tow of the sonar fish would produce a sonograph as in Figures 2.5 to 2.7 onto which distance increments from the start of tow would have been recorded. The ship would then be directed back along the previous tow line to sample substrate at positions where different patterns had occurred. Based on replicate Van Veen and/or Shipek grabs at each SSS site (n=364) to groundtruth the sonograph we were able to recognize consistent patterns for several major substrate types and utilized this information to help direct the sampling effort by nets and dredges.

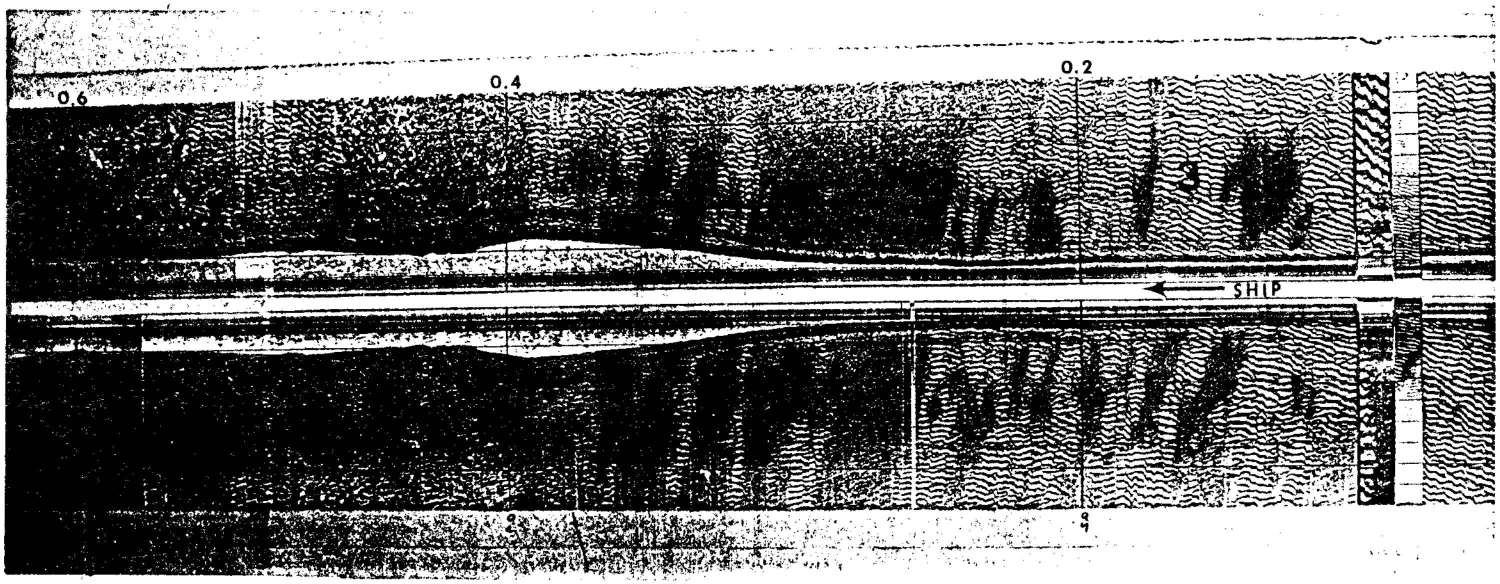


Figure 2.5 Side scan sonar trace showing several bottom features interpreted by ground-truthing with a Shipek grab and dredge. This station occurred 4 NM southwest of St. Paul in 58 m of water (Station 48, Fig. 2.3). The ship traveled down the mid course and the sonar fish scanned 75 m to port and starboard (each horizontal division = 15 m). The dip about NM 0.4 is due to a change in elevation of the sonar fish. (1) Low rock shelf, note slight increase in elevation relative to smooth sand but otherwise no conspicuous peaks are visible. (2) Fine, black sand. (3) Very coarse sand/small ("pea") gravel deposited in parallel ridges or waves. The distinct black lines are the face of ridges; white areas are shadows on the side away from the sonar fish. Based on geometric relationships, it is estimated that ridges are 1 to 1.5 m high and 2 to 3 m crest to crest.

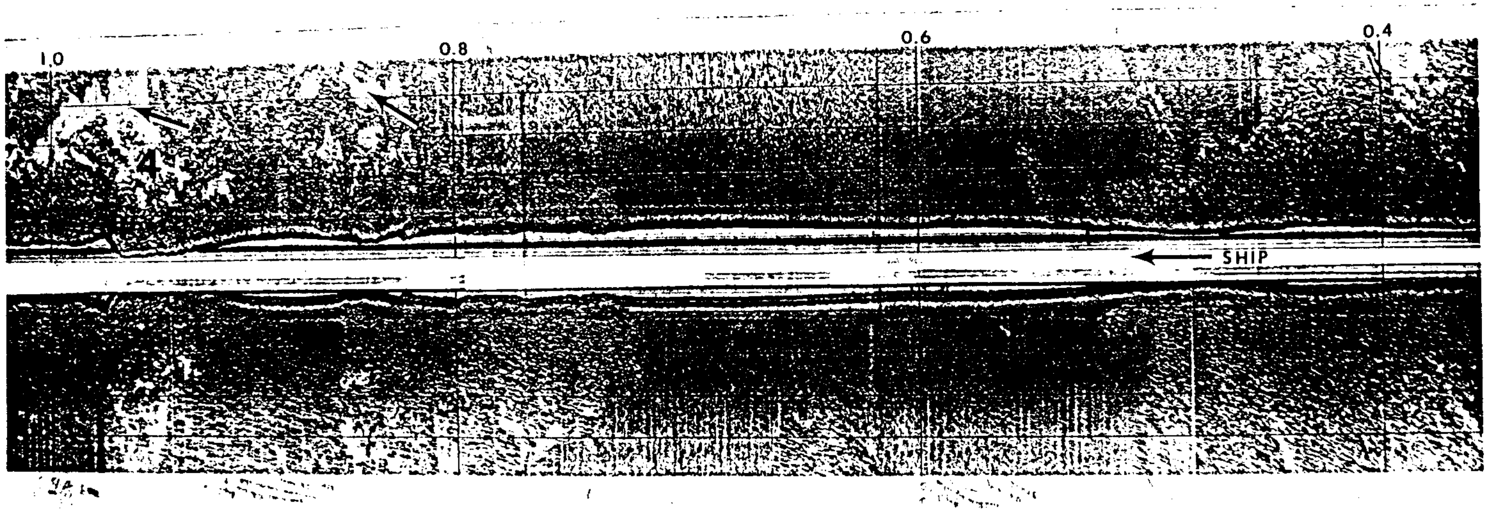


Figure 2.6 Side scan sonar trace over 1 NM about 5 NM southwest of St. Paul Island in 66 m of water (Station 43, Fig. 2.3). This example highlights the variability of substrates over short distances and resultant sampling problems. On the left, substrate No. 4 is large rock (note shadowing) with pockets of shellhash II (pulverized, no epiphytic growth; see Section 3.2.3) taken with the Shipek grab. This material covers about 300 m and is abruptly replaced by a smooth area (No. 2) of coarse sand and shellhash II that spans about 350 m (0.2 NM), followed on the right by a low rock shelf (No. 1) of relatively uniform height.

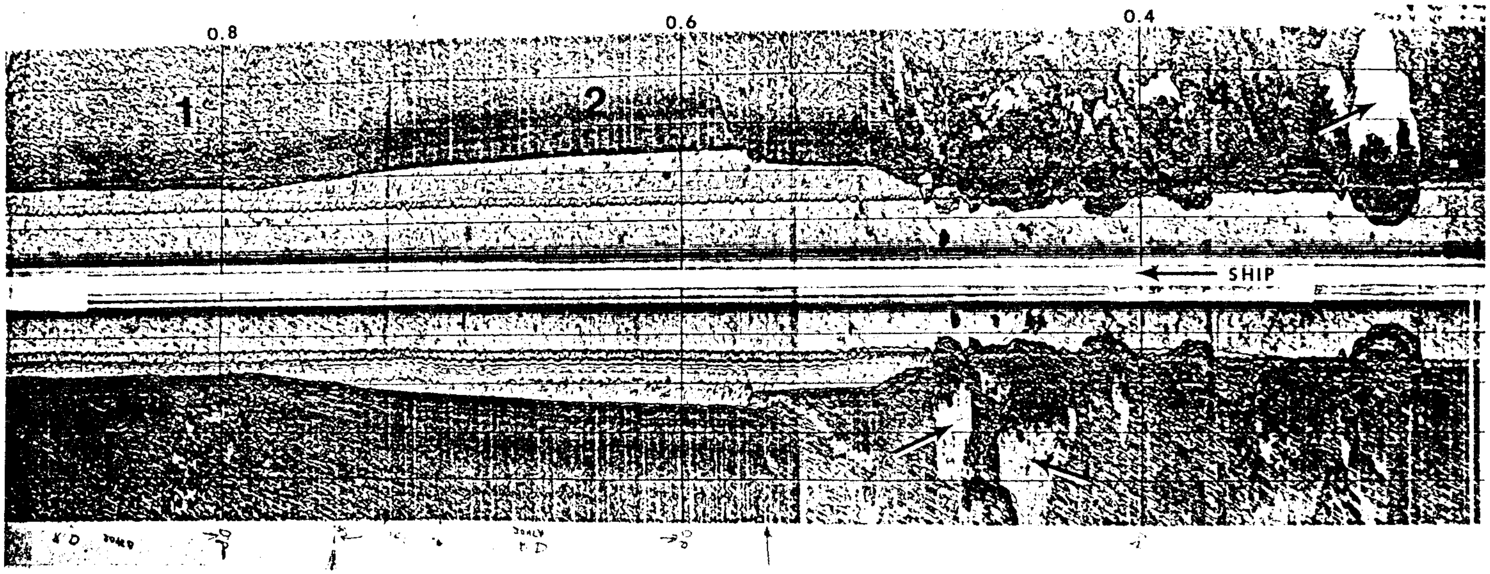


Figure 2.7 Side scan sonar trace over 1 NM about 6 NM southeast of St. Paul (near Otter Rock) at a depth of 62 m (Station 42, Fig. 2.3). Two types of rock formations are shown: (1) Low relief rock beds with associated pockets of shellhash I (intact or large pieces with epiphytic growth; see Section 3.2.3). (4) Prominent rock formations up to 12 m high. Note their height above the seafloor and conspicuous sonar shadows (arrows). (2) Fine to medium sand substrate. Such variation in bottom types over short distances underscores the patchy distribution of juvenile crab, and the benefit derived from use of side scan sonar in terms of deployment of appropriate gear on different substrates.

2.1.3 Particle Size Determination

Sediment samples were saved frozen for determination of particle size and total volatile solids. After thawing, samples were thoroughly mixed and 30 to 50 g were placed in 500 ml poly bottles. About 200 ml of water and 15 ml of dispersing agent were added and then shaken for 30 minutes. Samples were then washed through a 63 um sieve and the fraction retained in the sieve was transferred into an aluminum pan and dried at 90°C. Once the gravel-sand fraction was dry, the weight was recorded and the sample placed in a series of sieves of decreasing size (4.00, 2.00, 1.00, 0.50, 0.25, 0.125, 0.063 mm and a bottom pan) and placed in a "roto-shaker" for 20 minutes. The material retained on each sieve was weighed. The silt-clay fraction collected in the bottom pan was added to the poly bottles and placed into a 1000 ml graduated cylinder and the volume was brought to 1 liter with water. Twenty ml aliquots were taken at specific times after being thoroughly mixed with a plunger for 1 minute. The aliquots were placed in tared 50 ml beakers and dried at 90°C. The beakers were then weighed after reaching room temperature. A correction factor for the dispersing agent was calculated by placing 15 ml into a 1000 ml graduated cylinder. A 20 ml aliquot was taken at 10 cm and dried and weighed as the samples. This operation was repeated 3 times and an average correction factor was calculated.

Approximately 20 g of the sediment samples were placed in tared 50 ml beakers for volatile solids determination. The samples were dried at 90°C and the dry weight recorded. The beakers were then transferred to a muffle furnace and calcined at 650°C. Ash was weighed at room temperature and the total volatile solids calculated by difference.

2.2 Substrate Composition

2.2.1 Particle Size

From the May 1983 cruise, 80 stations (Fig. 2.8) were selected for sediment analysis and percent composition of several grain size categories (Appendix A.1). There was a noticeable correspondence between depth and grain size; the lower phi values (less than -3.0; lower phi = smaller grain size) were found deeper than 80 m and the larger phi values were at shallower depths, closer to the islands (Appendices A.1, A.2; Fig. 2.8).

Extremely high or low values of kurtosis imply that part of the sediment is sorted elsewhere and then is transported to the sample site. A new environment has less effective sorting energy and, thus, the two mixtures of sediment retain their individual characteristics. Most of the samples with an average phi value less than zero are positive-skewed, indicating the sediments are near their source and the grain size distribution is unimodal (Appendices A.1, A.2). Many of these samples were taken on the south side of St. Paul Island or in the basin between the two major islands (Appendix A.2; Fig. 2.1). The 10 samples with phi values larger than zero are all negative-skewed, and 8 of them have low kurtosis, indicating that additional material was transported from another location. The grain size distributions of these 8 sediment samples are strongly bimodal, clearly showing the presence of the two different materials.

Due to the heterogeneity of the substrates around the islands, the sediment analyses of the grab samples did not always reflect the nature of the bottom types: in certain areas samples were taken from relatively small sand patches within vast rock shelves. For a better qualified assessment of the bottom composition, it was necessary to consider other information sources, like the side scan sonar records, as well as the inspection of the substrate taken in the fishing gear.

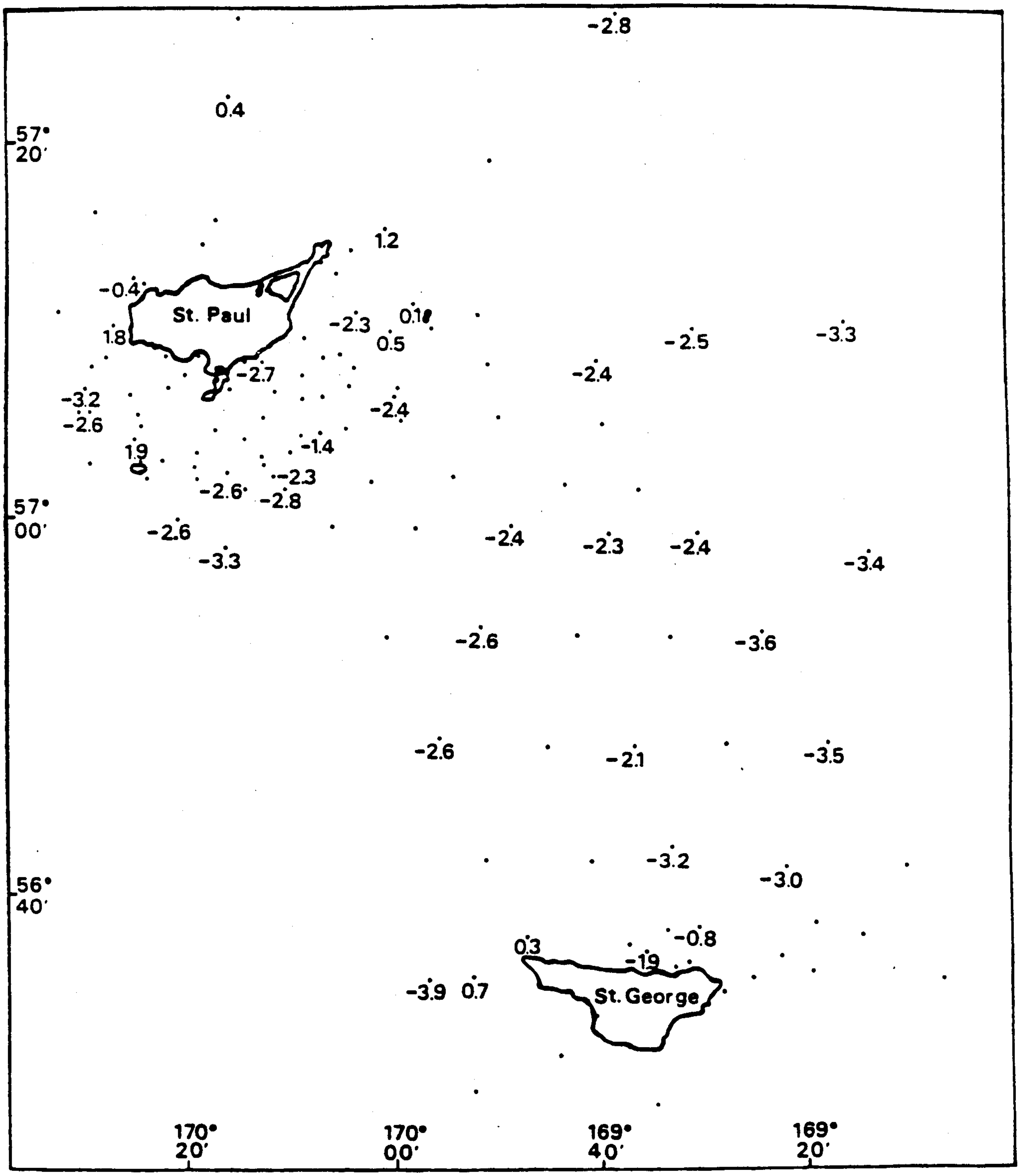


Figure 2.8 Mean phi values and location of the May 1983 stations chosen for sediment analysis.

2.2.2 Composite Side Scan

The side scan sonar proved to be a very valuable tool in the evaluation of bottom composition despite its limitations of resolution. The results of individual grid surveys (Fig. 2.2) according to five major sediment categories (rock, sand, mud, gravel, cobble) are shown in Appendices A.3 and A.4 for St. Paul and St. George Islands. The large basin between the two main islands showed little heterogenity in the side scan records and it was verified to be uniform sandy bottom by the grab samples. Nearshore, however, various bottom types were found, sometimes alternating between major categories (e.g., rock, gravel, sand) over distances of only a few hundred meters (Figs. 2.5 to 2.7). For example, in Figure 2.5 on the right of the sonar graph, a distinct area of coarse sand/small pea gravel formed in parallel ridges or waves is replaced over a distance of a couple of hundred meters by fine black sand followed next, after another hundred meters or so, by low rock shelf. A more extreme example is seen in Figure 2.6 in which, from right to left, a low rock shelf of relatively uniform height is abruptly replaced by a smooth area of coarse sand and shellhash (see Section 2.3) followed on the left by areas of very large and high rock outcroppings. Along the course of a single nautical mile, side scan traces in certain regions showed a relatively even mixture of several major substrate types that were considered "transition regions" and are depicted in Appendix A.3. Information from all sonographs taken around each island within the grid system shown in Figure 2.3 was summarized and major materials were extrapolated to construct a mosaic map of major substrate types (Figs. 2.9 and 2.10). In reference to Figure 2.1, most of the area surveyed around and between St. Paul and St. George Islands was relatively homogeneous sand. Very nearshore around each of

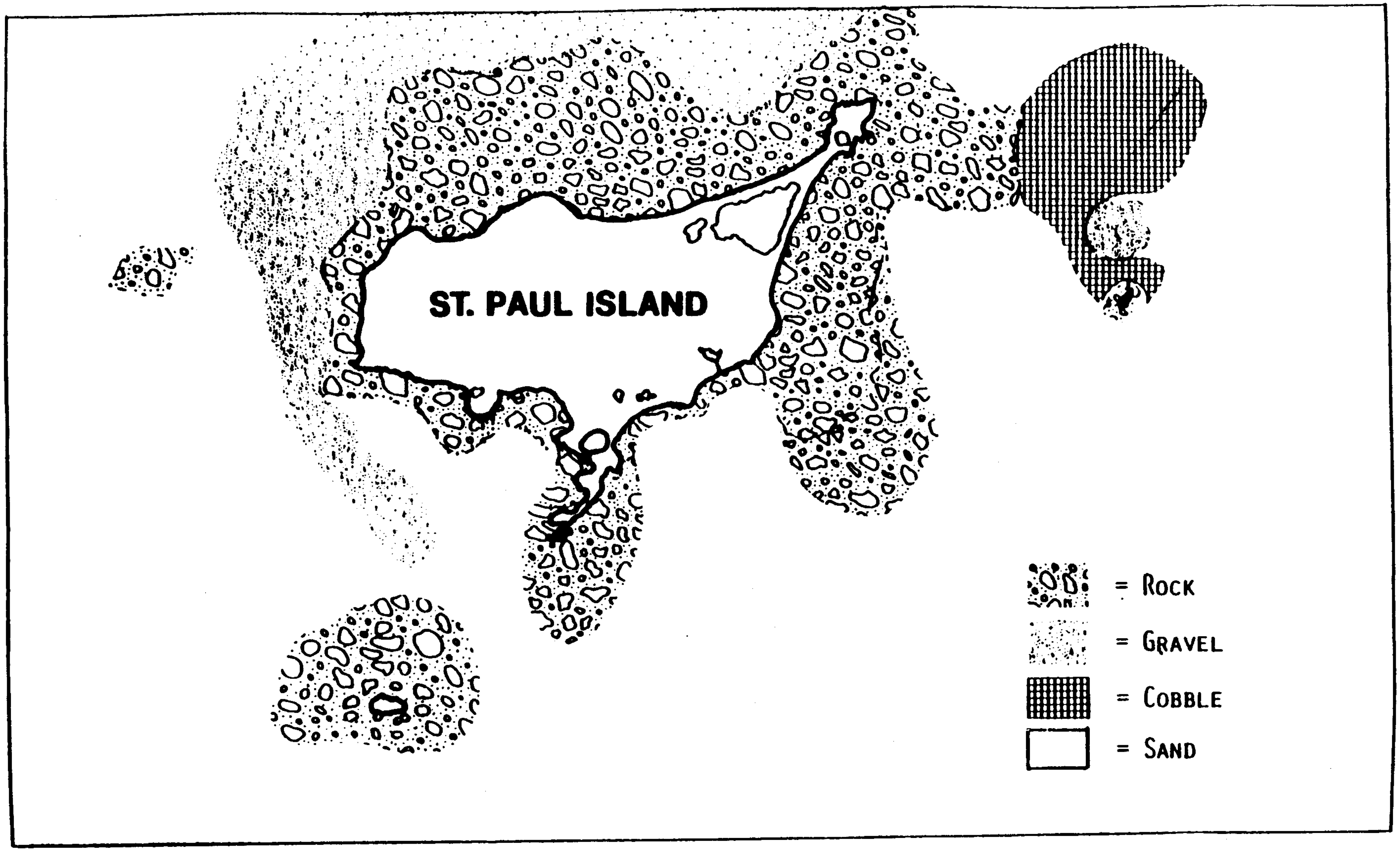


Figure 2.9 Summary map of substrate types around St. Paul Island compiled from side scan sonar, Shipek grabs, and rock dredge data.

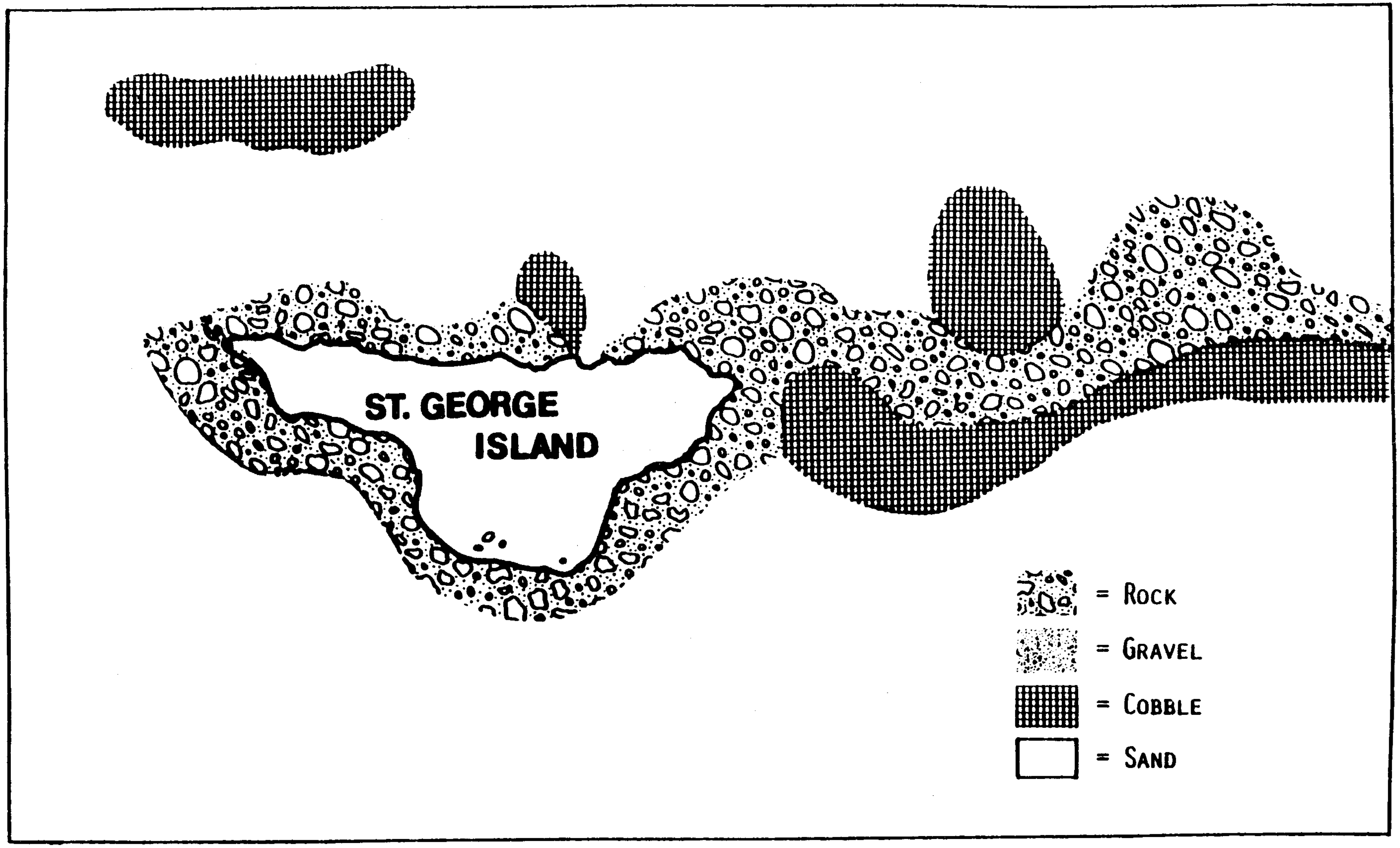


Figure 2.10 Summary map of substrate types around St. George Island compiled from side scan sonar, Shipek grabs, and rock dredge data.

these islands, and also around Walrus Island and Otter Island near St. Paul, areas of rock, gravel and cobble occurred. These maps that provided a sense of substrate composition and location were important aids in subsequent analyses of community composition (Section 3.0) and as the basis to characterize critical habitat for juvenile king crab. Collection, identification and enumeration of other species of animals captured during this survey (other than the target species, blue king and Korean hair crab) as originally intended in the context of the contract was to be a relatively small part of the project. Only limited information was to be gathered as a qualitative basis from which to draw generalized impressions about species assembleges that include blue king crab. However, the addition of side scan sonar, an ability to better direct survey effort, as well as use of two principal pieces of trawl gear (beam trawl and rock dredge; to be described later in this section), enabled us to sample a wide variety of substrates that seem to include several general assemblages ("communities") of animals. Because of the nature of gear used, however, there were limitations to the location and categories of animals captured. For instance, no infaunal species were caught with regularity (or reliability) by either of the gear and large demersal fish were probably not caught with any accuracy. Thus, "community" in a broad ecological sense as defined by Krebs (1972) to include groups of populations of plants and animals in a given place is not strictly correct. Rather, the community sampled in this survey was one composed largely of epibenthic, non-sessile invertebrates (both juveniles and adults) as well as a number of species of smaller demersal fish. The value gained in viewing the data on a multitude of fish and invertebrates caught is to provide some structure by which to characterize the habitat of blue king crab, both to contrast the extreme differences in habitat preferred by juvenile and adult stages as well as to understand the limitations of habitat available for survival and, in turn, a possible reason for the limited range of the species in the southeastern Bering Sea.

2.3 Shellhash: Types and Distribution

One of the most important habitats and substrates in the early life history of blue king crab is shellhash (shell debris) which occurs to any extent only around St. Paul Island and east of St. George. Shellhash was categorized in two ways.

Shellhash I (SH I) consisted of relatively intact shells or large pieces, often found with live molluscs of the same species indicating close proximity to the areas of origin (Fig. 2.11). The biological composition was some large gastropods (*Neptunea*), but mostly large bivalves like *Serripes* spp. and *Spisula* spp. This type of shellhash was often covered with a profusion of animal growth such as "feathery" bryozoans, barnacles, anemones, ascidians, etc. Other invertebrates also seek refuge in this habitat, such as hermit crabs and juvenile blue king and Korean hair crabs. Most SH I was found east of St. George Island and more patchily distributed around St. Paul Island (Figs. 2.12 and 2.13). Such shell debris occurred over rock shelves, cobble and sand, and divers reported a "pocket" distribution on low-relief rock beds.

A second type of shellhash (SH II) consisted of pulverized, well-washed small pieces of shell (Fig. 2.14). This type of shellhash was found north and southeast of St. Paul Island over smaller areas than SH I, at depths less than 50 m. The origin of this material is from the same species described for SH I, but appears to have been entrained in high energy regions and subjected to wave action and other processes of pulverization. The small size of this material and lack of attached

Figure 2.11 Shellhash type I, consisting of large, intact shells with epibenthic growth, associated with high density of juvenile blue king crab.

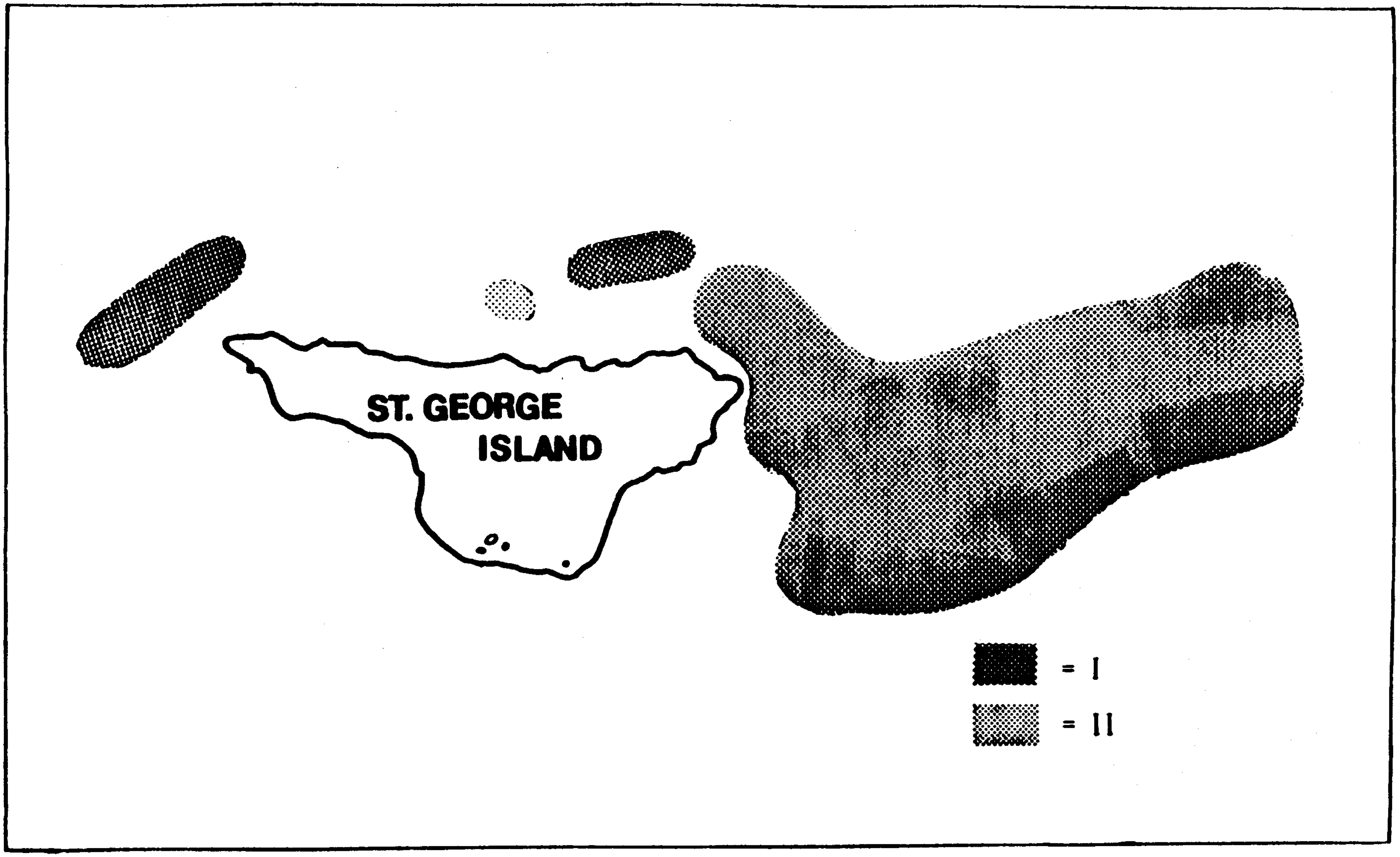


Figure 2.12 Extent of shellhash deposits around St. George Island. Shellhash type I is, for the most part, intact and covered with animal and plant growth. Type II is pulverized shellhash, very small pieces, with no epiphytic covering; typifies areas of low invertebrate numbers and biomass.

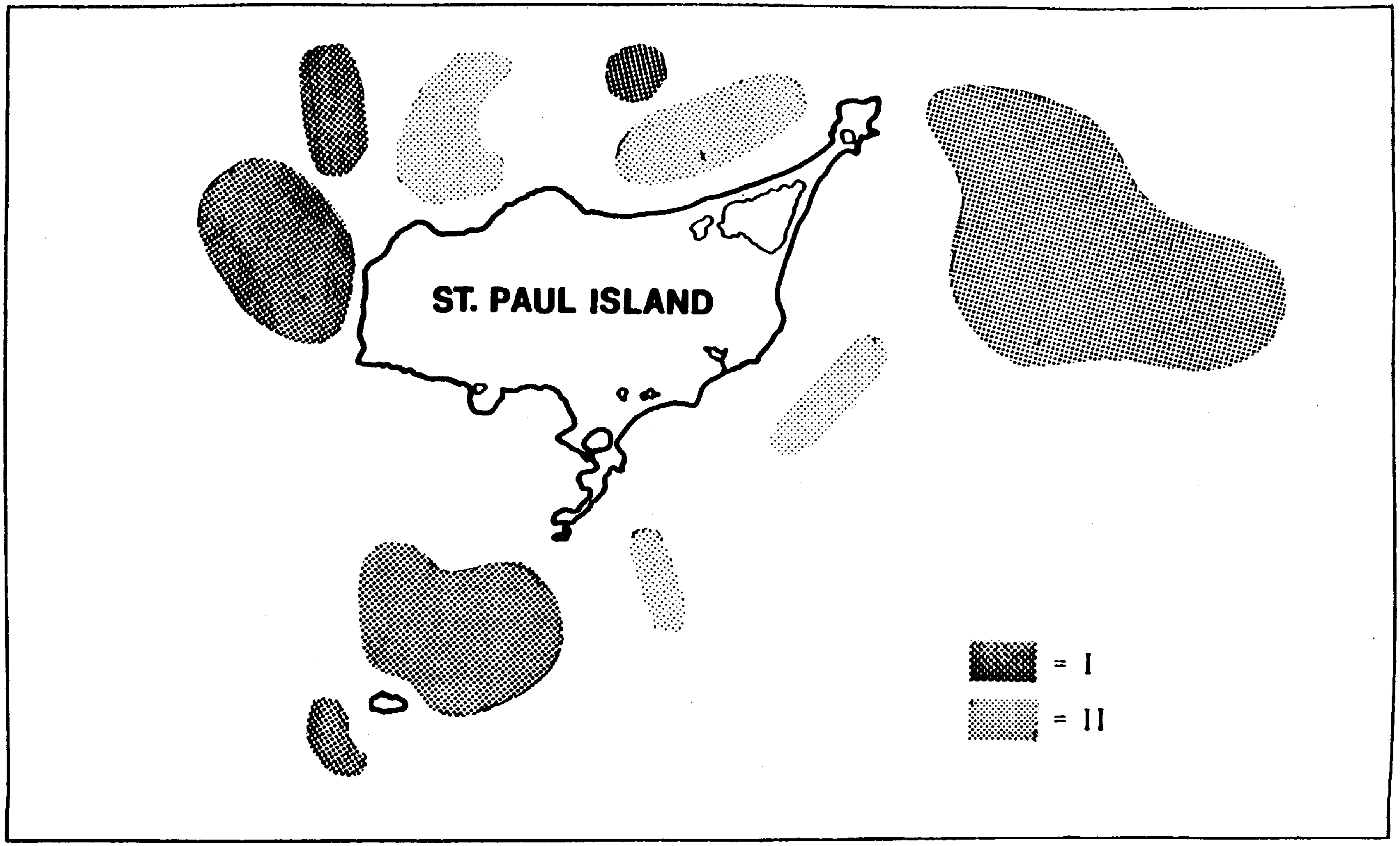


Figure 2.13 Extent of shellhash deposits around St. Paul Island. Shellhash type I is, for the most part, intact and covered with animal and plant growth. Type II is pulverized shellhash, very small pieces, with no epiphytic covering; typifies areas of low invertebrate numbers and biomass.

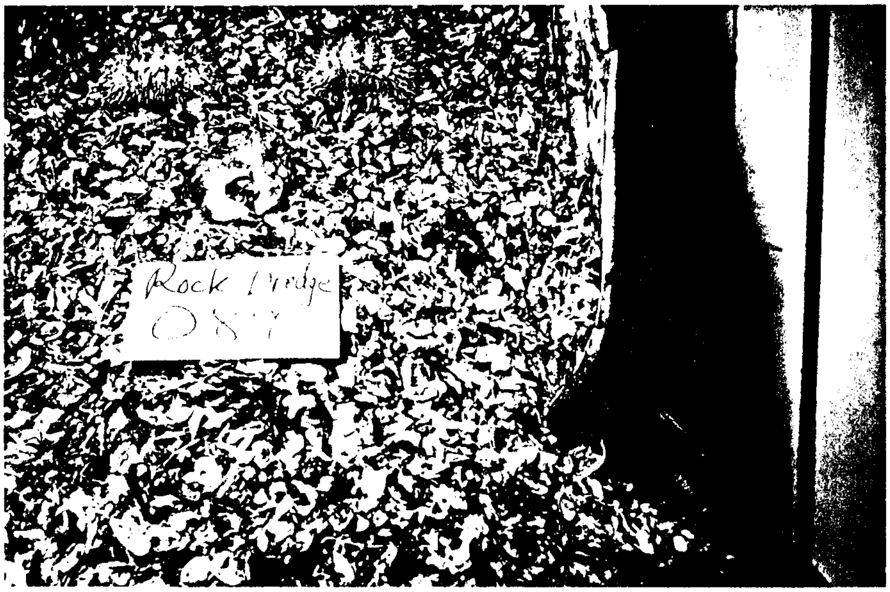


Figure 2.14 Shellhash type II, consisting of pulverized, well-washed shell material, associated with low numbers and biomass of blue king crab.

organisms appears to make it a poor habitat since animal density and diversity were low (Section 3.0).

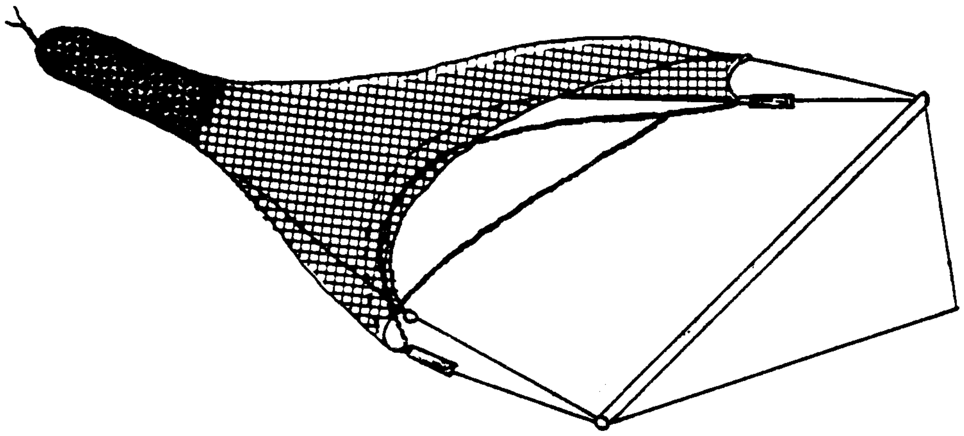
The above descriptions of SH I and SH II are the extreme cases, whereas a wide range of intact to broken shell with various amounts of attached epiphytic growth was taken. For this reason only a single shellhash (SH I) was considered when grouping stations for sediment classification. Those few stations where pulverized, well-washed, golden-colored shellhash (SH II; Fig. 2.14) was taken were classified as to the underlying substrate (usually rock).

3. COMMUNITY ANALYSIS AND STRUCTURE

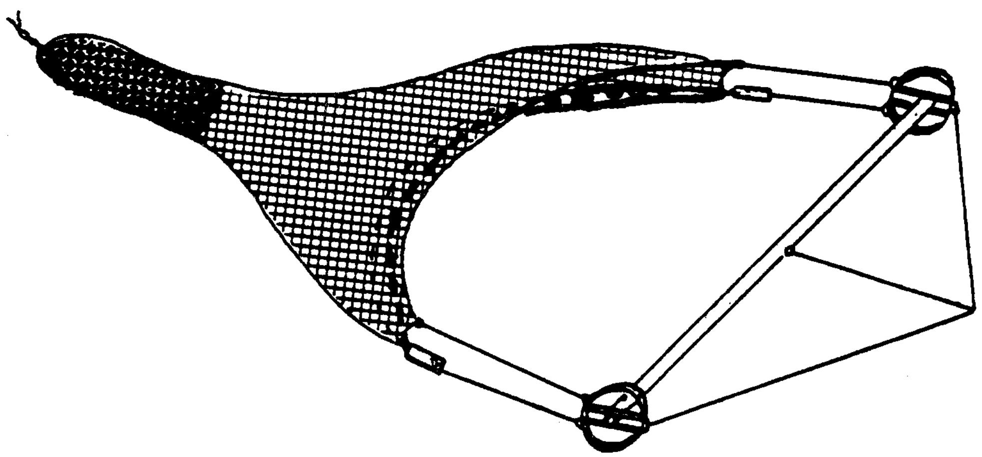
3.1 Epibenthic Sampling

Epibenthic sampling was performed with a 3 m wide beam trawl and a 90 cm wide biological rock dredge. Both pieces of gear had to be modified and reinforced for use on rough substrates around the Pribilof Islands (Figs. 3.1 and 3.2). Divers determined the effective fishing width of the beam trawl to be 2.3 m. Both the rock dredge bag and the cod end of the beam trawl were made of 6 mm knotless mesh. The choice of gear used at each station was based on available information regarding the composition of substrate. During the May 1983 cruise this knowledge was limited to general descriptions from nautical charts and modest verifications with a Shipek grab. When at least two consecutive attempts of collecting a sediment sample failed to gather any material, the substrate was assumed to be "hard" (rock shelf, boulders, etc.) and then the rock dredge was used.

The process of selecting gear improved substantially during the second cruise because of the use of the SSS. Analyses of the sonar traces allowed a quick decision on the gear and the location for the trawl. The beam trawl was primarily used to capture adult and older juvenile crab on relatively smooth bottoms of mud, sand, shellhash and gravel; the rock dredge was used most often to target on small juveniles within substrates such as cobble, shelf rock and shellhash. At some stations the variability of the substrate was such that both gear were used on different substrates within the single nautical mile of the SSS trace. Beam trawl tows usually lasted 10 minutes covering a distance of about 0.4 NM (0-8 km). Rock dredge tows were usually 5 minutes over a distance of 0.2 NM (0.4 km).

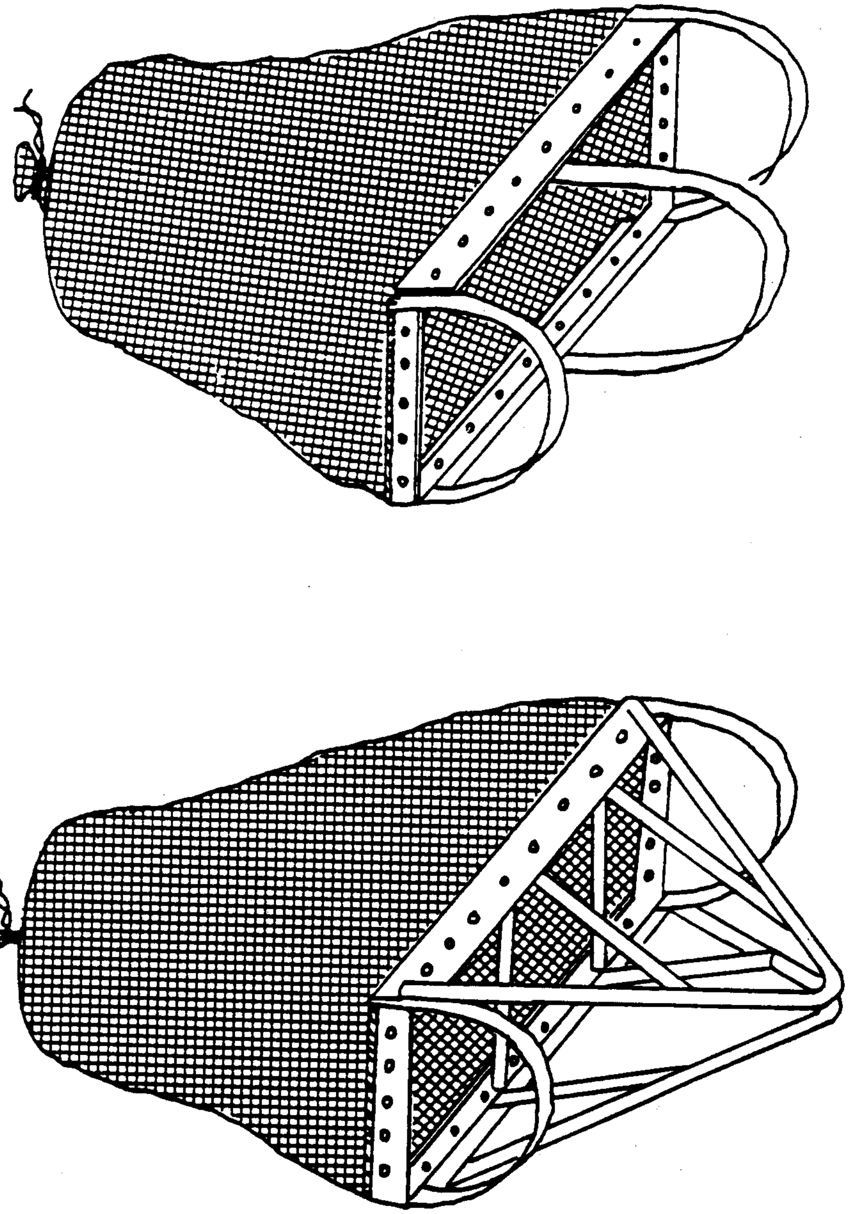


A



B

Figure 3.1 The original beam trawl (A) had an aluminum beam with double bridle and lightweight tickler chain. The modified beam trawl (B) employed a reinforced steel beam with steel runners, heavier (5/16") tickler chain, and a triple bridle.



A

B

Figure 3.2 The frame of the original biological rock dredge (A) proved too weak for Bering Sea work. It was reinforced as shown (B). The center bars also prevented large rocks from jamming the mouth of the dredge. Originally, heavy nylon chaffing gear was used, but conveyor belt material used subsequently proved the best chaffing gear (not shown).

3.1.1 Sample Processing

Small samples, generally less than 50 kg, were completely sorted but large catches were subsampled by volume and weight after carefully mixing the sample, and extrapolation factors were calculated. All species groups were identified to the lowest possible taxon, most often to genus and species. For various reasons, however, some species groups were only sorted to genus or family (e.g., Mytilidae). Once sorted, individuals were counted and total wet weights taken with a triple beam balance or with a larger fisheries balance if the species was too large or abundant.

Through cooperation with the NMFS, arrangements were made to reformat NODC files for the benthic data to the NMFS data system. Data were entered on the NMFS Burroughs computer, checked for consistency between file types, and analyzed using the wide array of programs available for calculating animal densities and abundance by size, area, or substrate, population estimation and size composition, and community structure via cluster analysis. A great deal of time was saved and much greater flexibility and accuracy was achieved by use of the vast wealth of computer programs on the NMFS system. These data will be entered on the NMFS database where it will be available for future use. Information was recorded on proper data forms, according to NMFS protocol (Mintel and Smith 1981). Species were assigned the proper 5 digit code from the Species Code Dictionary (from NMFS data-base system) and weights and numbers recorded.

3.1.2 SCUBA and Crab Pots

SCUBA divers and crab pots were used in shallow rocky nearshore areas which could not be sampled from the ship (R/V Miller Freeman). The ship's 7.6 m MonArk launch was used for these operations. Diving operations took place in May and August 1983, and commercial Dungeness crab pots covered with fine mesh to retain juvenile crabs were used in May only. Divers descended the MonArk's anchor line and swam either a striaght line transect or covered a circular area around the anchor. Color slides were taken of all transect sites with an underwater camera. Crab pots proved ineffective in capturing small juveniles due to their reclusive habits and were not used on the second and third cruises. During 10 dives of two or three divers each, only one juvenile crab of each target species was found. The crab pots worked well for fish and echinoderms, but only one adult male Korean hair crab was caught by this method. These procedures were time consuming and unproductive and thus, discontinued. The diving demonstrated, however, that few juvenile and probably no adult crab reside in the predominately rocky nearshore areas in depths less than 20 m.

3.2 Cluster Analyses

Data forms were coded according to NMFS standard formats and entered on a Burroughs B 7000 computer. Two main file types were used: a "haul" file, which contained information about the stations such as date, position, depth, bottom type, distance towed, gear used, etc., and a "catch" file with a species code, total number and weight for each species found at a particular station.

3.2.1 Approach

Biological associations and distribution patterns were studied through cluster analysis techniques. Four programs from the NMFS program library were used for this purpose: "Cluster/Start", "Cluster", "Cluster/Draw" and "Cluster/Map". The program "Cluster/Start" prepares the data matrix to be used on program "Cluster", based on the haul file, the catch file and a list of species to be included in the analyses. The data matrix consists of catch-per-unit-of-effort (CPUE) values for the species considered at each sample station. The CPUE file will accept a variety of units and that used in these analyses was numbers per hectare (no/ha, based on area swept by the sampling gear; i.e., density) because it was considered a more reliable measure than weights (which were not always taken), or numbers per unit time of trawl, and avoided underestimating the importance of small organisms within the community.

The program "Cluster" performs the analysis itself by calculating the similarity (or dissimilarity) values and combining the entities according to these values. The program is very flexible and allows the user to execute several transformations and standardizations of the data matrix along with a wide option of similarity coefficients and clustering strategy combinations. It also allows a choice between "normal" or "inverse" classifications, that is, clustering by stations or by species.

The last two programs, "Cluster/Draw" and "Cluster/Map" give graphic representations of the clusters produced in the form of dendrograms and geographic maps showing the location of the different station clusters.

A wide variety of fish and invertebrates were collected during the cruises that totalled more than 200 different taxonomic groups, most of which were identified to species. Considering the number of stations sampled each cruise (up to 147), the size of such a data matrix causes two difficulties: 1) the computer's capacity to handle such volumes of data and, 2) the possibility that station-species associations could be masked by "indifferent" species. The term "indifferent" refers to species occurring randomly and independently from each other over a certain area, with no apparent preference or limitation within that area (Williams and Stephenson 1973).

This extensive species list was reduced to its dominant elements to facilitate the analyses by removing species far too rare to have a decisive role in the classification. In this way, all species or taxonomic groups present at less than 3.5% of the stations during each cruise were disregarded. Also, some groups that had not been identified consistently during the cruises were excluded from the analyses. "Hermit crabs", for example, were excluded from the May and August cruises although they were among the 10 most abundant groups both in no/ha and g/ha because they had never been identified to a level lower than family (Paguridae) during these cruises. Finally some species were grouped into higher taxonomic categories like genera to assure a coherent classification. From these processes, the species used in the analyses were reduced to a maximum of 62 (Table 3.1).

Data for the analyses were not transformed in any way because such processes are often used to reduce the effect of very abundant catches at some stations, but for the purpose of this study it was felt that outstanding catches may have important ecological implications such as propitious habitats.

3.2.2 Dissimilarity Values

The Bray-Curtis dissimilarity measure was chosen because of its wide use in marine ecology (Field 1969; Day et al. 1971; Carter 1978; Chance and Deutsch 1980; Walters and McPhail 1982; Davis et al. 1983) and because it is more sensitive to occasional large values (Clifford and Stephenson 1975, p. 58). If n is the number of attributes (species) and X1j and X2j are the values of the jth attribute (CPUE=density of the jth species) for any pair of entities (stations 1 and 2) the Bray-Curtis coefficient is:

Table 3.1 List of fish and invertebrates used in the cluster analysis.

Class Ascidacea

- Boltenia sp.
- Colonial tunicates
- Solitary tunicates

Class Anthozoa

- Sea anemones

Class Stelleroidea

- Asterias amurensis
- Evasterias troschelli
- Gorgonocephalus caryi
- Henricia sp.
- Leptasterias polaris
- Lethasterias nanimensis
- Ophiopholis aculeata (2)
- Pteraster tesselatus

Class Echinoidea

- Echinarachnius parma
- Strongylocentrotus droebachiensis

Class Holothuroidea

- Cucumaria sp.

Class Gastropoda

- Buccinum sp. (2)
- Fusitriton oregonensis
- Natica spp. (1)
- Neptunea spp.
- Nudibranchs

Class Bivalvia

- Chlamys sp.
- Clinocardium spp. (1)
- Hiatella arctica (2)
- Mytilidae (*)
- Pododesmus macrochisma
- Serripes sp. (2)

Class Cirripedia

- Balanus sp.

Class Malacostraca

Order Decapoda

- Argis spp.
- Crangon dalli (1)
- Crangon spp. (2)
- Hippolytidae (2)
- Pandalus spp.
- Spirontocaris spp.
- Cancer oregonensis
- Chionoecetes spp.
- Dermaturus mandtii
- Elassochirus cavimanus (2)
- Elassochirus gilli (2)
- Elassochirus tenuimanus (2)
- Erimacrus isenbeckii
- Hapalogaster grebnitzkii
- Hyas coarctatus
- Hyas lyratus
- Labidochirus splendescens (2)
- Oregonia gracilis
- Pagurus capillatus (2)
- Pagurus confragosus (2)
- Pagurus dalli (2)
- Pagurus ochotensis (s)
- Paralithodes camtschatica
- Paralithodes platypus

Class Osteichthyes

Order Pleuronectiformes

- Atheresthes stomias
- Hippoglossoides elassodon
- Hippoglossus stenolepis
- Lepidopsetta bilineata
- Limanda aspera

Order Scorpaeniformes

- Agonus acipenserinus
- Agonids (1)
- Aspidophoroides bartoni
- Gymnocanthus galeatus (2)
- Gymnocanthus spp.
- Gemilepidotus jordani
- Hypsagonus quadricornis (2)
- Liparis spp.
- Myoxocephalus groenlandicus (2)
- Psycrolutes paradoxus (2)
- Sarritor frenatus (1)
- Sarritor leptorinchus (2)
- Triglops spp.

Order Gadiformes

- Theragra chalcogramma (1)

Order Perciformes

- Ammodytes hexapterus
- Bathymaster signatus (1)
- Bathymasteridae
- Stichaeidae

Order Ophidiiformes

- Zoarcidae (1)

(1) May and August 1983 only.
(2) April 1984 only.
(*) More than 90% of the mussels caught were Modiolus modiolus.

$$\frac{\sum X1j - X2j}{\sum X1j + X2j}$$

The clustering strategy used was the "flexible sorting" first proposed by Lance and Williams (1967) and later used successfully on marine benthic data (Stephenson et al. 1970, 1972, 1974; Stephenson and Williams 1971; Williams and Stephenson 1973; Holt and Strawn 1983). Like all other strategies, it starts by fusing the pair of entities i, j with the smallest dissimilarity (more similar, according to the coefficients calculated) to form a group of entities k. Then a new entity h (or a group of entities already fused together) will be added that minimize the distance

$$Dhk = Dhi + Dhj + Dij$$

where D's are the distances between the groups, h, i, j and k; $Ai = Aj$ and $Ai + Aj + B = 1$ and B is the "cluster intensity coefficient" (Williams 1971).

Several authors have used a value of -0.25 for a cluster intensity coefficient and it appears to have become a standard setting for preliminary investigation of classificatory problems. During the preparatory phase of this analysis, values of -0.3, -0.5 and -0.6 were also tried and -0.5 was finally adopted since this value produced more consistent and better structured dendrograms. With this coefficient the clustering strategy acted as a moderately spaced dilating strategy: i.e., the chance that an individual entity will act as the nucleus of a new group rather than join a pre-existing one is slightly increased.

After each run of the program, the resulting dendrogram was studied for composition of the clusters at different dissimilarity levels and for consistency of their groupings. With station groups defined, the species composition and abundance at the stations that constituted each major cluster were studied.

Data from each cruise were treated separately to disconnect from the seasonal variation or year-to-year differences in species abundance and composition. Data from the August 1983 cruise were further divided according to gear type (beam trawl = BT; rock dredge = RD) since a large number of stations were sampled with both gear during that cruise. Although some differences were observed in the fishing performance of both gear (particularly for the most mobile species like fishes), the main reason for this separation was that they were used over different substrates, even at the same stations (1 NM SSS survey), and therefore could not be considered as comparative or repetitive hauls. This was not considered necessary for the May and April cruises since there was almost no overlapping use of the two gear at the same station as was commonly done in August.

An analysis of variance (ANOVA) of the abundance as mean no/ha and g/ha at the stations in each cluster was performed for each species to establish some measure of significance in the differences occurring at each cluster. When the ANOVA indicated a significant difference (at the 1% level) between clusters, pairwise t-tests were performed to determine at which cluster group a given species was more abundant. Data for these ANOVA and t-tests were log-transformed (log (n+1) or log (W+1)) to "normalize" the data and meet one of the basic assumptions of the t-test, that the data for each group is obtained from a normal population (Zar 1974).

3.3 Physical Environment: Temperature

Sediment composition and general substrate categories were discussed in Section 2.2, and these are important components of community analyses and definition of critical habitat for crab in later sections. The only other physical measurement of some importance taken on the cruises was bottom and surface temperature. CTD casts were taken at most stations and the salinity around the Pribilof Islands was 32 $^{o}/oo$. There was little difference between surface and bottom salinities which were not different between the three sampling periods.

Bottom water temperatures were colder at St. Paul than at St. George Island in spring of both 1983 and 1984 (Figs. 3.3 and 3.4). 1984 was substantially colder and bottom water temperatures were typically 2 to 3°C lower than at the same time in 1983. The distinct difference in temperature between the two islands can be seen in Figure 3.4 when in late April of 1984 temperatures were almost 2°C around St. George Island, but almost -1°C nearshore of St. Paul. Surface temperatures in the spring of both years were virtually identical to those on the bottom, indicating an isothermal water column (Fig. 3.5, Appendix B.1). In May 1983, when larvae of both target species of crab were abundant in the water column, surface temperatures ranged between 2-4°C (Fig. 3.5). In April of 1984, however, surface temperatures ranged from approximately 2°C at St. George to -0.5°C near St. Paul and sea ice was present on the north side of St. Paul (Appendix B.1). By August 1983 bottom water temperatures nearshore of St. Paul Island had increased to almost 8°C (Appendix B.2), but were only about 5.5°C near St. George Island. Surface water in August 1983 was nearly uniform throughout the survey between the two islands at about 8.5°C (Appendix B.3).

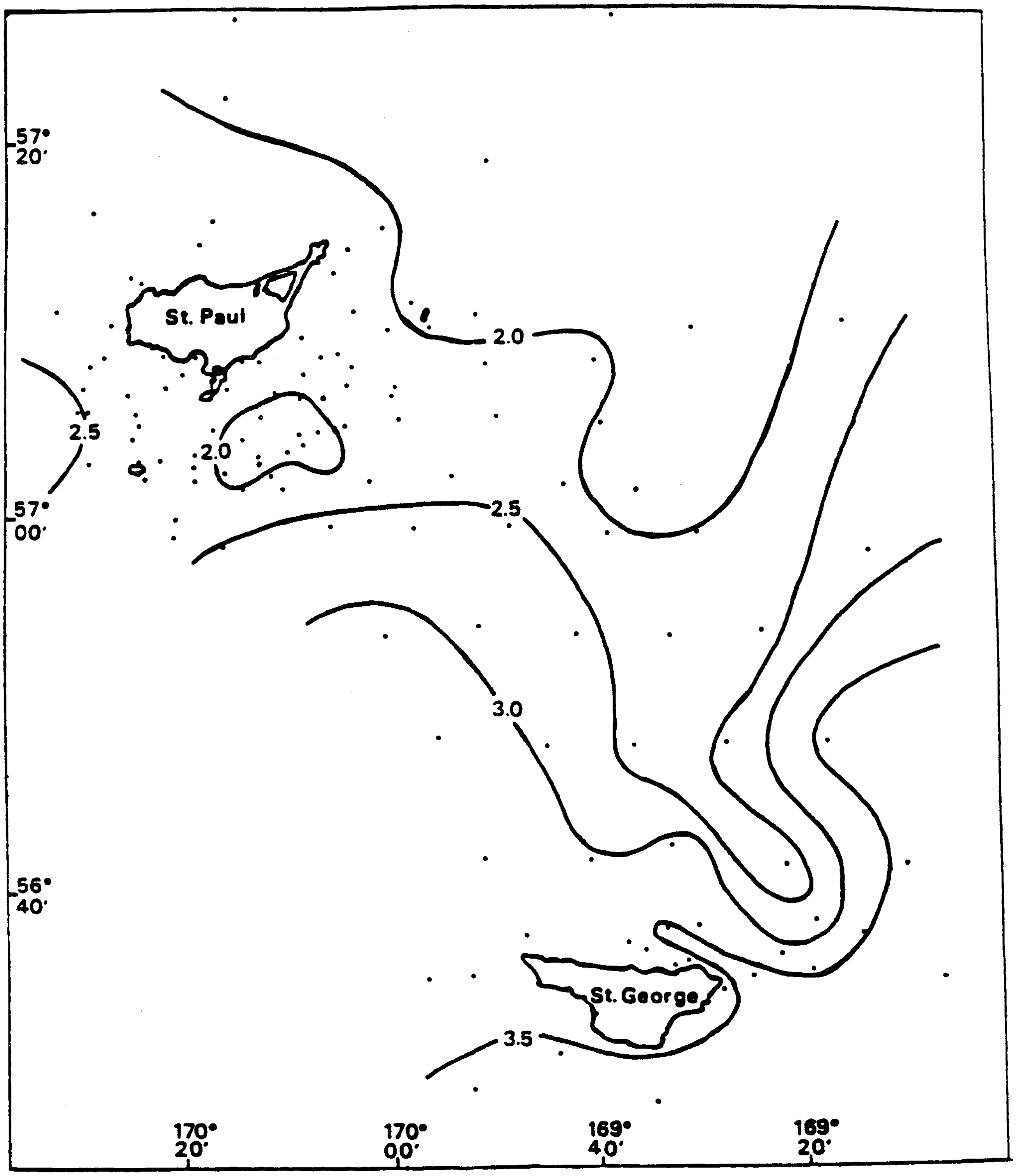


Figure 3.3 Bottom temperatures (°C), May 1983.

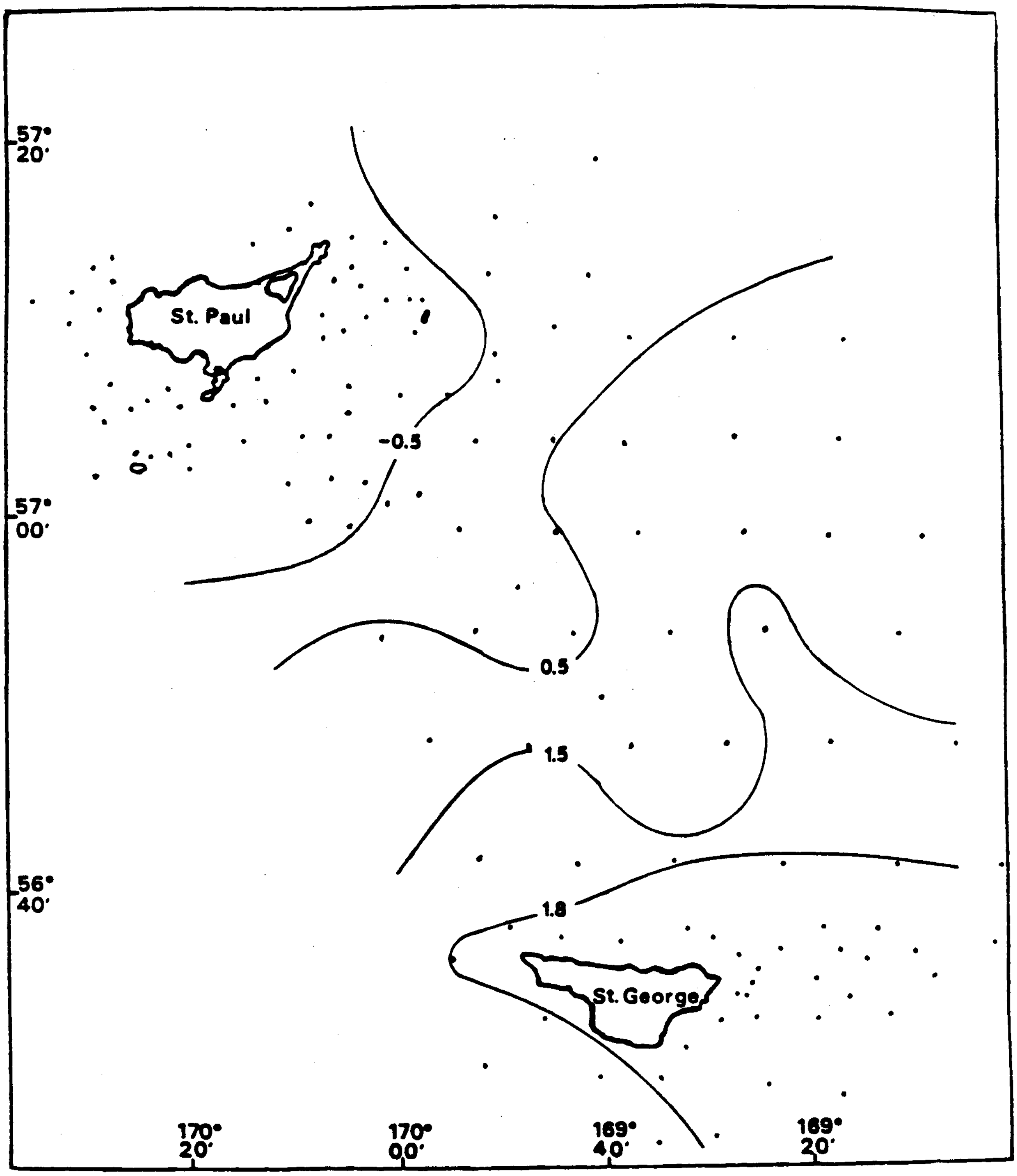


Figure 3.4 Bottom temperatures (°C), April 1984.

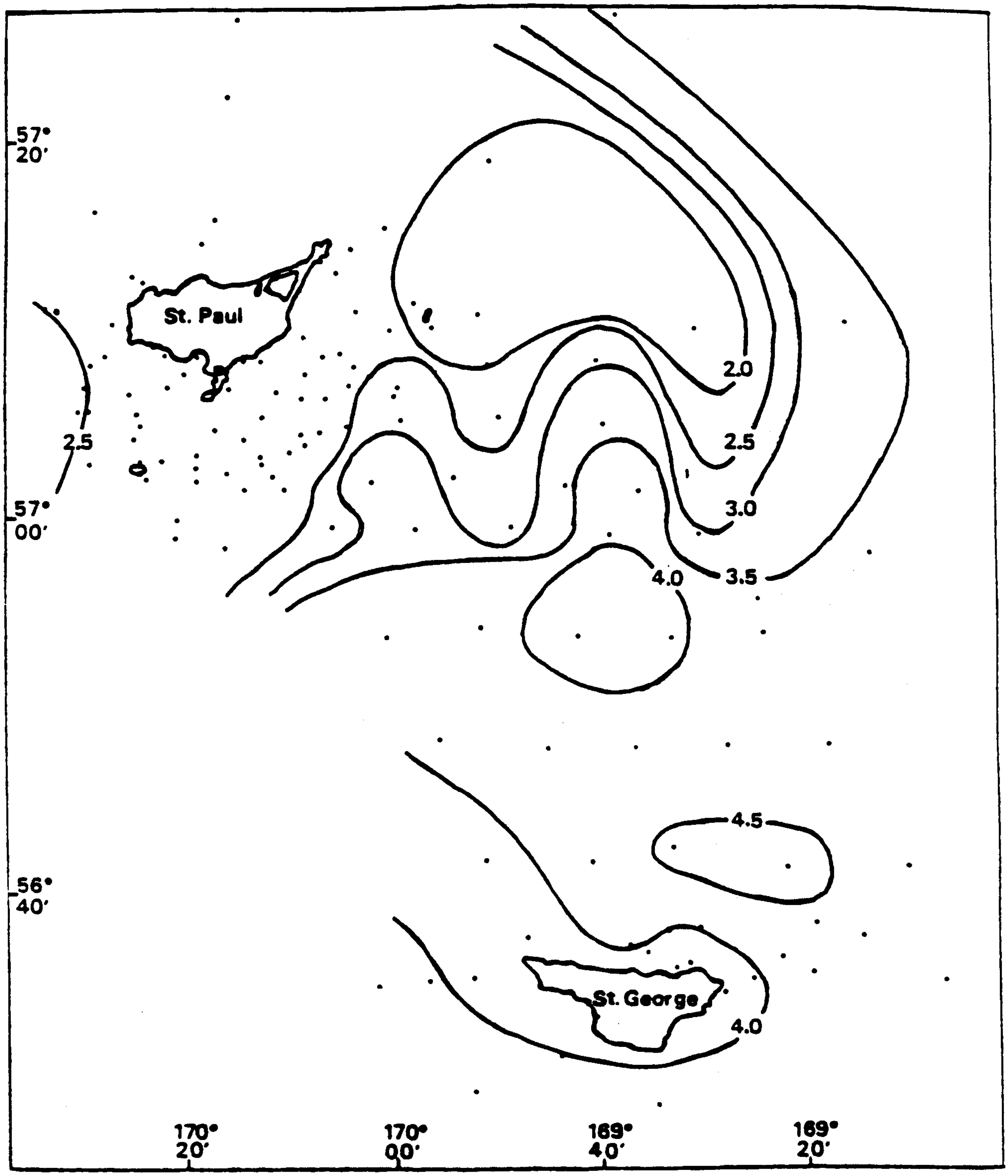


Figure 3.5 Surfaces temperatures (°C), May 1983.

3.4 Community Composition and Structure

3.4.1 Species Studied and Station Clusters

The species considered for the analyses of the biological data from each cruise, according to the selection criteria already mentioned, varied due to changes in abundance. In spite of this variation, 48 species or taxonomic groups consistently appeared in all the samples at the top of rankings. Altogether 57 species were selected for the analyses of the May and August 1983 data and 66 were considered for the April 1984 cruise, including 8 species of hermit crabs identified during this cruise only. Table 3.1 lists all fish and invertebrates used in the cluster analyses. Four final data groups were analyzed by clustering: May, all gear; August, RD and BT separately; April, all gear.

The resultant dendrograms grouped the stations of each cruise according to increasing dissimilarity based on the density (no/ha) at each station of the species considered (Fig. 3.6 for May; Appendices B.4, B.5, B.6 for August and April). These dendrograms were examined at different dissimilarity levels, but the level adopted as the point of truncation to define station groups was the one believed to make the most ecological sense. For this reason, the May dendrogram, as an example, is truncated at two different levels of dissimilarity: at a dissimilarity value of 4, clusters 1 and 2 are defined and at a value of 11, cluster 3 is evident (Fig. 3.6). In all four cases (cruises and gear above), 3 major clusters were selected that grouped stations with the most similar biological characteristics in terms of species caught and their densities. In the dendrograms, each vertical line at the zero dissimilarity value represents a single station and they are linked as increasingly larger groups as their similarity decreases. The horizontal lines linking two stations or two groups of stations show the dissimilarity between them. The station

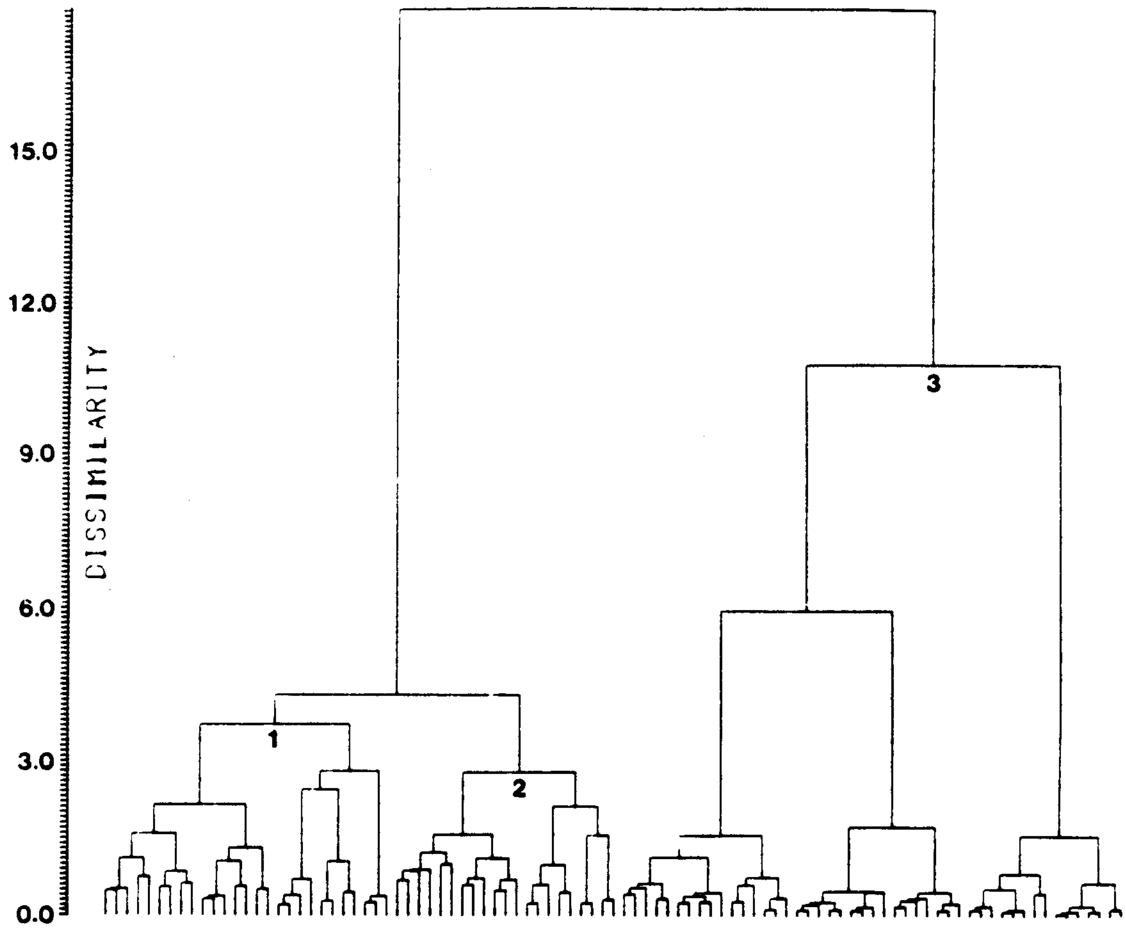


Figure 3.6 Dendrogram showing the relationship between the stations of the May 1983 cruise, beam trawls and rock dredges combined. Numbers 1, 2, and 3 indicate cluster groups common to all cruises (see Appendices B.4-6).

numbers are not shown in the figures for lack of space but station groups defined by each of the four dendrograms are shown in Figures 3.7, 3.8 and 3.9. The cluster numbers (1,2,3) were arbitrarily assigned after the analyses and designate cluster groups (CG) of similar substrate and species characteristics throughout the different trips; all clusters with the same number have similar characteristics.

The geographic locations of the stations grouped within each of the 3 major clusters are shown in Figures 3.7 to 3.9. A perceptible pattern of station distribution is evident within each cluster during each of the three different cruises. Stations in Cluster Group 1 (CG 1) occurred near the main two islands within the 60 m isobath around St. Paul Island and particularly along the submarine ridge that extends east of St. George Island and somewhat to the north as well (Fig. 3.7). Stations in Cluster Group 2 (CG 2) were also in shallow water around St. Paul, but notably very few of them were found near St. George Island except in April (Fig. 3.8). Finally, stations belonging to Cluster Group 3 (CG 3) were located in deeper water generally greater than 60 m in the basin between the two main islands. Rock dredge stations of CG 3 in August (Fig. 3.9) were not so clearly segregated relative to the other trips since this gear was only used at restricted, nearshore stations on rough substrates where the beam trawl could not be used accurately. However, despite the geographically different locations, these stations still had characteristics that justify inclusion with the other stations in CG 3 based on biological associations.

3.4.2 Cluster Groups and Substrate Type

The extensive analyses of substrate characteristics given in Section 2.2 provided major attributes with which to characterize stations within the three CGs. SSS traces (Figs. 2.5 to 2.7) and resultant maps of major

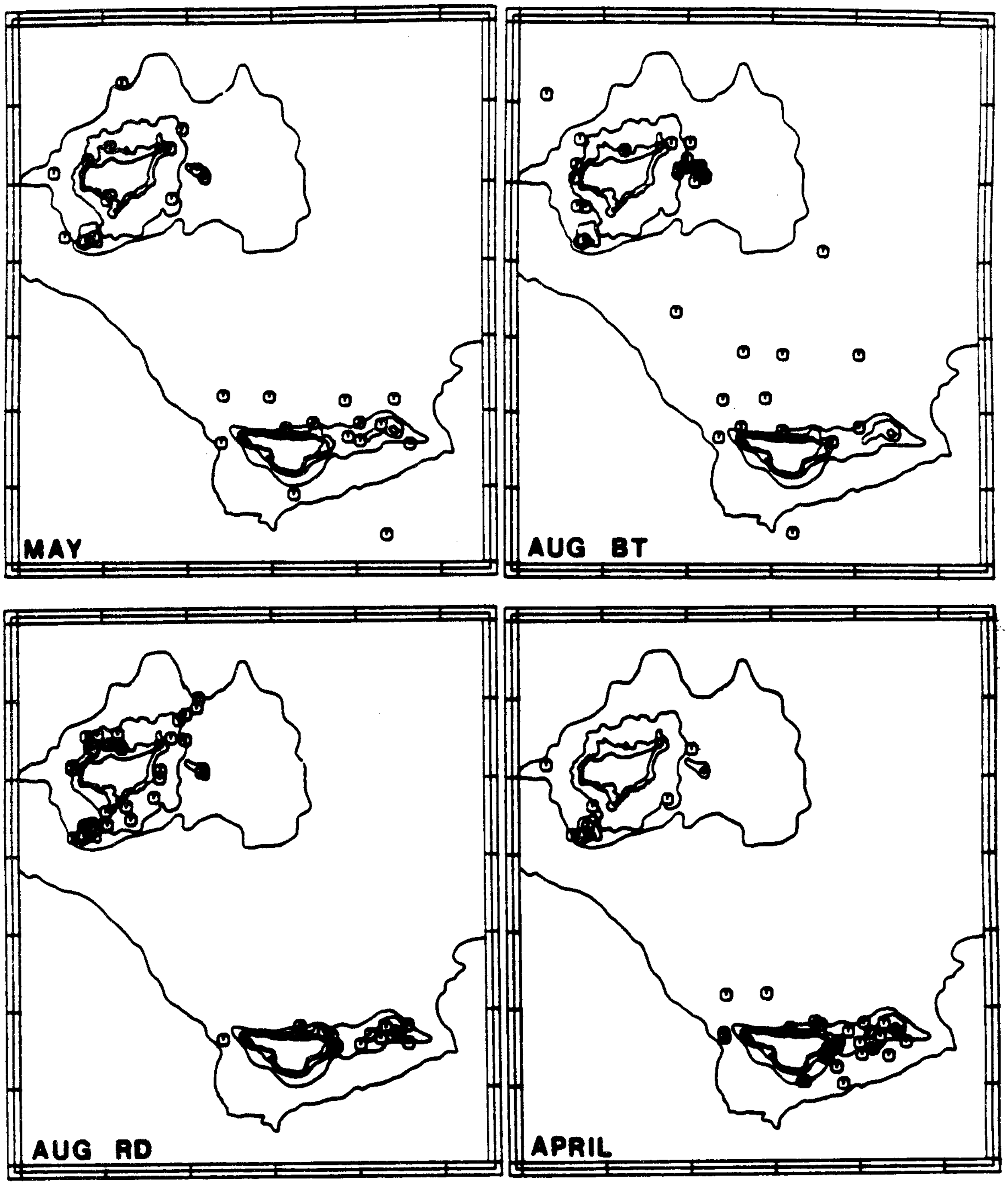


Figure 3.7 Geographical locations of stations in Cluster Group 1 formed for each cruise and rock dredge and beam trawl data separately in August 1983. Substrate at these stations is composed primarily of cobble and rock and extensive shellhash (type I), and is an area of high density of juvenile blue king crab.

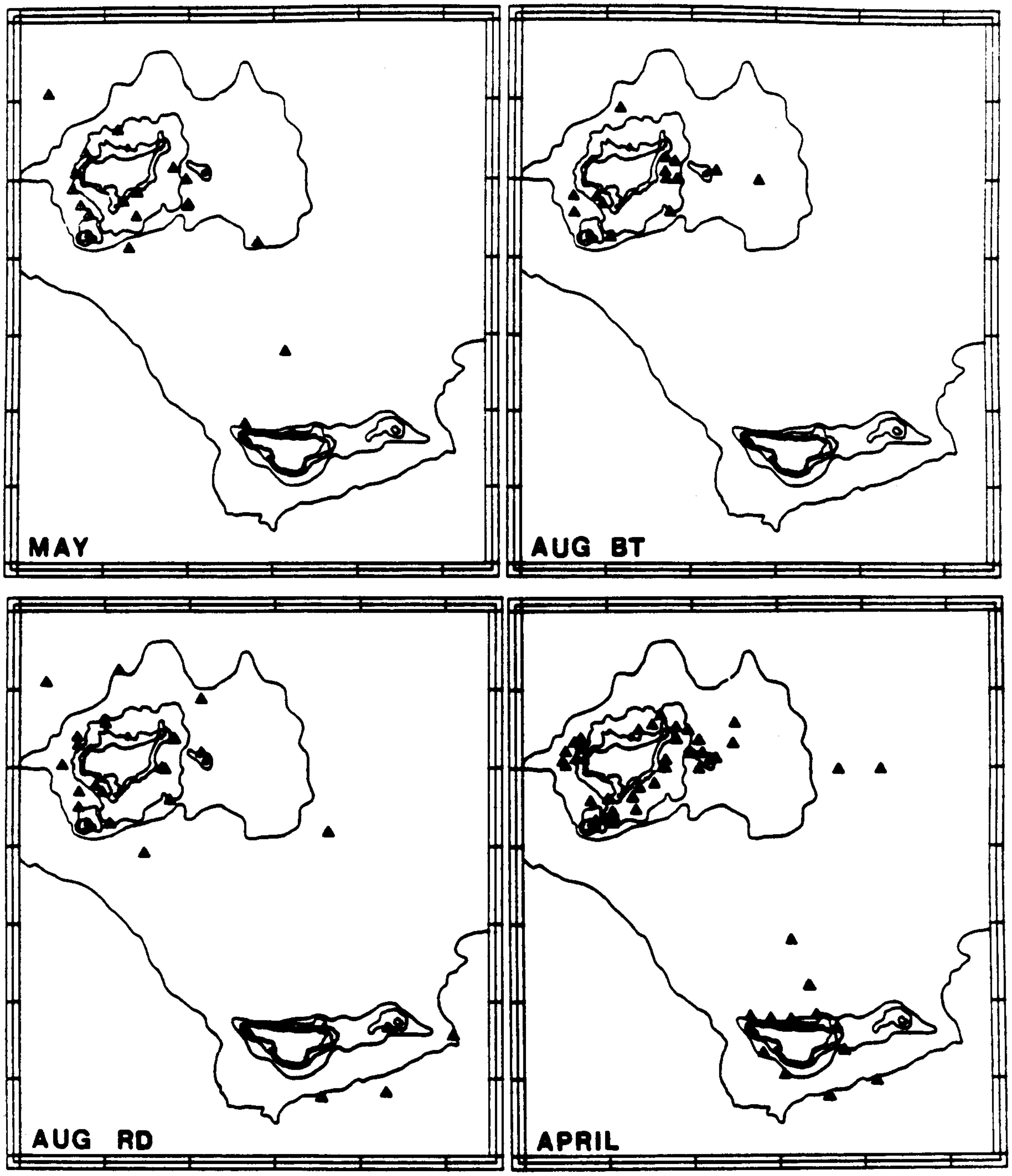


Figure 3.8 Geographical locations of stations in Cluster Group 2. Here, the substrate was a mixture of sand, cobble, rock and shell, and is viewed as transitional between Cluster Groups 1 and 3.

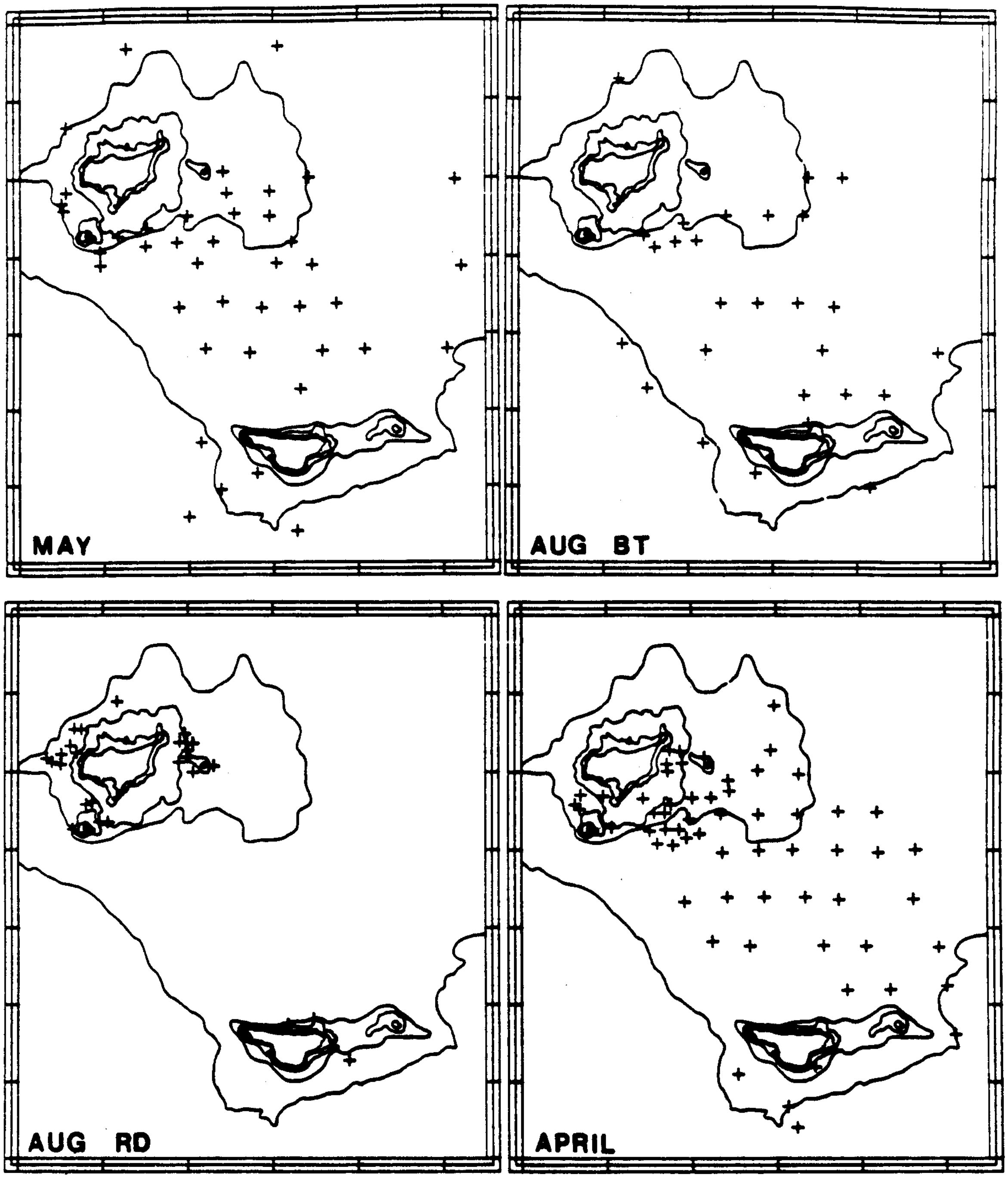


Figure 3.9 Geographical locations of stations in Cluster Group 3. Substrate is mainly mud and sand and very little shellhash. Adult blue king crab were typically located at stations in this cluster group.

sediment types (Figs. 2.9, 2.10; rock, cobble, gravel and sand) including shellhash (Figs. 2.12 and 2.13) help to give perspective to stations of CG's shown in Figures 3.7 to 3.9. For ease of reference between CG's and general substrate categories, the latter were coded as follows (Table 3.2):

Substrate Type 1 (ST 1) includes sandy bottoms with phi values ranging from mud to gravel (0.063 to 4 mm). Grain sizes in this rather wide range were lumped together because the sediment analyses indicated very poor sorting, with most of the samples having an average phi value between fine and coarse sand (Appendices A.1 and A.2). This substrate generally occurs outside the 60 m isobath in the basin between St. Paul and St. George Islands except to the southeast of St. Paul where sandy bottoms are found nearshore (Fig. 2.8).

Substrate Type 2 (ST 2) defines rocky habitats composed of particles from pebble and cobble to boulders and rock shelves. These different rock formations occurs around all four islands of the group (Figs. 2.9 and 2.10) and to the east of St. George Island forming a submarine ridge.

Substrate Types 3 and 4 (ST 3 and ST 4) comprised the two categories of shellhash (shell debris) described in Section 2.3. SH I (ST 3) consisted of relatively intact shells or large pieces, while SH II (ST 4) consisted of pulverized, well-washed small pieces of shell (Section 2.3; Figs. 2.11 to 2.14).

Stations of CG 1 (Fig. 3.7) are characterized by a preponderance of ST 2 and ST 3 (Table 3.2). Rock and SH I were found at more than 60% of the stations and constituted as much as 90% among RD stations of the August 1983 cruise. Another distinctive property of CG 1 is the low number of stations with sandy substrates included in this group: the highest proportion of all sand substrates sampled by BT was 22% in August 1983, but

Table 3.2 Summary of the substrate characteristics of the stations that constituted each of the major clusters.

		Number of stations					Percentage Within clusters					Percentage Between clusters			
May - Both gears															
	Substrate *	1	2	3	4	T	1	2	3	4	T	1	2	3	4
Cluster	Average depth (m)														
1	59	6	10	10	1	27	22	37	37	4	100	8	91	71	50
2	50	16	1	3	1	21	76	5	14	5	100	24	9	21	50
3	71	46	0	1	0	47	98	0	2	0	100	68	0	7	0
T		68	11	14	2	95						100	100	100	100
August - Beam trawl															
	Substrate *	1	2	3	4	T	1	2	3	4	T	1	2	3	4
Cluster	Average depth (m)														
1	60	11	4	14	1	30	37	13	47	3	100	22	100	82	100
2	44	13	0	1	0	14	93	0	7	0	100	27	0	6	0
3	77	25	0	2	0	27	93	0	7	0	100	51	0	12	0
T		49	4	17	1	71						100	100	100	100
August - Rock dredge															
	Substrate *	1	2	3	4	T	1	2	3	4	T	1	2	3	4
Cluster	Average depth (m)														
3	54	10	4	11	1	26	39	15	42	4	100	42	12	31	14
2	55	14	7	3	1	25	56	28	12	4	100	58	23	8	14
1	40	0	20	22	5	47	0	43	47	10	100	0	65	61	72
T		24	31	36	7	98						100	100	100	100
April - Both gears															
	Substrate *	1	2	3	4	T	1	2	3	4	T	1	2	3	4
Cluster	Average depth (m)														
2	54	15	5	18	13	51	29	10	35	26	100	22	42	38	72
1	60	2	4	26	3	35	6	11	74	9	100	3	33	54	17
3	66	52	3	4	2	61	85	5	7	3	100	75	25	8	11
T		69	12	48	18	147						100	100	100	100

* Substrate type: 1= Mud to granule; 2=Pebble to boulders and rock shelves; 3= Shell hash I ; 4=Shell hash II (see text for shell hash categories).

this value was only 8% and 3% for the May 1983 and April 1984 cruises, respectively, and no sand stations were included in CG 1 for RD samples in August 1983 (Table 3.2).

CG 3 (Fig. 3.9) typically included stations with a high proportion of ST 1. Sandy substrates were most common among station groups from the May and August BT samples and April cruises and comprised 98%, 93% and 85% of the stations, respectively. August RD stations grouped in CG 3 also showed a majority of sandy substrates (56%) although not so marked as in the other cases (Table 3.2). In addition, CG 3 included the lowest number of stations with SH II (ST 4). Fourteen percent of all stations of ST 4 sampled with the RD in August and 11% of those classified as ST 4 in April were included in CG 3. No SH I substrate was included in CG 3 from the May cruise or from the BT samples of the August cruise (but the number of stations with this substrate category were so few that this absence may not be representative).

CG 2 (Fig. 3.8) contained stations whose substrate proportions were generally intermediary between those of CG 1 and 3 (Table 3.2). There was a high proportion of sandy substrates but, except for the April data, Chi-square tests showed no significant difference between the observed proportions of any substrate category and the expected values (Table 3.3). These characteristics suggest that stations of CG 2 may be transitory between those of CGs 1 and 3; a hypothesis that is substantiated by biological data (Section 3.5). Chi-square tests showed that substrate distinctions between CG 1 and 3 were significant at the 1% level (except for CG 3, BT stations, of the August cruise Table 3.3). It is important to remember that the cluster analyses were performed using density data as No/ha. No consideration was given to any substrate attributes and the clusters were formed solely on the basis of biological characteristics of

Table 3.3 Chi-square tests of the number of stations with each substrate type in each cluster. Ho : the substrate types are distributed in the clusters proportionately to the total number of stations in each cluster. The number of stations is followed by the expected number (in parentheses) if Ho is true.

May 1983

Cluster	Substrate type 1	2	3	4	T	Chi square
1	6 (19.3)	10 (3.1)	10 (4.0)	1 (0.6)	27	33.74 **
2	16 (15.1)	1 (2.5)	3 (3.0)	1 (0.4)	21	1.61
3	46 (33.6)	0 (5.4)	1 (7.0)	0 (1.0)	47	16.04 **
T	68	11	14	2	95	

August 1983 Beam trawl

Cluster	1	2	3	4	T	Chi square
1	11 (20.7)	4 (1.7)	14 (7.2)	1 (0.4)	30	14.96 **
2	13 (9.7)	0 (0.8)	1 (3.3)	0 (0.2)	14	3.79
3	25 (18.6)	0 (1.5)	2 (6.5)	0 (0.4)	27	7.16
T	49	4	17	1	71	

August 1983 Rock dredge

Cluster	1	2	3	4	T	Chi square
1	0 (11.5)	20 (14.9)	22 (17.2)	5 (3.4)	47	15.38 **
2	10 (6.4)	4 (8.2)	11 (9.6)	1 (1.8)	26	4.86
3	14 (6.1)	7 (7.9)	3 (9.2)	1 (1.8)	25	14.75 **
T	24	31	36	7	98	

April 1984

Cluster	1	2	3	4	T	Chi square
1	2 (16.4)	4 (2.9)	26 (11.4)	3 (4.3)	35	32.09 **
2	15 (23.9)	5 (4.2)	18 (16.7)	13 (6.2)	51	10.92 *
3	52 (28.7)	3 (4.9)	4 (19.9)	2 (7.5)	61	36.58 **
T	69	12	48	18	147	

the stations (NOTE: see Appendix B.13 for a discussion of clustering techniques and the data used).

3.5 Species Associations: Communities

Based on station groupings, the biological characteristics of each cluster group were studied in terms of species frequency of occurrence, density (as No/ha and g/ha) and individual average weights. The results of these analyses are given in Table 3.4 as an example of results for May, and in Appendices B.7, B.8 and B.9 for August BT, RD and April, respectively. These tables only list the 26 most frequent, abundant and persistent species within a given cluster. Appendix Table B.9 (April cruise) also includes 8 species of hermit crabs. Frequency of occurrence and abundance, both as numbers and biomass, were considered when studying the characteristics of the different CGs and establishing species associations and substrate relationships for cluster groups. Analyses of variance and pairwise t-tests were performed for the abundance and weights as No/ha and g/ha as a measure of differences between clusters. Theoretical and mathematical considerations of these tests are debated in the discussion but for now it is important to say that they are biased. Henceforth, the terms "significance test" and "significant" will be used for the sake of brevity but also contain some provisos.

Another measure of the extent of the association of a given species to a CG is the fidelity. The simplest definition of fidelity is the ratio of the frequency of occurrence within a station group to the overall frequency of occurrence in the study area, expressed as a percentage (Stephenson et al. 1970). Appendix Tables B.10, B.11 and B.12 give the fidelity values to each of the cluster groups of the 26 species considered.

Table 3.4 List of dominant species, frequency of occurrence, average density (in number/hectare and grams/hectare), and average individual weights at the stations that constituted each of the major clusters from the May 1983 cruise.

General Taxonomic Group	Species	Cluster number	Freq (%)	N (No/ha)	W (g/ha)	W/N (g)
Coelenterata	Sea Anemones	1	40.7	113.7	9826.7	86.4
		2	42.9	63.6	31415.9	494.0
		3	40.4	55.6	32028.8	576.1
Echinodermata	A. amurensis	1	7.4	14.7	1032.2 S	70.2
		2	33.3	259.0	54202.9	209.3
		3	38.3	77.2	18185.7 S	235.6
	Henricia sp.	1	11.1	60.9 *	237.9 *	3.9
		2	0.0	0.0	0.0	0.0
		3	2.1	0.2	12.1	60.5
	L. nanimensis	1	14.8	14.0	3412.9	243.8
		2	19.0	4.2	1751.5	417.0
		3	25.5	5.4	1074.0	198.5
	S. droebachiensis	1	55.6	601.7 *	28495.6 *	47.4
		2	23.8	56.3	3162.0	56.2
		3	2.1	7.5	370.0	49.3
	Cucumaria sp.	1	11.1	89.9	72376.4	805.1
		2	9.5	448.1	204622.8	456.6
		3	0.0	0.0	0.0	0.0
Mollusca	F. oregonensis	1	37.0	239.8 *	10130.7 *	42.2
		2	9.5	18.8	2618.9	139.3
		3	4.3	1.5	23.0	15.3
	Neptunea spp.	1	14.8	44.4 S	2933.4 S	66.1
		2	33.3	92.6	8999.2	97.2
		3	57.4	84.0 S	14328.4 S	170.6
	Nudibranchs	1	48.1	224.3	552.6	2.5
		2	42.9	59.1	66.0	1.1
		3	57.4	72.2	120.6	1.7
	Chlamys sp.	1	55.6	5279.5 *	55793.1 *	10.6
		2	23.8	56.8	450.7	7.9
		3	8.5	15.1	283.9	18.8
	Mytilidae	1	44.4	2801.7 *	78420.4 *	28.0
		2	14.3	13.6	791.1	58.2
		3	0.0	0.0	0.0	0.0

Table 3.4 (continued)

General Taxonomic Group	Species	Cluster number	Freq (%)	N (No/ha)	W (g/ha)	W/N (g)
	P. macrochisma	1	66.7	613.1 *	124384.2 *	202.9
		2	14.3	29.0 *	3700.7 *	127.6
		3	4.3	37.3	2567.2	68.8
Crustacea	Cirripedia	1	22.2	82.5 S	3899.3 S	47.3
		2	14.3	3.9	240.3	61.6
		3	4.3	3.1 S	0.9 S	0.3
	Pandalus spp.	1	25.9	2306.2	829.4	0.4
		2	28.6	28.3	60.8	2.1
		3	53.2	78.3	56.6	0.7
	C. oregonensis	1	63.0	580.6 *	489.7 *	0.8
		2	28.6	18.5	49.0	2.6
		3	12.8	7.9	8.9	1.1
	Chionocetes spp.	1	37.0	1138.1	3266.6 *	2.9
		2	71.4	298.1	6986.7 *	23.4
		3	100.0	4819.0 *	55495.1 *	11.5
	E. isenbeckii	1	18.5	84.9	3144.1	37.0
		2	52.4	179.0	2844.7	15.9
		3	44.7	19.8	4863.7	245.2
	H. lyratus	1	33.3	475.3	929.0	2.0
		2	28.6	35.2	259.4	7.4
		3	29.8	13.7	67.6	4.9
	O. gracilis	1	85.2	1049.3 *	1082.5	1.0
		2	61.9	158.2 *	868.1	5.5
		3	29.8	106.4 *	122.8 *	1.2
	P. platypus	1	37.0	302.8	2822.3	9.3
		2	28.6	14.0	4596.9	328.4
		3	46.8	22.1	19035.8	861.3
Fish	A. bartoni	1	18.5	64.3	54.3	0.8
		2	38.1	0.0	38.0	2733.2
		3	36.2	11.4	13.4	1.2
	Cyclopteridae	1	22.2	145.5 S	191.8	1.3
		2	28.6	8.0	26.4	3.3
		3	19.1	4.9 S	19.5	4.0
	H. jordani	1	14.8	27.6	3559.9	129.0
		2	42.9	18.6	6420.8	345.2
		3	40.4	16.1	8409.0	522.3

Table 3.4 (continued)

General Taxonomic Group	Species	Cluster number	Freq (%)	N (No/ha)	W (g/ha)	W/N (g)
	H. elassodon	1	0.0	0.0 S	0.0 S	0.0
		2	23.8	11.3	182.9	16.2
		3	42.6	21.8 S	395.1 S	18.1
	H. stenolepis	1	0.0	0.0	0.0	0.0
		2	23.8	2.6 *	1043.4 *	401.3
		3	4.3	0.4	88.7	221.8
	L. bilineata	1	14.8	46.7 *	229.1 *	4.9
		2	66.7	408.9	13751.0	33.6
		3	70.2	227.0	9033.2	39.8

* Values are significantly different, at the 1% level, from the values of the other two clusters (see text).

S Two values are marked with this symbol when they differ significantly, but none of them is significantly different from the third.

3.5.1 Cluster Group 1

The starfish Henricia was always most abundant in CG 1 and both density and biomass (g/ha) were significantly higher than at CG 3. Although the differences with CG 2 were not always significant, frequency of occurrence at CG 2 was more than double that of CG 3, (Table 3.4; Appendix B.7 to B.9). Fidelity to CG 1 was over 70% for all cases but April (Appendix B.10).

The green sea urchin Strongylocentrotus droebachiensis was constantly one of the most frequent and abundant of the species in CG 1. Frequency of occurrence ranged from 55.6% to 91.5% and the density varied from 600 to 1800/ha (Table 3.4; Appendix B.7 to B.9). These values were significantly different from CG 2 and CG 3 except for the August RD stations when it was also found in high densities in CG 2. Fidelity to CG 1 was consistently high, between 62.3% and 77.8%, and ranked second in overall fidelity (Appendix B.10).

The cucumbers (Cucumaria) were the group with the highest biomass, with average values often in excess of 100,000 g/ha. They were always more frequent at CG 1 and signfiicantly more abundant (both as No/ha and g/ha) during August (BT) and April (Appendix B.7 to B.9); with a fidelity to CG 1 of 61.3% they ranked fourth overall.

Fusitriton oregonensis was most frequent in CG 1, with percentages varying between 26.7% and 62.9%, values always higher than those of CG 3. Density and biomass were often higher at CG 1 (except for the August RD stations when biomass was higher at CG 2), but these values were significant only during May and April (Table 3.4; Appendix B.9).

Chlamys occurred most freuqently and was signficantly more abundant in CG 1 (5280/ha, May) than in CGs 2 (57/ha) and CGs 3 (15/ha). The overall fidelity to CG 1 was fairly high (52.0%) denoting a preference for the stations in these groups over CG 2 and CG 3.

Mussels (Mytilidae) were most frequent in CG 1, ranging from 30% to 63.8% and, although they also occurred frequently in CG 2 in April (58.8%) and RD stations in August (57.7%), densities were significantly higher for all cases. Average biomass values were among the highest, with a maximum of 152,561 g/ha for August RD of CG 1. Fidelity to CG 1 was also high at 57.9% overall, 80.0% and 90% during May and August BT, respectively (Appendix B.10).

Pododesmus macrochisma ranked third in overall fidelity to CG 1 with per cruise values between 52.9% and 84.6%. Frequencies of occurrence ranged from 36.7% to 87.2%, the former corresponding to August stations sampled by BT, which may have not been very effective in catching this bivalve.

Barnacles (Cirripedia) were more frequent and significantly more abundant in CG 1 than in CG 3. The frequency of occurrence in CG 1 varied between 16.7% and 38.8% and the density was fairly constant (83, 110 and 110/ha for May, August RD and April, respectively). Fidelity to CG 1 ranged from 54.5% to 91.7% and it was top ranked overall.

Cancer oregonensis was significantly more frequent and abundant in CG 1 except for the RD stations of the August cruise when it was more abundant in CG 2. These numbers, however, were not statistically different and it was more frequent in CG 1 (89.4%) than in CG 2 (69.2%) (Appendix B.8). Also, fidelity of this species to CG 1 (62.7%) was much higher than to CG 2 (26.9%) (Appendices B.10 and B.11).

Of the eight species of hermit crabs considered in April, only Elassochirus cavimanus occurred more frequently and was significantly more abundant (both as No/ha and g/ha) in CG 1. Frequency of occurrence was

62.9%, 33.3% and 14.8% for CG 1, 2 and 3, respectively.

Oregonia gracilis usually occurred more frequently in CG 1, ranging from 80.0% to 97.9%, but it was also very frequent in CG 2. Densities were also higher in CG 1 and CG 2, but significantly so only in May (1049/ha and 158/ha in CGs 1 and 2, respectively) and for the BT stations of August (Table 3.4; Appendix B.7). Overall, fidelity to CG 1 (43.5%) was higher than to CG 2 (31.3%).

Blue king crab occurred frequently in CG 1 and CG 3 but densities were generally higher in CG 1 and average individual weights much smaller than in CG 2. Although there was no statistical difference between clusters either in No/ha or g/ha, extensive populations of juvenile blue king crab (densities often in excess of 2500/ha) were found nearshore around St. Paul Island and east of St. George Island (CG 1) while adult crabs were often found in the basin between the islands (CG 3). An exception to adult distribution in May and April as larvae were hatching, was the presence of mature females nearshore and to the east of St. Paul Island.

3.5.2 Cluster Group 3

Gastropods of the genus Neptunea were ranked second in fidelity to CG 3. They were always more frequent in CG 3 and significantly more abundant than in CG 1 except for the August RD, when the difference was not significant. The average individual weights for Neptunea of CG 3 (about 160 g) varied very little between cruises but were much higher than those of CG 1 which ranged from 32 to 156 g (Table 3.4; Appendix B.7 to B.9). These values suggested a size segregation similar to that for blue king crab.

Tanner crabs (Chionocetes) were consistently more abundant in CG 3 and all values of density and biomass were significantly higher than those of CG 1. They were found at all stations of CG 2 in May and August BT and at 95.1% of the stations of April CG 3. Only CG 3 of the August RD had relatively low frequency occurrence (52.0%) but still much higher than that of CG 1 (8.5%). Total biomass (as g/ha) was significantly higher (more than an order of magnitude) in CG 3 than in CG 1 except for the August RD stations.

The hermit crab Labidochirus splendescens was most frequent at CG 3 (during the April cruise), being present at 63.9% of the stations. Fidelity to CG 3 was very high (75.0%) and ranked fourth for that trip (Appendix B.12). Pagurus ochotensis was present at 70.5% of the stations in CG 3 of April and was also significantly more abundant both as No/ha and g/ha. Fidelity to CG 3 was 73%, among the highest for that cruise (Appendix B.9 and B.12).

The fish Aspidophoroides bartoni had a fidelity to CG 3 higher than to CG 2 (55.3% vs 23.4%) but it was more frequent in CG 2 in May and August RD and densities (No/ha) were higher at CG 1 except for the August RD stations. These numbers, however, were not signficantly different from those of CG 2 and CG 3 (Table 3.4; Appendix B.7 to B.9) seems to suggest a wider distribution of this species across the different cluster groups.

Flathead sole (Hippoglossoides elassodon) were found mainly at stations in CG 3, with frequencies ranging from 4.0% to 51.9%, the lowest value corresponding to the RD stations of August. This gear may have not efficiently sampled these active swimmers, but no flathead sole were found in CG 1 in May, August or April. Abundances were significantly higher in CG 3 compared to CG 1 and in August were 35.7 and 12.7/ha, respectively (Appendix B.7). Fidelity to CG 3 ranked first at 78.7% overall, while it ranked least in CG 1 and CG 2 (Appendices B.10 and B.12).

Rock sole (Lepidopsetta bilineata) were very frequent in both CG 2 and CG 3, however, fidelity to CG 3 was almost twice the value as for CG 2 (56.1 vs 28.0%).

3.5.3 Cluster Group 2

No species were consistently (and significantly) dominant in CG 2 throughout trips. The starfish Asterias amurensis was always more abundant (both in No/ha and g/ha) at CG 2 but density was significantly higher only for the August RD. Korean hair crab often occurred more frequently at CG 2 (except during the April cruise), but abundance, both in No/ha and biomass, was inconclusive. Fidelity of this crab species to CG 3 (44.3%) was higher than to CG 2 (35.7%) but nevertheless the difference did not show a clear association of the crab to any group.

3.6 The Sea Urchin Community

Although there is no uniformly accepted definition of "community", Stephenson (1973) has indicated that community boundaries could be recognized either by abiotic or biotic criteria. Fager (1963) gave an operational definition of community as a group of species that are often found together. Kihara (1983) stated that communities are formed with the core species which are stable despite environmental fluctuations. The stable core species group can be regarded as the dominant species group.

The most abundant and stable species in CG 1 is the green sea urchin and, therefore, is the core species to characterize the community defined by CG 1. The frequency of occurrence within CG 1 varied from 55.6% in May to 91.4% in April. The abundance ranged between 602 and 1949 individuals/ha in May and April, respectively. These values were significantly higher than abundances within the other two cluster groups for the May and April cruises and for the BT stations of the August cruise. Individual average weights ranged from 20.0 to 52.0 g for the BT and RD stations, respectively, of the August cruise. The frequency of occurrence as well as the abundance was noticeably lower in the other two CGs, showing a clear affinity of this species to stations in CG 1. A measure of this affinity (i.e., the extent to which a species is confined to a given set of stations) is the fidelity. Green sea urchins were second on the list with an overall fidelity of 67.3% of 8 top-ranked species that had fidelity values over 50% (Appendix B.10).

Since other species also occurred frequently and were abundant in CG 1, the structure of the Sea Urchin Community can be defined by the following species: Cirripedia, the crab Cancer oregonensis, the gastropod Fusitriton oregonensis, the bivalves Chlamys sp., Pododesmus macrochisma and Modiolus mussels, the starfish Henricia sp. and the sea cucumber Cucumaria sp. (Fig. 3.10). The hermit crab Elassochirus cavimanus, only considered in April, occurred frequently in CG 1 and was significantly more abundant than in CG 2 and CG 3 and, therefore, included in the Sea Urchin Community.

The Sea Urchin Community is typically found nearshore to the south and east of St. Paul Island, and east of St. George Island along the submarine ridge. It occurs on a gravel-cobble-rock substrate that is often overlain with SH I material (Fig. 3.10). This is a habitat, and therefore community that is spatially very limited around the Pribilof Islands and certainly over much of the SEBS shelf.

It is also a community (CG 1) that includes juvenile stages of blue king crab, associated primarily with SH I. Juvenile crab up to 20 mm CL, but most often less than 10 mm CL, were found in large numbers east of St. Paul and St. George Islands. Table 3.4 and Appendices B.7 to B.9 show much

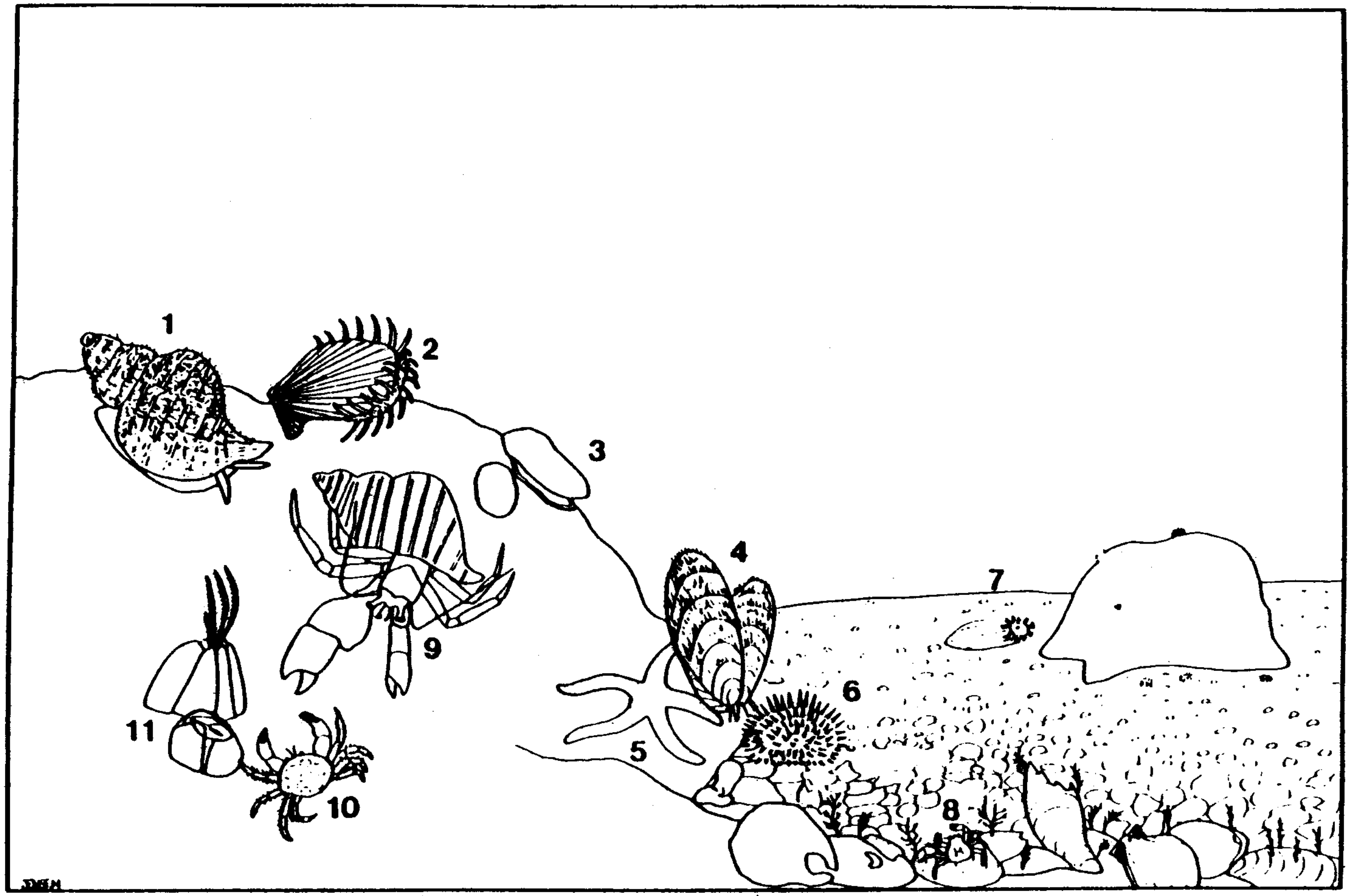


Figure 3.10 Sea urchin community, typical of rock and cobble habitat nearshore of St. Paul and St. George islands. 1, Fusitriton oregonensis; 2, Chlamys spp.; 3, Pododesmus macrochisma; 4, Mytilidae; 5, Henricia spp.; 6, Strongylocentrotus droebachiensis; 7, Cucumaria spp.; 8, juvenile Paralithodes platypus; 9, Elassochirus cavimanus; 10, Cancer oregonensis; 11, Cirripedia.

lower average individual weights in CG 1 versus CG 3 as evidence of spatial segregation of small juveniles and adult crabs. Although the ANOVA did not show consistent significant differences in abundance between clusters (probably because of large variability between stations), there is strong evidence of the dependence of the juvenile blue king crab on substrates like rock and SH I that afford refuge from predators (Section 4.0). Survival of juveniles that fail to settle to such habitats may be seriously reduced. During this early life history stage, juvenile blue king crabs are critically tied to the Sea Urchin Community and its characteristic habitat (Fig. 3.10).

3.7 The Tanner Crab Community

The dominant species in CG 3 are Tanner crabs of the genus *Chinocetes* spp. (*C. bairdi*, *C. opilio*) and a hybrid of the two species. All 3 crab were sympatric in their distribution and were, therefore, considered together for community analyses. The frequency of occurrence within CG 3 varied between 51.0% for the RD stations of the August cruise, to 100% of May and August BT stations and abundance of this species ranged from 550 to 4819 individuals/ha. The Tanner Crab Community also included the flathead sole, the rock sole, and the gastropod *Neptunea* (Fig. 3.11). Adult blue king crabs are most often found at the stations in CG 3, typically on sand substrate between the islands. Adult female crab move closer to St. Paul Island at the time of larval hatching (Armstrong et al. 1985; Section 4.0) probably as an adaptation that retains larvae nearshore where substrate for juvenile settlement (Sea Urchin Community) is optimal. After the eggs hatch, the females become more widely distributed through the Tanner Crab Community. The hermit crabs *Labidochirus splendescens* and *Pagurus ochotensis* both have high frequency of occurrence and are significantly

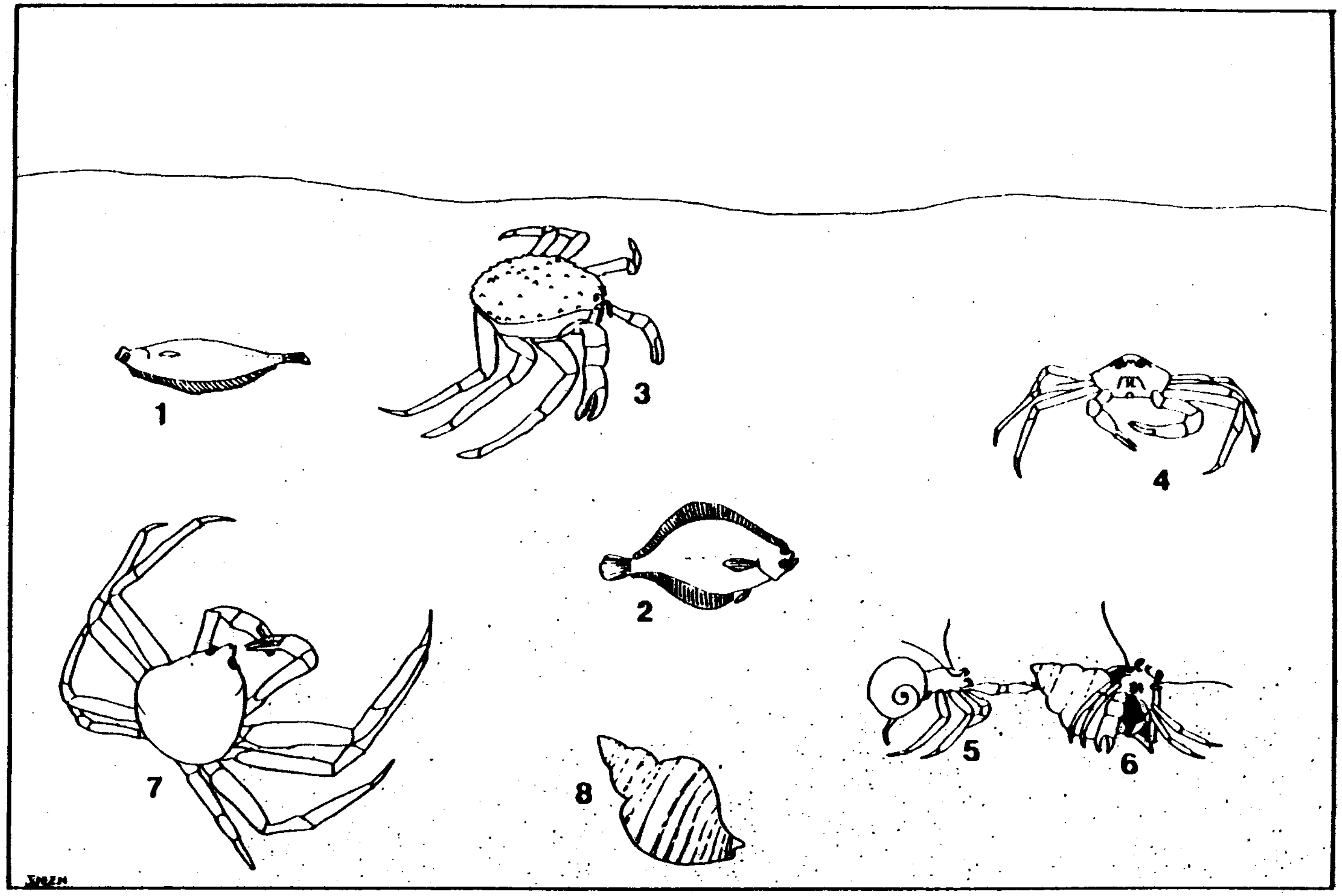


Figure 3.11 Tanner crab community, characteristic of sand/mud substrate between St. Paul and St. George islands. 1, Lepidopsetta bilineata; 2, Hippoglossoides elassodon; 3, Paralithodes platypus; 4, Chionoecetes opilio; 5, Labidochirus splendescens; 6, Pagurus ochotensis; 7, Chionoecetes bairdi; 8, Neptunea spp.

more abundant in CG 3 than in either CG 1 or CG 2.

Assuming that the abiotic marine environment influences the abundance and biomass diversity of benthic species and partially structures their communities, it is necessary to infer a relationship between the Sea Urchin Community on the rocky/cobble substrate with SH I (CG 1), and also between the Tanner Crab Community and the predominantly sandy bottoms of CG 3. Some of the relationships are obvious to the biologist: sessile invertebrates from the Sea Urchin Community (sea urchin itself, mussels, barnacles and *Pododesmus marcrochisma*) need hard substrates to develop after larval settlement. Other species are not so clearly associated with this kind of substrate (e.g., *Cancer oregonensis*, *Fusitriton oregonensis*, the starfish *Henricia*, the hermit crab *E. cavimanus* and juvenile blue king crab). The relationship could be based on the need for refuge among rock cavities and shells, on more complex interactions with the environment, or on other organisms of the community through predator-prey associations or competition with other species. Still, the clustering method proved useful to identify species assemblages and distribution of the communities.

Jewett and Feder (1981) studied epifaunal invertebrates in the Bering and Chukchi Seas and found Tanner crab (*C. opilio*) to be the most frequent and abundant species. At depths between 40 and 100 m, the average combined biomass for *C. opilio* and *C. bairdi* in the SEBS was 13,270 g/ha. This value is remarkably similar to the averages for stations of CG 3 in August (BT) and April (15,969 and 12,292 g/ha, respectively), and within the same order of magnitude of their average biomass during the May cruise (55,496 g/ha). *Asterias amurensis* was abundant in shallow water (< 40 m) at an average biomass of 15,720 g/ha. At the Pribilof Islands this starfish reached 97,000 g/ha (August RD) and an average biomass over 20,000 g/ha was common. Jewett and Feder found *Neptunea ventricosa* and *N. heros* were more abundant between 40 and 100 m at an average biomass of 1800 g/ha. In this study, Neptunea were also more abundant at the deeper (40-90 m) stations of CG 3, but since several species were grouped together, biomass comparisons cannot be made.

Lees et al. (1980) studied the epifauna of rocky subtidal habitats in Cook Inlet and listed the green sea urchin as the main herbivore at Jakolof Bay, with densities often in excess of 20,000/ha, almost an order of magnitude greater than 1,800/ha found in April at the Pribilof Islands. Sea urchins were also quite abundant at Seldovia Point and Kachemak Bay. Modiolus modiolus was also very common at Jakolof Bay (average wet tissue weight 7.8 kg/m^2), Kachemak Bay and on the west side of the Cook Inlet. Fusitriton oregonensis was listed as the most important snail at Jakolof Bay. Other important epibenthic invertebrates on rocky substrates included starfishes Crossaster papposus, Henricia leviusculus and H. sanguinolenta; the clams Macoma, Saxidomus gigantous and Humilaria kennerlyi; the barnacle Balanus nubilus and sea cucumbers Cucumaria miniata and C. vegae, among others. Most of these species are also important components of the Sea Urchin Community (rocky substrate) characteristic of CG 1 at the Pribilof Islands.

4. BLUE KING CRAB

The primary objective of this program was to study the general life history, ecology, distribution and population dynamics of blue king crab around the Pribilof Islands in order to have such data as background necessary to assess potential impacts of oil spills. In this section we present the results of those studies for three major life history stages (larvae, juveniles, adults) as well as details of approach and methods and materials used to carry out the studies. All such information is applicable to Korean hair crab investigations as well and will not be repeated in the next section (5.0) unless specific comments on methods and materials different from those used for blue king crab are necessary. The reader should come back to this section for information concerning approaches when reading the Korean hair crab section.

One approach taken to display data on distribution and abundance was to group stations within strata that were established throughout the study region, and modified for different life history stages and in consideration of features such as depth and substrate. Details of strata configurations and station groups are presented within specific sections dealing with life history stages, but a general approach is shown in Figure 4.1. This division of strata represents a compromise between the more extended distribution of adults and larvae, and more restricted distribution of juveniles. The larger Strata 1, 2, 3, 4, 5 and 6 reflect general distribution of crab and station arrays used to portray regional differences in larval and adult populations, whereas smaller Strata 11, 21, 31, 41 and 61 more closely conform to the limits of distribution of juveniles. Appendices C.1, C.2 and C.3 show station locations during the three cruises relative to these strata.

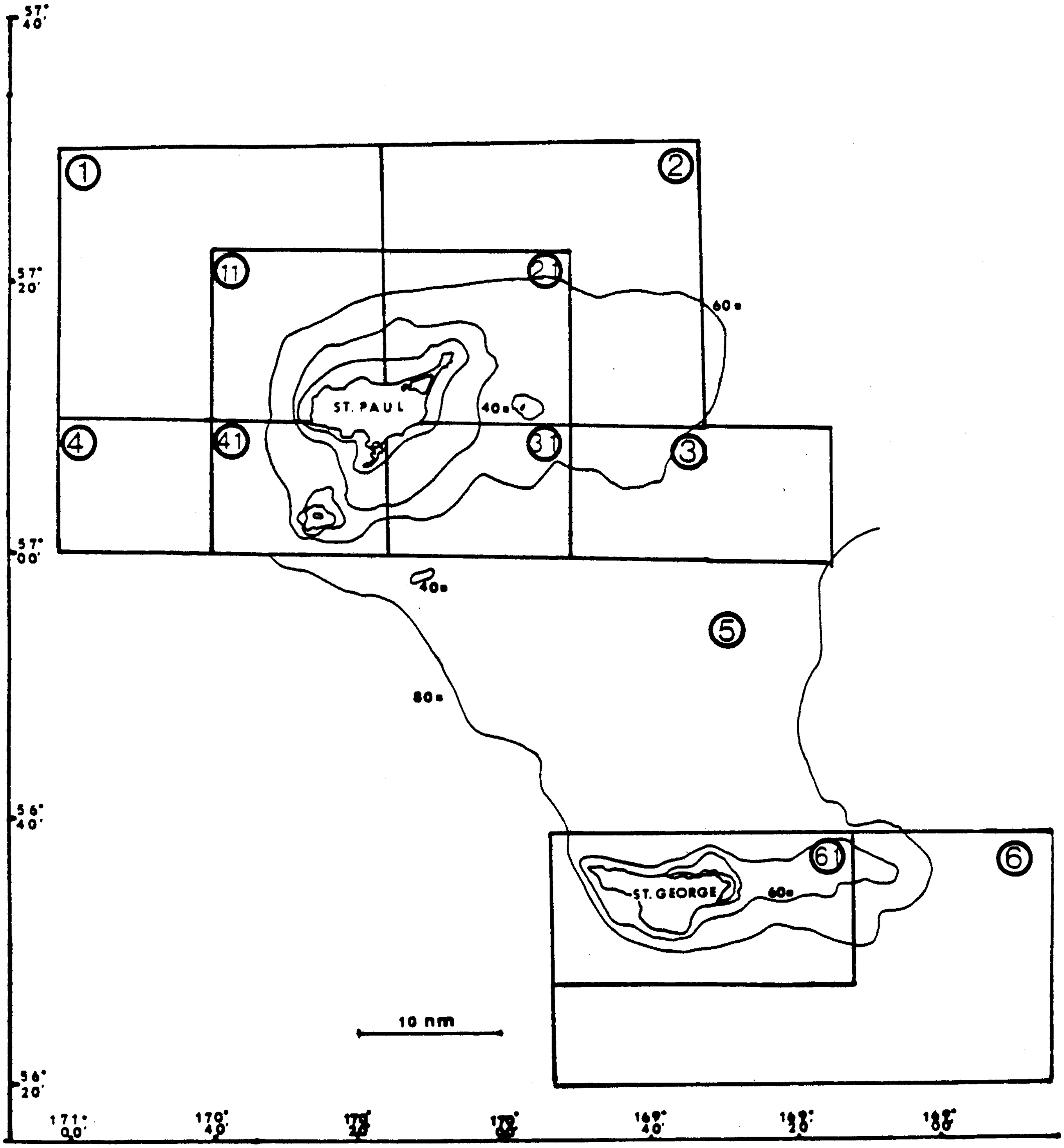


Figure 4.1 Stratum configuration of geographical areas. Inshore areas (strata 11-41 and 61) are included within the boundaries of large blocks, strata 1-4 and 6.

4.1 Larvae

4.1.1 Approach

Larvae were present in the water column in May 1983 and April 1984 but not in August 1983. Collection stations were the same as those shown in figures of survey design (Figs. 2.1 and 2.2), although in April 1984 fewer zooplankton samples were taken around St. Paul Island because of sea ice and lack of larvae.

Plankton samples were generally taken with twin 60 cm bongo nets with a mesh of 505 um. These nets were towed obliquely according to CALCOFI procedure (Smith and Richardson 1977) to a depth of 80 m or five meters above the bottom, whichever was less. Each net was fitted with a General Oceanics "bullet" flowmeter. Usually, the sample from net #1 was preserved, and the sample from net #2 was examined alive with notes taken and larvae removed for onboard experiments and dry weights. If a problem (e.g., jellyfish clogging) occurred with net #1, then net #2 was preserved. All zooplankton samples were preserved in 5% buffered (with sodium borate) formalin in seawater.

A 1 m Tucker trawl, rigged to open and close at depth, and a modified Sameoto neuston sampler were used to monitor diel vertical distributions of the crab larvae. Nets and cups for these sampling devices were also 505 um mesh, and carried the "bullet" flowmeters. Tow duration for both gears was always 10 minutes. During May 1983, sampling of vertical distribution was done at 50 m, 25 m, and the surface every six hours for 24 hours. During April 1984, vertical distribution was sampled with oblique Tucker trawl tows from 60 to 41 m, 40 to 21 m, and 20 m to the surface every three hours for 24 hours. No such work on vertical distribution was done in August 1983, because larvae were not present.

Processing: Plankton samples were rinsed with fresh water and sorted for the target species with a dissecting microscope. Entire samples were sorted whenever possible; however, it was necessary to split some samples to 0.50, 0.25 or 0.125. Splitting, when necessary, was largely due to excessive amounts of chain-forming diatoms or, more rarely, large numbers of crab larvae.

BKC larvae were staged according to Hoffman (1968) and Sato (1958); Korean hair crab larvae according to Kurata (1963). Counts were made for each stage, and the larvae preserved in 70% ethanol. The remaining plankton samples were again preserved in formalin. Voucher specimens of each species and stage were deposited at the California Academy of Sciences.

Dry weight analysis: Larvae of all stages of both crab species caught during the May 1983 cruise were placed in pre-weighed aluminum boats, dried at 60°C and stored in a dessicator. These larvae were then weighed to the nearest microgram with a Cahn electrobalance. The boats with the larvae were then put into a muffle furnace at 550°C for 24 hours and subsequently reweighed to obtain an ash-free dry weight.

NODC Data Format: Plankton data for the 1983 May and August, and 1984 April cruises were coded according to NODC file type 124 and entered into the University of Washington Cyber computer. Programs which calculated larval densities per 1000 m^3 and per 100 m^2 of sea surface were run only on May and April bongo tow data since no larvae of our target species were found in August samples, and larval densities were also calculated for neuston and Tucker trawls deployed.

4.1.2 Timing of Hatch and Molt Frequency

In 1983 the apparent timing of hatch for BKC larvae occurred during the last two weeks of April. This estimate was derived by examination of the weekly stage frequency distribution of larvae during May (Fig. 4.2). Since stage II zoeae (Z II) were already present they would have had to hatchout three weeks earlier, approximately April 19-24.

In 1984, BKC larvae hatched during a period of very cold water. BKC stage I zoeae (Z1) first appeared on April 18th in the mid-island area (Stratum 5), south of the 0°C bottom temperature isobath (see Fig. 4.5). Water around St. Paul Island that month was very cold, typically -0.5°C to -1.0°C and ice packs on the north and east side were common (Appendix B.1). Appearance of Z1 larvae in late April 1984 marked the earliest onset of BKC hatchout since Z1 were the only stage found throughout the three week cruise. Hatchout for the majority of the larval population around St. Paul Island that year had not yet occurred as evidenced by high abundance of ovigerous females (eyed eggs) around Walrus Island off the east shore of St. Paul where bottom water was about -1.0°C.

During the May 1983 cruise larval stages Z1 to Z3 BKC occurred in the plankton. Z1 larvae were collected at 63% of all stations, Z2 at 68%, and Z3 at 27% of stations.

During May 1983, a year of higher spring temperature (more normal?) a larval development rate of 2.5 to 3.0 weeks per stage was estimated from the data on BKC. Larvae were primarily Z1 during the first week of collection (5/10 to 5/15), Z1 and Z2 during the second week (5/16 to 5/21), and mostly Z2 and Z3 during the last week (5/22 to 5/26) (Fig. 4.2). The percentage of Z1 larvae between the first and second week dropped from 87% to 61%, indicating that a large proportion had molted. By the third week, 5/22 to 5/26, only 10% of the larvae were Z1 indicating that once hatching

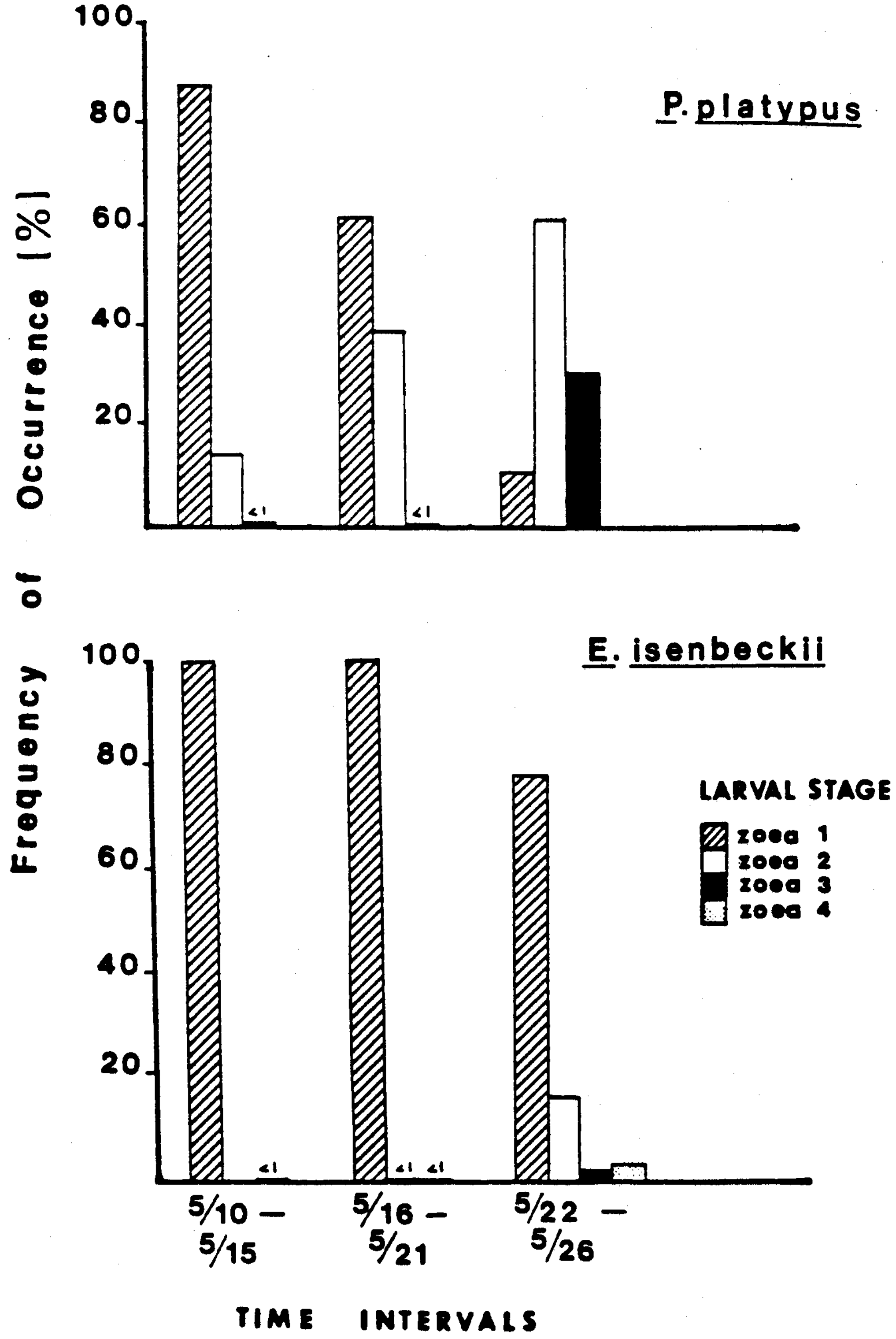


Figure 4.2 Percent stage frequency of Paralithodes platypus and Erimacrus isenbeckii larvae during Leg I, May 1983.

commences, the majority of the larval population emerges out over a three week period.

In April 1984 only Z1 BKC larvae were collected at 38% of 79 plankton stations. Larvae found from April 18 until May 4 represented the very beginning of hatch and thus Z2 zoeae would not even be expected until the second week of May.

Body weights of BKC larvae are compared to red king crab (RKC) larvae in Figure 4.3. Zoeae of BKC are considerably larger at each of the first three zoeal stages than RKC (Table 4.1, Fig. 4.3). Whole body dry weights ranged from a mean of 0.44 mg for Z1 to 0.83 mg for Z3 (Table 4.1). Of the total body weight, the exoskeleton is about 41% for Z1 and 26% for Z2. (Table 4.1).

4.1.3 Distribution and Abundance

BKC larvae occurred at 82% of 117 plankton stations sampled in May. The greatest densities of zoeae were found in the area southeast of St. Paul Island corresponding to Stratum 3 (Str 3) and the northern edge of Str 5 (Fig. 4.4), although larvae were widely distributed throughout the whole sample area. Larvae were present at 73% of plankton stations in Str 1, 75% of Str 2, 100% of Str 3, 94% of Str 4, 76% of Str 5, and 67% of Str 6, and generally in highest abundance at stations located in depths between 40-70 m.

Although the frequency of occurrence was high in most strata around the islands, relative density was quite different. Density as number larvae/100 m^2 was highest around St. Paul Island at about 2300 to 4300 larvae/100 m^2, averaged within strata (Fig. 4.5). Around St. George Island the mean density was only 450/100 m^2, although $\pm$ 1SD was often about 100% of the mean in most strata (Fig. 4.5), which points out high station-to-station variability. The very restricted distribution of BKC larvae around

Table 4.1 Larval blue king crab dry weight analysis, May 1983. Mean values reported in milligrams (mean ± 1 SD).

	Stage I	Stage II	Stage III
Whole Body			
Dry weight	.443 ± .039 n = 10	.533 ± .104 n = 11	.829 ± .156 n = 10
Ash free dry wt	.304 ± .036	.378 ± .087	.677 ± .141
Ash weight	.139 ± .039	.155 ± .041	.152 ± .034
% ash	31.2 ± 7.4	29.4 ± 6.8	18.6 ± 3.6
Exoskeleton			
Dry weight	.181 ± .049	.146 ± .054	ND
Ash weight	.121 ± .040	.096 ± .033	ND
% ash	65.8 ± 7.3	66.3 ± 5.4	ND

ND = no data.

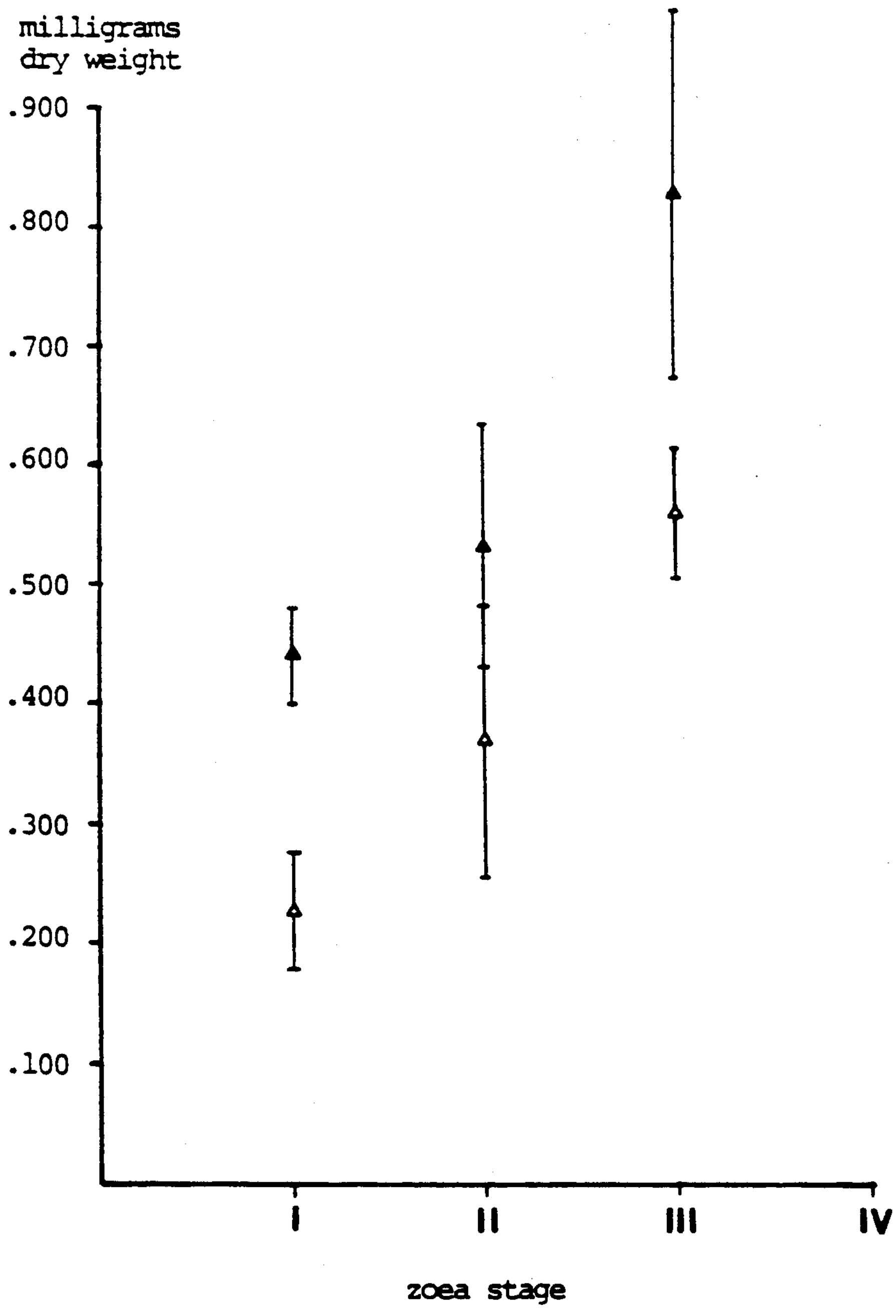


Figure 4.3 Comparison of Paralithodes camtschatica ( ) and P. platypus ( ) zoeal weight/stage growth. Shown are means ± 1 SD.

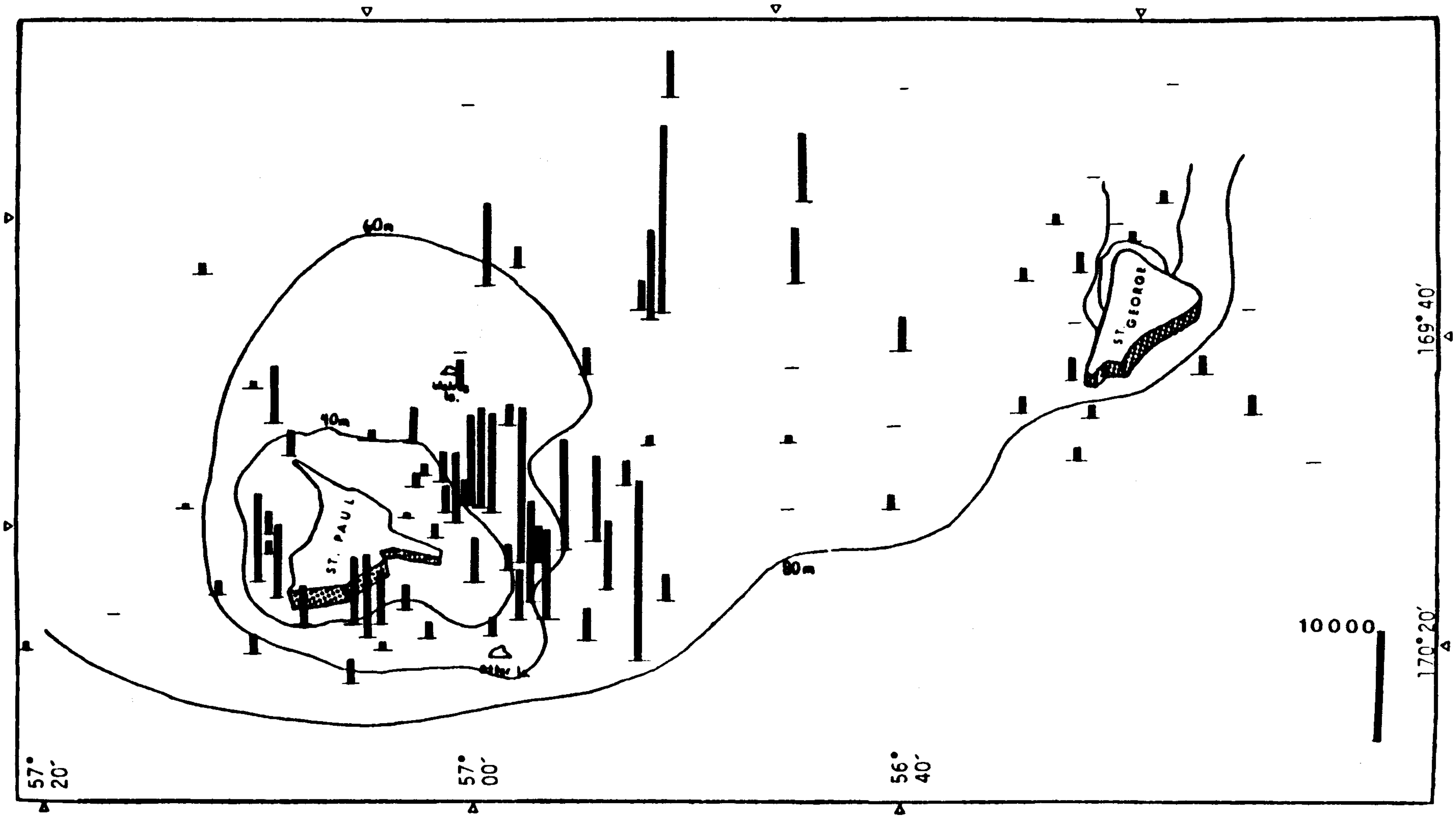


Figure 4.4 <u>Paralithodes platypus</u> larvae, May 1983, number of zoeae/100 m².

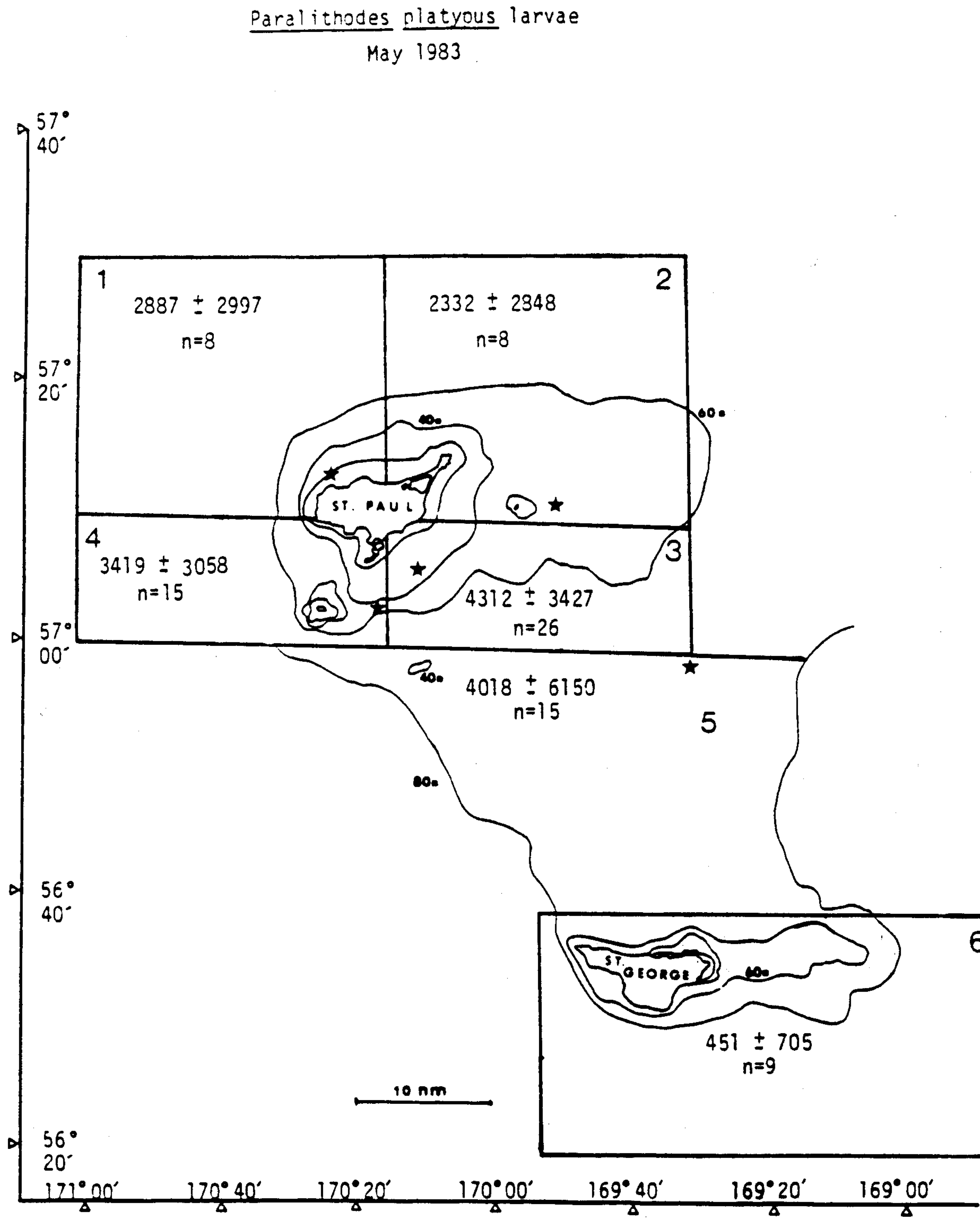


Figure 4.5 Paralithodes platypus larval abundance (no. larvae/100 m²) by strata, May 1983. Shown are mean ± 1 SD and number of stations with larvae; stars indicate stations with the highest abundance per stratum.

St. Paul Island is evident in Figure 4.4 and also highlighted by reference to Figure 2.1 that shows the extent of sampling in May; many zooplankton samples taken just offshore west, north and east of St. Paul had few or no zoeae.

In April 1984 the spatial picture of BKC larvae was very different than in May 1983. Areas of even moderate density of larvae occurred only between the two main islands near and primarily south of the 0°C isotherm toward St. George Island (Fig. 4.6). Mean densities of larvae per stratum were exceedingly low, virtually zero around St. Paul and St. George Islands, and only about 750/100 m^2 between the two (Fig. 4.7).

Vertical Distribution and Abundance: In May 1983 a diel study was conducted at a single station with a neuston net to sample surface water and a Tucker trawl to sample two discrete depths, 25 m and 50 m. No BKC larvae were ever taken in the surface tows with the neuston net (Fig. 4.8). Larvae were fairly equally distributed within the 25 m and 50 m intervals except during the highest light period at 1400 when they were all aggregated at 50 m depth. Water temperatures of between 2.3°C at the surface to 2.1°C on the bottom indicated an almost isothermal temperature profile. Bongo tows that accompanied each time series showed a variation in larval density by more than a factor of ten from a low of 240 larvae/1000 m^3 at evening (20:00) to 3,400 larvae/1000 m^3 at morning (0800).

In April 1984 another diel study was undertaken at a single station in the area of relatively high abundance shown in Figure 4.6. The neuston net was not deployed since no BKC larvae had been taken in the neuston layer the previous year. Instead, Tucker trawls were fished at intervals of 60-41 m, 40-21 m, and 20-0 m. During all periods, larvae were most prevalent

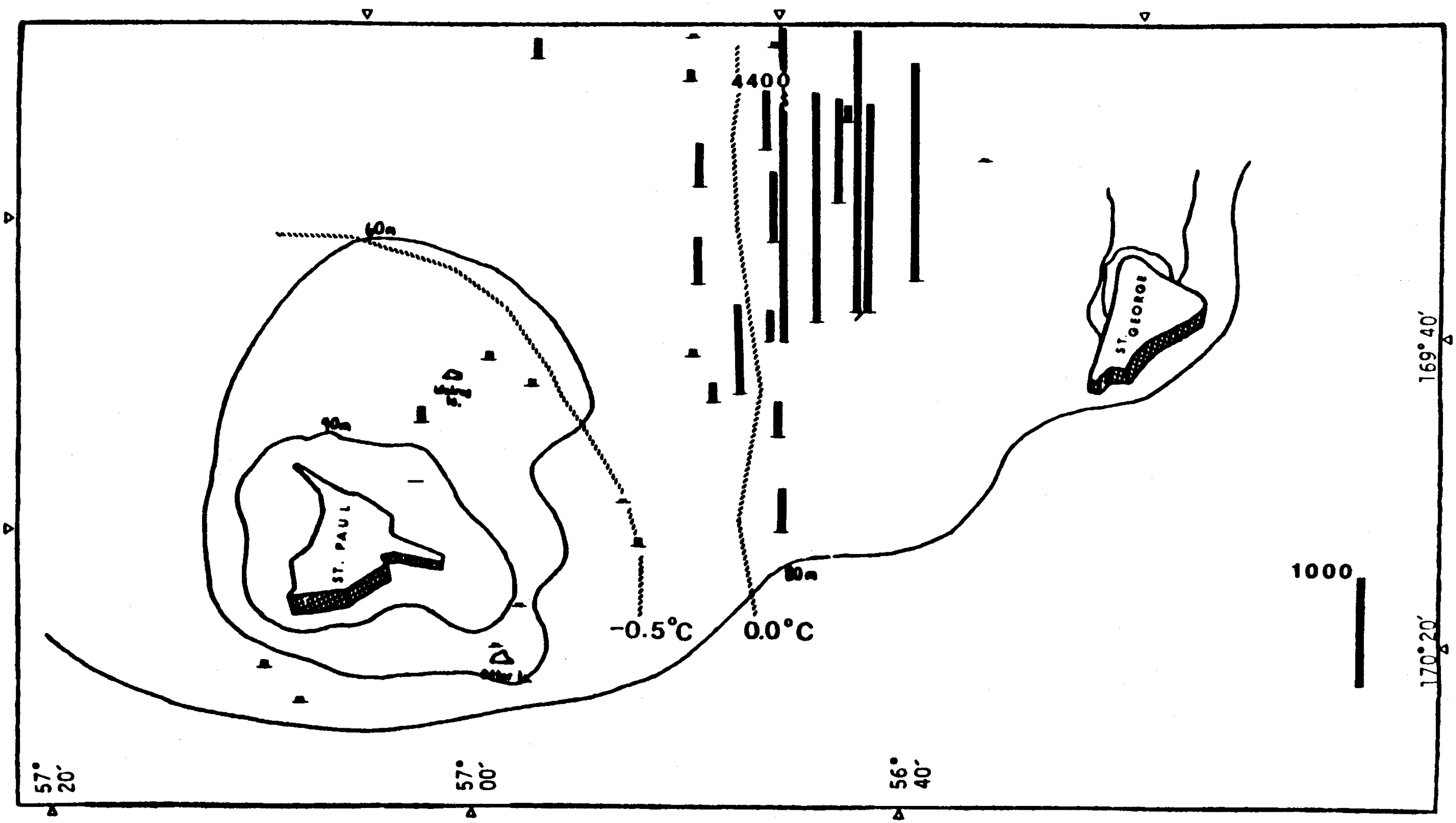


Figure 4.6 Paralithodes platypus larvae, April 1984, number of zoeae/100 m².

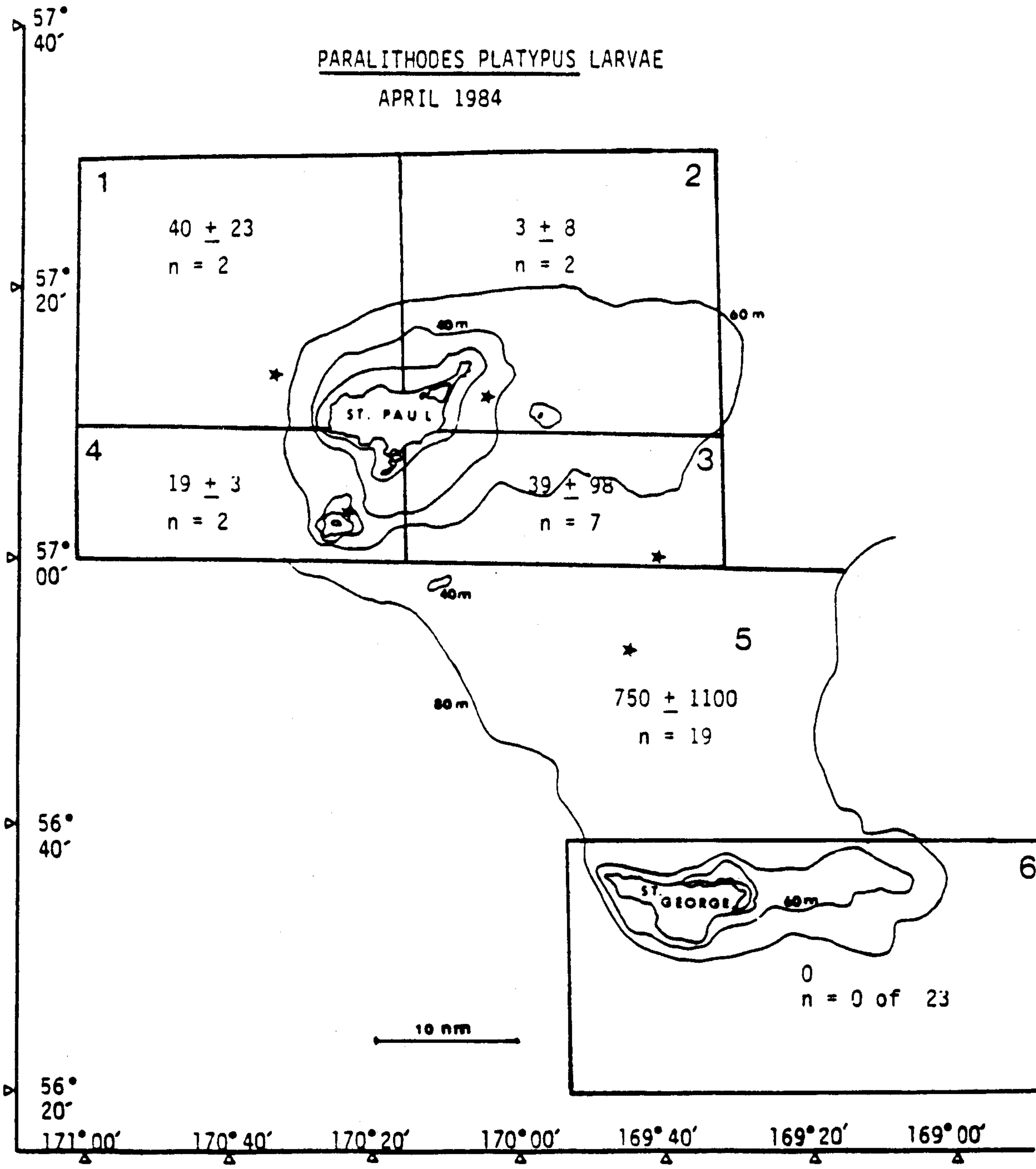


Figure 4.7 Paralithodes platypus larval abundance (no. larvae/100 m²) by strata, April 1984. Shown are mean ± 1 SD and number of stations with larvae; stars indicate stations with the highest abundance per stratum.

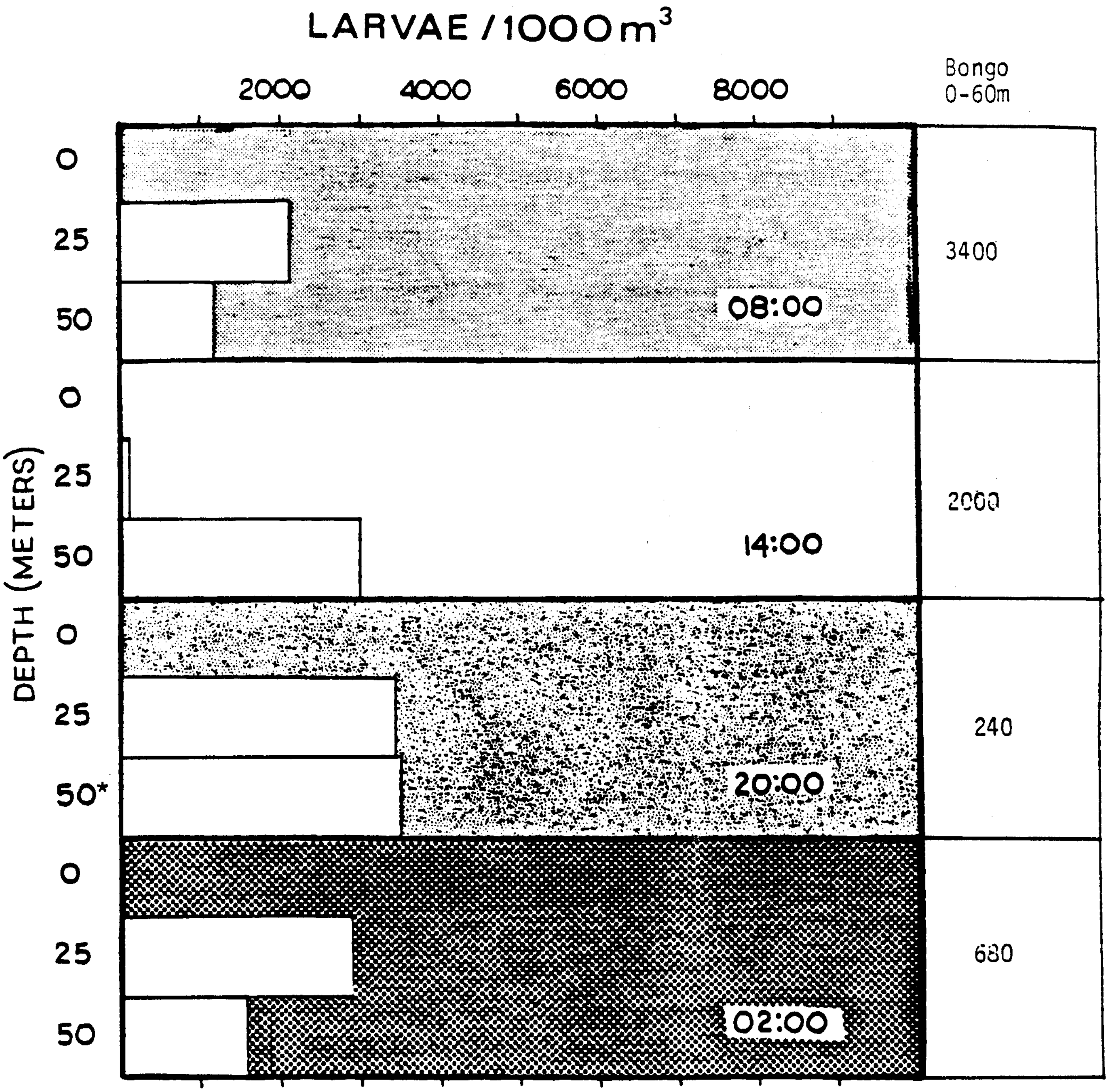


Figure 4.8 Larval Paralithodes platypus depth distribution, May 1983. Diel station was sampled by neuston, Tucker, and bongo tows. Times on right are local mean time.
*Poor tow--neuston net fished 50 m-surface.

in the 41-60 m depth interval at densities 2 to 4 X greater than at shallower intervals (Fig. 4.9), and there was no indication of a diel vertical migration as suggested by data from the previous May.

The limited data taken over 24 hr at a fixed station suggests the possibility of diel vertical migration by zoeae, but is far from conclusive. The broad depth intervals of 25 m between fixed-depth Tucker trawls in May 1983, left too much depth unsampled where larvae might have aggregated. The strongest conclusion drawn from the data is that larvae move to depth during daylight hours and redistribute higher in the water column when light is reduced. The lack of zoeal stages in the neuston is probably consistent with behavior and location of this stage (Armstrong et al. 1986), but abundance in the depth interval from 1 to 24 m could be high in reduced light.

4.2 Sampling Approach to Quantification of Juveniles and Adults

As a prelude to presentation of results concerning distribution and abundance of both juvenile and adult stages of BKC and KHC (Korean hair crab), some discussion of methodology is necessary. The general survey design was presented in Section 2.1 and the reader is referred to figures that show location of sample stations (Figs. 2.1, 2.2 and 2.4). Substrate composition of maps of major sediment types were discussed and presented in Section 2.2, and the occurrence of this material becomes an important point in discussion of results of juvenile distribution both for BKC and KHC. Community structure was presented in Section 3.0 and the relationship of juvenile and adult stages to the Sea Urchin Community and Tanner Crab Community, respectively, were given in Sections 3.6 and 3.7.

4.2.1 Comparison of Sampling Gear

A general discussion of epibenthic sampling gear was given in Section 3.1; the beam trawl and rock dredge are shown in Figures 3.1 and 3.2. As

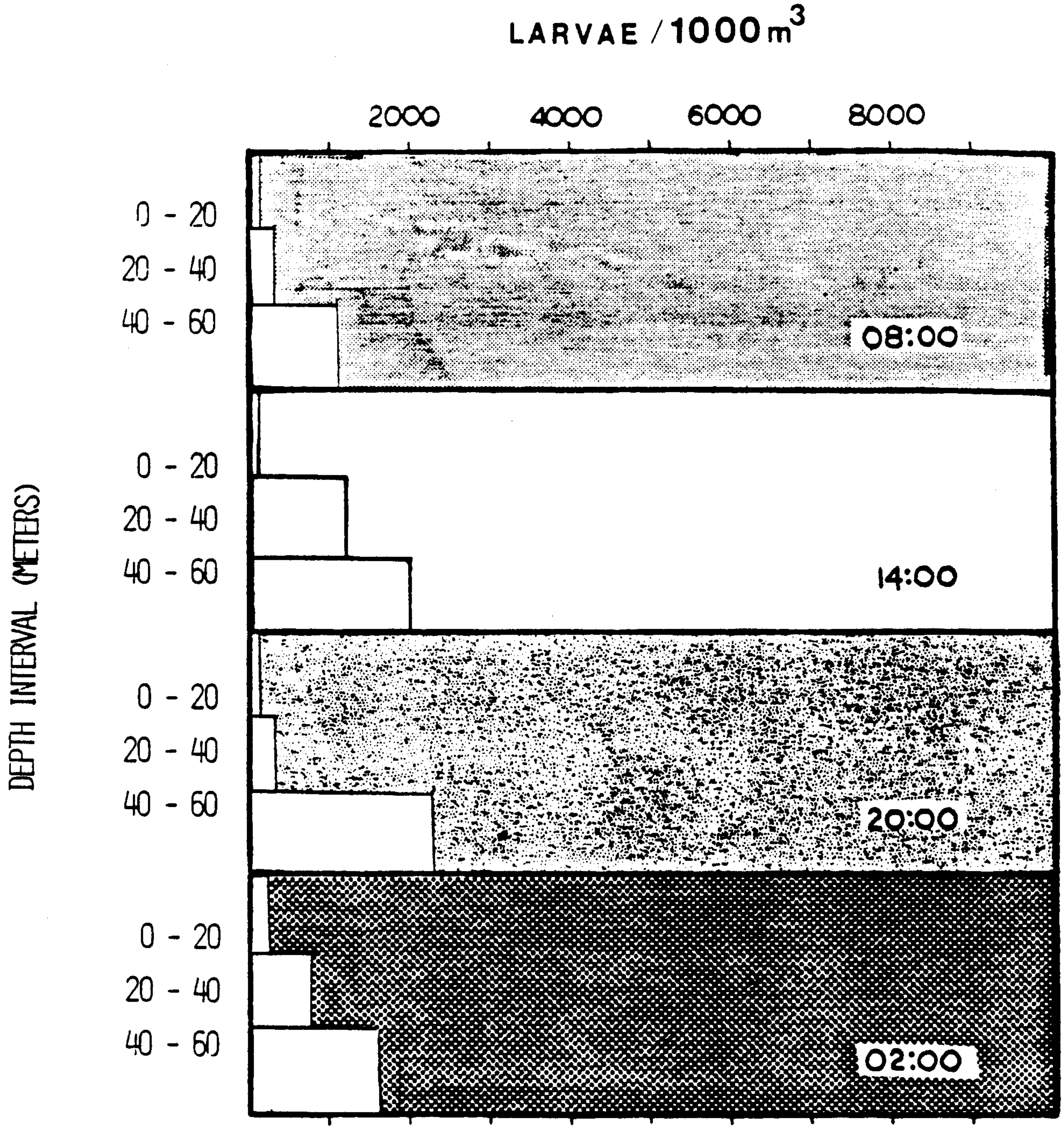


Figure 4.9 Paralithodes platypus larvae, April 1984, number of zoeae/1,000 m³, diel vertical distribution, Tucker trawls only.

previously noted, these two pieces of gear were used in conjunction with SSS traces to direct sampling effort with the RD and BT. A comparison of the percent of adult males, females and juvenile stages of BKC and KHC caught by each gear is given in Table 4.2. In May 1983 a trynet was used for part of the cruise until an adequate beam trawl was developed. The beam trawl was the favored piece of gear because resultant catches (No/ha) were always higher than with the trynet. Adults of both BKC and KHC were caught by the BT and virtually none were taken with the RD. Juvenile stages of both species were taken primarily with the RD, but a significant fraction were taken with the BT as well (Table 4.2). A further comparison of the effectiveness of each net for capture of juvenile stages of both BKC and KHC was conducted as a paired test at 12 stations in August 1983. Mean juvenile density of BKC was significantly greater with the rock dredge (1912/ha) than with the beam trawl (35/ha). Similarly, the mean catch of KHC was 432/ha with the RD and 52/ha with the BT (Table 4.3).

4.2.2 Estimation of Population Abundance

Strata: As discussed in Section 4.1 for larvae, stations throughout the survey area were grouped in order to gain a sense of difference in spatial extent and relative abundance of juvenile and adult populations. Programs available at NMFS provided a calculation of total abundance along with estimates of variance and 95% confidence intervals based on groupings of stations into strata. Several strata configurations were utilized during this program that reflected differences in the ecology of the two major benthic life history stages (juveniles and adults).

Large and small geographic strata: As shown in Figure 4.1, large geographic strata numbered 1 through 6 were established to encompass the entire survey area and reflected the more extensive distribution of adults

Table 4.2 Gear selectivity as measured by percentage of crab caught by each gear for beam trawls (BT), try nets (Try), and rock dredges (RD).

Species and group	Total no. caught	Month	Percentage by gear		
			BT	Try	RD
Blue king crab					
Adult males	12	May	33.0	67.0	0
	0	Aug	0	--	0
	30	Apr	100.0	--	0
Adult females	84	May	64.2	30.9	4.9
	30	Aug	100.0	--	0
	119	Apr	100.0	--	0
Juveniles	574	May	12.4	1.0	86.6
	2,060	Aug	6.0	--	93.7
	633	Apr	35.0	--	65.0
Korean hair crab					
Adult males	62	May	58.0	42.0	0
	75	Aug	90.7	9.3	0
	67	Apr	96.0	0	4.0
Adult females	48	May	93.8	6.2	0
	18	Aug	100.0	0	0
	16	Apr	100.0	0	0
Juveniles	148	May	73.0	7.4	19.6
	3,653	Aug	5.5	0	94.5
	840	Apr	11.0	0	89.0

Table 4.3 Rock dredge vs. beam trawl paired at 12 stations: density (no./ha) of blue king crab juveniles (YOY to 3+ yr) and Korean hair crab. Catch results were significantly different at the 95% confidence level as analyzed by a paired t-test.

	Blue king crab		Korean hair crab	
	Rock dredge	Beam trawl	Rock dredge	Beam trawl
	3,227.0	16.3	230.5	8.1
	5,645.1	122.3	573.9	0.0
	272.3	43.7	474.7	6.9
	191.3	0.0	191.7	7.9
	128.6	0.0	1,050.9	14.3
	4,034.9	48.5	372.5	75.4
	46.1	0.0	114.2	0.0
	4,611.5	102.3	0.0	36.8
	1,951.8	14.3	1,576.4	410.0
	456.9	0.0	0.0	45.6
	2,388.6	57.4	597.2	6.4
	0.0	13.5	0.0	13.5
Mean	1,912.9*	34.9	431.8**	52.1

* Rock dredge > Beam trawl, P = 0.05.

** Rock dredge > Beam trawl, P = 0.01.

and juveniles. Smaller geographic strata numbered 11 through 61 (Table 4.1) more closely approximated the distribution of juvenile stages. Information about each of these strata is given in Table 4.4 and includes the total area and the number of RD and BT stations collected during each cruise as well as general comments and locations. The difference in relative size between these two strata configurations is also depicted in Table 4.4 where the six larger strata cover a combined area of 3,446 NM^2 or 11,820 km^2 (1 NM^2 = 3.43 km^2).

Depth strata: Another approach to grouping stations was based on depth intervals which seem to reflect relative density of juvenile and adult crabs. Depth strata around St. Paul Island were 15 m to 40 m and 41 m to 60 m, and for St. George Island were 15 m to 60 m and >60 m to a maximum of 80 m (Fig. 4.10; Table 4.4). Depth strata were used primarily to calculate population size of juveniles rather than adults.

Sediment strata: In order to further refine estimates of juvenile BKC and KHC abundance based on type and extent of habitat, stations from all three cruises were also grouped according to sediment type as discussed in Section 2.2. As for all strata configurations, areas of sediment in several categories were calculated with a computerized digitizer at NMFS based on maps of sediment distribution given in Figures 2.9 through 2.13 for shell and sediment categories of rock, gravel, cobble and sand. A summary of strata information based on sediment that includes area trawl stations and general location and other comments is given in Table 4.5.

Of the three categories of strata configured for population estimates, this last one based on sediment type was considered most accurate for juvenile stages. A summary of the number of positive stations (stations at which crab were caught) per total number of stations taken during each

Table 4.4 Strata information used to calculate abundance of blue king and Korean hair crab around the Pribilof Islands. Included are the number of rock dredge (RD) and beam trawl (BT) stations by cruise that occurred in various strata (strata shown in Figs. 2.7 and 2.8).

Stratum number	NM²	Total stations: May 83 RD	May 83 BT	Aug 83 RD	Aug 83 BT	Apr 84 RD	Apr 84 BT	Location and comments
1	480	6	5	28	6	9	NS	NW St. Paul. These strata are large and include areas inhabited by both adult and juvenile stages.
2	449	5	6	23	18	11	17	NE St. Paul.
3	499	1	24	5	12	5	23	SE St. Paul. Extended east to include area of juvenile and adult abundance in April 1984.
4	232	5	8	17	7	12	3	SW St. Paul.
5	978	2	23	1	17	2	20	Basin area between St. Paul and St. George islands.
6	808	6	11	24	11	27	16	Area around all of St. George.
Total	3,446	25	87	98	76	66	79	
11	145	6	2	27	5	9	NS	NW St. Paul, subarea of Stratum 1.
21	147	5	2	23	17	11	11	NE St. Paul, subarea of Stratum 2.
31	120	1	14	4	6	5	15	SE St. Paul, subarea of Stratum 3.
41	118	5	8	17	7	12	3	SW St. Paul, subarea of Stratum 4.
61	280	5	8	19	10	24	13	Subarea of St. George Stratum 6.
Total	810	25	34	90	45	61	42	
SP15-40	83	9	6	29	8	16	4	St. Paul, area between 15- and 40-m isobaths around entire island.
SP40-60	445	5	24	37	28	13	19	St. Paul, area between 40- and 60-m isobaths.
SG15-60	79	3	2	16	2	13	3	St. George, area between 15- and 60-m isobaths, bounded by Stratum 5 on the north.
SG>60	223	2	6	5	5	10	8	St. George, area between 60 m and about 80 m.
Total	830	19	38	87	38	52	34	

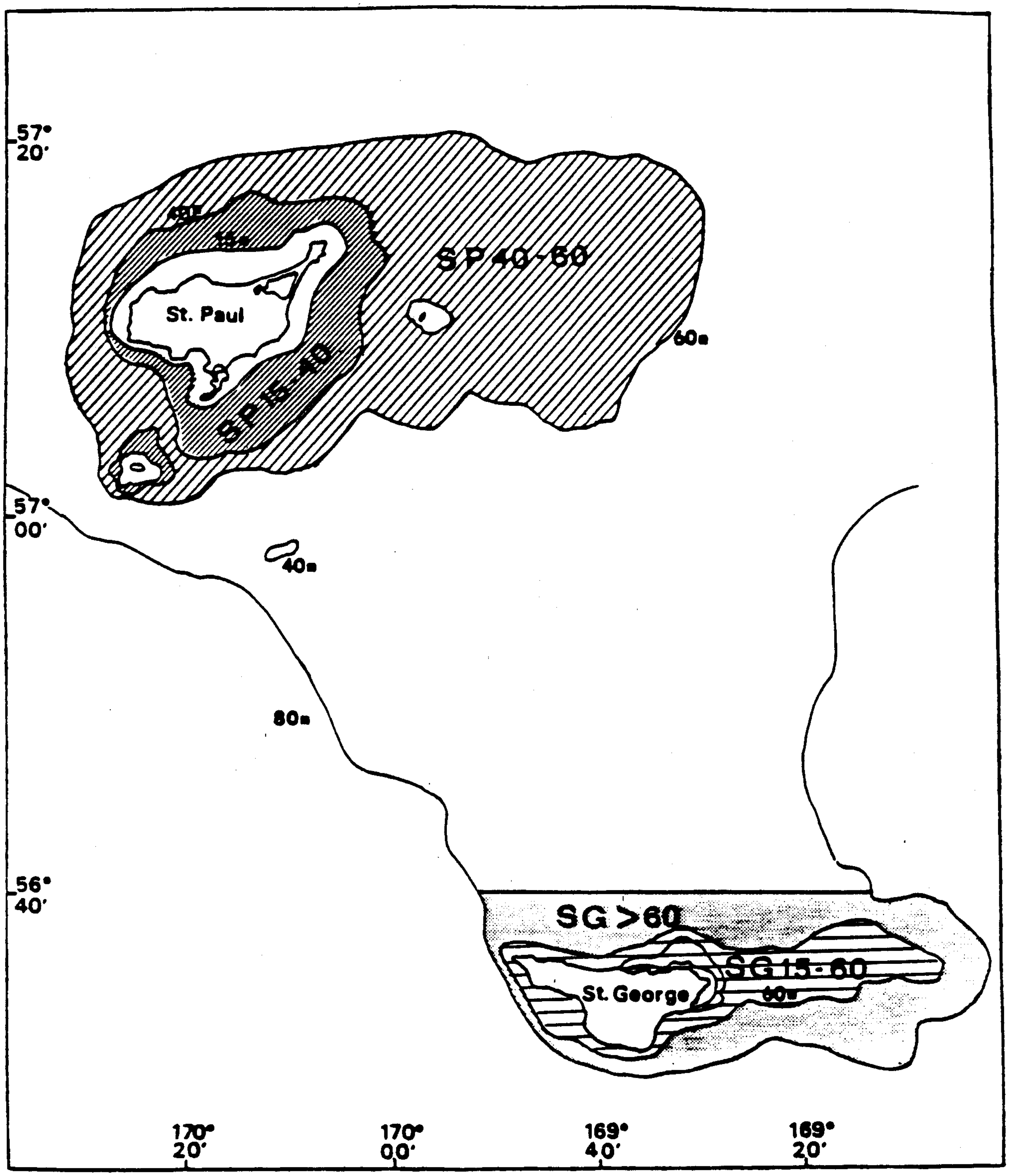


Figure 4.10 Depth strata around St. Paul (SP) and St. George (SG) islands; intervals in meters (see Table 4.4 for areas).

Table 4.5 Sediment strata information used to calculate abundance of blue king and Korean hair crab around the Pribilof Islands.

Stratum number	NM² (km²)	Total stations May 83 RD	May 83 BT	Aug 83 RD	Aug 83 BT	Apr 84 RD	Apr 84 BT	Location and comments
102	260	1	3	NS	1	3	5	St. George sand, boundaries 169°55' to the west, ≧90 m contour to the east.
105	33	1	1	2	NS	1	NS	St. George rock.
110	13	NS	4	1	1	1	2	St. George cobble.
114	67	4	3	18	5	20	5	St. George shellhash.
Subtotal	343 (1,176)	6	11	21	7	25	12	
115	976 (3,348)	2	19	1	16	2	22	Sandy basin area between St. Paul and St. George <90 m, 57°00'N to 56°40'N and 170°40'W to 169°20'W.
122	563	1	18	2	18	5	30	St. Paul sand, 170°15'W to 169°33'W and 57°00'N to 57°22'N.
123	200	2	6	7	6	2*	2*	St. Paul sand, 170°15'W to 170°40'W and 57°00'N to 57°22'N.
125	70	5	1	25	3	10	NS	St. Paul rock.
128	23	1	1	9	5	2	1	St. Paul cobble.
135	48	8	3	29	11	18	7	St. Paul shellhash.
Subtotal	904 (3,101)	17	29	73	43	37	40	
Total	2,253 (7,728)	25	59	95	66	64	74	

NS = Not sampled.

* Sea ice restricted sampling.

cruise with each gear type and in each stratum configuration is given in Appendix C.4.

4.3 Juveniles

4.3.1 Size-at-Age Groupings

Two general sizes of BKC were caught during these cruises, one that ranged from about 2.8 mm to 33 mm CL and the other that ranged from about 80 mm to 174 mm CL. The relative proportions of small and large crab were highly dependent on the type of gear used and also the bottom substrate. For instance, the BT used on both shellhash and sand around St. Paul Island caught both small juveniles and adult crab (Figs. 4.11 and 4.12) whereas the RD caught almost exclusively small juvenile crabs (Fig. 4.13). Additional size frequency data on BKC is contained in Appendices C.5 and C.6. BKC are very small at settlement, averaging 2.8 mm CL as first instars and 3.6, 4.6, 5.3 and 6.2 mm CL at second through fifth instars, respectively. Weight increase between the first and fifth instars is substantial, from about 2.5 to 20.0 mg ash free dry weight (Fig. 4.14). Based on all available size frequency data from the three cruises, tentative size-at-age ranges are established for the first four age classes of juveniles as well as for subadults and adults (Table 4.6). If metamorphosis and settlement occurs by early August (based on high abundance of first instars during mid-August cruise 1983), then very little growth occurs during the subsequent year since, by April 1984, juveniles in the size range of 2.8 mm to 6.2 mm were still common. From a sense of size-at-age, the proportion of crab caught by both the RD and BT were separated according to age class and percent frequency is shown in Figure 4.15. During each cruise a much higher proportion of the total juveniles caught by the RD were younger age classes (smaller crab), mostly 0+ and 1+

SHELLHASH, ST. PAUL, BT

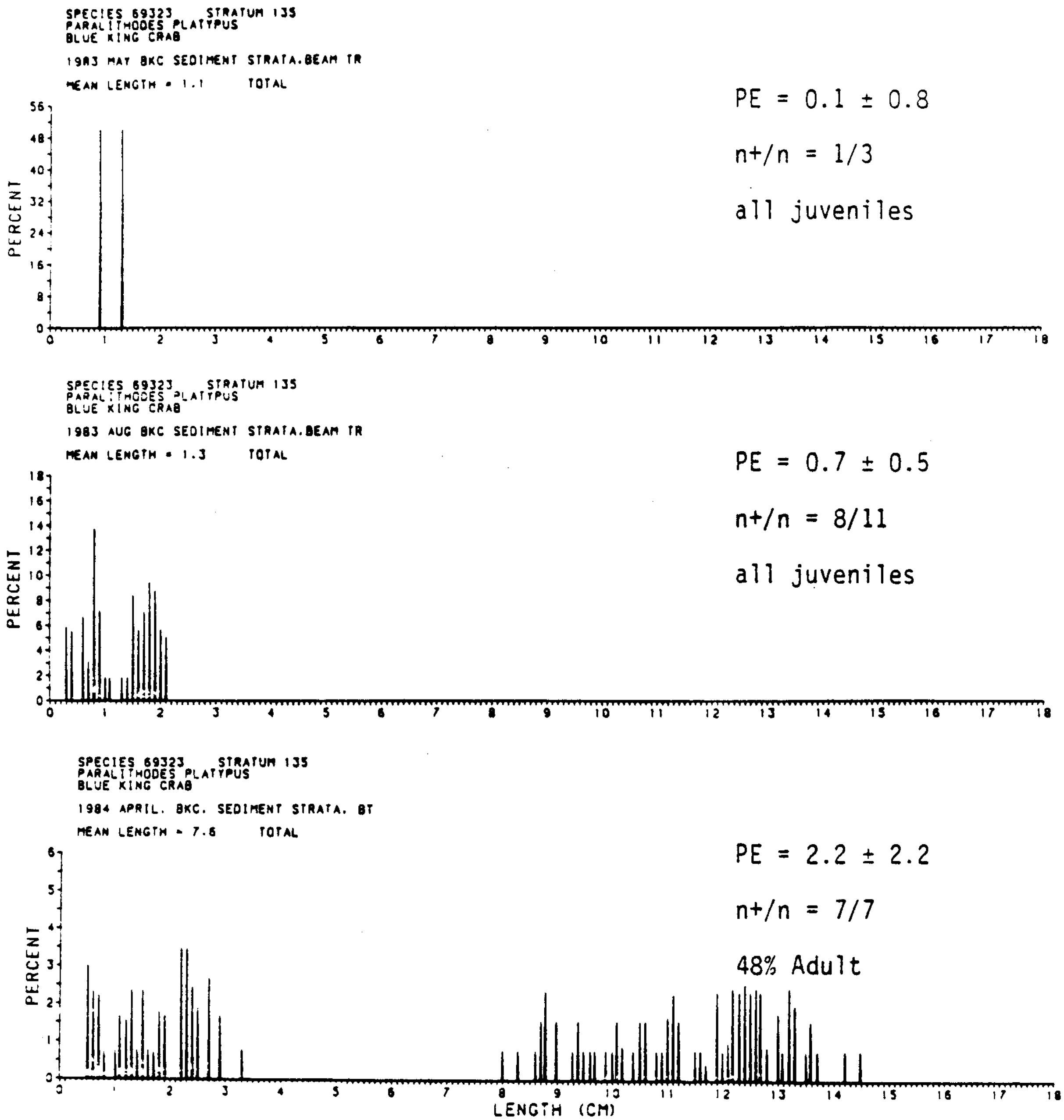


Figure 4.11 Carapace length frequencies of blue king crab collected in May and August 1983 and April 1984 by beam trawls from stratum 135, the shellhash stratum of the sediment strata configuration. Populations estimate (PE) in millions of crab, number of stations with crab/total number of stations sampled (n+/n), and percentage of the total population that were adults are also given.

SAND, ST. PAUL, BT

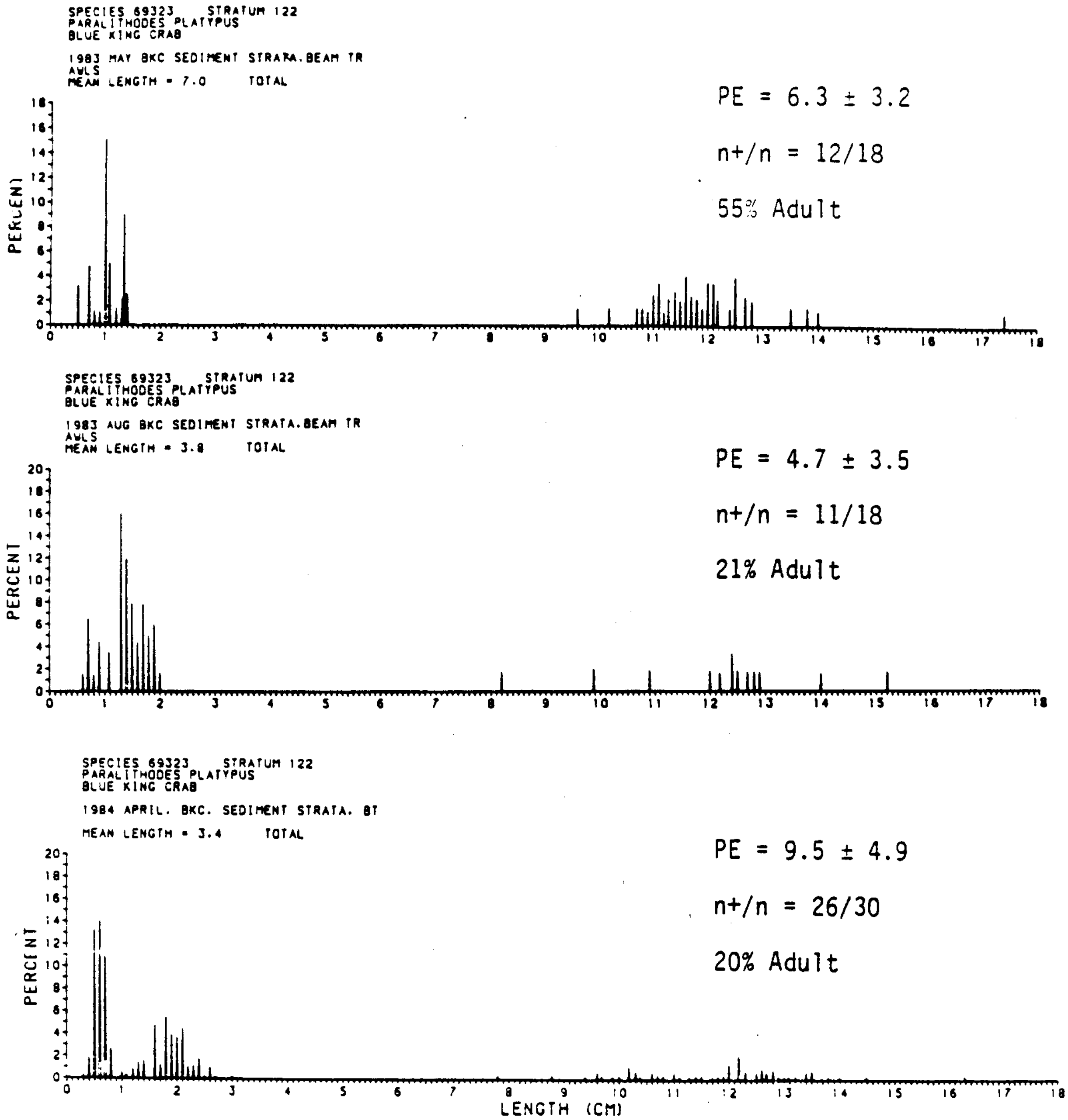


Figure 4.12 Carapace length frequencies of blue king crab collected in May and August 1983 and April 1984 by beam trawls from stratum 122, the sand substrate stratum to the east of St. Paul Island. Population estimate (PE) in millions of crab, number of stations with crab/total number of stations sampled (n+/n), and percentage of the total population that were adults are also given.

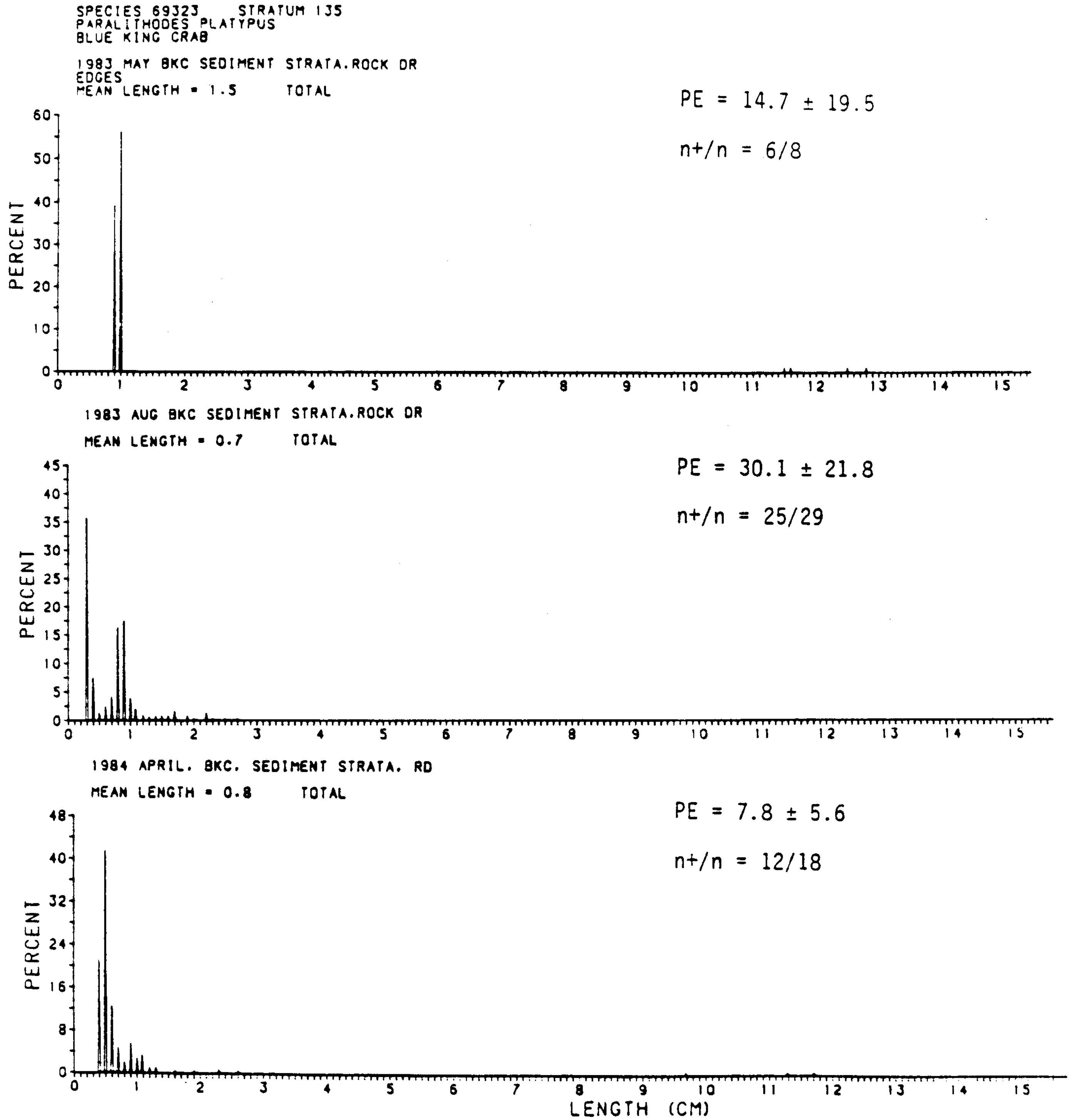


Figure 4.13 Carapace length frequencies of blue king crab collected in May and August 1983 and April 1984 by rock dredges in shellhash stratum 135 (sediment strata configuration). Population estimate (PE) in millions of crab, number of stations with crab/total number of stations sampled (n+/n), and percentage of the total population that were adults are also given.

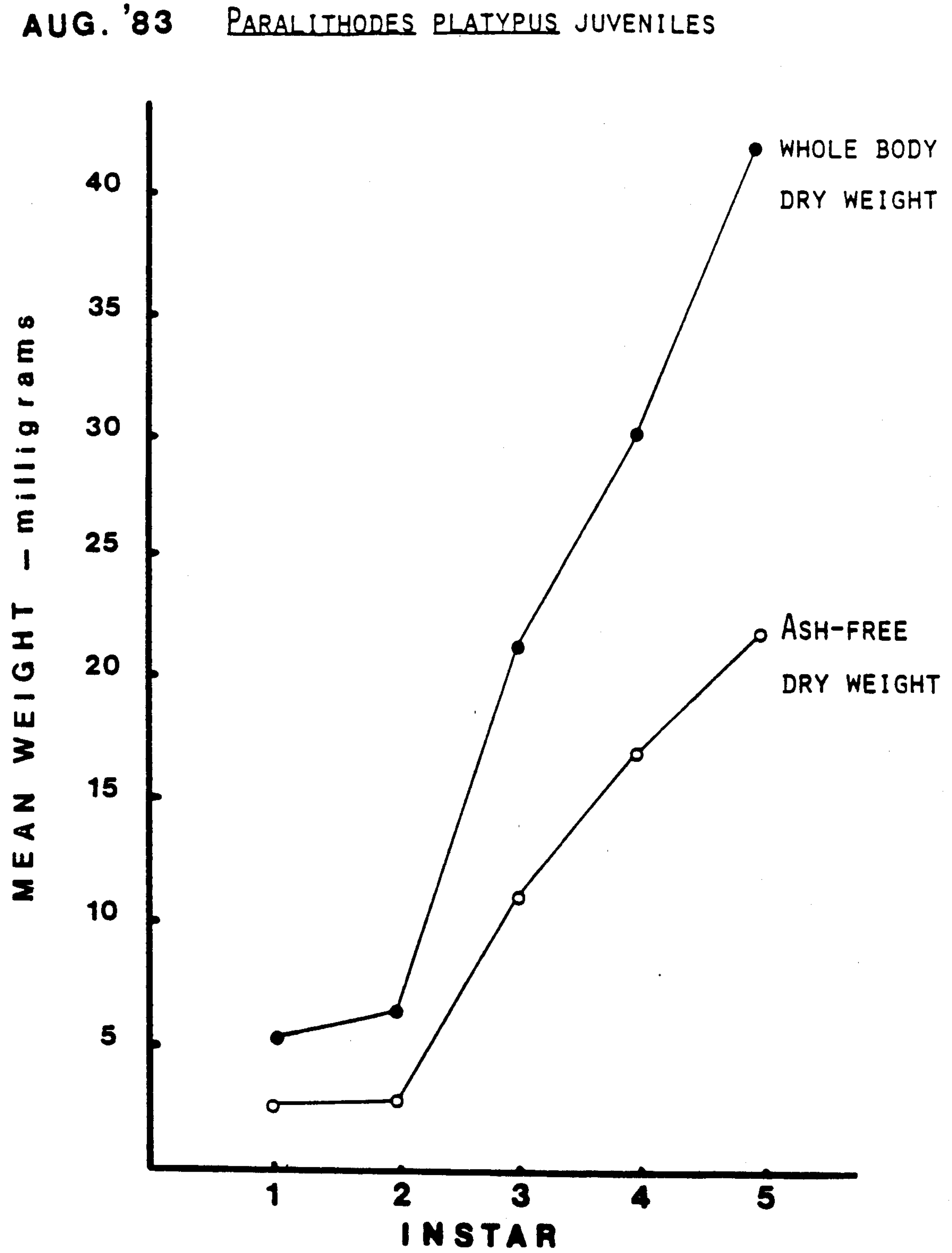


Figure 4.14 Paralithodes platypus juveniles, whole body dry weights vs. ash-free dry weights for 1st-5th instars, August 1983.

Table 4.6 Tentative size-at-age categories for blue king crab and Korean hair crab.

Species and age class	Size
Blue king crab	(Carapace length in mm)
0+	>2.8 - 6.5
1+	>6.5 - 12.5
2+	>12.5 - 19.5
3+	>19.5 - 33.5
Subadult	>34.0 - 94.9 if female or >27.5 - 99.9 if male
Adult	>95 if female, >100 if male
Korean hair crab	(Carapace width in mm)
0+	3 - 9.5
Juvenile	>9.5 - 40
Adult	>40*

* All Korean hair crab greater than 20 mm CW were considered adults, but males do not reach sexual maturity until they are 70 mm CW. Thus, our estimates may overestimate the number of mature males at this stage of analysis.

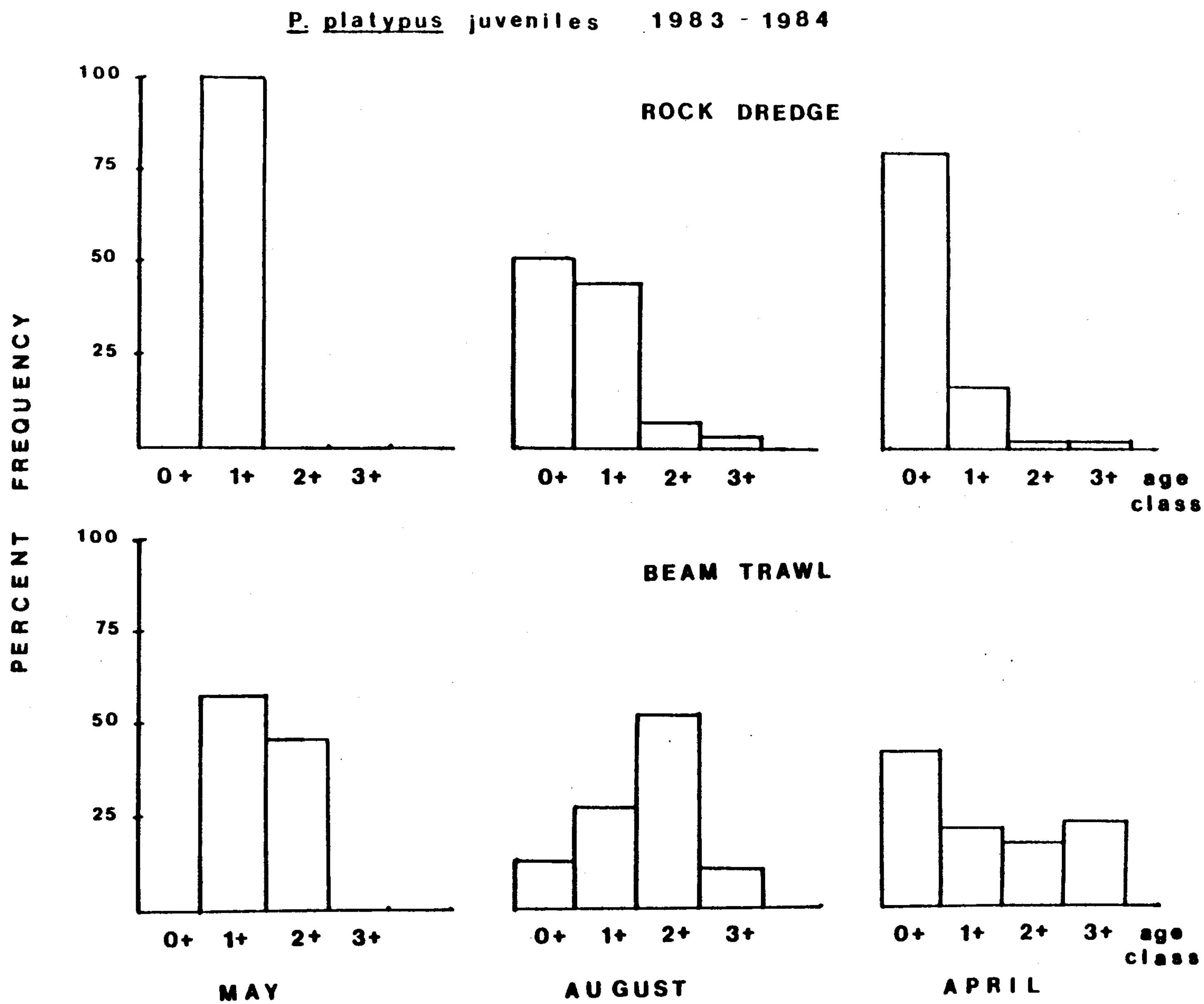


Figure 4.15 Percent frequency of age classes (0+ to 3+) of the Paralithodes platypus juvenile population taken by gear and by month from the inshore area (strata 11-41) around St. Paul Island, 1983-84.

whereas the BT caught predominantly 1+ and 2+ age classes near St. Paul Island.

4.3.2 Distribution and Density

The great majority of juvenile BKC occurred in three limited areas around the Pribilof Islands: west/northwest and east of St. Paul Island, and along a relatively narrow ridge east of St. George Island (Fig. 4.16; Appendices C.7 and C.8). In May 1983, juvenile density ranged from 132 to 3975 crab/ha throughout the survey area but was generally less than 200 crab/ha (Appendix C.7). Mean density at St. Paul Island equalled 1247 (± 1657, 1 SD) compared to 310 ± 85 crab/ha for the more sparsely populated area around St. George Island. These juveniles were predominately from the 1982 year class (size 4-10 mm; Fig. 4.13; Appendix C.5). BT values in May 1983 ranged from 7 to 250 crab/ha with a mean of 28 (± 19) crab/ha for the area east of St. Paul and a mean of 13 (± 6) crab/ha for the inter-island sandy basin (Appendix C.7). These densities reflect fewer juvenile crab caught by the BT compared to the RD and lower catches offshore in 60-80 m depths as opposed to nearshore. These juveniles were predominately 7 to 14 mm CL crab from the 1981 year class (Appendix C.5).

In August 1983 after settlement of the 1983 (0+) year class, large numbers of juveniles were caught with the RD all around and nearshore of St. Paul Island and east of St. George Island between 40-60 m contours (Fig. 4.16). Densities around St. Paul Island ranged from 37 to 16,962 crab/ha with a mean of 1530 (± 2977) crab/ha, and around St. George Island from 40 to 5580 crab/ha with a mean of 1630 (± 2204) crab/ha. These higher densities were represented by size modes around 4 to 5 mm CL (0+) and 8 to 11 mm CL (1+) (Fig. 4.13). August BTs (not pictured) ranged from 5 to 122 crab/ha with a mean of 41 crab/ha to the east of St. Paul Island and a mean

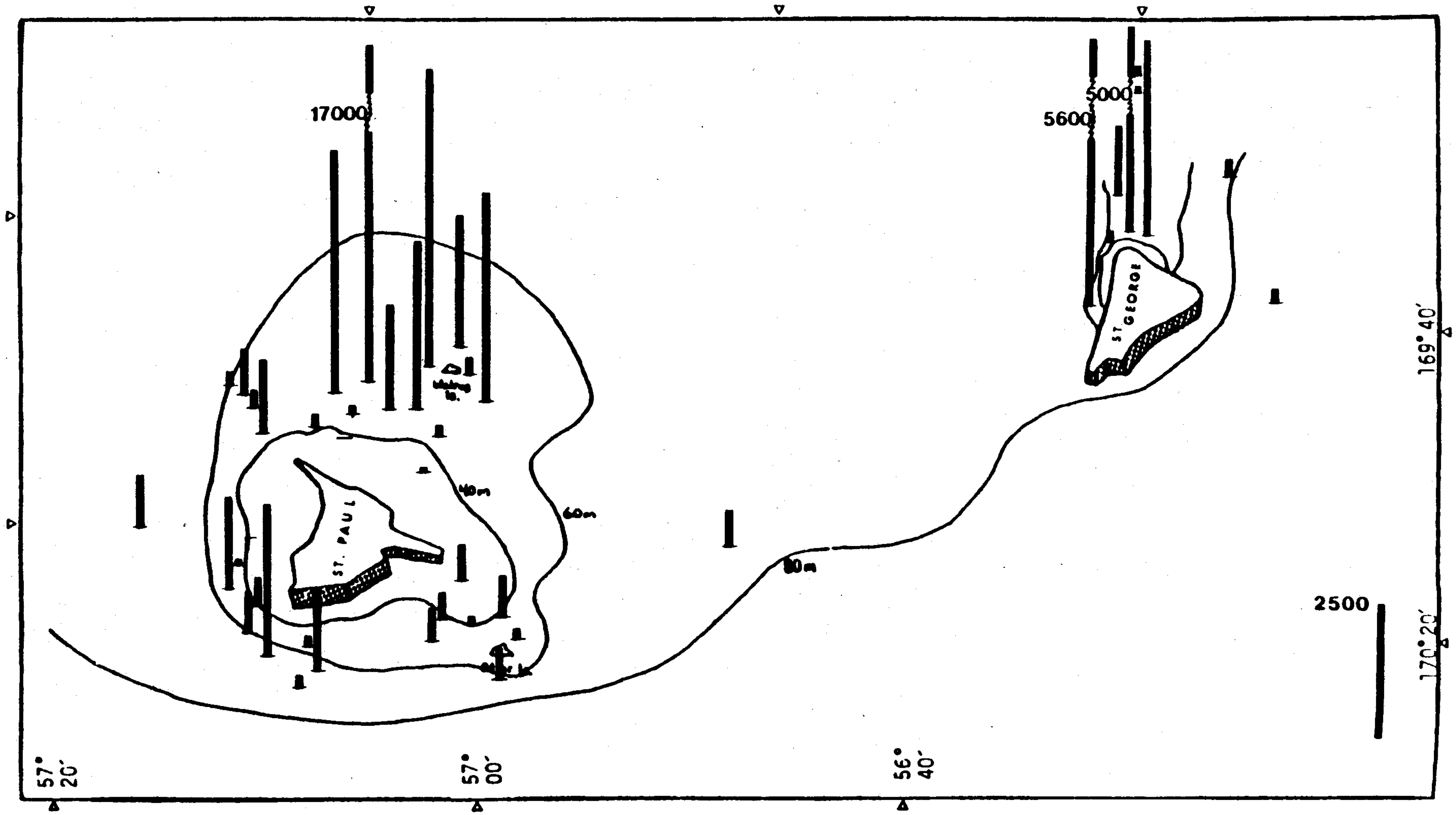


Figure 4.16 Juvenile Paralithodes platypus distribution and abundance, August 1983, expressed as number of juvenile crab/hectare caught by rock dredges only.

of 13 crab/ha over the inter-island sandy plain.

April BKC juvenile density as determined by RD ranged from 42 to 2053 crab/ha with a mean of 570 ($\pm$ 692) crab/ha at St. Paul island and a mean of 425 ($\pm$ 586) crab/ha for St. George Island (Appendix C.8). Catches by the BT ranged from 3 to 218 crab/ha with a mean of 49 ($\pm$ 57) crab/ha around St. Paul Island and a mean of 32 ($\pm$ 34) crab/ha for the inter-island area (not pictured). Only two tows at St. George Island caught juvenile BKC. These April 1984 means were slightly higher than the mean juvenile density found one year earlier in May 1983.

During all three cruises, the highest densities of juvenile BKC consistently occurred on shellhash (SH I, intact or large pieces, Section 2.3). Table 4.7 compares densities and shows a declining order from SH I, gravel-cobble, rock, to sand; the same trend is also true of the BT.

4.3.3 Estimated Population Abundance

As discussed in Section 4.2.2, several configurations of strata were used to group stations for population estimates (NMFS Burroughs, BIOMASS program). For juvenile BKC (and KHC in Section 5.0) there is a great possibility of drastically overestimating abundance by use of largest geographical Str 1 to 6 (Fig. 4.1), and ultimately the sediment strata seem most appropriate (the numbers of total stations and number at which crab were caught are given in Appendix C.4).

A sense of the magnitude of difference in population estimates using data for the same year and gear (RD or BT) for various strata configurations is shown in Figure 4.17 for August 1983 (estimates for May 1983 and April 1984 are given in Appendices C.9, C.10). For example, using RD data around St. George Island, juvenile BKC estimated abundance is 264, 105, 29.3 and 38.3 million for strata 6 and 61, sediment and depth, respectively (Fig.

Table 4.7 Substrate distribution of juvenile blue king crab on sediments at St. Paul Island, May 1983-April 1984. Sample size (number of tows with crab/total number of tows) and mean density (crabs/ha) ± 2 SD are given. Data for rock dredges. See Table 4.5 for strata numbers and locations.

Sediment Type (Stratum Number)	May 1983		August 1983		April 1984	
	Sample size	Density	Sample size	Density	Sample size	Density
Sand (122 + 123)	0/3	0	1/10	15 ± 47	1/7	8 ± 20
Rock (125)	0/5	0	8/25	100 ± 345	2/10	21 ± 54
Gravel-Cobble (128)	0/1	0	6/9	654 ± 602	0/2	0
Shellhash (135)	5/8	780 ± 1318	25/29	1815 ± 3454	12/18	461 ± 674

Table 4.8 Juvenile blue king crab population estimates in millions of crab for the sediment strata. See Table 4.5 for locations; Fig. 4.17 for comparative values.

	Rock Dredge			Beam Trawl		
	May 83	Aug 83	Apr 84	May 83	Aug 83	Apr 84
St. Paul Island	14.7	43.5	10.4	2.8	4.7	8.7
St. George Island	8.3	29.3	7.3	1.9	0.2	0.6
Subtotal	23.0	72.8	17.7	4.7	4.9	9.3
Inter-island area	33.1*	226.9*	--	1.7	2.2	6.8
Total	56.1	299.7	17.7	6.4	7.1	16.1

* Only one or two rock dredge samples were taken in this area (Stratum 5) each cruise, so estimates are tenuous (see Table 4.4 for no. of stations).

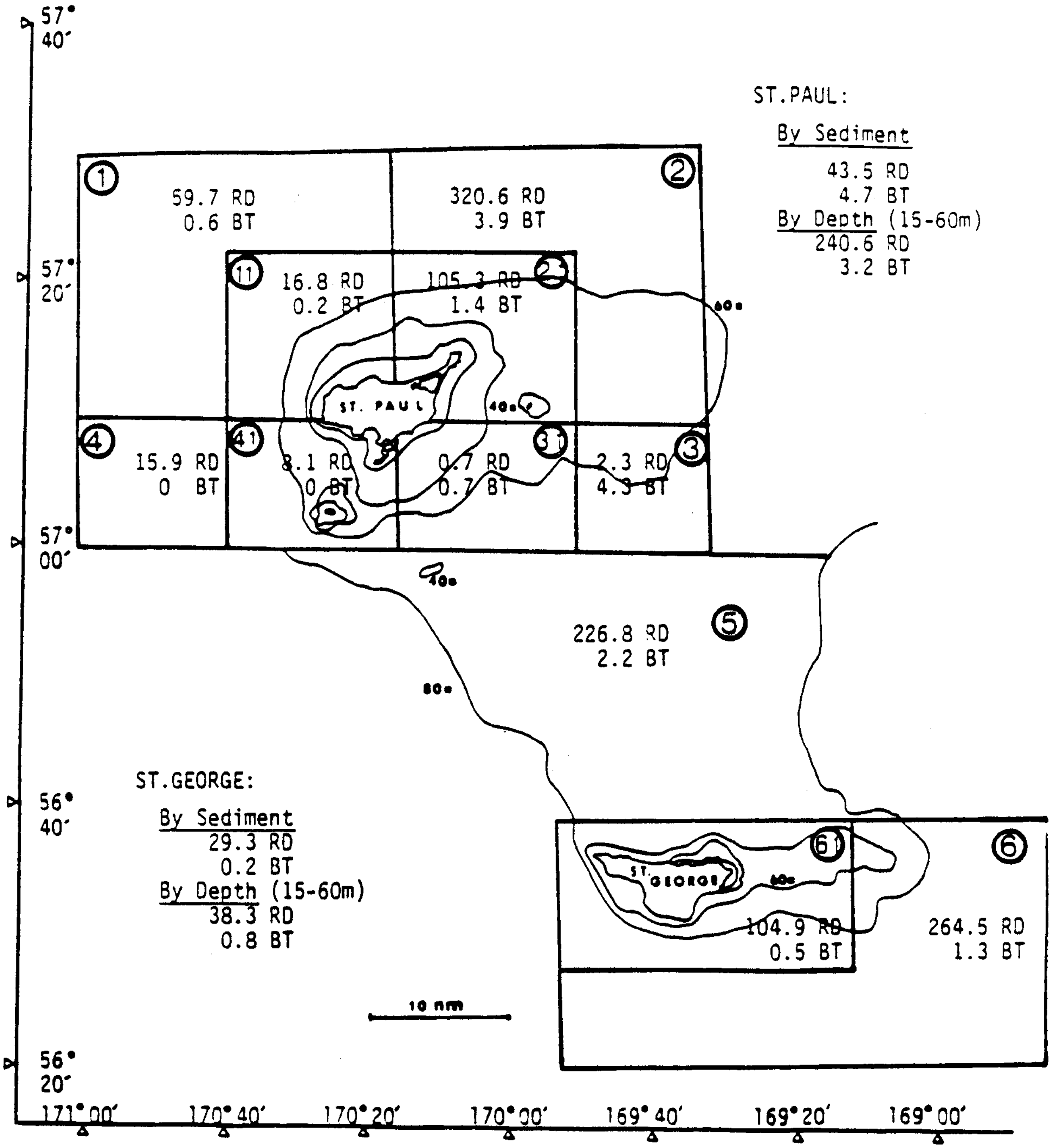


Figure 4.17 Population estimates for Paralithodes platypus juveniles in August 1983 by strata. Separate estimates, expressed as number of crab x 10^6, are given for each gear; RD = rock dredge, BT = beam trawl. Estimates for nearshore strata 11-41 and 61 can be compared to the island totals figured for both the sediment and depth strata.

4.17). Some sense of the variation associated with these estimates can be had in Appendices C.11 to C.13, which show that ± 2 standard errors (SE) are generally 80% to 120% of the mean.

The most reliable spatial bases for an estimate of abundance are the sediment strata (Table 4.8). Juvenile population estimates were always higher for the RD than BT, and usually for the sediment strata at St. Paul Island compared to St. George Island (Fig. 4.17; Table 4.8). In May 1983, the combined RD total around both islands was 23 million (Table 4.8) plus 33.1 million from the inter-island area for a total of 56.1 million (a similar total estimate based on the depth strata for both islands is 108.6 million, Appendix C.11). By August the estimates for St. Paul and St. George Island increased about 3 X to 43.5 and 29.3 million (72.8) total, respectively, while a 7 X increase between the islands brought the total to about 300 million juveniles; most newly settled 0+. Through the fall and winter of 1983/84 the two-island estimate declined 4 X to about 17.7 million crab (no mid-island RD data was taken).

Juvenile population estimates based on BT data did not follow the trend of low spring-high summer abundance (Table 4.8). Values for May and August 1983 were 6.4 and 7.1 million, respectively, but increased to 16.1 million in April 1984. This trend might reflect greater vulnerability to the net with increased size since juveniles in SH I were generally larger in April (20 to 30 mm CL; Fig. 4.11).

4.4 Adults

4.4.1 Seasonal Distribution and Abundance

There was a marked seasonal change in the distribution and relative density of BKC around the Pribilof Islands, notably, higher density nearshore around St. Paul Island in spring and more dispersed offshore distribution and lower density in summer. In May 1983 most crab were located east of St. Paul Island beyond the 60 m isobath and were predominantly females (Fig. 4.18). Adult females were most concentrated in large geographic Strata 3 and 5 (Figs. 4.1 and 4.18) and had a mean density of 29 (± 20) crab/ha. Adult males were rare in the study area and were taken at only four of 70 BT stations at a mean density of 9 crab/ha (Fig. 4.18). No adult crabs were taken anywhere around St. George Island. By August, BKCs were much more dispersed and farther offshore, midway between the islands, and were taken in only 14 of 66 BT tows in the sandy basin between the two islands that corresponds to geographic Stratum 5 (Fig. 4.19). Density was low at a mean of 13 (± 11) crab/ha and all were females.

BKC had once again moved nearshore of St. Paul Island by April 1984 and, at this time, males were more common within the population (Fig. 4.20). The highest densities of crab occurred between the 40 m and 60 m isobath to the east of St. Paul Island around Walrus Island. The mean density of adult females was 24 (± 33) crab/ha at 27 of 74 BT stations. Male density at 11 of 74 BT stations was 20 (± 39) crab/ha (Fig. 4.20). Many of the females in this area were old shelled and carried eyed eggs about to hatch or were new shelled females that had just extruded an egg mass (see Section 4.5). Aggregation of crab in this area implies an onshore movement for the combined purposes of egg hatch and mating. For these purposes the habitat around St. Paul Island is apparently important to this species since neither adult male or female BKC were ever found around St. George Island during all three cruises (Figs. 4.18 to 4.20).

4.4.2 Estimated Population Abundance

As noted with juveniles, several means of estimating abundance were employed that give relatively consistent results in the case of adult crab.

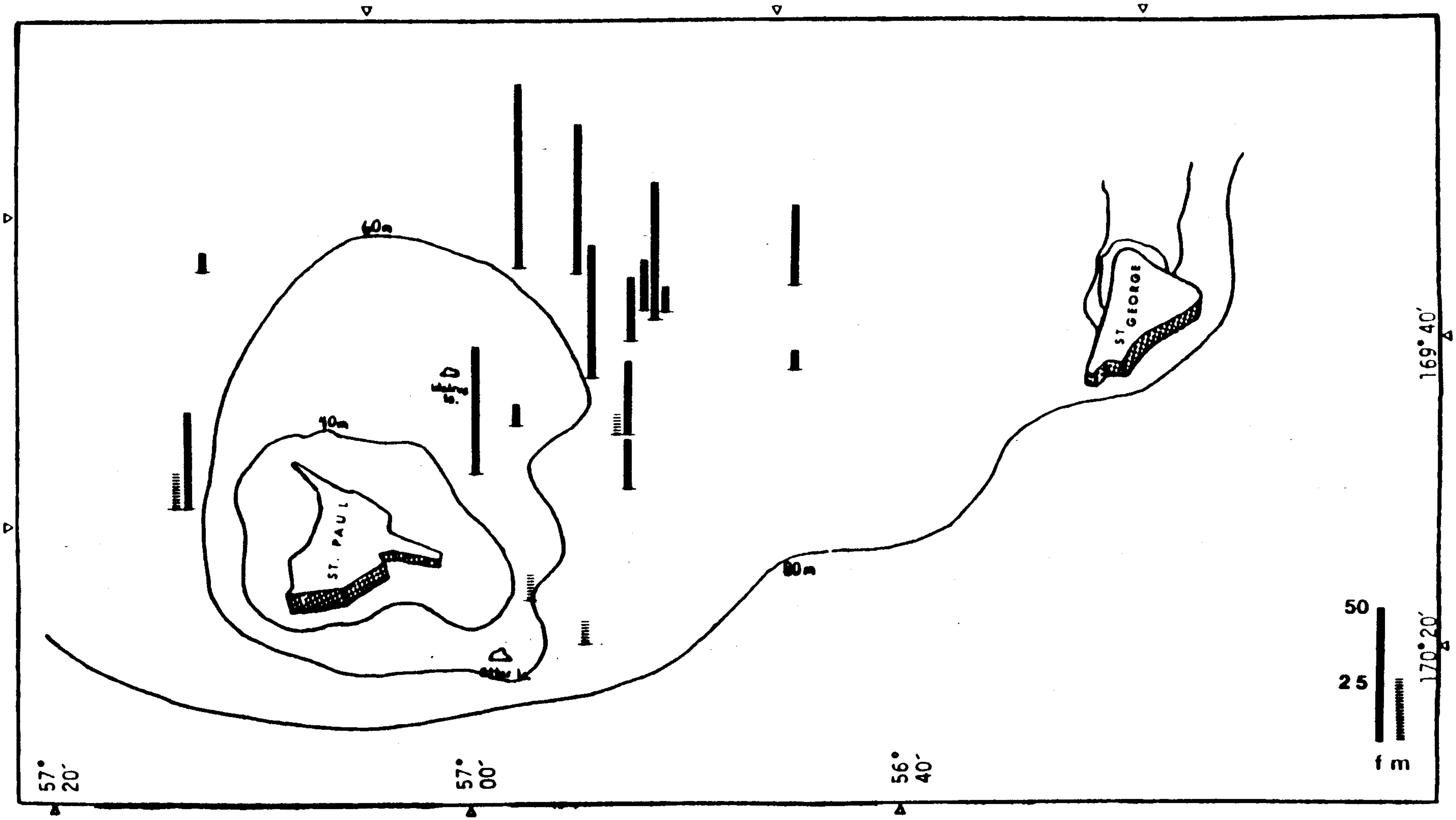


Figure 4.18 Paralithodes platypus adults, May 1983, expressed as number of crab/hectare taken by beam trawls, females (solid bars) and males (striped bars).

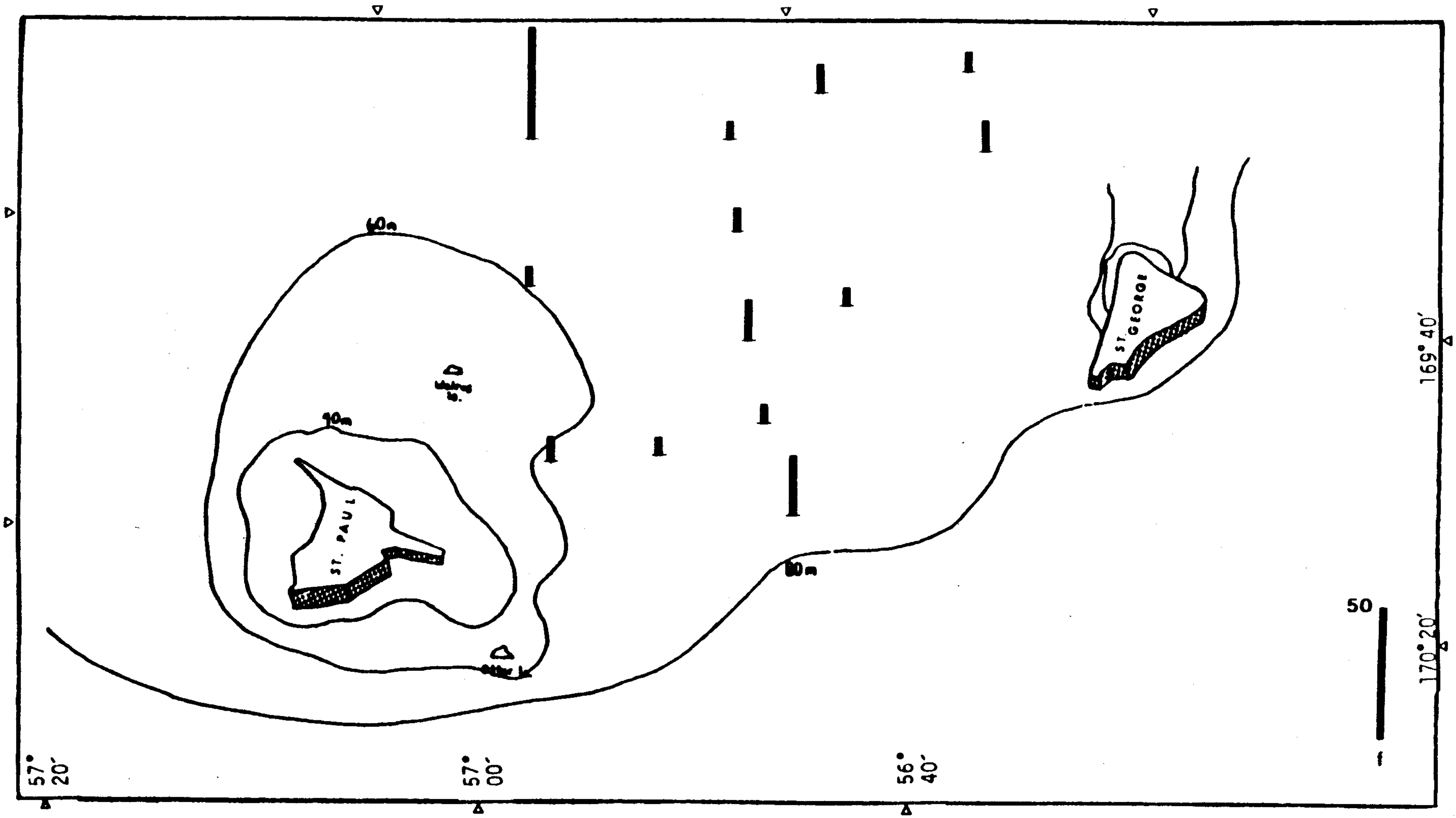


Figure 4.19 Paralithodes platypus adult distribution and abundance, August 1983, expressed as number of crab/hectare taken by beam trawls, females only. No males were taken during this cruise.

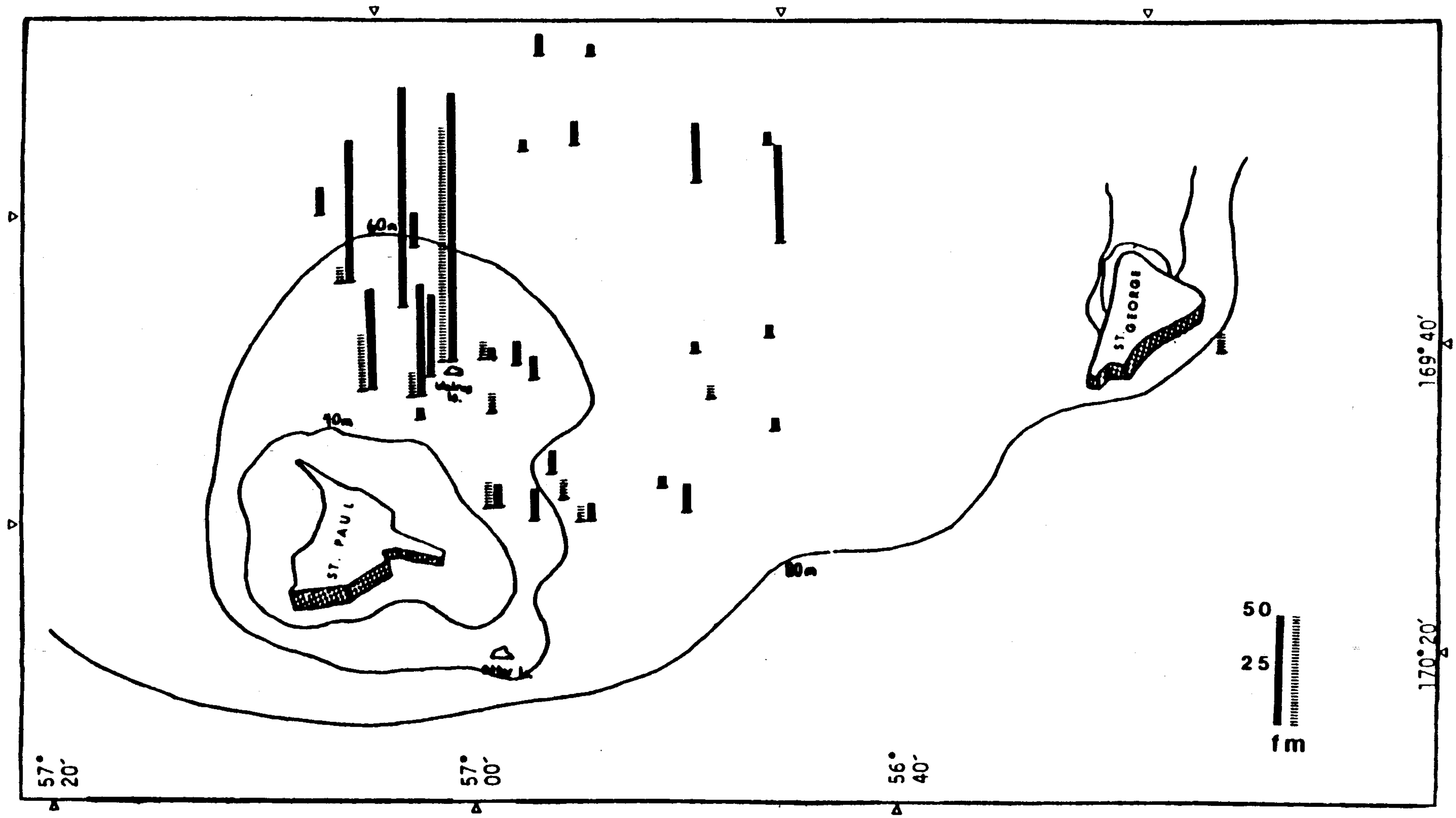


Figure 4.20 Paralithodes platypus adult distribution and abundance, April 1984, expressed as number of crab/hectare taken by beam trawls, females (solid bars) and males (striped bars).

In general, results based on the six large geographic strata (Fig. 4.1) are considered the best estimator of adult abundance because of the wider distribution of this stage. In May 1983 the greatest abundance of adult BKC around the Pribilof Islands occurred in Stratum 3 to the southeast of St. Paul Island and in Stratum 5, the basin between the two islands (Fig. 4.21; similar population estimates for August and April are given in Appendices C.14 to C.17). In May 1983 the estimated total adult population around the Pribilof Islands was 10.3 million crab, 8.3 of which were female (Table 4.9). By August the population had declined about fourfold to about 2.4 million crab, all of which were females, but by the following April 1984 the population had risen to 8.7 million crab, 6.8 million of which were females (Table 4.9). As occurred the previous spring, the bulk of the female population in April was located east of St. Paul Island in large geographic Strata 2 and 3 (Appendix C.16).

It is interesting that the population of total BKC around the Pribilof Islands in 1983 estimated from the NMFS groundfish survey (Otto 1986) was 12.2 million. Since their total population is similar to our "adult population" based on size frequency data, the two estimates can be taken to encompass the same size range of crab. NMFS surveys are typically run from June to August in the Pribilof stations and most likely taken in early to mid July. Our May 1983 estimate of total crab was 10.3 million, very close to that of NMFS in the same year.

In 1984 the NMFS estimate for total population abundance was only 4.8 million, about half of our April value of 8.7 million (Table 4.9). Our survey in mid spring nearshore of St. Paul may have resulted in a higher estimate because of more aggregation, whereas the NMFS survey in summer comes after crab have dispersed.

Table 4.9 Adult blue king crab population estimates from geographical strata, 1983-84, by sex as taken by beam trawls. Values are expressed in millions of crab.

Strata	May 1983			August 1983			April 1984		
	Total Adults	Adult Female	Adult Male	Total Adults	Adult Female	Adult Male	Total Adults	Adult Female	Adult Male
1	1.6	1.2	0.4	0	0	0	NS	NS	NS
2	2.8	1.6	1.2	0	0	0	6.2	4.7	1.5
3	3.5	3.3	0.2	0.3	0.3	0	0.8	0.6	0.2
4	0.2	0	0.2	0	0	0	0	0	0
SP subtotal	8.1	6.1	2.0	0.3	0.3	0	7.0	5.3	1.7
5	2.2	2.2	0	1.8	1.8	0	1.6	1.5	0.1
SG subtotal 6	0	0	0	0	0	0	0.1	0	0.1
Total	10.3	8.3	2.0	2.4	2.4	0	8.7	6.8	1.9
11	0	0	0	0	0	0	NS	NS	NS
21	0	0	0	0	0	0	2.1	1.3	0.8
31	0.5	0.4	0.1	trace	trace	0	0.2	0.1	0.1
41	0.1	0	0.1	0	0	0	0	0	0
SP subtotal	0.6	0.4	0.2	0.05	0.05	0	2.3	1.4	0.9
SG subtotal 61	0	0	0	0	0	0	0.05	0	0.05
Total	0.6	0.4	0.2	0.05	0.05	0	2.3	1.4	0.9

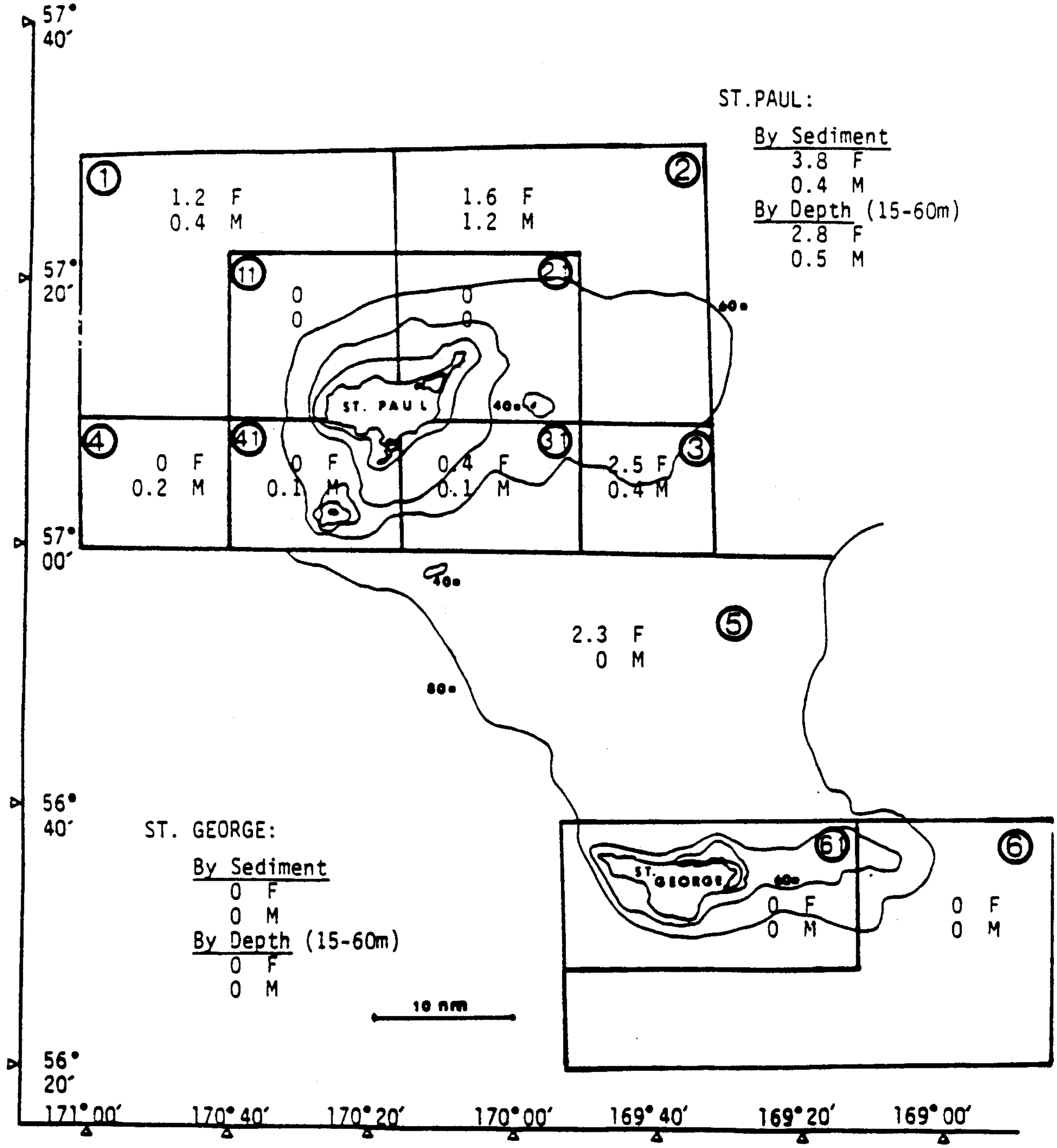


Figure 4.21 Population estimates for Paralithodes platypus adults by sex and strata for beam trawl data in May 1983. Estimates are expressed as millions of crab.

Table 4.10 Summary of mean carapace lengths (CL) and gonosomatic indices (GSI) for female blue king crab near the Pribilof Islands, 1983-84.

Cruise	Egg category	Shell	Number caught	Number dissected	%	$\bar{x}$ CL (SD)	$\bar{x}$ GSI (SD)
May 1983	New eggs	1-2	12	11	14	122.9 (9.0)	1.5 (0.7)
	Eyed eggs; not premolt	3	3	3	4	115.3 (2.5)	5.7 (3.1)
	Empty egg cases; not premolt	3	51	8	61	118.5 (9.7)	6.3 (2.1)
	Empty egg cases--trace	4	13	8	15	122.0 (8.9)	2.5 (1.4)
	Empty egg cases; premolt	3	1	1	1	102	14.8
	No eggs or cases	2	4	4	5	90.5 (9.9)	3.4 (2.0)
Aug 1983	Eggs	2	5	5	17	126.0 (16.3)	5.9 (1.0)
	Empty egg cases	3-4	25	17	83	120.5 (10.0)	11.9 (3.6)
Apr 1983	New eggs	1-2	57	9	46	117.8 (10.2)	2.3 (0.7)
	Eyed eggs; not premolt	3	44	11	36	124.5 (9.7)	7.5 (1.8)
	Eyed eggs; premolt	3	9	6	7	111.9 (10.7)	22.1 (5.5)
	Empty egg cases; not premolt	3	1	0	1	132	--
	No eggs or cases	2-3	13	3	10	103.3 (13.5)	7.2 (5.1)

4.5 Reproduction

4.5.1 Materials and Methods

All adult BKC and KHC in the samples were measured for carapace length (carapace width for KHC), weight and shell condition (SC) in accord with standard NMFS categories as follows: 1=soft shell; 2=new shell; 3=old shell; 4=very old shell (possibly skip molt). To determine molt condition in specimens not sacrified for reproductive analyses, the dactyl of a walking leg was broken and the presence or absence of an underlying new exoskeleton noted. Egg condition and clutch size were recorded for ovigerous specimens and a small portion of eggs was fixed in Bouin's solution and later transferred to 70% ethanol. Non-ovigerous females were checked for empty egg cases and, in the case of KHC gonapore plugs. Female BKC greater than 90 mm CL were dissected aboard ship and a small piece of ovary was also fixed in Bouin's solution, transferred to 70% ethanol and later embedded in paraffin, sectioned at 8 um, and stained with Weigert's hematoxylin and eosin Y. The remaining eggs of each female were stripped from the pleopods, and the eggs, ovary and body were dried separately to constant weight at 50°C; samples of each were then ashed at 550°C for 24 hours.

Embryonic stage and rate of development were determined from preserved egg samples examined under a dissecting scope and compared to developmental stages illustrated for RKC in Marukawa (1933). Ova diameters were measured using an ocular micrometer on a compound microscope at 100X magnification; only the largest and roundest ova were measured and the average diameter calculated. An ash-free gonosomatic index (ovary weight as a percentage of the total body weight), was calculated by dividing the ash-free ovary weight by the total ash-free body weight and multiplying by 100 (similar to Somerton and MacIntosh 1985, who used wet weight). All references to gonosomatic indices (GSI) will refer to this ash-free index.

Similarly, for females carrying newly extruded egg masses, an egg index (EI) was calculated by dividing the ash-free egg weight by the ash-free weight of the remaining body.

4.5.2 Gametogenesis and Embryonic Development

May 1983: From a total of 84 female BKC caught, 35 were dissected for study (Table 4.10). Only 15 ovigerous specimens were captured, 12 with newly extruded eggs and clean, new shells, and three with eyed eggs which were in the process of hatching (caught the second day of the May survey, 5/11/83). The majority (62%) of non-ovigerous adult females had old shells (SC 3) and carried large clutches of empty egg cases from the hatch that spring, while some females (15%) had extremely old shells (SC 4) and carried only traces of egg cases from the previous year.

Ovigerous females carrying newly extruded eggs had very thin, white ovaries with a mean GSI of only 1.5%; histological examination revealed only immature and fragmented, degenerating ova (Fig. 4.22). Specimens carrying eyed eggs had small pink ovaries with an average GSI of 5.7%, and developing ova contained some yolk and averaged 388 um (Fig. 4.23). The remaining females with old shells (SC 3) and empty egg cases averaged 6.3% while a single specimen in pre-molt condition had a GSI of 14.8% and ova diameters greater than 800 um (Fig. 4.24).

Examination of eggs from new shell females revealed several early stages of embryonic development, from invagination to the appearance of two cephalic lobes (Figs. 4.25 and 4.26). Eyed eggs were fully developed and some were in the process of hatching.

August 1983: Only 30 adult female BKC were captured on the August cruise, and these had dispersed somewhat farther offshore of the islands than in May. Of these, all five ovigerous specimens and 17 others with

Figure 4.22 Section of ovary from a female blue king crab taken in May 1983 and carrying a newly extruded egg mass. Only immature and degenerating ova and connective tissue remain. DO, degenerating ova; IO, immature ova; Y, yolk.

Figure 4.23 Section of developing ovary from female blue king crab caught in May 1983 and carrying eyed eggs. IO, immature ova; Y, yolk.

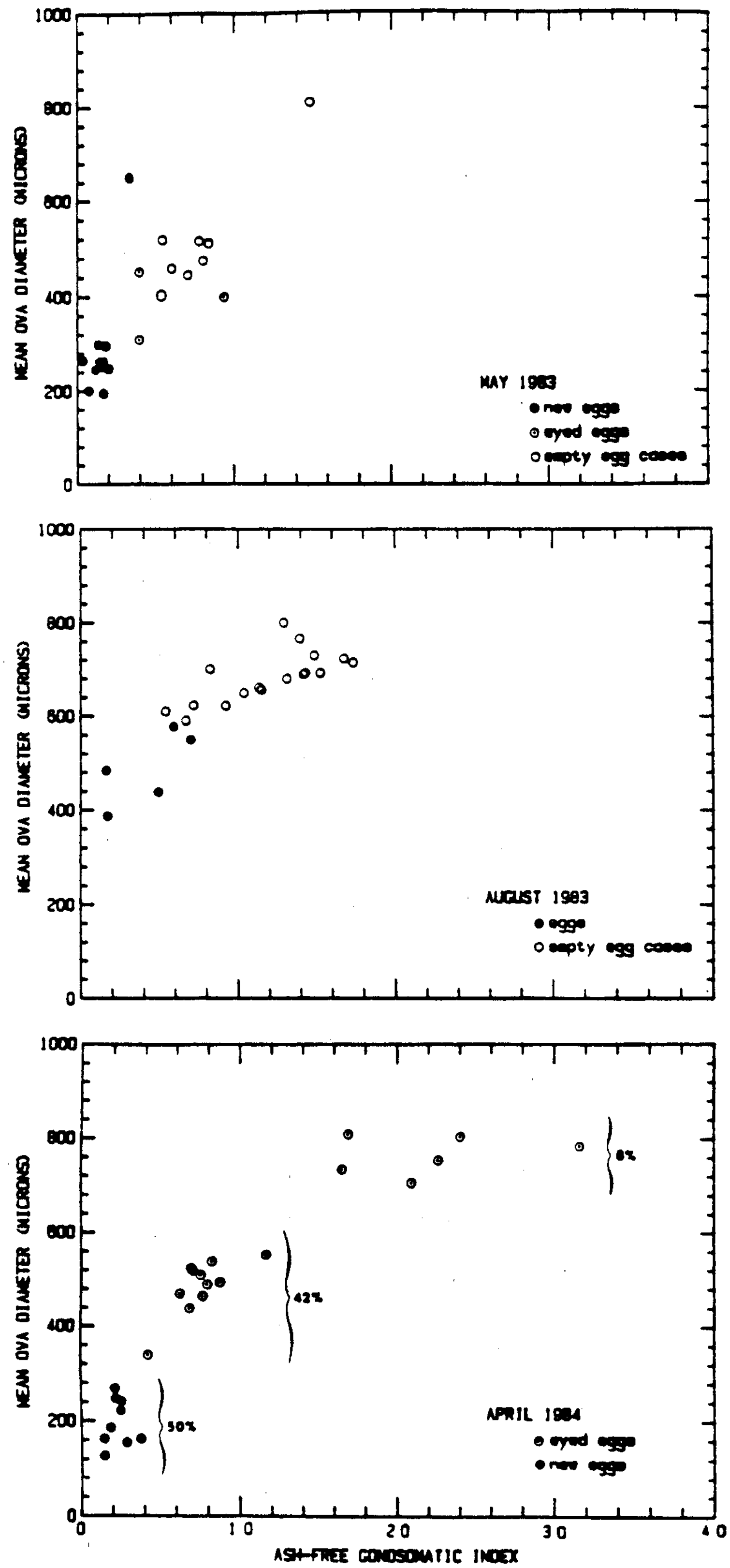


Figure 4.24 Mean ova diameters and ash-free gonosomatic indices for female blue king crab, 1983-84.

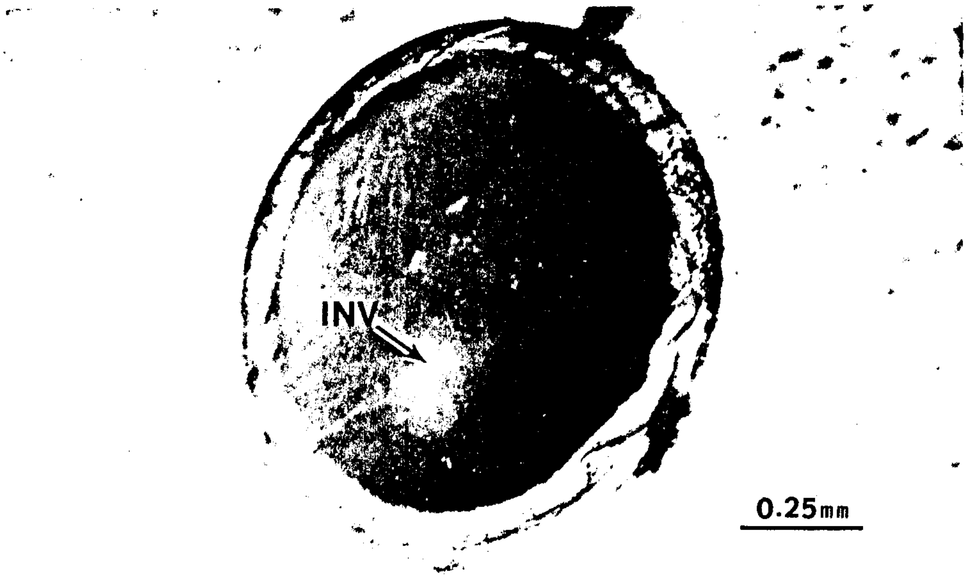


Figure 4.25 Egg from a new shell female blue king crab taken in May 1983, showing initial invagination. INV, invagination.

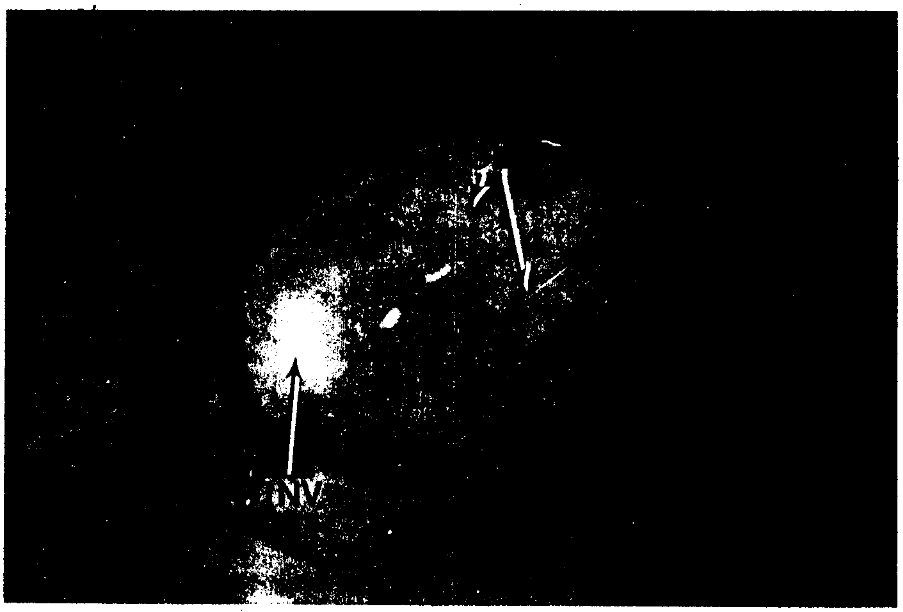


Figure 4.26 Egg from a new shell female blue king crab taken in May 1983, with cephalic lobes beginning to appear. CL, cephalic lobes; INV, invagination.

empty eggs cases were dissected (Table 4.10). Those with eggs had spawned that spring and had clean, fairly new shells in category SC 2, and the remaining specimens were all SC 3 or SC 4 and carried empty egg cases.

The GSI for the 5 ovigerous specimens averaged 5.9% compared to 11.9% for the non-ovigerous females (Fig. 4.24). Ova diameters of non-ovigerous August specimens averaged 682 um while the mean of the ovigerous females was 487 um. Ovaries from both types contained fairly large, developing ova with yolk and immature ova that apparently were not developing (Figs. 4.27 and 4.28). As in May, the extent of egg development varied slightly, ranging from embryos with well developed cephalic lobes and antennae (Fig. 4.29) to large embryos with a fully developed telson (Fig. 4.30).

April 1984: In early spring, 124 female crabs were caught ranging in size from 78 to 145 mm CL, and 29 specimens were dissected (Table 4.10). Of 110 ovigerous specimens (caught primarily east of St. Paul), 46% had new shells (SC 1,2) and newly extruded egg masses and 43% were old shell (SC 3, molted previous spring 1983) and carried eyed eggs; only one had empty egg cases. Examination of females carrying eyed eggs revealed two distinct groups: one composed of specimens with small ovaries and a second characterized by large, well-developed ovaries (Fig. 4.24). Those with small ovaries tended to be large (X = 124.5 mm CL) with a mean GSI of 7.5% and an average ova diameter of 486 um (Table 4.10). The second group was characterized by having large ovaries with a mean GSI of 22.1% and an average ova diameter of 766 um; these were in premolt condition as evidenced by a new dactyl when the old one was broken off. This group comprised only 7% of the females caught, and averaged only 111.9 mm CL.

Eggs from new shell females were in the morula stage (Marukawa 1933) or earlier, while the eyed eggs were usually in the process of hatching.

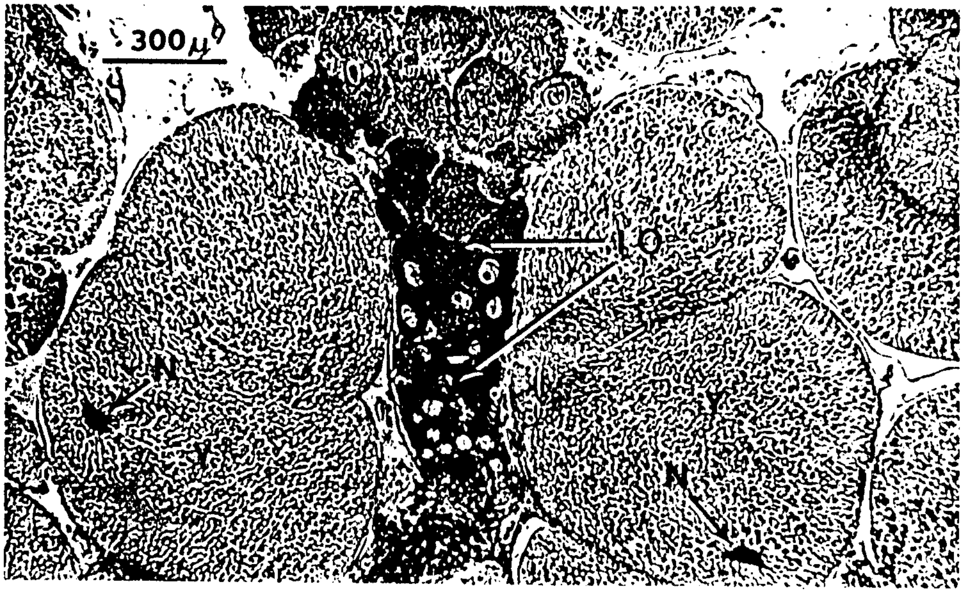


Figure 4.27 Section from a developing female blue king crab ovary showing large, well developed ova with yolk and small, non-vittelogenic ova. IO, immature ova; N, nucleus; Y, yolk.

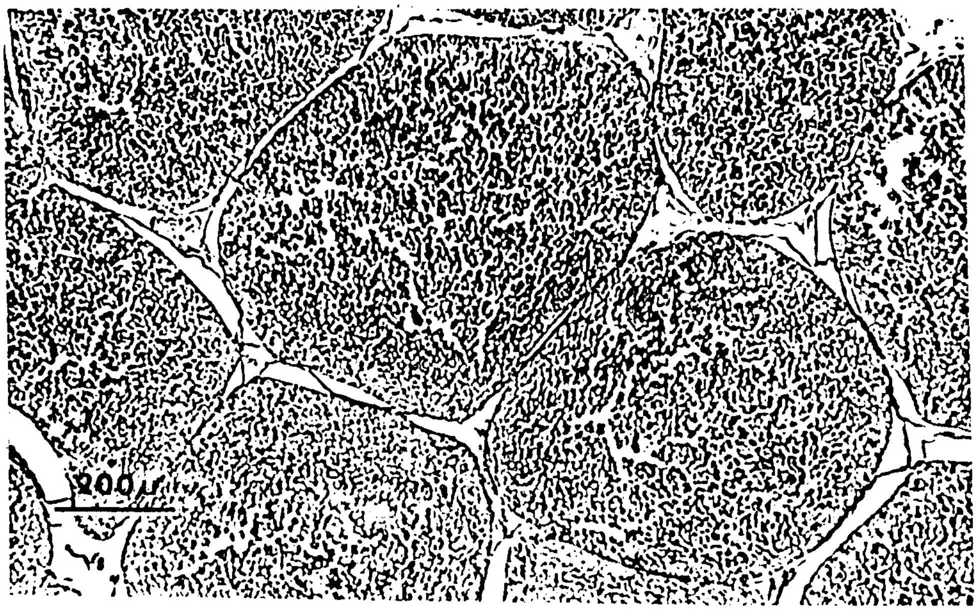


Figure 4.28 Example of a large, fully developed ovary from a blue king crab, August 1983.

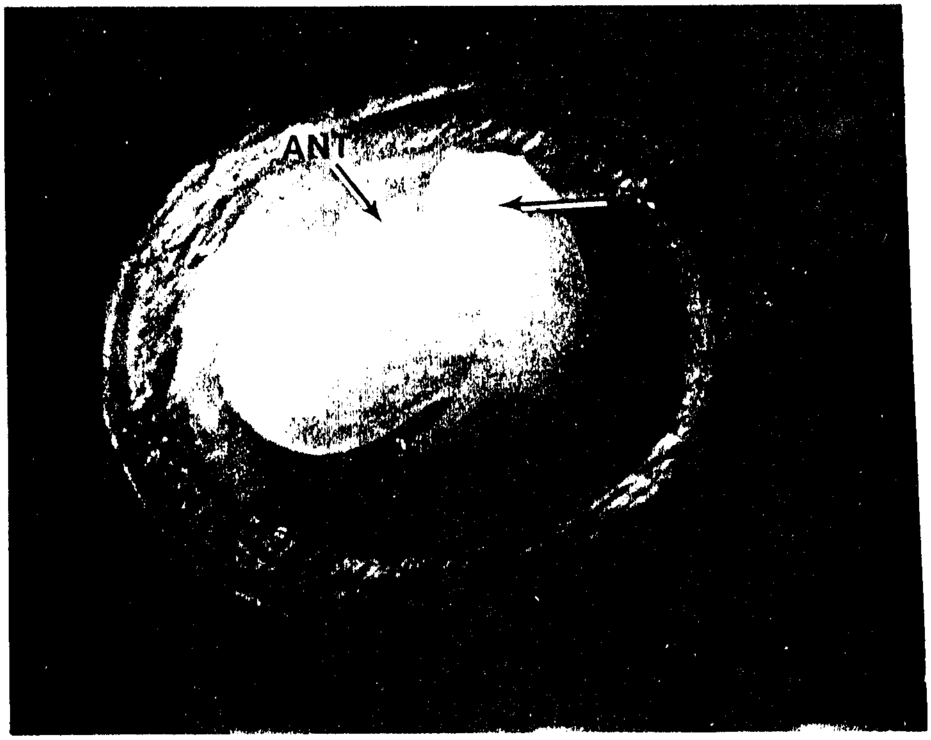


Figure 4.29 Egg from a female blue king crab caught in August 1983 showing embryo with prominent eyestalks and antennae. ANT, antennae; ES, eyestalk.

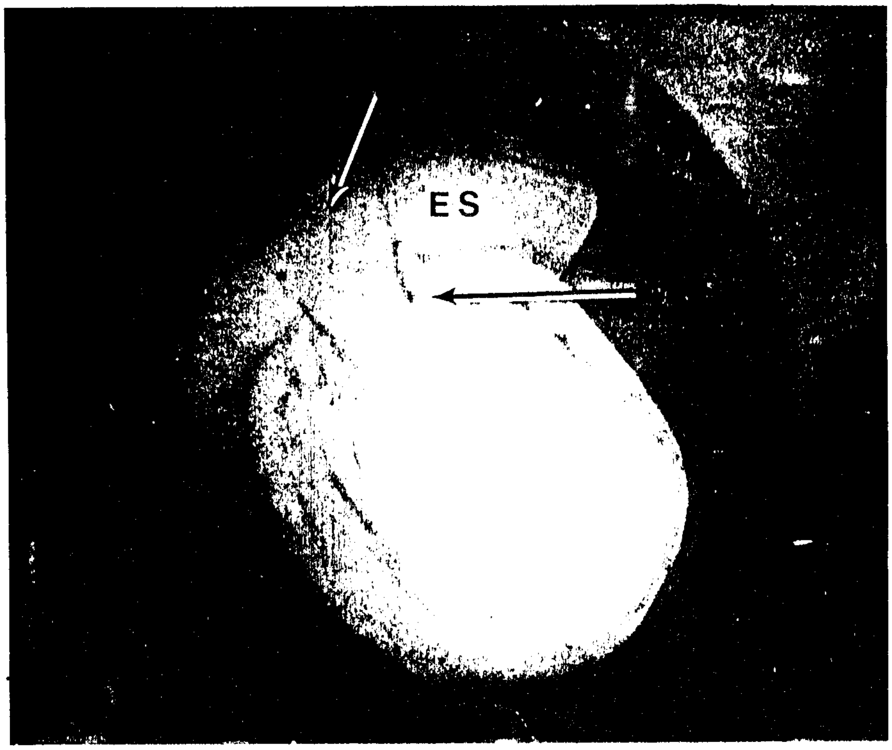


Figure 4.30 Egg from a female blue king crab taken in August 1983; large embryo with a well-developed telson. ES, eyestalk; T, telson; MXP, maxilliped.

4.5.3 Discussion

Histological exmaination of ovarian tissues revealed at least two temporally distinct stages of reproductive growth for each sampling period. In an annually reproducing population composed of individuals which spawn biennially, these radically different conditions would be expected since all individuals will not breed in the same year.

While direct examination of the ovary and calculation of the GSI would appear to provide the most reliable assessment of an individual's reproductive condition, these must be used in conjunction with shell condition and egg development to accurately determine where an animal is in the reproductive cycle. A simplistic example would be an individual with an extremely small ovary. Depending on shell condition, size, and the presence or absence of eggs, it could fall into one of several categories: an immature specimen, one that has just extruded eggs, or possibly a senescent individual. Our sample of 238 female crabs spanning two consecutive years allows all of these factors to be correlated with plankton data to provide the following scenario for BKC reproduction.

Female BKC molt, mate, and extrude a clutch of eggs in late March through mid-April. Following extrusion, the spent ovary consists primarily of connective tissue, accessory cells, immature ova and degenerating ova and comprises less than 3% of their total ash-free body weight. Immature ova appear to remain intact, probably to develop in the subsequent year, while those that underwent vitellogenesis but did not attain full size appear to degenerate and are reabsorbed.

By late summer of the same year, ovaries of these ovigerous females have grown to 6% of the body weight (GSI) and are brown or pink in color; individual ova average nearly 500 um in diameter and contain yolk. The eggs carried externally already contain well-developed embryos that possess eyestalks and even a telson.

By April of the following year, eggs are eyed and hatching and ovarian growth has increased the GSI to 7.5%. These animals have now reached the same stage in the reproductive cycle as those with eyed eggs or empty cases caught the previous May. Following through again to August, females now have very old shells (about 16 months since last molt), empty egg cases, and large, purple ovaries. Ova are full of yolk and average 700 um in diameter, and the GSI is about 12%. Finally, females caught in the spring in premolt condition with large ovaries round out the cycle. The GSI averages over 20% and ova are greater than 800 um in diameter, approaching the cross sectional width of external eggs reported to be about 1000 um by Sasakawa (1975b) and Somerton and MacIntosh (1985).

According to our data the 19 month embryonic period proposed by Sasakawa (1975a) is not accurate for Pribilof Island BKC, as noted by Somerton and MacIntosh (1985). Under the 19 month hypothesis, eggs are extruded in November and hatch in May of the second spring. At the Pribilofs, all females caught with uneyed eggs in the spring of 1983 and 1984 had new, clean shells, and carried either newly extruded eggs or those in the process of hatching. In Sasakawa's scheme, eggs extruded in November would contain embryos that are at least moderately differentiated six months later in April, but no evidence whatever was found for a "midpoint" spring embryo in our samples. Nor is there evidence in our data for a 14 to 15 month embryonic period as proposed by Somerton and MacIntosh (1985) in which eggs extruded the previous February through April hatch within the population primarily in May and June, and the event is complete by July. Our data show that in both 1983 and 1984 eggs were extruded primarily in April based on shell condition (often soft, always thin, clean and spines very sharp), and very little differentiation of embryos (a few cellular divisions, no gastrula). Larvae also hatch in April as evidenced in both years by our zooplankton collections. In 1984, larval densities of 2000 to 4000/100 m^2 were estimated and all were Z1 zoea between April 12 to 30. In early May 1983, most larvae (densities 2000 to 8000/100 m^2) were Z1 but the population was molting to Z2. Armstrong et al. (1985) estimated the duration of zoeal stages for BKC to be about 2.5 to 3.0 weeks. Thus, the May 1983 Z1 zoeal population was probably hatched in mid-April. Further evidence that BKC larvae hatch around the Pribilof Islands in April or earlier (rather than May and June into July) is provided by Armstrong et al. (1983) who found a mixture of Z1 and Z2 zoeae in May, 1976 zooplankton samples, Z4 zoeae in June 1978, and high densities of only megalopae in July 1982. Thus, we interpret these data to indicate that embryonic development for BKC (egg extrusion to hatch) is 11 to 12 months, exactly in accord with embryonic development of RKC (Marukawa 1933; Wallace et al. 1949). This difference in interpretation of embryonic development to be less than or greater than 12 months is an important distinction in analysis of causes for a biennial reproductive cycle.

The rate of egg development from May to August 1983 corresponds to that described by Marukawa (1933) for RKC and this, coupled with larval data, indicates again that the embryonic period for BKC is similar to that for red: eggs are probably extruded from late March to May and hatch the following spring in April. Under this model, the anomaly noted by Somerton and MacIntosh (1985) that annually spawning females manage to hatch their eggs in only twelve months while biennially reproducing animals take 14-15 months is resolved. The timing of reproductive events and their relationship to ovarian development over a two year period are summarized in Fig. 4.31.

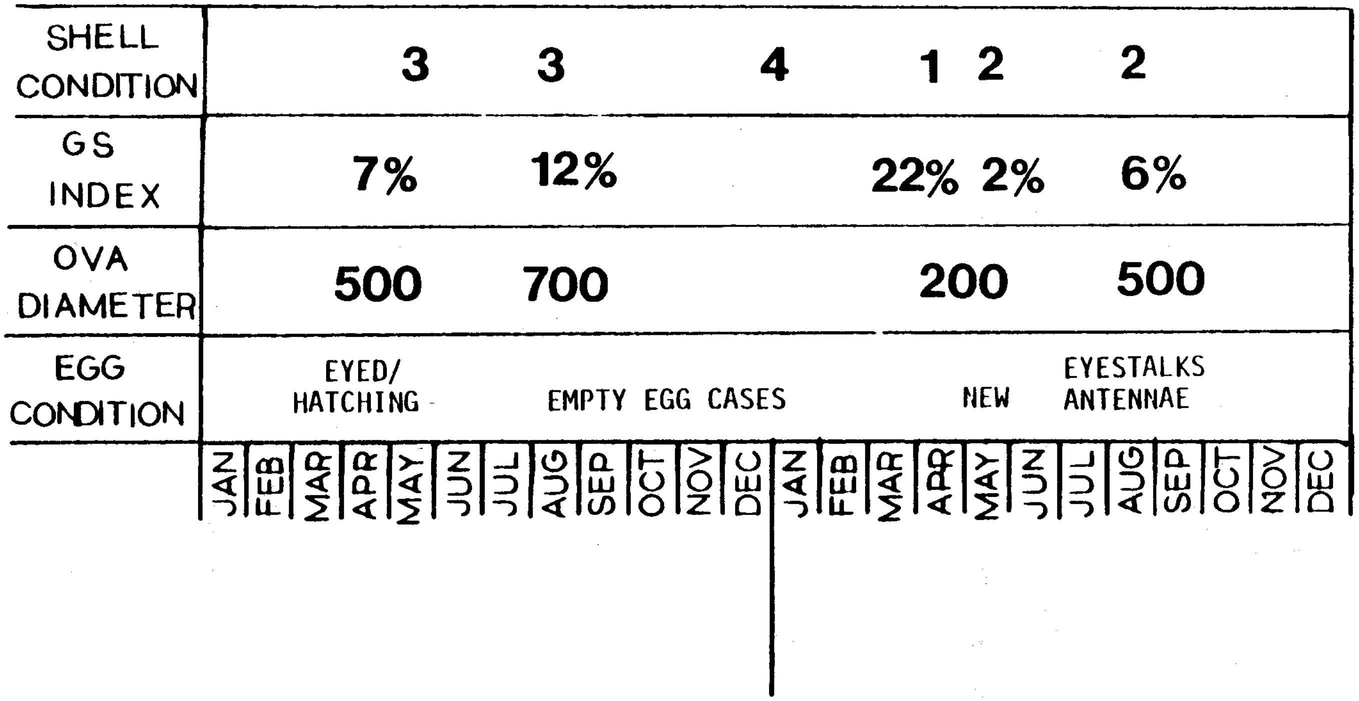


Figure 4.31 Timing of reproductive events and ovarian development for female blue king crab over a 2-year period.

The pattern of a biennial reproductive cycle is not consistent throughout the female population. Based on ovarian condition and readiness to molt, only one old shell female collected in May of 1983 showed signs of reproducing for two consecutive years. Most females between 100-115 mm CL had empty egg cases and were not ready to molt or extrude eggs. In April 1984, most small females (100-115 mm CL) carried newly extruded egg masses, so it was impossible to determine if any had reproduced the previous year because all evidence of prior spawning would be lost with their recent molt. However, of those small specimens carrying eyed eggs or empty egg cases, five out of six had large ovaries and were in premolt condition. The mean CL of annual spawners was 111.9 mm and significantly smaller compared to a mean of 124.9 mm for those with eyed eggs and undeveloped ovaries ($p<0.001$, Student t-test). This is somewhat consistent with the findings of Otto et al. (1979) who reported that BKC in the size range 101-110 mm CL reproduced annually and that biennial reproduction started with females 111-115 mm (however, larger samples are needed to determine if annual spawning is the rule for small females). Prior to egg extrusion the ovary is extremely large and purple in color, and the posterior lobes of the ovary are readily visible on the inside of the abdomen. This means of examination is useful in determining whether a female is close to spawning, and obviates the need to sacrifice the animal for an ovarian examination.

As reported by Somerton and MacIntosh (1985), some females appear to be reproductively inactive for periods of at least two years. This means that an individual female shows no sign of either carrying and hatching eggs within the year or developing a mature ovary prior to the spring molt. In our May 1983 sampling, nearly 15% of the adult females caught appeared to fit this category; only one was found in 1984. Although a few were large individuals (>130 mm CL) that may have been senescent, most ranged in size from 115 to 125 mm. These animals were characterized by having old worn shells and small white ovaries; remains of empty egg cases or filaments on the pleopods indicated that they had reproduced at least once. There was no evidence of rhizocephalan parasites or other apparent visible causes for this condition. It is tempting to speculate that there is a correlation between the low number of females with new eggs in May 1983 and a relatively high frequency of non-reproductive females observed at the same time. Causes of a non-reproductive state are not known but, apart from pathological perturbations (e.g., Hawkes et al. 1986), the condition implies some form of energetic stress in which less food than usual is acquired so that energy appropriations to somatic and gonadal growth are reduced. In this sense, it is interesting to note a significant difference was found in the mean egg indices of females carrying new eggs in May 1983 and April 1984 which averaged 24.9% (S.D.=3.1) and 31.6% (S.D.=4.2), respectively (Student t-test, $p<0.001$). An especially poor year in terms of food abundance or other variables in 1982 could conceivably account for poor growth, lower mean egg production and a high prevalence of non-reproductive females.

It is apparent that biennial reproduction in large female BKC is due to an inability to produce a fully developed ovary in one year. Why they are unable to do this while smaller individuals and the closely related RKC can is not clear. In general, the two species have allopatric distributions (Otto 1981), so environmental differences or a disparity in food resources could be important factors. BKC are found in areas of colder water than RKC (Slizkin 1971), which could contribute to slower overall growth. However, large ovigerous RKC ($\bar{X}$ = 149 mm CL) from the Pribilofs in April 1984 had well-developed ovaries and were in a premolt condition; thus, reduced growth due to cold temperatures seems an unlikely explanation unless these animals had immigrated from other areas.

It has been noted that many biennially reproducing species have additional energy expenditures, such as breeding migrations or egg brooding, which may make irregular or biennial reproduction advantageous (Bull and Shine 1979). Although females appear to congregate near the islanas to spawn (see Section 4.4), these movements are not any greater than those reported for RKC (Fukuhara 1985). Somerton and MacIntosh (1985) suggested that molting is the added energy expenditure associated with reproduction, however, molting is inextricably linked with mating in many annually reproducing decapods, including RKC.

The inability of large female BKC to produce a full ovary in one year, while many small females are able to reproduce annually, may be due to the added demands of producing a proportionately larger ovary while needing to produce a greater amount of somatic tissue for molting. If BKC live in areas with less or poorer quality food resources, or if feeding activity is reduced by colder water temperatures or a shorter growing season, it may be energetically infeasible to complete both sufficient ovarian and somatic growth for annual molting and egg extrusion.

4.6 General Discussion

The insular distribution of adult BKC shown by the annual NMFS groundfish surveys was reinforced in the present investigation of nearshore species ecology. Much more so than adults, juvenile stages of BKC are restricted to nearshore areas around the Pribilof Islands and the bulk of the population can be found within 10-15 km of St. Paul Island and east of St. George Island. The high degree of association between juvenile BKC and shellhash was unexpected, and yet may provide an important explanation of the limit of species distribution and range. The habitat needs of juveniles of several species of commercial decapods have been investigated, usually within the context of estuarine nursery areas. Stevens and Armstrong (1984) found that juveniles of Dungeness crab (*Cancer magister*) were much more abundant in eelgrass beds of coastal estuaries than on open intertidal flats or in subtidal channels that did not provide some form of epibenthic cover. In a more recent study, Armstrong and Gunderson (1985) found that young-of-the-year juvenile Dungeness crab were critically dependent on shellhash, principally that of oyster and *Mya arenaria*; this the only other reported instance of a close association between juvenile crab and shellhash of which we are aware. Juvenile penaeid shrimp in estuaries along the Gulf states are most commonly found in vegetated areas where *Spartina* provides cover and habitat. Zimmerman et al. (1984) reported densities of shrimp an order of magnitude greater in vegetated areas within a Galveston salt marsh than found over open mud and sand flats. In estuaries of North Carolina (Weinstein 1979) and in Chesapeake Bay (Heck and Thoman 1984) marshes and eelgrass (*Zostera marina*) support much higher densities and biomass of juvenile stages of blue crab (*Callinectes sapidus*) and penaeid shrimp than occur in open unprotected areas.

Relatively little work has been done on habitat requirements of juvenile stages of coastal commercial decapods with the exception of several species of lobster. Pottle and Elner (1982) demonstrated a distinct preference of juvenile *Homarus americanus* for gravel when given that as a choice along with silt-clay. Juveniles were able to excavate burrows in gravel which they occupy during daylight to avoid predators. Howard (1980) hypothesized that the size composition of lobster populations (*Homarus gammarus*) along the English coast is controlled by substrate size and composition as well as by nearbed current speeds which, if too fast, augment juveniles' need for rocky outcrop areas (Howard and Nunny 1983).

Only very limited work has been done specifically on the distribution and habitat requirements of young stages of juvenile BKC and RKC in the SEBS and Gulf of Alaska. Sundberg and Clausen (1979) documented a higher incidence of juvenile RKC in rocky areas of lower Cook Inlet than elsewhere on more open unprotected bottom. Jewett and Powell (1981) described general nearshore ecology and breeding biology of RKC around Kodiak Island and described a similar propensity of small juveniles to occupy rocky niches in that area as well. In the SEBS McMurray et al. (1984) presented the results of a broad scale survey of juvenile RKC distribution from Unimak Island through Bristol Bay, and reported a higher incidence of small juveniles (<28 mm CL) on substrates of gravel or cobble, usually in association with biological material that provides a three dimensional habitat. Such invertebrates as stalked ascidians (Boltenia ovifera), bryozoans and colonial tube dwelling polychaetes were frequently associated with small RKC found inshore of the 50 m isobath.

In the present study small 0+ and somewhat older age classes of juvenile BKC were consistently associated with a gravel to cobble substrate, but more so with various forms of shellhash around both St. George and St. Paul Islands. It is assumed that such shell material is the principal form of refuge afforded newly metamorphosed and small sized juvenile crab that are otherwise predated by a variety of other invertebrates and fish. The strict association with shell may in part explain the limits of species distribution, particularly in contrast to that of the RKC. Small juvenile RKC are from metamorphosis much more spherical than are BKC and have an exceedingly spinose morphology that, presumably helps to decrease predation. Coupled with the physical attribute of spines to inhibit predation is the well known behavioral process of podding that is also viewed as an anti-predator component of early life history (Powell and Nickerson 1965). In marked contrast, juveniles of BKC are compressed dorsoventrally and have virtually no appreciable spinose pattern to the carapace. The low, rather flat matrices in stacked shell, particularly of the several bivalves that dominate shellhash around the Pribilof Islands, probably serves as a very effective habitat for small juvenile stages of this closely related (to RKC) but anatomically different species.

In general, the exceedingly thick cover of shellhash found around the Pribilof Islands may be peculiar to such insular habitats. Large populations of bivalves that produce the shellhash were found around the islands, and current patterns in the vicinity may be such that empty shell is retained in the area. Elsewhere in the SEBS, particularly along the North Aleutian Shelf from Unimak Island to Kvichak Bay and west to Cape Newenham, we have never observed, despite numerous trawls and rock dredges, similar aggregations of shellhash as seen at the Pribilofs although large infaunal populations of certain bivalves exist in the area (McDonald et al. 1981). Blue king crab at St. Lawrence and St. Matthew islands are probably also dependent on shellhash during the small juvenile stage, although a study of nearshore distribution of juvenile crab or shell substrate has not been done. Whether BKC populations are isolated or exchange between the islands is also not known. Prevailing currents might carry larvae from the Pribilof Islands somewhat north toward St. Matthew and St. Lawrence, but transport would not likely occur in the opposite direction. Long distance migration of adult crab between these islands has also not been documented and, in fact, the annual NMFS groundfish survey shows virtually no occurrence of adults between islands (although movement in seasons other than that of the survey might occur).

The very restricted distribution of juvenile BKC around the Pribilof Islands and apparent dependence of this early life history stage on particular benthic material makes the overall life history of this species somewhat precarious. Females are apparently situated nearshore at the time of egg hatch in the spring and larvae (based on our two cruises in May 1983 and April 1984) are certainly distributed in greatest density nearshore around the islands or at least in the open water between them. However, given the extended larval period of this species, which is estimated to range from about 3.5 to 4.0 months (Armstrong et al., unpublished data), and the very limited benthic habitat to which they must settle and metamorphose for successful juvenile survival, it seems likely that this species may experience year class failures in certain years.

Summaries of current patterns in the SEBS, and particularly in the vicinity of the Pribilof Islands, show a general northwest direction and slow speeds along the shelf break past the islands (Kinder and Schumacher 1981a; Schumacher and Reed 1983). On the local scale of the Pribilof Islands there must, however, be current patterns and eddies that normally retain larvae nearshore to enhance settlement on the limited refuge substrate found in the area. However, in certain years it seems quite probable that anomolous events may cause transport of larvae well beyond the Pribilof Islands which results in settlement and metamorphosis of megalopae on substrates where survival is exceedingly low. It is striking that after several hundred benthic trawls and rock dredges over a relatively wide area around each of the islands, no juveniles between approximately 30-85 mm CL were caught, a size range that probably encompasses several age classes.

Uncertainties of annual recruitment success, the strict dependence of early life history stages on nearshore habitat around the Pribilof Islands, the unique reproductive biology of this species (biennial spawning of females, Somerton and MacIntosh 1985); and the uncertainties concerning growth rate are all issues that should be considered and studied for better management of the fishery. Of further interest to us is the relationship between juvenile BKC and their shell habitat, particularly population dynamics of the molluscan species themselves, their frequency of recruitment and age at death, as well as age of shells before physical and biological processes reduce them to sizes suitable as crab habitat. Importance of gastropod shell to benthic communities that are comprised of hermit crabs, octopus and fish has long been recognized and the impact of reduction in shell supply and/or configuration has recently been reviewed by McLean (1983). Future BKC research should include studies of the dynamics of molluscan populations that supply refuge for juveniles of this commercial crab species.

5. KOREAN HAIR CRAB

5.1 Larvae

5.1.1 Approach

Collection and processing of plankton samples is described in Section 4.1.1.

5.1.2 Timing of Hatch and Molt Frequency

Larval KHC collected during the first and second weeks of the May 1983 cruise were 99% stage 1 zoeae (Z1) (Fig. 5.1). Near the end of May (5/22-5/26) larvae were still predominantly Z1, but 16% had reached Z2, indicating the majority would probably molt in the last week of May. The presence of Z3 and Z4 larvae suggests that some eggs had hatched in early April.

No zoeae or megalopae were captured on the August cruise; this coupled with large numbers of first instars on the benthos indicated that 1983 settlement was already complete. KHC larvae were also absent from April 1984 samples, and it is likely that extremely cold water temperatures that spring delayed egg hatch.

The growth of KHC zoeae is shown in Fig. 5.2. Mean whole body dry weights ranged from 0.16 mg for Z1 to 0.49 mg for Z4. The weight at the second zoeal stage is anomalous; however, this value was derived from a very small sample (n=3) and is probably inaccurate (Appendix D1). No Z5 or megalopae were captured and weighed.

5.1.3 Distribution and Abundance

KHC larvae were caught at 70% of 117 plankton stations in May of 1983. Zoeae were most abundant south of St. Paul Island in Str 3 and 4 and along the northern boundary of Str 5 (Fig. 5.3) while few were found between the

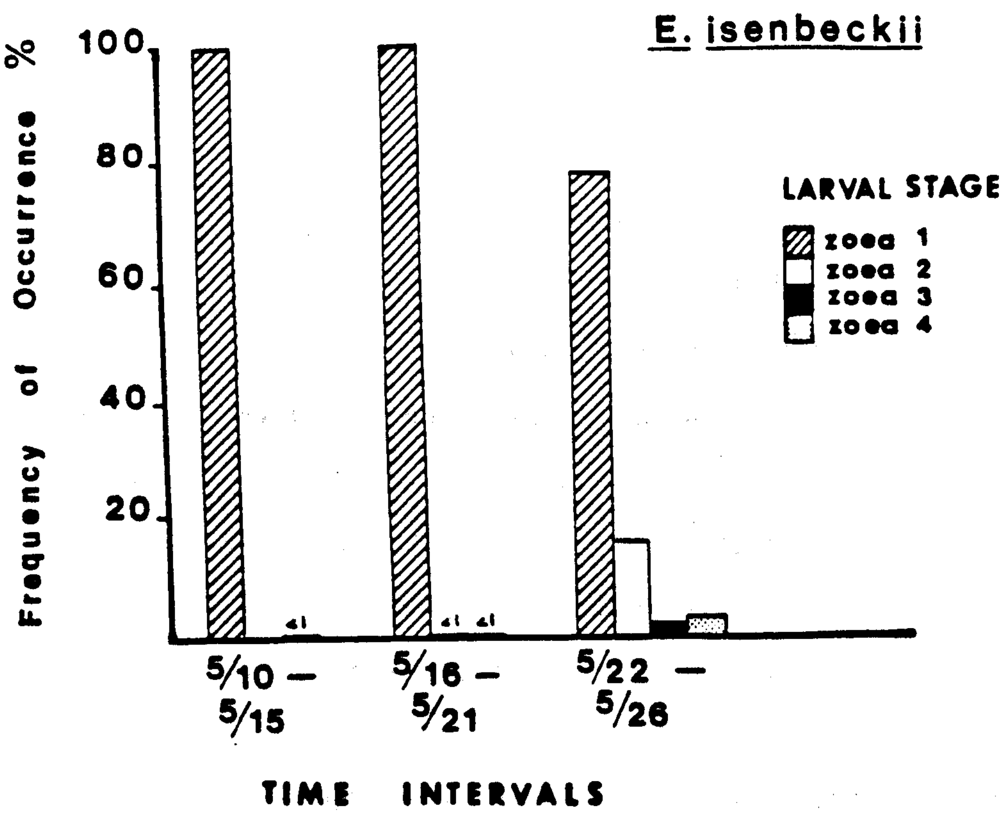


Figure 5.1 Percent stage frequency of Erimacrus isenbeckii larvae, May 1983.

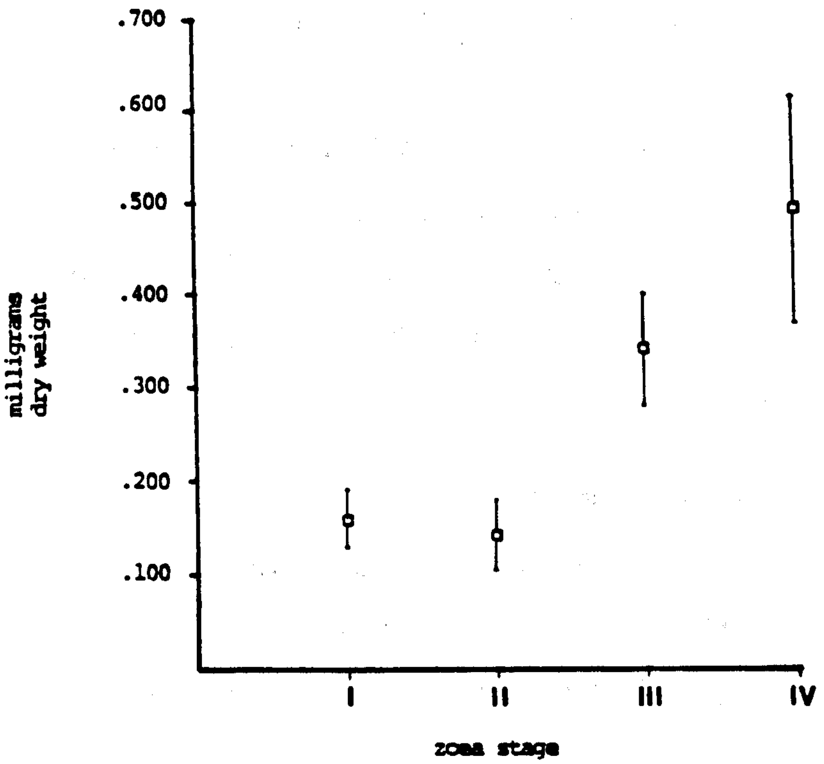


Figure 5.2 Erimacrus isenbeckii zoeal weight/stage growth.

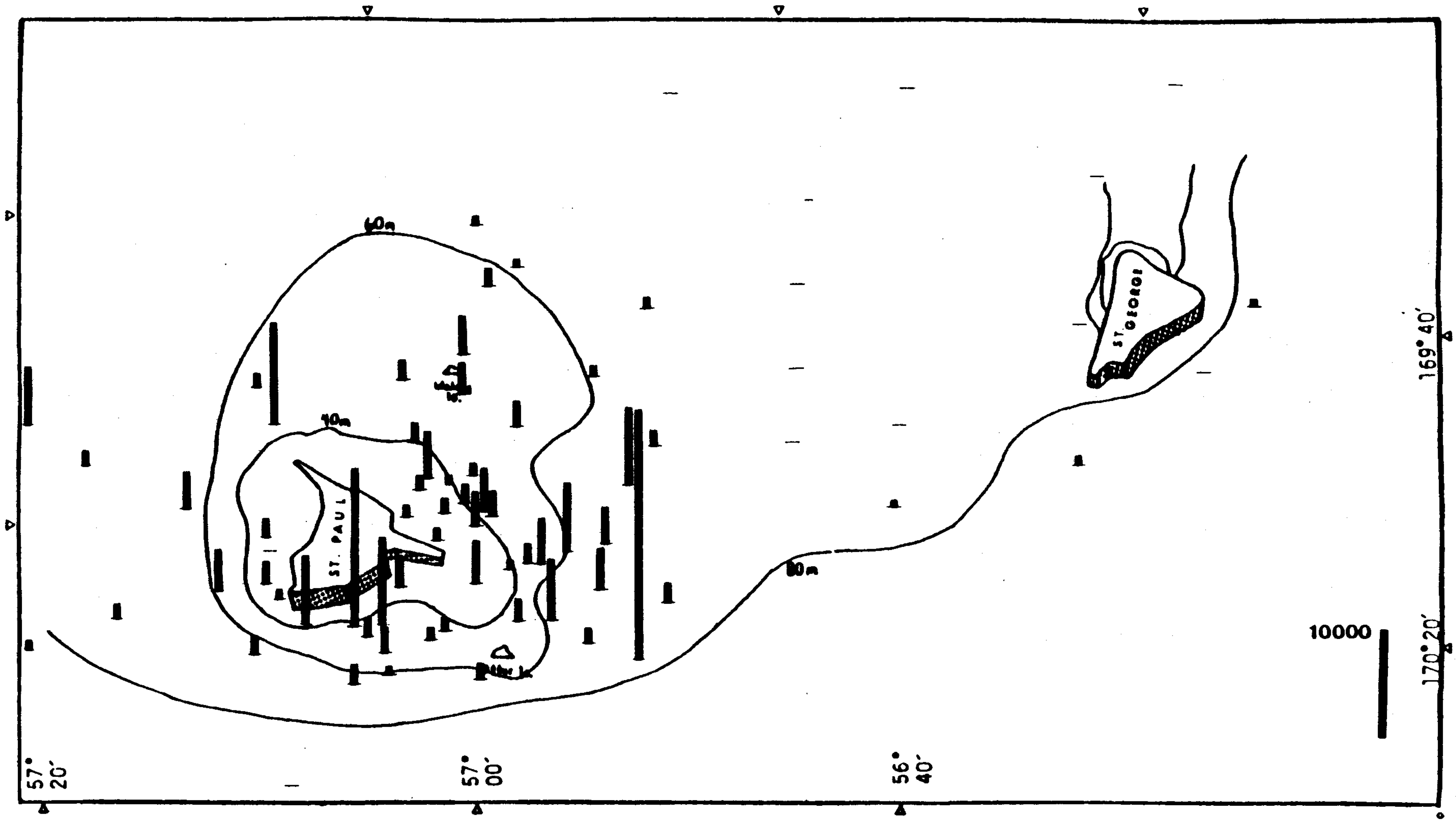


Figure 5.3 Erimacrus isenbeckii larvae, May 1983, number of zoeae/100 m².

islands or near St. George Island. Larvae were present at 87% of plankton stations in Str 1, 75% of Str 2, 93% of Str 3, 94% of Str 4, 48% of Str 5, and 33% of Str 6. Calculations of mean larval abundance for May (Fig. 5.4) show a more uniform distribution of larvae around St. Paul Island (Str 1-4). Means for those four strata ranged from 2100 to 2900 larvae/100m^2. Highest single station larval concentrations (starred locations) ranged from 6,200 (Str 1) to 14,700 (Str 4) larvae/100m^2 around St. Paul Island and the greatest catch of larvae, 23,000/100m^2, was taken within Str. 5. Again, large standard deviations emphasize the patchiness of larval distribution.

Vertical Distribution and Abundance: In May 1983 KHC larvae exhibited an interesting pattern of diel movement as shown in Fig. 5.5. Zoea were taken in neuston tows during all but the lightest hours of the day, and were especially common at night (02:00). During the early morning they were dispersed throughout the water column but most abundant at 25 m. During the strongest daylight period (14:00) none were caught at the 0-20 m interval and generally very few zoea were found (400 larvae/1000m^3 compared to 1000+ larvae/1000m^3 taken by the bongos during the other time periods). At evening (20:00) larvae were found back at the surface and at night (02:00) they were throughout the water column but predominantly in the upper 20 m. No comparison between years could be made since larvae were not yet available in April 1984.

5.2 Juveniles

5.2.1 Size-at-Age Groupings

Discrete instar sizes are not apparent in frequency histograms of juvenile KHC from any of the three cruises (Appendices D2 and D3). In August 1983 rock dredge samples, 80% of the hair crab catch consisted of juveniles 5-6 mm CW (range 3-7 mm); these animals are believed to represent

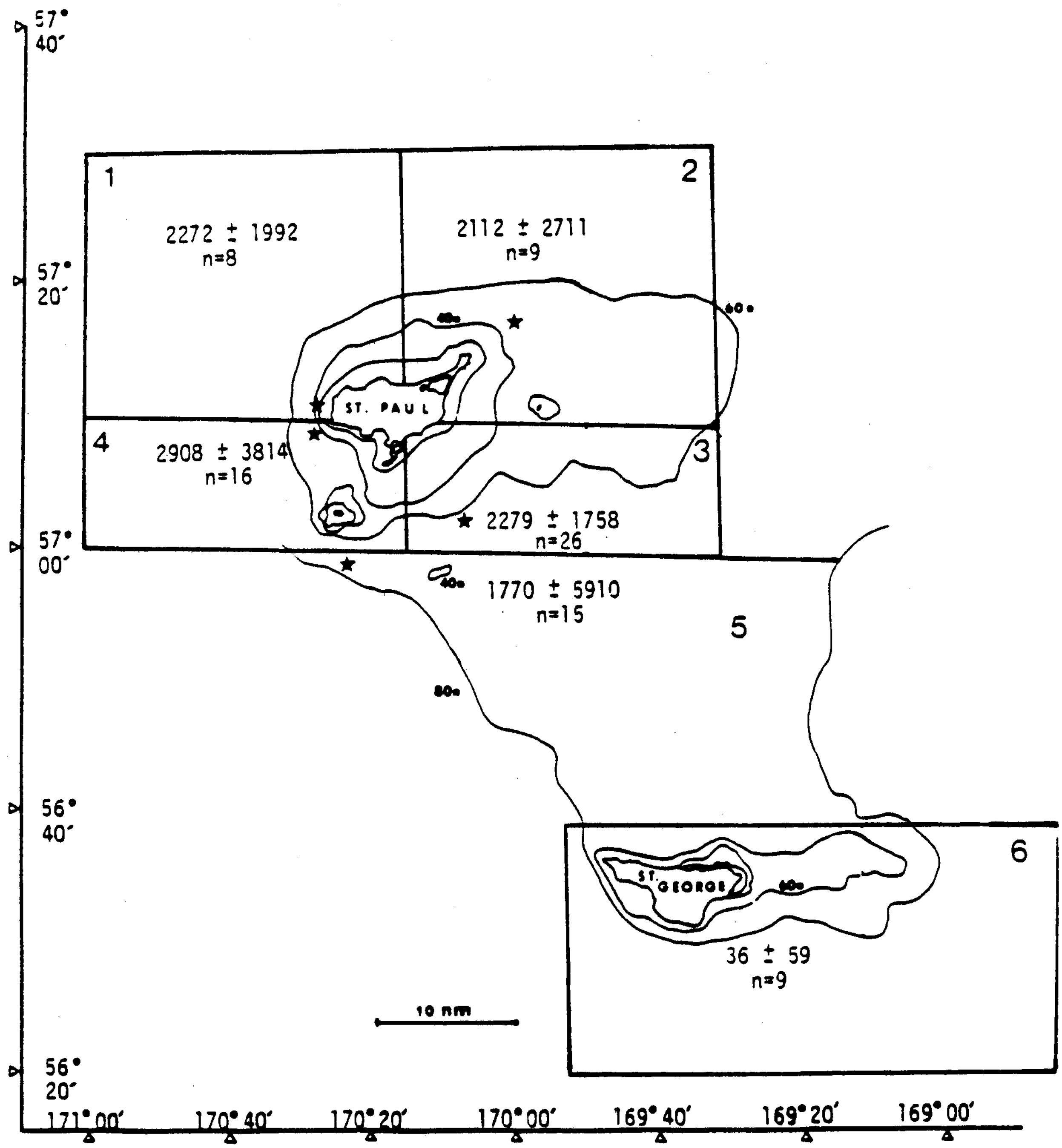


Figure 5.4 Erimacrus isenbeckii larval abundance (no. larvae/100 m²) by strata, May 1983. Shown are mean ± 1 SD and number of stations with larvae; stars indicate stations with the highest abundance per stratum.

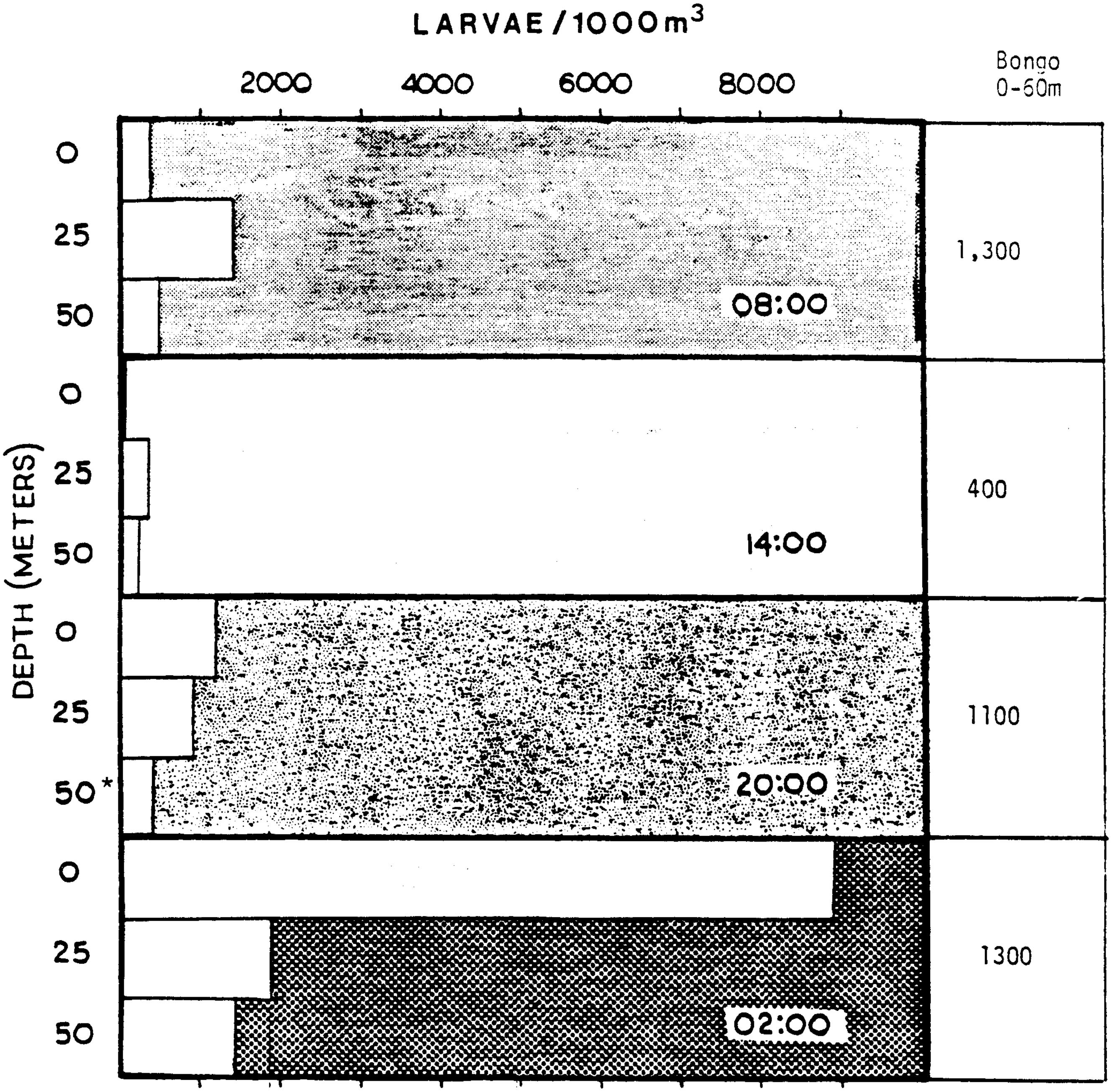


Figure 5.5 Larval Erimacrus isenbeckii depth distribution, May 1983. Diel station was sampled by neuston, Tucker, and bongo tows. Times on right are local mean time.
*Poor tow--neuston net fished 50 m-surface.

the newly-settled 1983 year class. Infrequently caught in the rock dredge but common in August beam trawls were larger individuals (histogram peaks at 11 mm and 15 mm CW) believed to be the 1982 and 1981 year classes, respectively.

There appeared to be very little growth over winter, the smallest crabs caught in April 1984 measuring only 7-8 mm CW. The animals believed to represent the 1982 year class ranged from 13-15 mm while the 1981 juveniles had reached 18-22 mm.

5.2.2 Distribution and Density

For all three cruises, juvenile KHC were most abundant near the northeastern and western tips of St. Paul Island. Densities caught by BT in May 1983 ranged from 7 to 203 crab/ha and were 431 to 2044 crab/ha based on the rock dredge. Juveniles were found at only one beam trawl station near St. George Island (Fig. 5.6).

Juvenile densities in August 1983 were strikingly different than found the previous May. Extremely high concentrations of newly settled juveniles (Append. D.2, D.3) were found all around St. Paul Island, especially to the north and east within a depth of 60 m (Fig. 5.7). Stations around St. Paul Island had a mean density of 3930 $\pm$ 13,015 (range 40-86,480) crab/ha at 44 of 95 rock dredge stations, a 4x increase in mean density over May. Four stations at St. George Island had trace catches of juvenile KHC ($\bar{x}$ = 214 $\pm$ 102 crab/ha). Beam trawls generally caught older juveniles and the mean density for August was 55 $\pm$ 90 (range 6-448) crab/ha at 26 of 71 stations, comparable to May densities. A comparison of the distribution of spawning adults during May 1983 with the juvenile distribution the following August (Figs. 5.7 and 5.10) shows the retention of the new year class within the 60 m contour of St. Paul Island after a northeasterly displacement from the foci

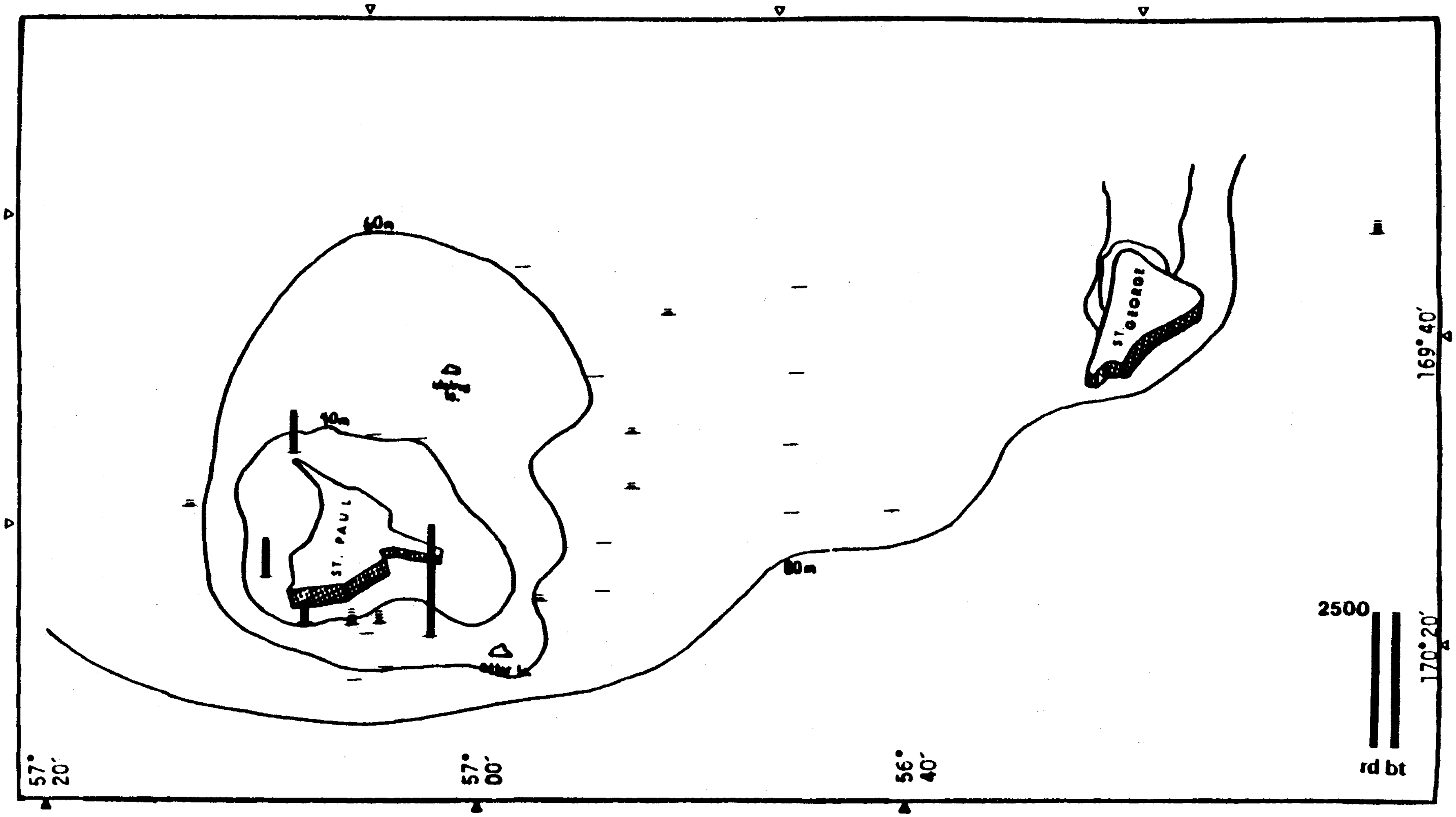


Figure 5.6 Erimacrus isenbeckii juvenile distribution and abundance, May 1983, expressed as number of juveniles/hectare taken by rock dredges (solid bars) and beam trawls (striped bars).

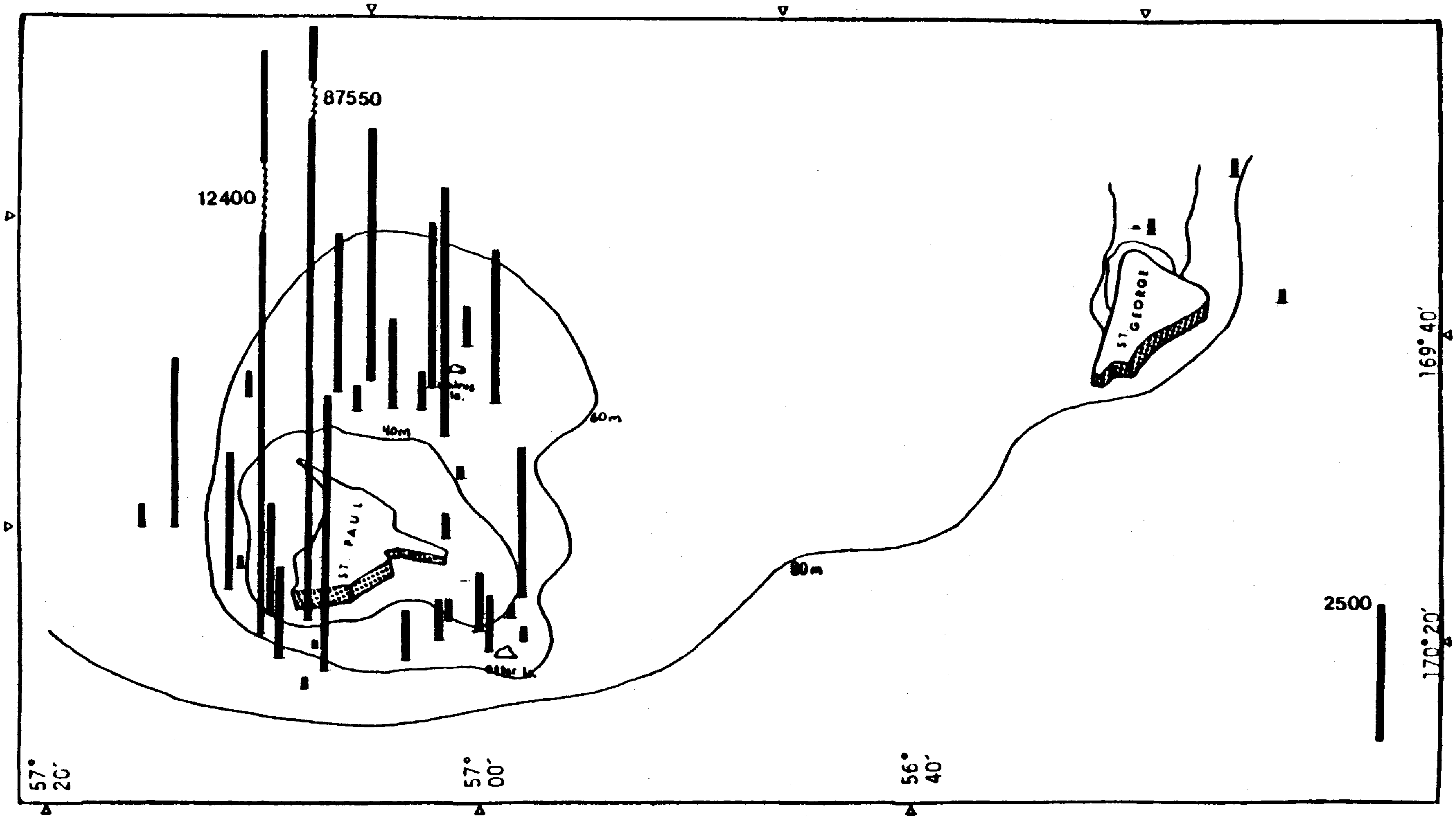


Figure 5.7 Erimacrus isenbeckii juvenile distribution and abundance, August 1983, expressed as number of juveniles/hectare taken by rock dredges. The size limit of 3.0-12.5 mm carapace width on this group denoted these as young-of-the-year and 1+ age classes.

of larval release.

By April 1984 a large concentration of KHC juveniles remained at the northeast corner of St. Paul Island, along with some to the east of Otter Island (Fig. 5.8). Relatively few crab were found east of St. Paul Island near Walrus Island, where large numbers of YOY and 1+ age classes had been found the previous August. Compared to the very low density of KHC juveniles measured during the May 1983 cruise, the density of crab in April 1984 was very high. Mean density of KHC juveniles caught at 17 of 74 rock dredge stations was 1285 $\pm$ 2080 (range 90-9020) crab/ha, compared to a mean of 19 $\pm$ 15 (range 5-55) crab/ha for 17 of 74 beam trawl stations. This was approximately a 36% decline in mean densities compared with previous August values for both beam trawl and rock dredge gear.

Young KHC were strongly associated with gravel-cobble substrate, and were also common in shellhash areas. Juveniles were present in 100% of the gravel-cobble tows and 71% of the shellhash rock dredge tows near St. Paul Island during the three cruises. In contrast, only 10% of the sand and 20% of the rock shelf stations yielded juvenile KHC (Appendix D4).

Overwinter survival in shellhash areas appeared good; unfortunately inclement weather and sea ice precluded taking April samples in the gravel-cobble areas that had exhibited extremely high densities of instars the previous summer north and northeast of St. Paul Island. Newly settled instars are dusky gray, specked with small light spots, a color pattern well suited to match this type of bottom. Specimens kept in aquaria would bury in this material and become virtually indistinguishable from their surroundings.

5.2.3 Estimated Population Abundance

As with juvenile BKC, the most reliable basis for estimating abundance of KHC juveniles was through the use of the sediment strata (Table 5.1).

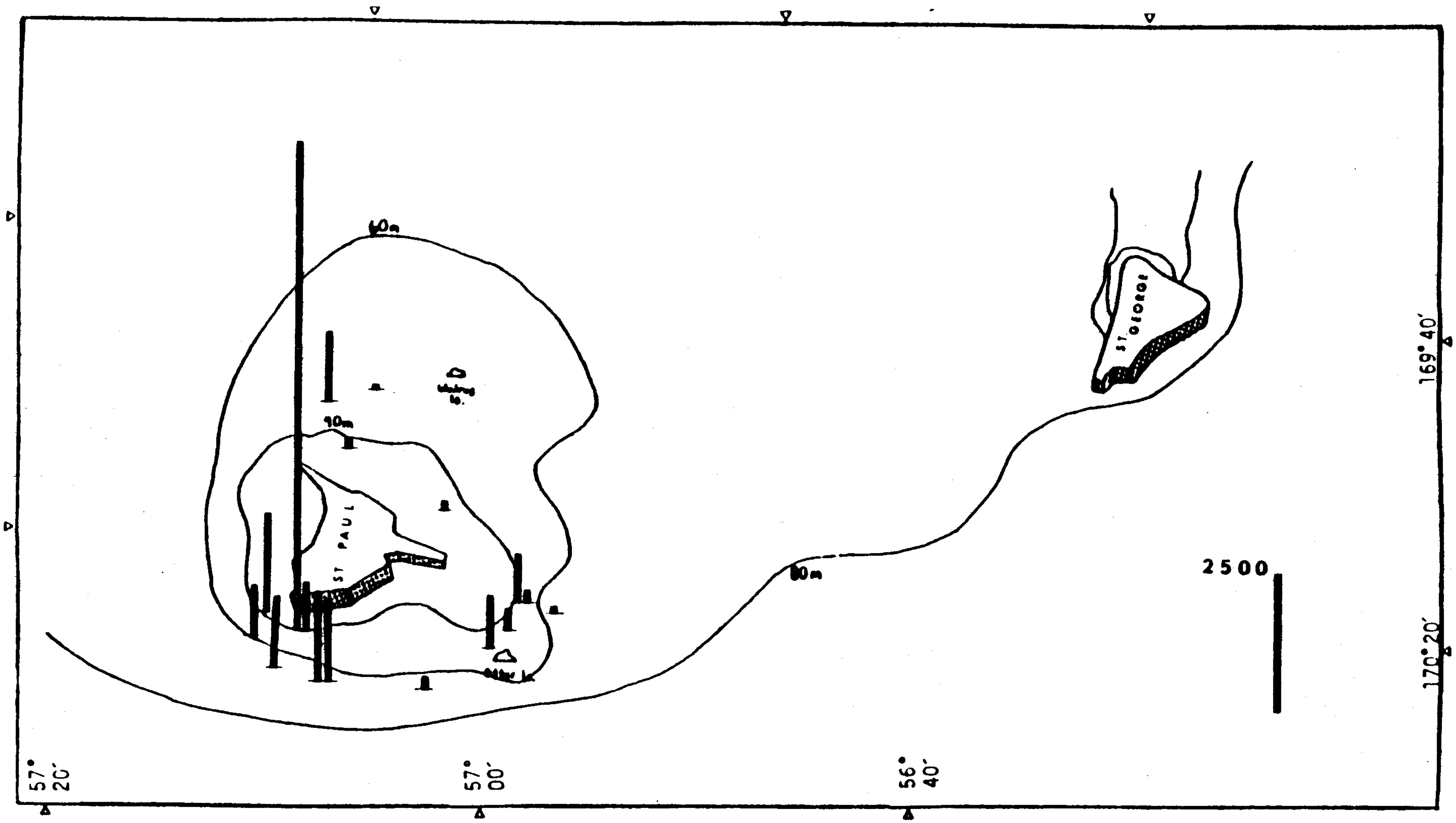


Figure 5.8 Erimacrus isenbeckii juveniles distribution and abundance, April 1984, expressed as number of juveniles/hectare taken by rock dredges.

Table 5.1 Juvenile Korean hair crab population estimates in millions of crab from the sediment strata by island, gear, and month.

	Rock Dredge			Beam Trawl		
	May 83	Aug 83	Apr 84	May 83	Aug 83	Apr 84
St. Paul Island	29.0	224.2	26.2	5.6	9.6	4.3
St. George Island	0	0.8	0	0	0.3	0.2
Mid-Island area	0	0	0	2.2	0.9	0.7
Total	29.0	225.0	26.2	7.8	10.8	5.2

Table 5.2 Korean hair crab size groupings.

Age class	Size (Carapace width in mm)
0+	3 - 9.5
Juvenile	>9.5 - 40
Adult	>40*

* All crabs greater than 40 mm CW were considered adults, but males do not reach sexual maturity until they are 70 mm CW. Thus, our estimates may overestimate the number of mature males at this stage of analysis.

This is due to the very insular nature of juvenile KHC as depicted in Figs. 5.6 to 5.8. The May rock dredge juvenile population estimate based on these strata was 29 million for crab 6-21 mm CW (Appendix D5).

In August the population estimate increased 676% to 225 million crab, primarily from settlement of the 1983 YOY age class (Fig. 5.9). Our population estimate for older (10-39 mm CW; ages +1-1/2, +2-1/2) increased 38% over May to 10.8 million crab.

Nine months later, in April 1984, the sediment strata rock dredge population estimate had dropped to 26.2 million crab (Appendix D6). Sea ice and poor weather prevented sampling in some of the areas that had exhibited the highest abundance the previous August; consequently the precipitous decline in the population estimate is probably more apparent than real.

5.3 Adults

5.3.1 Seasonal Distribution and Abundance

Adult KHC were consistently more abundant near St. Paul Island during all three cruises, and generally at depths greater than 40 m. In May 1983 adult females (>40 mm CW) were primarily west and south of St. Paul Island; males (>70 mm CW) were in these same areas and extended slightly more to the east. Only males were found near St. George Island, at a single station (Fig. 5.10).

Female abundance was lower and they were more widely distributed in August, but male density was high and they appeared to be aggregated near Walrus Island (Fig. 5.11). As in May, KHC were found at only one station near St. George and all specimens were male. By the following April males and females had both become more widely dispersed but males were still abundant near Walrus Usland (Fig. 5.12).

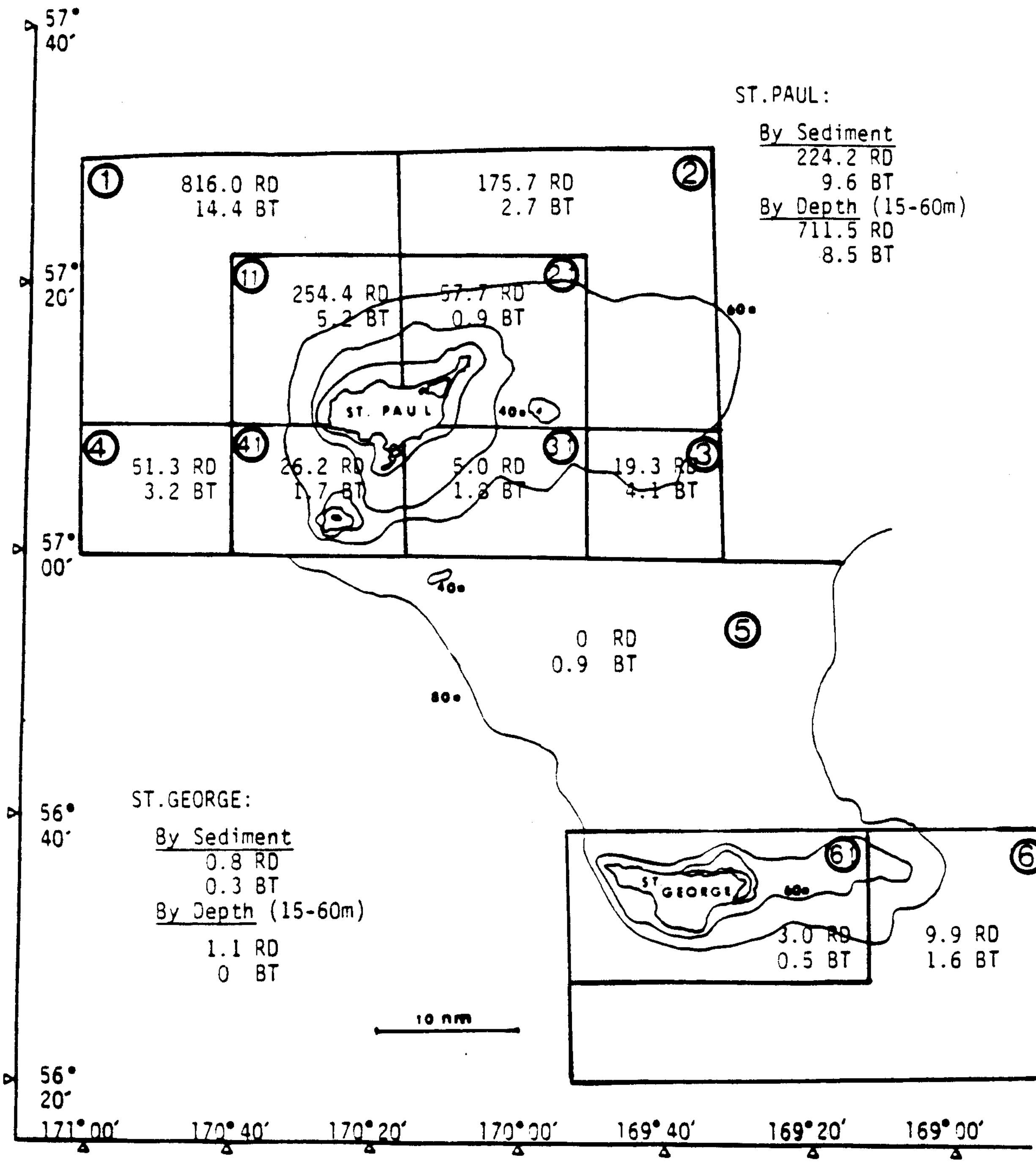


Figure 5.9 Population estimates for Erimacrus isenbeckii juveniles in August 1983 by strata. Separate estimates, expressed as number of juveniles x 10^6, are given for each gear; RD = rock dredge, BT = beam trawl. Estimates for nearshore strata 11-41 and 61 can be compared to the island totals figured for both the sediment and depth strata.

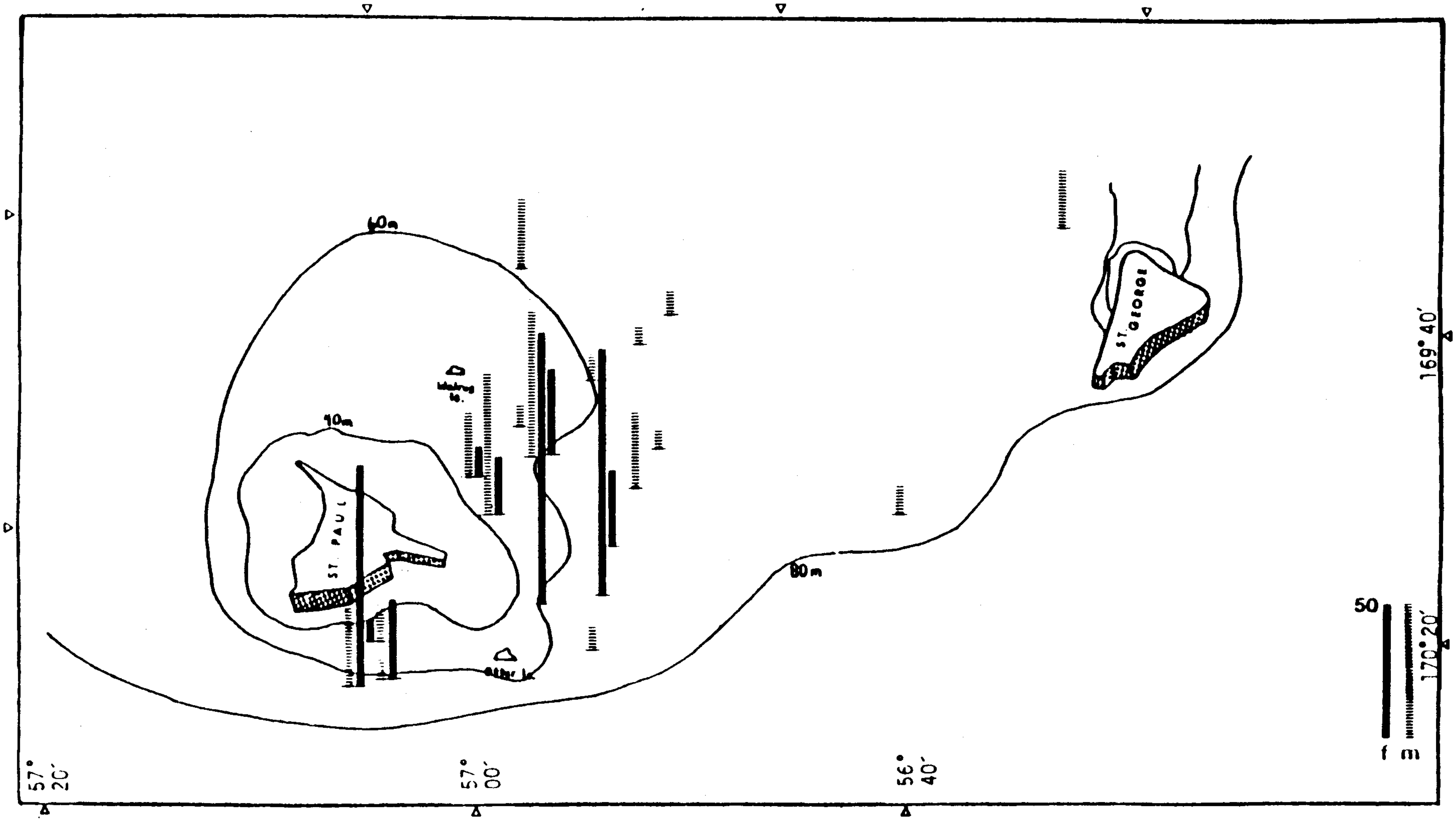


Figure 5.10 Erimacrus isenbeckii adult distribution and abundance, May 1983, expressed as number of crab/hectare taken by beam trawls, females (solid bars) and males (striped bars).

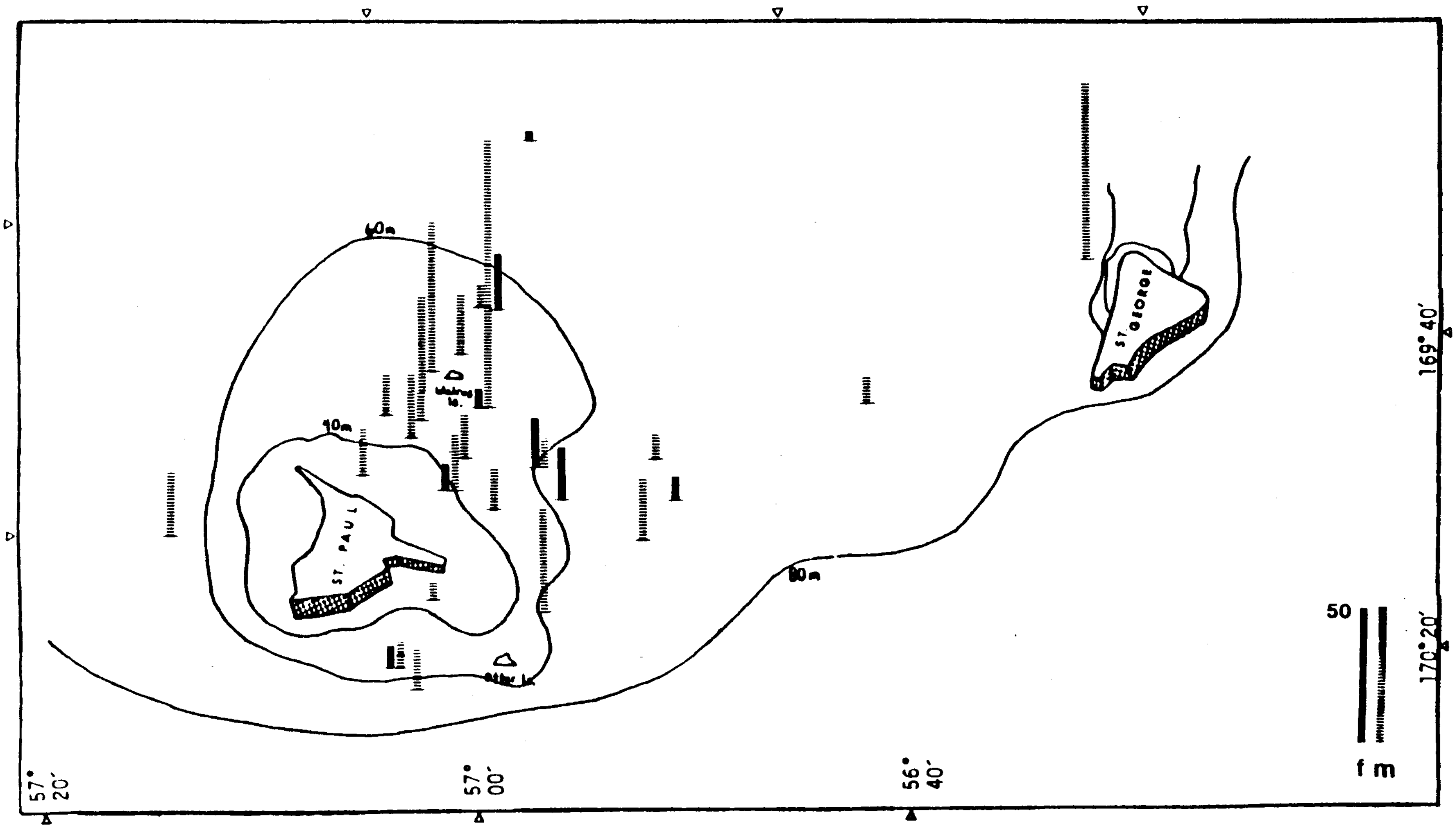


Figure 5.11 Erimacrus isenbeckii adult distribution and abundance, August 1983, expressed as number of crab/hectare taken by beam trawls, females (solid bars) and males (striped bars).

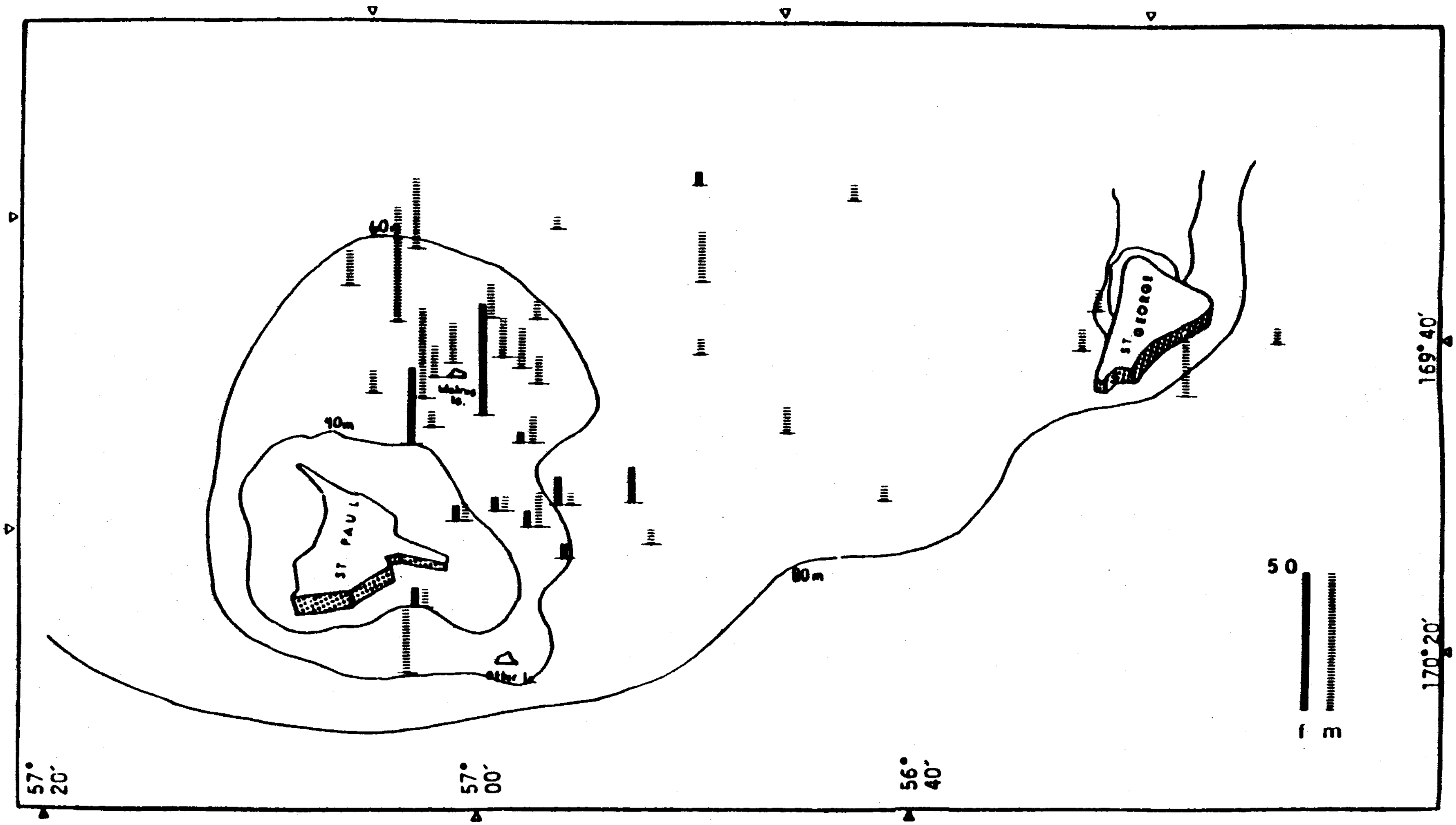


Figure 5.12 Erimacrus isenbeckii adult distribution and abundance, April 1984, expressed as number of crab/hectare taken by beam trawls, females (solid bars) and males (striped bars).

5.3.2 Estimated Population Abundance

An adult population of 8.1 million KHC was calculated for May 1983 and was comprised of 4.5 million females and 3.6 million males (Fig. 5.13). This estimate was derived from the sediment strata scheme for adults taken on sandy substrate; estimates for other strata are given in appendix tables D7 to D13.

By August the population estimate for adults had declined 47% to a total of 3.6 million crab (0.9 million females; 2.7 million males; Appendix D14). The total population estimate remained approximately the same in April 1984, with a decline in females to 0.5 million being offset by an increase in males to 3.1 million (Appendix D15).

5.4 Reproduction

5.4.1 Materials and Methods

All techniques involved in the analysis of reproductive condition are described in Section 4.5.1.

4.5.2 Results

May 1983: 48 adult female KHC crab were caught in May but only three specimens were ovigerous; two bearing eyed eggs and one with new eggs. Of the remaining animals, 21 had new shells (SC2) and plugged gonopores and 12 had old shells (SC3) and empty egg cases. One had both an old shell with empty egg cases and gonopore plugs. The remaining 11 specimens had no sign of eggs or plugs; eight had new shells and three had old shells.

August 1983: A total of 25 female KHC were taken in August and none were ovigerous. Only three specimens had plugged gonopores; one was SC1, one SC2, and the third SC3. Of the remaining animals, one was SC1, 14 were SC2, five were SC3 (two with empty egg cases), and two specimens were SC4.

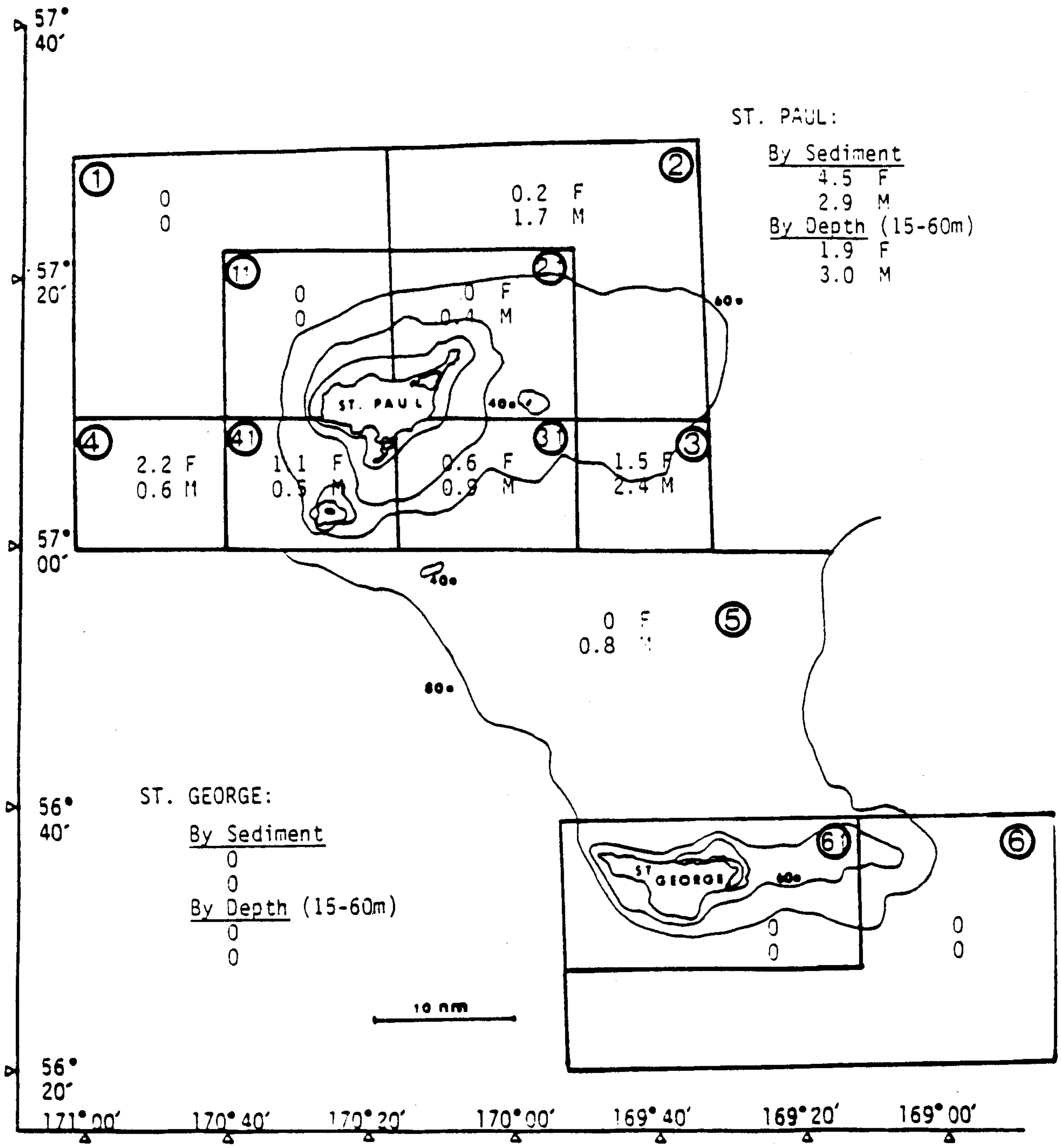


Figure 5.13 Population estimates for Erimacrus isenbeckii adults by sex and strata for beam trawls in May 1983. Estimates are expressed as number of crab x 10^6 for adult females and males.

April 1984: Only 13 adult female KHC were caught in April. Of these, two were ovigerous, one bearing eyed eggs and the other new eggs.

5.4.3 Discussion

No well-defined reproductive cycle for KHC could be discerned from data of the present study. Although largely due to the paucity of reproductively active adult female crabs, it is also a result of the remarkably inconsistent findings for the few available specimens. Females taken in May of 1983 generally fell into two categories: those with eyed eggs or empty egg cases and old shells (SC3), and those with fairly new shells (SC1,2) and plugged gonopores. Sakurai et al (1972) reported that older females mated earlier than smaller specimens, and consequently extrude their eggs sooner. It is possible that the specimens with new shells had already released their larvae, molted and mated by the time of our survey. The mean size of new shell individuals was 68 mm ($\pm$ 5.2) compared to 57 mm ($\pm$ 10.2) for those with old shells. If larger individuals mate and extrude their eggs earlier than the smaller crabs it is possible that their eggs also hatch earlier.

In August, very few animals had gonopore plugs. Since these plugs generally protrude considerably and appear to be subject to breakage or abrasion, it seems likely that the number of females with obvious external plugs would diminish with time. The occurrence of specimens with plugs on only one side suggests that the excess material may eventually slough off. Unfortunately, the internal passages of the gonopores were not checked for signs of a plug.

The presence of large ovaries (and large ova) in some of the August specimens, accounting for as much as 17% of the total weight, may indicate that some individuals were close to spawning. The older shell animals tended to be slightly larger (62.6 $\pm$ 10.9 mm CW) than the new shell animals (43.8 mm

$\pm$ 10 mm CW). If females do indeed molt and mate after releasing their larvae, this would be consistent with the May data. It does little, however, to explain the large drop in the average sizes of the two groups.

Sampling was least successful in April of 1984, when only 13 adult female KHC were caught. It was expected that most females would be ovigerous at this time of the year, but only two of the 13 bore eggs. Ovigerous female *Cancer magister* are often found buried under several centimeters of substrate (Jensen and Williams, School of Fisheries, U. of W., pers. obs.); which if true for female KHC would mean very low catchability in the gear of our study.

The occurrence of one specimen with new eggs in April and one in May of the previous year suggests that a second hatch of larvae may occur later in the summer. The soft-shelled female with gonopore plugs captured in August indicates that at least some individuals are molting and mating at that time of year.

6. POTENTIAL IMPACT OF OIL ON CRAB

As originally hypothesized in the proposal to OCSEAP for this project, BKC are indeed as insular a species as first suggested by NMFS survey data (Otto 1986). More so than adult animals, both larvae and juveniles have highly restricted distribution over the SEBS that occurs around the Pribilof and other islands. Both early life history stages require nearshore distribution, and although larvae may be possibly transported great distances (as theorized for RKC along the North Aleutian Shelf; Hebard 1959; Haynes 1974; Armstrong et al. 1983), it is imperative that they metamorphose very nearshore for subsequent survival as small juveniles. The restricted distribution of early juvenile BKC stages on and in substrates such as shellhash and gravel/cobble that are limited to the Pribilof Islands (compared to hundreds of km in all directions) underscores the unique habitat required by this species. Although adults may range more widely, their return nearshore of St. Paul in spring attests to the need that larvae, and in turn juveniles, be hatched and retained nearshore. For these reasons there seems to be a high probability that if oil reaches these islands in appreciable quantities, the impact on BKC (and KHC) could be great depending on a variety of biological and physical parameters (see Laevastu et al., 1985, for an overview of relevant factors).

Realization that crab (and other species groups) are vulnerable to oil mishaps in the SEBS came from a series of modelling workshops and synthesis meetings held in the early 1980's (Sonntag et al. 1980; Hameedi 1982; Thorsteinson 1983). As a result, OCSEAP has sponsored a series of research programs (including the present study) to elucidate for the first time many aspects of king crab general life history and ecology in the SEBS. The results provide a better basis from which to predict and assess effects of oil spills, and to improve impact models developed for this purpose.

Two models of physical transport processes, water movements and biological interactions and responses to oil in the Bering Sea have been constructed (Leendertse and Liu 1981; Sonntag et al. 1980). Several models of water transport and circulation have been based on net current directions and velocity (Hebard 1959; Kinder and Schumacher 1981b; Schumacher and Reed 1983), and on methane profiles (Cline et al. 1981).

To improve predictive capability, OCSEAP contracted with NMFS to develop a comprehensive series of models that simulate effects of oil mishaps on a variety of species by including a wide parameter field for both physical and biological processes (see multiple reports in OCSEAP Final Rep. Series Vol. 36, Parts 1 and 2; especially Laevastu et al. 1985 for an overview). The sophistication and complexity of these models is generally greater than earlier versions for transport, mixing and weathering of oil, as well as for inclusion of a wide array of biological processes and life history stages poorly quantified in earlier models (e.g. Sonntag et al. 1980).

Hebard (1959) described currents moving to the northwest through Unimak Pass, with a component then moving northeast along the North Aleutian Shelf (NAS). Although the direction of the current is highly variable and to a great extent tidally driven, there is a net movement of 2.0-5.5 cm/sec eastward and northward into Bristol Bay. Kinder and Schumacher (1981b) and Schumacher and Reed (1983) summarized data for current patterns in the SEBS and showed weak currents of 2-5 cm/sec along the NAS and 1-5 cm/sec moving northwest over the St. George Basin to the Pribilof Islands (Fig. 6.1). They stressed that instantaneous flow can be substantially greater than these averages (up to twenty times greater than the long-term vector) and the direction quite variable. Cline et al. (1981)

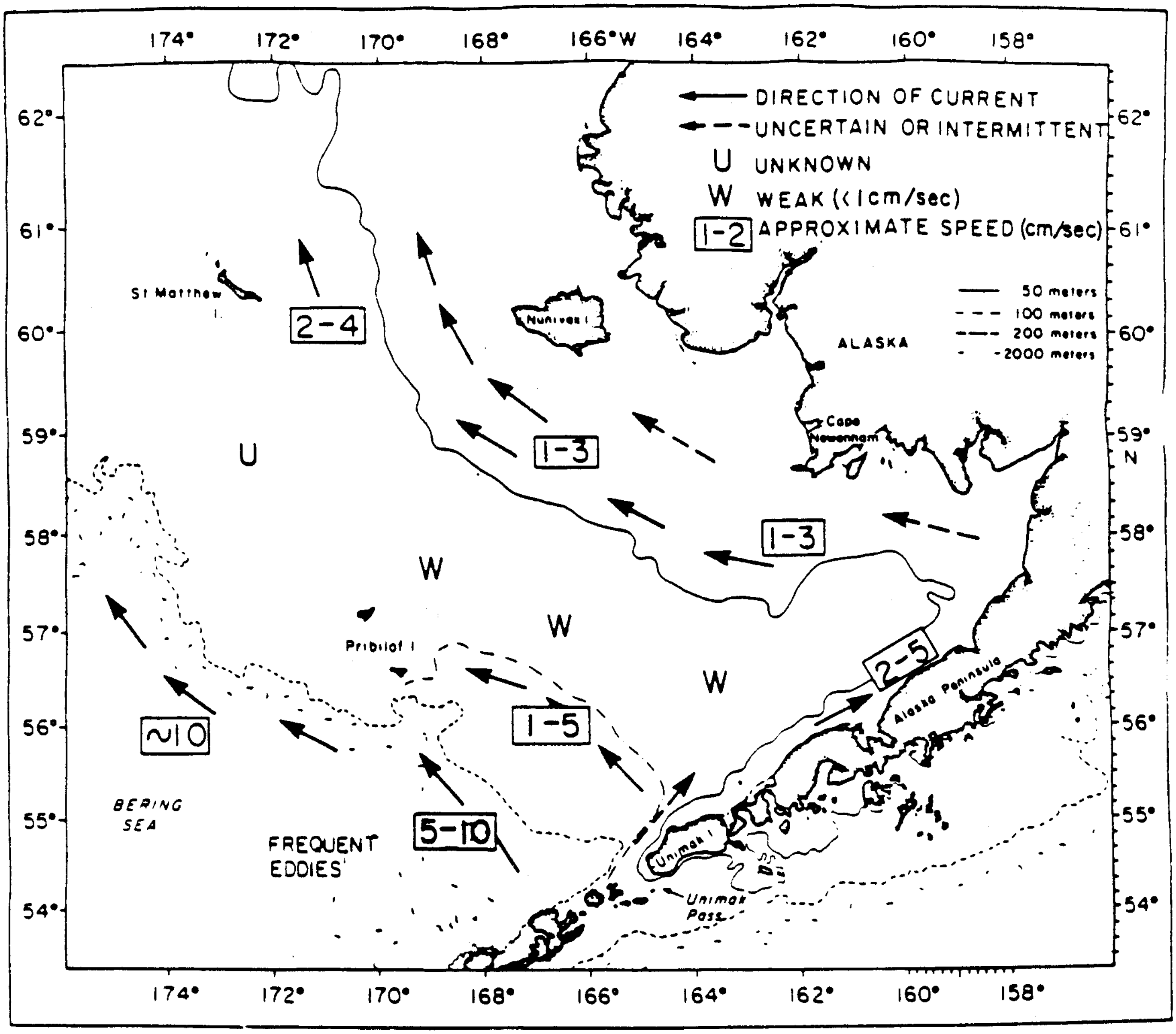


Figure 6.1 Current directions and net speed over the southeastern Bering Sea shelf (from Kinder and Schumacher 1981a).

used methane profiles to calculate current speeds of 7 cm/sec northeast along the NAS and 5 cm/sec northwest over the St. George Basin. Both values are in close agreement with current meter readings. Such information can be used to gauge the movement of crab larvae in currents relative to origins and surface speeds of oil movement. These exercises have been done by Leendertse and Liu (1981) and Sonntag, et al. (1980).

In order to study the direction of surface oil trajectory following oil spills from lease sale areas in the SEBS (Fig. 4.5), Leendertse and Liu (1981) ran computer simulations based on average wind events in winter and in summer (Fig. 4.5). During summer and fall, oil from spills in the St. George Basin and along the NAS would be moved by prevailing winds eastward over the middle shelf and south to the NAS coast at Unimak Island (Fig. 4.5). In the winter, oil would be transported northwest off the shelf or towards the Pribilof Islands (Figs. 6.2A and 6.2B) and could affect Alaskan species of shrimp and crab including Dungeness crab, king and Tanner crab, and pandalid shrimp.

Hydrocarbon toxicity to decapod Crustacea has been studied for several species that occur in Alaskan lease sale areas. Rice et al. (1975) and Vanderhorst et al. (1976) reported that 96-hr LC50 values for juvenile and adult pandalid shrimp range from 0.8-11.0 mg/l for the water soluble fraction (WSF). Pandalid larvae, however, are a more sensitive life history stage as evidenced by 96-hr LC50 values from 1.0 mg/l WSF down to 0.3 mg/l for single aromatic compounds such as naphthalene (Mecklenburg et al. 1977; Rice et al. 1976, 1979). Sublethal effects including failure to swim and/or molt inhibition occurred at concentrations from 0.7 to 0.3 mg/l WSF. A 96-hr exposure of pandalid larvae to 0.6 mg/l WSF caused a 70% reduction in molting from ZI to Z2 (Mecklenburg et al. 1977). Dungeness crab zoeae were susceptible to WSF as low as 0.22 mg/l (Caldwell et al.

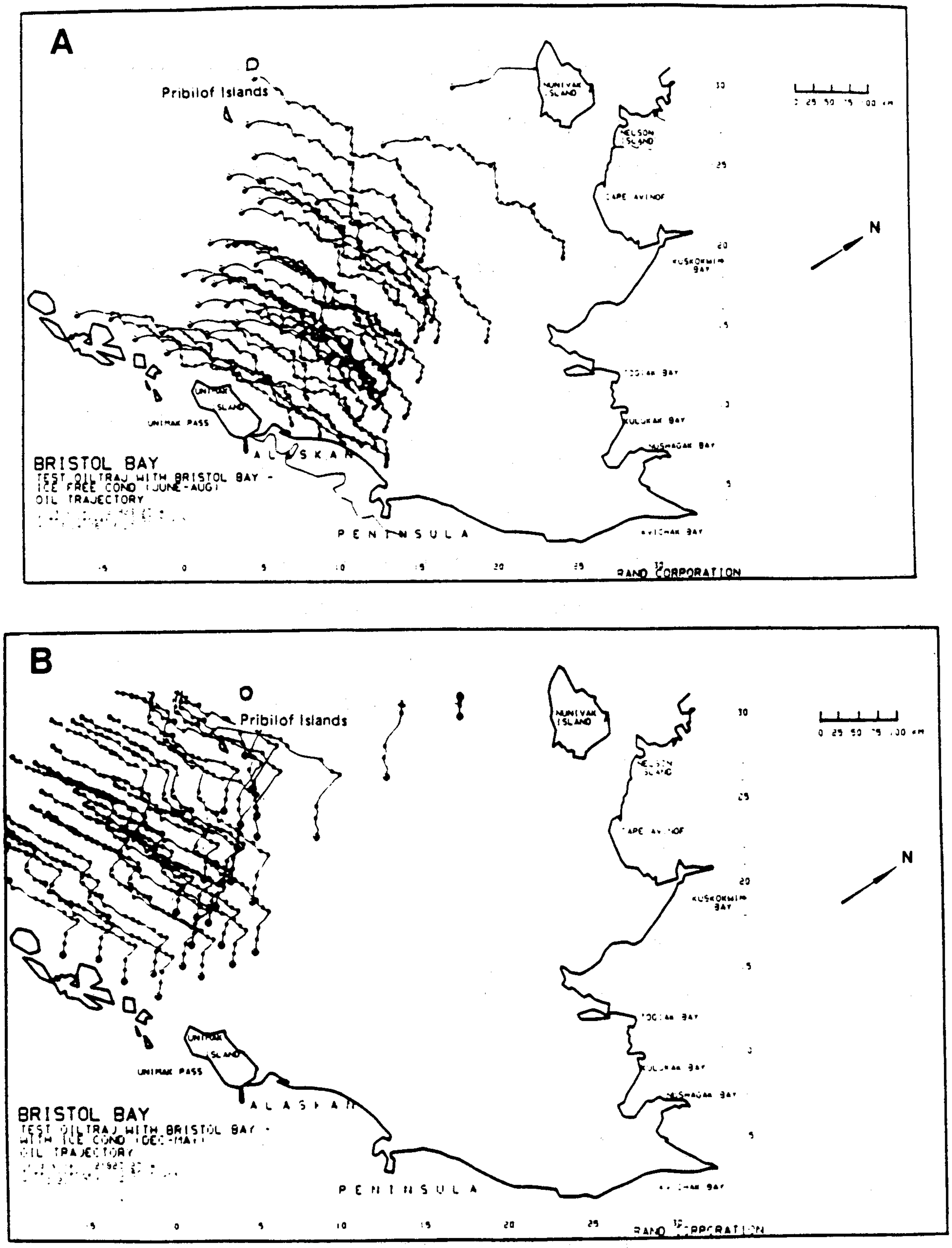


Figure 6.2 Surface oil trajectories during summer (A) and winter (B) in the southeastern Bering Sea (from Leendertse and Liu 1981).

1977). Larval king and Tanner crab are equally sensitive to hydrocarbons. Death of RKC larvae or failure to swim was caused by 0.8 to 2.0 mg/l WSF (Brodersen et al. 1977; Mecklenburg et al. 1977), and Chionoecetes bairdi larvae were immobilized by a 96-hr exposure to 1.7 mg/l WSF (Brodersen et al. 1977).

Studies with other larval decapods indicate that toxic oil concentrations may be even lower than those discussed above when based on assays of single hydrocarbons, exposures longer than 96 hr, or based on sensitive sublethal criteria. Larval lobster (Homarus americanus) ceased feeding at 0.19 mg/l WSF and had a 30-day LC50 value of 0.14 mg/l (Wells and Sprague 1976). Specific compounds such as naphthalene are very toxic and caused narcotization followed by death of pandalid shrimp and crab larvae at concentrations of 8-12 ug/l during exposures of less than 24 hr (Sanborn and Malins 1977). Toxic oil concentrations range as low as 0.15 mg/l WSF and may be somewhat lower for specific compounds. Moore and Dwyer (1974) give a sublethal range of 0.001-0.1 mg/l WSF as stressful to larvae. Wells and Sprague (1976) suggest a multiplier of 0.03 should be applied to LC50 concentrations to establish "safe" levels; this would result in acceptable concentrations less than 1 ug/l. Armstrong et al. (1983) noted that the toxic threshold value of 0.2 mg/l WSF used in oil spill scenarios should be lowered to 0.05 to 0.1 mg/l in light of this evidence.

A model was constructed by Gallagher and Pola (1985) to predict the extent of area affected by various spill and accident scenarios in the Bering Sea. As a basis for comparison of the predicted aerial extent of hydrocarbon contamination in several ranges of concentrations, they also presented a range of soluble aromatics judged to be toxic. For benthic crustaceans (e.g. crabs) this was 1-10 ppm (mg/l). This range applied to benthic adult and juvenile stages might be accurate, and for larvae would assumably be much lower as previously discussed. Armstrong et al. (1976) found a 100x increase in toxicity of methoxychlor (DDT analog) to Dungeness crab (Cancer magister) when comparing adult and larval stages, both in acute and chronic tests. The extreme difference in relative susceptibility of different life history stages of the same species underscores the need to consider oil impact in terms of concentrations and classes of hydrocarbons at several points in the water column and on the benthos (see detailed output of several models of transport, weathering, mixing, etc. of oil computed by the National Marine Fisheries Service, OCSEAP Final Rep. Series Vol. 36, Parts 1 and 2, 1985).

Impact on BKC: In terms of most parameters that could lead to an oil mishap in the SEBS and subsequent impact on crab, BKC are more vulnerable to the consequences of oil release than are RKC. Armstrong et al. (1983) discussed the potential impact of various oil spill scenarios on RKC along the NAS and, in general, it was an issue of space (i.e., whether or not a spill of sufficient size would cover an area adequately large to impact this more widely distributed species of king crab). In the case of BKC at the Pribilof Islands, the data presented in this report show that the species is very restricted in its distribution and therefore, simply from a spatial perspective, much more vulnerable to oil mishap; i.e. if oil reaches the Pribilof Islands, a relatively greater proportion of the BKC population would be affected than would RKC along the NAS exposed in a comparable scenario.

The approach to assessment of potential impact and the resultant estimate of animals affected is a highly subjective process that depends on the data sets used, the rigor and complexity of models, and the tendency of individuals to be conservative or "worst case" in their approach, often as a reflection of their point of view on the subject. Certainly this issue of susceptibility of BKC to oil exposure around the Pribilof Islands is just such a case, where impact assessment is a variable process and resultant predictions about the nature and extent of impact will change with scenarios and data sets.

However oil arrives at the Pribilof Islands by whatever combination of wind, currents, and location in an impact model, any area of several thousand km^2 affected could have a significant impact on the species. Impact scenarios considered by participants in the Alaska workshops and reviewed by Armstrong et al. (1983), approached or exceeded several thousand km^2 affected following spills of several hundred thousand barrels of oil.

A more variable scale of effect for crab and other fisheries species was generated from oil impact models developed by the NMFS group (Leavastu et al. 1985) which considered blowout (20,000 bbl/day x 15 days) and accident (240,000 bbl - 10,000 bbl/hr x 10 days) scenarios, and oil components in categories of WSF and TARS (weathered, non-volatilized fraction delivered to the benthos). Results of the blowout scenario showed that concentrations of WSF greater than 0.1 ppm covered only 130 km^2, and TARS about 250 km^2. After an "accident", WSF and TARS in excess of 1.0 ppm covered 380 and 752 km^2, respectively, and in excess of 0.1 ppm covered 1160 and 1548 km^2, respectively. Various strata defined to calculate BKC larval and juvenile abundance around the Pribilof islands are on the order of 1,000 to 3,000 km^2 in area (Tables 4.4 and 4.5). Especially the areas east and southeast of St. Paul island where both larvae and small juveniles were found in high density, range around 1100 km^2 (Fig. 4.1, Table 4.4); rock, cobble and shellhash around St. Paul total only about 480 km^2 (Table

4.5). The results of NMFS simulations of spill scenarios if applied to areas of high abundance of larval and juvenile BKC around the Pribilof Islands, indicate the potential for extensive exposure of much of the population to hydrocarbons at concentrations that might be acutely lethal or chronically toxic in some way (e.g. reduced feeding, vacating habitat and higher risk of predation).

Life history of BKC around the Pribilof Islands is already somewhat tenuous under natural situations quite apart from any additional impact caused by possible oil spills in the area. Oil that inundates the Pribilof Islands or is mixed to the benthos (see review by Curl and Manen 1982; Schumacher 1982) could affect the species in several ways. Mature crab apparently move to the nearshore region sometime in late winter or early spring so that females may both hatch eggs in the vicinity as well as molt and breed. As noted in Section 4.5, this species is on a biennial reproductive cycle which means that a major fraction of the female population is not reproducing in consecutive years. Therefore, larval production is accounted for by a variable portion of the female population (Somerton and MacIntosh 1985; this study). Based on evidence gathered in the present program, it seems apparent that larvae must be retained nearshore of the Pribilof Islands in order to ensure a successful year class because of the dependence of juvenile stages on nearshore shellhash habitat. Size-frequency data show that year classes fail entirely from time to time, probably because of adverse transport of larvae away from the Pribilof Islands (see Section 4.1). In over 400 benthic trawls and dredges during the three cruises of this study, no crab between 30 to about 80 mm CL were caught, a size range that represents at least two year classes. Therefore, failure of recruitment around the Pribilof Islands does occur for reasons quite apart from oil spills.

If, on the other hand, significant portions of the nearshore area around St. Paul are affected by oil of sufficiently high concentration (Leavastu et al. 1985, "accident" sceanrio WSF >0.1 ppm, 1160 km^2 for 21 days), it is reasonable to assume that larval production could be eliminated that year if the spill occurs between April through July. The second life history stage potentially affected by oil mishaps are juveniles which are also distributed nearshore around both islands. Whether or not oil from a spill mixes to the benthos in substantial quantities is a theoretical consideration that is dependent on the amount of oil, time and dispersion, severity of storms, and general turbulence (see reviews by Schumacher 1982; Curl and Manen 1982). If, by whatever means, significant quantities of hydrocarbons do reach the benthos, then the potential impact on juvenile stages could be high. Once mixed to the bottom, oil could affect animals either through acute or chronic toxicity (see review by Curl and Manen 1982; Armstrong et al. 1983) or through destruction of habitat.

The most unique feature of BKC ecology around the Pribilof Islands is the strong association between juvenile stages and shellhash habitat (see Section 4.0). If shell is coated with oil and is no longer usable by juvenile crab, then resultant mortality (if not from oil per se) could be quite high by virture of lost refuge from predators. Shell is apparently a relatively scarce commodity around the Pribilof Islands and, in quantity, may take a long time to accumulate. The age of several of the bivalve species that we measured aboard ship was typically in excess of 30 years and the size frequency of shell suggests that species do not recruit annually. Once an animal dies, its shell may exist for some years unless broken down by chemical or mechanical processes. If significant tracts of shell were lost on the east side of St. Paul Island due to contamination by oil mixed to the benthos, it is likely that several years would be required for that area to recover, either by weathering of the oil or replacement of the shell.

The only areas of consistently high juvenile abundance were on the east side of St. Paul and St. George Islands closest to the lease sale areas in the St. George Basin. Adult crab are probably much less susceptible to oil impacts than are either larval or juvenile stages. Armstrong et al. (1983) reviewed the literature dealing with possible modes of toxicity and impact on adult stages. Apart from overt and acute toxicity, the most likely impact was viewed in terms of reproduction. Adult mating is probably based on chemosensory cues that could be attenuated by exposure to hydrocarbons (Pearson et al. 1980) or by exposure of eggs and resultant loss of embryos. Based on our data, it is not known whether female crab incubate eggs through the entire 11 month cycle near the Pribilof Islands. If not, then it is unlikely that exposure of eggs some distance offshore would be any significant threat. More probable is impairment of reproduction by curtailment of chemosensory-based location and copulation of adult male and female crab. High density and discrete aggregations of crab on the east side of St. Paul near Walrus Island are consistent with the hypothesis that males move nearshore to copulate when the receptive females molt. Since reproduction occurs on a biennial basis, reduction of reproductive effort could have a serious effect on larval production the following year.

7. REFERENCES CITED

Alaska Dept. of Fish and Game. 1983. Fishing Report. Westward region shellfish report to the Alaska Board of Fisheries. March 1983. 330 pp.

Alexander, V. and H.J. Niebauer. 1981. Oeanography of the Eastern Bering Sea ice edge zone in spring. Limn. & Oceano. 26:1111-1126.

Armstrong, D. and D. Gunderson. 1985. The role of estuaries in Dungeness crab early life history: a case study in Grays Harbor, Washington. Alaska Sea Grant Dungeness Crab Symp., October 1984.

Armstrong, D., D. Buchanan, M. Mallon, R. Caldwell, and R. Millemann. 1976. Toxicity of the insecticide methoxychlor to the Dungeness crab Cancer magister. Mar. Biol. 38:239-252.

Armstrong, D., L. Incze, J. Armstrong and D. Wencker. 1981. Distribution and abundance of decapod crustacean larvae in the S.E. Bering Sea with emphasis on commercial species. Pp. 365-597 in: Environmental Assessment of the Alaska Continental Shelf. NOAA/OMPA Annual Rept. Vol. 2.

Armstrong, D.A., L. Incze, D. Wencker and J. Armstrong. 1986. Distribution and abundance of decapod crustacean larvae in the southeastern Bering Sea with emphasis on commercial species. In: U.S. Dep. Commer., NOAA, OCSEAP Final Rep. 53(1986):479-878.

Armstrong, D.A., L.K. Thorsteinson and C. Manen. 1984. Coastal habitats and species, Chapter 3. In: The North Aleutian Shelf Environment and Possible Consequences of Offshore Oil and Gas Development, L. Thorsteinson (ed.), Anchorage, AK, 9-11 March 1982. OCSEAP, 159 pp.

Armstrong, D., J. Armstrong, R. Palacios, G. Williams and G. Jensen. 1985. Early life history of juvenile blue king crab, Paralithodes platypus around the Pribilof Islands. P. 211-229, in: Proceedings of the International King Crab Symposium. Alaska Sea Grant Rpt. No. 85-12. 507 pp.

Broderson, C.C., S.D. Rice, J.W. Short, T.A. Mecklenburg, and J.F. Karinen. 1977. Sensitivity of larval and adult Alaskan shrimps and crabs to acute exposures of the water-soluble fraction of Cook Inlet crude oil. Pp. 575-578 in: Proceedings of the 1977 Oil Spill Conference (Prevention, Behavior, Control, Cleanup). American Petroleum Institute, Washington, D.C.

Bull, J.J. and R. Shine. 1979. Iteroparous animals that skip opportunities for reproduction. Am. Nat. 114(2):296-316.

Caldwell, R.S., E.M. Caldrone, and M.H. Mallon. 1977. Effects of a sea water fraction of Cook Inlet crude oil and its major aromatic components on larval stages of the Dungeness crab, Cancer magister Dana. Pp. 210-220 in: D.A. Wolfe (ed.), Fate and Effects of Petroleum Hydrocarbons in Marine Organisms and Ecosystems. Pergammon Press, New York. 428 pp.

Carter, R.A. 1978. The distribution of calanoid copepoda in the Agulhas current system off Natal, South Africa. CSIR, National Research Institute of Oeanology. Stellenbosch (South Africa), July 1978.

Chance, J.M. and W.G. Deutsch. 1980. A comparison of 4 similarity indexes in the cluster analysis of Susquehanna river USA macrobenthic samples. Proc. PA Acad. Sci. 54, 169-173.

Clifford H.T and W. Stephenson. 1975. An introduction to numerical classification. Academic Press, Inc., New York.

Cline, J., C. Katz, and H. Curl. 1981. Circulation processes in Bristol Bay, Alaska using dissolved methane as a tracer. Pp. 29-86 in: Environmental Assessment of the Alaskan Continental Shelf, Annual Report. Vol. V. Transport. OCSEAP, BLM/NOAA, Boulder, CO.

Curl, H. and C. Manen. 1982. Shellfish resources. Pp. 141-159 in: J. Hameedi (ed.), The St. George Basin Environment and Possible Consequences of Planned Offshore Oil and Gas Development. OCSEAP, Proc. Synthesis Workshop, April 1981, Anchorage. 162 pp.

Davis, C.L., K. Koop, D.G. Muir and F.T. Robb. 1983. Bacterial diversity in adjacent kelp-dominated ecosystems. Mar. Ecol. 13, 115-119.

Day, J.H., J.G. Field, and M.P. Montgomery. 1971. The use of numerical methods to determine distribution of the benthic fauna across the continental shelf off North Carolina. J. Anim. Ecol. 40:93-123.

Fager, E.W. 1963. Communities of organisms. In: Hill, M.N. (ed.), The Sea. Vol 2. New York Interscience, N.Y.: 415-437.

Favorite, F., A.J. Dodimead, and K. Nasu. 1976. Oceanography of the subarctic Pacific region. International North Pacific Fisheries Commission Bulletin, 33, 187 pp.

Field, J.G. 1969. The use of the information statistic in the numerical classification of heterogeneous systems. J. Ecol. 57,565-569.

Field, J.G. and G. MacFarlane. 1968. Numerical methods in marine ecology. 1. A quantative "similarity" analysis of rocky shore samples in False Bay, South Africa. Zool. Africana 3(2): 119-137.

Gallagher, A. and N. Pola. 1985. The uptake and depuration of petroleum hydrocarbons in marine species - a simulation study. U.S. Dep. Commer., NOAA, OCSEAP Final Rep. 36(1):241-317.

Hameedi, M.J. 1982. The St. George Basin Environment and Possible Consequences of Planned Offshore Oil and Gas Development. Synthesis meeting proceedings, April 1981. OCSEAP/NOAA, U.S. Dept. Commerce, Juneau, AK.

Hawkes, C.R., R.T. Meyers, and T.C. Shirley. 1986. Length-weight relationships of blue, Paralithodes platypus, and golden, Lithodes aequispina, king crabs parasitized by the rhizocephalan, Briarosaccus callosus Boschma. Fishery Bulletin, 84:327-332.

Hayes, M.L. 1983. Variation in the abundance of crab and shrimp with some hypotheses on its relationship to environmental causes. In: W. Wooster (ed.), From Year to Year: Interannual Variability of the Environment and Fisheries of the Gulf of Alaska and Eastern Bering Sea. Washington Sea Grant Pub. WSG-WO-83-3. University of Washington.

Haynes, E.b. 1974. Distribution and relative abundance of larvae of king crab, Paralithodes camtschatica, in the southeastern Bering Sea. Fish. Bull. 72(3):804-812.

Hebard, J.R. 1959. Currents in southeastern Bering Sea and possible effects upon king crab larvae. U.S. Fish. Wildl. Serv., Spec. Sci. Rept. Fish., No. 293, 11 pp.

Heck, K. and T. Thoman. 1984. The nursery role of seagrass meadows in the upper and lower reaches of the Chesapeake Bay. Estuaries, 7:70-92.

Hoffman, E.G. 1968. Description of laboratory-reared larvae of Paralithodes platypus (Decapoda, Anomura, Lithodidae). J. Fish. Res. Bd. Can. 25(3):439-455.

Holt, J. and K. Strawn. 1983. Community structure of macrozooplankton in Trinity and upper Galveston Bays. Estuaries, (6) 1.

Howard, A. 1980. Substrate controls on the size composition of lobster (Homarus gammarus) populations. J. Cons. Int. Explor. Mer. 39:130-133.

Howard, A. and R. Nunny. 1983. Effects of near-bed current speeds on the distribution and behavior of the lobster, Homarus gammarus (L.). J. Exp. Mar. Biol. Ecol., 71:27-42.

INPFC. 1982. International North Pacific Fishery Commission 1982 Annual Report II. King crab investigations in the eastern Bering Sea.

Jewett, S. and H. Feder. 1981. Epifaunal invertebrates of the continental shelf of the eastern Bering and Chukchi Seas. pp. 1131-1153 in: D. Hood and J. Calder (eds.), The Eastern Bering Sea Shelf: Oceanography and Resources, Vol. 2. NOAA/OMPA, Seattle, WA.

Jewett, S. and G. Powell. 1981. Nearshore movement of king crab. Alaska Seas and Coasts, 9(3):6-8.

Kihara, K. 1983. Structures of the benthic species communities and their variations in the Eastern Bering Sea. Bull. Jap. Soc. of Sci. Fisheries, 49(1):41-47.

Kinder, T.H. and J.D. Schumacher. 1981a. Hydrographic structure over the continental shelf of the southeastern Bering Sea. Pp. 31-52 in: D.W. Hood and J.A. Calder, (eds.), Vol. I, NOAA/OMPA, University of Washington Press, Seattle. 1339 pp.

Kinder, T.H. and J.D. Schumacher. 1981b. Hydrographic structure over the continental shelf of the southeastern Bering Sea. Pp 53-76 _in_: D.W. Hood and J.A. Calder (eds.), The Eastern Bering Sea Sehlf: Oceanography and Resources, Vol. I, NOAA/OMPA, University of Washington Press, Seattle. 1339 pp.

Kinder, T.H., J.D. Schumacher, and D.V. Hansen. 1980. Observation of a baroclinic eddy: an example of mesoscale variability in the Bering Sea. J. Phys. Oceano. 10:1228-1245.

Krebs, C.J. 1972. Ecology. Harper and Row, San Francisco. 694 pp.

Kurata, H. 1963. Larvae of decapoda crustaces of Hokkaido 1. Atelecyclidae (Atelecyclinae). Bull. Hokkaido Reg. Fish. Res. Lab. 27:13-24. (_In_ Japanese, English abstract).

Leauvastu, T., R. Marasco, N. Bax, F. Fredin, F. Fukuhara, A. Gallagher, T. Honkalehto, J. Ingraham, P. Livingston, R. Miyahara and N. Pola. 1985. Evaluation of the effects of oil development on the commercial fisheries in the eastern Bering Sea. U.S. Dep. Commer., NOAA, OCSEAP Final Rep. 36(1):1-48.

Leendertse, J.J. and S.K. Liu. 1981. Modeling of tides and circulations of the Bering Sea. Pp. 87-108 _in_: Environmental assessment of the Alaskan Continental shelf, Annual reports. Vol. V. Transport. OCSEAP, BLM/NOAA, Boulder, CO.

Lees, D.C., J.P. Houghton, D.E. Erickson, W.B. Driskell and D.E. Boettcher. 1980. Ecological studies of intertidal and shallow subtidal habitats in lower Cook Inlet, Alaska. u.S. Dept. Comm., NOAA, OCSEAP, Final Rept. 44(1986):1-436.

Liu, S.K. and J.J. Leendertse. 1981. Oil-spill analysis and simulation for the proposed oil-lease area in the St. George Basin, Alaska. The Rand Corp., WD-1026-NOAA.

MacIntosh, R., R. Otto, and A. Fukuyama. 1979. Size at sexual maturity and incidence of partial clutches in female king crab (_Paralithodes camtschatica_ and _P. platypus_) and Tanner crab (_Chionoecetes bairdi_, _C. opilio_, and _C. bairdi_ x _C. opilio_) in the southeastern Bering Sea in 1975-1979. Intern. Pacific Fish. Comm. Document Ser. No. 2245. 7 pp.

MacIntosh, R.A. and D.A. Somerton. 1983. Large marine gastropods of the eastern Bering Sea. Pp. 1215-1228 _in_: D. Hood and J. Calder (eds.), The Eastern Bering Sea Shelf: Oceanogrpahy and Resources, Vol. 2. NOAA/OMPA, Seattle, WA.

Makarov, R.R. 1966. Larvae of the shrimps and crabs of the west Kamchatkam shelf and their distribution. (Translated from Russian by B. Haigh). Natl. Lending Libr. Sci. Technol., Boston Spa, Yorkshire. 199 pp.

Marukawa, H. 1933. Biological and fishery research on Japanese king crab _Paralithodes camtschatica_ (Tilesius) (_in_ Japanese, English summary). J. Imp. Fish. Exp. Stn. Tokyo 4(37):1-152.

McDonald, J., H.M. Feder and M. Hoberg. 1981. Bivalve mollusks of the southeastern Bering Sea. Pp. 1155-1204 in: The Eastern Bering Sea shelf: oceanography and resources. Hood, D.W. and J.A. Clader (eds.), University of Washington Press, 1981.

McLean, R. 1983. Gastropod shells: A dynamic resource that helps shape benthic community structure. J. Exp. Mar. Biol. Ecol., 69:151-174.

McMurray, G., A.H. Vogel, P.A. Fishman, D.A. Armstrong and S.C. Jewett. 1984. Distribution of larval and juvenile red king crabs (Paralithodes camtschatica) in Bristol Bay. Draft final report, NOAA/OCSEAP. 145 pp.

Mecklenburg, T.A., S.D. Rice, and J.F. Karinen. 1977. Effects of Cook Inlet crude oil water soluble fraction on survival and molting of king crab (Paralithodes camtschatica) and coonstripe shrimp (Pandalus hypsinotus) larvae. Pp. 221-228 In: E.A. Wolfe (ed.), Fate and Effects of Petroleum Hydrocarbons in Marine Organisms and Ecosystems. Pergammon Press, New York. 478 pp.

Mintel, R.J. and G.b. Smith. 1981. A description of the resource survey data-base system of the Northwest and Alaska Fisheries Center, 1981. NOAA Technical Memorandum NMFS F/NWC-18. November 1981.

Moore, S. and R. Dwyer. 1974. Effects of oil on marine organisms; a critical assessment of published data. Water Resources 8:819-827.

Niebauer, H.J. 1981. Recent fluctuations in sea ice distribution in the eastern Bering Sea. Pp. 133-140 in: D.W. Hood and J.A. Calder (eds.), The Eastern bering Sea Shelf: Oceanography and Resources, Vo. I, NOAA/OMPA, University of Washington Press, Seattle. 1339 pp.

Niebauer, H.J. 1983. Multiyear sea ice variability in the eastern Bering Sea: an update. Journal of Geophysical Research, 88, 2733-2742.

Niebauer, H.J., . Alexander, and R.T. Cooney. 1981. Primary production at the eastern Bering Sea ice edge: the physical and biological regimes. Pp. 763-772 in: D.W. Hood and J.a. Calder (eds.), The Eastern Bering Sea Shelf: Oceanography and Resources, Vol. I, NOAA/OMPA, University of Washington Press, Seattle. 1339 pp.

NMFS (National Marine Fisheries Service). 1979. Manual of crab sampling methods for the trawl survey in the eastern Bering Sea, May 1979. NWAFC, NMFS, Kodiak Facility. 18 pp.

Otto, R. 1981. Eastern Bering Sea crab fisheries. Pp. 1037-1068 in: D.W. Hood and J.A. Calder (eds.), The Eastern Bering Sea Shelf: Oceanography and Resources, Vol. 2, NOAA/OMPA, University of Washington Press, Seattle. 1339 pp.

Otto, R. 1986. Management and assessment of eastern Bering Sea king crab stocks. Pp. 83-106 in: G. Jamieson and N. Bourne (eds.), North Pacific Workshop on Stock Assessment and Management of Invertebrates. Canadian Spl. Publ. Fish. Aquatic Sci. 92. 430 pp.

Otto, R.S., R.A. MacIntosh, A.K. Fukuyama, T.M. Armetta, and C.J. Pace. 1979. Eastern Bering Sea survey: King and Tanner crab. Northwest and Alaska Fisheries Center. Processed Report No. 79-14, National Marine Fisheries Service, Seattle, WA. 74 pp.

Otto, R.S., R.A. MacIntosh, T.M. Armetta, and S. Wilson. 1980. King and Tanner crab research in the eastern Bering Sea, 1980. (Documented submitted to the annual meeting of the International North Pacific Fisheries commission, Anchorage, Alaska, October 1980). U.S. Dept. Comm., NOAA/NMFS/NWAFC, 2725 Montlake Blvd. E., Seattle, WA 54 pp.

Otto, R., R. MacIntosh, T. Armetta, W. Meyers, and K. Stahl. 1981. United States crab research in eastern Bering Sea during 1981. Submitted for 1981 INPFC meeting. N.W. and Alaska Fish. Center, Seattle, WA. 61 pp.

Otto, R.S., R.A. MacIntosh, T.M. Armetta, and W.S. Meyers. 1983. United States crab research in the eastern Bering Sea during 1982. (Document submitted to the annual meeting of the International North Pacific Fisheries Commission, Tokyo, Japan, October 1982). NOAA/NWAFC/NMFS, 2725 Montlake Blvd. E., Seattle, Wa 57 pp.

Overland, J.E. and C.H. Pease. 1982. Cyclone climatology of the Bering Sea and its relation to sea ice extent. Monthly Weather Review, 110:5-13.

Pacific Packers Report. 1981. Shellfish: Recovery spurred by domestic demand. Vol. 79, pp. 38-45.

Pearson, W., P. Sugarman, D. Woodruff, T. Blaylock, and B. Olla. 1980. Detection of petroleum hydrocarbons by the Dungeness crab, Cancer magister. Fish. Bull. 78:821-826.

Pearson, W.H., D.L. Woodruff and B.J. Higgins. 1984. Feeding ecology of juvenile king and tanner crab in the southeastern Bering Sea. Final Report, NOAA/OCSEAP. 116 pp.

Pottle, R. and R. Biner. 1982. Substrate preference behavior of juvenile american lobster, Homarus americanus, in gravel and silt-clay sediments. Can. J. Fish. Aq. Sci., 39:928-932.

Powell, G.C. and R.B. Nickerson. 1965. Aggregations among juvenile king crabs Paralithodes camtschatica (Tilesius). Kodiak, Alaska. Animal Behavior, 13(23):374-380.

Rice, S.D., J.W. Short, C.C. Broderson, T.a. Mecklenburg, D.A. Moles, C.J. Misch, D.L. cheatham, and J.F. Karinen. 1975. Acute toxicity and uptake-depuration studies with Cook Inlet crude oil, Prudhoe Bay crude oil, No. 2 fuel oil and several subarctic marine organisms. Dec. 1, 1975. Northwest and Alaska Fisheries Center, NMFS, NOAA, U.S. Dept. of Commerce, Auke Bay Fisheries Laboratory, P.O. Box 155, Auke Bay, Alaska. Processed Report, 144 pp.

Sakurai, M., S. Vamishiro, S. Kawashima, N. Omni, and K. Abe. 1972. Fishes and fisheries in Kushiro. Kushiro series no. 13: Municipality of Kushiro, Chapter 2. (Not seen, cited by Otto et al. 1980).

Sanborn, H.R., and D.C. Malins. 1977. Toxicity and metabolism of naphthalene: A study with marine larval invertebrates. Proc. Soc. for Expt. Biol. Medicine. 154:151-155.

Sasakawa, Y. 1973. Studies on blue king crab resources in the western Bering Sea - I. Spawning cycle. Bull. Jap. Soc. Sci. Fish. 39(10):1031-1037.

Sasakawa, Y. 1975a. Studies on blue king crab resources in the western Bering Sea - II. Verification of spawning cycle and growth by tagging experiments. Bull. Jap. Soc. Sci. Fish. 41(9):937-940.

Sasakawa, Y. 1975b. Studies on blue king crab resources in the western Bering Sea - III. Ovarian weight, carried egg number and diameter. Bull. Jap. Soc. Sci. Fish. 41(9):941-944.

Sato, S. 1958. Studies on larval development and fishery biology of king crab, Paralithodes camtschatica (Tilesuis), (in Japanese, English summary). Bull. Hokkaido Reg. Fish. Res. Lab. 17:1-102.

Schumacher, J.D. 1982. Chapter 2. Transport and fate of spilled oil. Pp. 7-37 in: M.J. Hameedi (ed.), The St. George Basin Environment and Possible Consequences of Planned Offshore Oil and Gas Development. April 1981. OCSEAP, U.S. Dept. of Commerce, Juneau, AK.

Schumacher, J.D. and R. Reed. 1983. Interannual variability in the abiotic environment of the Bering Sea and Gulf of Alaska. in: W. Wooster (ed.), From year to Year: Interannual Variability of the Environment and Fisheries of the Gulf of Alaska and Eastern Bering Sea. Washington Sea Grant Pub. WSG-WO-83-3. University of Washington.

Slizkin, A.g. 1971. Ecologic description of the Bering Sea population of blue crab (Paralithodes platypus, Brandt, 1850). TINRO, Vol. 81, Vladkvostok 201-208. (Translation from Russian).

Smith, P.E. and S.L. Richardosn. 1977. Standard techniques for pelagic fish egg and larva surveys. FAO Fisheries Technical Paer No. 175. United Nations Food and Agriculture Organization, Rome. 100 pp.

Somerton, D.A. and R.A. MacIntosh. 1982. Aspects of the life hsitory of the blue king crab (Paralithodes platypus) in Alaska. (Document submitted to the annual meeting of the International North Pacific Fisheries Commission, Tokyo, Japan, October 1982). NOAA/NWAFC/NMFS, 2725 Montlake Blvd E., Seattle, WA. 19 pp.

Somerton, D. and R. MacIntosh. 1985. Reproductiove biology of the female blue king crab Parallithodes platypus near the Pribilof Islands, Alaska. J. Crustacean Biology, 5:365-376.

Sonntag, N., R. Everitt, D. Marmorek, and R. Hilborn. 1980. Report of the Bering Sea ecological processes study modelling workshop. Unprocessed report to OCSEAP/OMPA. 96 pp.

Stephenson, W. 1973. The validity of the community concept in marine biology. Proc. Roy. Soc. Queensl. 84, 73-86.

Stephenson, W. and W.T. Williams. 1971. A study of the benthos of soft bottoms, Seek Harbour, New Guinea, using numerical analysis. Aust. J. Mar. Freshwater Res. 22, 11-34.

Stephenson, W., Williams, W.T. and A.N. Lance. 1970. The macro-benthos of Moreton Bay. Ecol. Monogr. 40, 459-494.

Stephenson, W., Williams, W.T. and S. Cook. 1972. Computer analyses of Petersen's original data on bottom communities. Ecol. Monogr. 42, 387-415.

Stephenson, W., Williams, W.T. and Cook, S. 1974. The macrobenthos of soft bottoms in southern Moreton Bay (south of Peel Island). mem. Queensl. Mus. 17, 73-124.

Takeuchi, I. 1969. On the distribution of the larval stage of "Okurigani", Erimacrus isenbeckii and "Zuwai-gani", Chionoecetes opilio elongatus in the northeastern and eastern regions of Hokkaido in 1958. Bull. Hokkaido Reg. Fish. Lab. 35:20-43. (in Japanese, English abstract).

Vanderhorst, J., C. Gibson, L. Moore. 1976. Toxicity of No. 2 fuel oil to coonstripe shrimp. Marine Pollut. Bull. 7:106-108.

Wallace, M., C.J. Pertuit, and A.r. Hvatum. 1949. Contributions to the biology of the king crab, Paralithodes camtschatica. U.S. Fish. Wildlife Fish., Leaflet 340. 50 pp.

Walters, G.E. and M.J. McPhail. 1982. An atlas of demersal fish and invertebrate community structure in the eastern Bering Sea: Part I, 1978-81. NOAA Technical memorandum, NMFS F.NWC-35.

Weber, D.D. 1967. Growth of the immature king crab, Paralithodes camtschatica (Tilesius). Int. North Pac. Fish. Comm., Bull. 21, pp. 21-47.

Weinstein, M. 1979. Shallow marsh habitats as primary nurseries for fishes and shellfish, Cape Fear River, North Carolina. Fish. Bull., 77:339-357.

Wells, P.G., and J.B. Sprague. 1976. Effects of crude oil on american lobster (Homarus americanus) larvae in laboratory. J. Fish. Res. Board Can. 33:1604-1614.

Williams, W.T. 1971. Principles of clustering. Annual Rev. Ecol. Syst. 2, 303-326.

Williams, W.T. and Stephenson, W. 1973. The analysis of three dimensional data (sites x species x times) in marine ecology. J. Exp. Mar. Biol. Ecol. 11, 207-227.

Yoshida, H. 1941. On the reproduction of useful crabs in North Korea, Part II. Suisan Kenkyushi 36(7):116-123. (in English, translated from Japanese by Dr. Hack Chin Kim, NMFS, Seattle).

Zar, J.H. 1974. Biostatistical Analysis. Prentice-Hall, New Jersey. 718 pp.

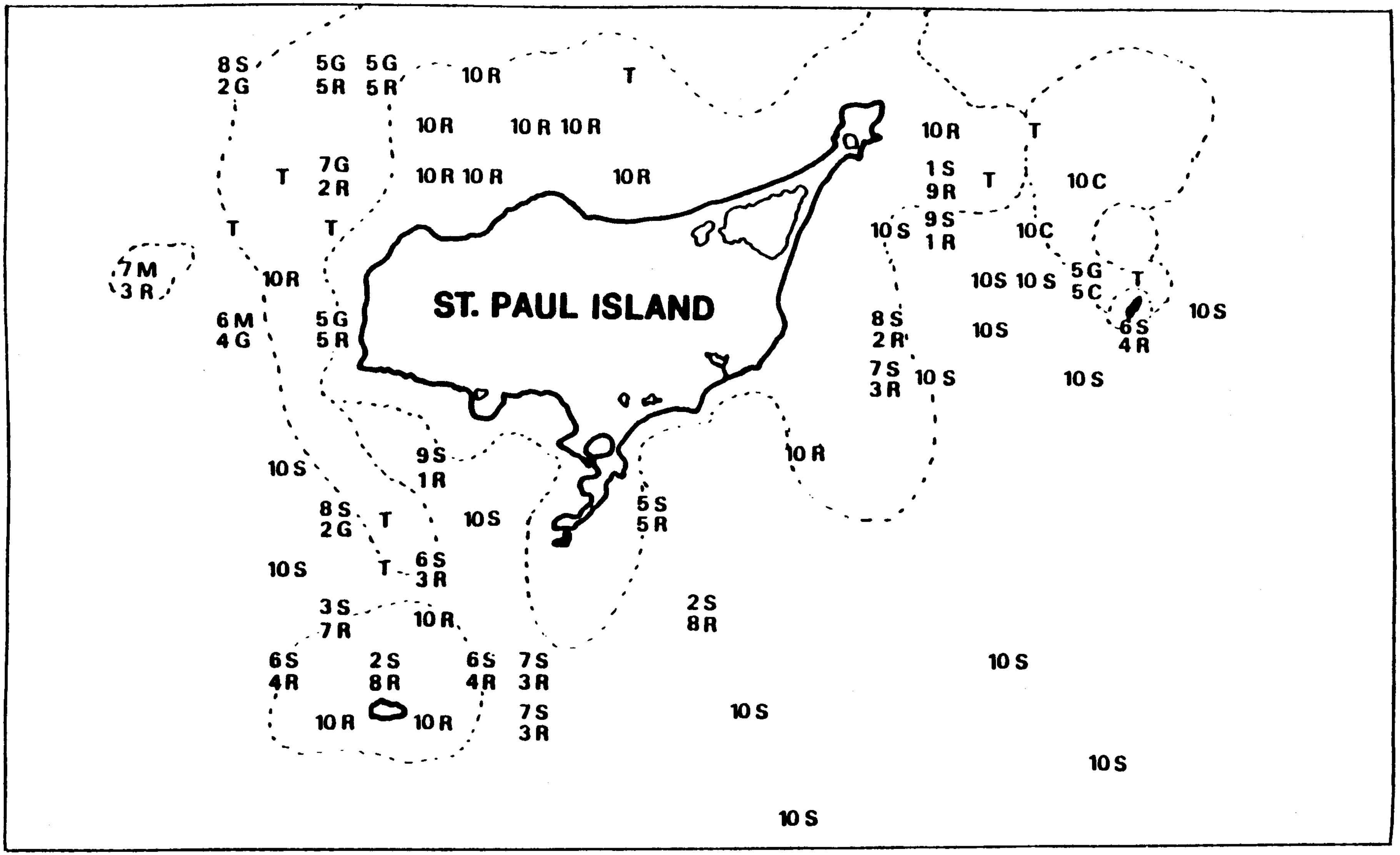
Zimmerman, R., T. Minello and G. Zamora. 1984. Selection of vegetated habitat by brown shrimp, *Penaeus aztecus*, in a Galveston Bay salt marsh. Fish. Bull., 82:325-326.

Appendix A.1 Sediment composition (%) of 80 selected stations from the May 1983 cruise.

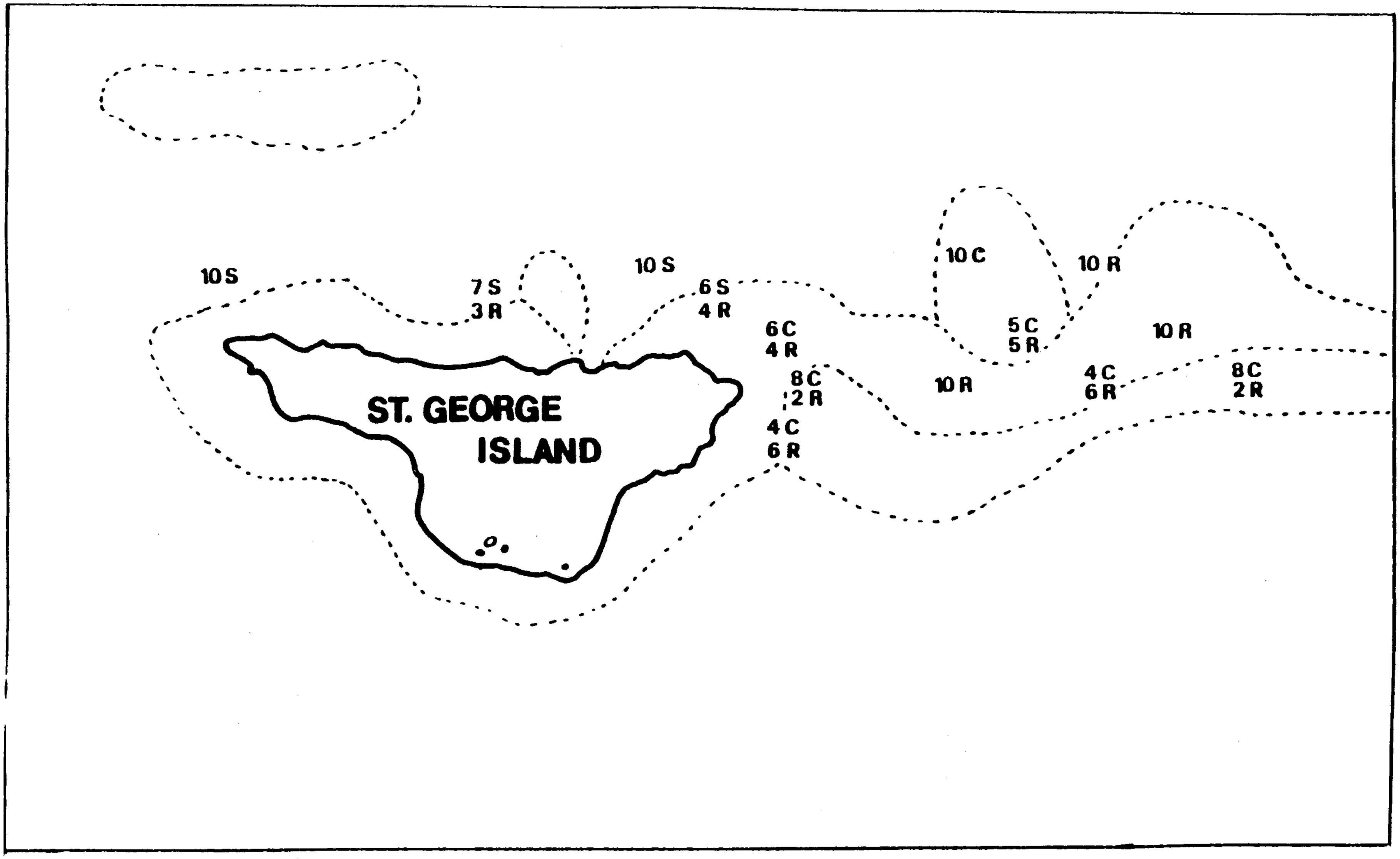
	PEBBLE	GRANULE	VERY COARSE SAND	COARSE SAND	MEDIUM SAND	VERY FINE SAND	FINE SAND	SILT AND CLAY
Grain size mm	> 2 > 4	2 to 1 4 - 2	1 to 0 2 - 1	0 to-1 1-0.5	-1 to-2 5-0 25	-2 to-3 25- 125	-3 to -4 125- 063	< -4 < 063
STATION								
1	.05	.41	.34	.24	.47	7.49	61.46	29.54
2	.50	1.44	.58	.28	35.56	55.75	2.42	3.48
3	.10	.41	.68	.40	2.80	90.81	2.81	1.99
4	.69	7.09	20.81	15.23	8.62	31.98	11.58	3.99
5	.80	1.18	.48	.16	10.69	82.43	1.28	2.98
6	.23	.18	.22	.31	9.48	76.84	11.03	1.72
9	.00	.06	.07	.06	1.13	86.85	9.77	2.07
10	67.22	23.94	4.81	.54	.26	.58	.69	1.95
12	.00	.18	.18	.92	40.98	48.15	1.47	8.12
15	4.99	1.01	1.13	.93	2.13	50.32	21.12	18.37
16	56.63	15.12	10.87	8.09	3.23	.84	.95	4.27
17	.26	3.18	35.90	35.69	10.34	1.89	1.37	11.38
18	.17	.58	20.42	71.42	5.78	.66	.26	.73
20	61.39	24.22	9.00	2.31	.50	.75	.93	.92
21	11.11	.16	.23	.03	.34	5.12	12.48	70.53
22	.12	.22	.17	.10	.99	77.20	10.57	10.63
23	.00	.00	.00	.06	.43	9.27	18.58	71.66
24	.00	.13	.13	.09	1.11	49.57	31.99	16.98
25	.00	.18	.91	2.45	2.40	74.72	11.44	7.89
26	10.32	25.81	30.36	21.04	6.45	1.81	.86	3.35
27	.00	.00	.14	1.25	33.68	56.54	6.63	1.75
30	45.12	23.89	12.29	7.03	3.72	4.90	1.28	1.77
31	24.13	5.37	10.10	12.03	21.31	22.68	1.16	3.22
32	17.39	6.77	4.50	5.35	12.71	24.17	14.98	14.12
33	.00	.14	.06	.45	4.69	26.80	44.23	23.63
34	.00	.02	.10	.38	2.95	24.97	41.91	29.67
35	.88	.46	.61	2.14	11.52	77.37	4.76	2.26
37	.97	.05	.26	.32	1.47	74.50	19.22	3.22
39	.90	.75	.32	1.30	13.38	76.29	5.17	1.98
40	59.81	4.88	4.36	.21	3.09	9.36	8.36	9.93
41	7.92	22.37	28.35	18.26	9.69	10.43	1.01	1.98
58	1.09	1.76	1.17	2.61	22.51	58.57	8.23	4.07
60	.00	.00	.75	1.78	3.24	63.61	26.94	3.68
63	.51	.28	.21	.17	4.83	72.24	19.66	2.11
67	.00	.83	.43	.47	2.07	37.19	38.13	20.[illegible]
68	1.46	.42	.17	.10	.45	66.03	26.20	6.17
69	3.04	1.78	.59	.19	.84	66.14	23.52	3.89
70	.41	.27	.13	.10	.46	26.98	57.35	14.30
72	.23	2.32	1.33	.87	2.52	71.22	17.63	3.88
73	3.88	2.30	1.04	.44	4.34	71.16	12.74	4.10
75	.00	.07	.15	.13	1.54	19.94	20.66	57.51
76	.58	.00	.07	.09	1.04	51.22	33.73	13.26
77	.00	.03	.05	.09	2.48	72.96	18.06	6.33
78	.77	.51	.47	.79	5.80	78.69	11.30	1.67
79	40.43	14.33	7.83	5.37	9.61	17.91	2.68	1.85
83	.22	1.18	.68	.31	3.85	81.70	5.76	1.30
84	.00	.07	.10	.12	1.05	78.32	15.71	4.64
85	2.80	.66	.26	.20	3.50	87.55	4.28	.77
86	.20	.51	.58	1.48	15.86	75.16	3.44	2.77
87	.00	.00	.00	.04	.97	16.95	57.73	24.30
88	1.04	.19	.10	.57	10.13	64.41	16.60	6.87
89	1.09	.17	.19	.22	3.73	87.47	4.26	2.88
90	.00	.06	.04	.06	.70	24.57	2.16	72.41
91	.00	.12	.14	.19	1.83	82.39	11.74	3.58
92	.20	.07	.19	.30	4.82	75.34	14.41	3.57
94	1.55	.13	.23	1.75	28.22	64.46	2.09	1.56
95	.00	.19	.13	.11	.77	27.39	53.48	17.94
96	.16	.31	.12	.15	1.15	18.12	55.71	24.27
97	.00	.04	.05	.19	3.73	53.08	29.63	13.28
98	.00	.13	.33	1.39	13.35	74.94	5.71	4.14
104	.00	.00	.10	.22	3.10	61.77	20.19	14.62
105	.00	.26	.05	.04	.56	37.93	52.85	8.30
106	1.22	2.57	3.90	6.09	31.40	45.79	4.60	4.43
108	26.54	6.21	4.23	3.19	11.53	39.15	3.58	5.60
111	.00	.04	.19	.96	54.81	43.12	.62	.27
112	1.76	5.21	5.87	8.54	11.95	49.72	10.05	5.91
113	14.87	29.49	9.84	17.37	23.87	3.01	.39	1.16
114	57.83	8.94	4.57	2.14	2.75	10.34	5.07	8.36
115	.00	.07	.09	.08	.31	12.05	32.54	54.86
119	.00	.08	.08	.08	.47	79.86	11.49	7.93
120	13.61	5.27	6.28	7.10	15.74	31.35	4.92	15.73
121	.00	.00	.07	.24	3.00	62.55	20.73	13.41
122	3.89	3.29	1.91	1.69	6.26	33.74	11.87	37.36
123	9.29	4.91	6.19	10.49	18.43	35.49	5.07	10.13
127	.00	.00	.00	.01	3.60	14.97	45.94	35.49
128	.00	.00	.04	.16	5.55	67.80	18.91	7.55
129	.00	.00	.17	.37	6.34	46.74	29.99	16.38
130	.16	1.84	.90	.45	21.40	70.30	2.81	2.25
136	.05	.71	.32	.14	5.91	83.46	5.82	3.58
137	.04	.10	.12	.09	1.07	80.02	12.54	5.91
139	2.60	.60	.23	.09	.90	72.99	16.15	6.54

Appendix A.2 Mean phi value, standard deviation, skewness and kurtosis of the grain size distribution of the 80 samples analyzed. ST = station.

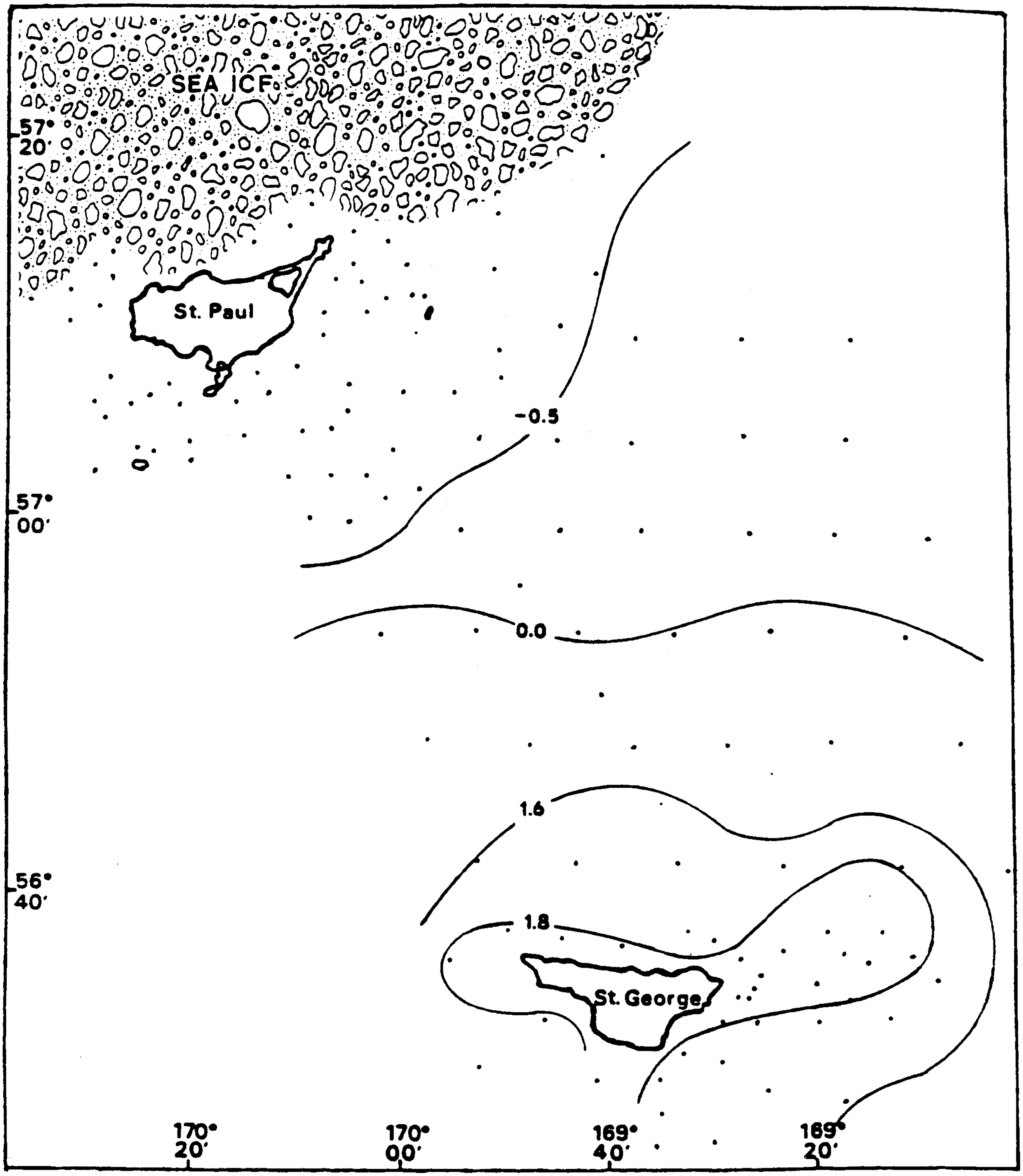
ST	MEAN PHI VALUE	S.D.	SKEW	KURT	ST	MEAN PHI VALUE	S.D.	SKEW	KURT
1	-3.67	.75	2.43	17.16	75	-3.83	.88	1.14	4.08
2	-2.13	.90	1.18	9.87	76	-3.06	.85	1.22	12.29
3	-2.49	.55	2.59	28.70	77	-2.78	.63	-1.12	5.45
4	-1.36	1.69	.14	1.92	78	-2.50	.77	2.88	20.56
5	-2.36	.81	2.77	18.79	79	.47	2.17	-.58	1.83
6	-2.52	.63	1.46	17.18	83	-2.41	.71	2.85	19.27
9	-2.62	.44	-1.35	15.46	84	-2.73	.57	-1.10	8.42
10	1.93	1.25	-3.64	17.69	85	-2.35	.96	3.97	20.40
12	-2.24	.87	-.96	4.88	86	-2.35	.73	1.36	12.76
15	-2.72	1.57	1.86	7.14	87	-3.55	.67	.29	3.03
16	1.36	1.78	-1.89	6.11	88	-2.63	.92	1.54	12.50
17	-.71	1.61	-1.35	3.94	89	-2.49	.72	3.43	29.33
18	-.39	.67	-1.66	13.93	90	-3.96	.90	1.24	3.33
20	1.83	1.19	-2.89	13.32	91	-2.66	.54	-.73	12.03
21	-3.46	2.20	2.17	6.08	92	-2.65	.64	.61	14.65
22	-2.79	.74	-.27	9.77	94	-2.15	.86	2.41	15.20
23	-4.11	.68	1.62	4.71	95	-3.37	.74	.72	6.58
24	-3.14	.80	-.11	3.99	96	-3.50	.80	1.74	12.42
25	-2.67	.80	.30	7.40	97	-3.02	.79	-.36	3.22
26	.37	1.50	-1.17	4.98	98	-2.46	.68	-.07	7.88
27	-2.24	.68	-.38	4.26	104	-2.96	.79	-.68	3.15
30	1.21	1.69	-1.52	4.72	105	-3.18	.68	.76	8.39
31	-.40	2.05	.16	1.84	106	-1.92	1.23	.97	5.29
32	-1.42	2.39	.50	1.90	108	-.77	2.35	.34	1.60
33	-3.35	.87	.61	4.05	111	-1.94	.56	-.15	3.99
34	-3.47	.85	.52	3.21	112	-1.98	1.54	.94	3.70
35	-2.35	.82	2.43	16.19	113	.28	1.61	-.33	2.29
37	-2.68	.77	2.70	22.72	114	.74	2.51	-1.04	2.44
39	-2.35	.81	2.62	17.13	115	-3.91	.74	1.26	5.59
40	.57	2.69	-.89	2.03	119	-2.76	.63	-1.37	7.56
41	.05	1.58	-.65	3.02	120	-1.49	2.21	.51	2.24
58	-2.23	1.08	1.49	8.25	121	-2.94	.77	-.74	3.22
60	-2.75	.72	.60	6.58	122	-2.89	1.81	1.43	4.76
63	-2.64	.71	2.19	19.78	123	-1.51	1.94	.62	2.74
67	-3.22	.95	1.15	7.39	127	-3.63	.79	.68	3.01
68	-2.78	.94	2.61	17.45	128	-2.78	.69	-.88	4.17
69	-2.56	1.23	2.63	11.57	129	-3.05	.86	-.11	2.85
70	-3.32	.80	2.20	16.75	130	-2.25	.83	1.89	11.81
72	-2.57	.97	2.13	11.33	136	-2.53	.65	1.35	17.85
73	-2.34	1.33	2.31	9.11	137	-2.72	.60	-.80	10.83



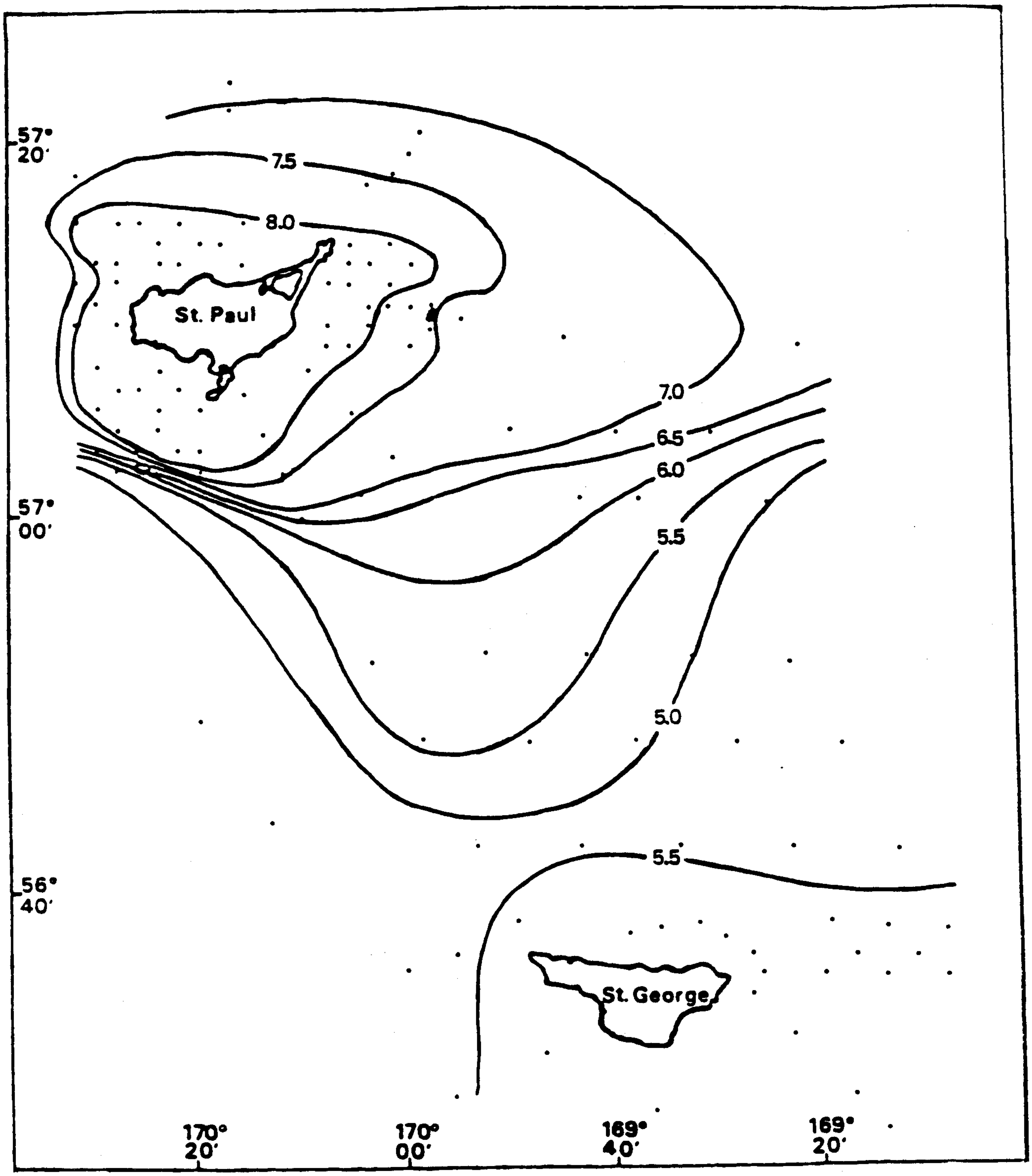
Appendix A.3 Summary of side scan sonar data on substrate type at each station, St. Paul Island. Over the linear distance of 1 NM at each station, the percent bottom type of each category present was summed and set on a scale of 10. R = rock, S = sand, M = mud, G = gravel, C = cobble, T = transition area where at least three substrates were found in equal proportion.



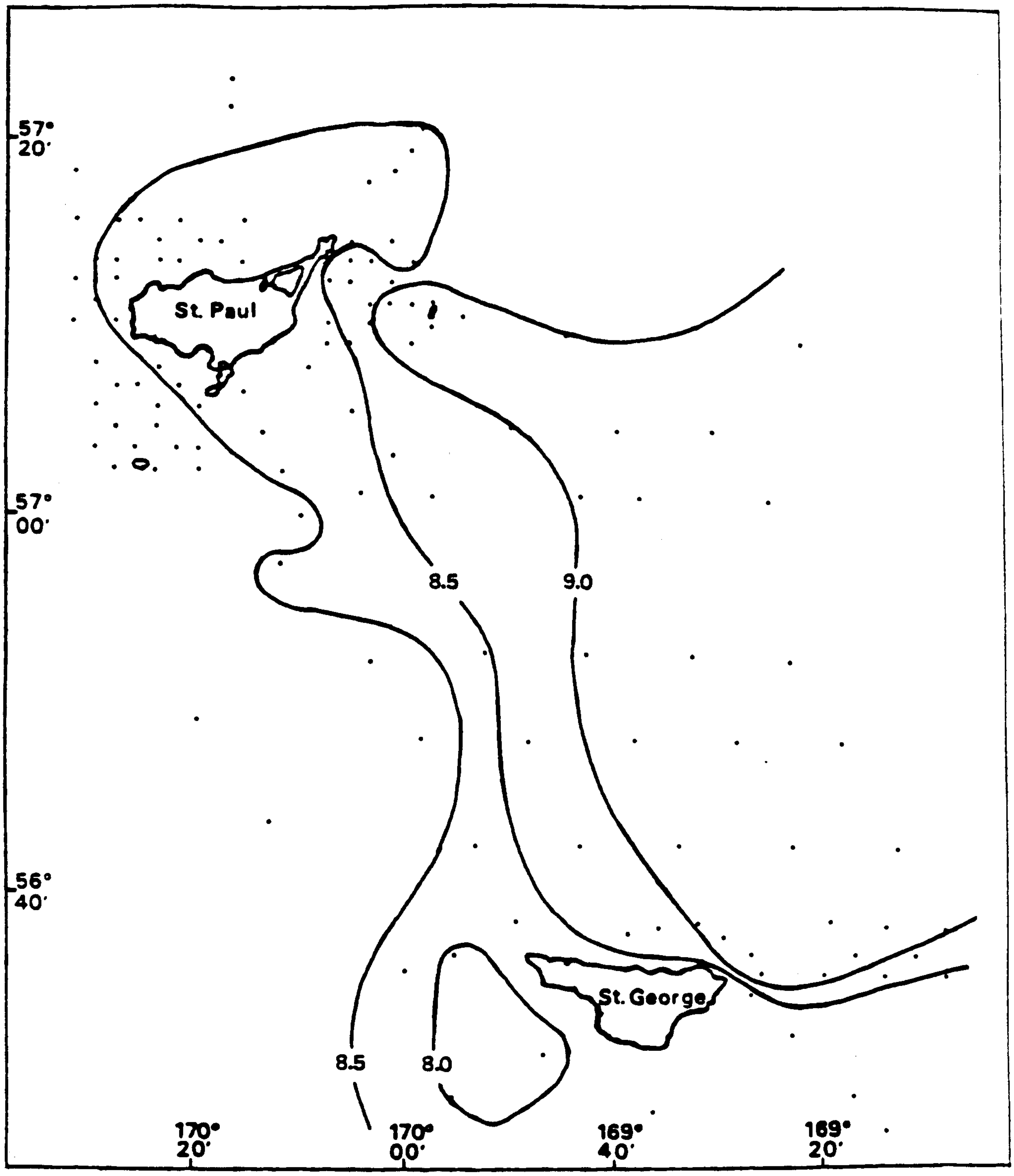
Appendix A.4 Summary of side scan sonar data on substrate type at each station, St. George Island. Over the linear distance of 1 NM at each station, the percent bottom type of each category present was summed and set on a scale of 10. R = rock, S = sand, C = cobble.



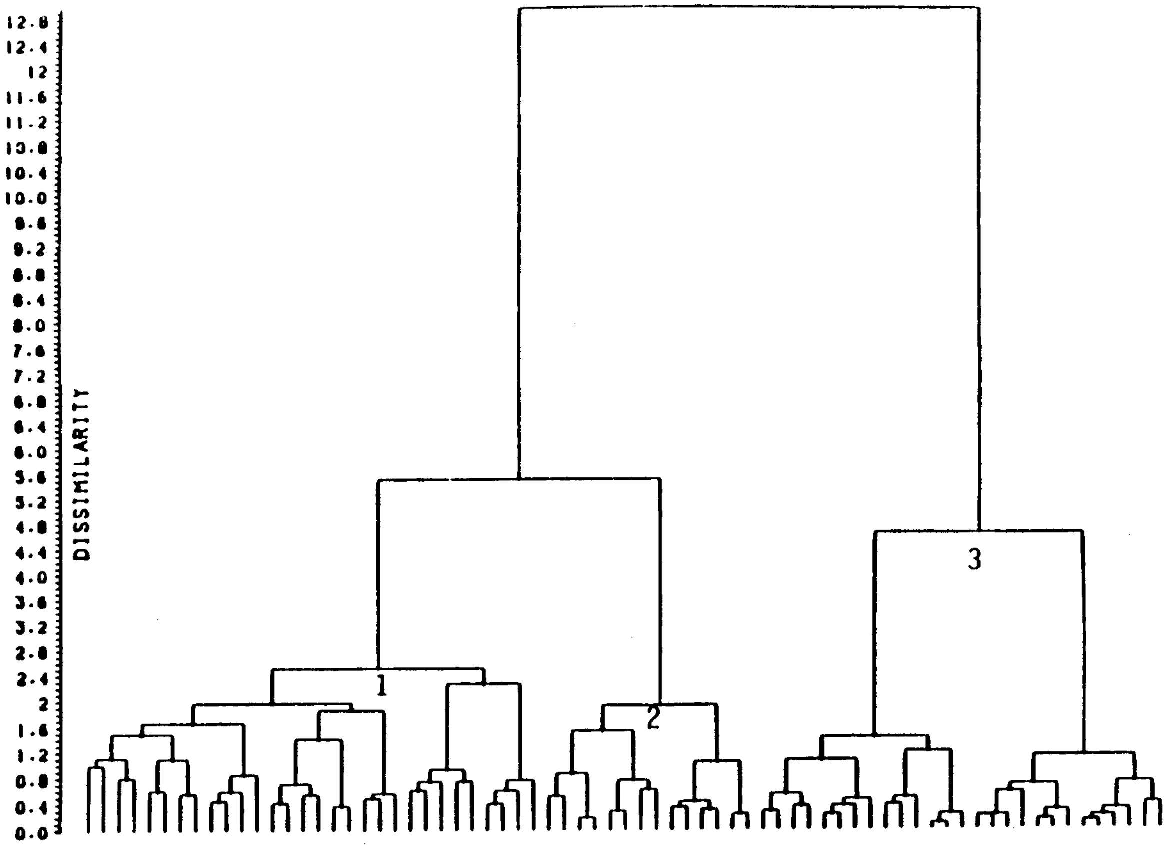
Appendix B.1 Surface temperatures (°C), April 1984.



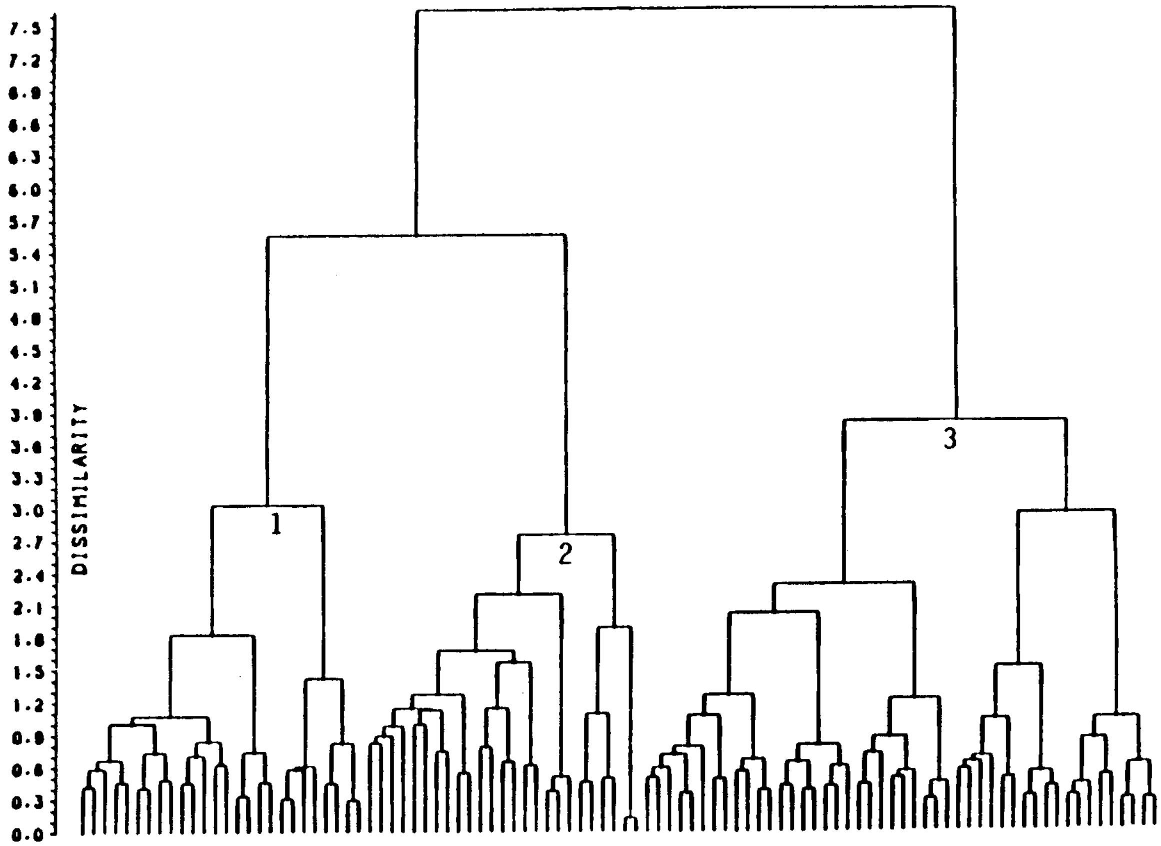
Appendix B.2 Bottom temperatures (°C), August 1983.



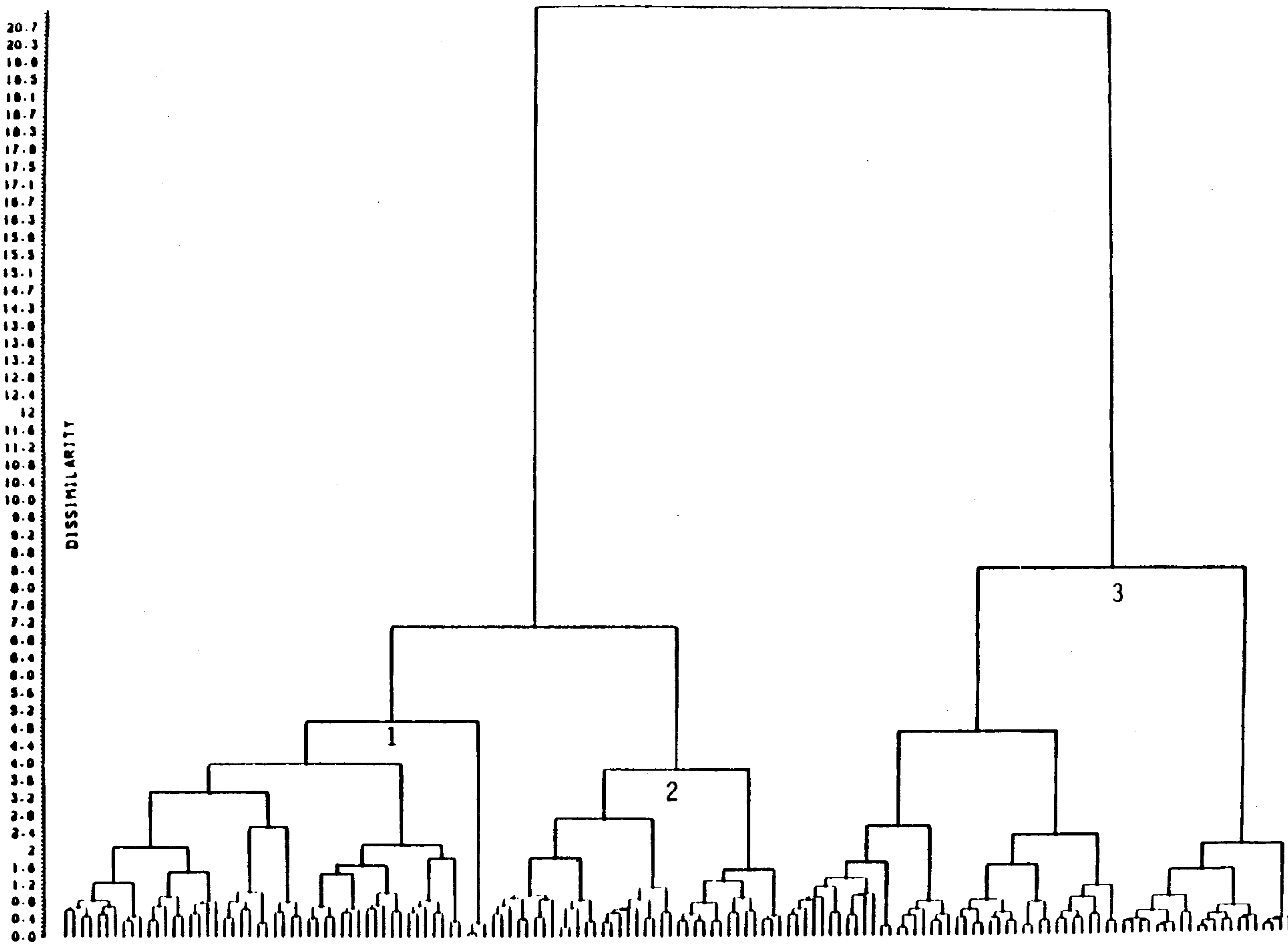
Appendix B.3 Surface temperatures (°C), August 1983.



Appendix B.4 Dendrogram showing the relationship between the beam trawl stations of the August 1983 cruise.



Appendix B.5 Dendrogram showing the relationship between the rock dredge stations of the August 1983 cruise.



Appendix B.6 Dendrogram showing the relationship between the stations of the April 1984 cruise, beam trawls and rock dredges combined.

Appendix B.7 List of the dominant species, frequency of occurrence, average density (in no./ha and g/ha), and average individual weights at the stations that constituted each of the major clusters from the beam trawl hauls in the August 1983 cruise.

General Taxonomic Group	Species	Cluster number	Freq (%)	N (no/ha)	W (g/ha)	W/N (g)
Coelenterata	Sea Anemones	1	50.0	191.9	43307.6	225.7
		2	21.4	3.1	2514.2	811.0
		3	51.9	173.7	61798.0	355.8
Echinodermata	A. amurensis	1	36.7	149.1	16745.8 S	112.3
		2	42.9	333.7	248449.0 S	744.5
		3	48.0	48.8	8657.1	177.4
	Henricia sp.	1	33.3	22.6 S	333.7 S	14.8
		2	14.3	3.2	10.0	3.1
		3	7.4	1.2 S	5.1 S	4.3
	L. nanimensis	1	50.0	45.5	5892.8	129.5
		2	35.7	18.6	4018.8	216.1
		3	55.6	15.4	4369.4	283.7
	S. droebachiensi	1	70.0	1111.2 *	22239.9 *	20.0
		2	21.4	3.3	610.3	184.9
		3	11.1	3.6	107.1	29.8
	Cucumaria sp.	1	36.7	101.3 S	59009.8 S	582.5
		2	21.4	6.3	7112.5	1129.0
		3	3.7	0.3 S	305.4 S	1018.0
Mollusca	F. oregonensis	1	26.7	73.6	5131.7	69.7
		2	0.0	0.0	0.0	0.0
		3	18.5	39.7	2744.9	69.1
	Neptunea spp.	1	6.7	1.6	249.9	156.2
		2	21.4	4.9	1017.3	207.6
		3	66.7	68.1 *	10645.2 *	156.3
	Nudibranchs	1	76.7	61.9 *	974.9 *	15.7
		2	35.7	9.6	10.3	1.1
		3	25.9	12.7	537.4	42.3
	Chlamys sp.	1	56.7	445.8 *	7545.5 *	16.9
		2	14.3	2.1	39.7	18.9
		3	18.5	15.8	210.6	13.3
	Mytilidae	1	30.0	37.8 S	634.7 S	16.8
		2	7.1	0.5	2.2	4.4
		3	0.0	0.0 S	0.0 S	0.0

General Taxonomic Group	Species	Cluster number	Freq (%)	N (no/ha)	W (g/ha)	W/N (g)
	P. macrochisma	1	36.7	98.7 S	6000.3 S	60.8
		2	7.1	15.3	1305.1	85.3
		3	3.7	0.2 S	1.5 S	7.5
Crustacea	Cirripedia	1	16.7	8.9	105.7	11.9
		2	7.1	0.5	53.3	106.6
		3	0.0	0.0	0.0	0.0
	Pandalus spp.	1	43.3	1184.6 S	1469.9 S	1.2
		2	28.6	34.2	38.5	1.1
		3	7.4	11.1 S	10.9 S	1.0
	C. oregonensis	1	53.3	41.7 *	96.9 *	2.3
		2	7.1	2.8	3.7	1.3
		3	22.2	4.2	11.6	2.8
	Chionocetes spp.	1	43.3	73.7	1550.7	21.0
		2	71.4	301.1	1331.8	4.4
		3	100.0	3216.7 *	15969.3 *	5.0
	E. isenbeckii	1	36.7	22.8 S	6024.8	264.2
		2	78.6	83.0 S	9567.4	115.3
		3	44.4	15.4	4129.7	268.2
	H. lyratus	1	53.3	133.3	1824.2	13.7
		2	42.9	81.2	1467.4	18.1
		3	66.7	34.2	92.7	2.7
	O. gracilis	1	86.7	716.0 *	8648.2	12.1
		2	78.6	107.5	638.7	5.9
		3	48.1	16.8	48.4 *	2.9
	P. platypus	1	50.0	17.0	1554.6	91.4
		2	14.3	5.8 S	0.1 S	0.0
		3	66.7	22.5 S	7720.6 S	343.1
Fish	A. bartoni	1	36.7	14.5	93.6	6.5
		2	7.1	0.5	0.1	0.2
		3	51.9	9.8	10.5	1.1
	Cyclopteridae	1	66.7	43.5	200.5	4.6
		2	71.4	52.6	114.5	2.2
		3	70.4	85.3	492.1	5.8
	H. jordani	1	33.3	40.4 S	16693.8 S	413.2
		2	0.0	0.0 S	0.0 S	0.0
		3	22.2	6.1	1488.4	244.0

Appendix B. 7 (continued)

General Taxonomic Group	Species	Cluster number	Freq (%)	N (no/ha)	W (g/ha)	W/N (g)
	H. elassodon	1	16.7	12.7	100.7	7.9
		2	0.0	0.0	0.0	0.0
		3	51.9	35.7 *	1824.5 *	51.1
	H. stenolepis	1	23.3	14.5	256.6	17.7
		2	85.7	126.9 *	896.9 *	7.1
		3	22.2	2.9	2.8	1.0
	L. bilineata	1	63.3	416.9	6313.6	15.1
		2	100.0	1434.9 *	60340.2 *	42.1
		3	81.5	156.9	11838.6	75.5

* Values are significantly different, at the 1% level, from the values of the other two clusters (see text).

S Two values are marked with this symbol when they differ significantly, but none of them is significantly different from the third.

Appendix B.8 List of the dominant species, frequency of occurrence, average density (in no./ha and g/ha), and average individual weights at the stations that constituted each of the major clusters from the rock dredge hauls in August 1983.

General Taxonomic Group	Species	Cluster number	Freq (%)	N (no/ha)	W (g/ha)	W/N (g)
Coelenterata	Sea Anemones	1	42.6	85.0	3715.2	43.7
		2	65.4	814.5 *	15799.7	19.4
		3	32.0	157.1	12949.4	82.4
Echinodermata	A. amurensis	1	27.7	45.3	3374.8	74.5
		2	65.4	1076.1 *	97072.9 *	90.2
		3	28.0	147.9	21380.5	144.6
	Henricia sp.	1	42.6	93.9 S	315.2 S	3.4
		2	15.4	50.3	487.6	9.7
		3	8.0	37.9 S	132.9 S	3.5
	L. nanimensis	1	25.5	44.2	6535.8	147.9
		2	26.9	53.7	7787.8	145.0
		3	4.0	2.4	1166.5	486.0
	S. droebachiensis	1	91.5	1190.7	61923.3	52.0
		2	76.9	999.9	50189.3	50.2
		3	24.0	138.0 *	4870.4 *	35.3
	Cucumaria sp.	1	44.7	157.8	105041.2	665.7
		2	23.0	89.5	61766.1	690.1
		3	12.0	58.3	54911.8	941.9
Mollusca	F. oregonensis	1	31.9	279.9	7366.5	26.3
		2	19.2	102.1	8640.3	84.6
		3	16.0	74.5	4439.2	59.6
	Neptunea spp.	1	2.1	1.9	60.4	31.8
		2	0.0	0.0	0.0	0.0
		3	12.0	5.8	927.3	159.9
	Nudibranchs	1	40.4	66.0	449.5	6.8
		2	50.0	171.0	418.7	2.5
		3	28.0	29.5	38.9	1.3
	Chlamys sp.	1	53.2	152.8 *	1394.0 *	9.1
		2	80.8	3557.0 *	35343.4 *	9.9
		3	20.0	61.9 *	1416.1 *	22.9
	Mytilidae	1	63.8	1187.6	152560.7	128.5
		2	57.7	488.8	22185.0	45.4
		3	8.0	1086.4 *	88488.6 *	81.5

Appendix B.8 (continued)

General Taxonomic Group	Species	Cluster number	Freq (%)	N (no/ha)	W (g/ha)	W/N (g)
	P. macrochisma	1	87.2	1029.7 *	72392.4 *	70.3
		2	50.0	1000.7	68713.1	51.8
		3	16.0	1640.1	89179.8	54.4
Crustacea	Cirripedia	1	38.8	110.1 S	6284.1 S	57.1
		2	15.4	65.3	1956.7	30.0
		3	4.0	40.7 S	1561.0 S	38.4
	Pandalus spp.	1	36.2	529.2	443.8	0.8
		2	65.4	2144.3 *	2386.6 *	1.1
		3	20.0	90.1	82.4	0.9
	C. oregonensis	1	89.4	828.9	1179.8	1.4
		2	69.2	1926.7	3746.6	1.9
		3	28.0	46.4 *	45.6 *	1.0
	Chionocetes spp	1	8.5	37.6 *	41.9 *	1.1
		2	38.5	308.4	930.4	3.0
		3	52.0	550.9	378.0	0.7
	E. isenbeckii	1	36.2	124.7	213.8	1.7
		2	76.9	2706.7 *	3566.0 *	1.3
		3	44.0	3707.2	1989.7	0.5
	H. lyratus	1	42.6	167.8	490.8	2.9
		2	84.6	1939.6 *	6743.8 *	3.5
		3	24.0	76.5	174.1	2.3
	O. gracilis	1	97.9	1756.1	7720.5	4.4
		2	84.6	2561.7	16912.2	6.6
		3	52.0	843.9 *	1108.3 *	1.3
	P. platypus	1	55.3	412.6	88.4	0.2
		2	80.8	2109.7 *	1473.1 S	0.7
		3	28.0	218.9	398.2 S	1.8
Fish	A. bartoni	1	6.4	7.7	6.6	0.9
		2	15.4	24.9	29.6	1.2
		3	12.0	5.9	4.3	0.7
	Cyclopteridae	1	53.2	187.2	445.1	2.4
		2	65.4	414.6 S	564.8 S	1.4
		3	32.0	60.9 S	45.1 S	0.7
	H. jordani	1	6.4	6.4	1313.3	205.2
		2	0.0	0.0	0.0	0.0
		3	0.0	0.0	0.0	0.0

Appendix B.8 (continued)

General Taxonomic Group	Species	Cluster number	Freq (%)	N (no/ha)	W (g/ha)	W/N (g)
	H. elassodon	1	0.0	0.0	0.0	0.0
		2	0.0	0.0	0.0	0.0
		3	4.0	4.0	15.8	4.0
	H. stenolepis	1	10.6	17.8	24.8	1.4
		2	0.0	0.0	0.0	0.0
		3	20.0	73.6	34.5	0.5
	L. bilineata	1	14.9	16.6	369.2	22.2
		2	23.1	150.2	1166.3	7.7
		3	24.0	167.1	184.1	1.1

* Values are significantly different, at the 1% level, from the values of the other two clusters (see text).

S Two values are marked with this symbol when they differ significantly, but none of them is significantly different from the third.

Appendix B.9 List of the dominant species, frequency of occurrence, average density (in no./ha and g/ha), and average individual weights at the stations that constituted each of the major clusters from the April 1984 cruise.

General Taxonomic Group	Species	Cluster number	Freq (%)	N (no/ha)	W (g/ha)	W/N (g)
Coelenterata	Sea Anemones	1	45.7	148.0	13031.8	88.1
		2	49.0	301.4	46431.3	154.1
		3	55.7	100.2	17884.6	178.6
Echinodermata	_A. amurensis_	1	5.7	13.4 *	1148.6 *	85.7
		2	64.7	567.8	61358.8 *	108.1
		3	72.1	223.3	40253.6 *	180.3
	Henricia sp.	1	48.6	107.5	736.7	6.9
		2	43.1	75.0	432.7	5.8
		3	9.8	2.4 *	8.3 *	3.5
	L. nanimensis	1	31.4	83.7	18100.4	216.3
		2	43.1	55.7	4570.4	82.1
		3	57.4	18.6	3372.1	181.3
	S. droebachiensis	1	91.4	1849.4 *	67832.6 *	36.7
		2	11.8	349.9 *	24996.3 *	71.4
		3	16.4	4.3 *	317.7 *	73.9
	Cucumaria sp.	1	85.7	307.9 *	194300.2 *	631.0
		2	43.1	121.7 *	60069.5 *	493.6
		3	6.6	4.1 *	868.4 *	211.8
Mollusca	_F. oregonensis_	1	62.9	280.2 *	16352.7 *	58.4
		2	17.6	19.7	2119.2	107.6
		3	16.4	3.8	260.6	68.6
	Neptunea spp.	1	14.3	14.4	798.6	55.5
		2	25.5	31.9	1485.7	46.6
		3	78.7	78.4 *	12598.7 *	160.7
	Nudibranchs	1	25.7	45.5	224.7	4.9
		2	25.5	25.7 S	351.8	13.7
		3	59.0	55.5 S	57.0	1.0
	Chlamys sp.	1	62.9	2892.7 *	49102.2	17.0
		2	47.1	328.0 *	5223.8	15.9
		3	11.5	4.1 *	65.2 *	15.9
	Mytilidae	1	62.9	2234.6 *	23783.1	10.6
		2	58.8	1297.1	49447.6	38.1
		3	3.3	0.9	2.4 *	2.7

Appendix B.9 (continued)

General Taxonomic Group	Species	Cluster number	Freq (%)	N (no/ha)	W (g/ha)	W/N (g)
	P. macrochisma	1	77.1	3667.2 *	143096.4 *	39.0
		2	37.3	202.7 *	8492.5 *	41.9
		3	8.2	11.2 *	807.3 *	72.1
Crustacea	Cirripedia	1	31.4	109.9 *	8000.4 *	72.8
		2	2.0	1.4	117.7	85.9
		3	0.0	0.0	0.0	0.0
	Pandalus spp.	1	68.6	963.2 *	998.7 *	1.0
		2	43.1	136.5	224.2	1.6
		3	55.7	14.4	18.6	1.3
	C. oregonensis	1	91.4	1272.8 *	1765.4 *	1.4
		2	68.6	168.9 *	349.2 *	2.1
		3	34.4	3.8 *	13.1 *	3.4
	Chionocetes spp.	1	5.7	4.0 *	442.9 *	110.7
		2	43.1	211.8 *	6772.1 *	32.0
		3	95.1	1284.4 *	12291.7 *	9.6
	E. cavimanus	1	62.9	167.6 *	994.2 *	5.9
		2	33.3	64.9 *	392.6	6.0
		3	14.8	6.1 *	71.6	11.7
	E. tenuimanus	1	48.6	311.6	1675.1	5.4
		2	58.8	216.0	682.9	3.2
		3	26.2	30.4 *	315.0 *	10.4
	E. isenbeckii	1	11.4	40.1 S	1888.5	47.1
		2	47.1	407.3 S	1822.2	4.5
		3	62.3	16.2	3581.2 *	221.1
	H. lyratus	1	57.1	575.2	117.6 *	0.2
		2	66.7	300.3 S	2606.3 *	8.7
		3	65.6	26.9 S	213.9 *	8.0
	L. splendescens	1	0.0	0.0 *	0.0 *	0.0
		2	25.5	34.2 *	71.0 *	2.1
		3	63.9	57.6 *	69.7 *	1.2
	O. gracilis	1	80.0	1107.4	3201.0	2.9
		2	82.4	698.5	4692.1	6.7
		3	52.5	20.4 *	117.5 *	5.8
	P. aleuticus	1	0.0	0.0	0.0	0.0
		2	11.8	2.6	26.2	10.1
		3	37.7	39.6 *	561.2 *	14.2

Appendix B.9 (continued)

General Taxonomic Group	Species	Cluster number	Freq (%)	N (no/ha)	W (g/ha)	W/N (g)
	P. capillatus	1	5.7	4.3 S	24.4	5.7
		2	17.6	18.1	200.1	11.1
		3	41.0	18.8 S	200.6 *	10.7
	P. confragosus	1	2.9	19.6 S	27.1	1.4
		2	11.8	16.5	40.6	2.5
		3	37.7	15.4 S	96.4 *	6.3
	P. dalli	1	68.6	1125.3	1803.6	1.6
		2	92.2	795.6 S	1395.0	1.8
		3	83.6	207.2 S	995.6	4.8
	P. ochotensis	1	2.9	2.3	25.9 *	11.3
		2	29.4	35.8	584.9 *	16.3
		3	70.5	98.2 *	1592.6 *	16.2
	P. platypus	1	34.3	229.8	3140.9	13.7
		2	45.1	118.9	0.0	0.0
		3	70.5	29.0	7135.3 *	246.0
Fish	A. bartoni	1	2.9	11.9	17.6	1.5
		2	17.6	10.3	9.2	0.9
		3	29.5	2.4	5.0	2.1
	Cyclopteridae	1	45.7	135.0	362.1	2.7
		2	43.1	54.5	533.5	9.8
		3	59.0	19.0	152.2	8.0
	H. jordani	1	37.1	73.4	6031.4	82.2
		2	39.2	36.7	1728.7	47.1
		3	44.3	10.1	2033.6	201.3
	H. elassodon	1	0.0	0.0 S	0.0 S	0.0
		2	5.9	2.1	303.5	144.5
		3	21.3	2.0 S	201.2 S	100.6
	H. stenolepis	1	0.0	0.0 S	0.0 S	0.0
		2	9.8	5.6	13.5	2.4
		3	24.6	6.6 S	63.9 S	9.7
	L. bilineata	1	11.4	11.3 *	1313.5 *	116.2
		2	51.0	130.6 *	2966.1 *	22.7
		3	96.7	290.8 *	10917.5 *	37.5

* Values are significantly different, at the 1% level, from the values of the other two clusters (see text).

S Two values are marked with this symbol when they differ significantly, but none of them is significantly different from the third.

Appendix B.10 Fidelity to Cluster 1, expressed as the number of stations at which the species occurs in the cluster over the total occurrence for the cruise (%).

Species	May	August Beam trawl	August Rock dredge	April	Overall
Sea Anemones	28.2	46.9	44.4	21.3	32.5
A. amurensis	7.4	36.7	35.2	2.5	16.2
Henricia sp.	75.0	71.4	76.9	37.8	56.2
L. nanimensis	20.0	42.9	60.0	16.2	29.4
S. droebachiensis	71.4	77.8	62.3	66.7	67.3
Cucumaria sp.	60.0	73.3	70.0	53.6	61.3
F. oregonensis	71.4	61.5	62.5	53.7	59.8
Neptunea spp.	10.5	48.8	25.0	7.6	20.1
Nudibranchs	26.5	65.7	48.7	15.5	35.4
Chlamys sp.	62.5	70.8	49.0	41.5	52.0
Mytilidae	80.0	90.0	63.8	40.7	57.9
P. macrochisma	78.3	84.6	70.7	52.9	66.9
Cirripedia	54.5	83.3	78.3	91.7	76.9
Pandalus spp.	18.4	68.4	43.6	30.0	34.7
C. oregonensis	58.6	69.6	62.7	36.4	51.7
Chionocetes spp.	13.9	26.0	14.8	2.4	12.6
E. cavimanus	-	-	-	45.8	-
E. tenuimanus	-	-	-	27.0	-
E. isenbeckii	13.5	32.4	35.4	6.1	20.0
H. lyratus	31.0	40.0	41.7	21.3	30.8
L. splendescens	-	-	-	0.0	-
O. gracilis	46.0	52.0	56.8	27.5	43.5
P. aleuticus	-	-	-	0.0	-
P. capillatus	-	-	-	5.5	-
P. confragosus	-	-	-	3.4	-
P. dalli	-	-	-	19.7	-
P. ochotensis	-	-	-	1.7	-
P. platypus	26.3	42.9	48.1	15.4	30.7
A. bartoni	16.7	42.3	30.0	3.6	21.3
Cyclopteridae	28.6	40.8	50.0	21.6	34.5
H. jordani	12.5	62.5	100.0	21.7	27.0
H. elassodon	0.0	26.3	0.0	0.0	8.2
H. stenolepis	0.0	28.0	50.0	0.0	19.4
L. bilineata	7.8	34.5	36.8	4.5	15.9

Appendix B.11 Fidelity to Cluster 2, expressed as the number of stations at which the species occurs in the cluster over the total occurrence for the cruise (%).

Species	May	August Beam trawl	August Rock dredge	April	Overall
Sea Anemones	23.1	9.4	37.8	33.3	28.3
A. amurensis	25.9	20.0	45.9	41.8	36.4
Henricia sp.	0.0	14.3	15.4	48.9	31.5
L. nanimensis	20.0	14.3	35.0	32.4	26.6
S. droebachiensis	23.8	11.1	29.0	12.5	20.6
Cucumaria sp.	40.0	20.0	20.0	39.3	31.1
F. oregonensis	14.3	0.0	20.8	22.0	17.4
Neptunea spp.	18.4	7.3	0.0	19.7	15.4
Nudibranchs	18.4	14.3	33.3	22.4	22.1
Chlamys sp.	20.8	8.3	41.2	45.3	34.2
Mytilidae	20.0	10.0	31.9	55.6	38.9
P. macrochisma	13.0	7.7	22.4	37.3	24.8
Cirripedia	27.3	16.7	17.4	8.3	17.3
Pandalus spp.	15.8	21.1	43.6	27.5	27.8
C. oregonensis	20.7	4.3	26.9	39.8	29.0
Chionocetes spp.	20.8	20.0	37.0	26.8	24.7
E. cavimanus	-	-	-	45.8	-
E. tenuimanus	-	-	-	47.6	-
E. isenbeckii	29.7	32.4	41.7	36.4	35.7
H. lyratus	20.7	15.0	45.8	36.2	32.2
L. splendescens	-	-	-	25.0	-
O. gracilis	26.0	22.0	27.2	41.2	31.1
P. aleuticus	-	-	-	20.7	-
P. capillatus	-	-	-	24.9	-
P. confragosus	-	-	-	20.0	-
P. dalli	-	-	-	19.7	-
P. ochotensis	-	-	-	25.4	-
P. platypus	15.8	5.7	38.9	29.5	25.4
A. bartoni	26.7	3.9	40.0	32.1	23.4
Cyclopteridae	28.6	20.4	34.0	29.7	28.4
H. jordani	28.1	0.0	0.0	33.3	26.1
H. elassodon	20.0	0.0	0.0	18.8	13.1
H. stenolepis	71.4	48.0	0.0	25.0	35.5
L. bilineata	27.5	25.5	31.6	29.2	28.0

Appendix B.12 Fidelity to Cluster 3, expressed as the number of stations at which the species occurs in the cluster over the total occurrence for the cruise (%).

Species	May	August Beam trawl	August Rock dredge	April	Overall
Sea Anemones	48.7	43.8	17.8	45.3	39.3
A. amurensis	66.7	43.3	18.9	55.7	47.4
Henricia sp.	25.0	14.3	7.7	13.3	12.4
L. nanimensis	60.0	42.9	5.0	51.5	44.1
S. droebachiensis	4.8	11.1	8.7	20.8	12.1
Cucumaria sp.	0.0	6.7	10.0	7.1	7.5
F. oregonensis	14.3	38.5	16.7	24.4	22.8
Neptunea spp.	71.1	43.9	75.0	72.7	64.4
Nudibranchs	55.1	20.0	17.9	62.1	42.5
Chlamys sp.	16.7	20.8	9.8	13.2	13.8
Mytilidae	0.0	0.0	4.3	3.7	3.2
P. macrochisma	8.7	7.7	6.9	9.8	8.3
Cirripedia	18.2	0.0	4.4	0.0	5.8
Pandalus spp.	65.8	10.5	12.8	42.5	37.5
C. oregonensis	20.7	26.1	10.4	23.9	19.3
Chionocetes spp.	65.3	54.0	48.1	70.7	62.8
E. cavimanus	-	-	-	18.8	-
E. tenuimanus	-	-	-	25.4	-
E. isenbeckii	56.8	35.3	22.9	57.6	44.3
H. lyratus	48.3	45.0	12.5	42.6	37.0
L. splendescens	-	-	-	75.0	-
O. gracilis	28.0	26.0	16.0	31.4	25.4
P. aleuticus	-	-	-	79.3	-
P. capillatus	-	-	-	69.5	-
P. confragosus	-	-	-	76.6	-
P. dalli	-	-	-	41.8	-
P. ochotensis	-	-	-	72.9	-
P. platypus	57.9	51.4	13.0	55.1	43.9
A. bartoni	56.6	53.8	30.0	64.3	55.3
Cyclopteridae	42.8	38.8	16.0	48.6	37.1
H. jordani	59.4	37.5	0.0	45.0	46.8
H. elassodon	80.0	73.7	100.0	81.3	78.7
H. stenolepis	28.6	24.0	50.0	75.0	45.2
L. bilineata	64.7	40.0	31.6	66.3	56.1

Appendix B.13 Discussion of clustering techniques and use of data relative to Section 3.

Substrate assessment

Although the SSS was very effective in giving a general "picture" of the sampling area, intrinsic problems like the transverse and vertical resolution made it difficult to establish the nature of the finer substrates. Rocky areas with large cobble and boulders, pinnacles and even flat rocky shelves appeared clearly on the sonographs but difficulties arose when interpreting the substrate of areas with a "smooth", relatively uniform echo trace. Since the transverse resolution was 26 cm, these areas could have ranged from mud-sand to small cobble, including various amounts of shellhash. In practice, however, substrate larger than gravel was very seldom found to be present at these areas. Van Veen and Shipek grabs, along with observation of the substrate caught in the fishing gear were the main basis for the assessment of sand, gravel and shellhash areas. Grab samples probed a very small area and their effectiveness over gravel and cobble is questionable. Substrate trapped in the fishing gear reflects the composition over a greater area, but it is impossible to tell whether certain substrate was uniformly distributed or came from discrete locations along the trawl line. This question is particularly important to the disposition of shellhash, which divers reported occurs in patches nearshore of St. Paul Island.

Another difficulty is that there is no indication of the amounts of substrate on the bottom, i.e., the thickness of a gravel layer which could have been washed out of the net or depth of a shellhash layer. For these reasons some misclassifications of stations and substrate may have occurred. Nevertheless, Figures 2.9 and 2.10 represent fairly well the general distribution of the different substrates found around the islands, although limits are not clear cut and some areas are not as homogeneous as the figures may suggest.

Cluster analyses

Numerical classification and computer programs greatly increase the power of data analyses and at the same time avoid subjective biases. This is particularly true for the analysis itself and the clustering process where mathematical formulas precisely establish the relationship between the different entities (stations), give an exact measure of their similarity and organize them according to a fixed hierarchical method. However, there are a number of steps before and after the analyses where decisions must be made by the researcher which compromise the objectivity the method tries to ensure. Choice of data and strategies, along with the interpretation of the results lay with the investigator who must set somewhat arbitrary limits and use personal judgment.

Choice of Data

The choice of data involved two processes independent from each other: 1) the choice of species to be used in the analyses; and 2) the selection of an attribute to characterize these species.

There are no uniform criteria among biologists on which to base selection of the species to be considered. Several authors have used an arbitrary limit on the frequency of occurrence, and all species found less frequently are discarded. The reason for this is because species which occur only once or at very few stations cannot contribute much to an overall distribution pattern or help to characterize communities, in the sense that community is defined in this study. The cutoff point can not be too high as to exclude most of the species because, as pointed out by Day et al. (1971), rare species could be very selective of environmental conditions and thus better indicators than common species, which tolerate a wide range of conditions. Also, there will be species that, although they occur very frequently, do so in a random way and independently from others, and therefore contribute little to the definition of the community distribution pattern. Willams and Stephenson (1973) proposed a method based on the sum of squares of the difference between the number of a given species and the mean number of the species found at one site, for all possible site pairs. This method was tried unsuccessfully and finally an arbitrary limit of 3.5% of occurrence for each cruise was used to reduce the number of species. After preliminary analyses, further reductions, based on abundance and fidelity to cluster group, discarded some species of widespread random distributions.

Among the attributes used to characterize species, presence/absence is the simplest one and it has been used mainly in taxonomic studies. In ecology, however, it is agreed that this binary coding loses important information and gives undue importance to the extremes of the range of a species. Numbers and weights are more appropriate measures for community studies and of the two, numbers are more easily obtained. Clifford and Stephenson (1975) stated that if weights are to be used, it is theoretically desirable that they be as biomass dry weight, excluding inert material, and Field and MacFarlane (1968) stated that the extra labor of weighing should not be undertaken unless justifiable.

Numbers were used in this study, standardized to counts/ha swept by the fishing gear to eliminate differences in towing distances and gear widths. Weights given in Table 3.4 and Appendices B.7 and B.9 in g/ha, refer to wet weights and although they were not used in the analyses, they were very helpful for interpreting the results, particularly when habitat preferences changed with life history stage, as in the case of the blue king crab.

Similarity Measures

A variety of formulas have been developed by several authors to give a measure of similarity (or dissimilarity) between entities, both in taxonomic and ecological works. Some of these measures were developed for a particular set of data and are restricted in their use. Others have been more accepted and widely used in various works. Of these measures, the Bray-Curtis and the Canberra metric dissimilarity measures have been most commonly used in benthic ecology (Field, 1969; Day et al, 1971; Carter, 1978; Chance and Deutsch, 1980; Walters and McPhail, 1982; Davis et al, 1983; Holt and Strawn, 1983).

If n is the number of attributes (species) and $X1j$ and $X2j$ (no/ha) are the values of the jth attribute for any pair of entities (sites) then these coefficients are:

Bray-Curtis
$$\frac{\sum X1j - X2j}{\sum (X1j + X2j)}$$

Canberra metric
$$\frac{1}{n} \sum \frac{X1j - X2j}{(X1j + X2j)}$$

The Canberra metric is a sum of fractions and therefore outstanding values only contribute to a fraction of the summation and therefore give a lower dissimilarity index, suggesting the sites are more similar. Also, when $X1j$ and $X2j$ are both zero, the fraction is taken to be zero, adding nothing to the summation but lowering the index since the divisor (n) is increased. Stations with few species in common will appear to be less dissimilar when measured by the Canberra metric than when measured by the Bray-Curtis coefficient. Nevertheless, in the earlier stages of this research both measures were tried before deciding for the Bray-Curtis coefficient.

Clustering Strategy

Again, several clustering strategies available to the researcher bring in an element of subjectivity to the analyses, although some properties of the different strategies may influence the decision on a particular case. Some strategies are "space contracting", others are "space dilating" and the remainder are "space conserving". In a space contracting strategy, the chance that an individual element will add to a group already formed, rather than act as the nucleus of a new group, is increased and the system is said to "chain". In a "space dilating" strategy, individual elements not yet in groups are more likely to produce groups of peripheral elements. Space contracting strategies are weakly clustering, giving "chains" of entities and are not of great conceptual value; space dilating strategies are strongly clustering and are of considerable conceptual value (Clifford and Stephenson, 1975).

Another desirable property in a clustering strategy is the dependence on groups properties prior to fusion. Some strategies, like nearest and furthest neighbor, only consider two entities (one in each group) to decide whether to fuse two groups. Others, such as group average, compares average values of the two groups to be fused together.

Flexible sorting, proposed by Lance and Williams (1967), has all the desired properties plus a variable clustering intensity according to the B coefficient. During the preliminary analyses, several values of B were tried before deciding for a value of -0.5.

Interpretation of the Results

With so many combinations of similarity measures and clustering strategies, it has been argued that methods are being chosen on a subjective basis to give the results that investigators have already conceptualized. There is some truth to this criticism, but it is also true that some rational and objective criteria can be established with which the researcher picks a "better" method. In ecological works, these criteria can be of two kinds: one refers to intrinsic characteristics of the groups formed and the other to the way extrinsic attributes are reflected in the classification (Clifford and Stephenson, 1975). In the first case, two way tables are most useful for spotting misclassifications and patterns of constancy and fidelity. Misclassifications certainly will occur since we cannot expect two species to have exactly the same distribution, but methods yielding too many of them, i.e., site groups with a series of low values where high ones are dominant, does not make much ecological sense. Constancy and fidelity tables for individual species are also very helpful when examining the results and deciding on cut off levels of dissimilarity. As dissimilarity increases, more groups are fused together and reference to these tables, along with extrinsic characteristics of the group formed, give useful information as to whether to truncate the dendrograms. The dissimilarity level for truncation does not have to be unique across the dendrogram. For the May and April cruises, dendrograms were truncated at two different levels since the groups thus formed gave a "better" classification in the sense that geographical distributions of the stations in the CGs had more correspondence to substrate patterns. Also, species found at the stations within a CG had better overall fidelity and constancy values.

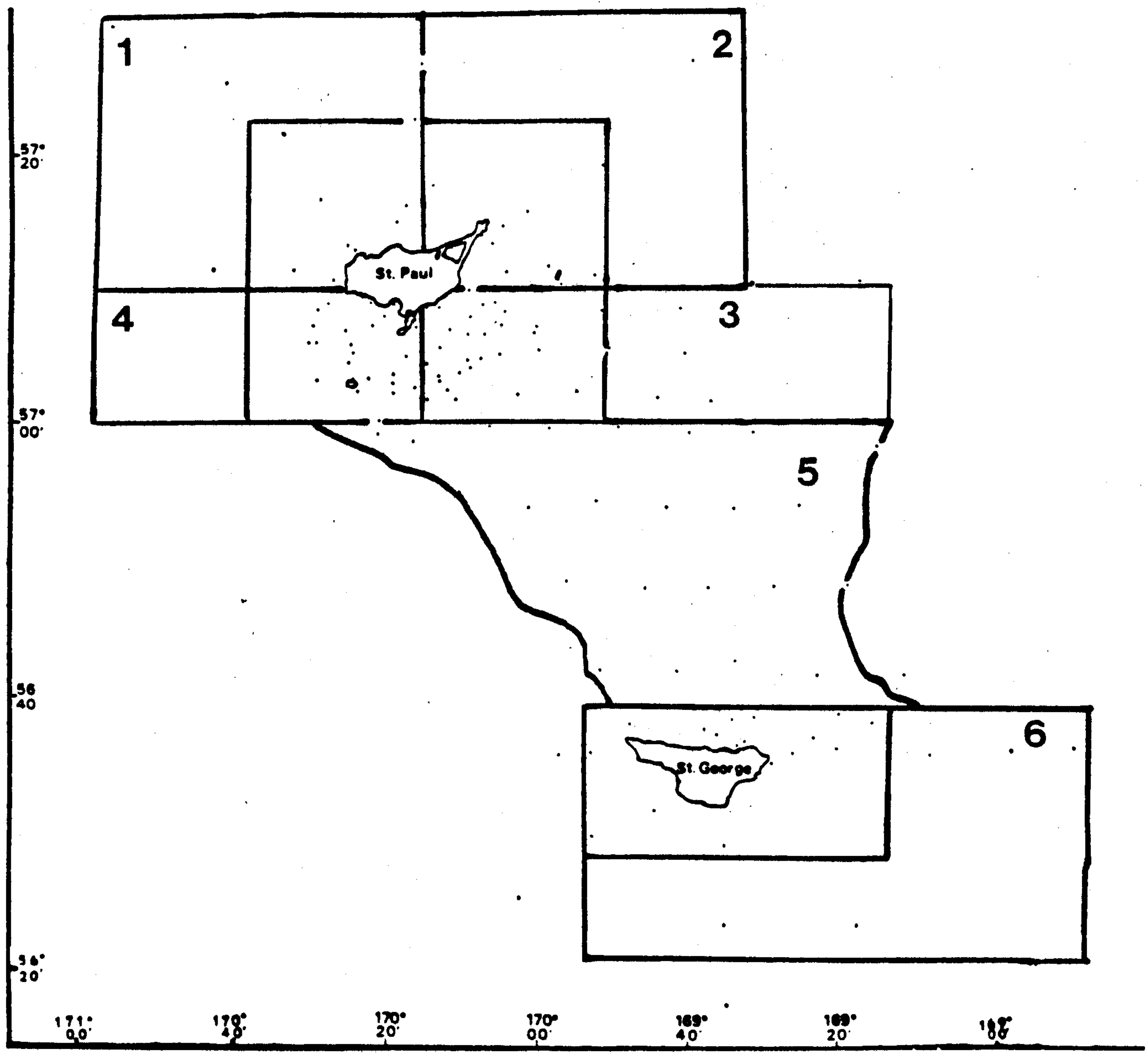
Extrinsic characteristics, like geographical distribution and substrate characteristics of the stations within different clusters must be carefully considered. When a method produces groups with mixed geographical distributions, the results must be viewed with skepticism unless other environmental factors with similar distribution can explain the heterogeneity. Substrate characteristics of the station groups were an important parameter in this study and always considered when analyzing different dendrograms. Chi square tests (Table 3.3) showed a significant difference between the bottom types of CG 1 and 3 that matched the geographical distribution of those stations and the substrate patterns around the islands.

Statistics

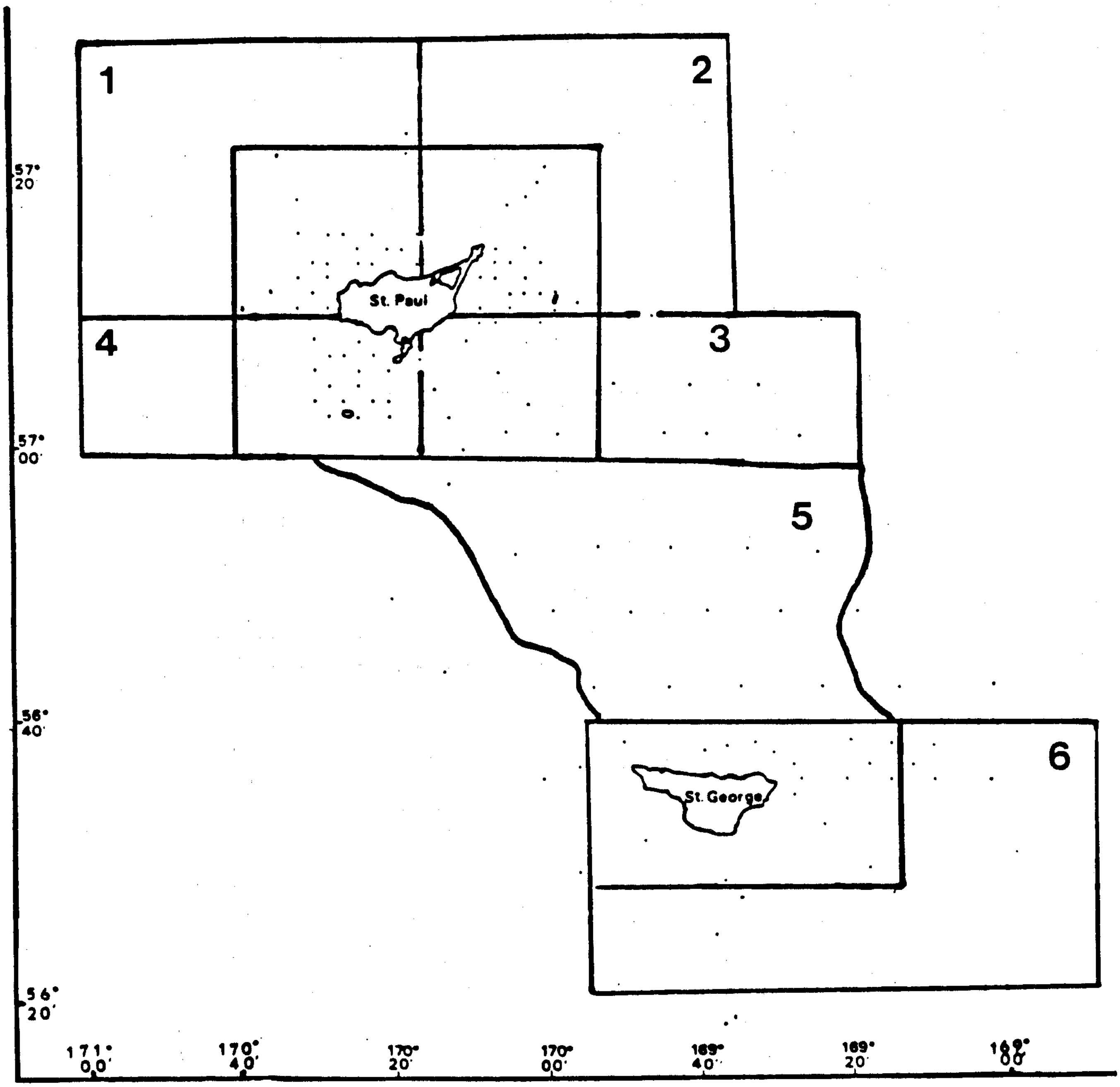
Examination of Table 3.4 and Appendices B.7 to B.9 show that while some species were caught almost exclusively at the stations in one of the clusters, others were more uniformly distributed across two or all three clusters and at comparable densities or frequencies. Whether these numbers are due to sampling variability or whether they reflect true differences in distribution and abundance would require a statistical test, but no such method has been developed to measure expected values or probabilities of random differences in this kind of numerical classification. Instead, an ANOVA and pairwise Student t-tests were performed with averages of the no/ha and g/ha at each cluster. The attribute used to define the clusters should not be used as the basis for a between-groups test of significance since the differences have been optimized. However, the clustering method groups stations according to their similarity when all species used in the analyses are considered. As stated before, some of these species may have a wide distribution and therefore will not have a considerable effect on the classification. In such cases, we can not expect their numbers (or weights) to be very different between the groups. In this sense, a t-test provided a measure of the extent to which an individual species contributed to define a cluster group.

The t-test, however, was designed to test whether two sample statistics, X1 and X2, are likely to have come from the same population. If three samples are taken from the same population, three pairs of t-tests are possible and the probability of a Type I error (wrongly concluding that two of the means estimate different parameters) is increased. With 20 means to be tested, this probability is 92 % (Zar, 1974). Since only 3 means were tested (average no/ha and g/ha at each of the 3 cluster groups for each trip) and values chosen for two means to be considered significantly different was 0.01, the overall probability of commiting a Type I error was probably less than 5 %, a value widely accepted in statistical works. Non-parametric tests, like the Mann-Whitney test, are "distribution free" and hence more appropriate when the assumptions of the t-test are severely violated, but large number of zeroes yield tied ranks which diminish the power of the test considerably, despite the corrections usually used in these cases (Zar, 1974).

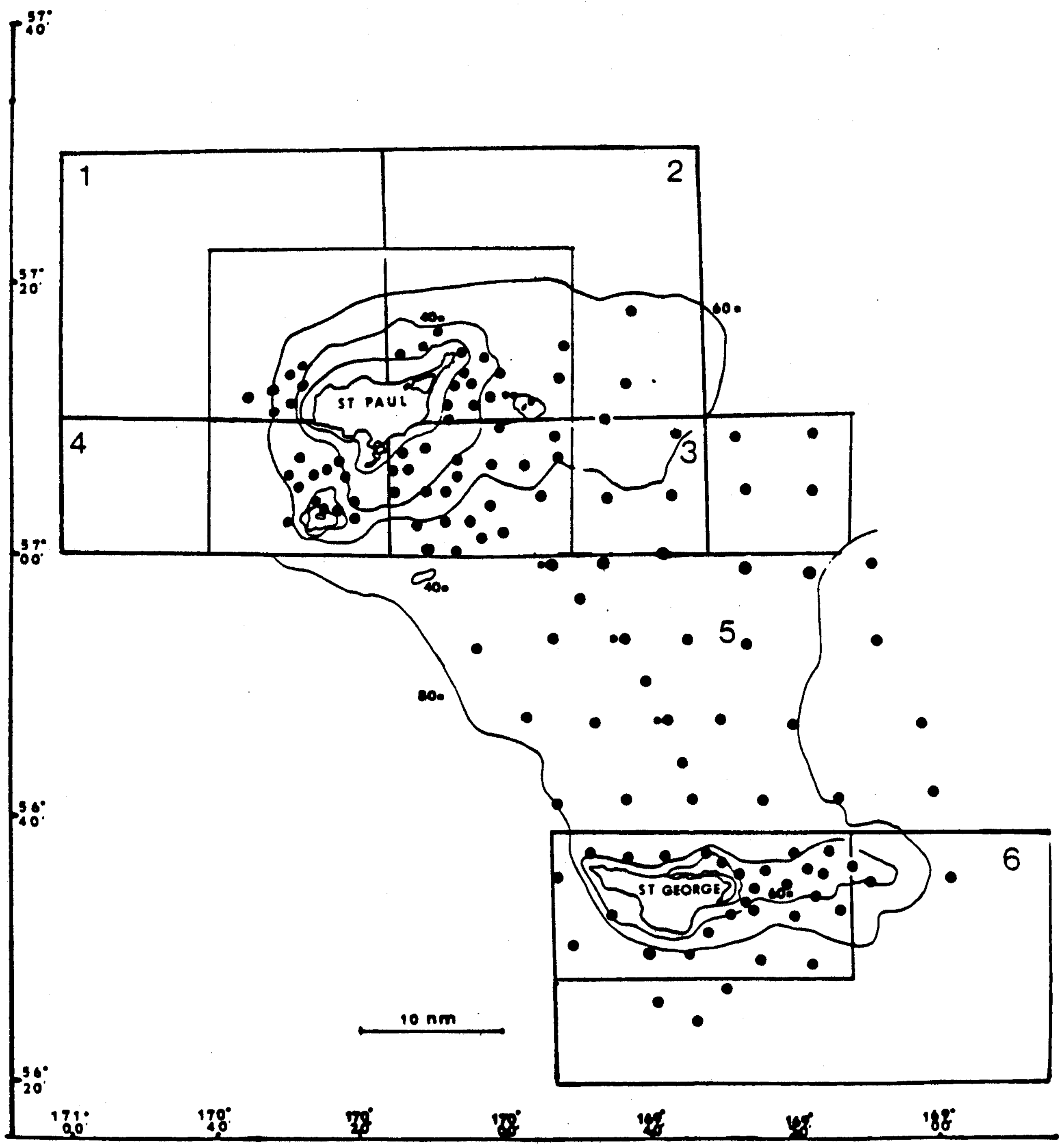
For these reasons, probability values given by the test are biased and they must be regarded carefully. Significant differences showed in Table 3.4 and Appendices B.7 to B.9 must be considered as showing values with a low (but unknown) probability of occurrence and therefore are useful as an indicator of possible differences but not as a true statistical probability.



Appendix C.1 May 1983 station locations in relation to strata boundaries.



Appendix C.2 August 1983 station locations in relation to strata boundaries.



Appendix C.3 April 1984 station locations in relation to strata boundaries.

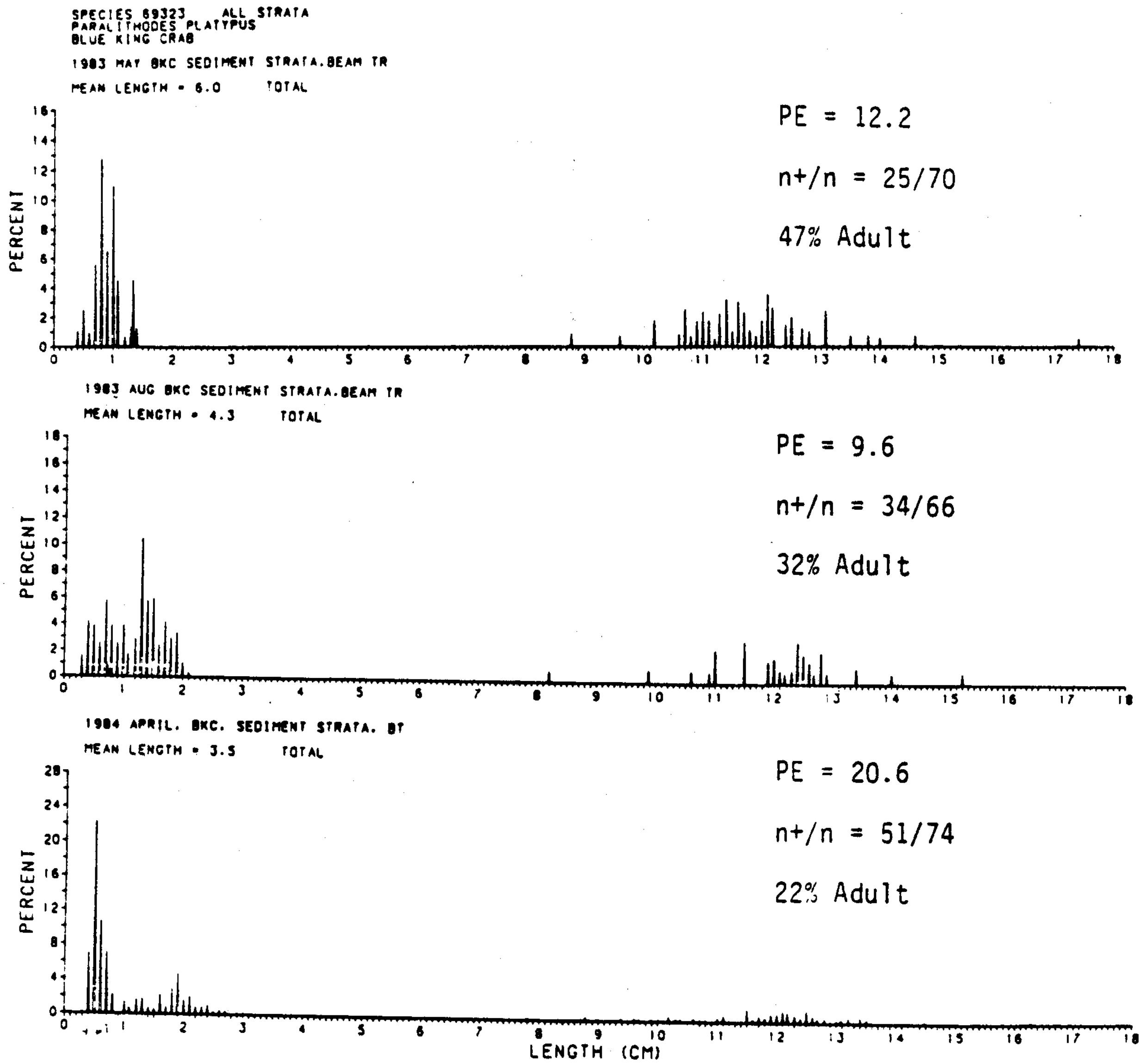
Appendix C.4 Strata groupings, areas, and sample sizes for blue king crab population estimates by rock dredge and beam trawl gear for three cruises. Numbers given are tows with crab/total tows.

Blue King Crab Population Estimate

		Rock Dredges			Beam Trawls		
		May	Aug	April	May	Aug	April
		Positive Tows / Total Tows			Positive Tows / Total Tows		
Stratum	Total Area (NM^2)						
1	480	1/6*	13/28	4/9	1/5*	1/6*	NS
2	449	3/5	19/23	4/11	4/6	8/18	13/17
3	499	0/1	1/5*	2/5	17/24	11/12	21/23
4	232	2/5	8/17	5/12	2/8	0/7	0/3
SP Sub Total	1660	6/17	41/73	15/37	24/43	20/43	34/43
5	978	1/2*	1/1*	0/2	9/23	14/17	14/20
SG Sub 6	808	3/6	13/24	10/27	1/11*	2/11	3/16
Total	3446	10/25	55/98	25/66	34/77	36/71	51/79
11	145	1/6	12/27	4/9	0/2	1/5*	NS
21	147	3/5	19/23	4/11	1/2*	8/17	8/11
31	120	0/1	1/4*	2/5	9/14	5/6	14/15
41	118	2/5	8/17	5/12	2/8	0/7	0/3
SP Sub	530	6/17	40/71	15/37	12/26	14/35	22/29
SG Sub 61	280	3/5	12/19	9/24	1/8*	2/10	3/13
Total	810	9/22	52/90	24/61	13/34	16/45	25/42
122	563	0/1	1/3	1/5*	12/18	11/18	26/30
123	200	0/2	1/7	0/2	2/6	1/6	0/2
125	70	0/5	8/25	2/10	0/1	0/3	NS
128	23	0/1	6/9	0/2	1/1*	0/5	0/1
135	48	6/8	25/29	12/18	1/3*	8/11	7/7
SP Sub	904	6/17	41/73	15/37	16/29	20/43	33/40
115	976	1/2*	1/1*	0/2	8/19	13/16	15/22
102	260	0/1	NS	0/3	0/3	0/1	3/5
105	33	1/1*	0/2	1/1*	NS	NS	NS
110	13	NS	0/1	0/1	0/1	0/1	0/2
114	67	2/4	13/18	9/20	1/3*	2/5	0/5
SG Sub	373	3/6	13/21	10/25	1/7*	2/7	3/12
Total	2253	10/25	55/95	25/64	25/55	35/66	51/74
SP 15-40 M	83	1/9*	9/29	4/16	1/6	0/8	1/4
40-60	445	4/5	27/37	8/13	15/24	10/23	16/19
SP Sub Total	528	5/14	36/26	12/29	16/30	10/31	17/23
SG 15-60 M	79	3/3	11/16	7/13	0/2	0/2	0/3
60-80	223	0/2	2/5	2/10	1/6*	2/5	3/8
Total	830	8/19	49/87	21/52	17/38	12/38	20/34

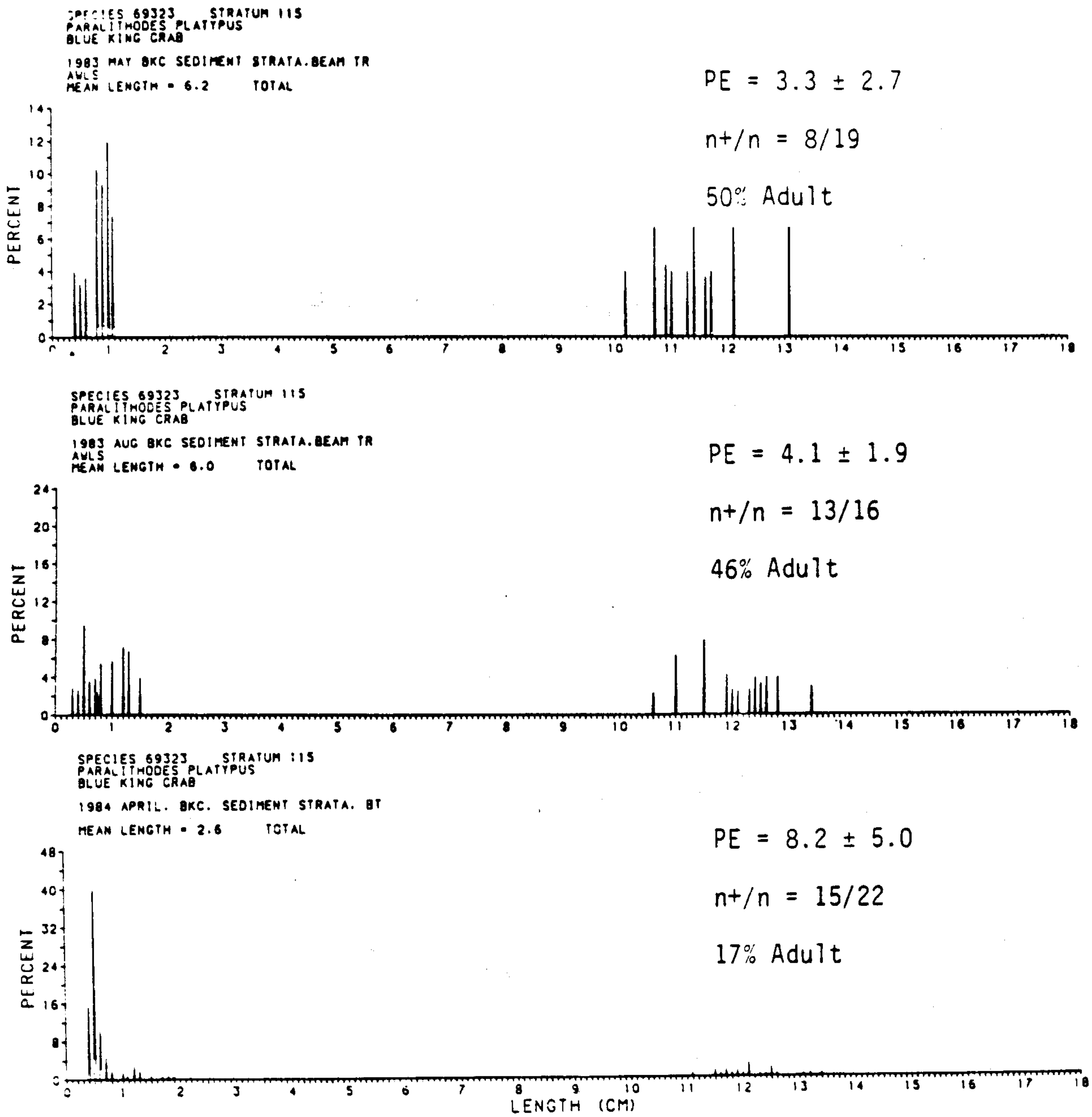
* Low sample size

ALL SEDIMENT STRATA, BEAM TRAWL

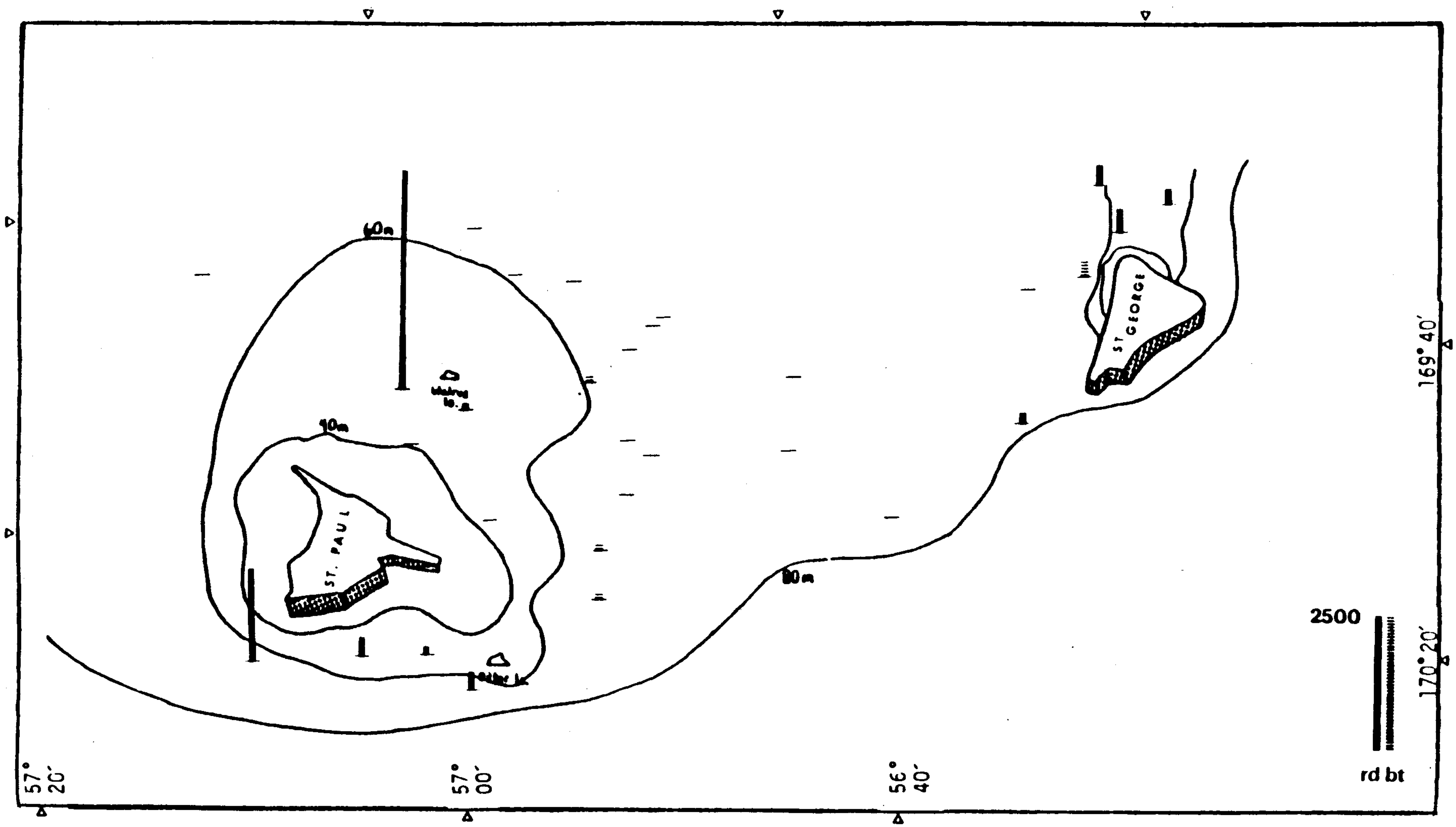


Appendix C.5 Carapace length frequencies of blue king crab collected in May and August 1983 and April 1984 by beam trawls within all strata of the sediment strata configuration. Population estimate (PE) in millions of crab, number of stations with crab/total number of stations sampled (n+/n), and percentage of the total population that were adults are also given.

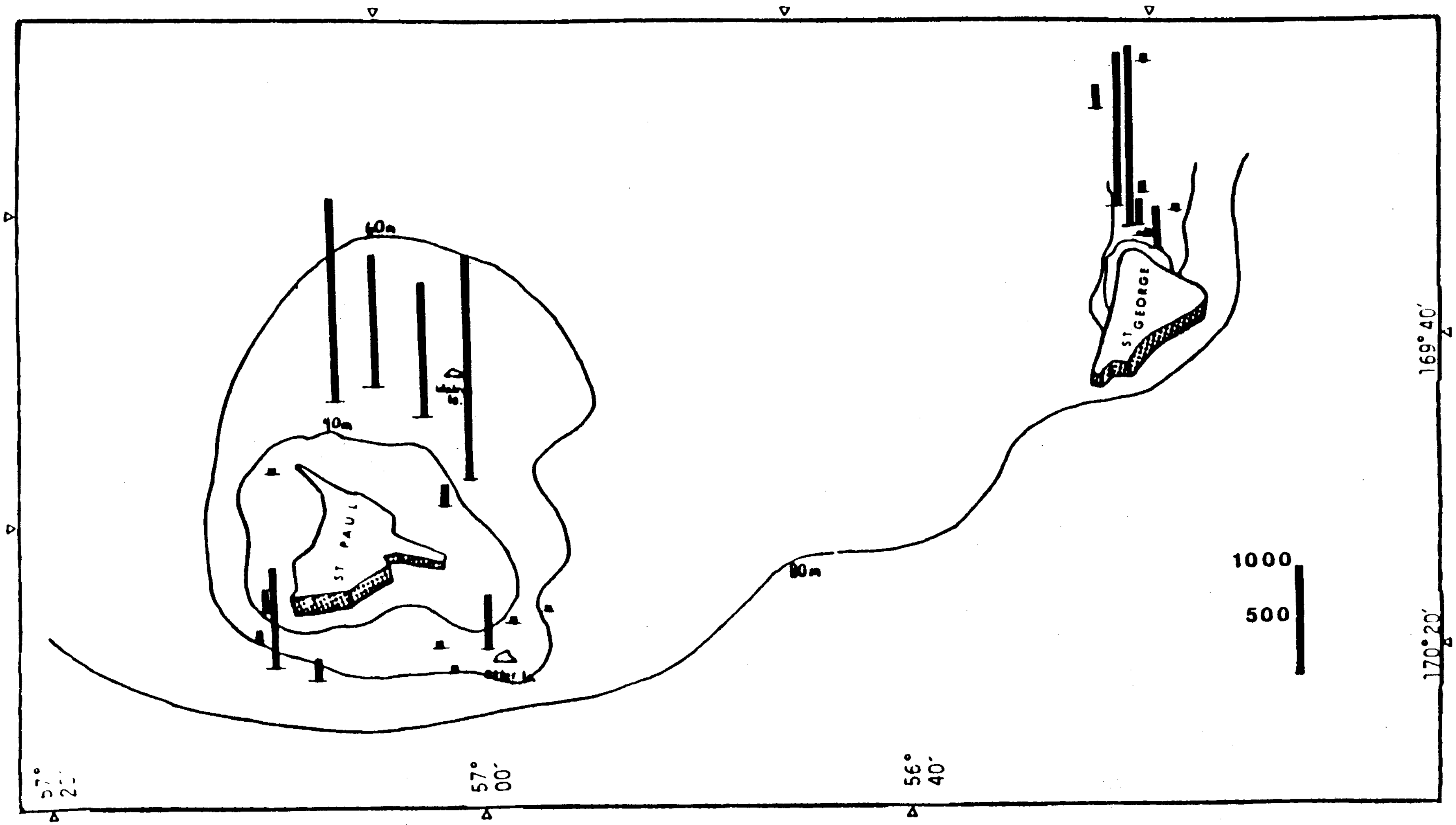
SAND, MID-ISLANDS, BEAM TRAWL



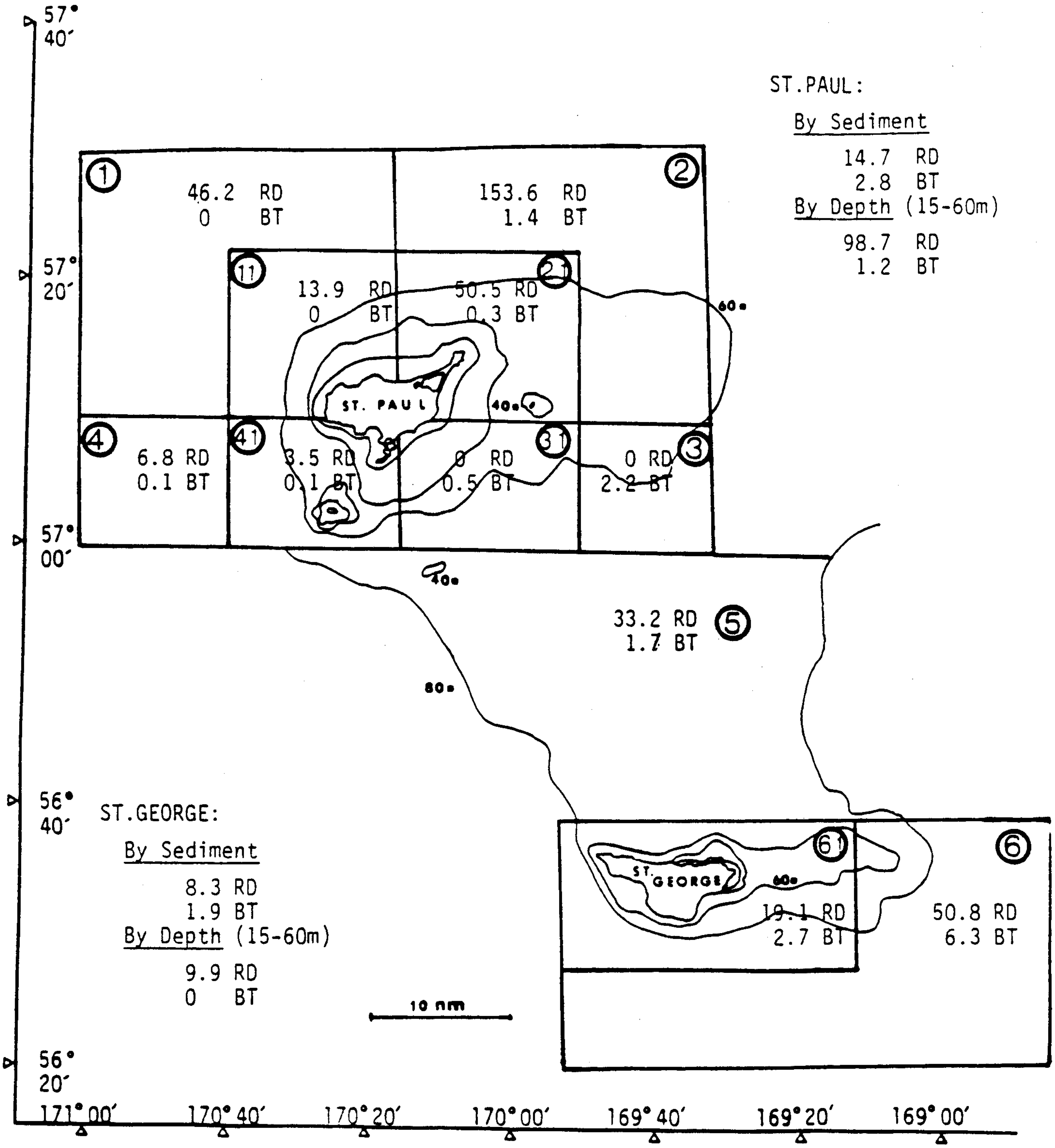
Appendix C.6 Carapace length frequencies of blue king crab collected in May and August 1983 and April 1984 by beam trawls from Stratum 115, the inter-island sandy plain. Population estimate (PE) in millions of crab, number of stations with crab/total number of stations sampled (n+/n), and percentage of the total population that were adults are also given.



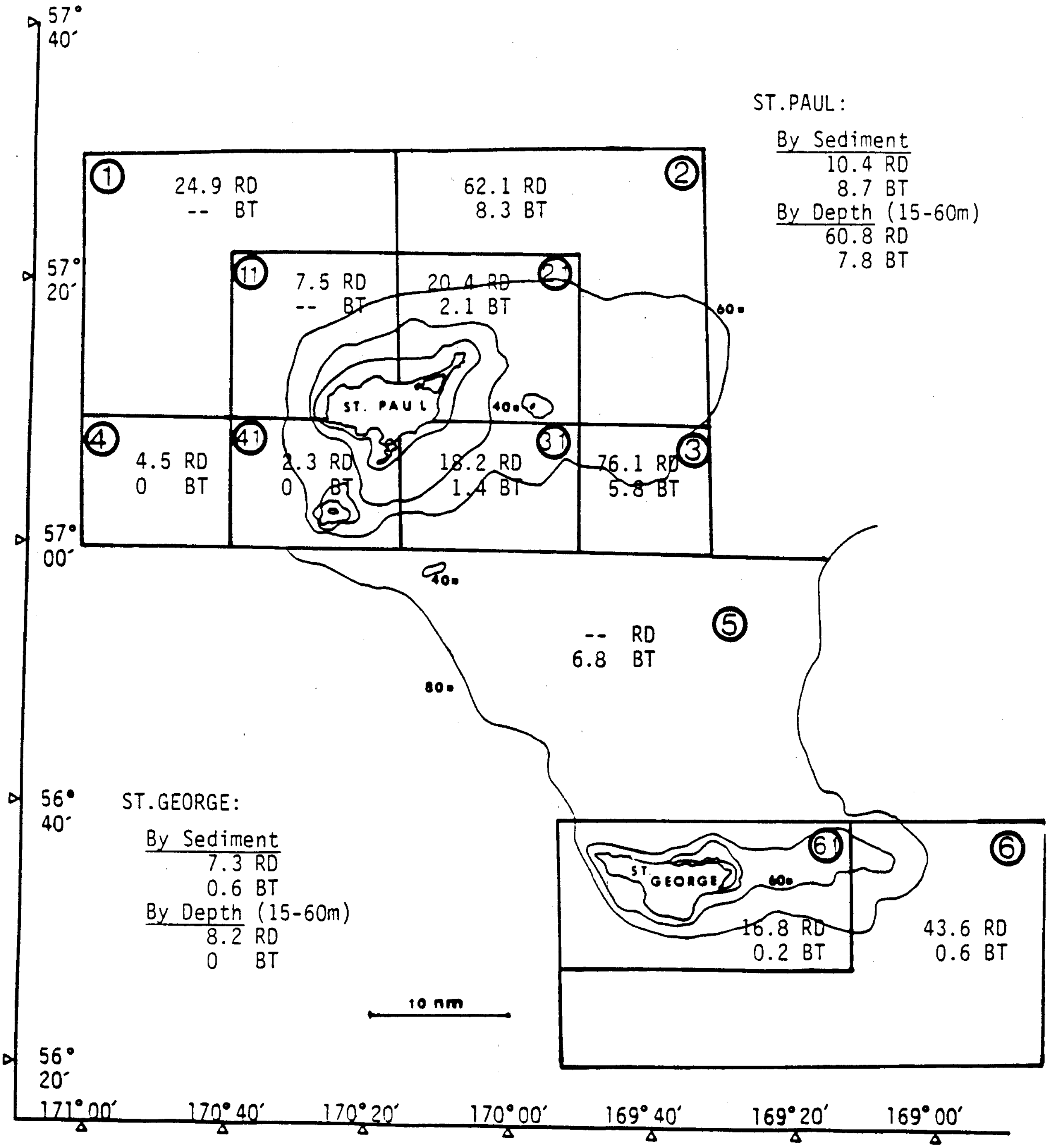
Appendix C.7 Juvenile <u>Paralithodes platypus</u> distribution and abundance, May 1983, expressed as number of juvenile crab/hectare. Solid bars indicate rock dredge and stiped bars are beam trawl catches.



Appendix C.8 Juveniles <u>Paralithodes platypus</u> distribution and abundance, April 1984, expressed as number of juvenile crab/hectare caught by rock dredges only.



Appendix C.9 Population estimates for Paralithodes platypus juveniles in May 1983 by strata. Separate estimates, expressed as number of crab x 10^6, are given for each gear; RD = rock dredge, BT = beam trawl. Estimates for nearshore strata 11-41 and 61 can be compared to the island totals figured for both the sediment and depth strata.



Appendix C.10 Population estimates for Paralithodes platypus juveniles in April 1984 by strata. Separate estimates, expressed as number of crab x 10^6, are given for each gear; RD = rock dredge, BT = beam trawl. Estimates for nearshore strata 11-41 and 61 can be compared to the island totals figured for both the sediment and depth strata.

Appendix C.11 Population estimates of juvenile blue king crab caught by rock dredges in May and August 1983 and April 1984 -- geographical strata. Values given are millions of crab.

Stratum	May Pop. Estimate	May ± 2SE	August Pop. Estimate	August ± 2SE	April Pop. Estimate	April ± 2SE
1	46.2	118.7	59.0	44.5	24.9	35.2
2	153.6	323.3	320.6	255.1	62.1	71.9
3	0		2.3	6.2	76.1	191.7
4	6.8	14.8	15.9	11.4	4.5	6.7
Sub Total SP	206.6	322.3	397.7	258.7	167.6	
5	33.2		226.8		--	
SG 6	50.5	62.9	264.5	220.4	43.6	44.2
Total	290.3	322.2	889.0	331.3	211.2	207.5
11	13.9	35.9	16.8	14.0	7.5	10.9
21	50.5	106.1	105.3	82.5	20.4	23.6
31	-		0.7	2.1	18.2	52.7
41	3.5	7.5	8.1	6.5	2.3	3.4
Sub Total SP	67.9		130.9		48.4	
61	19.1	24.9	104.9	102.6	16.8	17.2
Total	86.9	106.8	235.8	117.6	65.2	53.6

Appendix C.12 Population estimates of juvenile blue king crab caught by rock dredges in May and August 1983 and April 1984 -- sediment and depth strata. Values given are millions of crab.

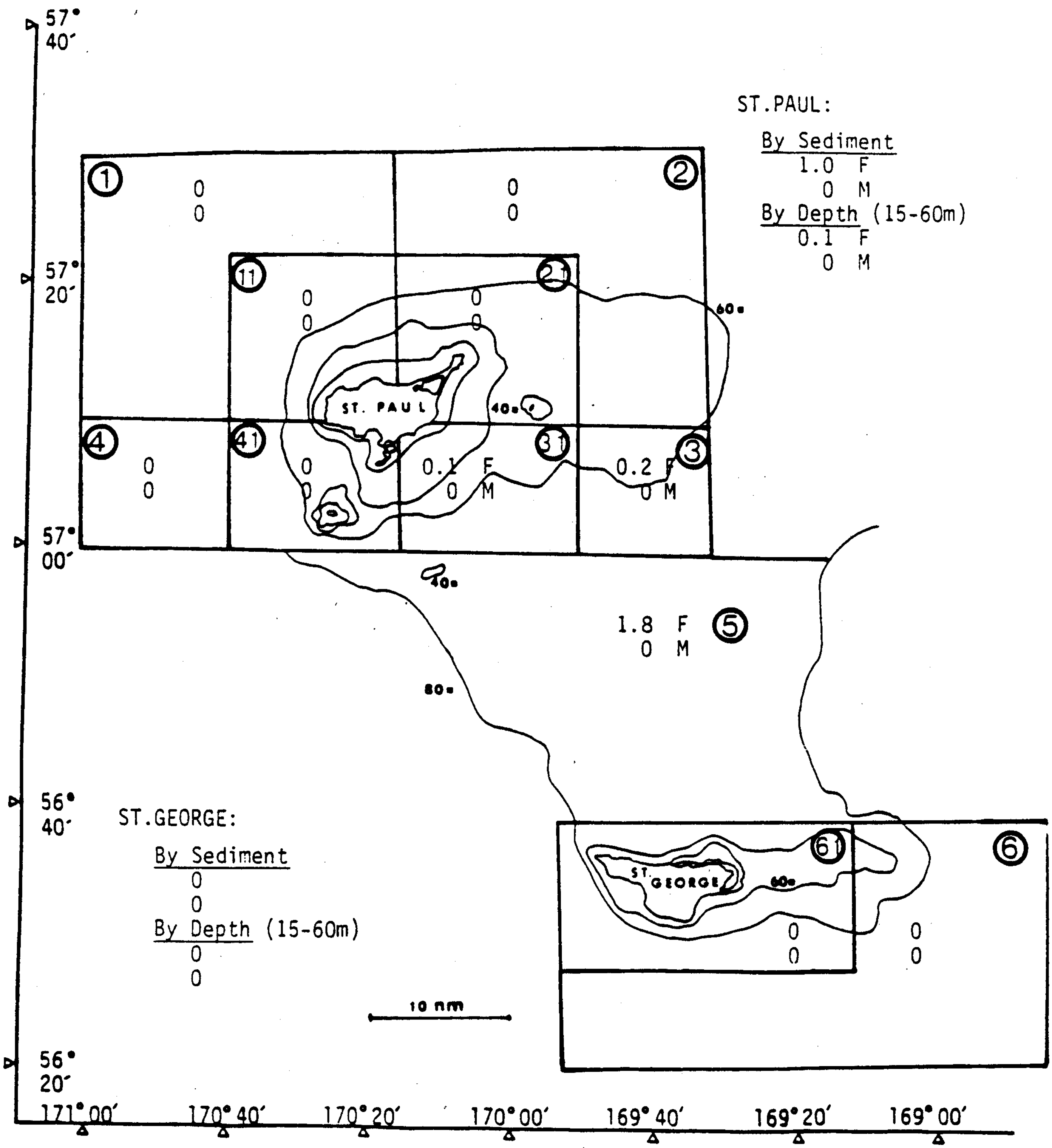
	May		August		April	
Stratum	Pop. Estimate	± 2SE	Pop. Estimate	± 2SE	Pop. Estimate	± 2SE
122	--		4.2	18.3	2.1	6.6
123	--		1.5	3.7	--	
125	--		2.7	3.5	0.5	0.9
128	--		5.0	3.7	--	
135	14.7	19.5	30.1	21.8	7.8	5.6
SP Sub Total	14.7	19.5	43.5	28.9	10.4	
115	33.1		226.9		--	
102	--		NS		--	
105	4.0		--		2.7	
110	NS		--		--	
114	4.3	7.8	29.3	23.9	4.6	5.0
SG Sub	8.3	7.9	29.3	23.9	7.3	
Total	56.1	433.7	299.7	35.1	17.7	9.0
SP 15-40	12.6	29.8	1.5	1.3	4.9	7.8
40-60	86.1	127.8	239.1	158.5	55.9	59.6
SP Sub Total	98.7		240.6		60.8	
SG 15-60	9.9	1.7	38.3	31.5	8.2	9.0
60-90	--		5.5	10.2	0.9	1.4
Total	108.6	132.5	284.3	160.6	69.9	60.2

Appendix C.13 Population estimates of blue king crab (proportion of adults given) caught by beam trawls in May and August 1983 and April 1984 -- geographical strata. Values given are millions of crab. Population estimates for juvenile crab are derived by 1.00 - Proportion of adults x Population estimate.

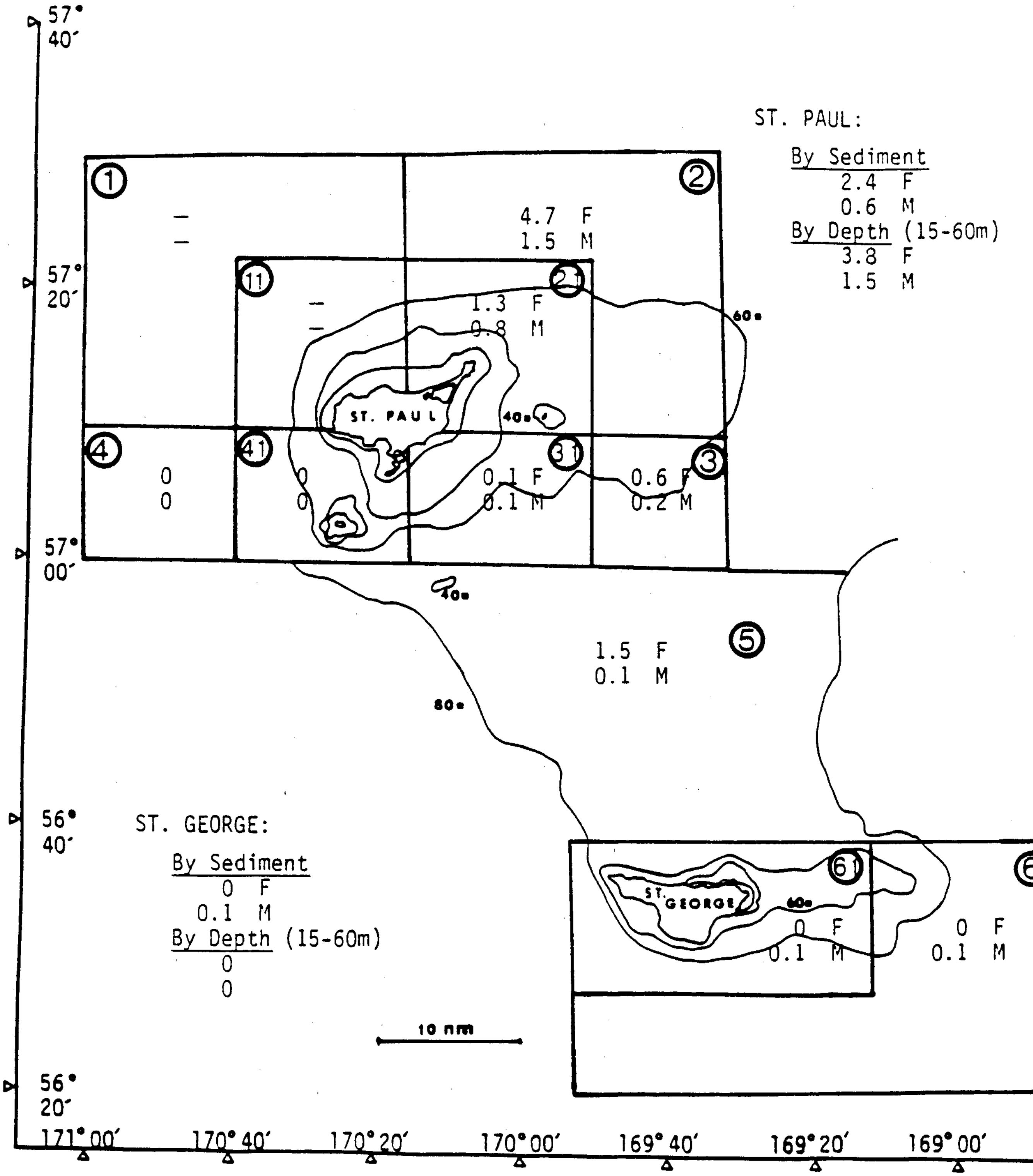
	May			August			April		
Stratum	Pop. Estimate	± 2SE	Proportion Adults	Pop. Estimate	± 2SE	Proportion Adults	Pop. Estimate	± 2SE	Proportion Adults
1	1.6	4.3	1.0	0.6	1.8	0	NS	-	
2	4.0	5.0	0.67	3.9	3.0	0	14.5	9.9	0.43
3	5.7	2.3	0.61	4.6	3.8	0.07	6.6	2.7	0.12
4	0.3	0.4	0.63	0			0	-	
SP Sub Total	11.6	6.0		9.1				21.0	
5	3.6	2.8	0.63	4.0	1.8	0.44	7.6	4.8	0.21
6	6.3	14.1	0	1.3	2.0	0	0.7	1.1	0.17
Total	21.5	14.8	0.47	14.4	5.2	0.16	29.4	11.1	0.28
11	0			0.2	0.8	0	NS		
21	0.3	4.2	0	1.4	1.0	0	4.2	4.5	0.49
31	1.0	0.6	0.51	0.8	0.9	0.06	1.6	0.7	0.13
41	0.1	0.3	0.63	0	-		0		
SP Sub Total	1.4			2.4			5.8		
61	2.7	6.5	0	0.5	0.3	0	0.3	0.5	0.18
Total	4.2	6.5	0.14	2.8	1.5	0.02	6.1	4.6	0.38

Appendix C.14 Population estimates of blue king crab (proportion of adults given) caught by beam trawls in May and August 1983 and April 1984 -- sediment and depth strata. Values given are millions of crab.

	May			August			April		
Stratum	Pop. Estimates	± 2SE	Proportion Adults	Pop. Estimate	± 2SE	Proportion Adults	Pop. Estimate	± 2SE	Proportion Adults
122	6.3	3.2	.55	4.7	3.5	0.21	9.5	4.9	0.20
123	0.3	0.5	1.0	0.3	0.7	0	0		
125	0			0			NS		
128	0.4		1.0	0			0		
135	0.1	0.8	0	0.7	0.5	0	2.2	2.2	0.48
SP Sub Total	7.1	3.1	0.60	5.7	3.5	0.18	11.7		0.26
115	3.3	2.7	0.50	4.1	1.9	0.46	8.2	5.0	0.17
102	0			0			0.7	1.5	0.17
105	NS			NS			NS		
110	0			0			0		
114	1.9	8.3	0	0.2	0.5	0	0		
SG Sub Total	1.9	8.3	0	0.2	0.5	0	0.7	1.5	0.17
Total	12.2	12.0	0.46	10.0	3.9	0.29	20.6	7.1	0.22
SP 15-40 M	0.3	0.9	0.75	0			0.1	0.1	0
40-60	4.4	2.0	0.78	3.5	2.2	0.01	13.0	9.0	0.41
SP Sub Total	4.7			3.5		0.01	13.1		
SG 15-60	0			0			0		
60-90	3.2	8.9	0	0.8	1.6	0	0.4	0.6	0.18
Total	7.9	8.7	0.43	4.3	2.6	0.01	13.5	8.9	0.41



Appendix C.15 Population estimates for Paralithodes platypus adults by sex and strata for beam trawl data in August 1983. Estimates are expressed as millions of crab.



Appendix C.16 Population estimates for Paralithodes platypus adults by sex and strata for beam trawl data in April 1984. Estimates are expressed as millions of crab.

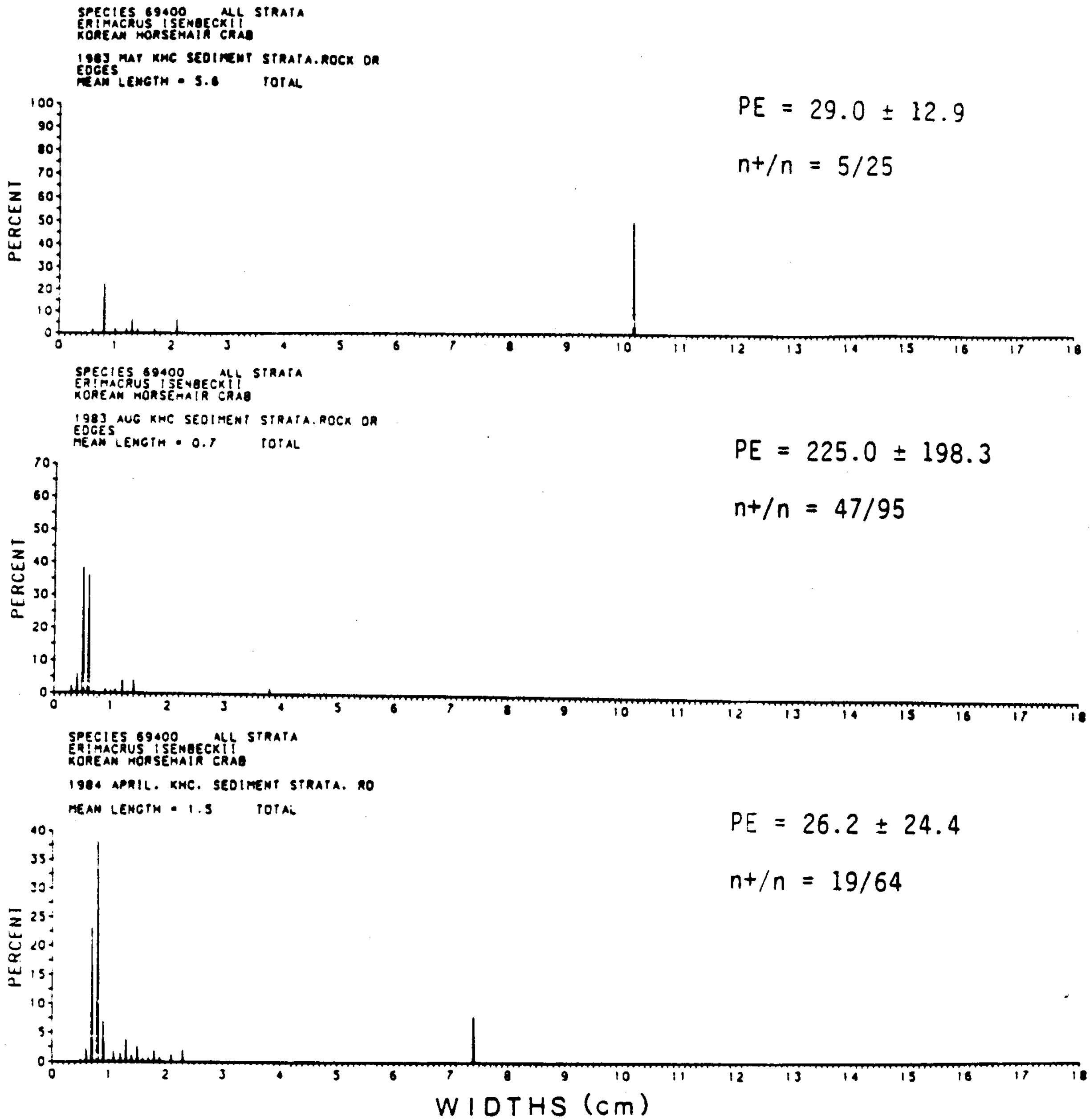
Appendix C.17 Adult blue king crab population estimates from sediment and depth strata, 1983-84, by sex, as taken by beam trawls. Values given are millions of crab.

Stratum	May			August			April		
	Total Adult	Adult Female	Adult Male	Total Adult	Adult Female	Adult Male	Total Adult	Adult Female	Adult Male
122	3.5	3.4	0.1	1.0	1.0	0	1.9	1.7	0.2
123	0.3	0.1	0.2	0	0	0	0	0	0
125	0	0	0	0	0	0	NS	NS	NS
128	0.4	0.3	0.1	0	0	0	0	0	0
135	0	0	0	0	0	0	1.1	0.7	0.4
SP Sub Total	4.2	3.8	0.4	1.0	1.0	0	3.0	2.4	0.6
115	1.7	1.7	0	1.9	1.9	0	1.4	1.3	0.1
102	0	0	0	0	0	0	0.1	0	0.1
105	NS	NS	NS	NS	NS	NS	NS	NS	NS
110	0	0	0	0	0	0	0	0	0
114	0	0	0	0	0	0	0	0	0
SG Sub Total	0	0	0	0	0	0	0.1	0	0.1
Total	5.9	5.5	0.4	2.9	2.9	0.0	4.5	3.7	0.8
SP 15-40m	0.2	0.1	0.1	0	0	0	0	0	0
40-60m	3.1	2.7	0.4	0.1	0.1	0	5.3	3.8	1.5
SP Sub Total	3.3	2.8	0.5	0.1	0.1	0	5.3	3.8	1.5
SG 15-60m	0	0	0	0	0	0	0	0	0
60-90m	0	0	0	0	0	0	0.1	0	0.1
Total	3.3	2.8	0.5	0.1	0.1	0	5.4	3.8	1.6

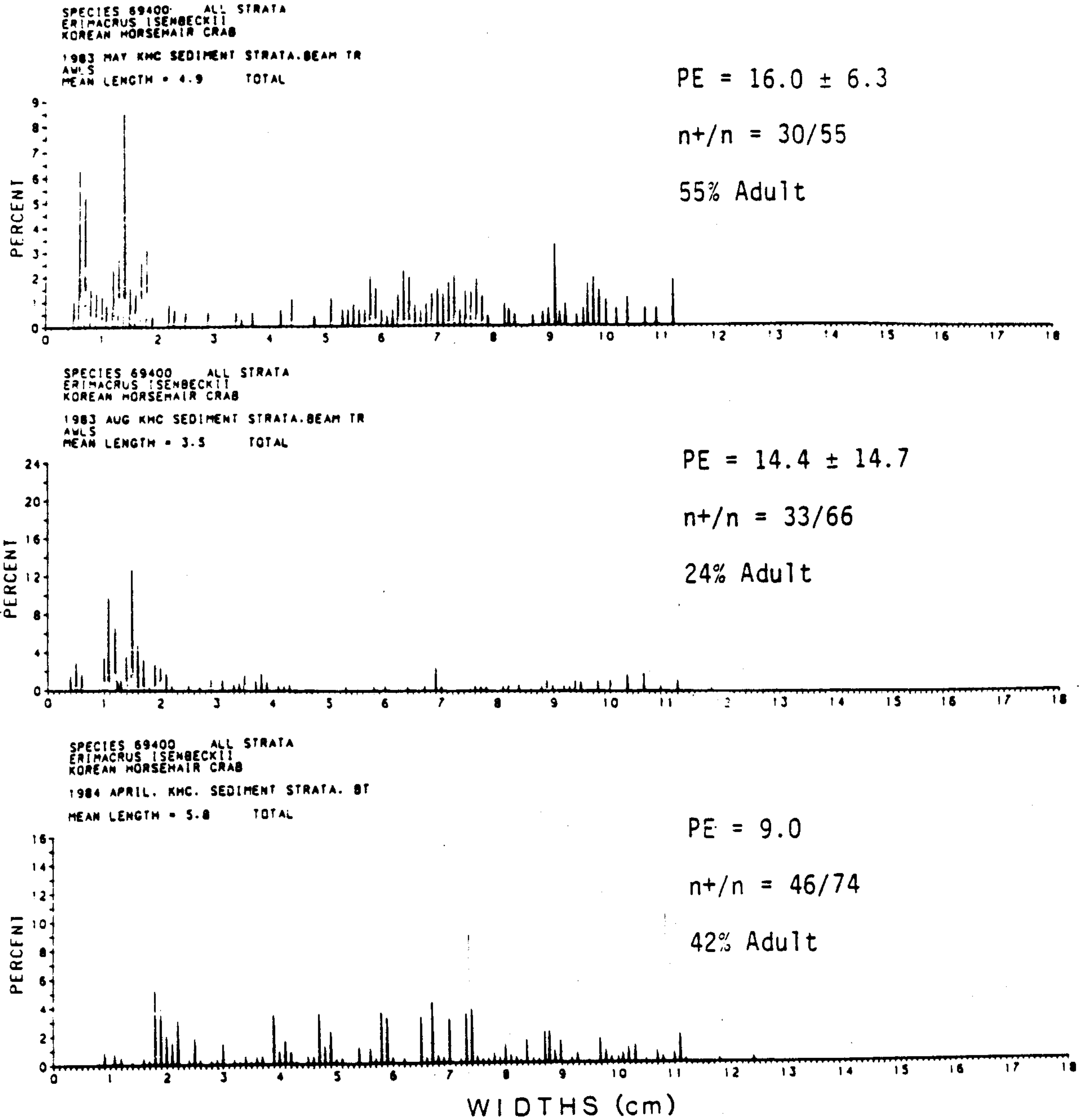
Appendix D.1 Larval Korean hair crab whole body dry weight analysis, May 1983. Mean values reported in milligrams (mean ± 1 SD).

	Stage I	Stage II	Stage III	Stage IV
Dry weight	.161 ± .034 n = 11	.144 ± .038 n = 3	.343 ± .062 n = 9	.496 ± .123 n = 17
Ash weight	.081 ± .025	.066 ± .020	.112 ± .029	.162 ± .046
% ash	50.5 ± 13.1	46.7 ± 1.5	32.7 ± 6.0	33.1 ± 8.4
Ash free	.080 ± .027	.078 ± .019	.232 ± .052	.335 ± .106

* Larvae that comprised these samples were taken from samples collected along the north Aleutian Shelf at the end of the May cruise.



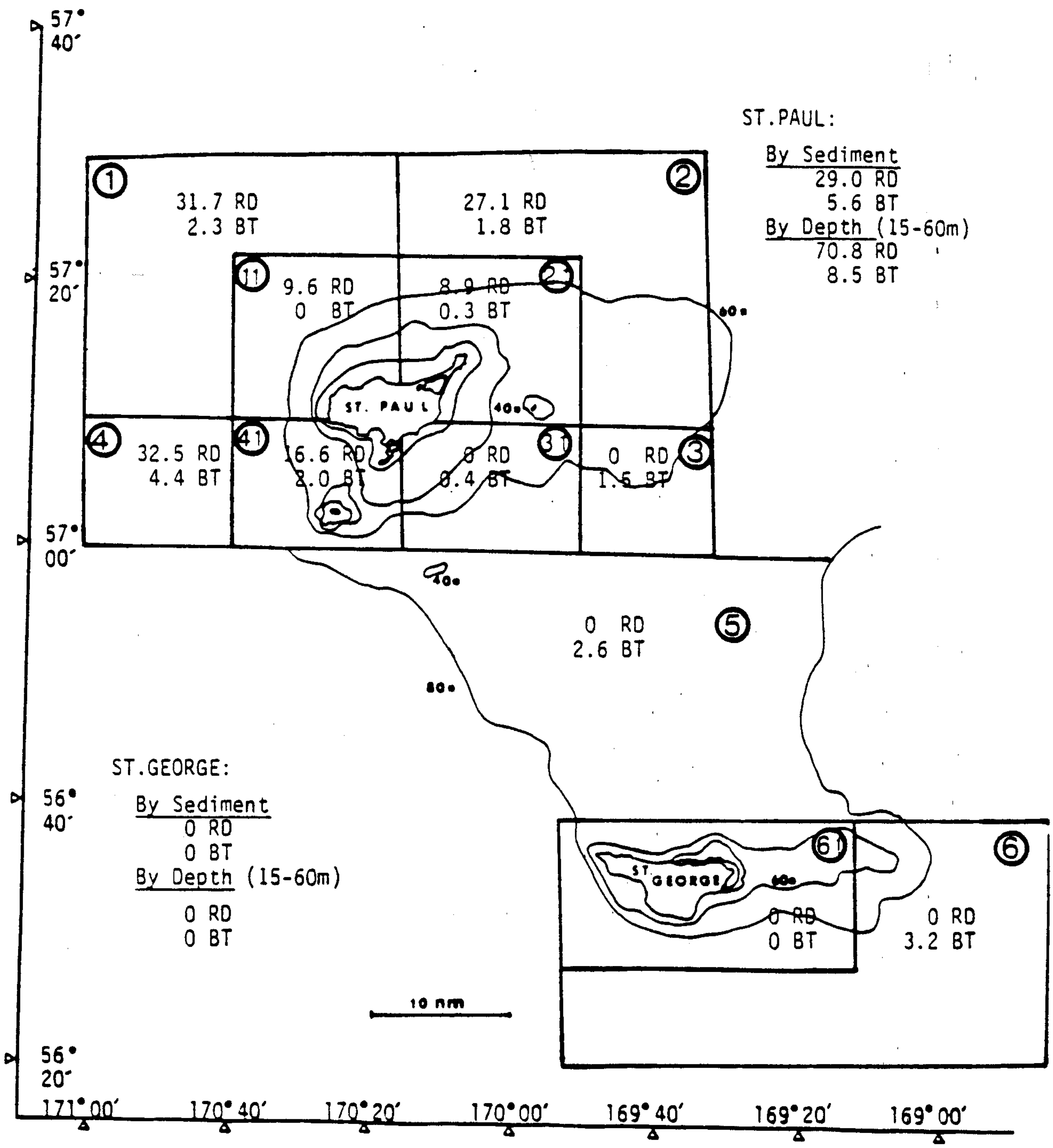
Appendix D.2 Carapace length frequencies of Korean hair crab collected in May and August 1983 and April 1984 by rock dredges within all strata of the sediment strata configuration. Population estimate (PE) in millions of crab and number of stations with crab/total number of stations sampled (n+/n) are also given.



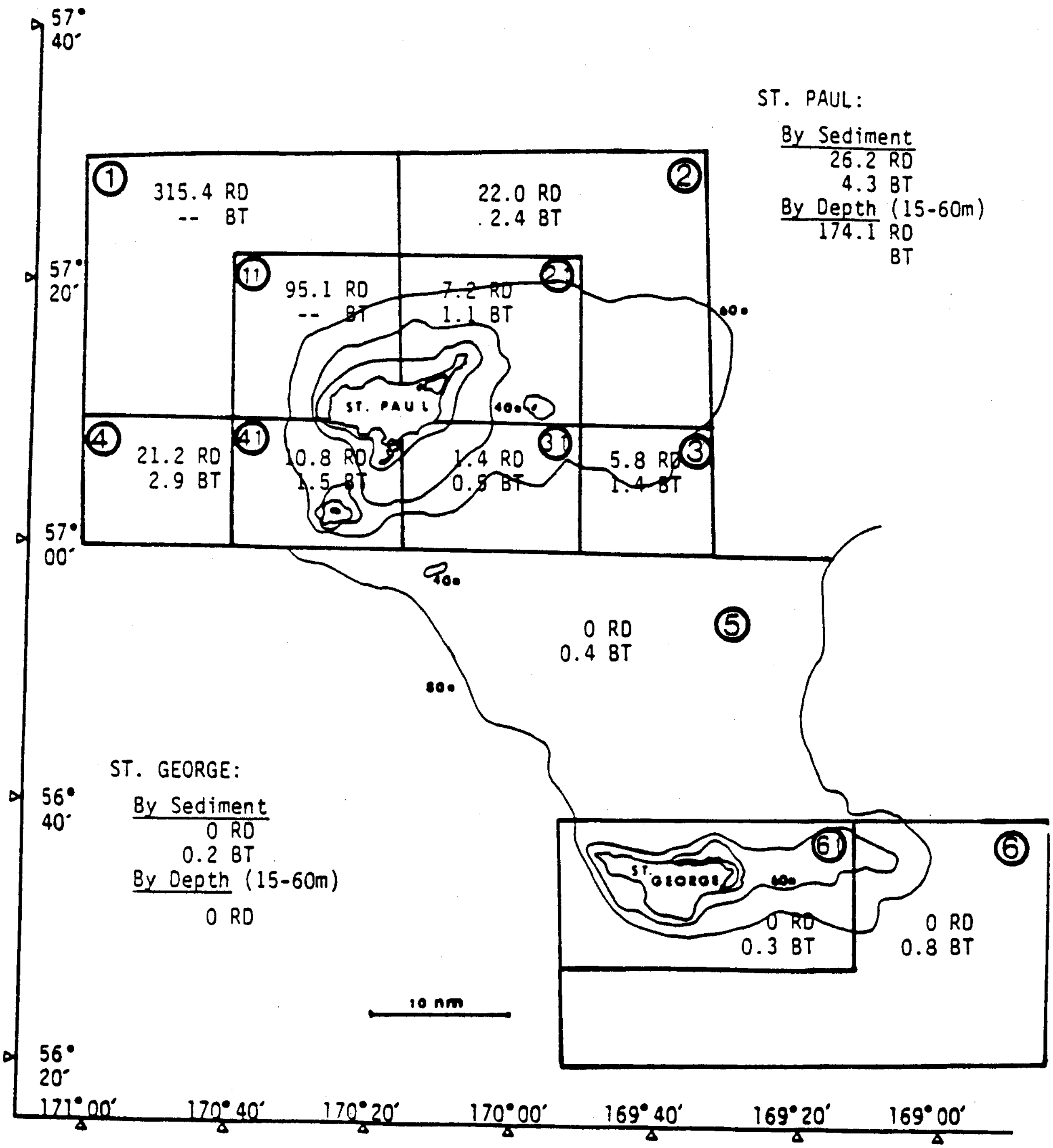
Appendix D.3 Carapace length frequencies of Korean hair crab collected in May and August 1983 and April 1984 by beam trawls within all strata of the sediment strata configuration. Population estimate (PE) in millions of crab, number of stations with crab/total number of stations sampled (n+/n), and percentage of the total population that were adults are also given.

Appendix D.4 Mean densities of juvenile Korean hair crab by sediment, May 1983-April 1984. Sample size (number of tows with crab/total number of tows) and mean density (crabs/ha) ± 2 SD are given. Data for rock dredges.

Sediment Type (Stratum Number)	May 1983		August 1983		April 1984	
	Sample size	Density	Sample size	Density	Sample size	Density
Sand (122 + 123)	0/3	0	2/10	15 ± 47	0/7	8 ± 20
Rock (125)	1/5	161 ± 361	5/25	77 ± 207	2/10	31 ± 66
Gravel-Cobble (128)	1/1	724	9/9	12924 ± 29204	2/2	544 ± 490
Shellhash (135)	2/8	309 ± 715	24/29	1326 ± 1604	13/18	1138 ± 2073



Appendix D.5 Population estimates for Erimacrus isenbeckii juveniles in May 1983 by strata. Separate estimates, expressed as number of crab x 10^6, are given for each gear; RD = rock dredge, BT = beam trawl. Estimates for nearshore strata 11-41 and 61 can be compared to the island totals figured for both the sediment and depth strata.



Appendix D.6 Population estimates for Erimacrus isenbeckii juveniles in April 1984 by strata. Separate estimates, expressed as number of crab x 10^6, are given for each gear; RD = rock dredge, BT = beam trawl. Estimates for nearshore strata 11-41 and 61 can be compared to the island totals figured for both the sediment and depth strata.

Appendix D.7 Strata groupings, areas, and sample sizes for Korean hair crab population estimates by rock dredge and beam trawl gear for three cruises. Numbers given are tows with crab/total tows.

Stratum	Total Area $(NM)^2$	Rock Dredges May	Rock Dredges August	Rock Dredges April	Beam Trawls May	Beam Trawls August	Beam Trawls April
		Positive Tows / Total Tows			Positive Tows / Total Tows		
1	480	2/6	17/28	7/9	1/5*	2/6	NS
2	449	2/5	14/23	4/11	4/6	13/18	14/17
3	499	0/1	3/5	1/5*	19/24	8/12	18/23
4	232	1/5*	10/17	7/12	7/8	4/7	2/3
SP Sub Total	1660	5/17	44/73	19/37	31/43	27/43	34/43
5	978	0/2	0/1	0/2	9/23	3/17	8/20
SG Sub 6	808	0/6	4/24	0/27	1/11*	1/11*	5/16
Total	3446	5/25	48/98	19/66	41/77	31/71	47/79
11	145	2/6	16/27	7/9	0/2	2/5	NS
21	147	2/5	14/23	4/11	2/2	12/17	9/11
31	120	0/1	2/4	1/5*	12/14	5/6	13/15
41	118	1/5*	10/17	7/12	7/8	4/7	2/3
SB Sub Total	530	5/17	42/71	19/37	21/26	23/35	24/29
61	280	0/5	3/19	0/24	0/8	1/10*	4/13
Total	810	5/22	45/90	19/61	21/34	24/45	28/42
122	563	1/1*	2/3	1/5*	13/18	15/18	24/30
123	200	0/2	3/7	0/2	5/6	3/6	1/2*
125	70	1/5*	6/25	2/10	0/1	0/3	NS
128	23	1/1*	9/9	2/2	1/1*	2/5	1/1*
135	48	2/8	24/29	14/18	3/3	9/11	7/7
SP Sub Total	904	5/17	44/73	19/37	22/29	29/43	33/40
115	976	0/2	0/1	0/2	8/19	3/16	9/22
102	260	0/1	NS	0/3	0/3	0/1	2/5
105	33	0/1	0/2	0/1	NS	NS	NS
110	13	NS	0/1	0/1	0/1	0/1	1/2*
114	67	0/4	3/18	0/20	0/3	1/5*	1/5*
SG Sub Total	373	0/6	3/21	0/25	0/7	1/7*	4/12
Total	2253	5/25	47/95	19/64	30/55	33/66	46/74
SP 15-40m	83	3/9	9/29	5/16	2/6	4/8	3/4
40-60	445	2/5	31/37	8/13	22/24	17/23	17/19
SP Sub Total	528	5/14	40/66	13/29	24/30	21/31	20/23
SG 15-60m	79	0/3	3/16	0/13	0/2	0/2	2/3
60-80	223	0/2	0/5	0/10	0/6	1/5*	2/8
Total	830	5/19	43/87	13/52	24/38	22/38	24/34

* Low sample size

Appendix D.8 Population estimates of Korean hair crab caught by rock dredges in May and August 1983 and April 1984 -- geographical strata. Values given are millions of crab.

	May		August		April	
Stratum	X 10^6 crab	$\pm$ 2SE	X 10^6 crab	$\pm$ 2SE	X 10^6 crab	$\pm$ 2SE
1	31.7	53.9	816.0	1082.7	315.4	347.3
2	27.1	77.6	175.7	114.8	22.0	40.2
3	0		19.3	43.0	5.8	18.5
4	32.5	103.2	51.3	53.0	21.2	18.5
SP Sub Total	91.3	101.8	106.3	108.7	364.4	
5	0		0		0	
6	0		9.9	10.5	0	
Total	91.3	101.8	1072.1	108.8	364.4	350.5
11	9.6	17.5	254.4	339.2	95.1	107.5
21	8.9	25.5	57.7	37.7	7.2	13.0
31	0		5.0	13.1	1.4	4.4
41	16.6	45.9	26.2	27.0	10.8	9.5
SP Sub Total	35.1		343.3		114.5	
61	0		3.0	3.8	0	
Total	35.1	47.5	346.3	341.6	114.5	106.2

Appendix D.9 Population estimates of Korean hair crab caught by rock dredges in May and August 1983 and April 1984 -- sediment and depth strata. Values given are millions of crab.

Stratum	May: Pop. Estimate X 10^6 crab	May: $\pm$ 2SE	August: Pop. Estimate X 10^6 crab	August: $\pm$ 2SE	April: Pop. Estimate X 10^6 crab	April: $\pm$ 2SE
122	14.3		9.0	19.5	2.1	6.6
123	0		84.5	144.9	0	
125	3.9		1.6	1.5	0.8	1.1
128	5.7		104.3	172.5	4.3	34.5
135	5.1	10.3	24.7	11.9	19.0	17.1
SP Sub Total	29.0	12.9	224.2	198.3	26.2	24.4
115	0		0		0	
102	0		NS		0	
105	0		0		0	
110	NS		0		0	
114	0		0.8		0	
SG Sub Total	0		0.8		0	
Total	29.0	12.9	225.0	198.3	26.2	24.4
SP 15-40m	6.2	7.7	4.1	3.1	2.9	4.1
40-60m	64.6	196.5	707.4	748.9	171.2	225.7
SP Sub Total	70.8		711.5		174.1	225.9
SG 15-60 m	0		1.1	1.4	0	
60-90 m	0		0		0	
Total	70.8	171.6	712.6	748.8	174.1	225.9

Appendix D.10 Population estimates of Korean hair crab caught by beam trawls in May and August 1983 and April 1984 -- geographical strata. Values given are millions of crab.

	May			August			April		
Stratum	Pop. Estimate X 10^6 crab	± 2SE	Proportion Adults	Pop. Estimate X 10^6 crab	± 2SE	Proportion Adults	Pop. Estimate X 10^6 crab	± 2SE	Proportion Adults
1	2.3	6.5	0	15.0	32.6	.04	NS		
2	3.7	4.8	.51	5.7	3.6	.52	4.3	2.5	.44
3	5.4	2.3	.73	5.7	5.4	.28	2.5	1.1	.43
4	7.2	5.4	.39	4.5	8.5	.28	3.9	8.6	.26
SP Sub Total	18.7	8.4	.46	30.9	34.7	.21	10.7		.37
5	3.4	2.6	.25	1.0	1.6	.13	0.9	0.6	.52
SG Sub Tot.6	3.2	7.0	0	2.4	5.3	.33	1.5	1.7	.46
Total	25.2	10.7	.38	34.3	33.6	.21	13.0	10.9	.40
11	0			5.4	12.7	.04	NS		
21	0.7	3.9	.52	1.9	1.2	.51	1.6	1.3	.33
31	1.9	0.8	.78	2.3	2.9	.23	0.7	0.4	.35
41	3.7	2.7	.45	2.3	4.4	.26	2.0	4.4	.25
SP Sub Total	6.3	2.9	.56	11.9		0.19	4.3		.30
SG Sub Tot.61	0			0.8	1.9	.33	0.6	0.7	.43
Total	6.3	2.9	.56	12.7	13.1	.20	4.9	5.3	.27

Appendix D.11 Population estimates of Korean hair crab caught by beam trawls in May and August 1983 and April 1984 -- sediment and depth strata. Values given are millions of crab.

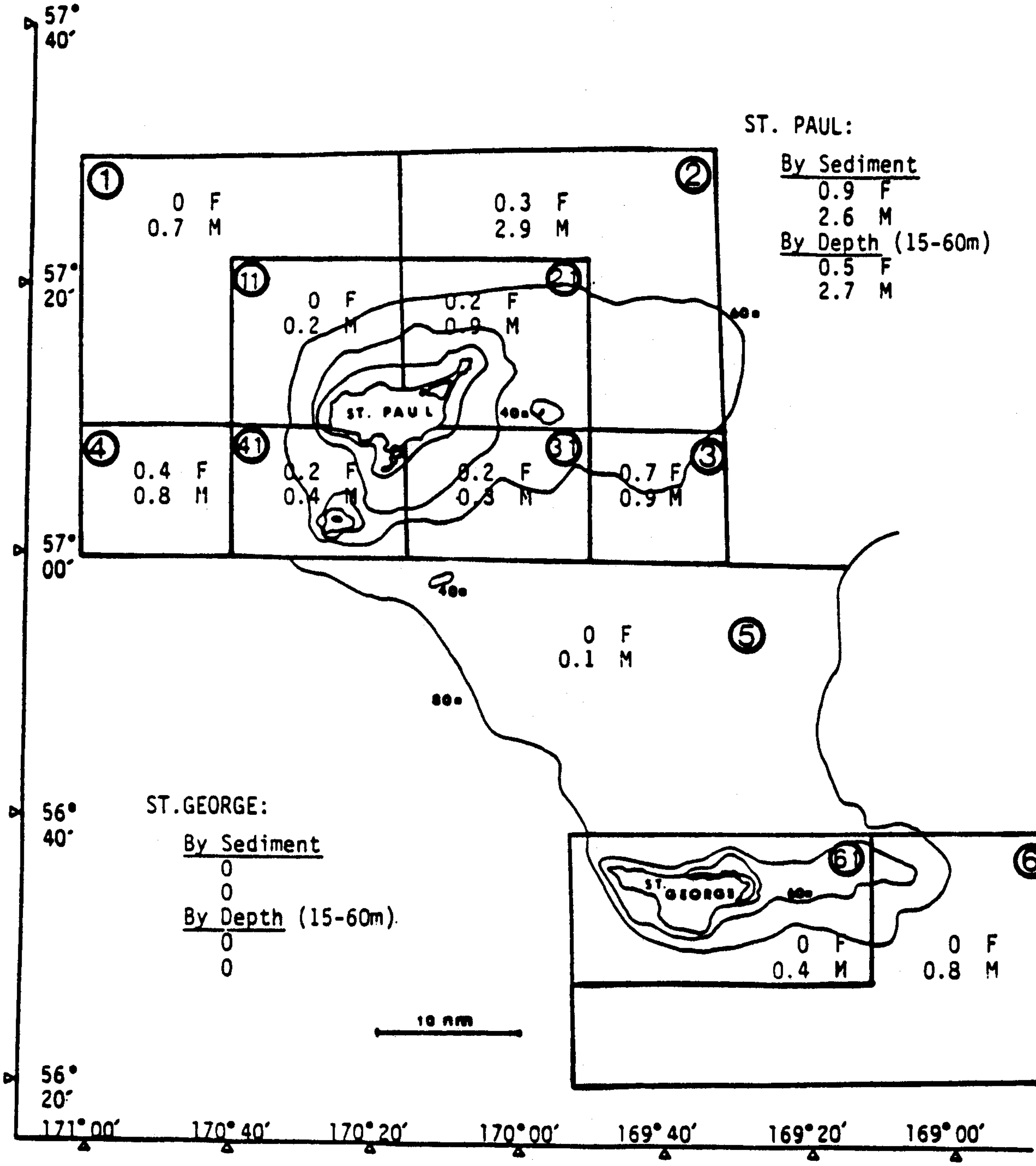
Stratum	May			August			April		
	Pop. Estimate X 10^6 crab	± 2SE	Proportion Adults	Pop. Estimate X 10^6 crab	± 2SE	Proportion Adults	Pop. Estimate X 10^6 crab	± 2SE	Proportion Adults
122	6.2	3.4	.67	5.8	3.9	.43	2.9	0.9	.49
123	4.1	4.7	.78	5.8	13.6	.08	2.8		.30
125	0			0			NS		
128	0.6		0	0.2	0.3	.13	0.5		.20
135	2.2	4.0	0	1.3	1.1	.43	0.8	0.7	.36
SP Sub Total	13.0	5.9	.57	13.1		.27	6.9		.38
115	3.0	2.4	.26	1.1	1.7	.13	1.4	1.3	.48
102	0			0			0.5	1.1	1.00
105	NS			NS			NS		
110	0			0			.01	0.2	1.00
114	0			0.4	1.2	.33	0.2	0.6	0
SG Sub Total	0			0.4	1.2	.33	0.7		.72
Total	16.0	6.3	.55	14.6	14.7	.24	9.0	37.3	.42
SP 15-40 m	0.3	0.8	1.00	0.3	0.4	.56	0.7	1.8	.15
40-60 m	8.2	3.6	.56	11.4	7.6	.27	4.1	2.3	.49
SP Sub Total	8.5		.58	11.7		.29	4.8		.44
SG 15-60 m	0			0			0.6	1.5	.30
60-90 m	0			1.4	4.1	.33	0.1	0.2	1.00
Total	8.5	3.7	.58	13.1	8.4	.28	5.5	2.7	.44

Appendix D.12 Adult Korean hair crab population estimates from sediment and depth strata, 1983-84, by sex, as taken by beam trawls. Values given are millions of crab.

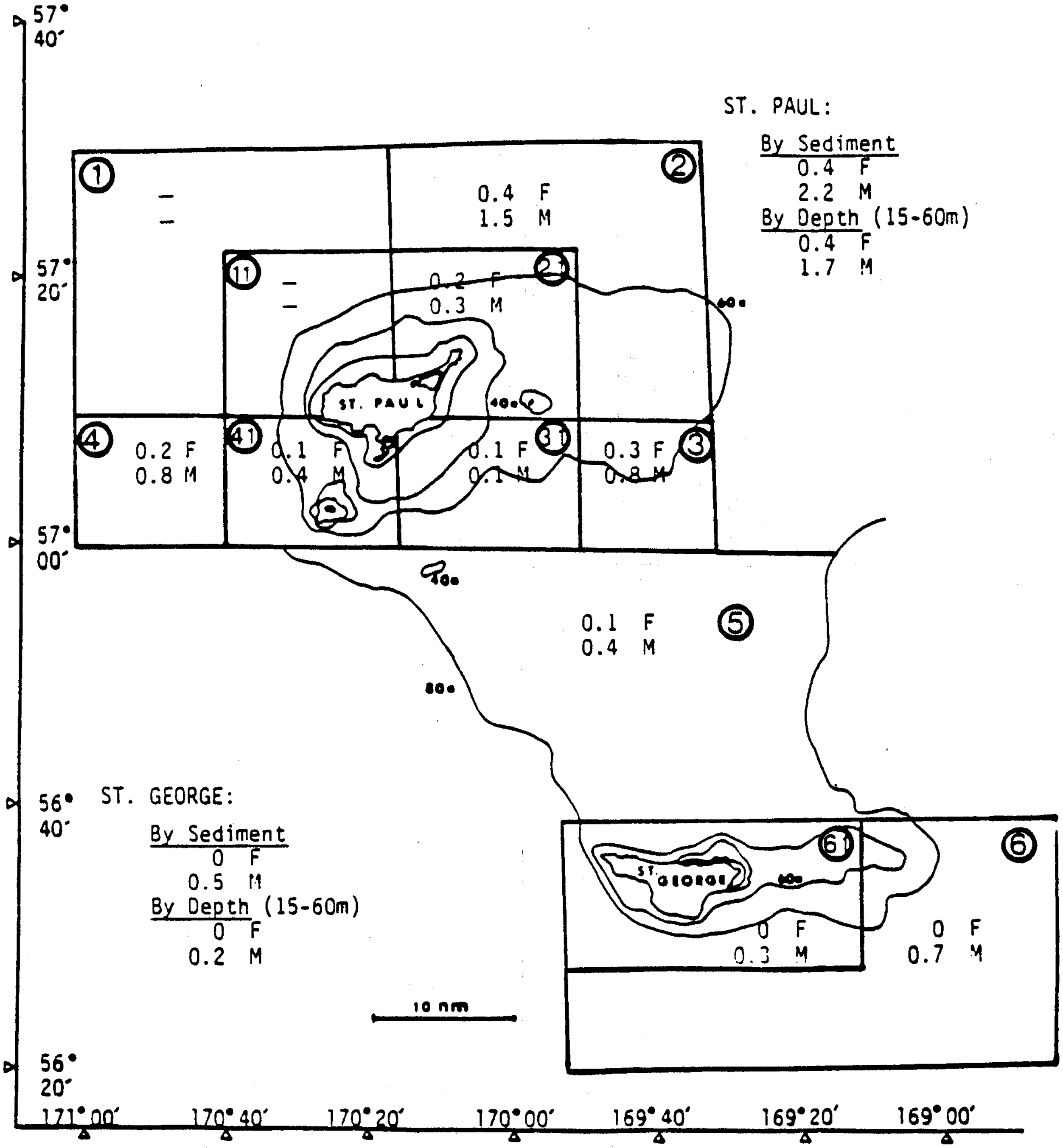
	May			August			April		
Stratum	Total Adult	Adult Female	Adult Male	Total Adult	Adult Female	Adult Male	Total Adult	Adult Female	Adult Male
122	4.2	2.0	2.2	2.4	0.8	1.6	1.4	0.3	1.1
123	3.2	2.5	0.7	0.5	0	0.5	0.8	0	0.8
125	0	0	0	0	0	0	NS	NS	NS
128	0	0	0	trace	trace	trace	0.1	.05	.05
135	0	0	0	0.6	0.1	0.5	0.3	0.1	0.2
SP Sub Total	7.4	4.5	2.9	3.5	0.9	2.6	2.6	0.4	2.2
115	0.8	0	0.8	0.2	0	0.2	0.7	0.1	0.6
102	0	0	0	0	0	0	0.5	0	0.5
105	NS	NS	NS	NS	NS	NS	NS	NS	NS
110	0	0	0	0	0	0	trace	trace	trace
114	0	0	0	0.1	0	0.1	0	0	0
SG Sub Total	0	0	0	0.1	0	0.1	0.5	0	0.5
Total	8.2	4.5	3.7	3.8	0.9	2.9	3.8	0.5	3.3
SP 15-40m	0.3	trace	0.3	0.2	trace	0.2	0.1	.05	.05
SP 40-60m	4.6	1.9	2.7	3.0	0.5	2.5	2.0	0.4	1.6
SP Sub Total	4.9	1.9	3.0	3.2	0.5	2.7	2.1	0.4	1.7
SG 15-60 m	0	0	0	0	0	0	0.2	0	0.2
60-90 m	0	0	0	0.5	0	0.5	0.1	0	0.1
Total	4.9	1.9	3.0	3.7	0.5	3.2	2.4	0.4	2.0

Appendix D.13 Adult Korean hair crab population estimates from geographical strata, 1983-84, by sex, as taken by beam trawls. Values given are millions of crab.

	May			August			April		
Stratum	Total Adult	Adult Female	Adult Male	Total Adult	Adult Female	Adult Male	Total Adult	Adult Female	Adult Male
1	0	0	0	0.7	0	0.7	NS	NS	NS
2	1.9	0.2	1.7	3.2	0.3	2.9	1.9	0.4	1.5
3	3.9	1.5	2.4	1.6	0.7	0.9	1.1	0.3	0.8
4	2.8	2.2	0.6	1.2	0.4	0.8	1.0	0.2	0.8
SP Sub Total	8.6	3.9	4.7	6.7	1.4	5.3	4.0	0.9	3.1
5	0.8	0	0.8	0.1	0	0.1	0.5	0.1	0.4
SG Sub Total 6	0	0	0	0.8	0	0.8	0.7	0	0.7
Total	9.4	3.9	5.5	7.6	1.4	6.2	5.2	1.0	4.2
11	0	0	0	0.2	0	0.2	NS	NS	NS
21	0.4	0	0.4	1.0	0.1	0.9	0.5	0.2	0.3
31	1.5	0.6	0.9	0.5	0.2	0.3	0.2	0.1	0.1
41	1.7	1.1	0.5	0.6	0.2	0.4	0.5	0.1	0.4
SP Sub Total	3.5	1.7	1.8	2.3	0.5	1.8	1.2	0.4	0.8
SG Sub Total 61	0	0	0	0.4	0	0.4	0.3	0	0.3
Total	3.5	1.7	1.8	2.7	0.5	2.2	1.5	0.4	1.1



Appendix D.14 Population estimates for Erimacrus isenbeckii adults by sex and strata for beam trawl data in August 1983. Estimates are expressed as millions of crab.



Appendix D.15 Population estimates for *Erimacrus isenbeckii* adults by sex and strata for beam trawl data in April 1984. Estimates are expressed as millions of crab.

DISTRIBUTION, ABUNDANCE, AND DIVERSITY OF EPIFAUNAL BENTHIC ORGANISMS IN ALITAK AND UGAK BAYS, KODIAK ISLAND, ALASKA

by

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SUMMARY OF OBJECTIVES, CONCLUSIONS, AND IMPLICATIONS WITH RESPECT TO OCS OIL AND GAS DEVELOPMENT

Little is known about the biology of the invertebrate components of the shallow, nearshore benthos of the bays of Kodiak Island, and yet these components may be the ones most significantly affected by the impact of oil derived from offshore petroleum operations. Baseline information on species composition is essential before industrial activities take place in waters adjacent to Kodiak Island. It was the intent of this investigation to collect information on the composition, distribution, and biology of the epifaunal invertebrate components of two bays of Kodiak Island.

The specific objectives of this study were:

1) A qualitative inventory of dominant benthic invertebrate epifaunal species within two study sites (Alitak and Ugak bays).
2) A description of spatial distribution patterns of selected benthic invertebrate epifaunal species in the designated study sites.
3) Observations of biological relationships between segments of the benthic biota in the designated study area.

Permanent stations were established in the two bays—28 stations in Alitak Bay and 25 stations in Ugak Bay. These 53 stations were occupied with a 400-mesh Eastern otter trawl on four separate cruises in June, July, and August of 1976 and March 1977. Taxonomic analysis of the epifauna collected delineated 12 phyla, 23 classes, 66 families, 79 genera, and 106 species. Arthropoda (Crustacea) dominated in species composition and biomass. Porifera, Cnidaria, Annelida, Mollusca, and Echinodermata accounted for only 2.0% of the biomass collected.

Differences in sex composition and stage of maturity of king and snow crabs between and within the two bays were noted. King crabs, *Paralithodes camtschatica,* occurred mainly at the outer stations of Alitak Bay and consisted mostly of egg-bearing females and juveniles. King crabs were well dispersed throughout Ugak Bay, and mainly consisted of juveniles. Snow crabs, *Chionoecetes bairdi,* in Alitak Bay were primarily juveniles; snow crabs in Ugak Bay were primarily adult males. Preliminary life history data for these crabs for the two bays are now available.

Food data for king and snow crabs from the two bays are also available; in conjunction with similar data from Cook Inlet and the Bering Sea, these data enhance our understanding of the trophic role of these crustaceans in their ecosystems. Additional food data for three species of flatfishes, as well as an assessment of the literature, have made it possible to develop a preliminary food web for benthic and nektobenthic species of Alitak and Ugak bays and the inshore waters around Kodiak Island. Comprehension of basic food interrelationships is essential for assessing the potential impact of oil on the crab-dominated benthic systems of the nearshore waters of Kodiak.

The importance of deposit-feeding clams in the diet of king and snow crabs in the two Kodiak bays has been demonstrated by preliminary feeding data collected there. An understanding of the relationship between oil, sediment, deposit-feeding clams, and crabs should be developed in a further attempt to understand the possible impact of oil on these two commercially important species of crabs in the Kodiak area.

Initial assessment of data suggests that a few unique, abundant, and/or large invertebrate species (king crab, snow crab, several species of clams) are characteristic of the bays investigated and that these species may be useful for monitoring purposes.

A complete understanding of the benthic systems in each bay can only be obtained when the infauna is also assessed in conjunction with the epifauna. Stomach analyses indicate that infaunal species are important food items for king and snow crabs. However, the infaunal components of the Kodiak shelf have not yet been investigated. A program designed to examine the infauna should be initiated.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

INTRODUCTION

General Nature and Scope of Study

The operations connected with oil exploration, production, and transportation in the Gulf of Alaska present a wide spectrum of potential dangers to the marine environment (see Olson and Burgess [1967] for general discussion of marine pollution problems). Adverse effects on a marine environment cannot be predicted or assessed unless background data pertaining to the area are recorded prior to industrial development.

Insufficient long-term information about an environment and the basic biology of species present can lead to erroneous interpretations of changes that might occur if the area becomes altered (see Pearson [1971, 1972], Nelson-Smith [1973], and Rosenberg [1973] for general discussions on benthic biological investigations in industrialized marine areas). Populations of marine species fluctuate over a time span of a few to 30 or more years (Lewis 1970).

Benthic organisms (primarily the infauna and sessile and slow-moving epifauna) are useful as indicator species for a disturbed area because they tend to remain in place, typically react to long-range environmental changes, and, by their presence, generally reflect the nature of the substratum. Consequently, the organisms of the infaunal benthos have frequently been chosen to monitor long-term pollution effects, and are believed to reflect the biological health of a marine area (see Pearson [1971, 1972, 1975] and Rosenberg [1973] for discussions on use of benthic organisms for monitoring pollution). The presence of large numbers of benthic epifaunal species of actual or potential commercial importance (crabs, shrimps, scallops, snails, finfishes) in the shelf ecosystem of Kodiak Island further dictates the necessity of understanding benthic communities since many commercial species feed on infaunal and small epifaunal residents of the benthos (see Zenkevitch [1963], Feder et al. [1977], and this report for a discussion of the interaction of commercial species and the benthos). Thus, drastic changes in density of the food benthos would affect the health and numbers of these fisheries organisms.

Experience in pollution-prone areas of England (Smith 1968), Scotland (Pearson 1972), and California (Straughan 1971) suggests that at the completion of an initial exploratory study, selected stations should be examined regularly on a long-term basis to determine any changes in species composition, diversity, abundance, and biomass. Long-term data should make it possible to differentiate between normal ecosystem variation and pollutant-induced biological alteration. An intensive investigation of the benthos of the Kodiak shelf, as well as its bays, is essential to an understanding of the trophic interactions there and the potential changes that could take place once oil-related activities are initiated. An intensive benthic biological program in the northeast Gulf of Alaska has emphasized the development of a qualitative and quantitative inventory of prominent species of the benthic infauna and epifauna there (Feder et al. 1976). In addition, a developing investigation concerned with the biology of selected benthic species from the northeast Gulf of Alaska and lower Cook Inlet will further our understanding of the overall Gulf of Alaska benthic system (Feder et al. 1977). A program designed to examine the subtidal benthos of the Kodiak shelf will expand the coverage of the Gulf of Alaska benthic system, and an assessment of the fauna of two Kodiak bays will extend investigations into little-known shallow-river benthic systems. The study reported here is a preliminary assessment of two shallow Kodiak Island bays, and is intended to precede a greater overall investigation of the Kodiak Island shelf.

Relevance to Problems of Petroleum Development

The effects of oil pollution on subtidal benthic organisms have generally been neglected; only the results of a few studies conducted after major oil spills have been published (see Boesch et al. [1974] for review of these papers). Thus, lack of a broad data base elsewhere makes it difficult to predict the effects of oil-related activity on the subtidal benthos of the Kodiak shelf and the two Kodiak bays investigated. However, the expansion of research activities into Kodiak waters should ultimately enable us to identify certain species or areas that might bear closer scrutiny once industrial activity is initiated. It must be emphasized that a considerable time span is needed to understand fluctuations in density of marine benthic species, and it cannot be expected that a short-term research program will result in predictive capabilities. Assessment of the environment must be conducted on a continuing basis.

Data indicating the effects of oil on most subtidal benthic invertebrates are fragmentary (Nelson-Smith 1973). The snow crab *Chionoecetes bairdi* is a conspicuous member of the shallow shelf of Kodiak Island and its bays, and supports an important commercial fishery. Laboratory experiments with snow crabs have shown that postmolt individuals lose most of their legs after exposure to Prudhoe Bay crude oil (Karinen and Rice 1974). Few other direct data based on laboratory experiments are available for subtidal benthic species (see Nelson-Smith [1973] for review). Experimentation on toxic effects of oil on other common members of the subtidal benthos should be strongly encouraged for the near future in Kodiak waters as well as for all Outer Continental Shelf (OCS) areas of investigation. In addition, potential effects of the loss of sensitive species to the trophic structure of the shelf must be examined. These problems can best be addressed once benthic food studies are made available as a result of OCSEAP research; e.g., see Feder et al. (1977) and Smith et al. (1977).

A direct relationship between trophic structure (feeding type) and bottom stability has been demonstrated by Rhoads (1974), who described a diesel-fuel oil spill that resulted in oil becoming adsorbed on sediment particles which in turn caused death of deposit feeders living on sublittoral muds. Bottom stability was altered with the death of these organisms, and a new complex of species became established in the altered substratum. Many common members of the infauna of the Gulf of Alaska are deposit feeders; thus, oil-related mortality of these species could result in a changed near-bottom sedimentary regime and alteration of species composition. In addition, the commercially important king and snow crabs, and some bottom fishes, use deposit feeders as food (Feder et al. 1977 and present report); thus, contamination of the bottom by oil might indirectly affect the commercial species around Kodiak Island.

CURRENT STATE OF KNOWLEDGE

Little is known about the biology of the invertebrate benthos of the Gulf of Alaska; the relevant data have been compiled by Rosenberg (1972) and AEIDC (1975). The exploratory trawl surveys conducted by the Kodiak Laboratory of the National Marine Fisheries Service (unpubl. data, no date) are the most extensive investigations of the benthic epifauna of the Kodiak shelf. However, caution must be exercised in interpreting data from these surveys because each survey was directed toward different groups or species and used different gear and sampling efforts. Some information on the epifauna in the vicinity of Kodiak Island is available from Alaska Department of Fish and Game king crab indexing surveys (unpubl. data, ADF&G, Box 686, Kodiak, AK 99615). The International Pacific Halibut Commission (1964) surveys parts of the Kodiak shelf annually, but the only invertebrates they record are the commercially important crabs.

Alitak Bay has a history as a king crab mating ground (Kingsbury and James 1971), and has been a major producer of commercial-sized crab in the Kodiak Island area since 1953 (Gray and Powell 1966). Outer Alitak Bay was also the site of king crab distribution, abundance, and composition studies (Gray and Powell 1966; Kingsbury et al. 1974) conducted by the Alaska Department of Fish and Game during the summers of 1962 and 1970.

STUDY AREA

Alitak Bay and Ugak Bay, located on the south and east sides of Kodiak Island, respectively, were the sites of benthic trawling activities during the summer of 1976 and March 1977 (Figs. 1 and 2).

SOURCES, METHODS, AND RATIONALE OF DATA COLLECTION

The epibenthos was sampled from the MV *Big Valley* during four cruises: 17–22 June, 18–28 July, and 19–29 August 1976; and 3–18 March 1977. Fifty-three permanent stations were established in conjunction with Alaska Department of Fish and Game surveys: 28 stations in Alitak Bay (Fig. 1) and 25 stations in Ugak Bay (Fig. 2). Thirty-minute tows were made at these stations using a commercial sized, 400-mesh Eastern otter trawl with a 12.2-m horizontal opening.

The numbers of stations occupied in each bay by cruise are as follows:

Cruise date	*Alitak Bay*	*Ugak Bay*	*Total stations*
17–12 Jun 1976	28	25	53
18–28 Jul 1976	28	25	53
19–29 Aug 1976	22	25	47
3–18 Mar 1977	21	23	44
Total	99	98	197

Bay stations were arbitrarily divided into three sections: inner stations, mid-bay stations, and outer stations (Figs. 1 and 2).

Invertebrates were sorted on board, given tentative identifications, counted, and weighed. Aliquot samples of individual species were preserved and labeled for final identification at the Institute of Marine Science, University of Alaska. Laboratory examination occasionally revealed more than one species in a sample that had been identified to a single species in the field (e.g., field identifications of *Eualus macilenta* were later found to also contain *E. gaimardii belcheri*). The counts and weights of the species in question were arbitrarily expanded from the laboratory species ratio to encompass the entire catch of the trawl.

After final identification, all invertebrates were assigned code numbers (Mueller 1975) to facilitate data analysis by computer. Representative and voucher samples of

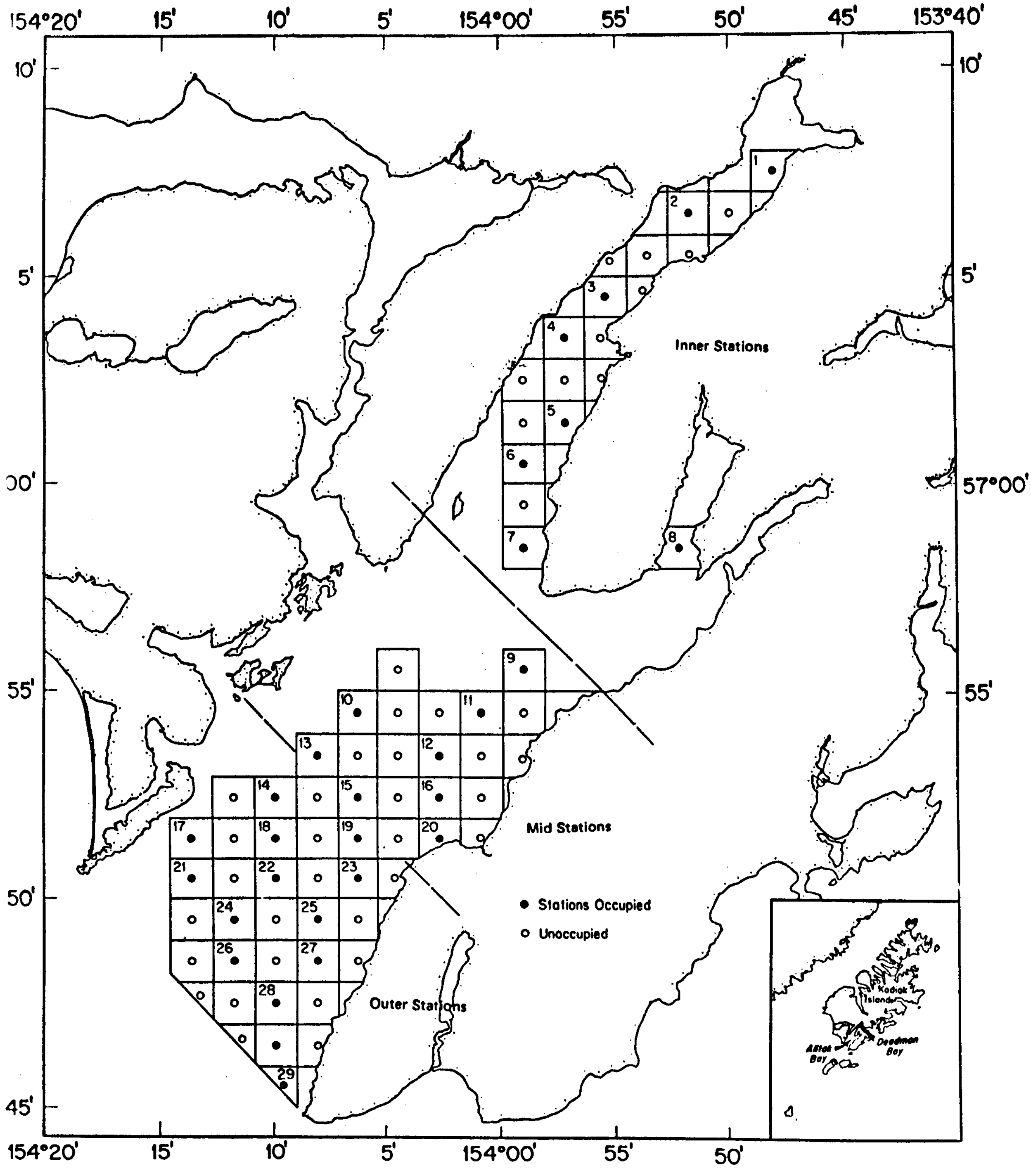

Figure 1.—Trawl station grid and stations occupied in Alitak Bay, Kodiak Island, Alaska, during June–August 1976 and March 1977. The oblique, dashed lines drawn across the bay divide it into three sections referred to in the text.

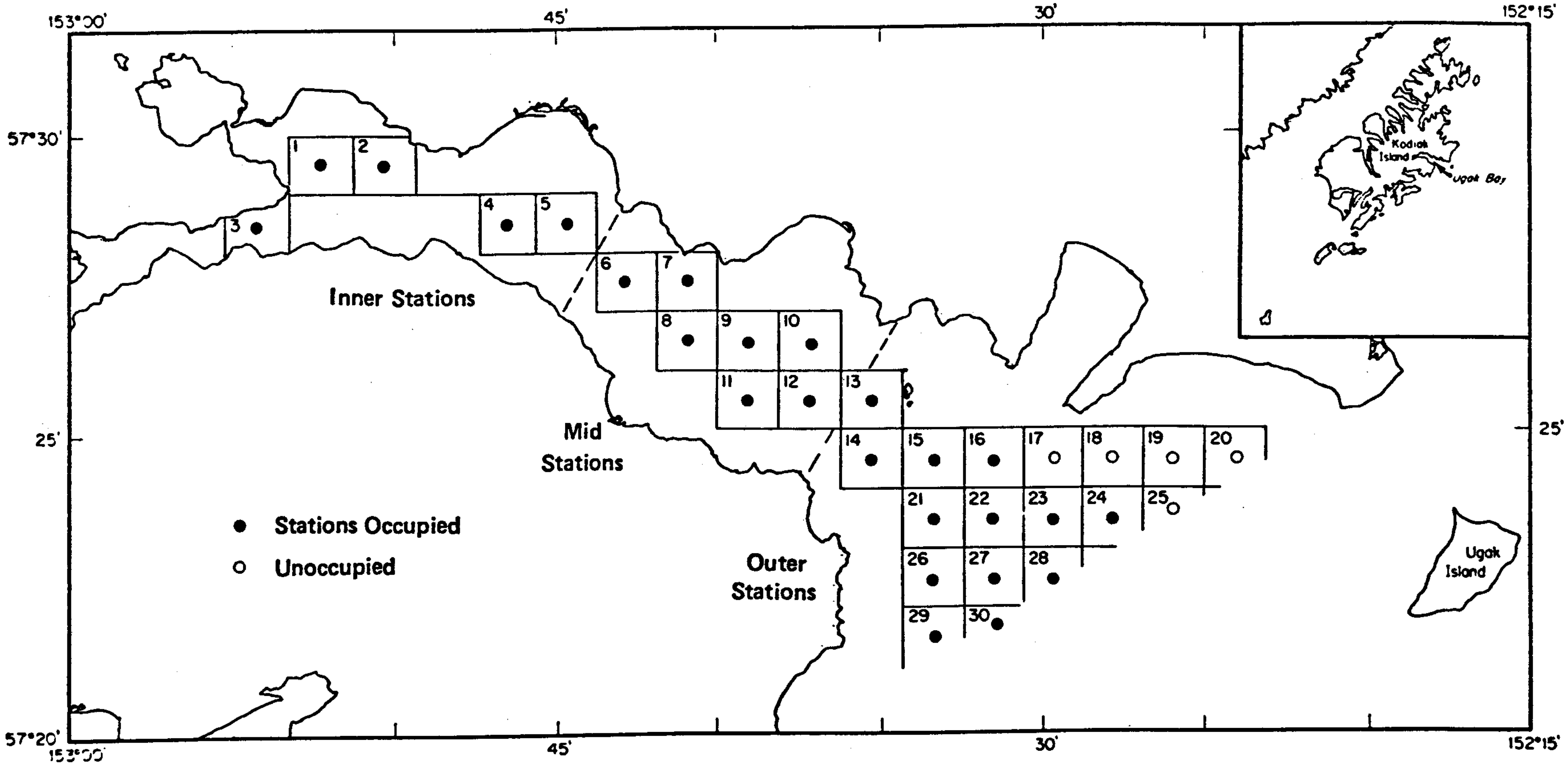

Figure 2.—Trawl station grid and stations occupied in Ugak Bay, Kodiak Island, Alaska, during June–August 1976 and March 1977. The oblique dashed lines drawn across the bay divide it into three sections referred to in the text.

invertebrates are temporarily stored at the Institute of Marine Science, University of Alaska, Fairbanks, Alaska.

The major limitation of the survey was that imposed by the selectivity of the otter trawl used. In addition, rocky-bottom areas could not be sampled since otter trawls of the type used can only be fished on relatively smooth bottoms. The location of stored commercial crab gear in Alitak Bay necessitated elimination of six stations (9 through 13) during the August sampling period; seven outer Alitak Bay stations (14, 18, 25–29) were eliminated in March 1977 due to heavy concentrations of ovigerous female king crabs.

Food data were collected by examining, either on board or in the laboratory, the stomachs of two species of crabs (*Chionoecetes bairdi* and *Paralithodes camtschatica*) and four species of flatfishes (*Limanda aspera, Platichthys stellatus, Hippoglossoides elassodon,* and *Lepidopsetta bilineata*). Male snow crabs (*C. bairdi*) between 85 and 180 mm carapace width and male king crabs (*P. camtschatica*) between 90 and 200 mm carapace length were examined. The importance of prey organisms in the diet is expressed as frequency of occurrence; i.e., the percentage of stomachs containing a particular food item.

King and snow crabs were separated by weight, sex, and state of maturity. Male king crabs were considered sexually mature if their wet weight was at least 2.0 kg. Male snow crabs were considered mature if their wet weight was at least 0.45 kg. Weight criteria established for maturity of both crab species are approximations based on the minimum weight of legal-size crabs (J. Hilsinger and S. Jewett, unpubl. data). Female king and snow crabs were classified as immature (pre-reproductive) or mature (reproductive or post-reproductive) based on the enlarged abdomen, modified pleopods, and egg clutch of the adults.

All station data not included in this report are on file at the National Oceanographic Data Center.

RESULTS

Distribution, Abundance, and Reproductive Biology

Alitak Bay

The average epifaunal invertebrate biomass for all Alitak Bay stations sampled was 6.24 g/m^2 (Table 1). The lowest biomass recorded was 3.17 g/m^2, in August 1976; the highest biomass was 10.59 g/m^2, in March 1977.

Taxonomic analysis of epifaunal invertebrates from Alitak Bay delineated 10 phyla, 16 classes, 46 families, 60 genera, and 79 species (Table 2 and Appendix Table 1). Arthropoda (Crustacea) and Mollusca dominated species representation with 34 and 22 species, respectively (Table 2 and Appendix Table 1). Arthropods accounted for 99.1% of the total invertebrate biomass (Table 3 and Appendix Table 2); 97.7% of this biomass was made up of the families Pandalidae, Lithodidae, and Majidae (Table 4 and Appendix Table 3). The leading species in each of these families, respectively, were the pink shrimp (*Pandalus borealis*), the king crab (*Paralithodes camtschatica*), and the snow crab (*Chionoecetes bairdi*) (Table 5 and Appendix Table 4). Although 22 species of Mollusca were represented, these species only accounted for 0.14% of the total invertebrate biomass (Table 3).

The average pink shrimp catch for all Alitak Bay stations in all sampling periods was 15.97 kg per tow (1,581.86 kg/99 tows; also see Table 5). Abundant catches of pink shrimp were obtained during June, July, and August 1976 from Alitak Bay stations 11–16 (Fig. 1). During March 1977 the largest catches came from stations 3–7 (Fig. 1). The largest single catch, 426.0 kg, was obtained in July at station 23.

Pink shrimp were not carrying eggs during June and July. However, in August, aqua-colored eggs were visible through the cephalothorax and/or were attached to the abdominal appendages. By the following March, the eggs had advanced to the eyed condition. Other pandalid and crangonid shrimps displayed similar timing of egg maturation.

The average king crab catch for all Alitak Bay tows was 44.10 kg per tow (4,365.87 kg/99 tows; also see Table 5). During June through August, Alitak Bay stations 21–29 had good catches. However, the largest catches were obtained in the outer stations during March 1977. Several 10-minute tows were made in this outer bay area, and these short tows produced full catches of adult female king crabs. Due to the high concentrations of these female crabs and the mortality which would probably result from continued sampling, trawling was discontinued in seven of the outer Alitak Bay stations.

Table 1.—Total epifaunal invertebrate biomass from benthic trawling activities in Alitak and Ugak bays, June–August and March 1977.

	Alitak Bay			Ugak Bay			Alitak and Ugak bays		
	Weight (kg)	Distance fished (km)	Biomass (g/m^2)	Weight (kg)	Distance fished (km)	Biomass (g/m^2)	Weight (kg)	Distance fished (km)	Biomass (g/m^2)
Jun 1976	2,998.427	47.15	5.21	1,264.732	42.50	2.43	4,263.159	89.65	3.98
Jul 1976	3,313.600	45.30	5.99	2,086.509	43.46	3.93	5,400.110	88.76	4.98
Aug 1976	1,431.266	36.98	3.17	1,862.656	41.14	3.71	3,293.922	78.12	3.45
Mar 1977	3,939.625	30.49	10.59	1,900.674	37.90	4.11	5,840.300	68.39	6.99
All months	11,682.919	159.92	6.24	7,114.572	165.00	3.54	18,797.493	324.92	4.74

Table 2.—Species taken by trawl from Alitak Bay, June–August 1976 and March 1977.

Phylum Porifera
- unidentified species

Phylum Cnidaria
- Class Hydrozoa
  - unidentified species
- Class Scyphozoa
  - unidentified species
- Class Anthozoa
  - Family Pennatulidae
    - *Ptilosarcus gurneyi* (Gray)
  - Family Actinostolidae
    - *Stomphia coccinea* (O. F. Müller)
  - Family Actiniidae
    - *Tealia crassicornis* (O. F. Müller)

Phylum Annelida
- Class Polychaeta
  - Family Polynoidae
    - unidentified species
  - Family Nereidae
    - *Nereis* sp.
  - Family Serpulidae
    - *Crucigera irregularis* Bush
- Class Hirudinea
  - Family Acanthochitonidae
    - *Notostomobdella* sp.

Phylum Mollusca
- Class Pelecypoda
  - Family Nuculonidae
    - *Nuculana fossa* Baird
    - *Yoldia thraciaeformis* Storer
  - Family Mytilidae
    - *Mytilus edulis* Linnaeus
    - *Musculus discors* (Gray)
  - Family Pectinidae
    - *Chlamys rubida* Hinds
    - *Pecten caurinus* Gould
  - Family Anomiidae
    - *Pododesmus macrochisma* Deshayes
  - Family Astartidae
    - *Astarte rollandi* Bernardi
    - *Astarte esquimalti* Baird
  - Family Cardiidae
    - *Clinocardium ciliatum* (Fabricius)
    - *Serripes groenlandicus* (Bruguiére)
  - Family Veneridae
    - *Saxidomus gigantea* (Deshayes)
    - *Protothaca staminea* (Conrad)
  - Family Tellinidae
    - *Macoma calcarea* (Gmelin)
  - Family Hiatellidae
    - *Hiatella arctica* (Linnaeus)

Phylum Mollusca (continued)
- Class Gastropoda
  - Family Calyptraeidae
    - *Crepidula numaria* Gould
  - Family Velutinidae
    - *Velutina* sp.
  - Family Cymatiidae
    - *Fusitriton oregonensis* (Pedfield)
  - Family Thaididae
    - *Nucella lamellosa* (Gmelin)
  - Family Neptunidae
    - *Neptunea lyrata* (Gmelin)
- Class Cephalopoda
  - Family Gonatidae
    - *Gonatus* sp.
  - Family Octopodidae
    - *Octopus* sp.

Phylum Arthropoda
- Class Crustacea
  - Family Balanidae
    - *Balanus balanus* Pilsbury
    - *Balanus hesperius* Pilsbury
    - *Balanus rostratus* Pilsbury
  - Order Amphipoda
    - unidentified species
  - Order Decapoda
    - Family Pandalidae
      - *Pandalus borealis* Kröyer
      - *Pandalus goniurus* Stimpson
      - *Pandalus hypsinotus* Brandt
      - *Pandalopsis dispar* Rathbun
    - Family Hippolytidae
      - *Eualus biunguis* Rathbun
      - *Eualus gaimardii belcheri* (Bell)
      - *Eualus macilenta* (Kröyer)
    - Family Crangonidae
      - *Crangon dalli* Rathbun
      - *Crangon communis* Rathbun
      - *Sclerocrangon boreas* (Phipps)
      - *Argis* sp.
      - *Argis lar* (Owen)
      - *Argis dentata* (Rathbun)
      - *Argis crassa* Rathbun
    - Family Paguridae
      - *Pagurus* sp.
      - *Pagurus ochotensis* Brandt
      - *Pagurus aleuticus* (Benedict)
      - *Pagurus capillatus* (Benedict)
      - *Pagurus kennerlyi* (Stimpson)
      - *Pagurus beringanus* (Benedict)
      - *Labidochirus splendescens* (Owen)

Table 2.—(continued)

Phylum Arthropoda (continued)
    Family Lithodidae
        Paralithodes camtschatica (Tilesius)
        Paralithodes platypus Brandt
    Family Majidae
        Oregonia gracilis Dana
        Hyas lyratus Dana
        Chionoecetes bairdi Rathbun
        Pugettia gracilis (Dana)
    Family Cancridae
        Cancer magister Dana
        Cancer oregonensis (Dana)
    Family Atelecyclidae
        Telmessus cheiragonus (Tilesius)

Phylum Sipunculida
        unidentified species

Phylum Ectoprocta
        unidentified species

Phylum Brachiopoda
  Class Articulata
    Family Dallinidae
        Terebratalia transversa (Sowerby)

Phylum Echinodermata
  Class Asteroidea
    Family Echinasteridae
        Henricia sp.
    Family Pterasteridae
        Pteraster tesselatus Fisher
    Family Asteridae
        Evasterias echinosoma (Stimpson)
        Evasterias troschelii (Stimpson)
        Stylasterias forreri (de Loriol)
        Pycnopodia helianthoides (Brandt)
    Family Strongylocentrotidae
        Strongylocentrotus droebachiensis (O. F. Müller)
  Class Holothuroidea
    Family Molpadiidae
        Molpadia sp.
    Family Cucumariidae
        Cucumaria sp.

Phylum Chordata
  Class Ascidiacea
        unidentified species

Table 3.—Number, weight, and density of major epifaunal invertebrate phyla of Alitak and Ugak bays, June–August 1976 and March 1977.

	Number of organisms		Weight (kg)		Percent of total weight		Mean grams per square meter	
Phylum	Alitak	Ugak	Alitak	Ugak	Alitak	Ugak	Alitak	Ugak
Porifera	649	1,037	43.86	89.35	0.38	1.25	0.022	0.044
Cnidaria	71	275	12.23	44.75	0.10	0.63	0.006	0.022
Mollusca	276	570	16.62	6.48	0.14	0.09	0.008	0.003
Arthropoda (Crustaceans only)	294,718	162,337	11,586.55	6,819.85	99.10	95.85	5.938	3.387
Echinodermata	77	577	22.62	137.36	0.19	1.93	0.011	0.068
Total	295,791	164,796	11,681.88	7,097.79	99.91	99.75	5.985	3.524

Table 4.—Number, weight, and density of major epifaunal invertebrate families of Alitak and Ugak bays, June–July 1976 and March 1977.

	Number of organisms		Weight (kg)		Percent of total weight		Mean grams per square meter	
Family	Alitak	Ugak	Alitak	Ugak	Alitak	Ugak	Alitak	Ugak
Actiniidae	32	249	8.31	43.26	0.07	0,60	0.004	0.021
Pandalidae	263,376	143,595	2,316.23	1,392.23	19.82	19.56	1.187	0.691
Hippolytidae	14,559	3,793	109.34	35.73	0.93	0.50	0.056	0.017
Lithodidae	3,013	3,460	4,366.32	2,586.71	37.37	36.35	2.237	1.285
Majidae	7,874	6,420	4,731.85	2,743.04	40.50	38.55	2.425	1.362
Asteridae	52	197	21.41	130.03	0.18	1.82	0.010	0.064
Total	288,906	157,714	11,553.46	6,931.00	98.87	97.38	5.919	3.440

Table 5.—Number, weight, and density of major epifaunal species of Arthropoda (Crustacea) from Alitak and Ugak bays, June–August 1976 and March 1977.

Species	Number of organisms		Weight (kg)		Percent of total weight		Mean grams per square meter	
	Alitak	Ugak	Alitak	Ugak	Alitak	Ugak	Alitak	Ugak
Pandalus borealis	81,668	91,225	1,581.86	881.96	13.54	12.40	0.810	0.438
Pandalus goniurus	33,109	26,688	270.15	253.04	2.31	3.56	0.138	0.125
Pandalus hypsinotus	45,509	25,343	414.10	253.81	3.54	3.57	0.212	0.126
Pandalopsis dispar	3,089	338	50.54	3.41	0.43	0.05	0.025	0.001
Eualus gaimardii belcheri	11,288	—	81.96	—	0.70	—	0.042	—
Argis dentata	2,349	1,600	17.84	11.33	0.15	0.16	0.009	0.005
Paralithodes camtschatica	3,012	3,460	4,365.87	2,586.71	37.37	36.36	2.237	1.285
Chionoecetes bairdi	7,772	6,085	4,728.56	2,740.74	40.47	38.52	2.423	1.361
Total	187,796	154,739	11,510.88	6,731.00	98.51	94.62	5.896	3.341

Ovigerous king crabs were collected in each of the four sampling periods. Many egg clutches were partially hatched and approximately 3% were completely hatched by March. No grasping was observed at the latter time. Differences in sex composition and stage of maturity were observed over the four sampling periods (Tables 6 and 7). The sex ratio of king crabs at the outer Alitak Bay stations from this study and from other studies (Gray and Powell 1966; Kingsbury and James 1971) is presented in Table 8.

The average snow crab catch was 47.76 kg per tow (4,728.56 kg/99 tows; also see Table 5). Large catches of snow crabs were obtained at Alitak Bay stations 2–5 from June through August. The largest catch, 119.51 kg, was recorded at Alitak Bay station 3 in July. The catch of snow crabs in Alitak Bay declined from June to August; the catch was up slightly in March. Adult males were the main component of the population during the summer sampling periods (Table 6); adult females carrying eyed-eggs were common in March (Table 7). Ovigerous snow crabs were present during all four sampling periods.

Ugak Bay

The average epifaunal invertebrate biomass for all Ugak Bay stations sampled was 3.54 g/m^2 (Table 1). The lowest and highest biomasses were recorded in June 1976 and March 1977, respectively.

During the four Ugak Bay sampling periods, in which 98 tows were made, epifaunal invertebrates were identified to 12 phyla, 19 classes, 50 families, 67 genera, and 84 species (Table 9 and Appendix Table 5). Arthropoda and Mollusca dominated Ugak Bay in species representation with 30 and 22 species present, respectively (Table 9). Crustaceans accounted for 95.8% of the total invertebrate biomass (see Appendix Tables 6–8 for biomass data); 87.2% of the crustacean biomass consisted of pink shrimp and king and snow crabs (Table 5).

The average pink shrimp catch for 98 Ugak Bay tows was 9.0 kg per tow (881.96 kg/98 tows; Table 5). Large catches of pink shrimp were obtained from Ugak Bay stations 10–14, 22, and 23 (Fig. 2) during June–August 1976. During March 1977 the greatest pink shrimp catches came from stations 6–14 (Fig. 2). The reproductive state of pink shrimp in Ugak Bay was similar to that observed for Alitak Bay.

King crabs were not as common in Ugak Bay as in Alitak Bay. The average catch in Ugak Bay for all stations and all sampling periods was nearly half the average catch in Alitak Bay; i.e., 26.40 kg per tow in Ugak Bay (2,586.71 kg/98 tows; Table 5) as opposed to 44.10 kg per tow in Alitak Bay. During June–August, large catches were made at Ugak Bay stations 1–4; the largest catch was 99.88 kg in August at station 4.

Table 6.—Sex and maturity composition of king crabs and snow crabs in Alitak and Ugak bays, June–August 1976.

Alitak Bay Stations

Alitak Bay stations	Composition	June King crab No.	June King crab %	June Snow crab No.	June Snow crab %	July King crab No.	July King crab %	July Snow crab No.	July Snow crab %	August King crab No.	August King crab %	August Snow crab No.	August Snow crab %
1–7 (inner)	Adult males	0	0	1,148	98	0	0	653	97	3	30	417	95
	Adult females[1]	0	0	8	1	0	0	16	2	7	70	11	3
	Juvenile males	0	0	0	0	0	0	0	0	0	0	2	<1
	Juvenile females	0	0	8	1	0	0	6	1	0	0	9	2
	Total	0	0	1,164	100	0	0	675	100	10	100	439	100
9–13, 15[2], 16, 20 (mid-bay)	Adult males	0	0	603	88	41	67	895	92	6	15	84	92
	Adult females[1]	1	100	55	8	4	6	53	6	16	39	4	4
	Juvenile males	0	0	0	0	13	21	14	1	14	34	2	2
	Juvenile females	0	0	27	4	4	6	8	1	5	12	2	2
	Total	1	100	685	100	62	100	970	100	41	100	92	100
14, 17, 18, 19, 21–29 (outer)	Adult males	25	7	1,037	76	28	4	583	61	21	8	178	67
	Adult females[1]	165	50	319	23	244	35	271	28	100	37	69	26
	Juvenile males	87	26	8	1	236	34	12	1	92	34	9	3
	Juvenile females	56	17	4	<1	186	27	93	10	56	21	11	4
	Total	333	100	1,368	100	694	100	959	100	269	100	267	100

Table 6.—(Continued)

Ugak Bay Stations

Ugak Bay stations	Composition	June King crab No.	June King crab %	June Snow crab No.	June Snow crab %	July King crab No.	July King crab %	July Snow crab No.	July Snow crab %	August King crab No.	August King crab %	August Snow crab No.	August Snow crab %
1–5	Adult males	8	7	180	87	23	2	214	42	20	5	190	77
(inner)	Adult females[1]	1	1	16	8	2	<1	59	12	5	1	19	8
	Juvenile males	43	38	0	0	397	43	196	38	193	50	18	7
	Juvenile females	61	54	11	5	511	55	42	8	169	44	21	8
	Total	113	100	207	100	933	100	511	100	387	100	248	100
6–12	Adult males	7	29	567	90	23	6	212	56	2	1	213	81
(mid-bay)	Adult females[1]	3	13	31	5	9	2	33	9	1	1	8	3
	Juvenile males	12	50	0	0	189	50	109	29	76	45	25	10
	Juvenile females	2	8	35	5	159	42	25	6	88	53	16	6
	Total	24	100	633	100	380	100	379	100	167	100	262	100
13–30	Adult males	21	29	591	83	21	8	728	62	2	<1	339	76
(outer)	Adult females[1]	7	10	38	5	36	13	61	5	9	1	23	5
	Juvenile males	29	40	0	0	149	53	189	16	379	57	59	14
	Juvenile females	15	21	79	12	73	26	200	17	282	42	24	5
	Total	72	100	708	100	279	100	1,178	100	672	100	445	100

[1] All adult female king and snow crabs in both bays were carrying eggs.

[2] Stations 9–13 in Alitak Bay were not sampled during August due to the presence of stored crab gear.

Table 7.—Sex and maturity composition of king crabs and snow crabs in Alitak and Ugak bays, March 1977.

		King crab		Snow crab	
Alitak Bay stations	Composition	No.	%	No.	%
1–7 (inner)	Adult males	1	50	99	51
	Adult females[1]	1	50	5	2
	Juvenile males	0	0	12	6
	Juvenile females	0	0	12	6
	Total	2	100	196	100
9–13, 15, 16, 17, 20 (mid-bay)	Adult males	66	24	109	29
	Adult females	184	67	36	9
	Juvenile males	22	8	146	39
	Juvenile females	2	1	88	23
	Total	274	100	379	100
19, 21–24 (outer)	Adult males	68	7	23	4
	Adult females	862	92	413	82
	Juvenile males	10	1	28	6
	Juvenile females	0	0	40	8
	Total	940	100	504	100
Ugak Bay stations					
1–5 (inner)	Adult males	0	0	94	27
	Adult females	13	12	48	14
	Juvenile males	37	33	190	55
	Juvenile females	61	55	14	4
	Total	111	100	346	100
6–12 (mid-bay)	Adult males	9	16	120	22
	Adult females	10	18	97	18
	Juvenile males	29	52	300	55
	Juvenile females	8	14	29	5
	Total	56	100	546	100
13–16, 21–23, 26–29 (outer)	Adult males	20	9	119	19
	Adult females	31	15	130	21
	Juvenile males	132	63	278	43
	Juvenile females	28	13	106	17
	Total	211	100	633	100

[1] All adult female king crabs and snow crabs in both bays were carrying eggs.

Table 8.—Sex ratios of king crabs in outer Alitak Bay.[1]

Date	Mature crabs			Immature crabs		
	Female	Male	Ratio[2]	Female	Male	Ratio[2]
Apr 1970[3]	1,440	421	3.42:1	77	60	1.28:1
May 1962[4]	584	366	1.60:1	21	28	0.75:1
Jun 1970[3]	359	198	1.81:1	66	103	0.64:1
Jun 1976	165	25	6.60:1	56	87	0.64:1
Jul 1976	244	28	8.71:1	186	236	0.79:1
Aug 1976	100	21	4.76:1	56	92	0.61:1
Mar 1977	1,047	135	7.76:1	2	32	0.06:1

[1] See Kingsbury et al. (1974) for data for months not reported here.
[2] Females per male.
[3] Kingsbury and James (1971).
[4] Gray and Powell (1966).

King crabs were well dispersed throughout Ugak Bay in all months. The catch during all sampling months was mainly juveniles (Tables 6 and 7). Ovigerous females were present in each of the four sampling periods. The king crab sex ratio in Ugak Bay is presented in Table 10. Seven grasping pairs were observed in March.

Snow crabs were usually dominant at all stations. Large catches were obtained at Ugak stations 9, 10, 13, and 22 during June through August. Station 9 had the largest catch, 89.08 kg, during March. The catch was composed mainly of adult males during June through August (Table 6). Ovigerous females and juvenile males and females were more common during March than June through August (Tables 6 and 7).

Table 9.—Species taken by trawl from Ugak Bay, June–August 1976 and March 1977.

Phylum Porifera
- unidentified species

Phylum Cnidaria
- Class Hydrozoa
  - Family Campanulariidae
    - *Campanularia* sp.
  - Family Lafoeidae
    - unidentified species
  - Family Sertulariidae
    - *Sertularella* sp.
    - *Sertularia* sp.
    - *Abietinaria* sp.
  - Family Plumulariidae
    - unidentified species
- Class Scyphozoa
  - unidentified species
- Class Anthozoa
  - Subclass Alcyonaria
    - Family Actinostolidae
      - *Stomphia coccinea* (O. F. Müller)
    - Family Actiniidae
      - *Tealia crassicornis* (O. F. Müller)

Phylum Ctenophora
- unidentified species

Phylum Annelida
- Class Polychaeta
  - Family Polynoidae
    - unidentified species
  - Family Spintheridae
    - *Spinther alaskensis* Hartman
  - Family Nereidae
    - *Nereis* sp.
  - Family Serpulidae
    - *Crucigera irregularis* Bush

Phylum Mollusca
- Class Pelecypoda
  - Family Nuculanidae
    - *Nuculana fossa* Baird
    - *Yoldia hyperborea* Lovén in Torell
  - Family Mytilidae
    - *Mytilus edulis* Linnaeus
    - *Musculus discors* (Gray)
    - *Modiolus modiolus* (Linnaeus)
  - Family Pectinidae
    - *Chlamys rubida* Hinds
    - *Pecten caurinus* Gould

Phylum Mollusca (continued)
    Family Cardiidae
        Clinocardium ciliatum (Fabricius)
        Clinocardium nuttallii Conrad
        Serripes groenlandicus (Bruguiére)
    Family Tellinidae
        Macoma calcarea (Gmelin)
        Macoma moesta (Deshayes)
    Family Hiatellidae
        Hiatella arctica (Linnaeus)
    Family Teredinidae
        Bankia sp.
        Bankia setacea Tryon
  Class Gastropoda
    Family Calyptraeidae
        Crepidula nummaria Gould
    Family Velutinidae
        Velutina sp.
    Family Cymatiidae
        Fusitriton oregonensis (Redfield)
    Family Thaididae
        Nucella lamellosa (Gmelin)
    Family Dorididae
        unidentified species
  Class Cephalopoda
    Family Gonatidae
        Gonatus sp.
    Family Octopodidae
        Octopus sp.

Phylum Arthropoda
  Class Crustacea
    Family Balanidae
        Balanus sp.
        Balanus balanus Pilsbury
   Order Isopoda
        unidentified species
   Order Decapoda
    Family Pandalidae
        Pandalus borealis Kröyer
        Pandalus goniurus Stimpson
        Pandalus hypsinotus Brandt
        Pandalopsis dispar Rathbun
    Family Hippolytidae
        Eualus biunguis Rathbun
        Eualus macilenta (Kröyer)
    Family Crangonidae
        Crangon dalli Rathbun
        Crangon communis Rathbun
        Argis sp.
        Argis lar (Owen)
        Argis dentata (Rathbun)

Phylum Arthropoda (continued)

- Family Paguridae
  - *Pagurus ochotensis* Brandt
  - *Pagurus aleuticus* (Benedict)
  - *Pagurus capillatus* (Benedict)
  - *Pagurus kennerlyi* (Stimpson)
  - *Pagurus beringanus* (Benedict)
  - *Elassochirus tenuimanus* (Dana)
- Family Lithodidae
  - *Paralithodes camtschatica* (Tilesius)
- Family Majidae
  - *Oregonia gracilis* Dana
  - *Hyas lyratus* Dana
  - *Chionoecetes bairdi* Rathbun
  - *Pugettia gracilis* (Dana)
- Family Cancridae
  - *Cancer* sp.
  - *Cancer magister* Dana
  - *Cancer oregonensis* (Dana)
- Family Atelecyclidae
  - *Telmessus cheiragonus* (Tilesius)
- Family Pinnotheridae
  - *Pinnixa occidentalis* Rathbun

Phylum Sipunculida

- unidentified species

Phylum Echiurida

- Class Echiuroidea
  - Family Echiuridae
    - *Echiurus echiurus* Fisher

Phylum Ectoprocta

- Class Cheilostomata
  - Family Flustridae
    - unidentified species
  - Family Microporidae
    - *Microporina* sp.
- Class Ctenostomata
  - Family Flustrellidae
    - *Flustrella* sp.

Phylum Brachiopoda

- Class Articulata
  - Family Cancellothridae
    - *Terebratulina unguicula* Carpenter
  - Family Dallinidae
    - *Terebratalia transversa* (Sowerby)

Table 9.—(continued)

Phylum Echinodermata
    Class Asteroidea
        Family Solasteridae
            Solaster stimpsoni Verrill
        Family Asteridae
            Evasterias echinosoma (Stimpson)
            Evasterias troschelii (Stimpson)
            Stylasterias forreri (de Loriol)
            Pycnopodia helianthoides (Brandt)
        Family Strongylocentrotidae
            Strongylocentrotus droebachiensis (O. F. Müller)
    Class Ophiuroidea
        Family Gorgonocephalidae
            Gorgonocephalus caryi (Lyman)
        Family Ophiactidae
            Ophiopholis aculeata (Linnaeus)
    Class Holothuroidea
        Family Cucumariidae
            Cucumaria sp.
Phylum Chordata
    Class Ascidiacea
        Family Styelidae
            Pelonaia corrugata Forbes Goods

Table 10.—Sex ratios of king crabs in Ugak Bay.

	Mature crabs			Immature crabs		
Date	Female	Male	Ratio[1]	Female	Male	Ratio[1]
Jun 1976	11	36	0.31:1	78	84	0.93:1
Jul 1976	47	67	0.70:1	743	735	1.01:1
Aug 1976	15	24	0.63:1	539	648	0.83:1
Mar 1977	54	29	1.86:1	97	198	0.49:1

[1] Females per male.

Feeding Data

King crab, snow crab, and yellowfin sole (*Limanda aspera*) stomach contents are listed in Table 11. King crabs from Alitak and Ugak bays fed almost exclusively on molluscs, crustaceans, and unidentified fishes. Snow crabs fed primarily on polychaetes, clams, and unidentified fishes. Sediment and plant material were also frequently present in snow crab stomachs.

Clams and fishes were the main organisms consumed by yellowfin sole. Flathead sole (*Hippoglossoides elassodon*) fed on euphausiids and caridean shrimps (five fish examined), and rock sole (*Lepidopsetta bilineata*) fed primarily on polychaetes and the clam *Nuculana fossa* (four fish examined). Of the 40 yellowfin sole stomachs examined in March (Alitak Bay), 38 were empty. The stomachs of 27 starry flounder (*Platichthys stellatus*) examined in March were also found to be empty.

The Kodiak Island food web shown in Figure 3 is based on data from this study, McDonald and Peterson (1976), Feder et al. (1977), and Jewett (1977). The food web is presented so that carbon flow is generally from bottom to top and always in the direction of the arrows. Data were insufficient to clearly identify major food pathways. Polychaetes, gastropods (snails), pelecypods (clams), amphipods, anomurans (hermit crabs), brachyurans (true crabs), and carideans (shrimps) are the major invertebrate food items in the web. Shrimps and crabs are important food items for most fishes as well as some of the crabs. Small fishes such as herring (*Clupea harengus pallasi*), capelin (*Mallotus villosus*), and sand lance (*Ammodytes hexapterus*) are important as food for larger predatory fishes such as Pacific cod (*Gadus macrocephalus*), king salmon (*Oncorhynchus tshawytscha*), and halibut (*Hippoglossus stenolepis*). (See Feder et al. [1977] for additional Gulf of Alaska food data.)

Feeding relationships for snow crabs, king crabs, and Pacific cod (data from Feder et al. 1977, Jewett 1977) are shown in more detail in Figures 4, 5, and 6, respectively. Snow and king crabs feed heavily on benthic animals that, in turn, rely in whole or in part on detritus, bacteria, benthic diatoms, and meiofauna for food (Figs. 5 and 6). Pacific cod feed primarily on animals that feed on small benthic invertebrates or scavenged animal remains (Fig. 6 and Table 12). The invertebrates in the two bays relied on a variety of feeding methods while the fishes tended to be predators (Table 12).

Number, weight, and frequency of occurrence calculations used in this report are based on Appendix Tables 1–8.

Table 11.—Percent frequency of occurrence of food items found in stomachs of king and snow crabs and yellowfin sole from Alitak and Ugak bays, June–August 1976 and March 1977.

Food item	Percent frequency of occurrence of food items found in stomachs of:					
	King crab		Snow crab		Yellowfin sole	
	Alitak N = 37	Ugak N = 10	Alitak N = 34	Ugak N = 36	Alitak N = 45	Ugak N = 12
Polychaeta	—	—	23.5	5.6	—	—
Nuculanidae	5.4	20.0	2.9	13.9	—	—
Nuculana fossa	13.5	20.0	—	—	—	—
Pelecypoda	10.8	30.0	26.5	27.8	6.7	—
Macoma sp.	—	—	—	—	2.2	—
Tellina sp.	—	—	—	2.8	—	—
Spisula polynyma	2.7	—	—	—	2.2	—
Siliqua alta	—	—	—	—	2.2	—
Mytilus edulis	—	—	—	2.8	—	—
Gastropoda	5.4	10.0	—	—	—	—
Margarites sp.	5.4	—	—	—	—	—
Fusitriton oregonensis	2.7	—	—	—	—	—
Octopi	—	—	—	—	4.4	—
Crustacea	2.7	—	—	5.6	—	—
Euphausiacea	2.7	—	—	—	—	—
Caridea	10.8	—	20.6	11.1	—	—
Crangonidae	—	—	—	2.8	—	—
Brachyura	—	—	2.9	13.9	—	—
Majidae	—	10.0	—	—	—	—
Chionoecetes bairdi	—	—	—	—	4.4	—
Atelecyclidae	2.7	—	—	—	—	—
Pisces	18.9	20.0	8.8	5.6	—	25.0
Stichaeidae	—	—	—	—	2.2	—
Osmeridae	—	—	—	—	—	8.3
Mallotus villosus	—	—	—	—	2.2	—
Unidentified plants	5.4	10.0	38.2	22.2	—	—
Sediment	—	—	55.9	27.8	—	—
Unidentified remains	—	—	2.9	—	—	—
Empty stomachs	32.4	30.0	11.8	30.6	84.4	58.3

Table 12.—Feeding methods[1] of organisms included in the Kodiak Island (Alitak and Ugak bays and other inshore waters) food web.

Phylum abbreviations: A = Annelida; M = Mollusca; Art = Arthropoda; Ecd = Echinodermata
Ctn = Chaetognatha; Cho = Chordata; × = dominant feeding method; o = other feeding method

Organism	Phylum	Deposit feeder	Suspension feeder	Scavenger	Predator	Unknown
Polychaeta	A	×	×	×	×	—
Gastropoda	M	×	—	×	×	—
Margarites	M	—	—	—	—	×
Fusitriton oregonensis	M	—	—	×	×	—
Nuculana fossa	M	×	—	—	—	—
Yoldia sp.	M	×	—	—	—	—
Spisula polynyma	M	—	×	—	—	—
Axinopsida sp.	M	—	—	—	—	×
Siliqua alta	M	—	—	—	—	×
Macoma sp.	M	×	o	—	—	—
Cephalopoda	M	—	—	×	×	—
Mysidacea	Art	—	×	×	×	—
Amphipoda	Art	×	—	×	×	—
Euphausiacea	Art	—	×	—	—	—
Pandalidae	Art	—	—	×	×	—
Pandalus borealis	Art	—	—	×	×	—
Crangonidae	Art	—	—	×	×	—
Paguridae	Art	—	—	×	×	—
Paralithodes camtschatica	Art	—	—	×	×	—
Majidae	Art	—	—	×	×	—
Hyas lyratus	Art	—	—	×	×	—
Chionoecetes bairdi	Art	—	—	×	×	—
Atelecyclidae	Art	—	—	—	—	×
Ophiuroidea	Ecd	×	×	×	×	—
Chaetognatha	Ctn	—	—	—	×	—
Clupea harengus pallasi (herring)	Cho	—	—	—	×	—

Table 12.—(continued)

Organism	Phylum	Deposit feeder	Suspension feeder	Scavenger	Predator	Unknown
Oncorhynchus gorbuscha (pink salmon)	Cho	—	—	—	×	—
O. keta (chum salmon)	Cho	—	—	—	×	—
O. kisutch (coho salmon)	Cho	—	—	—	×	—
O. nerka (red salmon)	Cho	—	—	—	×	—
O. tshawytscha (king salmon)	Cho	—	—	—	×	—
Osmeridae	Cho	—	—	—	×	—
Mallotus villosus (capelin)	Cho	—	—	—	×	—
Theragra chalcogramma (pollock)	Cho	—	—	—	×	—
Gadus macrocephalus (Pacific cod)	Cho	—	—	×	×	—
Lyconectes sp.	Cho	—	—	—	×	—
Ammodytes sp. (sand lance)	Cho	—	—	—	×	—
Scorpaenidae	Cho	—	—	—	×	—
Ophiodon sp. (lingcod)	Cho	—	—	—	×	—
Cottidae	Cho	—	—	—	×	—
Atheresthes stomias (arrowtooth flounder)	Cho	—	—	—	×	—
Hippoglossoides ellasodon (flathead sole)	Cho	—	—	—	×	—
Hippoglossus stenolepis (Pacific halibut)	Cho	—	—	—	×	—
Lepidopsetta bilineata (rock sole)	Cho	—	—	—	×	—
Limanda aspera (yellowfin sole)	Cho	—	—	—	×	—
Platichthys stellatus (starry flounder)	Cho	—	—	—	×	—

[1] Barnes 1968; Feder unpubl. data; Hart 1973; Newell 1970; Pearce and Thorson 1967; Rasmussen 1973.

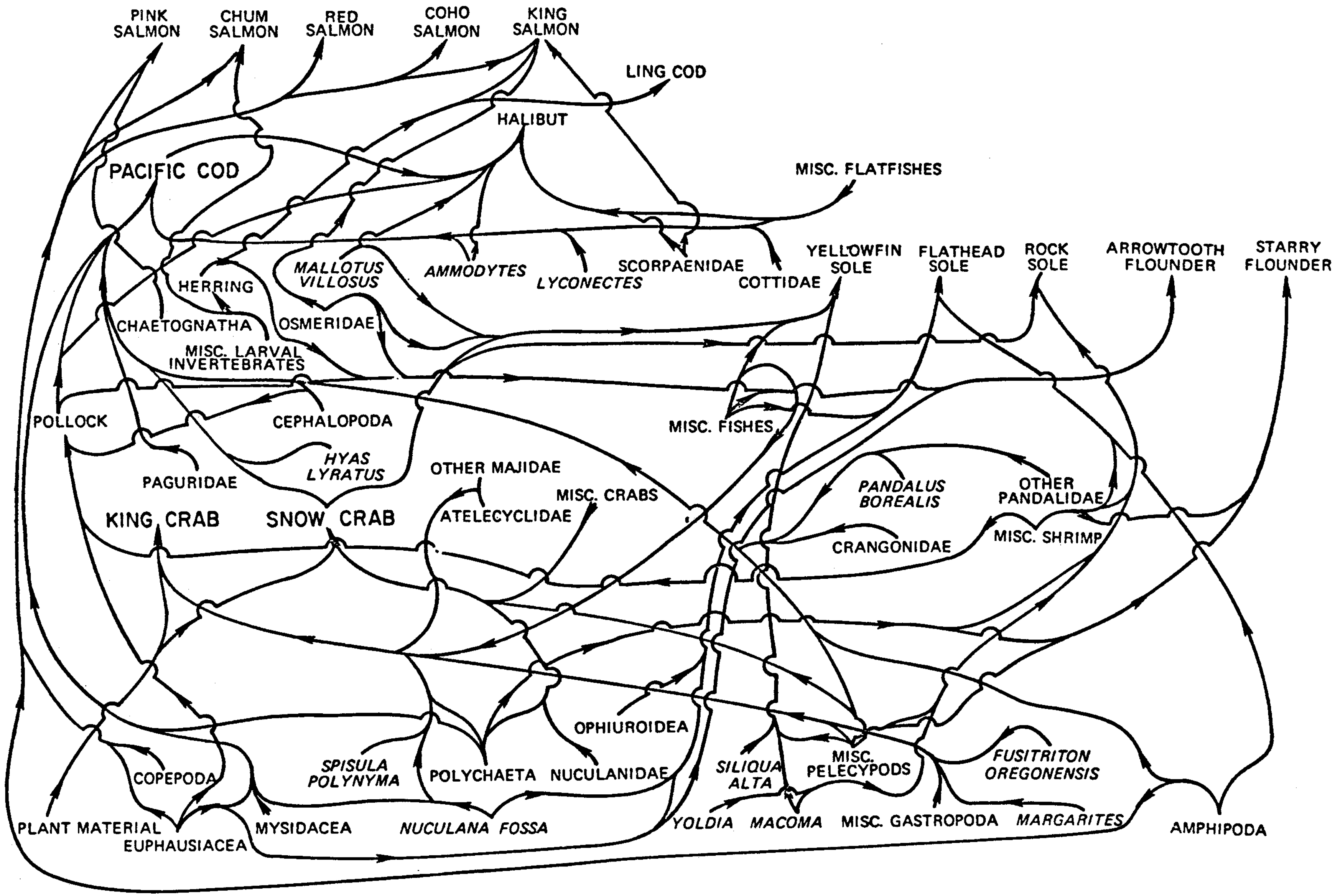

Figure 3.—Food web based on the epibenthic species taken from Alitak and Ugak bays and inshore waters around Kodiak Island, Alaska.

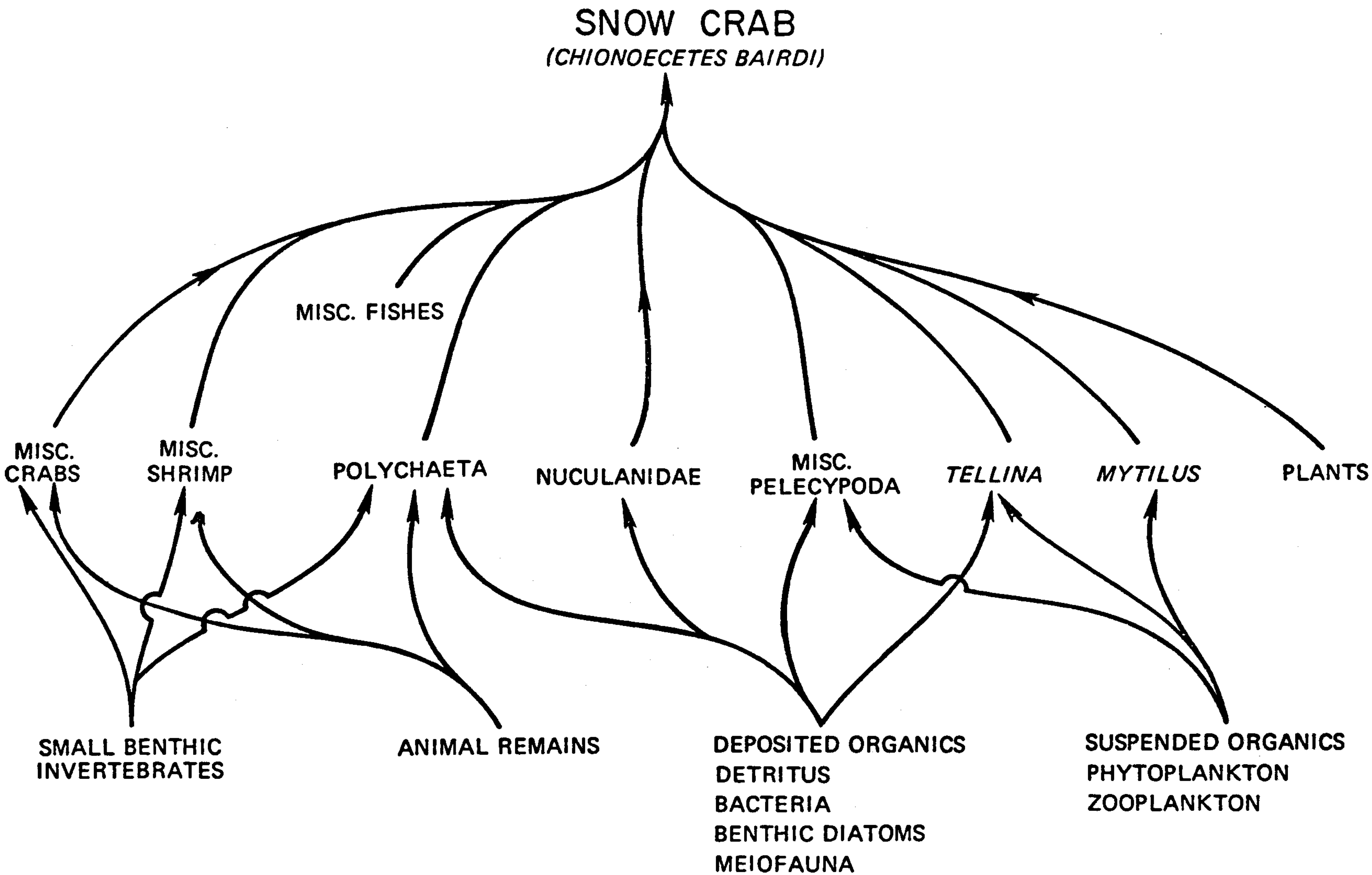

Figure 4.—Food web for the snow crab (*Chionoecetes bairdi*) in Alitak and Ugak bays and inshore waters around Kodiak Island, Alaska.

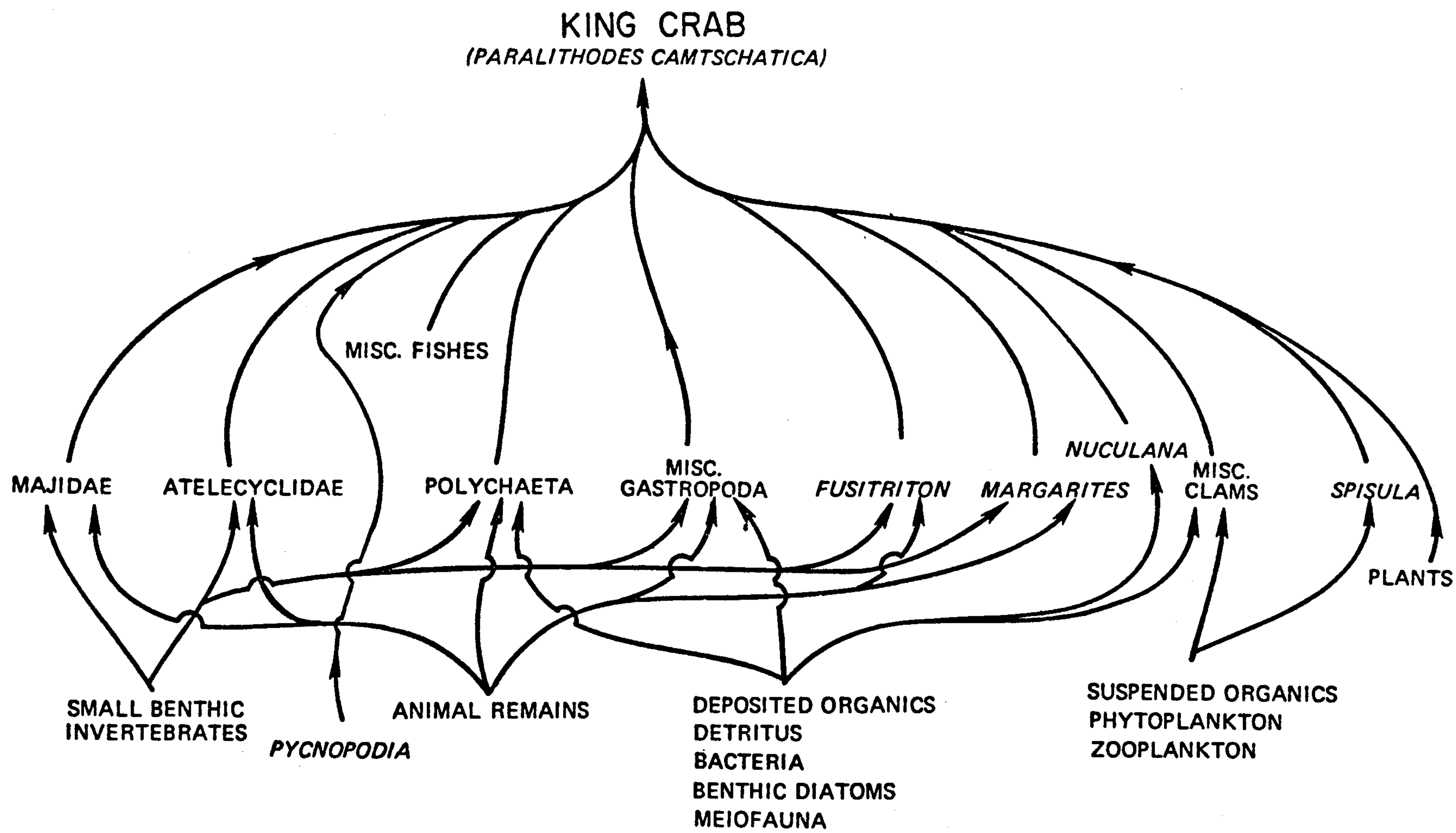

Figure 5—Food web for the king crab (*Paralithodes camtschatica*) in Alitak and Ugak bays and inshore waters around Kodiak Island, Alaska.

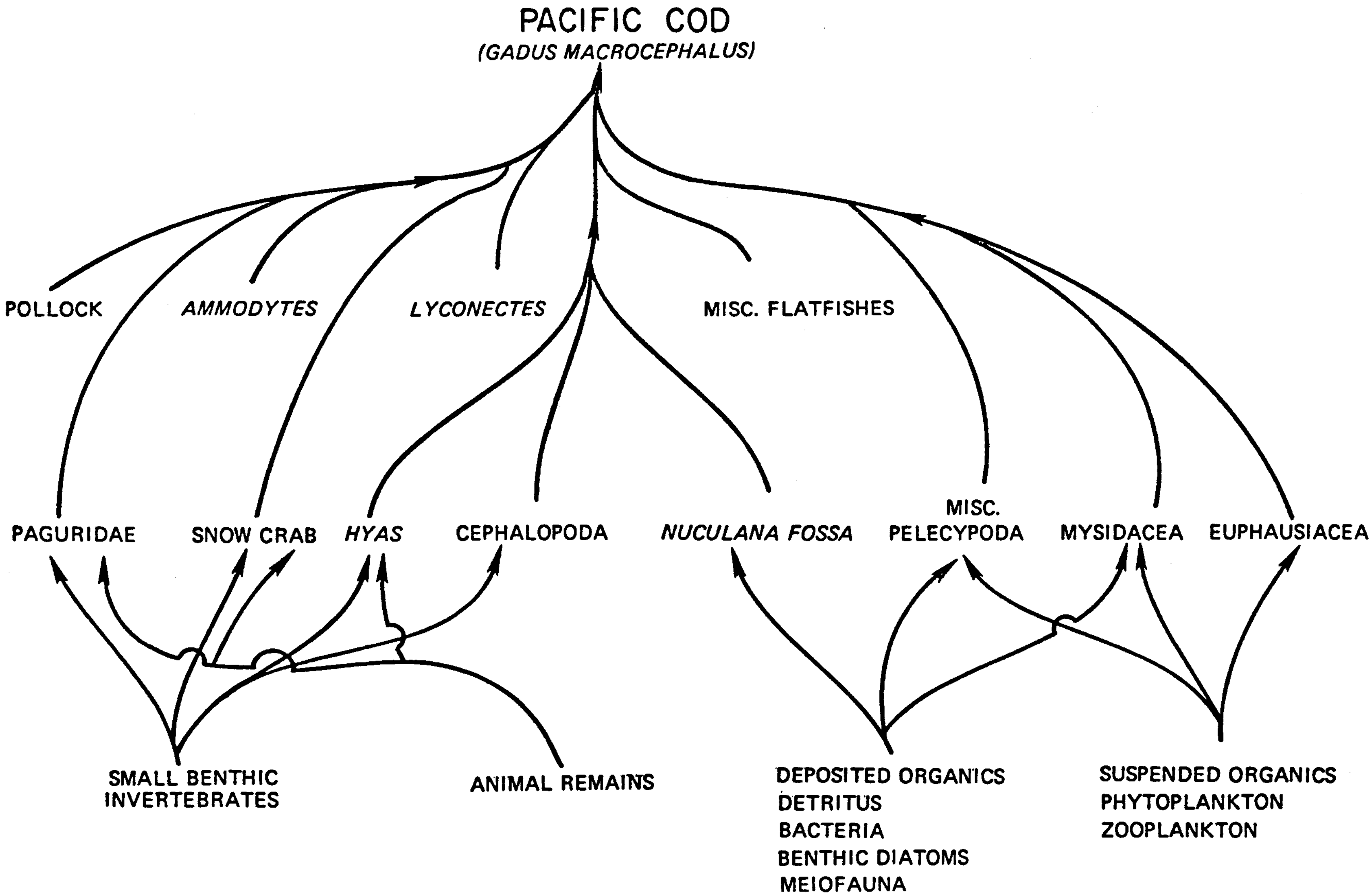

Figure 6.—Food web for the Pacific cod (*Gadus macrocephalus*) from inshore waters around Kodiak Island, Alaska. (Also see Jewett [1977] for comments on cod food habits in the Gulf of Alaska.)

DISCUSSION

Station Coverage

The trawl program discussed in this report represents the first intensive coverage of epifaunal invertebrates of Alitak and Ugak bays. Preliminary plans called for 28 stations to be occupied monthly in Alitak Bay and 25 stations in Ugak Bay for June, July, and August 1976, and March 1977. August sampling in Alitak Bay was hampered when stored crab gear prevented sampling of five stations. Seven outer Alitak Bay stations were eliminated in March 1977 due to high concentrations of ovigerous king crabs. During the four sampling periods, 99 stations were occupied in Alitak Bay and covered a total of 1.99 km^2. Station coverage in the 98 Ugak Bay stations totalled 2.03 km^2. The average distance fished at each station was 1.86 km.

Biomass

The epifaunal standing stock reported in the present study is similar to standing stock estimates reported in other OCSEAP benthic trawl studies (Jewett and Feder 1976; Feder et al. 1977). The total biomass of epifaunal invertebrates of the northeast Gulf of Alaska was 2.6 g/m^2 (Jewett and Feder 1976). The biomass determined for epifaunal invertebrates in the southeast Bering Sea was 3.3 g/m^2 in 1975 and 5.0 g/m^2 in 1976 (Feder et al. 1977). The average epifaunal biomass for Alitak and Ugak bays during all sampling months was 4.74 g/m^2 (Table 1).

Russian benthic investigations (Neyman 1963) provide biomass estimates based on grab samples for infauna and small epifauna from the southeast Bering Sea, with the lowest value reported as 55 g/m^2. Use of a commercial trawl results in the loss of infaunal and small epifaunal organisms that are an important part of the benthic biomass. Therefore, the total benthic biomass value is probably best expressed by combining both grab and trawl values. Combined infaunal and epifaunal surveys should be part of all future investigations designed by OCSEAP.

Species Composition and Diversity

Examination of the species composition of both bays revealed crustaceans and molluscs to be the major epifaunal invertebrates present. In general, epifaunal diversity was similar to that reported by Feder et al. (1976) and Jewett and Feder (1976) for the northeast Gulf of Alaska. The major differences between the northeast Gulf of Alaska and Kodiak fauna were the low numbers of species of annelids and echinoderms found in the Kodiak bays. The survey in the northeast Gulf of Alaska revealed 30 species of Annelida and 36 species of Echinodermata; however, these phyla in Alitak and Ugak bays only comprised 5 and 12 species, respectively. Hermit crabs (*Pagurus*) were the most diverse genus present, with six species collected (Tables 2 and 9).

King crabs live most of their lives on the deeper part of the continental shelf, coming into shallow water once a year to mate. Except during the mating season (mid-March to June), the sexes remain segregated in deeper water (Iverson 1966). Changing physical conditions from year to year may alter the periodicity of migration and breeding. The documented life history of king crabs reported elsewhere is reflected in the observations made on this crab in the Kodiak bays discussed in this report. Examination of sex composition and stage of maturity of king crabs from past and present studies in outer Alitak Bay indicates a high ratio of adult females to adult males during the mating season (Tables 6–8). The low numbers of adult male king crabs in Alitak Bay during the summer months probably reflect their departure following spawning. The migratory pattern of king crabs in Ugak Bay was not clearly defined during the study period. Segregation between sexes in juveniles is not apparent (Tables 6–8; Powell and Nickerson 1965).

Catches of king and snow crabs in Ugak Bay during the present study reflect a sex–maturity composition similar to that found during the Alaska Department of Fish and Game crab indexing studies in this bay; i.e., a predominance of juvenile king crabs of both sexes and adult male snow crabs from June through August (ADF&G, unpubl. data). Juvenile male and female king crabs and juvenile snow crabs were most common in March. Although Ugak Bay does not typically yield commercial-size king crabs, the outer bay is often fished for snow crabs (ADF&G, Kodiak, Alaska, snow crab catch statistics).

Food Habits

Chionoecetes bairdi and *Paralithodes camtschatica,* the main species examined for stomach contents in this study, were the most abundant and widely dispersed organisms present.

Inferences from this study, as well as other snow crab food data (Yasuda 1967; Feder et al. 1977; Feder, unpubl. data from Prince William Sound) concerning prey species, suggest that snow crab prey are area specific. Most of the important food items consumed by Alitak Bay and Ugak Bay snow crabs (i.e., polychaetes, clams, shrimps, plants, sediment) differed from food items used by snow crabs in Cook Inlet. Feder et al. (1977) examined 715 snow crabs in Cook Inlet and found that the main food items, in order of decreasing percent frequency of occurrence, were *Macoma* spp. (clams), *Pagurus* spp. (hermit crab), *Balanus* spp. (barnacles), and sediment. The only similar stomach items in the present study were clams and sediment. The role of sediment in crab feeding is not known. However, Moriarty (1977) reported on the occurrence of sediment in the food contents of five species of penaeid shrimps. The nutritional benefit of sediment intake to these shrimps appears to be derived from the film of organic carbon, inclusive of bacteria, on sand grains. Yasuda (1967) found benthic diatoms to be abundant in *Chionoecetes opilio elongatus* in the Bering Sea, and postulated that diatoms were taken indirectly with food and sediment.

King crab diets appear to be similar at different geographic locations. McLaughlin and Hebard (1961) found molluscs to be the most frequently consumed food group (69.0%) in Bering Sea king crabs (with pelecypods more frequent than gastropods). Echinoderms ranked second, appearing in 42.2% of the crabs. Takeuchi (1959, 1967) examined the stomach contents of king crabs from the west coast of Kamchatka, and found molluscs (primarily pelecypods) to be the dominant food group. Crustaceans and echinoderms were the second and third most important groups, respectively. Bering Sea king crabs examined by Feder et al. (1977) also showed pelecypod molluscs to be the dominant food, specifically *Clinocardium* sp. and *Nuculana* sp. *Nuculana,* a deposit feeder, is the most frequently occurring food used by king crabs at Alitak and Ugak bays. Gastropods and shrimps were food items of secondary importance in the present study. Although echinoderms were absent from the 46 king crabs examined, sand dollars (*Dendraster* sp.) are occasionally consumed by king crabs occupying the outer continental shelf between Alitak and Ugak bays (G. C. Powell, ADF&G, pers. comm.).

King crabs and snow crabs, the two commercially important animals of great abundance near Kodiak Island, feed on a wide variety of organisms. The king crab, with its large claws, takes snails, clams, and fishes, while the snow crab with its long, thin, curved claws, is better able to remove plant material, polychaetes, shrimps, and small clams from the bottom. Postlarval stages of king crabs were not preyed upon by any of the fishes examined. However, the soft-shelled stage of the king crab is probably preyed upon since soft-shelled snow crabs are known prey of octopus and sea stars (J. Hilsinger, unpubl. data). Juvenile snow crabs are major prey of Pacific cod (*Gadus macrocephalus*) on the Kodiak continental shelf (Jewett 1977).

The use of deposit-feeding animals as food, as well as the consistent uptake of sediment, by king and snow crabs in the Kodiak area may be critical in the event of oil contamination of sediments on crab feeding grounds.

CONCLUSIONS

There is now a satisfactory knowledge, on a station basis and for the months sampled, of the distribution and abundance of the major epifaunal invertebrates of the two study bays. Twelve phyla are represented in the collection. The important groups, in terms of species representation, in descending order of importance are the Arthropoda (Crustacea), Mollusca, Echinodermata, and Annelida. The latter three groups only accounted for less than 1.0% of the biomass collected in each bay, while Arthropoda accounted for 95.8% and 99.1% of the biomass in Ugak Bay and Alitak Bay, respectively.

Additional seasonal data are essential. Only when such continuing information is available can a reasonable biological assessment of the effect of an oil spill on these bays be made.

Differences in sex composition and stage of maturity of king and snow crabs between and within the two bays were evident. Throughout the sampling period in Alitak Bay, king crabs occurred mainly at the outer stations and consisted primarily of egg-bearing females and juveniles of both sexes. King crabs were well dispersed throughout Ugak Bay during this period, and consisted mainly of juveniles. Snow crabs in Alitak Bay were primarily juveniles, while mainly adult males inhabited Ugak Bay. Life history data for these crabs for March, June, July, and August are now available.

Preliminary feeding data for the most common epifaunal species of the two bays are presented in this report. Of special importance are the food data compiled for snow crabs and king crabs, the two commercially important crabs of the Kodiak area. These data in conjunction with similar data compiled for these crabs in Cook Inlet and the Bering Sea (Feder et al. 1977) should contribute to an understanding of the trophic role of the crabs in their respective ecosystems and the impact of oil on crab-dominated systems such as those found in Alitak and Ugak bays.

The importance of deposit-feeding clams in the diet of king and snow crabs is demonstrated for the two bays; this situation is also true for crabs observed elsewhere. A high probability exists that oil hydrocrabons will enter crabs via these deposit-feeding molluscs, suggesting that studies interrelating sediment, oil, deposit-feeding clams, and crabs should be initiated soon.

Sampling crabs and fishes using trawls and stomach analysis has made it possible to understand a major component (the epifauna) of two Kodiak bays. However, a full comprehension of the benthic system there will only be achieved when these studies are expanded to include an assessment of infauna as well. Data available suggest that adequate numbers of unique, abundant, and/or large species are available to permit nomination of likely monitoring candidates. Presumably, a monitoring program would be based primarily on recruitment, growth, food habits, and reproduction of the chosen species.

NEEDS FOR FURTHER STUDY

(1) Although the trawling activities were satisfactory for determination of the distribution and abundance of epifauna, a substantial component of both bays—the infauna—was not sampled. Since infaunal species represent important food items, it is essential that dredging be accomplished at the bay stations in the near future.

(2) The present study has produced a data base describing the abundance, density, and distribution of epibenthic invertebrates as well as notes on reproductive biology of commercially important crabs during June, July, and August 1976 and March 1977. Additional studies are needed during other seasons and years to describe seasonal and year-to-year variations in the distribution and relative abundance of the epifauna.

(3) Seasonal predator–prey relationships should be examined in conjunction with simultaneous infaunal sampling.

(4) It is essential that large samples of the dominant clam prey species be obtained to initiate recruitment, age, growth, and mortality studies. These data will then be comparable to similar data being collected for clams of Cook Inlet and the Bering Sea (Feder et al. 1977). Any future modeling efforts concerned with carbon or energy flow in the Kodiak area will need this type of information.

(5) No physical, chemical, and sediment data are currently available. This information should be obtained in the future in conjunction with all biological sampling efforts.

REFERENCES CITED

Arctic Environmental Information and Data Center. 1975. Kadyak—a background for living. Univ. Alaska, AEIDC Publ. No. B-75, Sea Grant Publ. No. 75-9. 326 pp.

Barnes, R. D. 1968. Invertebrate Zoology. W. B. Saunders Company, Philadelphia. 743 pp.

Boesch, D. F., C. H. Hershner, and J. H. Milgram. 1974. Oil Spills and the Marine Environment. Ballinger Publishing Co., Cambridge, Mass. 114 pp.

Feder, H. M., G. Mueller, G. Matheke, and S. Jewett. 1976. The distribution, abundance, diversity, and productivity of benthic organisms in the Gulf of Alaska. Ann. rep. to NOAA/OCSEAP, Research Unit 281, Inst. Mar. Sci., Univ. Alaska, Fairbanks. 174 pp.

Feder, H. M., K. Haflinger, J. Hilsinger, M. Hoberg, S. Jewett, G. Matheke, and G. Mueller. 1977. The distribution, abundance, diversity, and productivity of benthic organisms in the Gulf of Alaska and the Bering Sea. Ann. rep. to NOAA/OCSEAP, Research Unit 281, Inst. Mar. Sci., Univ. Alaska, Fairbanks. 340 pp.

Gray, G. W., and G. C. Powell. 1966. Sex ratios and distribution of spawning king crabs in Alitak Bay, Kodiak Island, Alaska (Decapoda, Anomura, Lithodidae). Crustaceana 10(3):303–309.

Hart, J. L. 1973. Pacific fishes of Canada. Fish. Res. Board Can. Bull. 180. 740 pp.

International Pacific Halibut Commission. 1964. Catch records of a trawl survey conducted by the Int. Pac. Halibut Comm. between Unimak Pass and Cape Spencer, Alaska from May 1961 to April 1963. Int. Pac. Halibut Comm. Doc. 36. 524 pp.

Iversen, E. F. 1966. The king-sized crab. Sea Frontiers 12(4):228–237.

Jewett, S. C. 1977. Food of the Pacific cod, *Gadus macrocephalus* Tilesius near Kodiak Island, Alaska. M.S. Thesis, Univ. Alaska. 23 pp.

Jewett, S. C., and H. M. Feder. 1976. Distribution and abundance of some epibenthic invertebrates of the northeast Gulf of Alaska, with notes on the feeding biology of selected species. Inst. Mar. Sci. Rep. R76–8, Univ. Alaska, Fairbanks. 61 pp.

Karinen, J. F., and S. D. Rice. 1974. Effects of Prudhoe Bay crude oil on molting tanner crabs, *Chionoecetes bairdi*. Mar. Fish. Rev. 36(7):31–37.

Kingsbury, A. P., and K. E..James. 1971. Abundance and composition of king crabs in the Alitak and Kaguyak bay areas during April and June 1970. Alaska Dep. Fish and Game Inf. Leafl. No. 152. 42 pp.

Kingsbury, A. P., N. P. Johnson, and R. J. Kaiser. 1974. King crab study. Completion report for period July 1, 1962 to June 30, 1972. Proj. No. 5-22-R, Comm. Fish Res. Dev. Act, prepared for NOAA, Natl. Mar. Fish. Serv. by Alaska Dep. Fish and Game. 93 pp.

Lewis, J. R. 1970. Problems and approaches to base-line studies in coastal communities. FAO Tech. Conf. on Marine Pollution and its Effect on Living Resources and Fishing. FIR:MP 70/E-22. 7 pp.

McDonald, K. B., and K. K. Petersen. 1976. Kodiak Island: physical environment, biota, and potential problems related to oil exploration. A scientific report based primarily on OCSEAP-sponsored research. Science Applications, Inc., Boulder, Colorado. 146 pp.

McLaughlin, P. A., and J. F. Hebard. 1961. Stomach contents of the Bering Sea king crab. Int. North Pac. Fish. Comm. Bull. 5:5–8.

Moriarty, D. J. W. 1977. Quantification of carbon, nitrogen and bacterial biomass in the food of some penaeid prawns. Aust. J. Freshwater Res. 28:113–118.

Mueller, G. 1975. A preliminary taxon list and code for ADP processing. Sea Grant Proj. A/77-02. 159 pp.

Nelson-Smith, A. 1973. Oil Pollution and Marine Ecology. Paul Elek (Scientific Books) Ltd., London. 260 pp.

Newell, R. G. 1970. Biology of Intertidal Animals. Logos Press Limited, London. 444 pp.

Neyman, A. A. 1963. Quantitative distribution of benthos and food supply of demersal fish in the eastern part of the Bering Sea. Tr. Vses. Nauchno-issled. Inst. Morsk. Rybn. Khoz. Okeanogr. 48 (Izv. Tikhookean. Nauchno-issled. Inst. Morsk. Rybn. Khoz. Okeanogr. 50): 145–205. (Transl. from Russian by Israel Prog. Sci. Transl., Soviet Fisheries Investigations of the Northeast Pacific, Part I, pp. 143–217.)

Olson, T. A., and F. J. Burgess, eds. 1967. Pollution and Marine Ecology. Interscience, New York. 364 pp.

Pearce, J. B., and G. Thorson. 1967. The feeding and reproductive biology of the red whelk, *Neptunea antiqua* (L.) (Gastropoda, Prosobranchia). Ophelia 4(2):277–314.

Pearson, T. H. 1971. The benthic ecology of Loch Linnhe and Loch Eil, a sea loch system on the west coast of Scotland. III. The effect on the benthic fauna of the introduction of pulp mill effluent. J. Exp. Mar. Biol. Ecol. 6:211–233.

Pearson, T. H. 1972. The effect of industrial effluent from pulp and paper mills on the marine benthic environment. Proc. R. Soc. Lond. B Biol. Sci. 130:469–485.

Pearson, T. H. 1975. The benthic ecology of Loch Linnhe and Loch Eil, a sea loch system on the west coast of Scotland. IV. Changes in the benthic fauna attributable to organic enrichment. J. Exp. Mar. Biol. Ecol. 20:1–41.

Powell, G. C., and R. B. Nickerson. 1965. Aggregations among juvenile king crabs (*Paralithodes camtschatica*, Tilesius), Kodiak, Alaska. Anim. Behav. 13:2–3.

Rasmussen, E. 1973. Systematics and ecology of the Iselfjord marine fauna. Ophelia 11(1–2):1–495.

Rhoads, D. C. 1974. Organism–sediment relations on the muddy sea floor. Oceanogr. Mar. Biol. Ann. Rev. 12:263–300.

Rosenberg, D. H. 1972. A review of the oceanography and renewable resources of the northern Gulf of Alaska. Report R72-23, Inst. Mar. Sci., Univ. Alaska, Fairbanks. Sea Grant Report 73-3, 690 pp.

Rosenberg, R. 1973. Succession in benthic macrofauna in a Swedish fjord subsequent to the closure of a sulphite pulp mill. Oilos 24:244–258.

Smith, J. E., ed. 1968. Torrey Canyon Pollution and Marine Life. Cambridge Univ. Press, Cambridge. 196 pp.

Smith, R. L., A. C. Paulson, and J. Rose. 1976. Food and feeding relationships in the benthic and demersal fishes of the Gulf of Alaska and Bering Sea. NOAA/OCSEAP, Environ. Assess. Alaskan Continental Shelf, Ann. Rep. 7:471–508.

Straughan, D. 1971. Biological and oceanographical survey of the Santa Barbara Channel oil spill, 1969–1970. Allan Hancock Foundation, Univ. Southern California, Los Angeles. 425 pp.

Takeuchi, I. 1959. Food of king crab (*Paralithodes camtschatica*) off the west coast of Kamchatka in 1958. Bull. Hokkaido Reg. Fish. Res. Lab. 20:67–75. (Transl. from Japanese, Fish. Res. Board Can. Transl. Ser. No. 1193.)

Takeuchi, I. 1967. Food of king crab, *Paralithodes camtschatica*, off the west coast of the Kamtchatka Peninsula, 1958–1964. Bull. Jpn. Sea Reg. Fish. Res. Lab. 33:32–44. (Transl. from Japanese, Fish. Res. Board Can. Transl. Ser. No. 1194.)

Yasuda, T. 1967. Feeding habits of the zuwaigani, *Chionoecetes opilio elongatus*, in Wakasa Bay. I. Specific composition of the stomach contents. Bull. Jpn. Soc. Sci. Fish. 33(4):315–319. (Transl. from Japanese, Fish. Res. Board Can. Transl. Ser. No. 1111.)

Zenkevitch, L. A. 1963. Biology of the Seas of the USSR. George Allen and Unwin., Ltd., London. 955 pp.

APPENDIX

The following Appendix tables are taken from computer printouts of OCSEAP data submitted to the National Oceanographic Data Center.

Appendix Table 1

OCCURRENCE OF EACH SPECIES IN ALITAK BAY - JUNE, JULY, AND AUGUST 1976, AND MARCH 1977

A total of 99 stations were occupied. Taxonomic names represent the lowest level of identification.

Taxonomic name	Cumulative occurrence	% of all[1] occurrence	% of all[2] stations
Porifera	20	2.632	20.619
Hydrozoa	3	0.395	3.093
Scyphozoa	1	0.132	1.031
Ptilosarcus gurneyi	8	1.053	8.247
Stomphia coccinea	1	0.132	1.031
Actiniidae	7	0.921	7.216
Tealia crassicornis	1	0.132	1.031
Polychaeta	1	0.132	1.031
Polynoidae	1	0.132	1.031
Nereis sp.	2	0.263	2.062
Crucigera irregularis	1	0.132	1.031
Hirudinea	1	0.132	1.031
Notostomobdella sp.	8	1.053	8.247
Nuculana fossa	5	0.658	5.155
Yoldia thraciaeformis	1	0.132	1.031
Mytilus edulis	1	0.132	1.031
Musculus discors	3	0.395	3.093
Chlamys rubida	4	0.526	4.124
Pecten caurinus	1	0.132	1.031
Pododesmus macrochisma	1	0.132	1.031
Astarte rollandi	1	0.132	1.031
Astarte esquimalti	1	0.132	1.031
Clinocardium ciliatum	1	0.132	1.031
Serripes groenlandicus	2	0.263	2.062
Saxidomus gigantea	1	0.132	1.031
Protothaca staminea	1	0.132	1.031
Macoma calcarea	5	0.658	5.155
Hiatella arctica	6	0.789	6.186

Appendix Table 1 (continued)

Taxonomic name	Cumulative occurrence	% of all[1] occurrence	% of all[2] stations
Crepidula nummaria	2	0.263	2.062
Velutina sp.	1	0.132	1.031
Fusitrition oregonensis	10	1.316	10.309
Nucella lamellosa	3	0.395	3.093
Neptunea lyrata	8	1.053	8.247
Gonatidae	1	0.132	1.031
Gonatus sp.	2	0.263	2.062
Octopus sp.	1	0.132	1.031
Balanus balanus	1	0.132	1.031
Balanus hesperius	3	0.395	3.093
Balanus rostratus	1	0.132	1.031
Amphipoda	1	0.132	1.031
Pandalus borealis	66	8.684	68.041
Pandalus goniurus	39	5.132	40.206
Pandalus hypsinotus	70	9.211	72.165
Pandalopsis dispar	19	2.500	19.588
Eualus biunguis	30	3.947	30.928
Eualus gaimardii belcheri	24	3.158	24.742
Eualus macilenta	14	1.842	14.433
Crangon dalli	17	2.237	17.526
Crangon communis	19	2.500	19.588
Sclerocrangon boreas	2	0.263	2.062
Argis sp.	3	0.395	3.093
Argis lar	14	1.842	14.433
Argis dentata	28	3.684	28.866
Argis crassa	3	0.395	3.093
Pagurus sp.	1	0.132	1.031
Pagurus ochotensis	18	2.368	18.557
Pagurus aleuticus	20	2.632	20.619
Pagurus capillatus	11	1.447	11.340

Appendix Table 1 (continued)

Taxonomic name	Cumulative occurrence	% of all[1] occurrence	% of all[2] stations
Pagurus kennerlyi	2	0.263	2.062
Pagurus beringanus	1	0.132	1.031
Labidochirus splendescens	5	0.658	5.155
Paralithodes camtschatica	66	8.684	68.041
Paralithodes platypus	1	0.132	1.031
Oregonia gracilis	16	2.105	16.495
Hyas lyratus	5	0.658	5.155
Chionoecetes bairdi	95	12.500	97.938
Pugettia gracilis	6	0.789	6.186
Cancer magister	6	0.789	6.186
Cancer oregonensis	5	0.658	5.155
Telmessus cheiragonus	1	0.132	1.031
Sipunculida	1	0.132	1.031
Ectoprocta	1	0.132	1.031
Terebratalia transversa	1	0.132	1.031
Henricia sp.	4	0.526	4.124
Pteraster tesselatus	1	0.132	1.031
Evasterias echinosoma	2	0.263	2.062
Evasterias troschelii	3	0.395	3.093
Stylasterias forreri	1	0.132	1.031
Pycnopodia helianthoides	1	0.132	1.031
Strongylocentrotus droebachiensis	6	0.789	6.186
Molpadia sp.	1	0.132	1.031
Cucumaria sp.	1	0.132	1.031
Chordata:Ascidiacea	7	0.921	7.216
TOTAL	760	100.000	-

[1] $\frac{\text{cumulative occurrence}}{\text{total cumulative occurrence}}$

[2] $\frac{\text{cumulative occurrence}}{\text{total no. of stations occupied}}$

Appendix Table 2

PERCENTAGE COMPOSITION BY WEIGHT OF ALL PHYLA FROM ALL STATIONS IN ALITAK BAY - JUNE, JULY, AND AUGUST 1976, AND MARCH 1977

Taxonomic name	Total No. indiv. (count)	% Count	Weight (gm)	% Weight	gm/m^2 all Sta.
Porifera	649	0.2193	43866.00	0.3755	0.02248
Cnidaria	71	0.0238	12230.72	0.1047	0.00627
Annelida	131	0.0443	233.00	0.0020	0.00012
Mollusca	276	0.0934	16629.67	0.1423	0.00852
Arthropoda:Crustacea	294718	99.5748	11586552.50	99.1751	5.93870
Sipunculida	1	0.0003	8.00	0.0001	0.00000
Ectoprocta	1	0.0003	225.00	0.0019	0.00012
Brachiopoda	2	0.0007	28.00	0.0002	0.00001
Echinodermata	78	0.0262	22622.67	0.1936	0.01160
Chordata:Ascidiacea	50	0.0168	524.33	0.0045	0.00027
TOTALS	295977	100.0000	11682919.89	100.0000	5.98810

Appendix Table 3

PERCENTAGE COMPOSITION OF ALL PHYLA BY FAMILY FROM ALL STATIONS IN ALITAK BAY - JUNE, JULY, AND AUGUST 1976, AND MARCH 1977

Taxonomic name	Total No. indiv. (count)	% Count	Weight (gm)	% Weight	gm/m^2 all Sta.
Porifera (unid. family)	649	0.2193	43866.00	0.3755	0.02248
Hydrozoa (unid. family)	4	0.0012	1854.33	0.0159	0.00095
Scyphozoa (unid. family)	1	0.0003	100.00	0.0009	0.00005
Pennatulacea pennatulidae	30	0.0102	597.00	0.0051	0.00031
Actinostolidae	4	0.0014	1360.00	0.0116	0.00070
Actiniidae	32	0.0107	8319.38	0.0712	0.00426
Polychaeta (unid. family)	8	0.0027	16.00	0.0001	0.00001
Polynoidae	2	0.0007	2.00	0.0000	0.00000
Nereidae	10	0.0034	22.00	0.0002	0.00001
Serpulidae	100	0.0338	170.00	0.0015	0.00009
Hirudinea (unid. family)	2	0.0006	1.67	0.0000	0.00000
Acanthochitonidae	9	0.0032	21.33	0.0002	0.00001
Nuculanidae	7	0.0023	55.67	0.0005	0.00003
Mytilidae	32	0.0108	748.00	0.0064	0.00038
Pectinidae	10	0.0034	1832.33	0.0157	0.00094
Anomiidae	4	0.0014	80.00	0.0007	0.00004
Astartidae	4	0.0014	8.00	0.0001	0.00000
Cardiidae	3	0.0010	650.00	0.0056	0.00033
Veneridae	3	0.0010	128.00	0.0011	0.00007

Appendix Table 3 (continued)

Taxonomic name	Total No. indiv. (count)	% Count	Weight (gm)	% Weight	gm/m^2 all Sta.
Tellinidae	12	0.0041	198.00	0.0017	0.00010
Hiatellidae	71	0.0240	46.00	0.0004	0.00002
Calyptraeidae	4	0.0014	3.00	0.0000	0.00000
Velutinidae	1	0.0003	2.00	0.0000	0.00000
Cymatiidae	103	0.0349	11380.33	0.0974	0.00583
Thaididae	4	0.0014	25.00	0.0002	0.00001
Neptuneidae	14	0.0047	1010.00	0.0086	0.00052
Gonatidae	3	0.0010	130.00	0.0011	0.00007
Octopodidae	1	0.0005	333.33	0.0029	0.00017
Balanidae	257	0.0868	3525.00	0.0302	0.00181
Amphipoda (unid. family)	2	0.0007	1.00	0.0000	0.00000
Pandalidae	263376	88.9854	2316668.75	19.8295	1.18741
Hippolytidae	14560	4.9191	109340.33	0.9359	0.05604
Crangonidae	5277	1.7830	40458.00	0.3463	0.02074
Paguridae	328	0.1107	6643.21	0.0569	0.00340
Lithodidae	3013	1.0180	4366325.50	37.3736	2.23797
Majidae	7874	2.6604	4731857.00	40.5024	2.42532
Cancridae	31	0.0104	11563.67	0.0990	0.00593
Atelecyclidae	1	0.0003	170.00	0.0015	0.00009
Sipunculida (unid. family)	1	0.0003	8.00	0.0001	0.00000

Appendix Table 3 (continued)

Taxonomic name	Total No. indiv. (count)	% Count	Weight (gm)	% Weight	gm/m^2 all Sta.
Ectoprocta (unid. family)	1	0.0003	225.00	0.0019	0.00012
Dallinidae	2	0.0007	28.00	0.0002	0.00001
Echinasteridae	7	0.0024	198.00	0.0017	0.00010
Pterasteridae	1	0.0003	45.00	0.0004	0.00002
Asteridae	52	0.0176	21411.00	0.1833	0.01097
Strongylocentrotidae	15	0.0053	40.67	0.0003	0.00002
Molpadiidae	1	0.0003	20.00	0.0002	0.00001
Cucumariidae	1	0.0003	908.00	0.0078	0.00047
Chordata:Ascidiacea (unid. family)	50	0.0168	524.33	0.0045	0.00027

Appendix Table 4

PERCENTAGE COMPOSITION OF ALL PHYLA BY SPECIES FROM ALL STATIONS IN ALITAK BAY - JUNE, JULY, AND AUGUST 1976, AND MARCH 1977

Taxonomic names represent the lowest level of identification.

Taxonomic name	Total No. indiv. (count)	% Count	Weight (gm)	% Weight	gm/m^2 Occurrence station	gm/m^2 All Sta.	% of Phylum (count)	% of Phylum (weight)
Porifera	649	0.2	43866.00	0.38	0.1080	0.02248	100.00	100.00
Hydrozoa	4	0.0	1854.33	0.02	0.0329	0.00095	5.20	15.16
Scyphozoa	1	0.0	100.00	0.00	0.0044	0.00005	1.42	0.82
Ptilosarcus gurneyi	30	0.0	597.00	0.01	0.0038	0.00031	43.00	4.88
Stomphia coccinea	4	0.0	1360.00	0.01	0.0603	0.00070	5.67	11.12
Actiniidae	30	0.0	8119.38	0.07	0.0554	0.00416	41.88	66.39
Tealia crassicornis	2	0.0	200.00	0.00	0.0178	0.00010	2.84	1.64
Polychaeta	8	0.0	16.00	0.00	0.0014	0.00001	6.11	6.87
Polynoidae	2	0.0	2.00	0.00	0.0002	0.00000	1.53	0.86
Nereis sp.	10	0.0	22.00	0.00	0.0010	0.00001	7.63	9.44
Crucigera irregularis	100	0.0	170.00	0.00	0.0151	0.00009	76.34	72.96
Hirudinea	2	0.0	1.67	0.00	0.0001	0.00000	1.27	0.72
Notostomobdella sp.	9	0.0	21.33	0.00	0.0001	0.00001	7.12	9.16
Nuculana fossa	6	0.0	5.67	0.00	0.0001	0.00000	2.05	0.03
Yoldia thraciaeformis	1	0.0	50.00	0.00	0.0022	0.00003	0.36	0.30
Mytilus edulis	2	0.0	80.00	0.00	0.0071	0.00004	0.72	0.48
Musculus discors	30	0.0	668.00	0.01	0.0148	0.00034	10.86	4.02
Chlamys rubida	8	0.0	1307.33	0.01	0.0232	0.00067	2.77	7.86
Pecten caurinus	3	0.0	525.00	0.00	0.0233	0.00027	0.90	3.16

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Appendix Table 4 (continued)

Taxonomic name	Total No. indiv. (count)	% Count	Weight (gm)	% Weight	gm/m^2 Occurrence station	gm/m^2 All Sta.	% of Phylum (count)	% of Phylum (weight)
Amphipoda	2	0.0	1.00	0.00	0.0001	0.00000	0.00	0.00
Pandalus borealis	81668	61.4	1581865.13	13.54	1.1129	0.81079	61.64	13.65
Pandalus goniurus	33109	11.2	270151.00	2.31	0.3193	0.13847	11.23	2.33
Pandalus hypsinotus	45510	15.4	414110.61	3.54	0.2846	0.21225	15.44	3.57
Pandalopsis dispar	3090	1.0	50542.00	0.43	0.1244	0.02591	1.05	0.44
Eualus biunguis	2409	0.8	20219.67	0.17	0.0326	0.01036	0.82	0.17
Eualus gaimardii belcheri	11289	3.8	81966.67	0.70	0.1513	0.04201	3.83	0.71
Eualus macilenta	862	0.3	7154.00	0.06	0.0226	0.00367	0.29	0.06
Crangon dalli	660	0.2	5816.33	0.05	0.0184	0.00298	0.22	0.05
Crangon communis	696	0.2	4893.67	0.04	0.0117	0.00251	0.24	0.04
Sclerocrangon boreas	87	0.0	289.00	0.00	0.0129	0.00015	0.03	0.00
Argis sp.	217	0.1	2825.00	0.02	0.0501	0.00145	0.07	0.02
Argis lar	1261	0.4	8770.00	0.08	0.0278	0.00450	0.43	0.08
Argis dentata	2350	0.8	17841.00	0.15	0.0293	0.00914	0.80	0.15
Argis crassa	7	0.0	23.00	0.00	0.0007	0.00001	0.00	0.00
Pagurus sp.	2	0.0	2.00	0.00	0.0002	0.00000	0.00	0.00
Pagurus ochotensis	192	0.1	3443.21	0.03	0.0109	0.00176	0.07	0.03
Pagurus aleuticus	82	0.0	2583.33	0.02	0.0064	0.00132	0.03	0.02
Pagurus capillatus	23	0.0	356.67	0.00	0.0017	0.00018	0.01	0.00

Appendix Table 4 (continued)

Taxonomic name	Total No. indiv. (count)	% Count	Weight (gm)	% Weight	gm/m^2 Occurrence station	gm/m^2 All Sta.	% of Phylum (count)	% of Phylum (weight)
Pagurus kennerlyi	20	0.0	190.00	0.00	0.0085	0.00010	0.01	0.00
Pagurus beringanus	3	0.0	15.00	0.00	0.0013	0.00001	0.00	0.00
Labidochirus splendescens	5	0.0	53.00	0.00	0.0006	0.00003	0.00	0.00
Paralithodes camtschatica	3012	1.0	4365871.50	37.37	3.4268	2.23773	1.02	37.68
Paralithodes platypus	1	0.0	454.00	0.00	0.0201	0.00023	0.00	0.00
Oregonia gracilis	57	0.0	743.00	0.01	0.0023	0.00038	0.02	0.01
Hyas lyratus	35	0.0	2478.00	0.02	0.0314	0.00127	0.01	0.02
Chionoecetes bairdi	7773	2.6	4728562.00	40.47	2.4518	2.42363	2.64	40.81
Pugettia gracilis	9	0.0	74.00	0.00	0.0007	0.00004	0.00	0.00
Cancer magister	16	0.0	11519.67	0.10	0.0851	0.00590	0.01	0.10
Cancer oregonensis	15	0.0	44.00	0.00	0.0006	0.00002	0.01	0.00
Telmessus cheiragonus	1	0.0	170.00	0.00	0.0151	0.00009	0.00	0.00
Sipunculida	1	0.0	8.00	0.00	0.0004	0.00000	100.00	100.00
Ectoprocta	1	0.0	225.00	0.00	0.0200	0.00012	100.00	100.00
Terebratalia transversa	2	0.0	28.00	0.00	0.0025	0.00001	100.00	100.00
Henricia sp.	7	0.0	198.00	0.00	0.0025	0.00010	9.01	0.88
Pteraster tesselatus	1	0.0	45.00	0.00	0.0020	0.00002	1.29	0.20
Evasterias echinosoma	7	0.0	5598.00	0.05	0.1657	0.00287	9.01	24.75
Evasterias troschelii	42	0.0	14473.00	0.12	0.3215	0.00742	54.08	63.98

Appendix Table 4 (continued)

Taxonomic name	Total No. indiv. (count)	% Count	Weight (gm)	% Weight	gm/m^2 Occurrence station	gm/m^2 All Sta.	% of Phylum (count)	% of Phylum (weight)
Stylasterias forreri	2	0.0	1250.00	0.01	0.1114	0.00064	2.58	5.53
Pycnopodia helianthoides	1	0.0	90.00	0.00	0.0040	0.00005	1.29	0.40
Strongylocentrotus droebachiensis	16	0.0	40.67	0.00	0.0004	0.00002	20.17	0.18
Molpadia sp.	1	0.0	20.00	0.00	0.0009	0.00001	1.29	0.09
Cucumaria sp.	1	0.0	908.00	0.01	0.0402	0.00047	1.29	4.01
Chordata:Ascidiacea	50	0.0	524.33	0.00	0.0039	0.00027	100.00	100.00

Appendix Table 5

OCCURRENCE OF EACH SPECIES IN UGAK BAY - JUNE, JULY, AND AUGUST 1976, AND MARCH 1977

A total of 98 stations were occupied. Taxonomic names represent lowest level of identification.

Taxonomic name	Cumulative occurrence	% of all[1] occurrence	% of all[2] stations
Porifera	32	3.493	32.653
Hydrozoa	4	0.437	4.082
Campanularia sp.	1	0.109	1.020
Lafoeidae	1	0.109	1.020
Sertulariidae	1	0.109	1.020
Sertularella sp.	1	0.109	1.020
Sertularia sp.	1	0.109	1.020
Abietinaria sp.	1	0.109	1.020
Plumulariidae	1	0.109	1.020
Scyphozoa	1	0.109	1.020
Stomphia coccinea	1	0.109	1.020
Actiniidae	20	2.183	20.408
Tealia crassicornis	2	0.218	2.041
Ctenophora	1	0.109	1.020
Polychaeta	6	0.655	6.122
Polynoidae	3	0.328	3.061
Spinther alaskensis	1	0.109	1.020
Nereis sp.	1	0.109	1.020
Crucigera irregularis	2	0.218	2.041
Nuculana fossa	13	1.419	13.265
Yoldia hyperborea	4	0.437	4.082
Mytilus edulis	3	0.328	3.061
Musculus discors	1	0.109	1.020
Modiolus modiolus	1	0.109	1.020
Chlamys rubida	2	0.218	2.041
Pecten caurinus	3	0.328	3.061
Clinocardium ciliatum	10	1.092	10.204
Clinocardium nuttallii	3	0.328	3.061

Appendix Table 5 (continued)

Taxonomic name	Cumulative occurrence	% of all[1] occurrence	% of all[2] stations
Serripes groenlandicus	6	0.655	6.122
Macoma calcarea	4	0.437	4.082
Macoma moesta	3	0.328	3.061
Hiatella arctica	4	0.437	4.082
Bankia sp.	1	0.109	1.020
Bankia setacea	3	0.328	3.061
Crepidula nummaria	1	0.109	1.020
Velutina sp.	1	0.109	1.020
Fusitrition oregonensis	4	0.437	4.082
Nucella lamellosa	1	0.109	1.020
Dorididae	1	0.109	1.020
Gonatus sp.	1	0.109	1.020
Octopus sp.	1	0.109	1.020
Balanus sp.	1	0.109	1.020
Balanus balanus	10	1.092	10.204
Isopoda	1	0.109	1.020
Pandalus borealis	73	7.969	74.490
Pandalus goniurus	25	2.729	25.510
Pandalus hypsinotus	72	7.860	73.469
Pandalopsis dispar	10	1.092	10.204
Eualus biunguis	38	4.148	38.776
Eualus macilenta	3	0.328	3.061
Crangon dalli	33	3.603	33.673
Crangon communis	26	2.838	26.531
Argis sp.	6	0.655	6.122
Argis lar	9	0.983	9.184
Argis dentata	41	4.476	41.837
Pagurus ochotensis	23	2.511	23.469
Pagurus aleuticus	37	4.039	37.755
Pagurus capillatus	9	0.983	9.184

Appendix Table 5 (continued)

Taxonomic name	Cumulative occurrence	% of all[1] occurrence	% of all[2] stations
Pagurus kennerlyi	1	0.109	1.020
Pagurus beringanus	2	0.218	2.041
Elassochirus tenuimanus	3	0.328	3.061
Paralithodes camtschatica	93	10.153	94.898
Oregonia gracilis	17	1.856	17.347
Hyas lyratus	4	0.437	4.082
Chionoecetes bairdi	97	10.590	98.980
Pugettia gracilis	11	1.201	11.224
Cancer sp.	1	0.109	1.020
Cancer magister	5	0.546	5.102
Cancer oregonensis	10	1.092	10.204
Telmessus cheiragonus	3	0.328	3.061
Pinnixa occidentalis	1	0.109	1.020
Echiurus echiurus alaskanus	1	0.109	1.020
Ectoprocta	1	0.109	1.020
Flustridae	1	0.109	1.020
Microporina sp.	1	0.109	1.020
Flustrella	1	0.109	1.020
Brachiopoda	1	0.109	1.020
Terebratulina unguicula	1	0.109	1.020
Terebratalia transversa	1	0.109	1.020
Solaster stimpsoni	2	0.218	2.041
Evasterias echinosoma	21	2.293	21.429
Evasterias troschelii	9	0.983	9.184
Stylasterias forreri	1	0.109	1.020
Pycnopodia helianthoides	2	0.218	2.041
Strongylocentrotus droebachiensis	22	2.402	22.449
Ophiuroidea	1	0.109	1.020
Gorgonocephalus caryi	1	0.109	1.020
Ophiopholis aculeata	1	0.109	1.020

Appendix Table 5 (continued)

Taxonomic name	Cumulative occurrence	% of all[1] occurrence	% of all[2] stations
Cucumaria sp.	5	0.546	5.102
Chordata:Ascidiacea	24	2.620	24.490
Pelonaia corrugata	2	0.218	2.041
TOTAL	916	100.000	-

[1] $\frac{\text{cumulative occurrence}}{\text{total cumulative occurrence}}$

[2] $\frac{\text{cumulative occurrence}}{\text{total no. of stations occupied}}$

Appendix Table 6

PERCENTAGE COMPOSITION BY WEIGHT OF ALL PHYLA FROM ALL STATIONS IN UGAK BAY - JUNE, JULY, AND AUGUST 1976, AND MARCH 1977

Taxonomic name	Total No. indiv. (count)	% Count	Weight (gm)	% Weight	gm/m^2 all Sta.
Porifera	1037	0.6207	89350.55	1.2559	0.04439
Cnidaria	275	0.1645	44755.90	0.6291	0.02223
Ctenophora	2	0.0012	40.00	0.0006	0.00002
Annelida	1692	1.0133	3980.02	0.0559	0.00198
Mollusca	570	0.3412	6482.70	0.0911	0.00322
Arthropoda:Crustacea	162337	97.1995	6819853.63	95.8575	3.38791
Echiuroidea	2	0.0010	25.00	0.0004	0.00001
Ectoprocta	291	0.1740	102.00	0.0014	0.00005
Brachiopoda	74	0.0446	362.14	0.0051	0.00018
Echinodermata	577	0.3456	137365.27	1.9308	0.06824
Chordata:Ascidiacea	158	0.0945	12255.86	0.1723	0.00609
TOTALS	167015	100.0000	7114573.07	100.0000	3.53430

Appendix Table 7

PERCENTAGE COMPOSITION OF ALL PHYLA BY FAMILY FROM ALL STATIONS IN UGAK BAY - JUNE, JULY, AND AUGUST 1976, AND MARCH 1977

Taxonomic name	Total No. indiv. (count)	% Count	Weight (gm)	% Weight	gm/m^2 all Sta.
Porifera (unid. family)	1037	0.6207	89350.55	1.2559	0.04439
Hydrozoa (unid. family)	6	0.0038	385.71	0.0054	0.00019
Campanulariidae	1	0.0009	28.57	0.0004	0.00001
Lafoeidae	1	0.0009	28.57	0.0004	0.00001
Sertulariidae	6	0.0034	342.86	0.0048	0.00017
Plumulariidae	1	0.0009	14.29	0.0002	0.00001
Scyphozoa (unid. family)	1	0.0006	45.00	0.0006	0.00002
Actinostolidae	8	0.0048	650.00	0.0091	0.00032
Actiniidae	249	0.1492	43260.90	0.6081	0.02149
Ctenophora (unid. family)	2	0.0012	40.00	0.0006	0.00002
Polychaeta (unid. family)	1556	0.9314	3877.57	0.0545	0.00193
Polynoidae	60	0.0362	61.81	0.0009	0.00003
Spintheridae	1	0.0009	1.43	0.0000	0.00000
Nereidae	3	0.0015	2.50	0.0000	0.00000
Serpulidae	72	0.0434	36.71	0.0005	0.00002
Nuculanidae	113	0.0678	102.74	0.0014	0.00005
Mytilidae	166	0.0993	948.14	0.0133	0.00047
Pectinidae	8	0.0051	2279.78	0.0320	0.00113
Cardiidae	51	0.0305	1690.00	0.0238	0.00084
Tellinidae	12	0.0072	702.62	0.0099	0.00035

Appendix Table 7 (continued)

Taxonomic name	Total No. indiv. (count)	% Count	Weight (gm)	% Weight	gm/m^2 all Sta.
Hiatellidae	54	0.0324	39.18	0.0006	0.00002
Teredinidae	150	0.0896	59.71	0.0008	0.00003
Calyptraeidae	1	0.0009	1.43	0.0000	0.00000
Velutinidae	1	0.0006	1.00	0.0000	0.00000
Cymatiidae	6	0.0037	353.33	0.0050	0.00018
Thaididae	2	0.0013	33.33	0.0005	0.00002
Dorididae	1	0.0009	1.43	0.0000	0.00000
Gonatidae	2	0.0012	20.00	0.0003	0.00001
Octopodidae	1	0.0006	250.00	0.0035	0.00012
Balanidae	65	0.0389	434.81	0.0061	0.00022
Isopoda (unid. family)	1	0.0006	1.00	0.0000	0.00000
Pandalidae	143596	85.9784	1392238.77	19.5688	0.69162
Hippolytidae	3793	2.2712	35734.55	0.5023	0.01775
Crangonidae	4589	2.7478	41478.04	0.5830	0.02061
Paguridae	266	0.1591	7927.65	0.1114	0.00394
Lithodidae	3460	2.0719	2586714.91	36.3580	1.28500
Majidae	6421	3.8445	2743048.47	38.5554	1.36267
Cancridae	137	0.0822	10856.42	0.1526	0.00539
Atelecyclidae	6	0.0035	1416.43	0.0199	0.00070
Pinnotheridae	3	0.0015	2.50	0.0000	0.00000
Echiuridae	2	0.0010	25.00	0.0004	0.00001

Appendix Table 7 (continued)

Taxonomic name	Total No. indiv. (count)	% Count	Weight (gm)	% Weight	gm/m^2 all Sta.
Ectoprocta (unid. family)	2	0.0012	2.00	0.0000	0.00000
Flustridae	1	0.0009	7.14	0.0001	0.00000
Microporidae	1	0.0009	7.14	0.0001	0.00000
Flustrellidae	286	0.1711	85.71	0.0012	0.00004
Brachiopoda (unid. family)	71	0.0428	357.14	0.0050	0.00018
Cancellothyrididae	1	0.0006	1.00	0.0000	0.00000
Dallinidae	2	0.0012	4.00	0.0001	0.00000
Solasteridae	4	0.0025	275.00	0.0039	0.00014
Asteridae	197	0.1180	130035.57	1.8277	0.06460
Strongylocentrotidae	336	0.2009	1346.13	0.0189	0.00067
Ophiuroidea (unid. family)	2	0.0012	2.00	0.0000	0.00000
Gorgonocephalidae	1	0.0008	80.00	0.0011	0.00004
Ophiactidae	29	0.0171	28.57	0.0004	0.00001
Cucumariidae	9	0.0051	5598.00	0.0787	0.00278
Chordata:Ascidiacea (unid. family)	128	0.0768	12190.71	0.1713	0.00606
Styelidae	30	0.0177	65.14	0.0009	0.00003

Appendix Table 8

PERCENTAGE COMPOSITION OF ALL PHYLA BY SPECIES FROM ALL STATIONS IN UGAK BAY - JUNE, JULY, AND AUGUST 1976, AND MARCH 1977

Taxonomic names represent the lowest level of identification.

Taxonomic name	Total No. indiv. (count)	% Count	Weight (gm)	% Weight	gm/m^2 Occurrence station	gm/m^2 All Sta.	% of Phylum (count)	% of Phylum (weight)
Porifera	1037	0.6	89350.55	1.26	0.1366	0.04439	100.00	100.00
Hydrozoa	6	0.0	385.71	0.01	0.0043	0.00019	2.34	0.86
Campanularia sp.	1	0.0	28.57	0.00	0.0013	0.00001	0.52	0.06
Lafoeidae	1	0.0	28.57	0.00	0.0013	0.00001	0.52	0.06
Sertulariidae	1	0.0	85.71	0.00	0.0038	0.00004	0.52	0.19
Sertularella sp.	1	0.0	85.71	0.00	0.0038	0.00004	0.52	0.19
Sertularia sp.	1	0.0	85.71	0.00	0.0038	0.00004	0.52	0.19
Abietinaria sp.	1	0.0	85.71	0.00	0.0038	0.00004	0.52	0.19
Plumulariidae	1	0.0	14.29	0.00	0.0006	0.00001	0.52	0.03
Scyphozoa	1	0.0	45.00	0.00	0.0020	0.00002	0.36	0.10
Stomphia coccinea	8	0.0	650.00	0.01	0.0579	0.00032	2.91	1.45
Actiniidae	246	0.1	43100.90	0.61	0.1108	0.02141	89.65	96.30
Tealia crassicornis	3	0.0	160.00	0.00	0.0035	0.00008	1.09	0.36
Ctenophora	2	0.0	40.00	0.00	0.0018	0.00002	100.00	100.00
Polychaeta	1556	0.9	3877.57	0.05	0.0344	0.00193	91.91	97.43
Polynoidae	61	0.0	61.81	0.00	0.0011	0.00003	3.57	1.55
Spinther alaskensis	1	0.0	1.43	0.00	0.0001	0.00000	0.08	0.04
Nereis sp.	3	0.0	2.50	0.00	0.0001	0.00000	0.15	0.06
Crucigera irregularis	72	0.0	36.71	0.00	0.0011	0.00002	4.28	0.92

Appendix Table 8 (continued)

Taxonomic name	Total No. indiv. (count)	% Count	Weight (gm)	% Weight	gm/m^2 Occurrence station	gm/m^2 All Sta.	% of Phylum (count)	% of Phylum (weight)
Nuculana fossa	103	0.1	74.07	0.00	0.0003	0.00004	18.00	1.14
Yoldia hyperborea	11	0.0	28.67	0.00	0.0004	0.00001	1.87	0.44
Mytilus edulis	48	0.0	480.00	0.01	0.0071	0.00024	8.35	7.40
Musculus discors	114	0.1	457.14	0.01	0.0203	0.00023	20.06	7.05
Modiolus modiolus	4	0.0	11.00	0.00	0.0005	0.00001	0.70	0.17
Chlamys rubida	3	0.0	21.11	0.00	0.0007	0.00001	0.55	0.33
Pecten caurinus	5	0.0	2258.67	0.03	0.0502	0.00112	0.94	34.84
Clinocardium ciliatum	33	0.0	321.67	0.00	0.0017	0.00016	5.85	4.96
Clinocardium nuttallii	5	0.0	996.67	0.01	0.0177	0.00050	0.82	15.37
Serripes groenlandicus	13	0.0	371.67	0.01	0.0033	0.00018	2.28	5.73
Macoma calcarea	6	0.0	520.95	0.01	0.0058	0.00026	1.07	8.04
Macoma moesta	6	0.0	181.67	0.00	0.0032	0.00009	1.05	2.80
Hiatella arctica	54	0.0	39.18	0.00	0.0004	0.00002	9.51	0.60
Bankia sp.	36	0.0	35.71	0.00	0.0032	0.00002	6.27	0.55
Bankia setacea	114	0.1	24.00	0.00	0.0004	0.00001	20.01	0.37
Crepidula nummaria	1	0.0	1.43	0.00	0.0001	0.00000	0.25	0.02
Velutina sp.	1	0.0	1.00	0.00	0.0001	0.00000	0.18	0.02
Fusitrition oregonensis	6	0.0	353.33	0.00	0.0052	0.00018	1.08	5.45
Nucella lamellosa	2	0.0	33.33	0.00	0.0015	0.00002	0.39	0.51
Dorididae	1	0.0	1.43	0.00	0.0001	0.00000	0.25	0.02

Appendix Table 8 (continued)

Taxonomic name	Total No. indiv. (count)	% Count	Weight (gm)	% Weight	gm/m^2 Occurrence station	gm/m^2 All Sta.	% of Phylum (count)	% of Phylum (weight)
Gonatus sp.	2	0.0	20.00	0.00	0.0009	0.00001	0.35	0.31
Octopus sp.	1	0.0	250.00	0.00	0.0111	0.00012	0.18	3.86
Balanus sp.	3	0.0	15.00	0.00	0.0013	0.00001	0.00	0.00
Balanus balanus	62	0.0	419.81	0.01	0.0021	0.00021	0.04	0.01
Isopoda	1	0.0	1.00	0.00	0.0000	0.00000	0.00	0.00
Pandalus borealis	91226	54.6	881963.02	12.40	0.5770	0.43813	56.20	12.93
Pandalus goniurus	26688	16.0	253044.02	3.56	0.4773	0.12570	16.44	3.71
Pandalus hypsinotus	25344	15.2	253817.72	3.57	0.1643	0.12609	15.61	3.72
Pandalopsis dispar	338	0.2	3414.00	0.05	0.0159	0.00170	0.21	0.05
Eualus biunguis	3737	2.2	35336.55	0.50	0.0432	0.01755	2.30	0.52
Eualus macilenta	56	0.0	398.00	0.01	0.0059	0.00020	0.03	0.01
Crangon dalli	1328	0.8	10970.75	0.15	0.0158	0.00545	0.82	0.16
Crangon communis	788	0.5	5342.95	0.08	0.0099	0.00265	0.49	0.08
Argis sp.	495	0.3	11192.00	0.16	0.0826	0.00556	0.30	0.16
Argis lar	377	0.2	2640.00	0.04	0.0130	0.00131	0.23	0.04
Argis dentata	1601	1.0	11332.34	0.16	0.0132	0.00563	0.99	0.17
Pagurus ochotensis	115	0.1	4253.33	0.06	0.0099	0.00211	0.07	0.06
Pagurus aleuticus	116	0.1	3302.73	0.05	0.0044	0.00164	0.07	0.05
Pagurus capillatus	27	0.0	288.02	0.00	0.0016	0.00014	0.02	0.00
Pagurus kennerlyi	1	0.0	28.57	0.00	0.0013	0.00001	0.00	0.00

Appendix Table 8 (continued)

Taxonomic name	Total No. indiv. (count)	% Count	Weight (gm)	% Weight	gm/m^2 Occurrence station	gm/m^2 All Sta.	% of Phylum (count)	% of Phylum (weight)
Pagurus beringanus	3	0.0	35.00	0.00	0.0008	0.00002	0.00	0.00
Elassochirus tenuimanus	4	0.0	20.00	0.00	0.0004	0.00001	0.00	0.00
Paralithodes camts-chatica	3460	2.1	2586714.91	36.36	1.3613	1.28500	2.13	37.93
Oregonia gracilis	121	0.1	1583.57	2.02	0.0045	0.00079	0.07	0.02
Hyas lyratus	13	0.0	424.29	0.01	0.0054	0.00021	0.01	0.01
Chionoecetes bairdi	6086	3.6	2740746.19	38.52	1.3770	1.36152	3.75	40.19
Pugettia gracilis	201	0.1	294.43	0.00	0.0013	0.00015	0.12	0.00
Cancer sp.	3	0.0	2.50	0.00	0.0001	0.00000	0.00	0.00
Cancer magister	10	0.0	10309.35	0.14	0.1016	0.00512	0.01	0.15
Cancer oregonensis	125	0.1	544.57	0.01	0.0030	0.00027	0.08	0.01
Telmessus cheiragonus	6	0.0	1416.43	0.02	0.0209	0.00070	0.00	0.02
Pinnixa occidentalis	3	0.0	2.50	0.00	0.0001	0.00000	0.00	0.00
Echiurus echiurus alaskensis	2	0.0	25.00	0.00	0.0011	0.00001	100.00	100.00
Ectoprocta	2	0.0	2.00	0.00	0.0001	0.00000	0.69	1.96
Flustridae	1	0.0	7.14	0.00	0.0003	0.00000	0.49	7.00
Microporina sp.	1	0.0	7.14	0.00	0.0003	0.00000	0.49	7.00
Flustrella	286	0.2	85.71	0.00	0.0038	0.00004	98.33	84.03
Brachiopoda	71	0.0	357.14	0.01	0.0158	0.00018	95.97	98.62
Terebratulina unguicula	1	0.0	1.00	0.00	0.0001	0.00000	1.34	0.28

Appendix Table 8 (continued)

Taxonomic name	Total No. indiv. (count)	% Count	Weight (gm)	% Weight	gm/m^2 Occurrence station	gm/m^2 All Sta.	% of Phylum (count)	% of Phylum (weight)
Terebratalia transversa	2	0.0	4.00	0.00	0.0004	0.00000	2.69	1.10
Solaster stimpsoni	4	0.0	275.00	0.00	0.0061	0.00014	0.72	0.20
Evasterias echinosoma	99	0.1	13268.89	0.19	0.0310	0.00659	17.12	9.66
Evasterias troschelii	22	0.0	4255.57	0.06	0.0236	0.00211	3.76	3.10
Stylasterias forreri	1	0.0	20.00	0.00	0.0009	0.00001	0.17	0.01
Pycnopodia helianthoides	76	0.0	112491.11	1.58	3.3287	0.05588	13.09	81.89
Strongylocentrotus droebachiensis	336	0.2	1346.13	0.02	0.0028	0.00067	58.13	0.98
Ophiuroidea	2	0.0	2.00	0.00	0.0001	0.00000	0.35	0.00
Gorgonocephalus caryi	1	0.0	80.00	0.00	0.0071	0.00004	0.23	0.06
Ophiopholis aculeata	29	0.0	28.57	0.00	0.0013	0.00001	4.95	0.02
Cucumaria sp.	9	0.0	5598.00	0.08	0.0496	0.00278	1.47	4.08
Chordata:Ascidiacea	128	0.1	12190.71	0.17	0.0246	0.00606	81.27	99.47
Pelonaia corrugata	30	0.0	65.14	0.00	0.0014	0.00003	18.73	0.53

DISTRIBUTION AND ABUNDANCE OF SOME EPIBENTHIC INVERTEBRATES OF THE NORTHEASTERN GULF OF ALASKA WITH NOTES ON THE FEEDING BIOLOGY OF SELECTED SPECIES

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SUMMARY OF OBJECTIVES, CONCLUSIONS, AND IMPLICATIONS WITH RESPECT TO OCS OIL AND GAS DEVELOPMENT

The objectives of this study were to obtain (1) a qualitative and quantitative inventory of dominant epibenthic species within the study area, (2) a description of spatial distribution patterns of selected benthic invertebrate species, and (3) preliminary observations of biological interrelationships between selected segments of the benthic biota.

The trawl survey was effective, and excellent spatial coverage was obtained. One hundred and thirty-three stations were successfully occupied, yielding a mean epifaunal invertebrate biomass of 2.6 g/m^2. Taxonomic analysis delineated 9 phyla, 19 classes, 82 families, 124 genera, and 168 species of invertebrates.

Three phyla—Mollusca, Arthropoda (Crustacea), and Echinodermata—dominated in species representation, with 47, 42, and 36 species taken, respectively. The same phyla dominated in biomass: Arthropoda contributed 71.4% of the total; Echinodermata, 19%; and Mollusca, 4.6%.

Snow crabs (*Chionoecetes bairdi*) contributed 66.2% of the total epifaunal invertebrate biomass. Other arthropods of significant biomass were the pink shrimp (*Pandalus borealis*) and the box crab (*Lopholithodes foraminatus*).

Important echinoderms were the brittle star *Ophiura sarsi*, the sea stars *Ctenodiscus crispatus* and *Pycnopodia helianthoides*, and the heart urchin, *Brisaster townsendi*.

Of the molluscs, the scallop *Pecten caurinus* and the snails *Neptunea lyrata* and *Fusitriton oregonensis* dominated.

Some areas of biological interest were identified. Stations 74-C and D, south of Hinchinbrook Entrance, had a high diversity of fishes and invertebrates. Most species found here were abundant. Stations 94-A and B, located off Icy Bay, were characterized by an abundance of three species of fishes and the near absence of epifaunal invertebrates.

The highest biomass values for *Chionoecetes bairdi, Pandalus borealis, Ophiura sarsi,* and *Ctenodiscus crispatus* were recorded southeast of Kayak Island, in the vicinity of the Copper River delta. Large concentrations of fishes were also found here. The productivity of this area is thought to be enhanced by the nutrients supplied by the Copper River and/or the presence of clockwise and counter-clockwise gyres.

Limited trophic interaction data were compiled during this survey. However, inferences from other Outer Continental Shelf Environmental Assessment Program (OCSEAP) investigations suggest that food groups used by the dominant northeast Gulf of Alaska invertebrates are somewhat similar throughout their ranges.

A large number of the epifaunal species collected in the study area were either sessile or slow-moving forms. It is probable that many of these organisms prey upon deposit-feeding infauna as they do in the waters of Cook Inlet, Kodiak, the Bering Sea, and the southeast Chukchi Sea. Many of these epifaunal species would be affected by oil spills either because of their inability to leave the area or as a result of their food dependence on deposit-feeding species that incorporate sediment in the feeding process. Experimentation on toxic effects of oil on snow crabs, king crabs, and pandalid shrimps has been carried out by other investigators.

Initial assessment of the data suggests that a few unique, abundant, and/or large benthic species (snow crabs, shrimps, brittle stars, sea stars) are characteristic of the areas investigated and that these species may represent organisms that could be useful for monitoring purposes. Two biological parameters that should be addressed in conjunction with petroleum-related activities are feeding and reproductive biology of important species. It is suggested that an intensive program designed to examine these parameters be initiated well in advance of industrial activity in the oil lease areas.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

INTRODUCTION

General Nature and Scope of Study

The operations connected with oil exploration, production, and transportation in the northeast Gulf of Alaska (NEGOA) will present a wide spectrum of potential dangers to the marine environment (see Olson and Burgess [1967] and Malins [1977] for general discussion of marine pollution problems). Adverse effects on the marine environment cannot be quantitatively assessed, or even predicted, unless background data are recorded prior to industrial development. Insufficient long-term information about an environment, and the basic biology of species in that environment, can lead to erroneous interpretations of changes in species composition and abundance that might occur if the area becomes altered by industrial activity (see Baker [1976], Nelson-Smith [1973], Pearson [1971, 1972, 1975], and Rosenberg [1973] for general discussions on benthic biological investigations in industrialized marine areas). Populations of marine species fluctuate over a time span of a few to 30 years (Lewis 1970 and personal communications), but such fluctuations are typically unexplainable because of absence of long-term data (Lewis 1970).

Benthic invertebrates (primarily the infauna but also sessile and slow-moving epifauna) are useful as indicator species for a disturbed area because they tend to remain in place, typically react to long-range environmental changes, and by their presence, generally reflect the nature of the substratum. Consequently, organisms of the infaunal benthos have frequently been chosen to monitor long-term pollution effects, and are believed to reflect the biological health of a marine area (see Pearson [1971, 1972, 1975] and Rosenberg [1973] for discussion of long-term use of benthic organisms for monitoring pollution). The presence of large numbers of benthic epifaunal species of actual or potential commercial importance (crabs, shrimps, snails, finfishes) in NEGOA further dictates the necessity of understanding benthic communities since many commercially important species feed on infaunal and small epifaunal residents of the benthos (see Zenkevitch [1963], Feder [1977a, 1978a], Feder et al. [1978], and Feder and Jewett [1977, 1978] for discussions of the interaction of commercially important species and the benthos). Any drastic changes in density of the food benthos could affect the health and numbers of these economically important species.

Experience in pollution-prone areas of England (Baker 1976; Smith 1968), Scotland (Pearson 1972, 1975), and California (Straughan 1971) suggests that at the completion of an exploratory study, selected stations should be examined regularly on a long-term basis to monitor species content, diversity, abundance, and biomass. Such long-term data acquisition in NEGOA should make it possible to differentiate between normal ecosystem variation and pollutant-induced alteration. Furthermore, intensive investigation of the food habits of benthic species of NEGOA are also essential in order to understand trophic interactions there and to predict changes that might take place once oil-related activities are initiated.

The intensive trawl study considered in this report delineates the major epifauna on the northeastern Gulf of Alaska shelf. The information obtained on faunal composition and abundance in this investigation now represents a general data base to which future changes can be compared. A major portion of this data is presented in Jewett and Feder (1976). Long-term studies on life histories and trophic interactions should ultimately define functional aspects of communities and ecosystems vulnerable to environmental damage, and should help determine rates at which damaged environments can recover.

Relevance to Problems of Petroleum Development

Lack of adequate data on a worldwide basis makes it difficult to predict the effects of oil-related activity on the subtidal benthos. However, the recent expansion of research activities in NEGOA should ultimately enable us to point with some confidence to certain species or areas there that might bear closer scrutiny once industrial activity is initiated. It must again be emphasized that a broad time frame is needed to comprehend long-term fluctuations in composition and density of benthic species; thus, it cannot be expected that short-term research programs will result in adequate predictive capabilities. Assessment of any ecological system must always be a continuing endeavour.

As indicated above, infaunal species tend to remain in place and, consequently, have been useful as indicator species for disturbed areas. Thus, close examination of stations with substantial complements of infaunal species is warranted (see Feder and Matheke [1979] for comments on infaunal benthos). Changes in the environment at these and other stations with a relatively large number of species might be reflected in a decrease in diversity of species with increased dominance of a few (see Nelson-Smith [1973] for further discussion of oil-related changes in diversity). Likewise, stations with substantial numbers of epifaunal species should be assessed on a continuing basis. The effect of loss or reduced numbers of specific epifaunal species to the overall trophic structure in NEGOA can be conjectured on the basis of available food studies (Feder 1977a, 1978a; Feder and Jewett 1977, 1978; Jewett 1978; Smith et al. 1978; Paul et al. 1979).

Data indicating the effect of oil on subtidal benthic invertebrates are fragmentary (Nelson-Smith 1973; Boesch et al. 1974; Malins 1977), but it is known that echinoderms are "notoriously sensitive to any reduction in water quality" (Nelson-Smith 1973). Echinoderms (ophiuroids: brittle stars; asteroids: sea stars; holothuroids: sea cucumbers) are conspicuous members of the benthos of NEGOA and could be affected by oil activities there. Two echinoderm groups, asteroids and ophiuroids, are often components of the diet of large crabs (Cunningham 1969; Feder 1977a, 1978b; G. Powell, ADF&G, pers. comm.) and a few species of demersal fishes (Smith et al. 1978; Wigley and Theroux 1965).

King crabs (*Paralithodes camtschatica*), snow crabs (*Chionoecetes bairdi*), and pandalid shrimps (e.g., *Pandalus borealis*) are conspicuous members of the shallow shelf of NEGOA and support commercial fisheries of considerable importance there. The effects of Cook Inlet crude oil water soluble fractions on the survival and molting of king crab and coonstripe shrimp (*Pandalus hypsinotus*) larvae were examined by Mecklenburg et al. (1976). Low concentrations (<0.54 ppm) of oil produced a moribund condition (cessation of swimming) in all larval stages and ultimately caused death. Molting of both species was permanently inhibited by exposing larvae for 72 hours at crude oil concentrations of 0.8 to 0.9 ppm. Larvae that failed to molt, died in 7 days. Laboratory experiments with postlarval *C. Bairdi* have shown that postmolt individuals lose most of their legs after exposure to Prudhoe Bay crude oil (Karinen and Rice 1974).

Little other direct data based on laboratory experiments are available for subtidal benthic species (see Nelson-Smith 1973). Thus, experimentation on toxic effects of oil on other common members of the subtidal benthos should be strongly encouraged in future Outer Continental Shelf (OCS) programs.

A direct relationship between trophic structure (feeding type) and bottom stability has been demonstrated (Rhoads 1974). After a diesel fuel spill, oil adsorbed onto sediment particles killed many deposit feeders living on sublittoral muds. Bottom stability was altered with the death of these organisms, and a new complex of species became established in the altered substratum. Many NEGOA infaunal species are deposit feeders; thus, oil-related mortality of these species could likewise result in a changed near-bottom sedimentary regime with subsequent alteration of species composition. An understanding of these species as well as epifaunal organisms and their interactions with each other is essential to the development of predictive capabilities required for the NEGOA outer continental shelf.

CURRENT STATE OF KNOWLEDGE

Little was known about the biology of the invertebrate benthos of the northeast Gulf of Alaska (NEGOA) at the time that OCSEAP studies were initiated there, although a compilation of some relevant data on the Gulf of Alaska was available (Rosenberg 1972). A short but intensive survey in the summer of 1975 added some benthic biological data for a specific area south of the Bering Glacier (Bakus and Chamberlain 1975). Results of the latter study are similar to those reported by Feder and Mueller (1975) in their OCSEAP investigation. Some scattered data based on trawl surveys by the Bureau of Commercial Fisheries (now National Marine Fisheries Service) were available, but much of the information on the invertebrate fauna was so general as to have little value.

In the summer and fall of 1961 and spring of 1962, otter trawls were used to survey the shellfishes and bottomfishes on the continental shelf and upper continental slope in the Gulf of Alaska (Hitz and Rathjen 1965). The surveys were part of a long-range program begun in 1950 to determine the size of bottomfish stocks in the northeastern Pacific Ocean between southern Oregon and northwest Alaska. Invertebrates taken in the trawls were of secondary interest, and only major groups and/or species were recorded. Invertebrates that comprised 27% of the total catch were grouped into eight categories: heart urchins (Echinodermata: Echinoidea), snow crab (*Chionoecetes biardi*), sea stars (Echinodermata: Asteroidea), Dungeness crab (*Cancer magister*), scallop (*Pecten caurinus*), shrimps (*Pandalus borealis, P. platyceros,* and *Pandalopsis dispar*), king crab (*Paralithodes camtschatica*), and miscellaneous invertebrates (e.g., sponges) (Hitz and Rathjen 1965). Heart urchins accounted for about 50% of the invertebrate catch and snow crab ranked second, representing about 22%. Approximately 20% of the total invertebrate catch was composed of sea stars.

Further knowledge of invertebrate stocks in the North Pacific is scant. The International Pacific Halibut Commission surveys parts of the Gulf of Alaska annually and records selected commercially important invertebrates; however, noncommercial species are discarded. The benthic investigations of Feder and Mueller (1975), Feder (1977a), and this report represent the first broad-based qualitative and quantitative examinations of the benthic infauna and epifauna on the shelf of the Gulf of Alaska. The history of commercial fisheries in the northeast Gulf of Alaska and data from fishing activities there have been reported by Ronholt et al. (1976).

Information in the literature has uncovered data that will aid in the interpretation of the biology of some dominant organisms in the Gulf of Alaska (see Feder 1977b).

Examination of trophic relationships of selected infaunal and epifaunal species was initiated in 1976 as a part of the lower Cook Inlet and Kodiak investigations (Feder 1977a; Feder and Jewett 1977). Food studies by Smith et al. (1978) and the present report will contribute to an understanding of trophic relationships in NEGOA.

STUDY AREA

One hundred and forty stations were occupied in conjunction with the National Marine Fisheries Service Resource Assessment trawl survey (Ronholt et al. 1976) which sampled a grid extending from the western tip of Montague Island (148° W longitude) to Yakutat Bay (140° W longitude) (Fig. 1). Samples were taken to a maximum depth of approximately 500 meters (274 fathoms).

SOURCES, METHODS, AND RATIONALE OF DATA COLLECTION

Epifauna were collected from the MV *North Pacific* in the northeastern Gulf of Alaska from 25 April to 7 August 1975. One-hour tows (a standard tow) were made at predetermined stations (Fig. 1) using a commercial sized, 400-mesh Eastern otter trawl with a 12.2 meter horizontal opening. All invertebrates currently of noncommercial importance were sorted on shipboard, given tentative identifications, counted, and weighed, and aliquot samples were preserved and labeled for final identification at the Institute of Marine Science, University of Alaska. Hermit crab weights included shell weights. Counts and weights of commercially important invertebrate species were recorded by National Marine Fisheries Service personnel, and the data were made available to the benthic invertebrate program.

Biomass per unit area (g/m^2) was calculated as W/CTw(Dx1000)) where W = weight (grams), Tw = width of trawl opening (meters), and (Dx1000) = distance fished (kilometers × 1000). The data basis for all calculations of biomass per square meter are included with the station data submitted to the National Oceanographic Data Center. Data from selected stations are included in the Appendix.

When laboratory examination revealed more than a single species in a field identification, the counts and weights of the species in question were arbitrarily expanded from the laboratory species ratio to encompass the entire catch of the trawl.

Limited feeding data were obtained from stomach examinations and recorded whenever time permitted. The frequency of occurrence method was used.

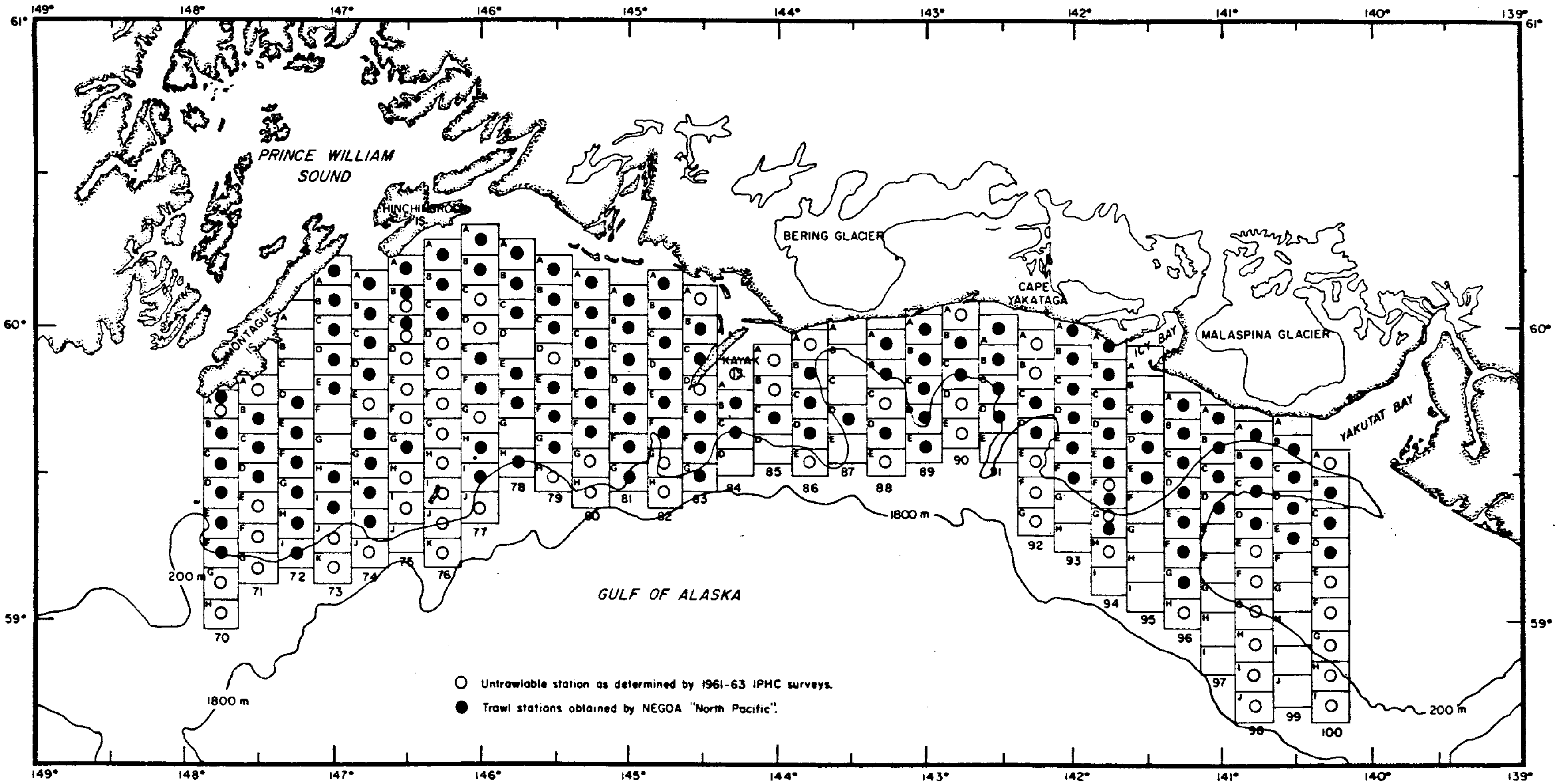

Figure 1.—Station grid established for the trawl survey on the continental shelf of the northeastern Gulf of Alaska, summer 1975

RESULTS

Distribution, Abundance, and Biomass

The benthic trawl program in the northeast Gulf of Alaska permitted the successful occupation of 133 stations. In 127.43 hours of trawling, 732.24 km were fished (8,933,328 m^2). The total epifaunal invertebrate biomass collected was 23,447.8 kg, yielding a mean of 2.6 g/m^2.

Taxonomic analysis delineated 9 phyla, 19 classes, 82 families, 124 genera, and 168 species of invertebrates. Three phyla—Mollusca, Arthropoda (Crustacea), and Echinodermata—dominated in species representation with 47, 42, and 36 species taken, respectively (Tables 1 and 2).

The same phyla also dominated in biomass: Arthropoda contributed 71.4% of the total; Echinodermata, 19.0%; and Mollusca, 4.6% (Tables 2 and 3).

Of the crustaceans, the families Majidae, Pandalidae, and Lithodidae were most important in terms of biomass. The snow crab *Chionoecetes bairdi* (family Majidae) contributed 66.2% of the total epifaunal invertebrate biomass and 92.6% of the arthropod biomass (Table 3). This species was widely distributed over the area sampled; the greatest density was found at Station 82-A[1] (see Appendix) where 892 kg of *C. bairdi* (1,984 individuals) were taken in a standard tow, or 19.8 g/m^2 (Fig. 2). The mean catch per unit effort (CPUE) for *C. bairdi* was 122 kg/hr (268 lb/hr).

Pink shrimp (*Pandalus borealis*) were also widespread, and accounted for 2.9% of the total invertebrate biomass (Table 3). The highest biomass was taken at Station 83-C, where 2.4 g/m^2 or 167.7 kg (370 lb) were taken in a standard tow (Fig. 3). The mean CPUE was 5.3 kg/hr (11.7 lb/hr).

Of the lithode crabs, the box crab (*Lopholithodes foraminatus*) was most abundant. This crab was the third most important crustacean by weight (Table 3). The greatest density was found at Station 86-D, where 55 of these crabs weighed 25.4 kg (56 lb), the equivalent of 0.3 g/m^2 (Fig. 4). The average CPUE of *L. foraminatus* was 0.19 kg/hr (2 lb/hr).

Four echinoderm species—a brittle star (*Ophiura sarsi*), two sea stars (*Ctenodiscus crispatus* and *Pycnopodia helianthoides*), and the heart urchin (*Brisaster townsendi*)—were found in large quantities (Table 3). The percent-weight composition of sea stars as a percentage of all echinoderms and all invertebrates was 35.3% and 6.7%, respectively (Table 2). Brittle stars (Ophiuroidea) were the second largest class of echinoderms collected,

[1] The data from 14 stations (74-C, 74-D, 80-B, 81-D, 82-A, 83-C, 83-E, 86-D, 89-A, 93-C, 94-A, 94-B, 97-C, 99-D) referred to in the text are compiled separately in the Appendix.

Table 1.—Invertebrates taken by trawl from the northeast Gulf of Alaska, 25 April–7 August 1975.

Phylum Porifera

unidentified species

Phylum Cnidaria
Class Hydrozoa
unidentified species
Class Scyphozoa
Family Pelagiidae
Chrysaora melanaster Brandt
Class Anthozoa
Subclass Alcyonaria
Eunephthya rubiformis (Pallas)
Family Primnoidae
Stylatula gracile (Gabb)
Family Pennatulidae
Ptilosarcus gurneyi (Gray)
Family Actiniidae
Tealia crassicornis (O. F. Müller)

Phylum Annelida
Class Polychaeta
Family Polynoidae
Arctonoe vittata (Grube)
Eunoe depressa Moore
Eunoe oerstedi Malmgren
Harmothoe multisetosa Moore
Hololepida magna Moore
Lepidonotus squamatus (Linnaeus)
Lepidonotus sp.
Polyeunoa tuta (Grube)
Family Polynodontidae
Peisidice aspera Johnson
Family Euphrosinidae
Euphrosine hortensis Moore
Family Syllidae
unidentified species
Family Nereidae
Ceratonereis paucidentata (Moore)
Ceratonereis sp.
Cheilonereis cyclurus (Harrington)
Nereis pelagica Linnaeus
Nereis vexillosa Grube
Nereis sp.
Family Nephtyidae
unidentified species
Family Glyceridae
Glycera sp.
Family Eunicidae
Eunice valens (Chamberlin)
Family Lumbrineridae
Lumbrineris similabris (Treadwell)

Table 1.—(continued)

Phylum Annelida (continued)
- Family Opheliidae
  - *Travisia pupa* Moore
- Family Sabellariidae
  - *Idanthyrsus armatus* Kinberg
- Family Terebellidae
  - *Amphitrite cirrata* O. F. Müller
- Family Sabellidae
  - *Euchone analis* (Kröyer)
- Family Serpulidae
  - *Crucigera irregularis* Bush
- Family Aphroditidae
  - *Aphrodita japonica* Marenzeller
  - *Aphrodita negligens* Moore
  - *Aphrodita* sp.
- Class Hirudinea
  - *Notostomobdella* sp.

Phylum Mollusca
- Class Polyplacophora
  - Family Mopaliidae
    - unidentified species
- Class Pelecypoda
  - Family Nuculanidae
    - *Nuculana fossa* Baird
  - Family Mytilidae
    - *Mytilus edulis* Linnaeus
    - *Musculus niger* (Gray)
    - *Modiolus modiolus* (Linnaeus)
  - Family Pectinidae
    - *Chlamys hastata hericia* (Gould)
    - *Pecten caurinus* Gould
    - *Delectopecten randolphi* (Dall)
  - Family Astartidae
    - *Astarte polaris* Dall
  - Family Carditidae
    - *Cyclocardia ventricosa* (Gould)
  - Family Cardiidae
    - *Clinocardium ciliatum* (Fabricius)
    - *Clinocardium fucanum* (Dall)
    - *Serripes groenlandicus* (Bruguière)
  - Family Veneridae
    - *Compsomyax subdiaphana* Carpenter
  - Family Mactridae
    - *Spisula polynyma* (Stimpson)
  - Family Myidae
    - unidentified species
  - Family Hiatellidae
    - *Hiatella arctica* (Linnaeus)

Table 1.—(continued)

Phylum Mollusca (continued)
- Family Teredinidae
  - *Bankia setacea* Tryon
- Family Lyonsiidae
  - unidentified species
- Class Gastropoda
  - Family Bathybembix
    - *Solariella obscura* (Couthouy)
    - *Lischkeia cidaris* (Carpenter)
  - Family Naticidae
    - *Natica clausa* Broderip and Sowerby
    - *Polinices monteronus* Dall
    - *Polinices lewisii* (Gould)
  - Family Cymatiidae
    - *Fusitriton oregonensis* (Redfield)
  - Family Muricidae
    - *Trophonopsis stuarti* (Smith)
  - Family Buccinidae
    - *Buccinum plectrum* Stimpson
    - *Beringius kennicotti* (Dall)
    - *Colus halli* (Dall)
    - *Morrisonella pacifica* (Dall)
    - *Neptunea lyrata* (Gmelin)
    - *Neptunea pribiloffensis* (Dall)
    - *Plicifusus* sp.
    - *Pyrulofusus harpa* (Mörch)
    - *Volutopsius filosus* Dall
  - Family Columbellidae
    - *Mitrella gouldi* (Carpenter)
  - Family Volutidae
    - *Arctomelon stearnsii* (Dall)
  - Family Turridae
    - *Oenopota* sp.
    - *Aforia circinata* (Dall)
  - Family Dorididae
    - unidentified species
  - Family Tritoniidae
    - *Tritonia exsulans* Bergh
    - *Tochuina tetraquetra* (Pallas)
  - Family Flabellinidae
    - *Flabellinopsis* sp.
- Class Cephalopoda
  - Family Sepiolidae
    - *Rossia pacifica* Berry
  - Family Gonatidae
    - *Gonatopsis borealis* Sasaki
    - *Gonatus magister* Berry
  - Family Octopodidae
    - *Octopus* sp.

Table 1.—(continued)

Phylum Arthropoda
  Class Crustacea
    Order Thoracica
      Family Lepadidae
        Lepas pectinata pacifica Henry
      Family Balanidae
        Balanus hesperius
        Balanus rostratus Hoek
        Balanus sp.
    Order Isopoda
      Family Aegidae
        Rocinela augustata Richardson
      Family Bopyridae
        Argeia pugettensis Dana
    Order Decapoda
      Family Pandalidae
        Pandalus borealis Kröyer
        Pandalus jordani Rathbun
        Pandalus montagui tridens Rathbun
        Pandalus platyceros Brandt
        Pandalus hypsinotus Brandt
        Pandalopsis dispar Rathbun
      Family Hippolytidae
        Spirontocaris lamellicornis (Dana)
        Spirontocaris arcuata Rathbun
        Eualus barbata (Rathbun)
        Eualus macrophthalma (Rathbun)
        Eualus suckleyi (Stimpson)
        Eualus pusiola (Kröyer)
      Family Crangonidae
        Crangon communis Rathbun
        Argis sp.
        Argis dentata (Rathbun)
        Argis ovifer (Rathbun)
        Argis alaskensis (Kingsley)
        Paracrangon echinata Dana
      Family Paguridae
        Pagurus ochotensis (Benedict)
        Pagurus aleuticus (Benedict)
        Pagurus kennerlyi (Stimpson)
        Pagurus confragosus (Benedict)
        Elassochirus tenuimanus (Dana)
        Elassochirus cavimanus (Miers)
        Labidochirus splendescens (Owen)
      Family Lithodidae
        Acantholithodes hispidus (Stimpson)
        Paralithodes camtschatica (Tilesius)
        Lopholithodes foraminatus (Stimpson)
        Rhinolithodes wosnessenskii Brandt
      Family Galatheidae
        Munida quadrispina Benedict

Table 1.—(continued)

Phylum Arthropoda (continued)	
Family Majiidae	
	Oregonia gracilis Dana
	Hyas lyratus Dana
	Chionoecetes bairdi Rathbun
	Chorilia longipes Dana
Family Cancridae	
	Cancer magister Dana
	Cancer oregonensis (Dana)
Phylum Ectoprocta	
	unidentified species
Phylum Brachiopoda	
Class Articulata	
Family Cancellothyrididae	
	Terebratulina unguicula Carpenter
Family Dallinidae	
	Laqueus californianus Koch
	Terebratalia transversa (Sowerby)
Phylum Echinodermata	
Class Asteroidea	
Family Asteropidae	
	Dermasterias imbricata (Grube)
Family Astropectinidae	
	Dipsacaster borealis Fisher
Family Benthopectinidae	
	Luidiaster dawsoni (Verrill)
	Nearchaster pedicellaris (Fisher)
Family Goniasteridae	
	Ceramaster patagonicus (Sladen)
	Hippasterias spinosa Verrill
	Mediaster aequalis Stimpson
	Pseudarchaster parelii (Düben and Koren)
Family Luiidae	
	Luidia foliolata Grube
Family Porcellanasteridae	
	Ctenodiscus crispatus (Retzius)
Family Echinasteridae	
	Henricia aspera Fisher
	Henricia sp.
	Poraniopsis inflata Fisher
Family Pterasteridae	
	Diplopteraster multipes (Sars)
	Pteraster tesselatus
Family Solasteridae	
	Crossaster borealis (Fisher)
	Crossaster papposus (Linnaeus)
	Lophaster furcilliger Fisher
	Lophaster furcilliger vexator Fisher
	Solaster dawsoni Verrill

Table 1.—(continued)

- Phylum Echinodermata (continued)
        - Family Asteridae
            - *Leptasterias* sp.
            - *Lethasterias nanimensis* (Verrill)
            - *Stylasterias forreri* (de Loriol)
            - *Pycnopodia helianthoides* (Brandt)
    - Class Echinoidea
        - Family Schizasteridae
            - *Brisaster townsendi*
        - Family Strongylocentrotidae
            - *Allocentrotus fragilis* (Jackson)
            - *Strongylocentrotus droebachiensis* (O. F. Müller)
    - Class Ophiuroidea
        - Family Amphiuridae
            - *Unioplus macraspis* (Clark)
        - Family Gorgonocephalidae
            - *Gorgonocephalus caryi* (Lyman)
        - Family Ophiactidae
            - *Ophiopholis aculeata* (Linnaeus)
        - Family Ophiuridae
            - *Amphiophiura ponderosa* (Lyman)
            - *Ophiura sarsi* Lütkin
    - Class Holothuroidea
        - Family Molpadiidae
            - *Molpadia* sp.
        - Family Cucumariidae
            - unidentified species
        - Family Psolidae
            - *Psolus chitinoides* H. L. Clark
    - Class Crinoidea
            - unidentified species

- Phylum Chordata
    - Class Phlebobranchia
        - Family Rhodosomatiidae
            - *Chelyosoma columbianum* Huntsman
    - Class Stolidobranchia
        - Family Pyuridae
            - *Halocynthia helgendorfi igaboja* Oka

Table 2.—Miscellaneous data for invertebrates collected by commercial trawl in the northeast Gulf of Alaska, 25 April–7 August 1975.

Phylum	Number of species	% of species	weight (kg)	% total weight
Mollusca	47	28.0	1,089.2	4.6
Arthropoda (Crustacea)	42	25.0	16,748.6	71.4
Echinodermata	36	21.4	4,462.0	19.0
Annelida	30	17.8	2.8	<0.1
Cnidaria	6	3.6	513.4	2.2
Brachiopoda	3	1.8	49.8	0.2
Chordata (Tunicata)	2	1.2	322.2	1.4
Ectoprocta	1	0.6	3.7	<0.1
Porifera	1	0.6	256.2	1.0
TOTAL	168	100.0	23,447.9	100.0

Phylum	Subgroup	Weight (kg)	% of phylum weight	% total weight
Arthropoda	Decapoda	16,692.60	99.7	71.4
Echinodermata	Asteroidea	1,575.99	35.3	6.7
	Ophiuroidea	1,492.81	33.5	6.4
	Holothuroidea	709.60	15.9	3.0
	Echinoidea	644.15	14.4	2.7
Mollusca	Gastropoda	557.70	51.2	2.4
	Pelecypoda	488.36	44.8	2.1
	Cephalopoda	36.91	3.4	0.1

Table 3.—Percentage composition by weight of leading invertebrate species collected during northeast Gulf of Alaska trawling investigations, 25 April–7 August 1975.

Phyla	% of total weight	Leading species	Average weight per individual	% of weight within phylum	% of weight from all phyla
Arthropoda	71.4	*Chionoecetes bairdi*	454 g	92.6	66.2
		Pandalus borealis	8 g	4.0	2.9
		Lopholithodes foraminatus	420 g	0.6	0.4
				97.2	69.5
Echinodermata	19.0	*Ophiura sarsi*	6 g	23.2	4.4
		Ctenodiscus crispatus	10 g	15.7	2.9
		Brisaster townsendi	10 g	11.2	2.1
		Pycnopodia helianthoides	482 g	10.3	2.0
				60.4	11.4
Mollusca	4.6	*Pecten caurinus*	350 g	43.4	2.0
		Neptunea lyrata	180 g	12.5	0.6
		Fusitriton oregonensis	100 g	11.5	0.5
	95.0			67.4	3.1

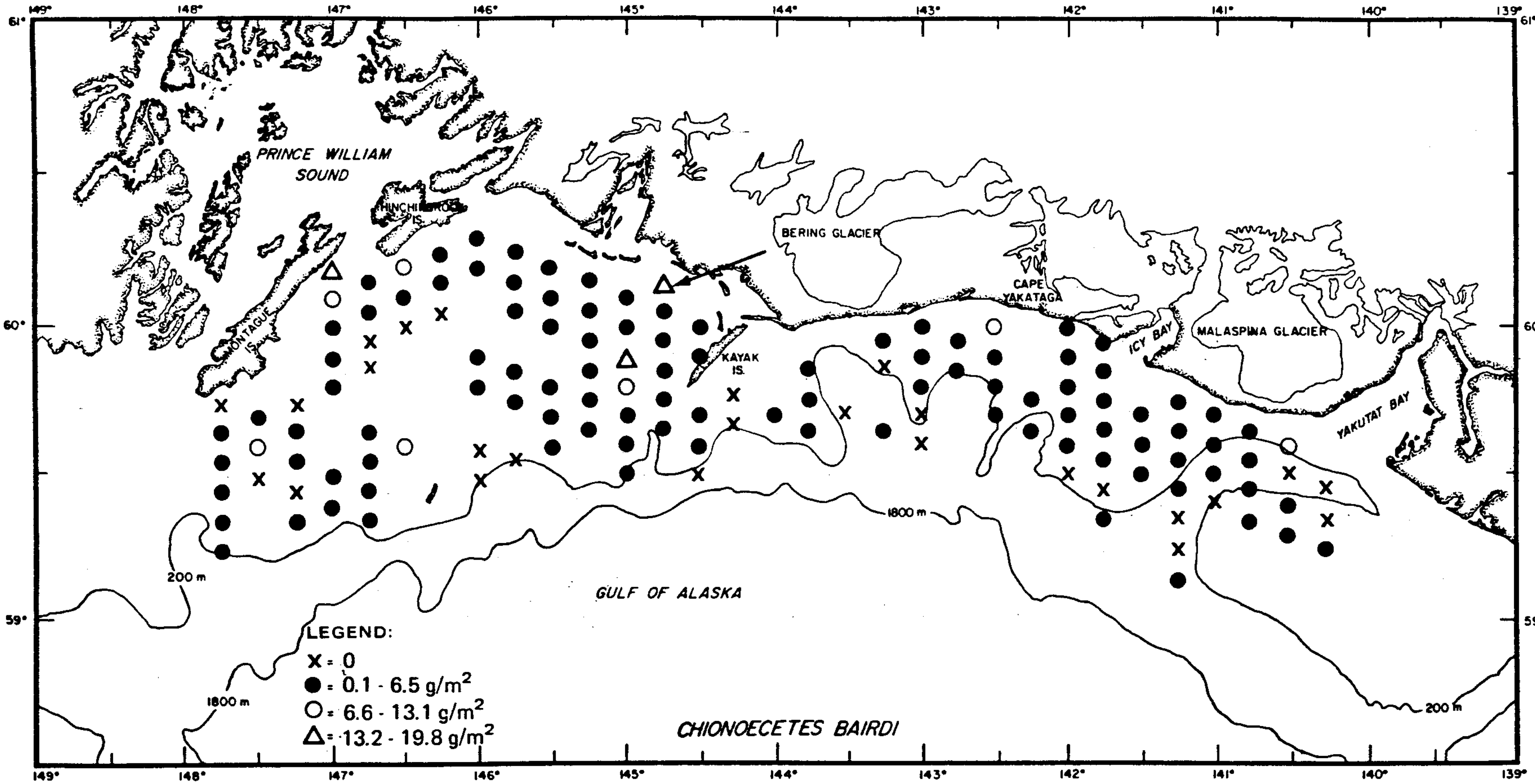

Figure 2.—Snow crab (*Chionoecetes bairdi*) distribution and abundance, northeastern Gulf of Alaska trawl survey, summer 1975. Arrow indicates highest density of *C. bairdi.*

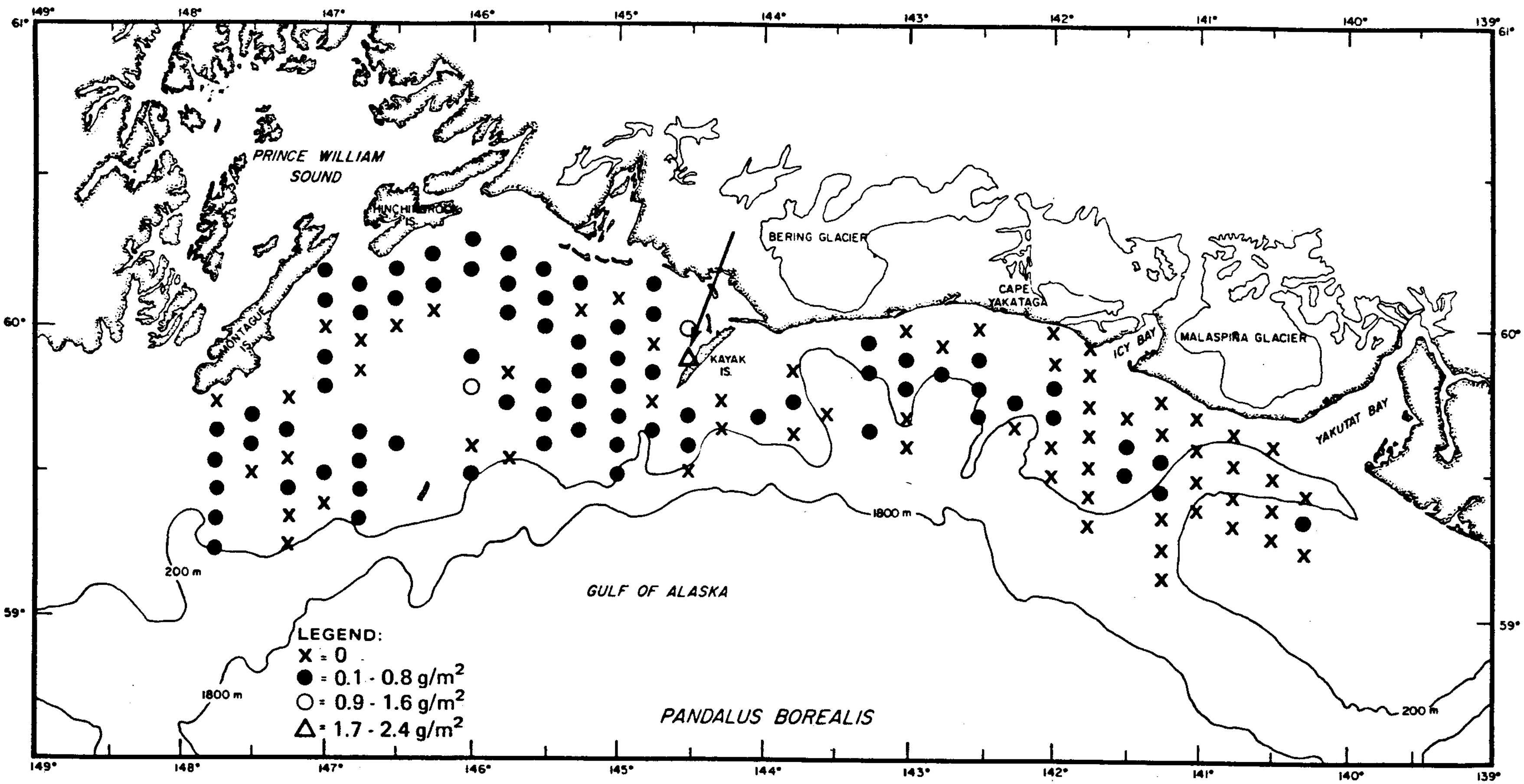

Figure 3.—Pink shrimp (*Pandalus borealis*) distribution and abundance, northeastern Gulf of Alaska trawl survey, summer 1975. Arrow indicates highest density of *P. borealis*.

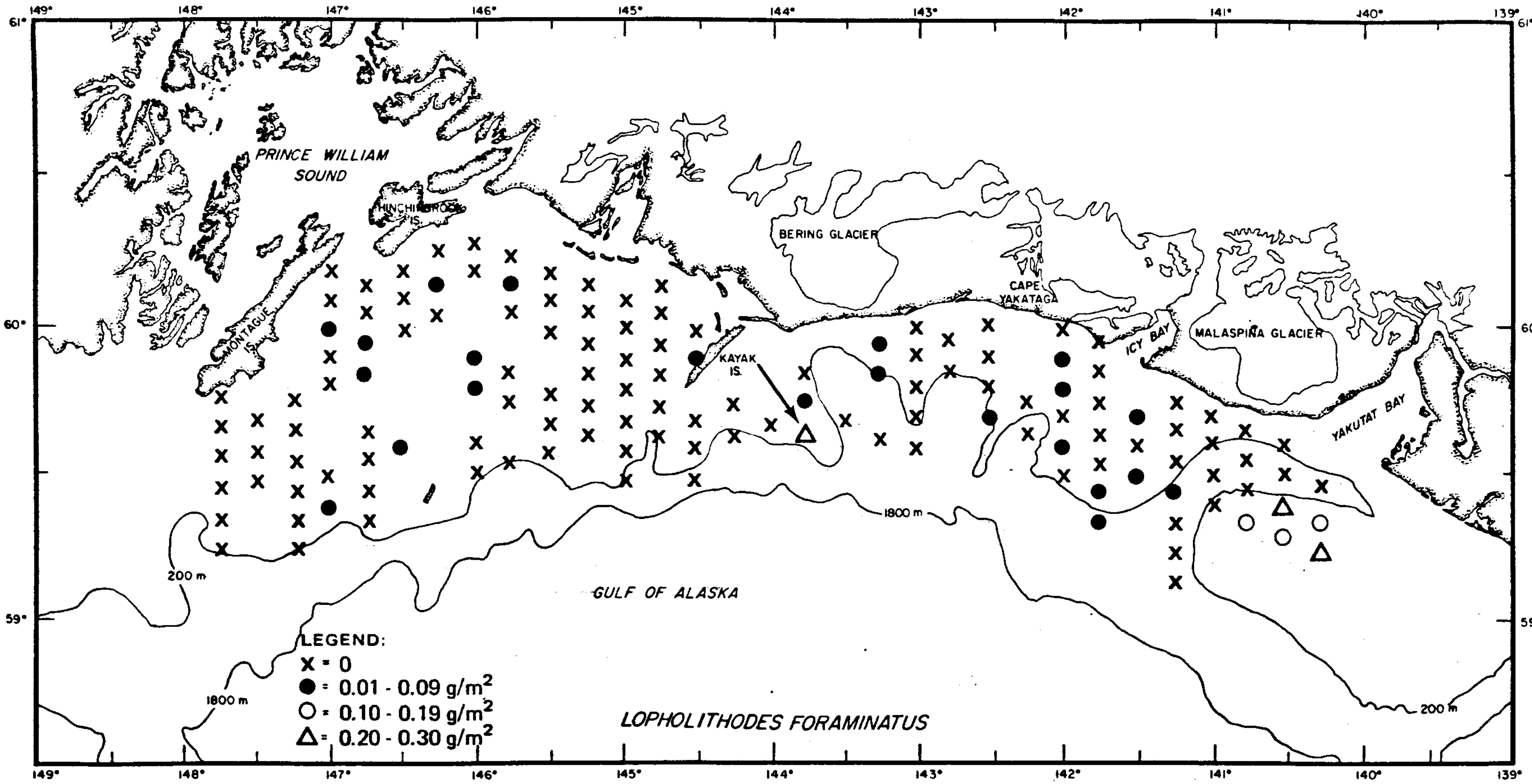

Figure 4.—Box crab (*Lopholithodes foraminatus*) distribution and abundance, northeastern Gulf of Alaska trawl survey, summer 1975. Arrow indicates highest density of *L. foraminatus*.

accounting for 33.5% of the echinoderm biomass and 6.4% of the total invertebrate biomass (Table 2). Sea cucumbers (Holothuroidea) and sea urchins and sand dollars (Echinoidea) comprised 15.9% and 14.4% of the echinoderm biomass, respectively (Table 2). *Ophiura sarsi* was the most abundant echinoderm, comprising 23.2% of the echinoderm biomass and 4.4% of the total invertebrate biomass. The largest catch of this brittle star, at Station 81-D, was 750 kg (1,653 lb) in a 1-hour tow, equivalent to 11.4 g/m² (Fig. 5). The average CPUE was 8.1 kg/hr (18 lb/hr). The greatest biomass for the small sea star *Ctenodiscus crispatus* was found at Station 80-B, with 0.8 g/m² or 55.8 kg (123 lb) taken per hour (Fig. 6). The average CPUE of this species was 5.5 kg/hr (12 lb/hr). *Pycnopodia helianthoides* was another widely distributed sea star. At Station 93-C, 170 of these large sea stars (average weight 0.453 kg) were taken (Fig. 7). At this station the biomass of *Pycnopodia* was 1.3 g/m² or 85.5 kg/hr (188 lb/hr). The average CPUE was 3.6 kg/hr (8 lb/hr). The heart urchin (*Brisaster townsendi*) accounted for approximately 11% of the echinoderm biomass taken in the trawl survey (Table 3). Station 97-C yielded the largest catch of this urchin, at 2.9 g/m² or 213 kg/hr (469 lb/hr); this represented 21,272 urchins collected during the tow (Fig. 8). The average CPUE was 3.9 kg/hr (8.6 lb/hr).

Although sea cucumbers (family Cucumariidae) were found at only seven stations, they ranked high in echinoderm weight composition. For example, the tow at Station 99-D contained approximately 2,600 sea cucumbers weighing 650 kg (1,433 lb), equivalent to 9.6 g/m² (Fig. 9). The average CPUE was 5.3 kg/hr (11.6 lb/hr).

Of the 47 species of molluscs collected, the scallop *Pecten* (=*Patinopecten*) *caurinus* was dominant. This large bivalve accounted for 2% of the total epifaunal invertebrate biomass and 43% of the molluscan biomass (Table 3). Station 83-E provided the largest catch of scallops, with 1.7 g/m² or 116 kg (370 lb) per standard tow (Fig. 10). The average CPUE was 3.7 kg/hr (8 lb/hr).

Snails of the family Buccinidae were the dominant gastropods. *Neptunea lyrata* was the most abundant. The greatest biomass of *N. lyrata* was taken at Station 89-A (Fig. 11), where 32.4 kg/hr (71 lb/hr) or 0.4 g/m² were taken. The average CPUE for this snail was 1.0 kg/hr (2 lb/hr). Other common buccinid snails were *Pyrulofusus harpa* and *Colus halli.*

The Oregon triton (*Fusitriton oregonensis*), family Cymatiidae, was another widespread and important gastropod (Fig. 12). It was most abundant at Station 74-C, where the density was 0.4 g/m² or 4.5 kg (10 lb) taken in a 35-minute (nonstandard) tow. The average CPUE for this snail was 1.0 kg/hr (2 lb/hr).

Two areas of biological interest in terms of species composition and diversity encompassed Stations 74-C and D, and Stations 94-A and B (Fig. 1). Stations 74-C and D contained seven species of fishes (*Hippoglossus stenolepis, Bathymaster signatus,*

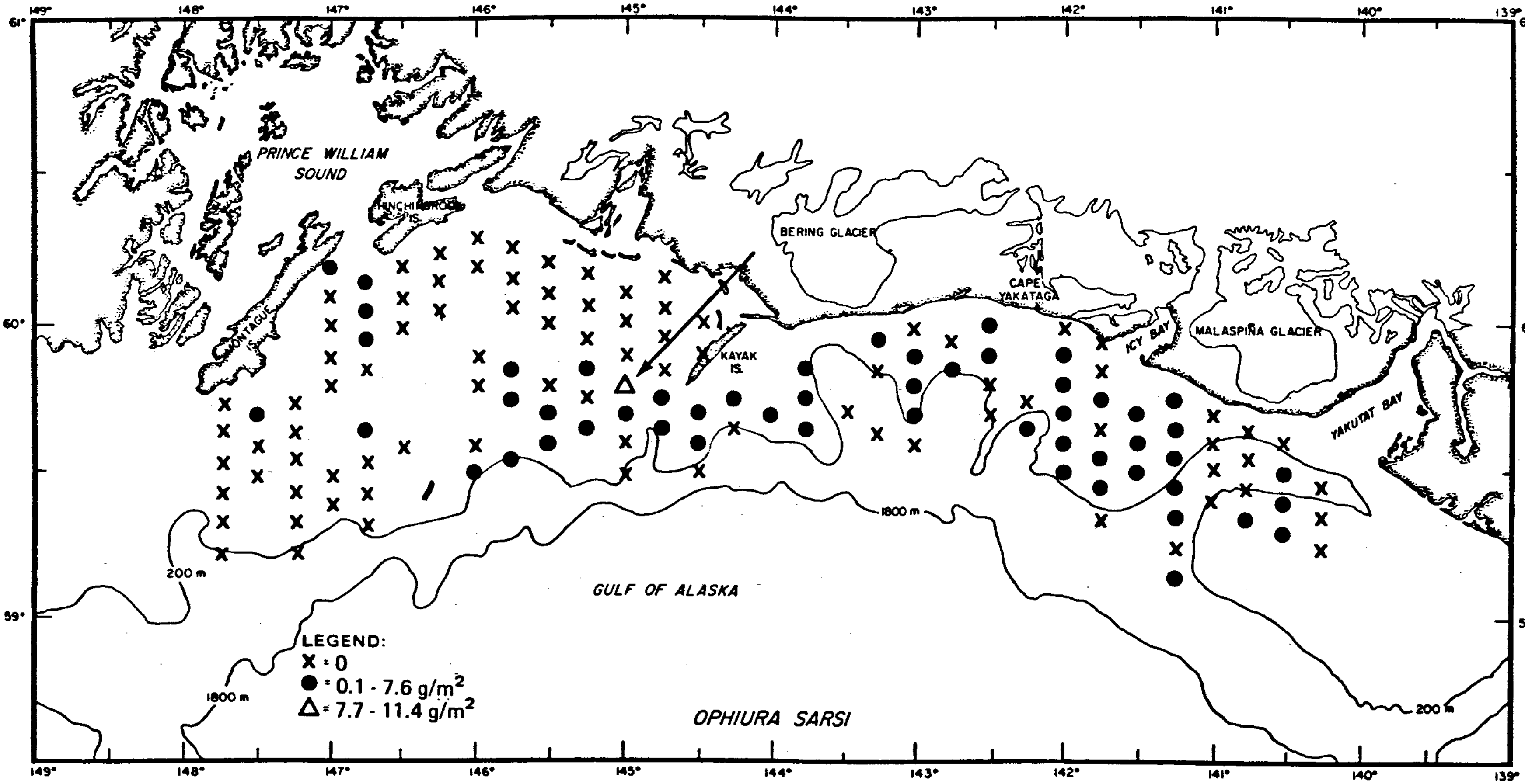

Figure 5.—Brittle star (*Ophiura sarsi*) distribution and abundance, northeastern Gulf of Alaska trawl survey, summer 1975. Arrow indicates highest density of *O. sarsi*.

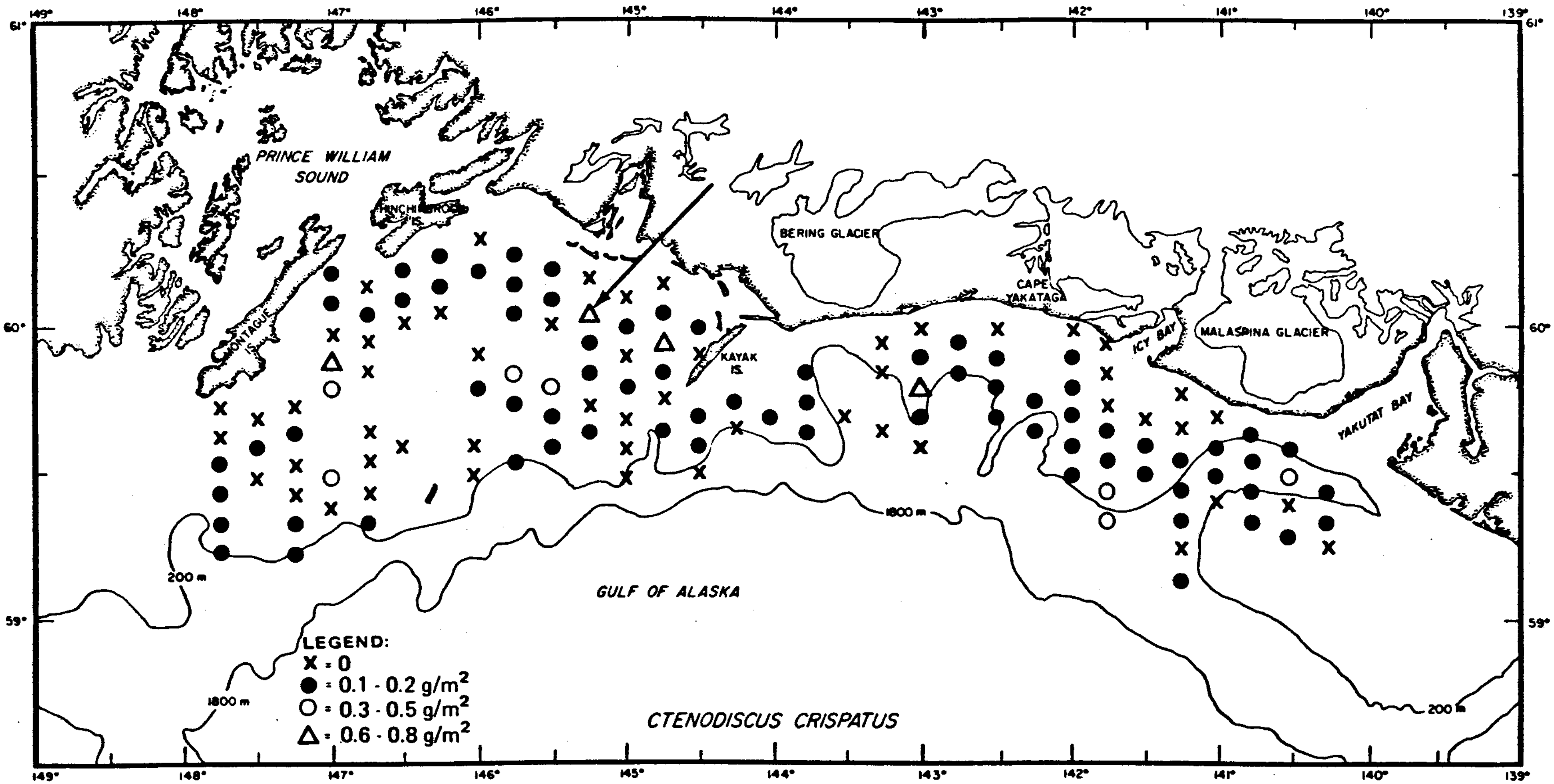

Figure 6.—Sea star (*Ctenodiscus crispatus*) distribution and abundance, northeastern Gulf of Alaska trawl survey, summer 1975. Arrow indicates highest density of *C. crispatus.*

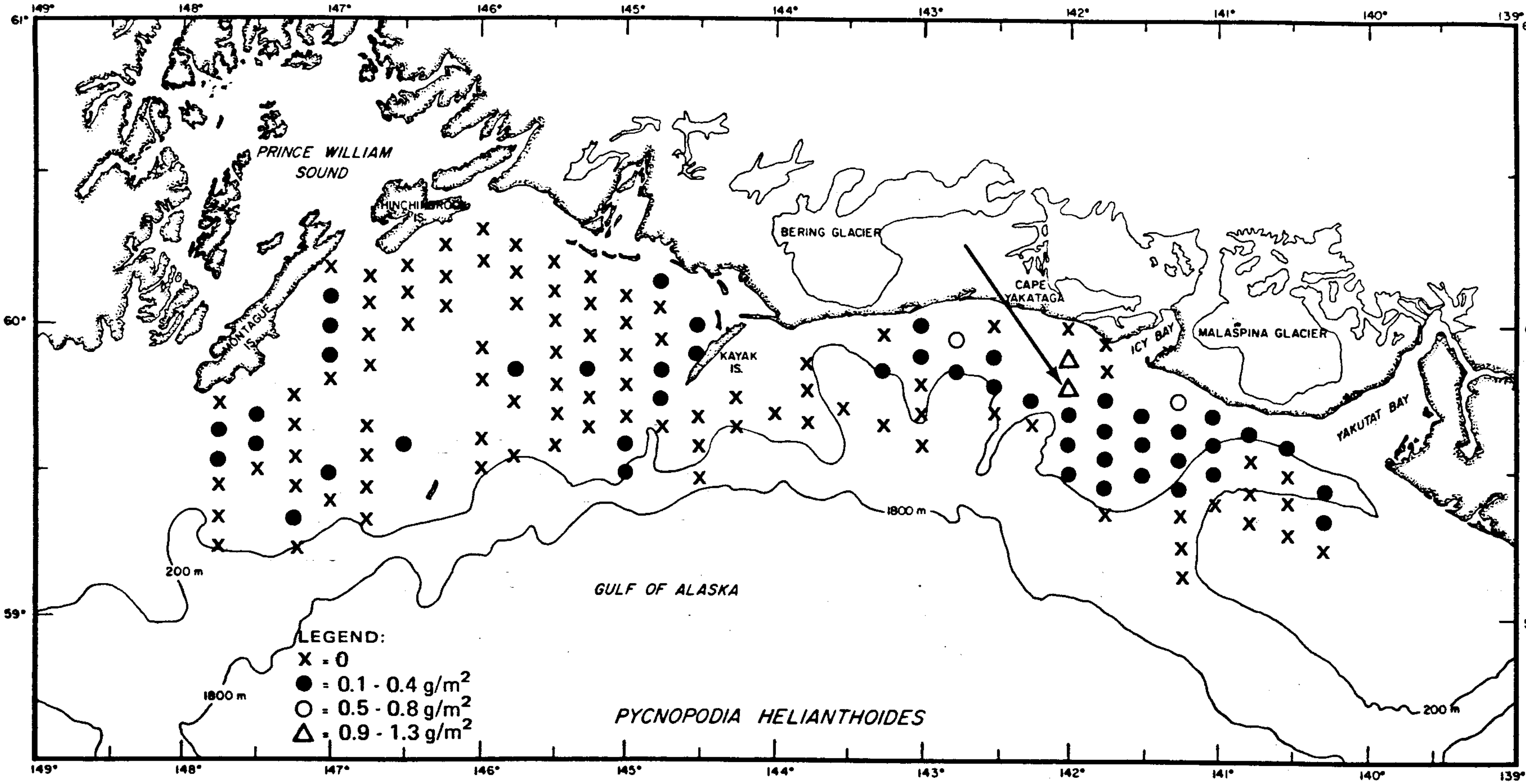

Figure 7.—Sea star (*Pycnopodia helianthoides*) distribution and abundance, northeastern Gulf of Alaska trawl survey, summer 1975. Arrow indicates highest density of *P. helianthoides*.

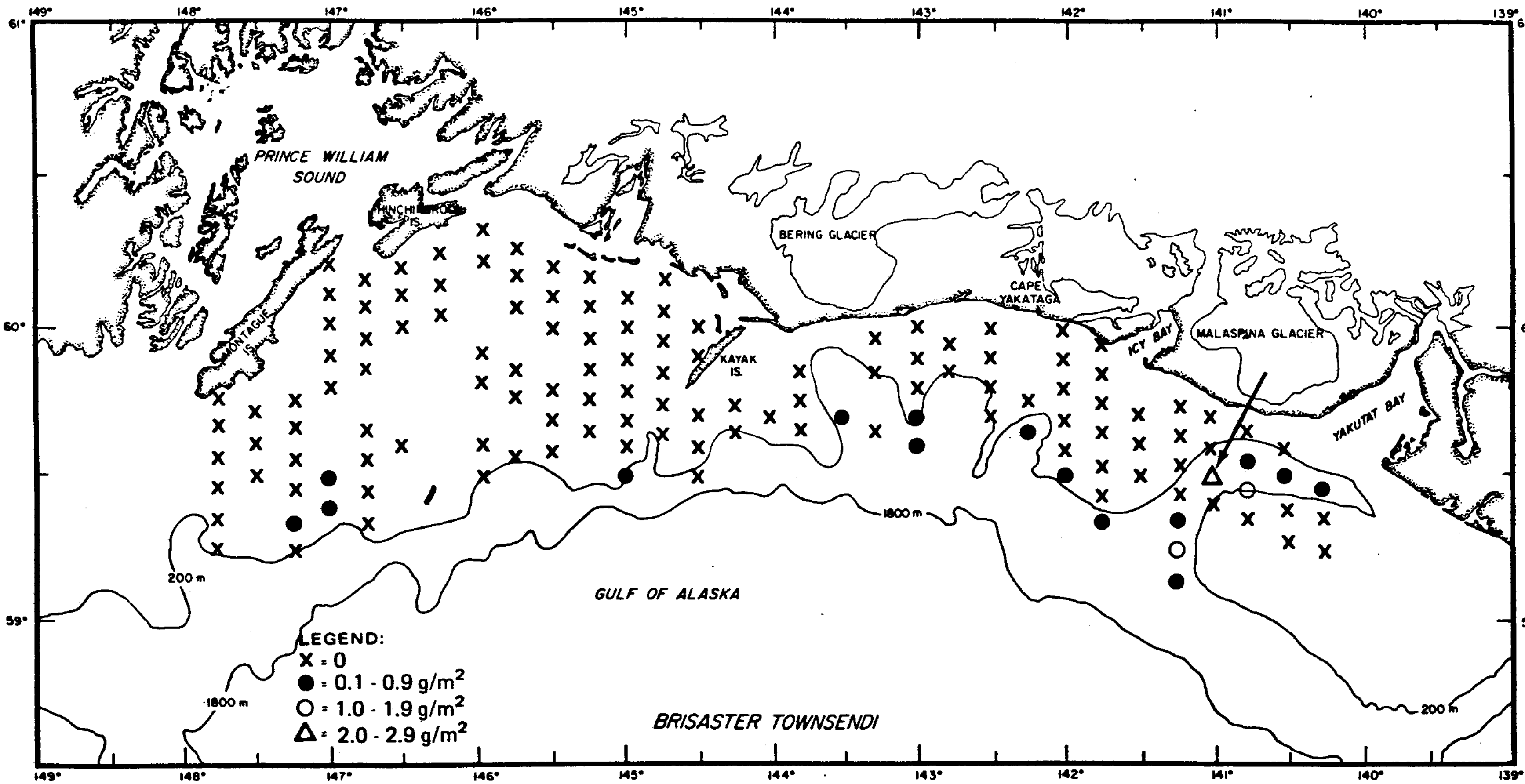

Figure 8.—Heart urchin (*Brisaster townsendi*) distribution and abundance, northeastern Gulf of Alaska trawl survey, summer 1975. Arrow indicates highest density of *B. townsendi.*

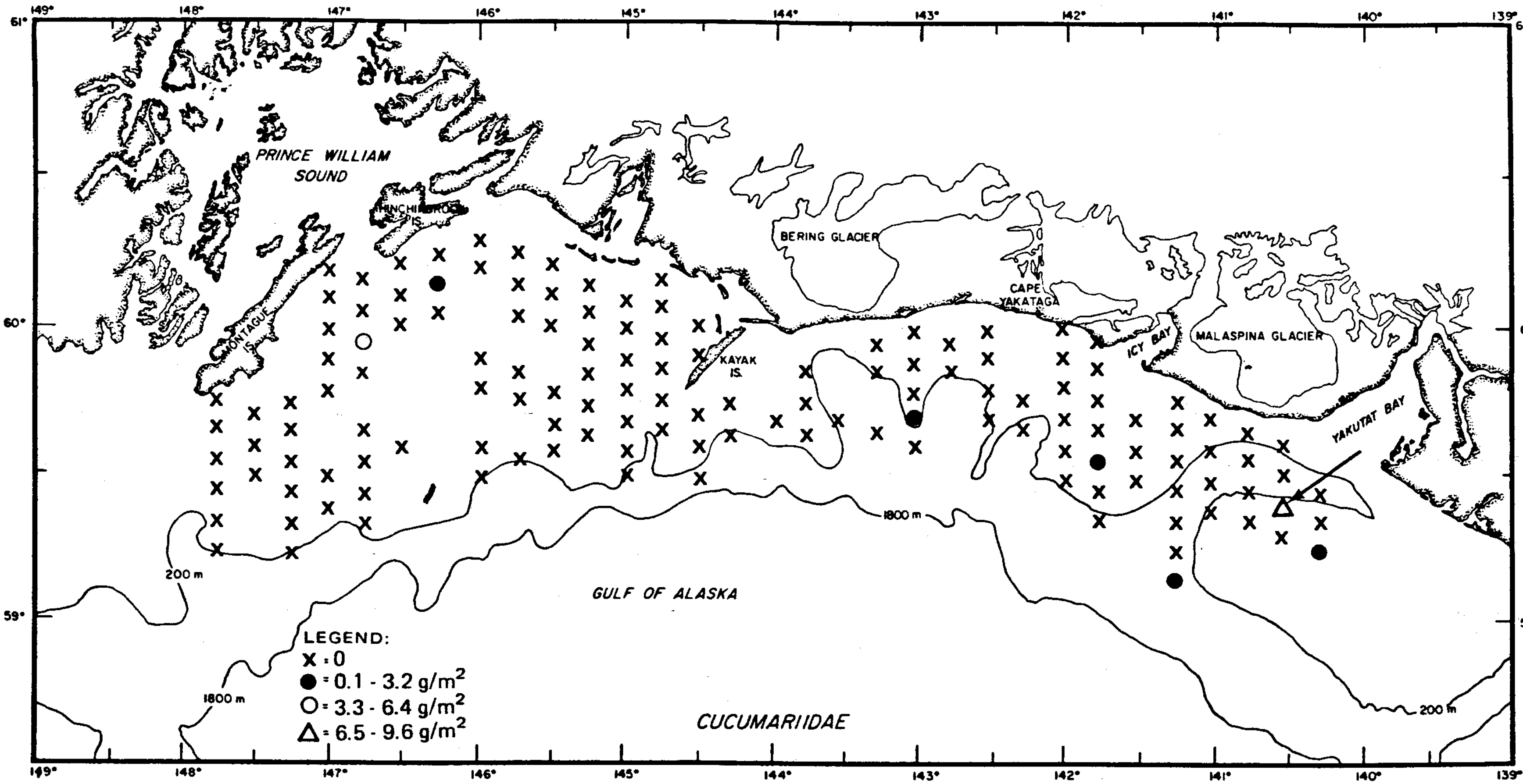

Figure 9.—Sea cucumber (Family Cucumariidae) distribution and abundance, northeastern Gulf of Alaska trawl survey, summer 1975. Arrow indicates highest density of Cucumariidae.

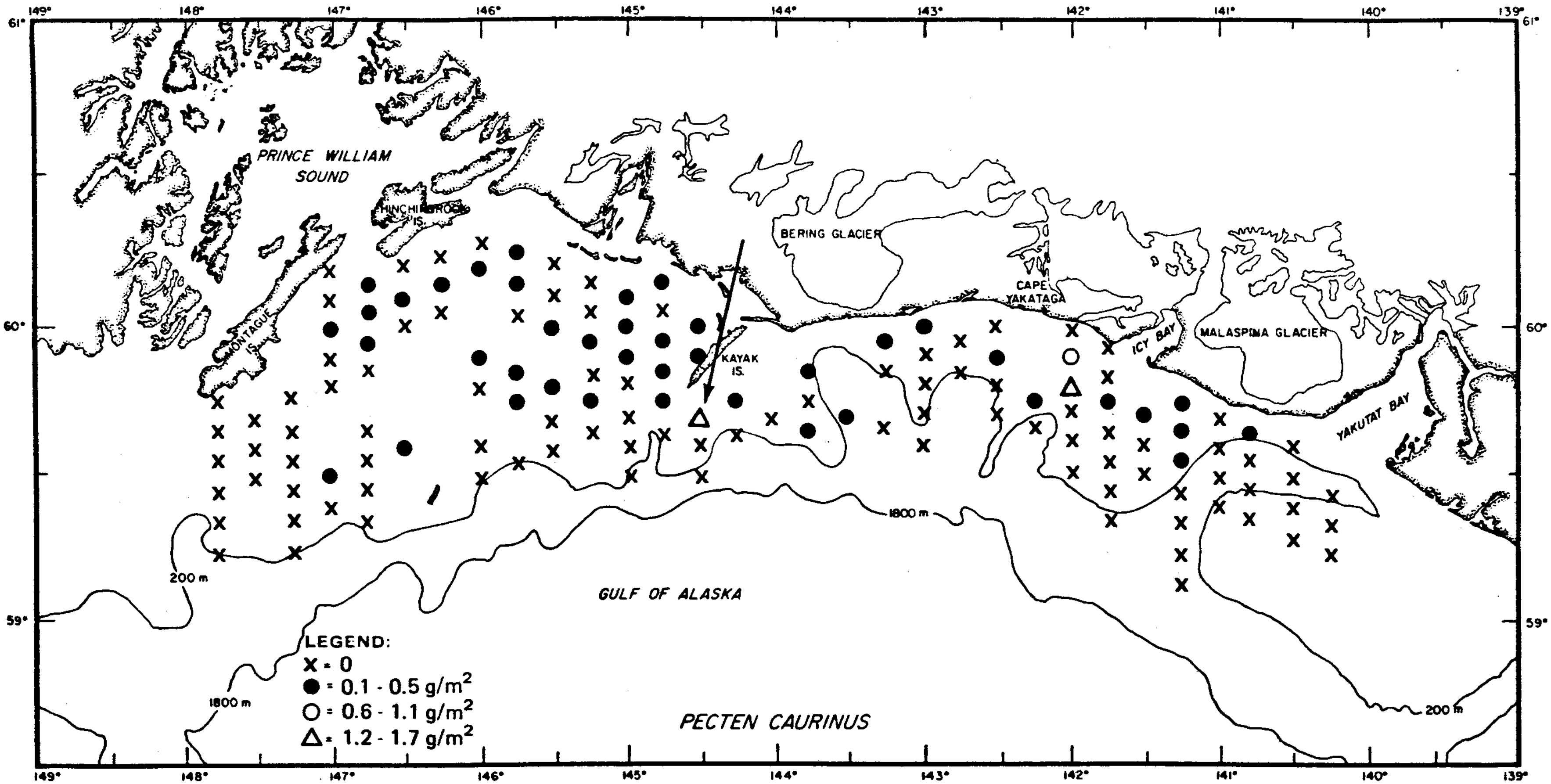

Figure 10.—Scallop (*Pecten caurinus*) distribution and abundance, northeastern Gulf of Alaska trawl survey, summer 1975. Arrow indicates highest density of *P. caurinus*.

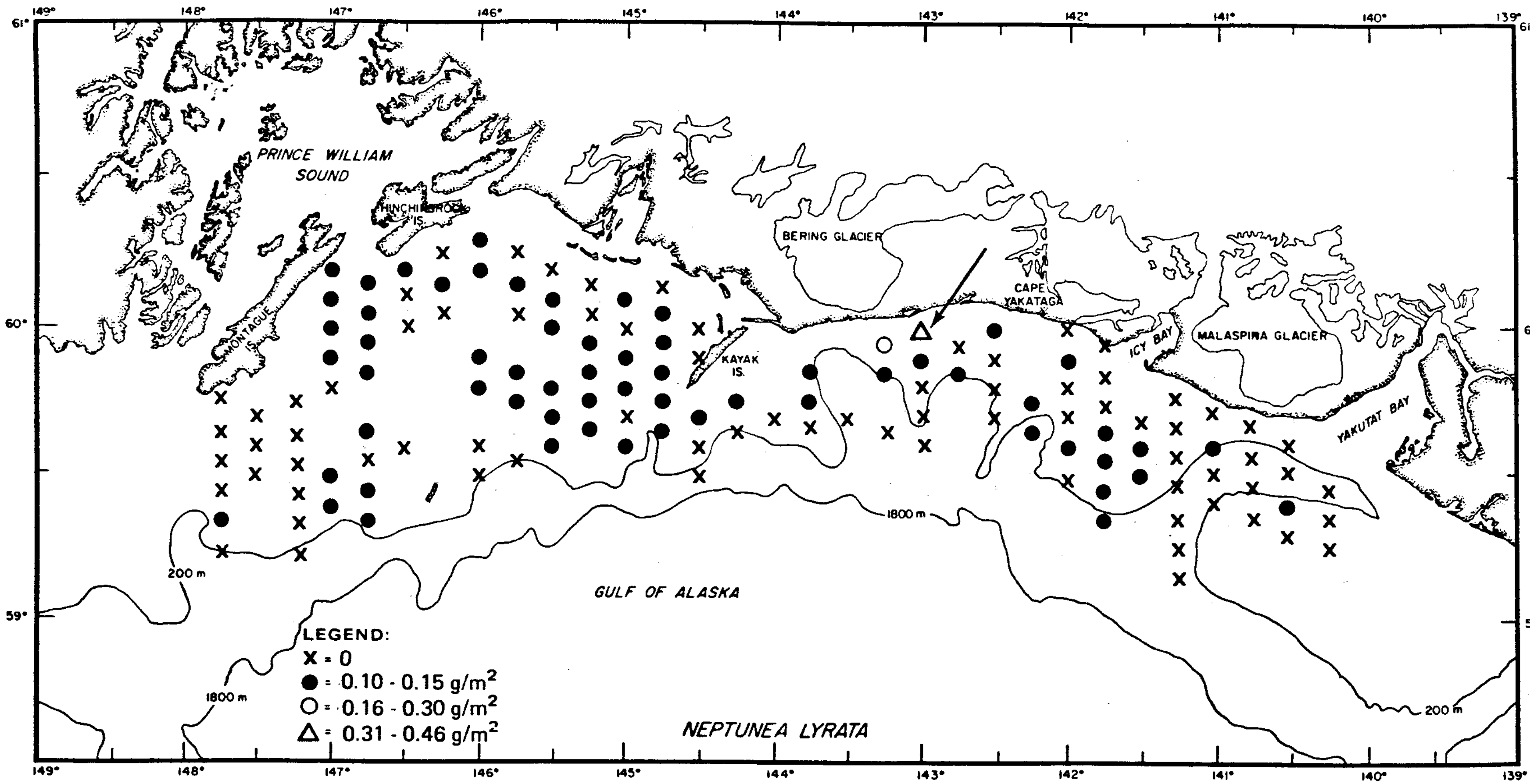

Figure 11.—Snail (*Neptunea lyrata*) distribution and abundance, northeastern Gulf of Alaska trawl survey, summer 1975. Arrow indicates highest density of *N. lyrata*.

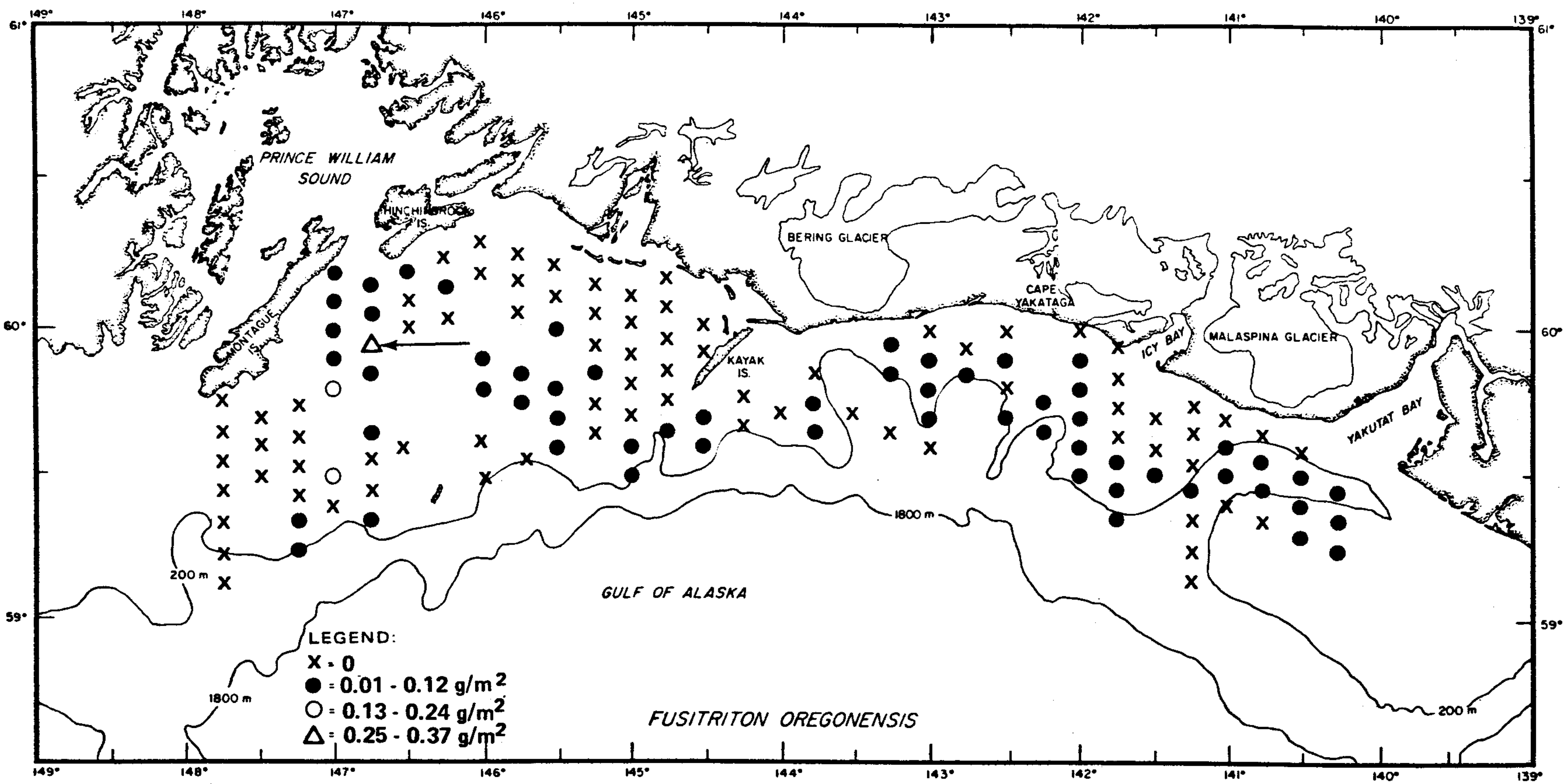

Figure 12.—Oregon triton (*Fusitriton oregonensis*) distribution and abundance, northeastern Gulf of Alaska, summer 1975. Arrow indicates highest density of *F. oregonensis*.

Lepidopsetta bilineata, Gadus macrocephalus, Hemilepidotus jordani, Atheresthes stomias, and *Glyptocephalus zachirus*), and had the highest diversity of invertebrates of all of the stations sampled. Crustaceans (14 species), echinoderms (13 species), and molluscs (13 species) made up 85% of the 47 species found there. The biomass of the ascidian *Halocynthia helgendorfi igaboja* at Station 74-C was 4.5 g/m^2 or 419.8 kg (925 lb) taken per hour. The Pacific halibut, *Hippoglossus stenolepis,* dominated the fish catch at Station 74-C; 1,299 kg (3,084 lb) were taken per hour, and each fish averaged 18.5 kg (41 lb). Stations 94-A and B, off Icy Bay, were characterized by an abundance of three species of fishes (*Platichthys stellatus, Theragra chalcogramma,* and *Isopsetta isolepis*), and the near-absence of epifaunal invertebrates. Although the number of fish species was low, biomass was high. At Station 94-B, 4,309 kg (9,499 lb) of fish were taken in the 1-hour tow.

Feeding Observations

Limited observations on the food habits of three species of sea stars and two species of flatfishes were made in the study area (Table 4).

The forcipulate sea star *Pycnopodia helianthoides,* a predatory echinoderm, was the most commonly encountered member of the family Asteridae. We examined 86 specimens for feeding habits; 69 (80.2%) had been feeding. By frequency of occurrence, the brittle star *Ophiura sarsi* was the dominant prey species found in 39.1% of the *Pycnopodia* stomachs examined (Table 4). The sea star *Ctenodiscus crispatus* occurred in 18.8% of the stomachs examined, and was second in importance as a prey species. Seventy-eight percent of the stations at which *Pycnopodia* was found also contained *C. crispatus* and/or *O. sarsi.* Other prey consumed by *Pycnopodia,* in order of dimishing frequency of occurrence, were the gastropods *Colus halli, Mitrella gouldi, Solariella obscura, Oenopota* sp., and *Natica clausa,* and the pelecypods *Serripes groenlandicus* and *Clinocardium ciliatum.*

Ctenodiscus crispatus, a non-selective deposit feeder, was typically found with its stomach full of sediment.

Three specimens of *Luidia foliolata,* a moderately sized (to 12 inches in diameter) sea star, were examined. The brittle star *Ophiura sarsi* and an unidentified polychaetous annelid were found in the stomachs of *Luidia. Ophiura sarsi* was also found in the stomach of the rose star (*Crossaster papposus*).

Starry flounders (*Platichthys stellatus*) dominated the catch off Icy Bay (Stations 94-A and B) (Fig. 1). The stomachs of 30 of them were examined. All of the starry flounders had been feeding heavily on three species of clams: *Yoldia seminuda, Siliqua alta,* and *Macoma dexiosttera.* All stomachs were full.

Table 4.—Stomach contents of selected epifaunal invertebrates and fishes from the northeast Gulf of Alaska, 25 April–7 August 1975.

Predator		Percent frequency of occurrence: % of feeding fishes	% of total fishes
Pycnopodia helianthoides (twenty-rayed star)			
Stomachs examined:	86		
Stomachs with food:	69	—	80.2
Stomach contents:	*Ophiura sarsi* (27)	39.1	31.4
	Ctenodiscus crispatus (13)	18.8	15.1
	Natica clausa (5)	7.2	5.8
	Colus halli (3)	4.3	3.5
	Cardiidae (3)	4.3	3.5
	Mitrella gouldi (3)	4.3	3.5
	Sediment (3)	4.3	3.5
	Buccinum plectrum (1)	1.4	1.2
	Solariella obscura (1)	1.4	1.2
	Oenopota sp. (1)	1.4	1.2
	Serripes groenlandicus (1)	1.4	1.2
	Clinocardium ciliatum (1)	1.4	1.2
	Lyonsiidae (1)	1.4	1.2
	Mediaster aequalis (1)	1.4	1.2
	Gorgonocephalus caryi (1)	1.4	1.2
	Unidentified gastropoda (1)	1.4	1.2
	Unidentified pelecypoda (1)	1.4	1.2
	Unidentified ophiuroidea (1)	1.4	1.2
Luidia foliolata (sea star)			
Stomachs examined:	3		
Only stomachs with food recorded			
Stomach contents:	*Ophiura sarsi* (2)	66.6	66.6
	Unidentified polychaeta (1)	33.3	33.3
Crossaster papposus (rose star)			
Stomachs examined:	1		
Only stomachs with food recorded			
Stomach contents:	*Ophiura sarsi*	100	100
Platichthys stellatus (starry flounder)			
Stomachs examined:	30		
Stomachs with food:	30		100
Stomach contents:	*Yoldia seminuda* (30)	100	100
	Siliqua sloati (30)	100	100
	Macoma dexiosttera (30)	100	100
Hippoglossoides elassodon (flathead sole)			
Stomachs examined:	2		
Stomachs with food:	2		100
Stomach contents:	*Ophiura sarsi*	100	100

Another common flatfish in NEGOA, the flathead sole (*Hippoglossoides elassodon*), was feeding on *Ophiura sarsi*.

Pollutants Taken by Trawl

Pollutants were recorded on the first two legs of the MV *North Pacific* cruise, which covered an area from Montague Island to Yakutat Bay. Of 58 stations, 33 (57%) contained debris which consisted primarily of plastic materials such as brown and green trash bags, pieces of clear plastic (bait wrappers), and plastic binding straps. Numerous plastics of Japanese or Korean origin were found. Other debris included tarred paper, bottles, a steel cable, rubber gloves, a rubber tire, and two derelict snow crab pots. The high frequency of occurrence of debris within the surveyed area may give some indication of the amount of pollution throughout the North Pacific (Jewett 1976).

DISCUSSION

This investigation represents the first intensive qualitative and quantitative study of the epifaunal invertebrates of the northeast Gulf of Alaska. Hitz and Rathjen (1965) surveyed bottomfishes and invertebrates of the continental shelf in the NEGOA; however, invertebrates were a secondary interest. Only major invertebrate species and/or groups were recorded. Additional data on commercially important shellfish species can be found in Ronholt et al. (1976).

The mean estimate of biomass, 2.6 g/m^2, for the northeast Gulf of Alaska is similar to estimates of 3.3 g/m^2 for the inner portion ($<$80 m) and 4.9 g/m^2 for the outer portion (mainly 80–400 m) of the continental shelf of the southeastern Bering Sea (Feder et al. 1978). Benthic trawl studies of Norton Sound and the Chukchi Sea–Kotzebue Sound area yielded biomass estimates of 3.7 g/m^2 and 3.3 g/m^2, respectively (Feder and Jewett 1978). Benthic investigations in NEGOA by Feder and Matheke (1979) provide biomass estimates from grab samples for infauna and small epifauna. The lowest value, 7 g/m^2, and the highest value, 638 g/m^2, differ from our estimates for NEGOA epifauna. The reason for the difference is the type of gear used. Use of a commercial bottom trawl results in the loss of many small epibenthic species, and does not usually collect infauna, both of which are important components of benthic biomass. Therefore, a more accurate estimate of benthic standing stock will always be gained by combining both grab and trawl values.

The OCSEAP trawl surveys in the southeastern Bering Sea and Norton Sound–southeastern Chukchi Sea–Kotzebue Sound areas provided extensive information on epifauna that can be compared with data from NEGOA (Jewett and Feder 1976; Ronholt et al. 1976; Feder and Jewett 1978). The southeastern Bering Sea exhibited greater epifaunal diversity (233 species) than NEGOA (168 species) and Norton Sound–Chukchi Sea–Kotzebue Sound (187 species). The northeast Gulf of Alaska epifaunal invertebrate biomass was dominated by Arthropoda (71.4%), Echinodermata (19.0%), and Mollusca (4.6%). The biomass in the southeastern Bering Sea stations that were less than 80 m in depth was likewise dominated by Arthropoda (58.0%), Echinodermata (22.0%), amd Mollusca (6.5%) (Feder et al. 1978). At southeastern Bering Sea stations between 80 and 400 m, the biomass was also dominated by Arthropoda (66.9%), Echinodermata (11.1%), and Mollusca (4.6%) (Feder et al 1978). In contrast, the Norton Sound region was dominated by Echinodermata (80.3%), Arthropoda (9.6%), and Mollusca (4.4%), and the Chukchi Sea–Kotzebue Sound region was dominated by Echinodermata (59.9%), Mollusca (12.8%), and Arthropoda (12.5%) (Feder and Jewett 1978). In general, arthropod biomass decreased toward higher latitudes and echinoderm biomass increased.

The highest biomass values for snow crab (*Chionoecetes bairdi*), pink shrimp (*Pandalus borealis*), common brittle star (*Ophiura sarsi*), and mud star (*Ctenodiscus crispatus*) were recorded southeast of Kayak Island, in the vicinity of the Copper River delta (Fig. 1). Large concentrations of fishes were also present in this area (see Ronholt et al. [1976] for distribution and density data for fishes there). Little is known about the productivity of this area, but primary and secondary production may be higher there as a result of nutrients supplied by the Copper River. Enhanced productivity may be related to the presence of gyres that extend vertically from the ocean surface to the bottom (Galt 1976).

The two dominant arthropods—snow crab (*Chionoecetes bairdi*) and pink shrimp (*Pandalus borealis*)—are widespread and commercially important in the northeast Gulf of Alaska. Snow crabs are a major food of the Pacific cod (*Gadus macrocephalus*) (Feder 1977a; Jewett 1978) and sculpins (*Myoxocephalus* spp.) (Jewett and Powell, unpubl. data). Pink shrimp are also a major food of the Pacific cod (Feder 1977a; Jewett 1978) as well as of the turbot (*Atheresthes stomias*) and the rex sole (*Glyptocephalus zachirus*) (Smith et al. 1978).

Although determination of the food of snow crabs was not a part of the NEGOA study, inferences from other investigations suggest that food groups used by snow crabs (*Chionoecetes* spp.) are somewhat similar throughout their range. *Chionoecetes opilio* examined in the Bering Sea fed mainly on unidentified polychaetes and brittle stars, mainly *Ophiura* sp. (Feder et al. 1978). The deposit-feeding clam *Nucula tenuis* dominated the diet of *C. opilio* from Norton Sound and the Chukchi Sea (Feder and Jewett 1978). *Chionoecetes opilio* from the Gulf of St. Lawrence fed mainly on clams (*Yoldia* sp.) and polychaetes (Powles 1968). *Chionoecetes opilio elongatus* from Japanese waters fed primarily on brittle stars (*Ophiura* sp.), young *C. opilio elongatus,* and protobranch clams (Yasuda 1967). Most of the items consumed by *C. bairdi* from two bays of Kodiak Island were polychaetes, clams (Nuculanidae), shrimps, plants, and sediment (Feder and Jewett 1977). Paul et al. (1979) examined stomachs of *C. bairdi* from lower Cook Inlet and found the main items to be clams (*Macoma* spp.), hermit crabs (*Pagurus* spp.), barnacles (*Balanus* spp.), and sediment. *Chionoecetes bairdi* in Port Valdez (Prince William Sound) contained polychaetes, clams, *C. bairdi,* other crustaceans, and some detrital material (Feder, unpubl. data). Further data on the distribution and abundance of potential prey species are necessary in order to better identify food species for better comparison of food from different areas.

The large sea star *Pycnopodia helianthoides* preyed almost entirely upon gastropod molluscs and echinoderms. *Pycnopodia* examined in Kodiak shallow waters preyed mainly on gastropods and pelecypods (Feder and Jewett, unpubl. data). Intertidal and shallow subtidal *P. helianthoides* from Prince William Sound were found to feed primarily on small bivalve molluscs (Paul and Feder 1975). This sea star is also capable of excavating for large clams (Mauzey et al. 1968; Paul and Feder 1975). Scuba divers have observed king crabs feeding on *Pycnopodia* near Kodiak Island (S. Jewett and G. Powell, pers. observ.).

The mud star (*Ctenodiscus crispatus*) and the heart urchin (*Brisaster townsendi*) were encountered in large numbers within the study area. Both of these echinoderms use carbon associated with bottom sediments as their major source of nutrition (Feder, unpubl. data). As deposit feeders, *Ctenodiscus* and *Brisaster* continuously rework and ingest sediments, and probably have an important role in recycling nutrients. A large proportion of the NEGOA infaunal species is composed of deposit feeders (Matheke et al. 1978).

The feeding habits of the common brittle star (*Ophiura sarsi*) probably include browsing, detritus feeding, and prey-capture techniques (Gentleman 1964; Kyte 1969). A few *O. sarsi* examined in NEGOA, the southeastern Bering Sea, and Port Valdez (Prince William Sound) mainly contained detrital material and sediment but also fragments of various small benthic invertebrates (Feder, unpubl. data). In turn, this brittle star is important food for the dover sole (*Microstomus pacificus*) and the flathead sole (*Hippoglossoides elassodon*) (Smith et al. 1978).

All of the specimens of the starry flounder (*Platichthys stellatus*) examined in this study had been feeding intensively and exclusively on three species of clams (*Yoldia seminuda, Siliqua sloati,* and *Macoma dexiosttera*). Clams, especially thin-shelled species, have been found to be important components in the diet of starry flounders by other investigators (Villadolid 1927; Orcutt 1950; Moiseev 1953; Miller 1965). Starry flounders from the northern Bering Sea and the southeastern Chukchi Sea were found to feed heavily on *Yoldia hyperborea* and the brittle star *Diamphiodia craterodmeta* (Feder and Jewett 1978). A definite seasonality in feeding intensity has been found to exist for this flounder: feeding stops during January through late May and resumes in late May or early June (Miller 1965; Feder and Jewett, unpubl. data). The degree of fullness of the starry flounders examined in this study may be evidence of a recently terminated fasting period. All of the specimens were taken at Stations 94-A and B on 3 June 1975. Clam populations in the Icy Bay area obviously play a vital role in the trophic dynamics of *P. stellatus*.

CONCLUSIONS

The major limitations of the survey were those imposed by the selectivity of the otter trawl used and the seasonal movements of certain species taken. In addition, rocky-bottom areas were not sampled since otter trawls of the type used can only be fished on a relatively smooth bottom. However, the study reported here was effective for determining the epibenthic invertebrates present on sediment bottom and for achieving maximum spatial coverage of the area. This report, in conjunction with the NEGOA infaunal investigation (Feder and Matheke 1979), will enhance our understanding of the shelf ecosystem.

Availability of many readily identifiable, biologically well-understood organisms is a preliminary to the development of monitoring programs. Sizeable biomasses of taxonomically well-known molluscs, crustaceans, and echinoderms were typical of most of our stations, and many species of these phyla were sufficiently abundant to represent organisms potentially useful as monitoring tools. The present investigation should clarify some aspects of the biology of many of these organisms and increase the reliability of future monitoring programs for the Gulf of Alaska.

NEEDS FOR FURTHER STUDY

The extensive trawl program permitted complete coverage of the benthos for epifaunal invertebrates. However, considerable effort is still needed to understand the NEGOA benthic system. It is especially important to collect chemical, physical, and geological data in conjunction with all future biological investigations.

Selected epifaunal species should be chosen for intensive study as soon as possible so that basic information will be available to a monitoring program. Biological parameters that should be examined are reproduction, recruitment, growth, age, feeding biology, and trophic interactions with other invertebrates and vertebrates.

Grouping techniques, such as cluster or recurrent group analysis, provide methods for delineating station and species groups. The outcome of such analyses can be used to delimit areas of monitoring programs. Future application of grouping techniques to epifaunal species should be strongly encouraged.

REFERENCES CITED

Baker, J. M. (ed.) 1976. Marine Ecology and Oil Pollution. John Wiley and Sons, New York. 566 pp.

Bakus, G. J., and D. W. Chamberlain. 1975. An oceanographic and marine biological study in the Gulf of Alaska. Report submitted to Atlantic Richfield Co. 57 pp.

Boesch, D. F., C. H. Hershner, and J. H. Milgram. 1974. Oil Spills and the Marine Environment. Ballinger Publ. Co., Cambridge, Mass. 114 pp.

Cunningham, D. 1969. A study of the food and feeding relationships of the Alaskan king crab, *Paralithodes camtschatica*. M.S. Thesis, San Diego State College. 78 pp.

Feder, H. M. 1977a. The distribution, abundance, diversity, and biology of benthic organisms in the Gulf of Alaska and the Bering Sea. Annual report to NOAA/OCSEAP, Research Unit 281/5/303. 340 pp.

Feder, H. M. 1977b. Summarization of existing literature and unpublished data on the distribution, abundance, and productivity of benthic organisms of the Gulf of Alaska and Bering and Chukchi seas. Final report to NOAA/OCSEAP, Research Unit 282/301. 7 pp. (Full report submitted to NOAA on magnetic tape.)

Feder, H. M. 1978a. Distribution, abundance, community structure, and trophic relationships of the nearshore benthos of the Kodiak shelf, Cook Inlet, northeast Gulf of Alaska, and the Bering Sea. Annual report to NOAA/OCSEAP, Research Unit 281/5/303. 296 pp.

Feder, H. M. 1978b. Distribution, abundance, community structure, and trophic relationships of the nearshore benthos of the Kodiak shelf, Cook Inlet, northeast Gulf of Alaska, and the Bering Sea. Quarterly report to NOAA/OCSEAP, Research Unit 5. 13 pp.

Feder, H. M., and S. C. Jewett. 1977. The distribution, abundance, and diversity of the epifaunal benthic organisms in two bays (Alitak and Ugak) of Kodiak Island, Alaska. OCSEAP Final Rep. 67:281–356.

Feder, H. M., and S. C. Jewett. 1978. Trawl survey of the epifaunal invertebrates of Norton Sound, southeastern Chukchi Sea, and Kotzebue Sound. Environ. Assess. Alaskan Continental Shelf, Final Rep., Biol. Studies 1:338–486.

Feder, H. M., and G. Matheke. 1979. Distribution, abundance, community structure, and trophic relationships of the benthic infauna of the northeast Gulf of Alaska. Environ. Assess. Alaskan Continental Shelf, Final Rep., Biol. Studies 6:1–256.

Feder, H. M., and G. Mueller. 1975. Environmental assessment of the northeast Gulf of Alaska: benthic biology. First year final report to NOAA/OCSEAP. Inst. Mar. Sci., Univ. Alaska, Fairbanks. 200 pp.

Feder, H. M., J. Hilsinger, M. Hoberg, S. C. Jewett, and J. R. Rose. 1978. Survey of the epifaunal invertebrates of the southeastern Bering Sea. Final report to NOAA/OCSEAP, Research Unit 5. 119 pp.

Galt, J. A. 1976. Circulation studies on the Alaskan Continental Shelf off the Copper River shelf. NOAA Tech. Rep., U.S. Government Printing Office, Washington, D.C. 36 pp.

Gentleman, S. 1964. Feeding mechanisms of *Ophiura sarsi*. Friday Harbor Lab., University of Washington, Zool. 533 Res. Paper 69.

Hitz, C. R., and W. F. Rathjen. 1965. Bottom trawling surveys of the northeastern Gulf of Alaska. Comm. Fish. Rev. 27(9):1–15.

Jewett, S. C. 1976. Pollutants of the northeast Gulf of Alaska. Mar. Pollut. Bull. 7:169.

Jewett, S. C., and H. M. Feder. 1976. Distribution and abundance of some epibenthic invertebrates of the northeast Gulf of Alaska with notes on the feeding biology of selected species. Inst. Mar. Sci. Rep. R76-8, Univ. Alaska, Fairbanks. 61 pp.

Jewett, S. C. 1978. Summer food of the Pacific cod, *Gadus macrocephalus,* near Kodiak Island, Alaska. Fish. Bull. 76:700-706.

Karinen, J. F., and S. D. Rice. 1974. Effects of Prudhoe Bay crude oil on molting tanner crabs, *Chionoecetes bairdi.* Mar. Fish. Rev. 36(7):31-37.

Kyte, M. A. 1969. A synopsis and key to the recent ophiuroidea of Washington state and southern British Columbia. J. Fish. Res. Board Can. 26:1727-1741.

Lewis, J. R. 1970. Problems and approaches to base-line studies in coastal communities. FAO Technical Conference on Marine Pollution and its Effect on Living Resources and Fishing. FIR:MP 70/E-22. 7 pp.

Malins, D. C. (ed.) 1977. Effects of Petroleum on Arctic and Subarctic Marine Environments and Organisms. Vol. 2, Biological effects. Academic Press, New York. 512 pp.

Matheke, G. E. M., H. M. Feder, and G. Mueller. 1978. Numerical analysis of the benthic infauna in the northeastern Gulf of Alaska. *In* D. N. Norton (ed.), Proceedings of the 27th Alaska Science Conference, Vol. 2.

Mauzey, K. P., C. Birkeland, and P. K. Dayton. 1968. Feeding behavior of asteroids and escape responses of their prey in the Puget Sound region. Ecology 49:603-619.

Mecklenburg, T. A., S. D. Rice, and J. F. Karinen. 1976. Effects of Cook Inlet crude oil water soluble fractions on survival and molting of king crab (*Paralithodes camtschatica*) and coonstripe shrimp (*Pandalus hypsinotus*) larvae. *In* Proceeding of the 27th Alaska Science Conference, Vol. 1.

Miller, B. S. 1965. Food and feeding studies on adults of two species of pleuronectids (*Platichthys stellatus* and *Psettichthys melanosticus*) in East Sound, Orcas Island (Washington). M.S. Thesis, Univ. Washington, Seattle. 131 pp.

Moiseev, P. A. 1953. Cod and flounders of the far eastern seas. Izvestiia Tikhookeanskovo N.-I. Inst. Rybnovo Khozinistva i Okeanografii, 40:1-287. (Fish. Res. Board Can. Transl. Ser. 119).

Nelson-Smith, A. 1973. Oil Pollution and Marine Ecology. Paul Elek (Scientific Books) Ltd., London. 260 pp.

Olson, T. A., and F. J. Burgess, eds. 1967. Pollution and Marine Ecology. Interscience, New York. 364 pp.

Orcutt, H. G. 1950. The life history of the starry flounder, *Platichthys stellatus* (Pallas). Calif. Fish and Game. Fish. Bull. 78. 64 pp.

Paul, A. J., and H. M. Feder. 1975. The food of the sea star *Pycnopodia helianthoides* (Brandt) in Prince William Sound, Alaska. Ophelia 14:15–22.

Paul, A. J., H. M. Feder, and S. C. Jewett. 1979. Food of the snow crab, *Chionoecetes bairdi* Rathbun 1924, from Cook Inlet, Alaska (Decapoda, Majidae). Crustaceana Suppl. 5:62–68.

Pearson, T. H. 1971. The benthic ecology of Loch Linnhe and Loch Eil, a sea loch system on the west coast of Scotland. III. The effect on the benthic fauna of the introduction of pulp mill effluent. J. Exp. Mar. Biol. Ecol. 6:211–233.

Pearson, T. H. 1972. The effect of industrial effluent from pulp and paper mills on the marine benthic environment. Proc. R. Soc. Lond. B, Biol. Sci. 130:469–485.

Pearson, T. H. 1975. The benthic ecology of Loch Linnhe and Loch Eil, a sea loch system on the west coast of Scotland. IV. Changes in the benthic fauna attributable to organic enrichment. J. Exp. Mar. Biol. Ecol. 20:1–41.

Powles, H. 1968. Distribution and biology of the spider crab *Chionoecetes opilio* in the Magdalen Shallows, Gulf of St. Lawrence. Fish. Res. Board Can. Mar. Rep. Ser. 997. 105 pp.

Rhoads, D. C. 1974. Organism-sediment relations on the muddy sea floor. Oceanogr. Mar. Biol. Ann. Rev. 12:263–300.

Ronholt, L. L., H. H. Shippen, and E. S. Brown. 1976. An assessment of the demersal fish and invertebrate resources of the northeastern Gulf of Alaska, Yakutat Bay to Cape Cleare, May–August 1975. Annual Rep., U.S. Dep. Commer., Natl. Oceanic Atmos. Admin., Natl. Mar. Fish. Serv. 184 pp.

Rosenberg, D. H. (ed.) 1972. A review of the oceanography and renewable resources of the northern Gulf of Alaska. IMS Rep. R72-23, Sea Grant Rep. 73-3, Univ. Alaska, Fairbanks. 690 pp.

Rosenberg, R. 1973. Succession in benthic macrofauna in a Swedish fjord subsequent to the closure of a sulphite pulp mill. Oikos 24:244–258.

Smith, J. E. (ed.) 1968. Torrey Canyon Pollution and Marine Life. Cambridge Univ. Press, Cambridge. 196 pp.

Smith, R., A. Paulson, and J. Rose. 1978. Food and feeding relationships in the benthic and demersal fishes of the Gulf of Alaska and Bering Sea. Environ. Assess. Alaskan Continental Shelf, Final Rep., Biol. Studies 1:33–107.

Straughan, D. 1971. Biological and oceanographical survey of the Santa Barbara Channel oil spill, 1969–1970. Allan Hancock Foundation, Univ. Southern California, Los Angeles. 425 pp.

Villadolid, D. V. 1927. The flatfishes (Heterosomata) of the Pacific coast of the United States. Ph.D. Thesis, Stanford Univ. 332 pp.

Wigley, R. L., and R. B. Theroux. 1965. Seasonal food habits of highland ground haddock. Trans. Am. Fish. Soc. 94(3):243–251.

Yasuda, T. 1967. Feeding habits of the zuwaigani, *Chionoecetes opilio elongatus*, in Wakasa Bay. I. Specific composition of the stomach contents. Bull. Jap. Soc. Sci. Fish. 33(4): 315–319. (Transl. from Japanese by Fish. Res. Board Can., Transl. Ser. 1111.)

Zenkevitch, L.A. 1963. Biology of the Seas of the USSR. George Allen and Unwin, Ltd., London. 955 pp.

APPENDIX

SELECTED GULF OF ALASKA BENTHIC TRAWL STATION DATA

MAY–AUGUST 1975
CRUISE NUMBER N0817

Appendix Table 1

TOW NUMBER 14; STATION NUMBER 74-C; PERCENT SAMPLED = 50.

(All counts and weights are projected to 100% of the sample).

Date Yr Mo Da	Time Hr/Min	Start Latitude Deg Min	Start Longitude Deg Min	Finish Latitude Deg Min	Finish Longitude Deg Min	Time Fished Min	Time Zone	Distance Fished (km)	Depth Fished (m)
75 5 8	1400	58 57.0	146 45.0	59 59.0	146 43.0	35	9	4.44	63.7-67.3

TAXON	COUNT No.	COUNT %	COUNT Per km	WET WEIGHT (gm) Total	WET WEIGHT (gm) %	WET WEIGHT (gm) Per km
INVERTEBRATES						
Porifera	6.0	0.1	1.4	2700.0	0.6	608.1
Ptilosarcus gurneyi	46.0	0.7	10.4	2760.0	0.7	621.6
Actiniidae	12.0	0.2	2.7	2400.0	0.6	540.5
Modiolus modiolus	20.0	0.3	4.5	2200.0	0.5	495.5
Chlamys hastata hericia	400.0	6.3	90.1	3200.0	0.8	720.7
Pecten caurinus	12.0	0.2	2.7	1320.0	0.3	297.3
Astarte polaris	8.0	0.1	1.8	80.0	0.0	18.0
Clinocardium fucanum	2.0	0.0	0.5	8.0	0.0	1.8
Serripes groenlandicus	4.0	0.1	0.9	800.0	0.2	180.2
Lischkeia cidaris	150.0	2.4	33.8	1800.0	0.4	405.4
Fusitriton oregonensis	260.0	4.1	58.6	19940.0	4.7	4491.0
Buccinum plectrum	40.0	0.6	9.0	800.0	0.2	180.2
Neptunea lyrata	30.0	0.5	6.8	5440.0	1.3	90.1
Pyrulofusus harpa	4.0	0.1	0.9	400.0	0.1	90.1
Tritoniidae	4.0	0.1	0.9	600.0	0.1	135.1
Tochuina tetraquetra	4.0	0.1	0.9	600.0	0.1	135.1
Balanus sp.	302.0	4.7	68.0	9060.0	2.1	2040.5

Appendix Table 1 (continued)

TAXON	COUNT No.	COUNT %	COUNT Per km	WET WEIGHT (gm) Total	WET WEIGHT (gm) %	WET WEIGHT (gm) Per km
Pandalus montagui tridens	12.0	0.2	2.7	96.0	0.0	21.6
Paracrangon echinata	24.0	0.4	5.4	168.0	0.0	37.8
Pagurus ochotensis	150.0	2.4	33.8	13600.0	3.2	3063.1
Pagurus aleuticus	12.0	0.2	2.7	1320.0	0.3	297.3
Pagurus kennerlyi	40.0	0.6	9.0	4520.0	1.1	1018.0
Elassochirus tenuimanus	40.0	0.6	9.0	4520.0	1.1	1018.0
Elassochirus cavimanus	38.0	0.6	8.6	4520.0	1.1	1018.0
Labidochirus splendescens	24.0	0.4	5.4	1200.0	0.3	270.3
Lopholithodes foraminatus	2.0	0.0	0.5	840.0	0.2	189.2
Rhinolithodes wosnessenskii	16.0	0.3	3.6	2880.0	0.7	648.6
Oregonia gracilis	14.0	0.2	3.2	2520.0	0.6	567.6
Hyas lyratus	20.0	0.3	4.5	3620.0	0.9	815.3
Cancer oregonensis	24.0	0.4	5.4	140.0	0.0	31.5
Terebratulina unguicula	864.0	13.5	194.6	6040.0	1.4	1360.4
Laqueus californianus	864.0	13.5	194.6	6040.0	1.4	1360.4
Terebratalia transversa	864.0	13.5	194.6	6040.0	1.4	1360.4
Ceramaster paragonicus	14.0	0.2	3.2	980.0	0.2	220.7
Henricia sp.	50.0	0.8	11.3	3500.0	0.8	788.3
Henricia aspera	12.0	0.2	2.7	1200.0	0.3	270.3
Poraniopsis inflata	6.0	0.1	1.4	1320.0	0.3	297.3
Pteraster tesselatus	90.0	1.4	20.3	19800.0	4.7	4459.5
Crossaster papposus	44.0	0.7	9.9	3520.0	0.8	792.8
Solaster dawsoni	24.0	0.4	5.4	4800.0	1.1	1081.1
Lethasterias nanimensis	20.0	0.3	4.5	4000.0	0.9	900.9
Stylasterias forreri	16.0	0.3	3.6	640.0	0.2	144.1
Strongylocentrotus droebachiensis	496.0	7.8	111.7	14880.0	3.5	3351.4
Gorgonocephalus caryi	12.0	0.2	2.7	480.0	0.1	108.1
Ophiura sarsi	24.0	0.4	5.4	140.0	0.0	31.5
Cucumariidae	36.0	0.6	8.1	12240.0	2.9	2756.8
Halocynthia hilgendorfi igaboja	1224.0	19.2	275.7	244940.0	57.7	55166.7

Appendix Table 1 (continued)

TAXON	COUNT No.	COUNT %	COUNT Per km	WET WEIGHT (gm) Total	WET WEIGHT (gm) %	WET WEIGHT (gm) Per km
VERTEBRATES						
Bathymaster signatus	-	-	-	64860.0	7.1	14608.1
Hippoglossus stenolepis	-	-	-	816480.0	88.9	183891.9
Lepidopsetta bilineata	-	-	-	37180.0	4.0	8373.9

COMMENTS

Weights of hermit crabs include their shells. This tow contains many small round rocks (4 cm in diameter), weights of some asidians include several small rocks which the asidians are attached.

Appendix Table 2

TOW NUMBER 146; STATION NUMBER 74-D; PERCENT SAMPLED = 100.

Date Yr Mo Da	Time Hr/Min	Start Latitude Deg Min	Start Longitude Deg Min	Finish Latitude Deg Min	Finish Longitude Deg Min	Time Fished Min	Time Zone	Distance Fished (km)	Depth Fished (m)
75 8 6	1305	59 53.0	146 51.0	59 51.0	146 53.0	30	9	3.52	67.3-71.0

TAXON	COUNT No.	COUNT %	COUNT Per km	WET WEIGHT (gm) Total	WET WEIGHT (gm) %	WET WEIGHT (gm) Per km
INVERTEBRATES						
Ptilosarcus gurneyi	50.0	1.0	14.2	3000.0	2.0	852.3
Artonoe vittata	1.0	0.0	0.3	1.0	0.0	0.3
Nereis pelagica	2.0	0.0	0.6	20.0	0.0	5.7
Eunice valens	2.0	0.0	0.6	2.0	0.0	0.6
Modiolus modiolus	6.0	0.1	1.7	660.0	0.4	187.5
Hiatella arctica	1.0	0.0	0.3	3.0	0.0	0.9
Lischkeia cidaris	1.0	0.0	0.3	12.0	0.0	3.4
Fusitriton oregonensis	20.0	0.4	5.7	2000.0	1.4	568.2
Trophonopsis stuarti	2.0	0.0	0.6	20.0	0.0	5.7
Neptunea lyrata	20.0	0.4	5.7	3600.0	2.4	1022.7
Dorididae	40.0	0.8	11.4	6000.0	4.1	1704.5
Tritonia exsulans	2.0	0.0	0.6	300.0	0.2	85.2
Balanus hesperius	11.0	0.2	3.1	330.0	0.2	93.8
Pandalus hypsinotus	200.0	4.0	56.8	1600.0	1.1	454.5
Paracrangon echinata	1.0	0.0	0.3	7.0	0.0	2.0
Pagurus kennerlyi	20.0	0.4	5.7	2200.0	1.5	625.0
Elassochirus cavimanus	4.0	0.1	1.1	480.0	0.3	136.4
Lopholithodes foraminatus	3.0	0.1	0.9	1260.0	0.9	358.0
Hyas lyratus	9.0	0.2	2.6	1620.0	1.1	460.2
Terebratulina unguicula	1000.0	20.1	284.1	7000.0	4.8	1988.6
Laqueus californianus	1000.0	20.1	284.1	7000.0	4.8	1988.6

Appendix Table 2 (continued)

TAXON	COUNT			WET WEIGHT (gm)		
	No.	%	Per km	Total	%	Per km
Terebratalia transversa	1000.0	20.1	284.1	7000.0	4.8	1988.6
Luidiaster dawsoni	2.0	0.0	0.6	440.0	0.3	125.0
Ceramaster patagonicus	2.0	0.0	0.6	140.0	0.1	39.8
Henricia aspera	8.0	0.2	2.3	800.0	0.5	227.3
Poraniopsis inflata	1.0	0.0	0.3	220.0	0.1	62.5
Pteraster tesselatus	30.0	0.6	8.5	6600.0	4.5	1875.0
Crossaster papposus	40.0	0.8	11.4	3200.0	2.2	909.1
Solaster dawsoni	3.0	0.1	0.9	600.0	0.4	170.5
Leptasterias sp.	3.0	0.1	0.9	27.0	0.0	7.7
Strongylocentrotus droebachiensis	1288.0	25.8	365.9	46720.0	31.7	13272.7
Gorgonocephalus caryi	9.0	0.2	2.6	3420.0	2.3	971.6
Halocynthia hilgendorfi igaboja	200.0	4.0	56.8	40000.0	27.2	11363.6
Chelyosoma columbianum	4.0	0.1	1.1	800.0	0.5	227.3
Halocynthia aurantium	1.0	0.0	0.3	200.0	0.1	56.8
VERTEBRATES						
Gadus macrocephalas	-	-	-	3180.0	3.7	903.4
Hemilepidotus jordani	-	-	-	3630.0	4.2	1031.3
Bathymaster signatus	-	-	-	33110.0	38.3	9406.3
Atheresthes stomias	-	-	-	17240.0	20.0	4897.7
Glyptocephalus zachirus	-	-	-	2940.0	3.4	835.2
Hippoglossus stenolepis	-	-	-	17240.0	20.0	2897.7
Lepidopsetta bilineata	-	-	-	9070.0	10.5	2576.5

COMMENTS

Halocynthia aurantium attached to pebbles, *Halocynthia hilgendorfi igaboja* with 3 species of Brachiopoda attached. Hermit crabs weighed with shell. Gulf of Alaska - Benthic trawl data - 3 May 1975 thru 7 August 1975. Hung up, web ripped. Pollutants were not recorded.

Appendix Table 3

TOW NUMBER 35; STATION NUMBER 80-B; PERCENT SAMPLED = 65.

(All counts and weights are projected to 100% of the sample).

Date Yr Mo Da	Time Hr/Min	Start Latitude Deg Min	Start Longitude Deg Min	Finish Latitude Deg Min	Finish Longitude Deg Min	Time Fished Min	Time Zone	Distance Fished (km)	Depth Fished (m)
75 5 24	1055	60 6.0	145 20.0	60 5.0	145 13.0	60	9	5.55	91.0-112.8

TAXON	COUNT No.	COUNT %	COUNT Per km	WET WEIGHT (gm) Total	WET WEIGHT (gm) %	WET WEIGHT (gm) Per km
INVERTEBRATES						
Ptilosarcus gurneyi	173.8	2.7	31.3	10446.2	3.0	1882.2
Buccinum plectrum	4.6	0.1	0.8	92.3	0.0	16.6
Octopus sp.	6.2	0.1	1.1	200.0	0.1	36.0
Pagurus ochotensis	6.2	0.1	1.1	553.8	0.2	99.8
Chionoecetes bairdi	615.4	9.6	110.8	279138.5	80.6	50295.2
Ctenodiscus crispatus	5581.5	87.4	1005.7	55815.4	16.1	10056.8
VERTEBRATES						
Gadus macrocephalus	-	-	-	55123.1	16.1	9932.1
Theragra chalcogramma	-	-	-	170261.5	49.7	30677.8
Atheresthes stomias	-	-	-	68384.6	20.0	12321.6
Hippoglossoides elassodon	-	-	-	48846.2	14.3	8801.1

COMMENTS

Weight of hermit crab includes their shells. Plastic found.

Appendix Table 4

TOW NUMBER 110; STATION NUMBER 81-D; PERCENT SAMPLED = 40.

(All counts and weights are projected to 100% of the sample).

Date Yr Mo Da	Time Hr/Min	Start Latitude Deg Min	Start Longitude Deg Min	Finish Latitude Deg Min	Finish Longitude Deg Min	Time Fished Min	Time Zone	Distance Fished (km)	Depth Fished (m)
75 7 15	1305	59 49.0	145 0	59 46.0	145 2.0	60	9	5.37	182.0-193.0

TAXON	COUNT No.	COUNT %	COUNT Per km	WET WEIGHT (gm) Total	WET WEIGHT (gm) %	WET WEIGHT (gm) Per km
INVERTEBRATES						
Actiniidae	2.5	0.0	0.5	500.0	0.0	93.1
Neptunea lyrata	2.5	0.0	0.5	450.0	0.0	83.8
Neptunea pribiloffensis	117.5	0.1	21.9	21150.0	1.5	3938.5
Tritonia exsulans	50.0	0.0	9.3	7500.0	0.5	1396.6
Gonatidae	2.5	0.0	0.5	50.0	0.0	9.3
Octopus sp.	2.5	0.0	0.5	225.0	0.0	41.9
Pandalus borealis	125.0	0.1	23.3	1000.0	0.1	186.2
Pandalopsis dispar	50.0	0.0	9.3	500.0	0.0	93.1
Pagurus aleuticus	25.0	0.0	4.7	275.0	0.0	51.2
Chionoecetes bairdi	1300.0	1.0	242.1	585000.0	42.3	108939.5
Pseudarchaster parelii	2.5	0.0	0.5	225.0	0.0	41.9
Ctenodiscus crispatus	1562.5	1.2	291.0	15625.0	1.1	2909.7
Ophiura sarsi	125000.0	97.5	23277.5	750000.0	54.2	139664.8
VERTEBRATES						
Raja rhina	-	-	-	32875.0	8.4	6122.0
Gadus macrocephalas	-	-	-	79375.0	20.3	14781.2
Sebastolobus alascanus	-	-	-	17575.0	4.5	3272.8

Appendix Table 4 (continued)

TAXON	COUNT No.	COUNT %	COUNT Per km	WET WEIGHT (gm) Total	WET WEIGHT (gm) %	WET WEIGHT (gm) Per km
Anoplopoma fimbria	-	-	-	19275.0	4.9	3589.4
Atheresthes stomias	-	-	-	46475.0	11.9	8654.6
Glyptocephalus zachirus	-	-	-	92975.0	23.8	17313.8
Hippoglossoides elassodon	-	-	-	2825.0	0.7	526.1
Microstomus pacificus	-	-	-	99775.0	25.5	18580.1

COMMENTS

Hermit crabs weighed with shell. Pollutants were not recorded.

Appendix Table 5

TOW NUMBER 106; STATION NUMBER 82-A; PERCENT SAMPLED = 50.

(All counts and weights are projected to 100% of the sample).

Date Yr Mo Da	Time Hr/Min	Start Latitude Deg Min	Start Longitude Deg Min	Finish Latitude Deg Min	Finish Longitude Deg Min	Time Fished Min	Time Zone	Distance Fished (km)	Depth Fished (m)
75 7 14	1300	60 7.0	144 46.0	60 6.0	144 41.0	55	9	3.70	49.1-51.0

TAXON	COUNT No.	COUNT %	COUNT Per km	WET WEIGHT (gm) Total	WET WEIGHT (gm) %	WET WEIGHT (gm) Per km
INVERTEBRATES						
Ptilosarcus gurneyi	324.0	10.7	87.6	19440.0	2.1	5254.1
Actiniidae	2.0	0.1	0.5	400.0	0.0	108.1
Nuculana fossa	8.0	0.3	2.2	8.0	0.0	2.2
Pecten caurinus	4.0	0.1	1.1	1400.0	0.1	378.4
Tritonia exsulans	2.0	0.1	0.5	300.0	0.0	81.1
Pandalus borealis	600.0	19.9	162.2	4800.0	0.5	1297.3
Pandalus hypsinotus	36.0	1.2	9.7	280.0	0.0	75.7
Eualis barbata	2.0	0.1	0.5	14.0	0.0	3.8
Eualis suckleyi	2.0	0.1	0.5	14.0	0.0	3.8
Crangon communis	4.0	0.1	1.1	28.0	0.0	7.6
Pagurus ochotensis	6.0	0.2	1.6	540.0	0.1	145.9
Chionoecetes bairdi	1984.0	65.8	536.3	892800.0	95.2	241297.3
Cancer magister	34.0	1.1	9.2	15300.0	1.6	4135.1
Pycnopodia helianthoides	6.0	0.2	1.6	2700.0	0.3	729.7
VERTEBRATES						
Theragra chalcogramma	-	-	-	32200.0	17.2	8702.7
Anoplopoma fimbria	-	-	-	4080.0	2.2	1102.7

Appendix Table 5 (continued)

TAXON	COUNT No.	COUNT %	COUNT Per km	WET WEIGHT (gm) Total	WET WEIGHT (gm) %	WET WEIGHT (gm) Per km
Agonus acipenserinus	-	-	-	15860.0	8.5	4286.5
Lumpenus sagitta	-	-	-	6160.0	3.3	1664.9
Atheresthes stomias	-	-	-	70760.0	37.9	19124.3
Hippoglossoides elassodon	-	-	-	57700.0	30.9	15594.6

COMMENTS

Hermit crabs weighed with shell. *Pycnopodia helianthoides* feeding on *Mitrella gouldi*. Pollutants were not recorded.

Appendix Table 6

TOW NUMBER 104; STATION NUMBER 83-C; PERCENT SAMPLED = 10.

(All counts and weights are projected to 100% of the sample).

Date	Time	Start		Finish		Time Fished	Time	Distance Fished	Depth Fished
Yr Mo Da	Hr/Min	Latitude Deg Min	Longitude Deg Min	Latitude Deg Min	Longitude Deg Min	Min	Zone	(km)	(m)
75 7 14	0745	59 52.0	144 38.0	59 56.0	144 34.0	60	9	5.55	54.6-54.6

TAXON	COUNT No.	COUNT %	COUNT Per km	WET WEIGHT (gm) Total	WET WEIGHT (gm) %	WET WEIGHT (gm) Per km
INVERTEBRATES						
Ptilosarcus gurneyi	222.0	1.0	39.6	13200.0	3.0	2378.4
Nuculana fossa	30.0	0.1	5.4	30.0	0.0	5.4
Pecten caurinus	30.0	0.1	5.4	10500.0	2.4	1891.9
Balanus herperius	10.0	0.0	1.8	300.0	0.1	54.1
Pandalus borealis	20970.0	95.8	3778.4	167700.0	38.5	30216.2
Pandalus hyspinotus	30.0	0.1	5.4	240.0	0.1	43.2
Eualis suckleyi	30.0	0.1	5.4	210.0	0.0	37.8
Lopholithodes foraminatus	10.0	0.0	1.8	4200.0	1.0	756.8
Chionoecetes bairdi	500.0	2.3	90.1	225000.0	51.6	40540.5
Cancer magister	10.0	0.0	1.8	4500.0	1.0	810.8
Pycnopodia helianthoides	20.0	0.1	3.6	9000.0	2.1	1621.6
Strongylocentrotus droebachiensis	30.0	0.1	5.4	900.0	0.2	162.2
Molpadia sp.	10.0	0.0	1.8	200.0	0.0	36.0
VERTEBRATES						
Raja binoculata	-	-	-	226800.0	52.1	40864.9
Theragra chalcogramma	-	-	-	54430.0	12.5	9807.2

Appendix Table 6 (continued)

TAXON	COUNT No.	COUNT %	COUNT Per km	WET WEIGHT (gm) Total	WET WEIGHT (gm) %	WET WEIGHT (gm) Per km
Anoplopoma fimbria	-	-	-	22600.0	5.2	4072.1
Atheresthes stomias	-	-	-	104320.0	24.0	18796.4
Hippoglossus stenolepis	-	-	-	27210.0	6.3	4902.7

Appendix Table 7

TOW NUMBER 142; STATION NUMBER 83-E; PERCENT SAMPLED = 100.

Date Yr Mo Da	Time Hr/Min	Start Latitude Deg Min	Start Longitude Deg Min	Finish Latitude Deg Min	Finish Longitude Deg Min	Time Fished Min	Time Zone	Distance Fished (km)	Depth Fished (m)
75 8 4	0800	59 43.0	144 37.0	59 41.0	144 33.0	60	9	5.55	129.2-131.0

TAXON	COUNT No.	COUNT %	COUNT Per km	WET WEIGHT (gm) Total	WET WEIGHT (gm) %	WET WEIGHT (gm) Per km
INVERTEBRATES						
Porifera	0.0	0.0	0.0	7900.0	4.7	1423.4
Nereis pelagica	1.0	0.0	0.2	10.0	0.0	1.8
Nereis vexillosa	1.0	0.0	0.2	10.0	0.0	1.8
Hirudinae	1.0	0.0	0.2	2.0	0.0	0.4
Mytilus edulis	100.0	2.4	18.0	2000.0	1.2	360.4
Pecten caurinus	330.0	7.8	59.5	115500.0	68.9	20810.8
Hiatella arctica	1.0	0.0	0.2	3.0	0.0	0.5
Fusitriton oregonensis	6.0	0.1	1.1	600.0	0.4	108.1
Buccinum plectrum	1.0	0.0	0.2	20.0	0.0	3.6
Neptunea lyrata	4.0	0.1	0.7	720.0	0.4	129.7
Pyrulofusus harpa	1.0	0.0	0.2	100.0	0.1	18.0
Octopus sp.	1.0	0.0	0.2	90.0	0.1	16.2
Lepas pectinata pacifica	1.0	0.0	0.2	30.0	0.0	5.4
Pandalus borealis	1100.0	26.1	198.2	8800.0	5.2	1585.6
Crangon communis	3.0	0.1	0.5	21.0	0.0	3.8
Argis dentata	1.0	0.0	0.2	7.0	0.0	1.3
Pagurus aleuticus	29.0	0.7	5.2	3190.0	1.9	574.8
Pagurus confragosus	12.0	0.3	2.2	1320.0	0.8	237.8
Elassochirus cavimanus	1.0	0.0	0.2	120.0	0.1	21.6
Hyas lyratus	6.0	0.1	1.1	1080.0	0.6	194.6

Appendix Table 7 (continued)

TAXON	COUNT No.	COUNT %	COUNT Per km	WET WEIGHT (gm) Total	WET WEIGHT (gm) %	WET WEIGHT (gm) Per km
Chionoecetes bairdi	17.0	0.4	3.1	7650.0	4.6	1378.4
Pseudarchaster parelii	1.0	0.0	0.2	90.0	0.1	16.2
Ctenodiscus crispatus	600.0	14.2	108.1	6000.0	3.6	1081.1
Henricia aspera	1.0	0.0	0.2	100.0	0.1	18.0
Gorgonocephalus caryi	1.0	0.0	0.2	380.0	0.2	68.5
Ophiura sarsi	2000.0	27.4	360.4	12000.0	7.2	2162.2
VERTEBRATES						
Raja kincaidi	-	-	-	2270.0	1.2	409.0
Raja rhina	-	-	-	3860.0	2.1	695.5
Thaleichthys pacificus	-	-	-	1360.0	0.7	245.0
Theragra chalcogramma	-	-	-	47170.0	25.9	8499.1
Ulca bolini	-	-	-	4540.0	2.5	818.0
Atheresthes stomias	-	-	-	82560.0	45.3	14875.7
Glyptocephalus zachirus	-	-	-	19500.0	10.7	3513.5
Hippoglossoides elassodon	-	-	-	5900.0	3.2	1063.1
Microstomus pacificus	-	-	-	14970.0	8.2	2697.3

COMMENTS

C. bairdi sexed, 12 males, 2 nongravid females, 3 gravid females. *Mytilus edulis* attached to Kelp holfast. Hermit crabs weighed with shell. Pollutants were not recorded.

Appendix Table 8

TOW NUMBER 42; STATION NUMBER 86-D; PERCENT SAMPLED = 100.

Date Yr Mo Da	Time Hr/Min	Start Latitude Deg Min	Start Longitude Deg Min	Finish Latitude Deg Min	Finish Longitude Deg Min	Time Fished Min	Time Zone	Distance Fished (km)	Depth Fished (m)
75 5 30	1240	59 40.0	143 44.0	59 41.0	143 47.0	65	9	7.22	127.4-140.1

TAXON	COUNT No.	COUNT %	COUNT Per km	WET WEIGHT (gm) Total	WET WEIGHT (gm) %	WET WEIGHT (gm) Per km
INVERTEBRATES						
Notostomobdella sp.	1.0	2.7	0.1	2.0	0.0	0.3
Pecten caurinus	1.0	0.2	0.1	350.0	1.0	48.5
Astarte polaris	90.0	17.6	12.5	900.0	2.5	124.7
Fusitriton oregonensis	4.0	0.8	0.6	400.0	1.1	55.4
Pyrulofusus harpa	1.0	0.2	0.1	100.0	0.3	13.9
Arctomelon stearnsii	1.0	0.2	0.1	180.0	0.5	24.9
Octopus sp.	1.0	0.2	0.1	90.0	0.2	12.5
Eualis barbata	8.0	1.6	1.1	56.0	0.2	7.8
Lopholithodes foraminatus	55.0	10.7	7.6	25400.0	70.2	3518.0
Chionoecetes bairdi	45.0	8.8	6.2	5890.0	16.3	818.8
Laqueus californianus	5.0	1.0	0.7	15.0	0.0	2.1
Ctenodiscus crispatus	136.0	26.6	18.8	1360.0	3.8	188.4
Allocentrotus fragilis	13.0	2.5	1.8	520.0	1.4	72.0
Strongylocentrotus droebachiensis	1.0	0.2	0.1	30.0	0.1	4.2
Ophiura sarsi	150.0	29.3	20.8	900.0	2.5	124.7
VERTEBRATES						
Atheresthes stomias	-	-	-	249480.0	57.2	34554.0

Appendix Table 8 (continued)

TAXON	COUNT No.	COUNT %	COUNT Per km	WET WEIGHT (gm) Total	WET WEIGHT (gm) %	WET WEIGHT (gm) Per km
VERTEBRATES (continued)						
Hippoglossoides elassodon	-	-	-	186880.0	42.8	25883.7

COMMENTS

Lopholithodes foraminatus - 48 males and 7 females

Appendix Table 9

TOW NUMBER 100; STATION NUMBER 89-A; PERCENT SAMPLED = 100.

Date Yr Mo Da	Time Hr/Min	Start Latitude Deg Min	Start Longitude Deg Min	Finish Latitude Deg Min	Finish Longitude Deg Min	Time Fished Min	Time Zone	Distance Fished (km)	Depth Fished (m)
75 7 12	1455	60 1.0	143 1.0	60 0.	142 55.0	60	9	5.74	67.3-71.0

TAXON	COUNT No.	COUNT %	COUNT Per km	WET WEIGHT (gm) Total	WET WEIGHT (gm) %	WET WEIGHT (gm) Per km
Eunoe depressa	1.0	0.2	0.2	1.0	0.0	0.2
Aphrodita sp.	2.0	0.3	0.3	12.0	0.0	2.1
Aphrodita japonica	1.0	0.2	0.2	10.0	0.0	1.7
Nuculana fossa	13.0	2.1	2.3	13.0	0.0	2.3
Pecten caurinus	3.0	0.5	0.5	1050.0	0.9	182.9
Astarte polaris	12.0	2.0	2.1	120.0	0.1	20.9
Natica clausa	3.0	0.5	0.5	36.0	0.0	6.3
Polinices monteronis	2.0	0.3	0.3	80.0	0.1	13.9
Buccinum plectrum	2.0	0.3	0.3	40.0	0.0	7.0
Beringius kennicotti	45.0	7.3	7.8	4950.0	4.3	862.4
Colus halli	2.0	0.3	0.3	36.0	0.0	6.3
Neptunea lyrata	180.0	29.3	31.4	32400.0	28.1	5644.6
Neptunea pribiloffensis	2.0	0.3	0.3	360.0	0.3	62.7
Pagurus ochotensis	39.0	6.3	6.8	3510.0	3.0	611.5
Pagurus aleuticus	24.0	3.9	4.2	2640.0	2.3	459.9
Pagurus kennerly	12.0	2.0	2.1	1320.0	1.1	230.0
Pagurus confragosus	130.0	21.1	22.6	14300.0	12.4	2491.3
Elassochirus tenuimanus	11.0	1.8	1.9	1320.0	1.1	230.0
Elassochirus cavimanus	4.0	0.7	0.7	440.0	0.4	76.7
Labidochirus splendescens	1.0	0.2	0.2	50.0	0.0	8.7
Oregonia gracilis	1.0	0.2	0.2	180.0	0.2	31.4
Hyas lyratus	13.0	2.1	2.3	2340.0	2.0	407.7
Chionoecetes bairdi	103.0	16.7	17.9	46350.0	40.2	8074.9

Appendix Table 9 (continued)

TAXON	COUNT No.	COUNT %	COUNT Per km	WET WEIGHT (gm) Total	WET WEIGHT (gm) %	WET WEIGHT (gm) Per km
Pseudarchaster parelii	1.0	0.2	0.2	90.0	0.1	15.7
Luidia foliolata	3.0	0.5	0.5	1350.0	1.2	235.2
Pycnopodia helianthoides	5.0	0.8	0.9	2250.0	2.0	392.0
VERTEBRATES						
Raja binoculata	-	-	-	51250.0	18.3	8928.6
Raja rhina	-	-	-	10430.0	3.7	1817.1
Raja stellulata	-	-	-	24490.0	8.7	4266.6
Gadus macrocephalas	-	-	-	91170.0	32.5	15883.3
Theragra chalcogramma	-	-	-	37190.0	13.3	6479.1
Atheresthes stomias	-	-	-	12700.0	4.5	2212.5
Glyptocephalus zachirus	-	-	-	48080.0	17.2	8376.3
Hippoglossoides elassodon	-	-	-	4980.0	1.8	867.6

COMMENTS

Hermit crabs weighed with shell. Pollutants were not recorded.

Appendix Table 10

TOW NUMBER 89; STATION NUMBER 93-C; PERCENT SAMPLED = 100.

Date Yr Mo Da	Time Hr/Min	Start Latitude Deg Min	Start Longitude Deg Min	Finish Latitude Deg Min	Finish Longitude Deg Min	Time Fished Min	Time Zone	Distance Fished (km)	Depth Fished (m)
75 7 9	1550	59 51.0	142 3.0	59 50.0	141 57.0	60	9	5.55	81.9-85.5

TAXON	COUNT No.	COUNT %	COUNT Per km	WET WEIGHT (gm) Total	WET WEIGHT (gm) %	WET WEIGHT (gm) Per km
INVERTEBRATES						
Actiniidae	2.0	0.3	0.4	180.0	0.1	32.4
Pecten caurinus	290.0	44.6	52.3	101500.0	52.5	18288.3
Cyclocardia ventricosa	1.0	0.2	0.2	4.0	0.0	0.7
Compsomya subdiaphana	1.0	0.2	0.2	4.0	0.0	0.7
Fusitriton oregonensis	1.0	0.2	0.2	70.0	0.0	12.6
Rocinela augustata	1.0	0.2	0.2	1.0	0.0	0.2
Pandalus borealis	1.0	0.2	0.2	4.0	0.0	0.7
Pandalus montagui tridens	6.0	0.9	1.1	50.0	0.0	9.0
Pandalus platyceros	1.0	0.2	0.2	45.0	0.0	8.1
Crangon communis	2.0	0.3	0.4	14.0	0.0	2.5
Argis ovifer	1.0	0.2	0.2	4.0	0.0	0.7
Pagurus ochotensis	1.0	0.2	0.2	90.0	0.0	16.2
Pagurus confragosus	2.0	0.3	0.4	180.0	0.1	32.4
Lopholithodes foraminatus	1.0	0.2	0.2	420.0	0.2	75.7
Chionoecetes bairdi	9.0	1.4	1.6	4050.0	2.1	729.7
Ctenodiscus crispatus	100.0	15.4	18.0	1000.0	0.5	180.2
Pycnopodia helianthoides	190.0	29.2	34.2	85500.0	44.2	15405.4
Ophiura sarsi	40.0	6.2	7.2	240.0	0.1	43.2

Appendix Table 10 (continued)

TAXON	COUNT No.	COUNT %	COUNT Per km	WET WEIGHT (gm) Total	WET WEIGHT (gm) %	WET WEIGHT (gm) Per km
VERTEBRATES						
Raja stellulata	-	-	-	4980.0	1.9	897.3
Gadus macrocephalas	-	-	-	20380.0	7.8	3672.1
Theragra chalcogramma	-	-	-	138160.0	52.8	24893.7
Atheresthes stomias	-	-	-	59110.0	22.6	10650.5
Hippoglossoides elassodon	-	-	-	17660.0	6.8	3182.0
Hippoglossus stenolepis	-	-	-	21290.0	8.1	3836.0

COMMENTS

Hermit crabs weighed with shells. *Pycnopodia helianthoides* feeding on *Ophiura sarsi* and *Ctenodiscus crispatus*. Pollutants were not recorded.

Appendix Table 11

TOW NUMBER 54; STATION NUMBER 94-A; PERCENT SAMPLED = 60.

(All counts and weights are projected to 100% of the sample).

Date Yr Mo Da	Time Hr/Min	Start Latitude Deg Min	Start Longitude Deg Min	Finish Latitude Deg Min	Finish Longitude Deg Min	Time Fished Min	Time Zone	Distance Fished (km)	Depth Fished (m)
75 6 3	0950	59 54.0	141 47.0	59 55.0	141 48.0	30	9	2.96	27.3-29.1

TAXON	COUNT No.	COUNT %	COUNT Per km	WET WEIGHT (gm) Total	WET WEIGHT (gm) %	WET WEIGHT (gm) Per km
INVERTEBRATES						
Pagurus aleuticus	6.7	50.0	2.3	750.0	20.0	253.4
Chionoecetes bairdi	3.3	25.0	1.1	1500.0	40.0	506.8
Cancer magister	3.3	25.0	1.1	1500.0	40.0	506.8
VERTEBRATES						
Theragra chalcogramma	-	-	-	127000.0	14.4	42905.4
Isopsetta isolepis	-	-	-	27200.0	3.1	9189.2
Platichthys stellatus	-	-	-	725750.0	82.5	245185.8

COMMENTS

All female *Cancer magister* had purple eggs with orange eyes. Weights of *Pagurus aleuticus* include their shells.

Appendix Table 12

TOW NUMBER 53; STATION NUMBER 94-B; PERCENT SAMPLED = 12.

(All counts and weights are projected to 100% of the sample).

Date Yr Mo Da	Time Hr/Min	Start Latitude Deg Min	Start Longitude Deg Min	Finish Latitude Deg Min	Finish Longitude Deg Min	Time Fished Min	Time Zone	Distance Fished (km)	Depth Fished (m)
75 6 3	0730	59 50.0	141 42.0	59 52.0	141 46.0	60	9	5.55	58.2-61.8

TAXON	COUNT No.	COUNT %	COUNT Per km	WET WEIGHT (gm) Total	WET WEIGHT (gm) %	WET WEIGHT (gm) Per km
INVERTEBRATES						
Eunephthya rubiformis	0.	0.	0.	3750.0	71.4	675.7
Chionoecetes bairdi	100.0	100.0	18.0	1500.0	28.6	270.3
VERTEBRATES						
Theragra chalcogramma	-	-	-	544250.0	12.6	98063.1
Isopsetta isolepis	-	-	-	215416.7	5.0	38813.8
Platichthys stellatus	-	-	-	3549416.7	92.4	639534.5

COMMENTS

All *Theragra chalcogramma* was approximately 10 cm long. *Platichthys stellatus* stomachs examined - all stomachs were full of three clams, *Yoldia seminuda, siliqua sloati*, and *Macoma dexiosttera*.

Appendix Table 13

TOW NUMBER 78; STATION NUMBER 97-C; PERCENT SAMPLED = 100.

Date Yr Mo Da	Time Hr/Min	Start Latitude Deg Min	Start Longitude Deg Min	Finish Latitude Deg Min	Finish Longitude Deg Min	Time Fished Min	Time Zone	Distance Fished (km)	Depth Fished (m)
75 7 5	1410	59 30.0	141 3.0	59 32.0	140 58.0	60	8	5.93	252.9-254.8

TAXON	COUNT No.	COUNT %	COUNT Per km	WET WEIGHT (gm) Total	WET WEIGHT (gm) %	WET WEIGHT (gm) Per km
Actiniidae	104.0	0.5	17.5	2630.0	1.1	443.5
Hirudinae	1.0	0.0	0.2	1.0	0.0	0.2
Fusitriton oregonensis	70.0	0.3	11.8	850.0	0.4	143.3
Neptunea pribiloffensis	7.0	0.0	1.2	1040.0	0.4	175.4
Tritonia exsulans	91.0	0.4	15.3	1365.0	5.7	2301.9
Gonatidae	12.0	0.1	2.0	270.0	0.1	45.5
Octopus sp.	1.0	0.0	0.2	90.0	0.0	15.2
Pandalopsis dispar	10.0	0.0	1.7	450.0	0.2	75.9
Eualis barbata	1.0	0.0	0.2	4.0	0.0	0.7
Eualis macrophthalma	21.0	0.1	3.5	180.0	0.1	30.4
Crangon communis	21.0	0.1	3.5	140.0	0.1	23.6
Pagurus confragosus	4.0	0.0	0.7	440.0	0.2	74.2
Chionoecetes bairdi	2.0	0.0	0.3	450.0	0.2	75.9
Hippasterias spinosa	1.0	0.0	0.2	220.0	0.1	37.1
Pseudarchaster parelii	16.0	0.1	2.7	1450.0	0.6	244.5
Ctenodiscus crispatus	80.0	0.4	13.5	1350.0	0.5	227.7
Pycnopodia helianthoides	3.0	0.0	0.5	1350.0	0.6	227.7
Brisaster townsendi	21273.0	97.9	3587.4	212730.0	89.6	35873.5
Holothuroidea	2.0	0.0	0.3	90.0	0.0	15.2
Molpadia sp.	2.0	0.0	0.3	90.0	0.0	15.2

Appendix Table 13 (continued)

TAXON	COUNT No.	COUNT %	COUNT Per km	WET WEIGHT (gm) Total	WET WEIGHT (gm) %	WET WEIGHT (gm) Per km
VERTEBRATES						
Squalus acanthias	-	-	-	49370.0	9.2	8325.5
Raja binoculata	-	-	-	41670.0	7.8	7027.0
Sebastes alutus	-	-	-	4070.0	0.8	686.3
Sebastolobus alascanus	-	-	-	81080.0	15.2	13672.8
Atheresthes stomias	-	-	-	138390.0	25.9	23337.3
Glyptocephalus zachirus	-	-	-	101920.0	19.1	17187.2
Microstomus pacificus	-	-	-	82670.0	15.5	13941.0
Platichthys stellatus	-	-	-	35560.0	6.7	5996.6

COMMENTS

Hermit crabs weighed with shell. Pollutants were not recorded.

Appendix Table 14

TOW NUMBER 70; STATION NUMBER 99-D; PERCENT SAMPLED = 100.

Date Yr Mo Da	Time Hr/Min	Start Latitude Deg Min	Start Longitude Deg Min	Finish Latitude Deg Min	Finish Longitude Deg Min	Time Fished Min	Time Zone	Distance Fished (km)	Depth Fished (m)
75 7 2	1635	59 25.0	140 29.0	59 25.0	140 32.0	60	8	5.55	141.9-154.7

TAXON	COUNT No.	COUNT %	COUNT Per km	WET WEIGHT (gm) Total	WET WEIGHT (gm) %	WET WEIGHT (gm) Per km
INVERTEBRATES						
Actiniidae	8.0	0.1	1.4	1810.0	0.2	326.1
Euphrosine hortensis	1.0	0.0	0.2	1.0	0.0	0.2
Crucigera irregularis	1.0	0.0	0.2	1.0	0.0	0.2
Aphrodita japonica	14.0	0.3	2.5	630.0	0.1	113.5
Fusitriton oregonensis	26.0	0.5	4.7	1990.0	0.2	358.6
Neptunea lyrata	20.0	0.4	3.6	2260.0	0.3	407.2
Pyrulofusus harpa	14.0	0.3	2.5	3170.0	0.4	571.2
Arctomelon stearnsii	14.0	0.3	2.5	1580.0	0.2	284.7
Dorididae	80.0	1.5	14.4	14490.0	1.7	2610.8
Octopus sp.	26.0	0.5	4.7	2340.0	0.3	421.6
Pandalus montagui tridens	429.0	8.0	77.3	3400.0	0.4	612.6
Spirontocaris arcuata	14.0	0.3	2.5	90.0	0.0	16.2
Argis ovifer	102.0	1.9	18.4	510.0	0.1	91.9
Elassochirus cavimanus	13.0	0.2	2.3	580.0	0.1	104.5
Acantholithodes hispidus	1.0	0.0	0.2	10.0	0.0	1.8
Lopholithodes foraminatus	40.0	0.7	7.2	16800.0	2.0	3027.0
Munida quadrispina	45.0	0.8	8.1	240.0	0.0	43.2
Oregonia gracilis	10.0	0.2	1.8	1800.0	0.2	324.3
Hyas lyratus	140.0	2.6	25.2	12680.0	1.5	2284.7
Chionoecetes bairdi	20.0	0.4	3.6	2260.0	0.3	407.2

Appendix Table 14 (continued)

TAXON	COUNT No.	COUNT %	COUNT Per km	WET WEIGHT (gm) Total	WET WEIGHT (gm) %	WET WEIGHT (gm) Per km
Chorilia longipes	10.0	0.2	1.8	600.0	0.1	108.1
Dipsacaster borealis	14.0	0.3	2.5	630.0	0.1	113.5
Ceramaster patagonicus	30.0	0.6	5.4	2710.0	0.3	488.3
Pseudarchaster parelii	200.0	3.7	36.0	18120.0	2.1	3264.9
Henricia aspera	653.0	12.2	117.7	59160.0	6.9	10659.5
Diplopteraster multipes	78.0	1.5	14.1	11770.0	1.4	2120.7
Crossaster papposus	40.0	0.7	7.2	3620.0	0.4	652.3
Lophaster furcilliger	4.0	0.1	0.7	450.0	0.1	81.1
Solaster dawsoni	40.0	0.7	7.2	9060.0	1.1	1632.4
Allocentrotus fragilis	41.0	0.8	7.4	1640.0	0.2	295.5
Strongylocentrotus droebachiensis	92.0	1.7	16.6	2760.0	0.3	497.3
Gorgonocephalus caryi	20.0	0.4	3.6	4530.0	0.5	816.2
Ophiura sarsi	400.0	7.4	72.1	900.0	0.1	162.2
Cucumariidae	2600.0	48.4	468.5	650000.0	76.2	117117.1
Halocynthia aurantium	130.0	2.4	23.4	20300.0	2.4	3657.7
VERTEBRATES						
Raja binoculata	-	-	-	15400.0	3.2	2774.8
Raja stellulata	-	-	-	10870.0	2.3	1958.6
Gadus macrocephalas	-	-	-	78140.0	16.4	14079.3
Sebastolobus alascanus	-	-	-	94220.0	19.8	16976.6
Sebastes alutus	-	-	-	27180.0	5.7	4897.3
Atheresthes stomias	-	-	-	219700.0	46.2	39585.6
Glyptocephalus zachirus	-	-	-	30500.0	6.4	5495.5

COMMENTS

Hermit crabs weighed with shell. *Crucigera irregularis* present on snail shell. Pollutants were not recorded.

REPRODUCTIVE SUCCESS IN DUNGENESS CRAB (*CANCER MAGISTER*) DURING LONG-TERM EXPOSURES TO OIL-CONTAMINATED SEDIMENTS

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ABSTRACT

Dungeness crab (*Cancer magister*) habitat in the nearshore waters of Alaska may be at risk from oil pollution. Transport of crude oil and expanded exploratory drilling in Alaskan waters increase the likelihood of accidental contamination of coastal sediments, and oil adsorbed by the sediments is likely to persist for years in subarctic and arctic waters. In contrast to other commercially important Alaskan crabs, Dungeness crabs completely bury themselves, particularly when spawning and incubating their eggs. Therefore, their eggs are in direct contact with sediments for extended periods and are vulnerable to any xenobiotics contaminating the habitat.

In Phase 1 of this study, we exposed adult female crabs to three dose levels of oiled sediments for one complete reproductive cycle (10 months) to determine effects on survival, uptake of hydrocarbons, hatching success, and viability of larvae. Each exposure tank, supplied with clean, flowing seawater, held nine female crabs on 15 cm of sediment with 0, 1.2, 3.7, or 8.6 μl Cook Inlet crude oil per gram of sediment. The doses and controls were run in triplicate. The crabs were monitored daily for survival and behavior. Hatching began in mid-April, and larvae were captured in a trap attached to the outlet of each tank. At three different times during the hatching period, we held larvae, in triplicate from each dose, in tubes to determine viability.

Dosed crabs produced significantly ($0.025 < P < 0.05$) lower numbers of larvae than control crabs. Control crabs produced a mean of 368,700 larvae/crab, and the low, mid, and high doses produced 225,500, 303,900, and 268,100 larvae/crab, respectively. Larvae from the high-dose tanks survived for significantly ($P < 0.005$) shorter periods (3.1 days) than larvae from the control tanks and low- and mid-dose tanks (5.3 days). Eggs from crabs in the high-dose tanks had significantly elevated levels of aromatic and aliphatic hydrocarbons, compared with eggs from crabs in control tanks.

In Phase 2, a subsequent 4-month experiment, we studied the effects of oiled-sediment exposures on mating and molting. Some of the females used in Phase 1 were continued in the Phase 2 exposures. The experimental tanks contained old (held over from Phase 1) control, old mid-dose, old high-dose, fresh high-dose, and new control sediments. Female crabs from Phase 1 exposures and previously unexposed male crabs were used in the old sediment tanks. Previously unexposed male and female crabs were placed on new sediments. All experimental conditions were triplicate except for the new control tank.

Clasping behavior and successful molting were low in all old-dose experimental conditions, and completely absent in crabs in the new high-dose tanks, but occurred in 75% of the pairs in the new control tank. The low rate of clasping and molting in all old,

14-month exposures was probably caused by a combination of confinement, diet, and oil. The briefer, 4-month exposure to freshly oiled sediment completely inhibited clasping behavior and molting.

Fifty-five percent of the female crabs that had not molted subsequently spawned and established fertile clutches. At the termination of the exposures, examination revealed the presence of fresh sperm in the spermathecas of over 90% of the females, indicating these females had copulated in the hard-shelled condition. We believe that spawning without molting is an adaptive response for using energy reserves that may have been depleted by a combination of stressors.

Exposure to oiled sediments results in lowered reproductive activity in Dungeness crabs, and the larvae produced are not as robust, as indicated by significantly shorter survival times, compared with control larvae. Therefore, over a period of time, the presence of oil in the habitat substrate may lower population densities.

TABLE OF CONTENTS

INTRODUCTION

The benthos is the ultimate sink for hydrocarbons in the marine environment. Oil may be introduced to the benthos directly in submarine spills, such as the *Ixtoc I* spill, or indirectly from surface spills (Jordan and Payne 1980; Karinen 1980; MacKay et al. 1981). Once hydrocarbons reach the sediments, they may persist for years (Burns and Teal 1979; Haines and Atlas 1982). Krebs and Burns (1977) followed the West Falmouth oil spill and found deleterious effects on *Uca pugnax* populations for as long as 7 years after the spill.

The potential for oil pollution to occur in productive benthic sediments in Alaska is great. Cook Inlet has had producing oil wells since 1958, and tankers have been transporting crude oil from the North Slope through Alaskan waters since 1977. In more recent years, active exploratory drilling has been expanded to several nearshore and offshore areas in Alaskan waters.

At some time during their life cycles, many marine organisms of commercial importance reside on, bury in, or have other interaction with sediments. Invertebrate eggs, larvae, juveniles, and adults accumulate hydrocarbons during extended periods of exposure to oil (Brodersen et al. 1977; Rice et al. 1983). Eggs carried by crabs are in close proximity to sediments, and are buried in sediments when the female burrows. Dungeness crabs (*Cancer magister*), particularly ovigerous females, spend much of their time buried. This behavior increases the chance that hydrocarbons incorporated in sediments and in interstitial waters may enter the eggs or the body of the crab or both and affect development of internally or externally carried eggs. Hydrocarbons may affect reproduction directly, by killing developing eggs and larvae; or indirectly, by increasing overall energy demands and causing a consequent reduction in production of gonad material.

Previous studies at the Auke Bay Laboratory (Karinen et al. 1983; Rice et al. 1983) on oiled-sediment interaction with juvenile king crabs (*Paralithodes camtschatica*) and ovigerous Tanner crabs (*Chionoecetes bairdi*) indicated no effects of oiled sediments on survival and reproduction but showed significant tissue uptake of hydrocarbons. Juvenile king crabs and adult Tanner crabs rarely bury themselves, so the whole body and developing eggs do not directly contact the sediments. In contrast, developing eggs of Dungeness crabs may be in direct contact with sediments for the entire incubation period (about 6 months).

Our objectives in Phase 1 of this study were to determine the effects of long-term (10-month) exposures to oil-contaminated sediments on survival, hatching success, and viability of larvae; and in Phase 2, to determine effects of 4- and 14-month exposures to oil-contaminated sediments on molting and mating.

METHODS

Phase 1 of the oil-sediment exposures was started with mature female Dungeness crabs (*Cancer magister*) in August 1983 and ended in early July 1984. Phase 2 of these exposures, using both female and male crabs, began in July 1984 and terminated in early November 1984. Some of the females from Phase 1 were used in the Phase 2 exposures.

Phase 1

The crabs were exposed in 12 loosely covered Living Stream tanks (208×60×60 cm) consisting of triplicate controls and doses. Each tank had seawater flowing through it at 3 liters/min, allowing for a complete exchange of water every 2.2 hours. Temperature (Fig. 1), light, and oxygen levels were not controlled but approximated natural environmental conditions.

We obtained sediment from the Auke Bay Recreation Area, near Juneau, Alaska, using a 7-inch by 2-foot dredge. This area is relatively pristine and is known to contain Dungeness crabs. Upon collection, the macrobenthos was removed, and the sediment was frozen in 5-gal buckets until needed. Four days before dosing, the sediment was allowed to thaw.

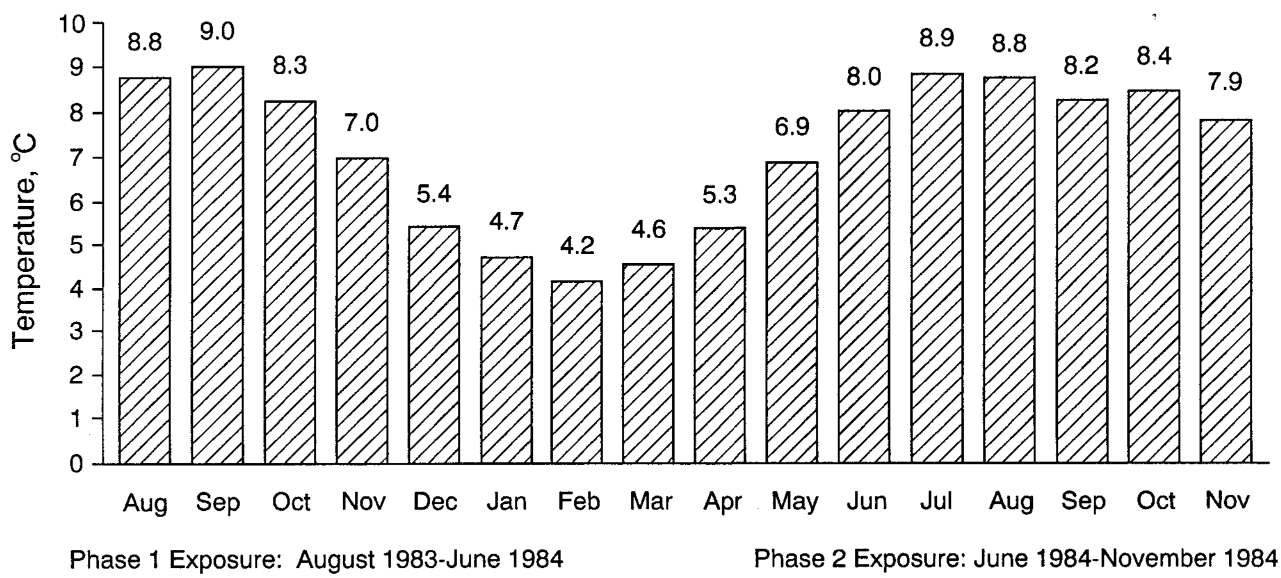

Figure 1.—Average seawater temperatures in Dungeness crab (*Cancer magister*) exposure tanks.

Nominal dosing levels were 0 (controls), 0.20, 0.80, and 2.00% v/v Cook Inlet Crude oil/sediment. The 2% dose was the maximum that the sediment could retain and hold. These doses were chosen because, after initial settling and evaporation, they should have approximated hydrocarbon levels which might be expected in the environment. Sediment (90%), sand (10%), and Cook Inlet crude oil in the appropriate amount were mixed in a portable cement mixer. Additional sand was used to prevent compaction that had occurred in a prior sediment exposure system. The particle composition of the sediment mixture was 11.6% gravel, 79.4% sand, 5.3% silt, and 3.7% clay. (The sediment was analyzed by Battelle-Northwest Research Laboratory, Sequim, WA.) The mixture was then placed in the bottom of the exposure tanks to a depth of about 15 cm. Selection of dosed tanks was random. We let the tanks condition with clean seawater flowing through them for 4 days, before introducing the test animals.

Recently molted, barren, but presumably mated, mature female Dungeness crabs were obtained by pot fishing or by divers in the Juneau or Sitka areas and held at the Auke Bay Laboratory in clean, flowing seawater at least 1 week prior to the exposures. Randomly selected, healthy crabs were examined for missing limbs and general condition, weighed, and measured, and spines were clipped in binary code (for individual identification), before crabs were placed in the exposure tanks. Exposures began with eight crabs per tank. A ninth crab was added later for measurement of hydrocarbon uptake in several tissues. They were fed chopped herring until satiated one or two times per week.

The sediment was analyzed by infrared spectrophotometry (IR) in August and November 1983 and in May 1984. Sediment was sampled from three locations in each tank, and the samples were analyzed individually (nine analyses per dose). The August 1983 samples (after 4 days of dosing and before we added the crabs) were a composite top and bottom sample (sediments were homogeneous at that time). Subsequent samples were divided into top and bottom portions, the top samples representing the top 2 cm of a 10-cm core. An aqueous slurry of each sample was extracted into Freon, and its absorbance at 2930 nm was measured by IR.

We monitored the crabs daily for survival, egg extrusion, and behavior (particularly burying activity). The location of each crab was noted, and a code of 1 (on top), 2 (partially buried), or 3 (completely buried) was assigned to indicate the depth of each crab. General activity levels and unusual behavior were also noted. Disturbance and handling of individual crabs were kept to a minimum.

At bimonthly intervals, egg samples were taken and fixed in Gilson's fluid for later examination. We used an adaptation of Boolootian's (1959) scheme of egg development stages to assess embryonic progress (see Appendix).

Starting in mid-April 1984, we measured hatching success and larval viability. Zoeae were captured in 10-inch circular, fine-mesh net traps that were attached to each tank outlet. Daily production from each tank was filtered and dried at 60°C to a constant weight (usually 24 hours). The dried weight was then divided by the number of gravid females in that tank to give production/crab. Individual larval weight was calculated by filtering a small number (200–500) of larvae, drying as above, weighing, and counting them. There were six replicates. The dry weight of a single larva was calculated to be 3.2×10^{-5}. We determined the number of larvae hatched by dividing the production weight by the weight of one larva. In the ANOVA analysis of the production data, we used a Y^2 transformation of larval production to overcome variance heterogeneity. Variance increased with decreased production and increased dose level.

Hatching was essentially completed by early July 1984, when the Phase 2 exposures began.

Larval viability was tested three different times during the hatching period. We tested viability by measuring survival time of unfed larvae. Twelve to fifteen larvae from each dose were carefully pipetted from a swarm in an exposure tank to a test tube (2.5×12.0 cm) filled with seawater (50 ml). Triplicate tubes were run for each dose. All tubes were placed in a rack in a flowing seawater bath. The temperature of the water was not controlled; it ranged from 5.6°C in April to 8.7°C in June. We examined the tubes daily for activity and survival and assigned a category reflecting each individual's activity pattern:

Swimming: in the water column.

On Bottom: alive and responsive to stimuli.

Opaque: dead.

In January 1984 and again in June 1984, we sacrificed one crab from each tank (three crabs per dose) for hydrocarbon analysis of various tissues. Gills, eggs, ovarian tissue, digestive gland (hepatopancreas), and muscle were frozen for later analysis of aromatic hydrocarbons. Samples were weighed, heated, digested in 10N NaOH, and extracted in hexane. The hexane extract was run through a silica gel column to separate the aliphatic fraction from the aromatic fraction. These fractions were then concentrated and analyzed by capillary column gas chromatography.

Standard statistical analyses, including means, 95% confidence intervals, and analyses of variance, were done where appropriate.

Phase 2

This phase of the study began in July 1984 and ended in November 1984. Our objectives were to determine the effects of exposure to oiled sediment on molting and mating.

Because the dose levels of oil in the sediment were stable during the Phase 1 long-term exposures (see Fig. 2), we used the three old (held over from Phase 1) control, three high-dose (2.0%), and three mid-dose (0.80%) tanks as part of the experimental design. In addition, we had one new control tank and three new, freshly oiled, high-dose (2%) tanks. Females in the holdover tanks were retained in their respective tanks insofar as possible for this phase. All male crabs and new females for the four new tanks were obtained from local waters 2 weeks before the beginning of these exposures.

The tanks were divided into four sections, each containing one male and one female, for a total of 52 pairs. We monitored the crabs daily, as described for Phase 1, paying particular attention to evidence of clasping which occurs prior to molting.

At the termination of the exposures in November, three females from each tank were sacrificed and tissues were frozen for aromatic hydrocarbon analyses, as described above.

RESULTS

Physical Parameters

Temperatures ranged from a low of 4.0°C in February 1984, during the Phase 1 exposures, to a high of 11.2°C in August 1984, during the Phase 2 exposures (Fig. 1). Although the temperature varied as much as 0.8°C from day to day, variation among tanks on any given day was <0.3°C. Oxygen levels in the seawater throughout the exposures approached saturation level, and salinity ranged from 28 to 30 ppt.

Sediment Hydrocarbons

The levels of oil adsorbed by sediment below 2 cm remained remarkably constant throughout the 10-month exposure period (Fig. 2, Table 1). Hydrocarbon levels in May 1984 (8.38 μl/g, high dose) were very similar to initial levels in August 1983 (8.86 μl/g, high dose), 4 days after dosing and before introduction of the crabs. In contrast,

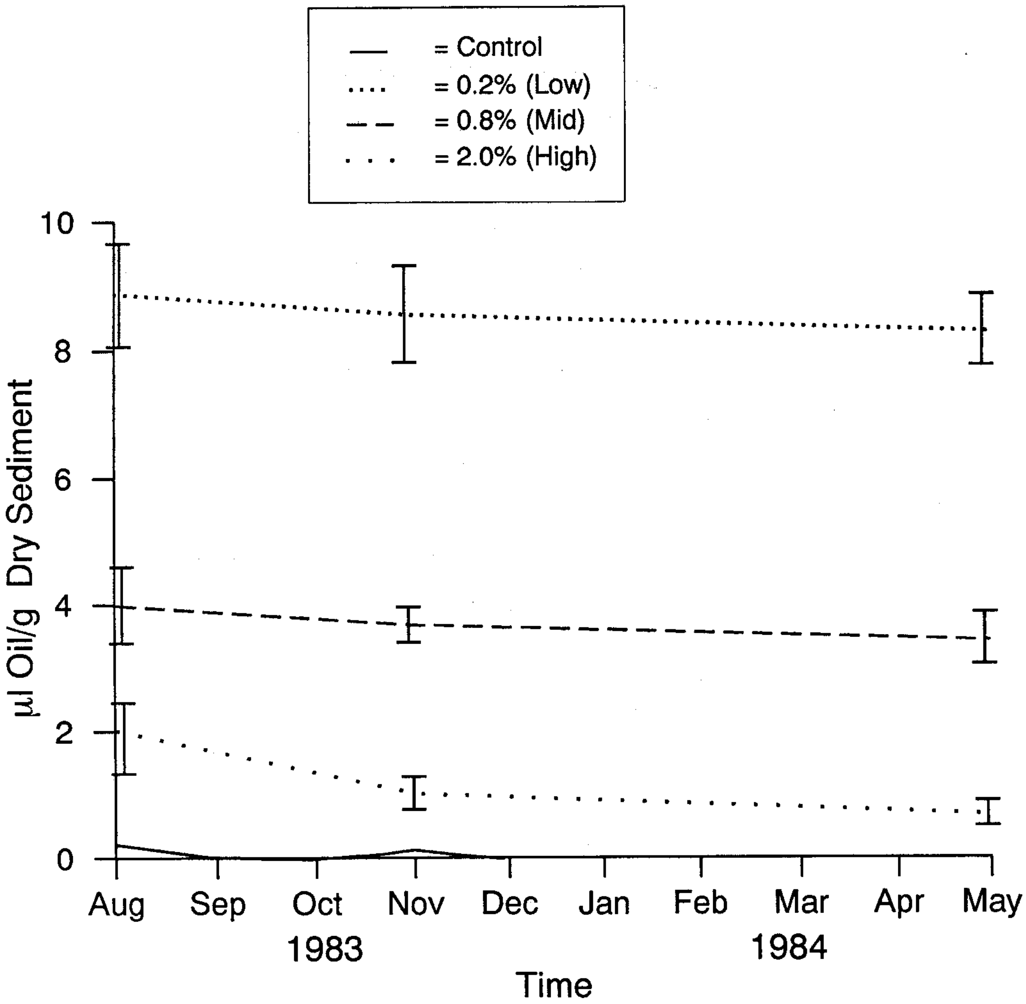

Figure 2.—Total sediment hydrocarbons in Dungeness crab (*Cancer magister*) exposure tanks. The November 1983 and May 1984 samples were taken below 2 cm; the August 1983 sample is a composite. N = 9. (Vertical lines = Standard Error.)

Table 1.—Aromatic hydrocarbons in sediments as measured by infrared spectrophotometry (μl/g oil/sediment). The top samples included the upper 2 cm of sediment; the bottom samples, 2–10 cm. Samples taken in August 1983 were a composite depth sample. Figures are means of triplicate samples within tanks and between tanks of the same dosing level (N = 9). Two-day ANOVA shows significant separation of values.

Dosing level	Top/Bottom	Bottom		Top	
	Aug. 1983	Nov. 1983	May 1984	Nov. 1983	May 1984
Control	0.14	0.13	0.01	0.17	0.05
0.20%	1.93	1.03	0.77	0.47	0.15
0.80%	3.98	3.70	3.55	0.95	0.28
2.00%	8.86	8.53	8.38	1.62	0.78

hydrocarbon levels in the upper 2 cm of sediment decreased with time; levels in May 1984, 9 months after initial dosing, were only 7–15% of the original values (Table 1). Even after several months of exposure, oil slicks were occasionally noted on the water surface of the mid- and high-dose tanks. After 2 months, analysis of the water above the sediments indicated there were no detectable hydrocarbons present.

Phase 1

Survival

There were some mortalities during the 10-month test, but they were not related to oil exposure. Overall survival was 86%; survival among doses varied from 93% in the mid-dose to 82% in the low dose (Fig. 3), but these differences were not statistically significant. Cause of death was usually unknown.

Behavior

The crabs were generally inactive during the day except when feeding; then they would move about the tank. The crabs in the high-dose tanks were hyperactive during the first month of the exposures. Frequency of burying increased after this time and averaged 40–70% in a tank on any given day, with differences being unrelated to dosing levels. Oil in the sediment did not inhibit burying behavior at any of the dosing levels after one month.

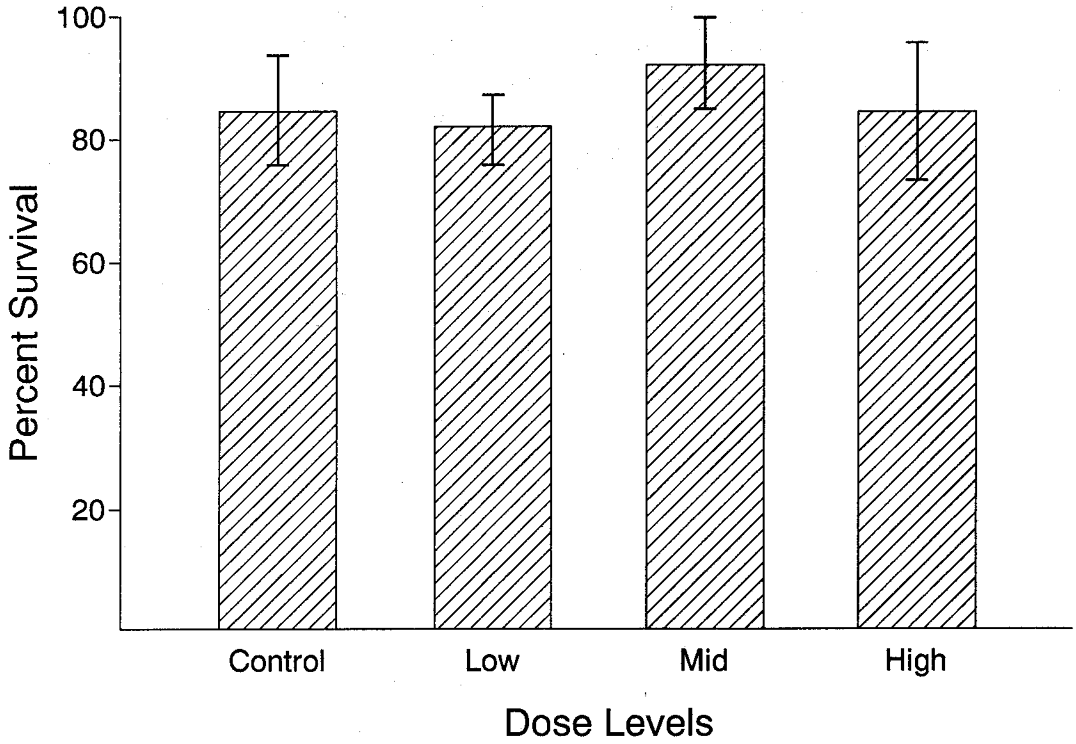

Figure 3.—Survival of female Dungeness crabs (*Cancer magister*) exposed to oiled sediments, August 1983 through June 1984. (Vertical lines = Standard Error.)

Egg Extrusion

Eighty percent of all crabs produced eggs with no significant differences among doses (Table 2). Female Dungeness crabs bury themselves during egg extrusion, and we wanted to disturb them as little as possible; therefore, it was difficult to determine when actual extrusion occurred. Successful establishment of clutches was observed in mid-September (1 month after exposures began) and continued through January 1984. Only five crabs produced clutches which we rated as less than half full (Table 2); all other clutches were assigned a three-fourths full or full rating. None of the crabs lost an entire clutch before hatching began in April 1984, but three crabs lost part of their clutches. Two of these had *Carcinomertes* sp. infestations in the egg masses. Obvious infestations of *Carcinomertes* sp. and nematodes occurred randomly in 10% of all crabs.

Table 2.—Reproductive data for Dungeness crabs (*Cancer magister*) exposed to oiled sediments, August 1983 through June 1984.

Dose level (μl/g)	Mean % gravid (±S.E.)	Number with clutches <½ full	Number with partial clutch loss	Mean dry weight (g) of clutch (±S.E.)	Mean number of larvae
Control	82 ± 10	1	0	11.43 ± 0.44	368,710
Low: 1.24	78 ± 6	2	2	6.99 ± 0.24*	225,480
Mid: 3.74	79 ± 5	1	0	9.42 ± 1.02*	303,870
High: 8.59	79 ± 15	1	1	8.31 ± 1.53*	268,060

* $0.025 < P < 0.05$

Microscopic examination of the eggs for developmental stages revealed a uniformly high (>97%) fertilization success. Developmental stages within an individual clutch were uniform, but there was variation among crabs within a tank.

Larval Production

Control crabs produced significantly ($0.025 < P < 0.05$) more larvae than the dosed crabs (Table 2); however, the reduced production among the dosed crabs was not linear. Control crabs hatched 368,700 larvae/crab, and crabs in the low-, mid-, and high-dose tanks hatched 225,500, 303,900, and 268,100 larvae/crab, respectively. Hatching started in mid-April and continued through the end of June. Time of hatching in the various tanks was unrelated to dosing.

Larval Viability

Larvae from crabs that were in the high-dose tanks lived for significantly shorter periods than larvae from control and lower-dose tanks (Fig. 4). Mean survival time of 50% of the larvae from the control, low-dose, and mid-dose tanks was 5.3 days, while 50% of the larvae from the high-dose tanks lived an average of only 3.1 days. Larvae hatching in the high-dose tanks behaved differently than larvae in the control, low-dose, and mid-dose tanks; they did not form the compact, tightly massed swarms observed in the control and lower-dose tanks.

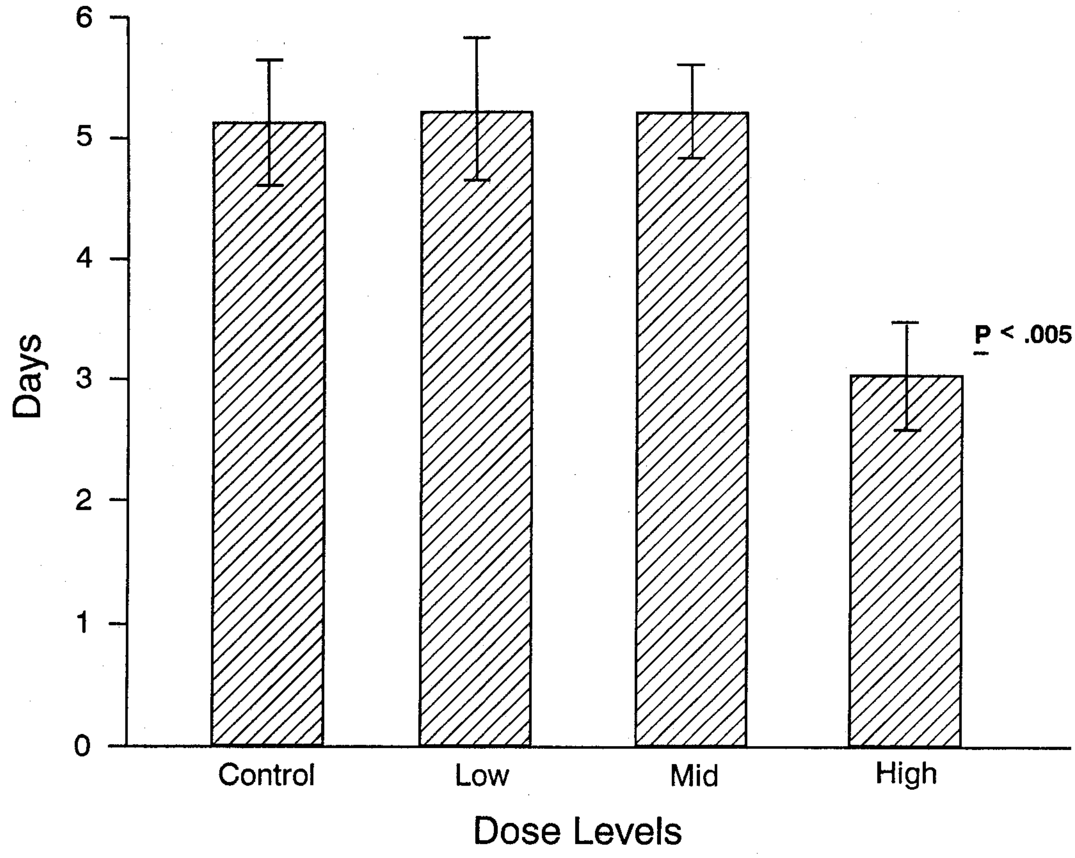

Figure 4.—Mean survival time of 50% of the larvae hatched from Dungeness crabs (*Cancer magister*) exposed to oil sediments. (Vertical lines = Standard Error.)

Hydrocarbon Uptake

Incubating eggs and the digestive gland tissue taken from crabs in the high dose showed significantly greater uptake of hydrocarbons than those from the control crabs (Table 3, Fig. 5). Samples were taken after 4, 10, and 14 months of exposure, but there was no correlation of uptake with time. Ovarian, muscle, and gill tissues showed no differences between control and dosed animals.

Phase 2

This phase began the first week in June and ended the first week in November. Survival of the crabs in both the new and the old high doses was significantly lower than that of control crabs (Table 4).

Table 3.—Mean hydrocarbon levels in tissues from Dungeness crabs (*Cancer magister*) exposed (4–14 months) to oiled sediments (ppm or $\mu g/g$).

Tissue	Dose	N	Mono-aromatics	Di-aromatics	Poly-aromatics	Aliphatics	Total hydro-carbons
Eggs	Control	4	1.0	0.2	0.9	1.8	3.9
	High (8.59 $\mu l/g$)	5	9.8**	13.1***	6.1**	29.0***	32.7**
Digestive gland	Control	13	2.2	1.2	32.2 n.s.	35.6	37.3 n.s.
	High	11	14.1*	5.9**	34.1	52.8*	51.3
Ovary	Control	11	0.7 n.s.	0.1 n.s.	0.8 n.s.	1.6 n.s.	9.9 n.s.
	High	12	0.8	0.2	0.8	1.8	11.8
Muscle	Control	6	0.8 n.s.	0.1 n.s.	0.2 n.s.	1.2 n.s.	0.6 n.s.
	High	6	0.4	0.1	0.1	0.5	0.8
Gill	Control	6	0.5 n.s.	0.2 n.s.	0.7 n.s.	1.4 n.s.	1.5 n.s.
	High	7	0.3	0.2	0.8	1.3	6.2

*** $0.01 < P < 0.025$
** $0.025 < P < 0.05$
* $0.05 < P < 0.10$
n.s. Not significant

Table 4.—Summary of data from female Dungeness crabs (*Cancer magister*) exposed to oiled sediments during the mating and molting phase, July to November 1984.

Dose	Number of females	Females survived (%)	Number of clasping pairs	Number molting	Number with eggs (no molt)	Fertile?
New Control	4	100	3	3	1	yes
Old Control	12	83	2	2	6	yes
Old Mid Dose	13*	87	1	1	3	yes
Old High Dose	13*	70	2	1	7	yes
New High Dose	15*	73	0	0	8	yes

* The crabs that died in July and early August were replaced with other females that had a similar history of exposure/nonexposure.

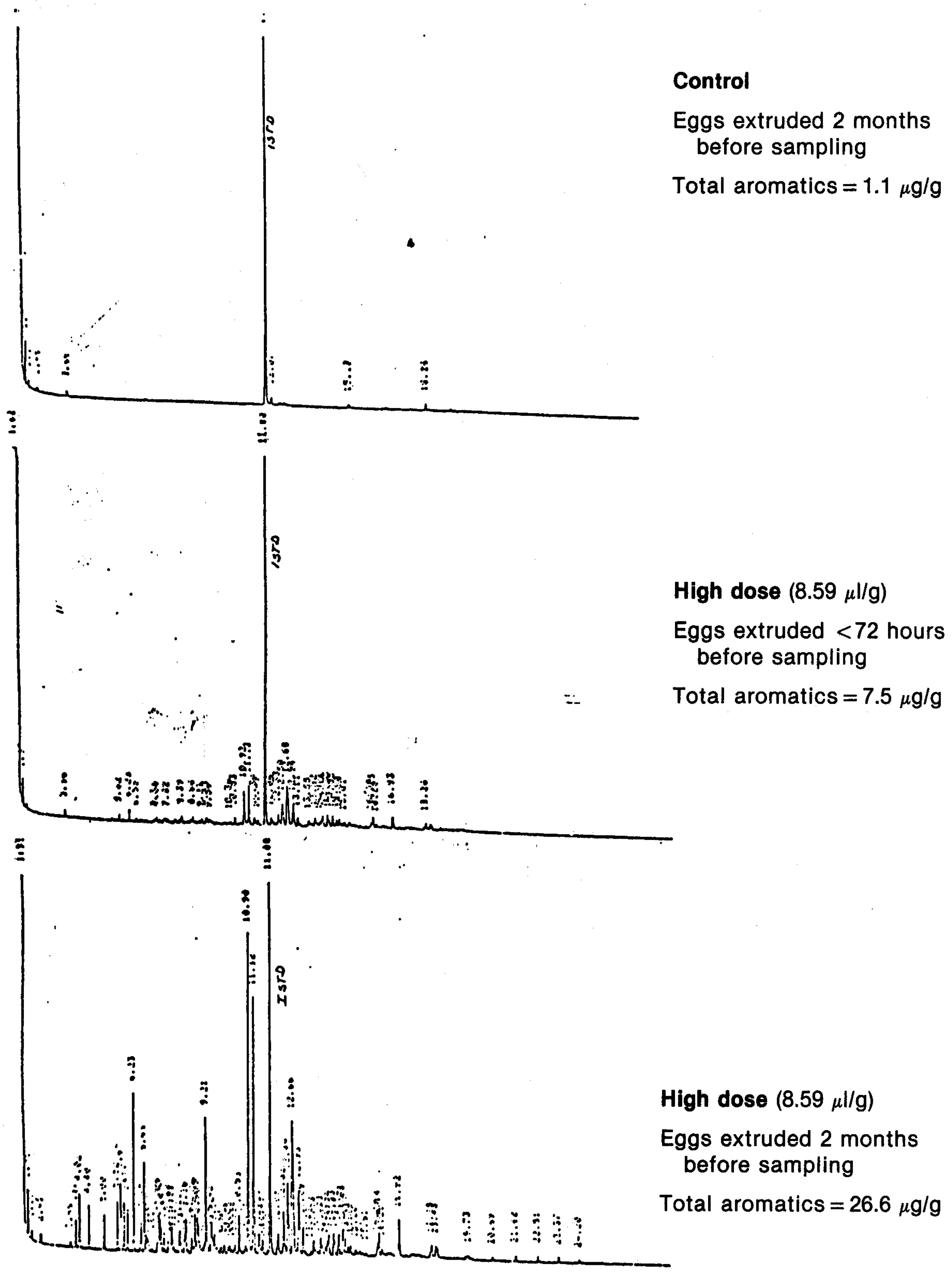

Figure 5.—Gas chromatographic scans of aromatic hydrocarbons in eggs from Dungeness crabs (*Cancer magister*) that had been exposed to oiled sediments for 4 months. Eggs giving the middle scan were not in direct contact with the sediment as long as the eggs shown in the scan below. ISTD = Internal Standard.

Clasping behavior, a prelude to molting in the female, was observed in 8 of the 52 pairs. This behavior preceded actual molting by 3–15 days and occurred from mid-August through the end of the exposures in November. Five of the eight pairs were controls, and none of the pairs in the new high dose ($\sim 8.59\ \mu l/g$) exhibited any clasping or other mating behavior. Seven of the eight females successfully molted; one female in an old high dose died while molting (Table 4).

None of the females that had molted and presumably mated extruded new clutches by the termination of the exposures in November. However, 25 (55%) of the females that had not molted extruded eggs and successfully established fertile clutches (Table 4). Most of the clutches in the females that had already been exposed in Phase 1 were paler than either the first clutches or those of crabs exposed beginning in July 1984. This was undoubtedly due to the absence of carotenoid pigment in their diet.

Copulation was not observed in any of the pairs, but when crabs were sampled in November for hydrocarbon analyses, fresh sperm was observed in >90% of the spermathecas, whether the crab had recently molted or not.

The hydrocarbon uptake data from the November 1984 sampling are included in the Phase 1 section.

DISCUSSION

Sediment Hydrocarbons

The persistence of oil in the sediments in temperate and arctic regions is fairly well documented (Krebs and Burns 1977). This was clearly corroborated in our exposures, which showed no significant losses of hydrocarbons from sediments below 2 cm over a 10-month period. Total hydrocarbons in the upper 2 cm did decline to 7–15% of the original values. Rice et al. (1983) observed greater losses of hydrocarbons in the deeper (15%) sediments during a similar, but shorter, series of oiled-sediment exposures with juvenile king crabs. Because sediment is agitated to a depth of about 6 cm during burying activity of Dungeness crabs, a similar decline in these exposures was expected. The only difference in the sediments between the two experiments was the addition of 10% sand in our exposure to minimize compaction.

Oil slicks on the water surface were seen frequently in the mid- and high-dose tanks at the beginning of the exposures and were observed occasionally throughout the course of the tests, even though there were no detectable hydrocarbons in the water-soluble fraction (WSF) of oil. Burying activity would periodically agitate the sediment and release some hydrocarbons.

Total survival was 86%, with no differences among the experimental groups. A similar series of exposures with Tanner crab (*Chionoecetes bairdi*) that lasted 14 months showed 93% survival (Karinen et al. 1983).

In their natural environment, Dungeness crabs frequently bury themselves in the sediment. During the course of these experiments the crabs buried themselves and remained inactive during the day. Except at the beginning of the experiment, when the animals in the mid- and high-dose tanks were restless, the presence of oil in the sediments did not inhibit this behavior. Olla et al. (1981) did not detect any changes in overall activity levels of Dungeness crabs during their tests with oiled sediments. Similar restlessness at the beginning of the exposures was noted in Tanner crabs (Karinen et al. 1983). The greater activity levels of the crabs in the mid and high doses at the beginning of the exposures was probably due to concentrations being well within the range of the crabs' ability to detect them (Pearson et al. 1980). The gradual disappearance of hydrocarbons from the water column (none detectable after 2 months) coincided with burying behavior identical to that of crabs in the control tanks.

Dungeness crabs may detect and avoid areas of oiled sediments, but Olla et al. (1981) found mixed results in their avoidance tests with oiled sediments and Dungeness crabs. They found that crabs avoided the highly oiled sand but tended to prefer moderately and low-oiled sediments to clean sand. (Their experimental concentrations of oil in sediment were much less than ours: 2,508, 192, and 18 ppm vs. 8,590, 3,740, and 1,240 ppm. Both studies used IR spectrophotometer for analysis.)

The high incidence of successful establishment of clutches, rated mid to full, was virtually identical to that found in a previous study with Tanner crabs (Karinen et al. 1983).

Stage of development of eggs from crabs in the same tank was variable and probably reflects the extended period of egg extrusion and fertilization (September–January) and actual hatching (mid-April to the end of June). In contrast, the stage of eggs in the brood pouches of Tanner crabs was remarkably similar among individuals within the same tank. Hatching of Tanner crab larvae took place over a 4-week period, in contrast to the Dungeness hatching period of less than 10 weeks.

Reduction in total output of larvae per Dungeness crab in the dosed tanks compared to controls contrasted with the results of an earlier series of exposures done by Karinen et al. (1983) with Tanner crabs. There was no difference in amount of larvae hatched in dosed tanks versus controls, and no apparent effect on viability of dosed and control larvae.

However, dosed Tanner larvae swarmed less than controls, similar to behavior observed in Dungeness larvae. Our results also contrasted with those in a study by Ebert et al. (1975). They compared hatching success (expressed as viable larvae released) in individual crabs taken from San Francisco Bay (polluted area) with crabs taken near Eureka-Crescent City, California (a relatively pristine area). Although hatching success in crabs from the Eureka-Crescent City area was greater (90% vs. 80%), this difference was not statistically significant. They used larval counts from a total of only 15 animals, and high variability seen in individual animals probably masked any difference in production from the two areas.

Shorter survival times for larvae from the high-dose tanks compared to control larvae indicate that the dosed larvae had lower energy reserves and were weakened. Viability tests done on Tanner crab larvae following hatching from similar exposure tests showed no difference between dosed and control larvae (Karinen et al. 1983).

Uptake of hydrocarbons in the egg masses of crabs exposed to the high dose is not surprising because of the close physical contact between the eggs and the oil present in the sediments. Direct uptake of hydrocarbons from the environment by brooding eggs is indicated by two factors. First, newly (< 72 h) extruded eggs of a crab in the high dose showed uptake levels that were intermediate between controls and other high-dose eggs that had been extruded over 2 months (Fig. 5). Second, ovarian tissue, even from crabs that had been exposed to the high dose for 14 months, showed no significant differences over control animals (Table 3). An earlier study (unpublished data) showed no difference between aromatic hydrocarbon levels in Tanner crab eggs from control and high-dosed crabs, although there were higher levels of aliphatic hydrocarbons in eggs from dosed crabs.

Digestive gland tissue from Dungeness crabs exposed to the high dose had approximately 1.5 times the level of aromatic hydrocarbons found in controls. Increased levels of hydrocarbons were also found in the digestive gland in juvenile king crabs that were exposed to oiled sediments (Rice et al. 1983). After 90 days of exposure to 2% oil-dosed sediment, aromatic and aliphatic hydrocarbon levels in exposed crabs were 60 and 130 times the levels in controls. Rice et al. (1983) also found increased levels of aromatic hydrocarbons in muscle tissue of juvenile king crabs exposed 90 days to 0.5 ppm WSF of Cook Inlet crude oil and increased levels of aliphatics in muscle from crabs exposed to 2% oiled sediment. They found sediment particles in the guts of the juvenile king crabs, indicating ingestion was a major avenue of uptake. We found virtually no uptake of either aromatic or aliphatic hydrocarbons in muscle tissue from Dungeness crabs exposed to our highest dose of oiled sediments.

The differences in reproductive response to oiled sediments between Dungeness and Tanner crab probably reflect differences in burying behavior of the two species. Brooding Tanner crab rarely bury, whereas gravid Dungeness crabs spend the majority of their time buried in sediments, allowing close contact between adsorbed oil and developing eggs.

The results of this 10-month study suggest that reproduction in Dungeness crabs may be impacted by exposure to oiled sediments, as shown by reduced larval production and viability and as reflected in uptake of aromatic and aliphatic hydrocarbons in incubating eggs. Krebs and Burns (1977) found behavioral peculiarities and reduced population densities of the fiddler crab, *Uca pugnax,* 7 years after the West Falmouth oil spill. So it is not surprising to infer, by extension, that Dungeness crab behavior, reproduction, and population densities may be altered or reduced by prolonged exposures to oiled sediments.

Phase 2

The low incidence of clasping and molting in all but the new control group was unexpected (Table 4). While no clasping and molting were exhibited in the new (4-month exposure) high dose and 75% of the crabs exhibited clasping and molting in the new controls, the incidence of these phenomena in the crabs held over from the long-term exposures (old control, old mid dose, old high dose) was quite low (8–16%). Clearly, exposure to oiled sediments for 14 months was not the lone cause of lack of clasping behavior and molting. Other stresses, such as confinement or lack of vital minerals, or both, and nutrients in their diet were probably operating in combination with exposure to the oil. The absence of molting in the new high dose (Table 4) does agree with findings of Karinen and Rice (1974), who found that brief (48 hours) exposure of premolt juvenile Tanner crabs to Prudhoe Bay crude oil inhibited molting.

It is generally believed that the reproductive biology of Dungeness crabs involves obligatory molting of the female before mating, and deposit of sperm in the spermatheca of the female while she is in a soft-shelled condition (Snow and Neilsen 1966; Wild 1983). Several months later, eggs are fertilized as they pass through the reproductive tract during spawning. Ebert et al. (1983) observed spawning in five crabs that had not molted; only one of those crabs oviposited a viable egg mass. We observed fresh sperm in spermathecas of crabs that were examined at the termination of Phase 2, which indicated that although the females had not molted, copulation had occurred.

The high incidence (55%) of extruded fertile eggs in females that had not molted suggests that the response to the combination of stressors (confinement, diet, and oiled sediments) is to use depleted energy reserves for spawning and forego the usual annual molting process.

CONCLUSION

The presence of oil in the substrate sediments of Dungeness crab habitat may lead to lower reproductive capability, lower viability of larvae, and, in combination with other stressors, inhibition of molting in adult female crabs. Over a period of time, these factors could reduce population levels in habitats affected by oil contamination.

REFERENCES CITED

Boolootian, R. A., A. C. Giese, A. Farmanfarmaian, and J. Tucker. 1959. Reproductive cycles of five West Coast crabs. Physiol. Zool. 32(4):213–220.

Brodersen, C. C., S. D. Rice, J. W. Short, T. A. Mecklenburg, and J. F. Karinen. 1977. Sensitivity of larval and adult Alaskan shrimp and crabs to acute exposures of the water-soluble fraction of Cook Inlet crude oil. Pages 575–578 *in* 1977 Oil Spill Conference (Prevention, Behavior, Control, Cleanup) Proceedings. American Petroleum Institute, Environmental Protection Agency, and U.S. Coast Guard, Washington, D.C. 640 p.

Burns, K. A., and J. M. Teal. 1979. The West Falmouth oil spill: hydrocarbons in the salt marsh ecosystem. Estuar. Coast. Mar. Sci. 8:349–360.

Ebert, E. E., A. W. Haseltine, J. L. Houk, and R. O. Kelly. 1983. Laboratory cultivation of the Dungeness crab, *Cancer magister.* Pages 259–309 *in* P. W. Wild and R. N. Tasto (editors), Life History, Environment, and Mariculture Studies of the Dungeness Crab, *Cancer magister,* with Emphasis on the Central California Fishery Resource. Calif. Dep. Fish and Game, Fish Bull. 172. 352 p.

Ebert, E. E., R. O. Kelly, and A. W. Haseltine. 1975. Observations on the larval hatching success of Dungeness crab, *Cancer magister,* from the San Francisco and Eureka-Crescent City regions. Calif. Dep. Fish and Game, Mar. Resour. Tech. Rep. No. 29. 14 p.

Haines, J. R., and R. M. Atlas. 1982. *In situ* microbial degradation of Prudhoe Bay crude oil in Beaufort Sea sediments. Mar. Environ. Res. 7:91–102.

Karinen, J. F. 1980. Petroleum in the deep sea environment: potential for damage to biota. Environ. Internat. 3:135–144.

Karinen, J. F., S. D. Rice, and M. M. Babcock. 1983. Long-term effects of petroleum hydrocarbons in sediment on reproduction and growth of crabs and shrimp in Alaska (specifically, *Chionoecetes bairidi*). Summary Report: L-RERP, P.L. 92-532, Sec. 202., Auke Bay Laboratory, Auke Bay, Alaska. 7 p.

Karinen, J. F., and S. D. Rice. 1974. Effects of Prudhoe Bay crude on molting Tanner crabs, *Chionoecetes bairdi.* Mar. Fish. Rev. 36(7):31–37.

Krebs, C. T., and K. A. Burns. 1977. Long-term effects of an oil spill on populations of the salt-marsh crab *Uca pugnax.* Science 197(4302):484–487.

MacKay, D., S. Paterson, P. D. Boehn, and D. L. Fiest. 1981. Physical-chemical weathering of petroleum hydrocarbons from the *Ixtoc I* blowout—chemical measurements and a weathering model. Pages 453–460 *in* 1981 Oil Spill Conference (Prevention, Behavior, Control, Cleanup) Proceedings. American Petroleum Institute, Environmental Protection Agency, and U.S. Coast Guard, Washington, D.C. 742 p.

Olla, B. L., W. H. Pearson, P. C. Sugarman, D. L. Woodruff, and J. W. Blaylock. 1981. The effects of petroleum hydrocarbons on chemoreception and behavior in the Dungeness crab, *Cancer magister.* EPA-600/7-81-093. 71 p.

Pearson, W. H., P. C. Sugarman, D. L. Woodruff, and J. W. Blaylock. 1980. Detection of petroleum hydrocarbons by the Dungeness crab, *Cancer magister.* Fish. Bull. 78(3):821–826.

Rice, S., J. F. Karinen, and C. C. Brodersen. 1983. Effects of oiled sediment on juvenile king crabs. OCSEAP Final Rep. 29:287–310.

Snow, C. D., and J. R. Neilsen. 1966. Premating and mating behavior of the Dungeness crab (*Cancer magister* Dana). J. Fish. Res. Bd. Can. 23(9):1319–1323.

Wild, P. W. 1983. The influence of seawater temperature on spawning, egg development, and hatching success of the Dungeness crab, *Cancer magister.* Pages 197–213 *in* P. W. Wild and R. N. Tasto (editors), Life History, Environment, and Mariculture Studies of the Dungeness Crab, *Cancer magister,* with Emphasis on the Central California Fishery Resource. Calif. Dep. Fish and Game, Fish Bull. 172. 352 p.

APPENDIX

Egg Development: Dungeness Crab (*Cancer magister*)
(Adapted from Boolootian 1959.)

Stage	*Identifying Features*
0	Undivided cell.
1	2–128 cells: no yolk-free section apparent.
2	Yolk-free (transparent) section apparent; beginning of invagination.
3	Distinct division of egg into yolk and yolk-free sections; space develops between chorion and embryo.
4	Eye pigment barely apparent (individual pigment spots barely discernible under 40x).
5	Eye pigment more apparent: individual pigment spots seen at 40x.
6	Eyes strongly pigmented; much yolk still present (>25% of egg volume); dorsal pigmentation becomes apparent.
7	Yolk reduced to two small patches.
8	No yolk present; prezoea stage recognizable.

DISTRIBUTION AND ABUNDANCE OF DECAPOD LARVAE OF THE KODIAK SHELF

by

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ABSTRACT

Four bays and the continental shelf on the eastern side of the Kodiak Island Archipelago were surveyed to establish baseline information on the early life histories of nearshore decapods. Five offshore and twelve inshore cruises were conducted from fall 1977 through winter 1979. Distribution and abundance data were collected to determine the areas where decapod larvae were most abundant, the depths they were found, and the time of year they were present. Ten different taxonomic groups, including 5 commercial species, were tested for significant differences in times of occurrence, distribution, and abundance through a series of analyses of variance on bongo net data. Regionally, crab and shrimp larvae were 2-3 times more abundant inshore than offshore. Vertical distribution studies showed that the 10-50 m strata contained a majority of the larvae encountered. Times of peak abundance varied through spring and summer depending upon the taxonomic group.

TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

LIST OF FIGURES

LIST OF FIGURES (Continued)

LIST OF FIGURES (Continued)

LIST OF TABLES

LIST OF TABLES (Continued)

LIST OF TABLES (Continued)

Table *Page*

INTRODUCTION

Surveys of ichthyoplankton and decapod crustacea larvae in continental shelf regions of the western Gulf of Alaska were conducted October 1977 through March 1979 by the NMFS, Northwest and Alaska Fisheries Center and the University of Washington, Fisheries Research Institute. The purpose was to establish baseline data on the early life histories of nearshore fish and shellfish around Kodiak Island. The Bureau of Land Management (now Minerals Management Service) through OCSEAP funded the work and the information from these surveys was incorporated into the data base used to evaluate impacts from offshore oil and gas development.

The distribution and abundance of finfish eggs and larvae in the inshore region of the Kodiak Island shelf were described by Rogers et al. (1979) and similar information for the offshore region was presented by Kendall et al. (1980). The latter authors also included a consolidated inshore-offshore summary of information on larvae of selected species of shrimp and crab. Limitations to the data base used for the decapod larvae portion of the report restricted its scope and precluded substantive conclusions relating to Reptantia and Natantia larvae.

The following revised analysis of decapod larvae information originally presented by Kendall et al. (1980) also incorporates new data not available for the previous report.

BACKGROUND INFORMATION

Description of the Study Area

The study area is generally bounded by latitudes 55°-59°N and longitudes 149°-155°W and covers approximately 75,000 km². This area encompasses the continental shelf east of Kodiak and Afognak islands from the headwaters of several bays seaward to the 2,000-m contour (Fig. 1). Locations sampled extend southwest from Portlock Bank to the Trinity Islands and include observations in Izhut, Chiniak, Kiliuda, and Kaiugnak bays.

Shallow banks separated by troughs running to the continental shelf edge generally characterize the bathymetry east of Kodiak and Afognak

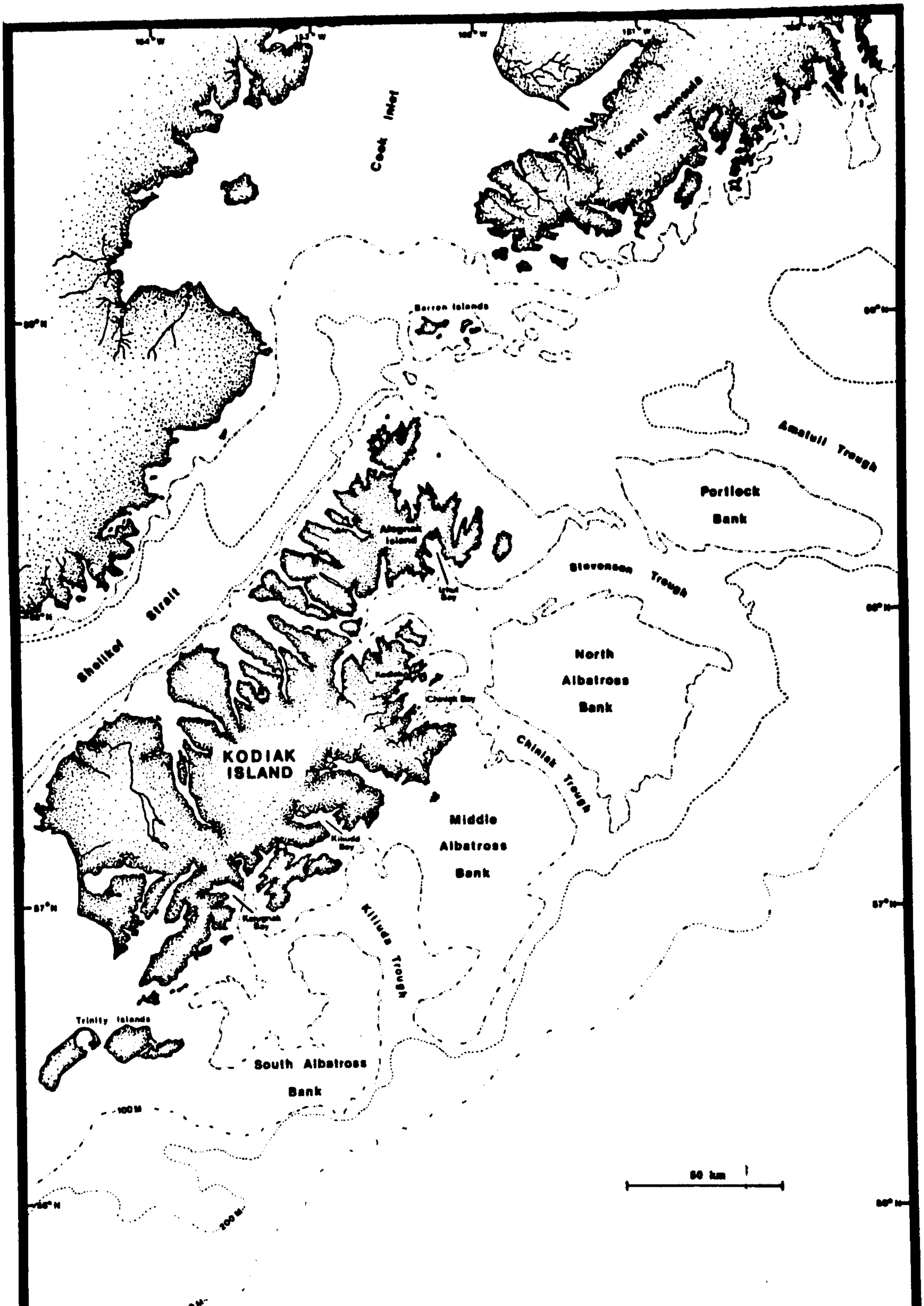


Figure 1.--Kodiak Island study area showing general bathymetry and principal bays and inlets.

islands. Four major troughs--Amatuli, Stevenson, Chiniak, and Kiliuda (Fig. 1)--traverse the rather wide shelf, which ranges from about 69 km to 110 km in width. These troughs (except for Amatuli, the northernmost) are offshore extensions of deepwater trenches out of bays in the study area and have a depth range of about 110-140 m. Four banks separate the troughs and have depth ranges of about 49-91 m; these are Portlock Bank and North, Middle, and South Albatross banks. In general, substrate composition changes rapidly within short distances on the rugged, uneven bottom and ranges from soft mud and sand to hard rock.

All four bays investigated during the study can be considered open systems with no sills or land masses to restrict interchange between the bay and ocean water masses.

Hydrography and Climate of the Study Area

The shelf area under investigation lies primarily between two surface current regimes: the Kenai current, which flows through Shelikof Strait on the west side of the study area (Schumacher and Reed 1979); and the Alaska Stream on the east (Ingraham 1979). Several authorities (Favorite and Ingraham 1977; Royer 1977; Schumacher et al. 1978; and others) indicate the continental shelf region around Kodiak Island is characterized by weak eddies and variable flow. On the shelf it is difficult to determine any basic order to flow other than that related to local winds and bathymetry (Kendall et al. 1980). If there is a general southwestward movement, it is perhaps only along the shelf edge.

Mean monthly sea surface temperatures in offshore areas range between 0.5°C and 12°C with frequent anomalies of ±3°C for individual months (Ingraham 1976). Surface water temperatures in the inshore areas appear somewhat warmer than offshore, ranging from 0.5° to 14°C. Depths greater than 100 m generally have temperatures warmer than 5°C; however, during anomalously cold years temperatures may be as low as 1.5°C. Inshore temperatures at depths greater than 100 m apparently range between 1° and 7°C (ADF&G temperature data).

Surface salinity indicates inshore dilution as well as an extensive continuity of mid-shelf maxima. Shelf edge surface salinity minima are traceable to discharges from the Copper River in the eastern Gulf of Alaska outside Prince William Sound (Ingraham 1979). Winter overturn in the offshore water column extends to depths of 75-100 m and therefore includes most of the study's bank areas (Kendall et al. 1980).

Marine influences dominate the climate of Kodiak Island's coastal regions. The range in air temperatures between annual maxima and minima is small throughout the region with the greatest range being 8.2°C on the western coast (Buck et al. 1975). Maximum summer average temperatures are usually less than 16°C with winter average minima about -6°C. Average temperature differences between air and water are usually greatest during fall and winter. Then the air is as much as 7°C colder than the water. Long-term average air temperature (1940-1970) for the northeast coast of Kodiak Island is 4.8°C (Buck et al. 1975).

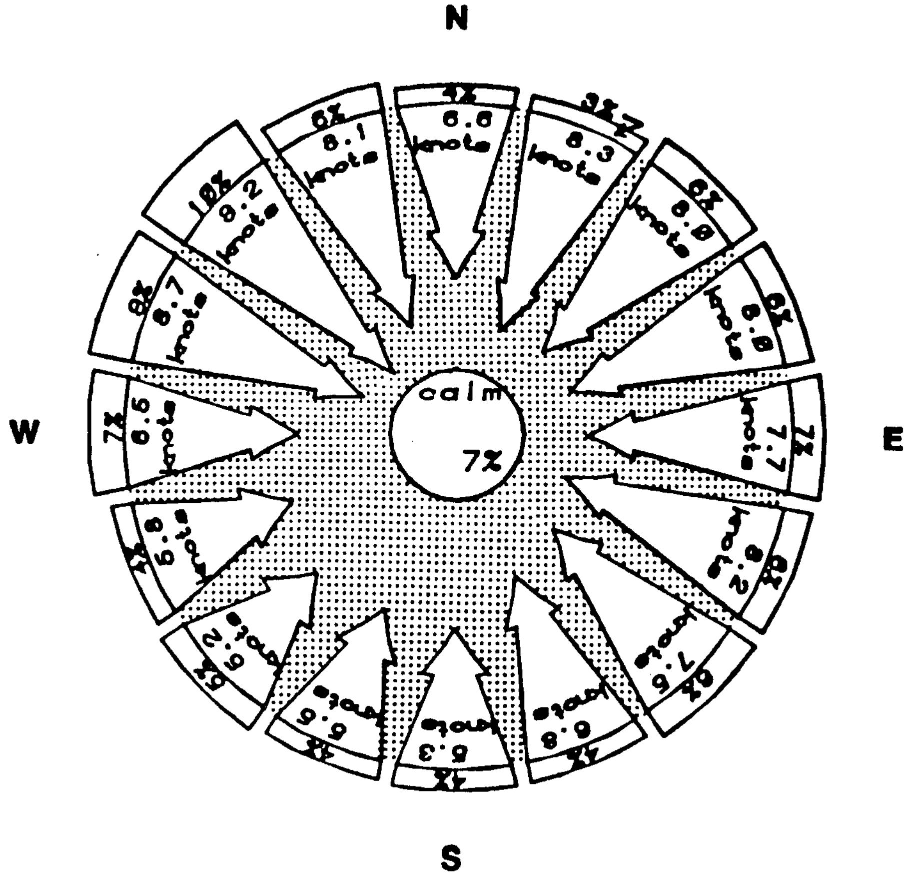
Storm movements through the western Gulf of Alaska determine the pressure patterns that establish wind flow in the study area. Strongest winds in offshore areas come primarily from the northwest and secondarily from the east through southeast (Buck et al. 1975). Inshore surface winds are somewhat similar; high velocity winds come most frequently from the northwest (Fig. 2).

MATERIALS AND METHODS

Survey Designs

The data for this report were gathered in two discrete sets of surveys. Five offshore cruises were conducted by the Northwest and Alaska Fisheries Center and twelve inshore cruises were performed by the Fisheries Research Institute of the University of Washington.

An offshore cruise was conducted during each season from fall 1977 to winter 1979 (Table 1). The sampling pattern was modified from a stratified design (Fig. 3) after completion of the first two cruises to a systematic centric design (Milne 1959) (Fig. 4). These patterns contained up to 88 stations and extended from the inshore region out to the continental slope. Inclement weather or operational difficulties occasionally caused deletion of stations from planned sampling. Of the five offshore cruises conducted during the study (Table 1), the first was not used in the analysis as it produced very little information.



Arrows indicate the average wind velocity. Arrow tails indicate the percent frequency of occurrence of wind direction.

Figure 2.--Long-term (1945-77) average wind velocity and percent frequency of occurrence of wind direction in Kodiak Island study area (adapted from Buck et al. 1975).

The series of 12 cruises in the inshore region of the study area were conducted in Izhut Bay on the south coast of Afognak Island, Chiniak Bay on the east coast of Kodiak Island, and Kiliuda and Kaiugnak bays on the southeast coast of Kodiak Island (Figs. 5 and 6). Sampling locations were initially limited to 5 stations within and closely adjacent to each of the four bays. Three additional stations (stations 6, 7, and 8) were added to the inner portions of Izhut and Kiliuda bays in May to increase sampling density in the inner portion of these bays. Consequently, 26 stations were sampled during each inshore cruise for the duration of the study (Figs. 5 and 6). Ten of these cruises were conducted in an almost continuous series on a biweekly basis from early spring through midsummer (Table 2). The remaining two surveys were conducted in November 1978 and early March 1979.

Table 1.—Cruises and cruise dates for the 1977-1979 OCSEAP offshore plankton surveys.

Cruise	Season	Date
4MF77	Fall	31 October-14 November 1977
4DI78	Spring	28 March-20 April 1978
2MF78	Summer	19 June-9 July 1978
1WE78	Fall	25 October-17 November 1978
1MF79	Winter	13 February-11 March 1979

Table 2.—Cruises and cruise dates for the 1978-1979 OCSEAP inshore plankton surveys.

Cruise	Season	Date
I	Spring	29 March-8 April 1978
II	Spring	10 April-17 April 1978
III	Spring	21 April-1 May 1978
IV	Spring	3 May-28 May 1978
V	Spring	31 May-6 June 1978
VI	Summer	14 June-26 June 1978
VII	Summer	28 June-18 July 1978
VIII	Summer	21 July-29 July 1978
IX	Summer	1 August-9 August 1978
X	Summer	15 August-21 August 1978
XI	Fall	4 November-13 November 1978
XII	Winter	4 March-16 March 1979

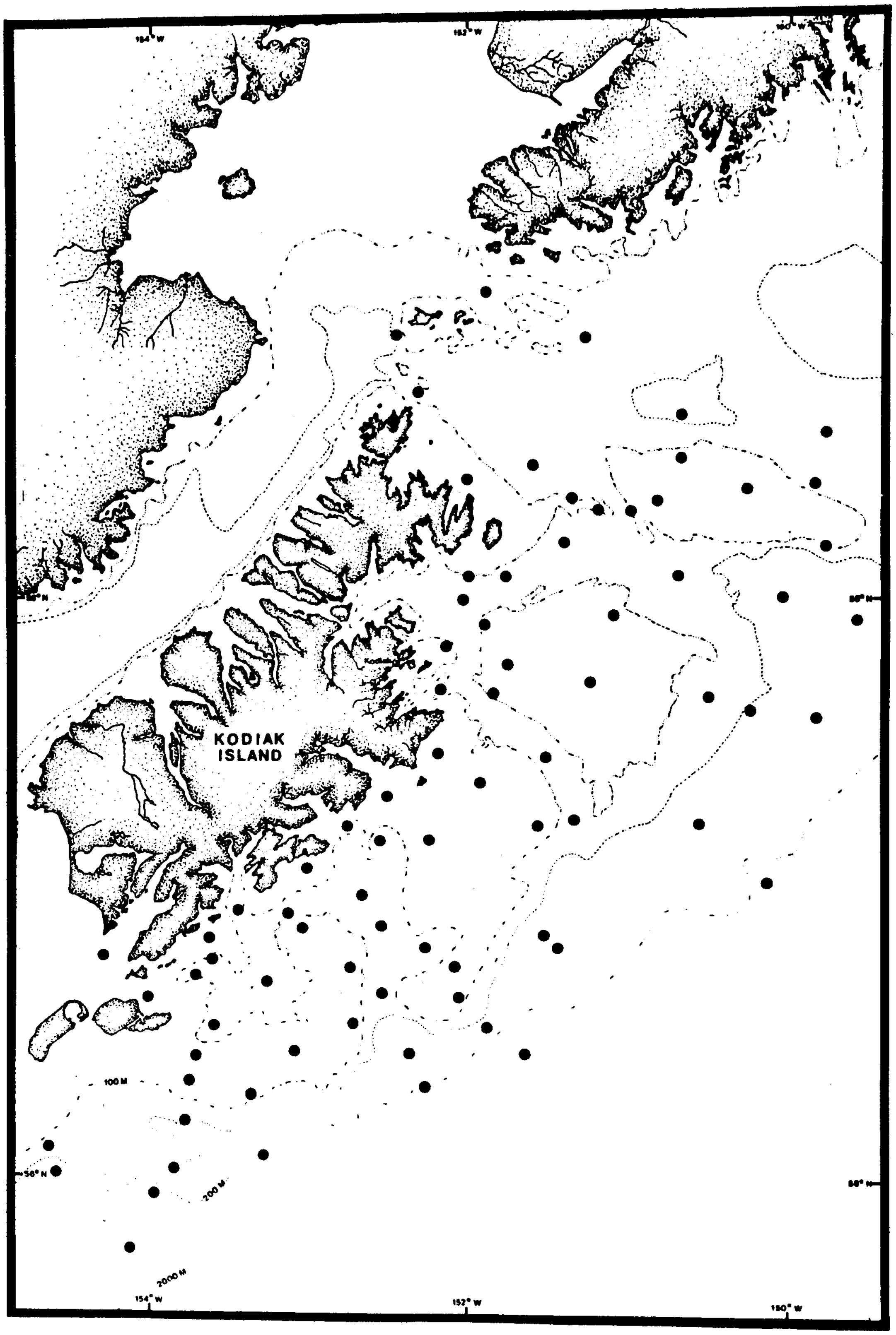


Figure 3.--Stratified station pattern used for offshore cruise 4DI78, spring 1978 (a similar pattern was used for 4MF77).

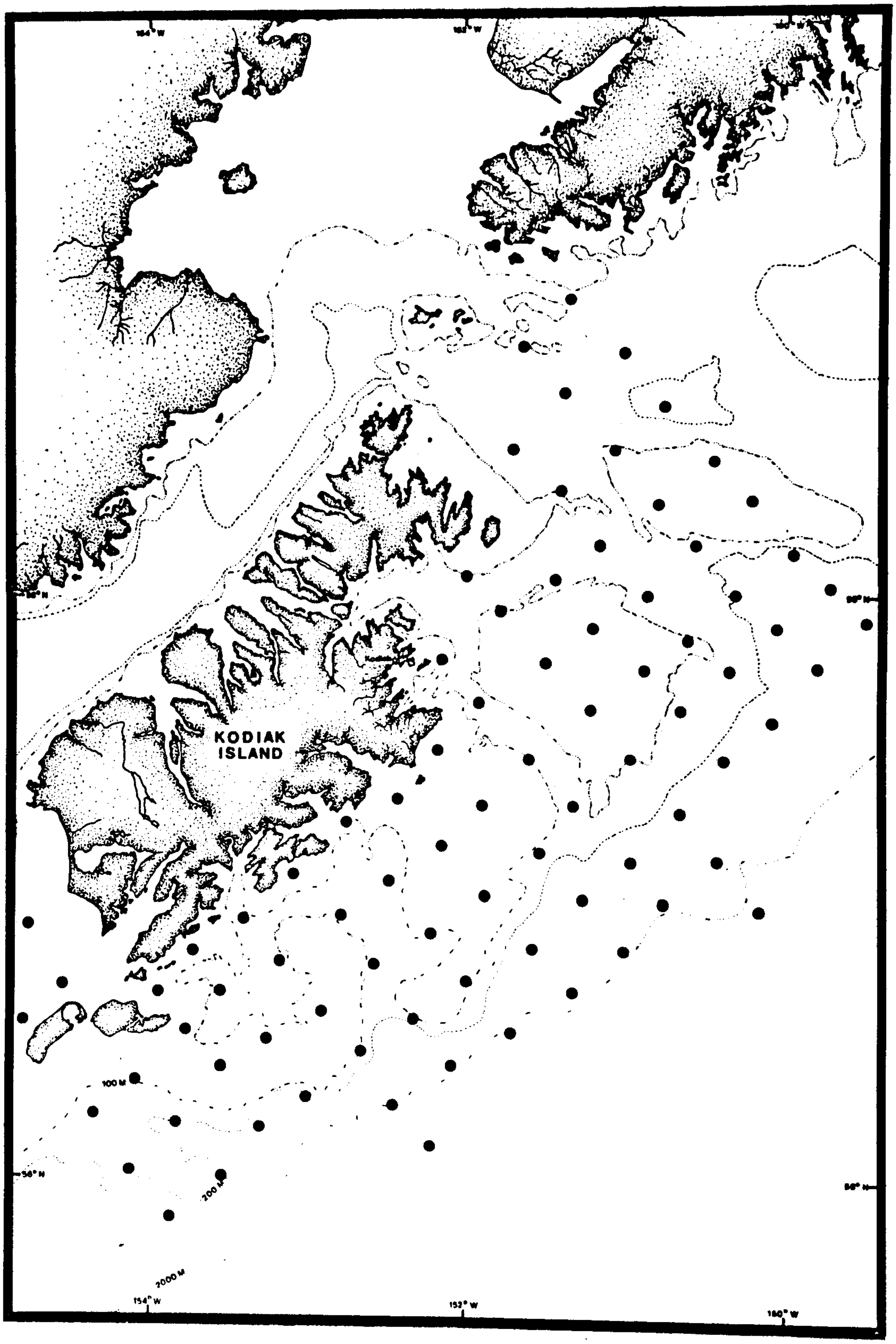


Figure 4.--Systematic centric station pattern used for offshore cruises 4MF78, 1WE78, and 1MF79 (summer, fall, and winter).

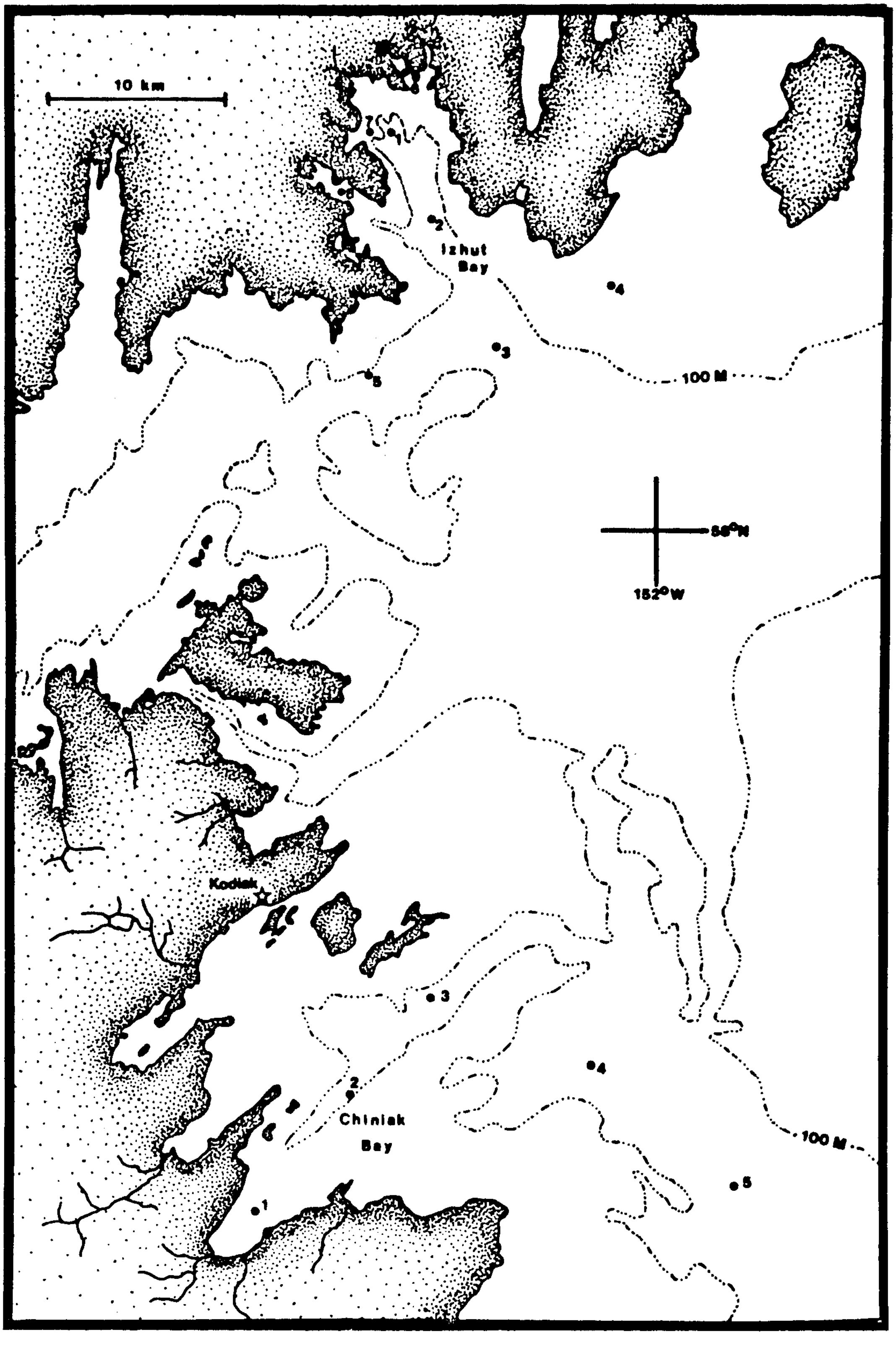


Figure 5.--Inshore station locations in Izhut and Chiniak bays (note added stations in Izhut Bay).

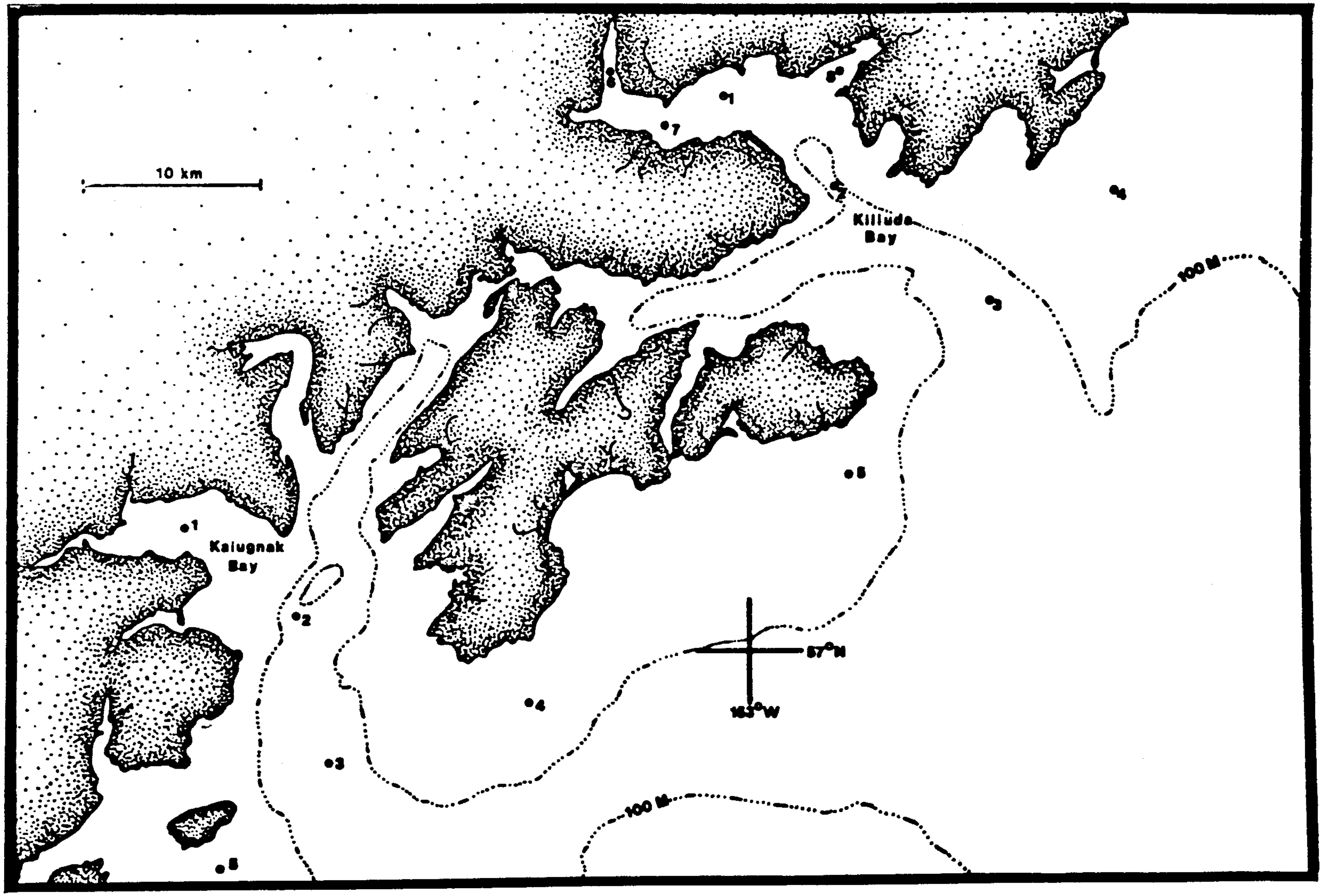


Figure 6.--Inshore station locations in Kiliuda and Kaiugnak bays.

Field Gear and Station Procedures

Samples analyzed in this report were obtained from three types of gear:

1) an aluminum MARMAP bongo sampler, 0.6 m inside diameter, with 0.505- and 0.333-mm-mesh nets for collecting larvae from surface to near bottom;
2) a Sameoto neuston sampler (Sameoto and Jaroszynski 1969) with a mouth opening of 0.3 m by 0.5 m and a 0.505-mm-mesh net for collecting larvae at the air-sea interface; and
3) a 1.0-m-square mechanical opening-closing Tucker trawl (Clark 1969) with three 0.505-mm-mesh nets for sampling discrete depths.

Field sampling generally followed standard MARMAP procedures (Smith and Richardson 1972).

A double oblique bongo tow was performed at every station during all cruises. The bongo nets were lowered at a rate of 50 m of wire per minute and retrieved at a rate of 20 m per minute, sampling from surface to within 5-10 m of the bottom, normally to a maximum depth of about 200 m. During lowering and retrieval, the ship's speed (approximately 2.0 knots, or 1.03 m/sec) was adjusted to maintain a 45° wire angle. Actual sampling depths varied, depending on wire angles.

The air-sea interface was sampled with the Sameoto neuston sampler for 5 minutes at a speed of about 2.0 knots (1.03 m/sec). This was done in conjunction with Tucker trawling at discrete depth sampling stations.

Discrete depth sampling via Tucker trawls was performed during both inshore and offshore surveys; however, sampling procedures varied substantially between surveys (Kendall et al. 1980, pages 8 and 28). The Tucker trawl and Sameoto samples from the inshore survey were used for analysis of vertical distribution and diel movement. This discrete depth sampling was conducted during day and night of each cruise at a station in both Izhut and Kiliuda bays (Fig. 4). The surface and five depth intervals (5-20, 20-40, 40-60, 60-80, 80-100 m) were sampled during each diel series. The Tucker trawl was lowered to the desired depth, tripped open with a messenger and towed for 5 or 10 minutes. After the prescribed time, the net was closed with another messenger and retrieved. The desired depth interval was maintained by varying vessel speed with respect to wire angle.

Gear and procedures described in this section pertain only to those data sets which were addressed in this report.

Sample processing

Plankton samples were preserved in the field in a 5% Formalin-seawater mixture buffered with sodium tetraborate. These preserved samples were shipped to a sorting contractor (Texas Instruments, Inc., Dallas, Texas) for initial processing. The contractor determined the settled volume (Kramer et al. 1972) and removed all fish eggs and fish larvae (i.e., samples were not split).

An aliquot of approximately 500 organisms was then split from the remaining portion of the bulk samples of the 0.333-mm bongo net and Tucker trawl hauls. All organisms in these aliquots were sorted into major categories (e.g., phylum, class, or order). The resulting Natantia and Reptantia larvae were sent to NWAFC Kodiak Facility where they were identified to the most precise taxonomic category and life stage possible, and enumerated. Literature references used to identify the decapod larvae are presented in Appendix B.

Further processing of selected series of bulk plankton samples was done (1) to evaluate the adequacy of the original 500-organism aliquots for indicating numbers of shrimp and crab zoeae present in the bulk samples (see Appendix A); and (2) to determine the larval decapod species composition in the inshore region's neuston samples. The original sorting contract had excluded neuston samples. The University of Washington, College of Fisheries and Oceanography did this work under contract, sorting from 35-85% (by volume) of the total plankton samples, depending on sample type (see Appendix A).

Data Analysis

Numbers of shrimp and crab larvae in each life history stage for each taxon in the aliquots were recorded. These numbers were converted to biomass or density indicies as follows.

Bongo:

$$\text{biomass} = n \times d \times 10/(s \times (\text{aper})^2 \times \pi \times l)$$

Sameoto and Tucker:

$$\text{density} = n \times 1000/(s \times h \times w \times l)$$

Where:

biomass = number of organisms/10 m^2

density = number of organisms/1000 m^2

n = number of organisms in subsample

s = subsample fraction of bulk sample

aper = radius of net opening in meters (0.3 for bongo)

h = effective fishing height of net opening in meters (0.15 for Sameoto, 1.0 for Tucker)

w = width of net opening in meters (0.5 for sameoto, 1.0 for Tucker)

l = length of tow in meters (computed from flowmeter readings)

d = depth of water sampled

Biomass data for each taxon from the bongo catches were used to determine geographic distributions for comparisons of different areas and seasons. Density data from the neuston and Tucker catches were used to investigate the depth distribution of organisms as a function of time of day.

A comparative analysis of distribution, abundance, and time of occurrence was performed for each decapod species (or species group) of ecologic or economic importance. For these analyses, each sampled bay in the study's inshore region was defined as a separate inshore subarea while the offshore region was separated into the subareas shown in Figure 7. They are described as follows:

Portlock subarea -- continental shelf regions offshore Marmot Bay encompassed by the points 57°48', 151°55'; 58°13', 151°55'; 58°45', 150°32'; 57°53', 148°58'; 57°21', 150°09'; and including Portlock Bank, Stevenson Trough, and North Albatross Bank.

Marmot subarea -- continental shelf regions offshore Chiniak and Ugak bays encompassed by 57°48', 151°55'; 57°13', 149°38'; 56°27',

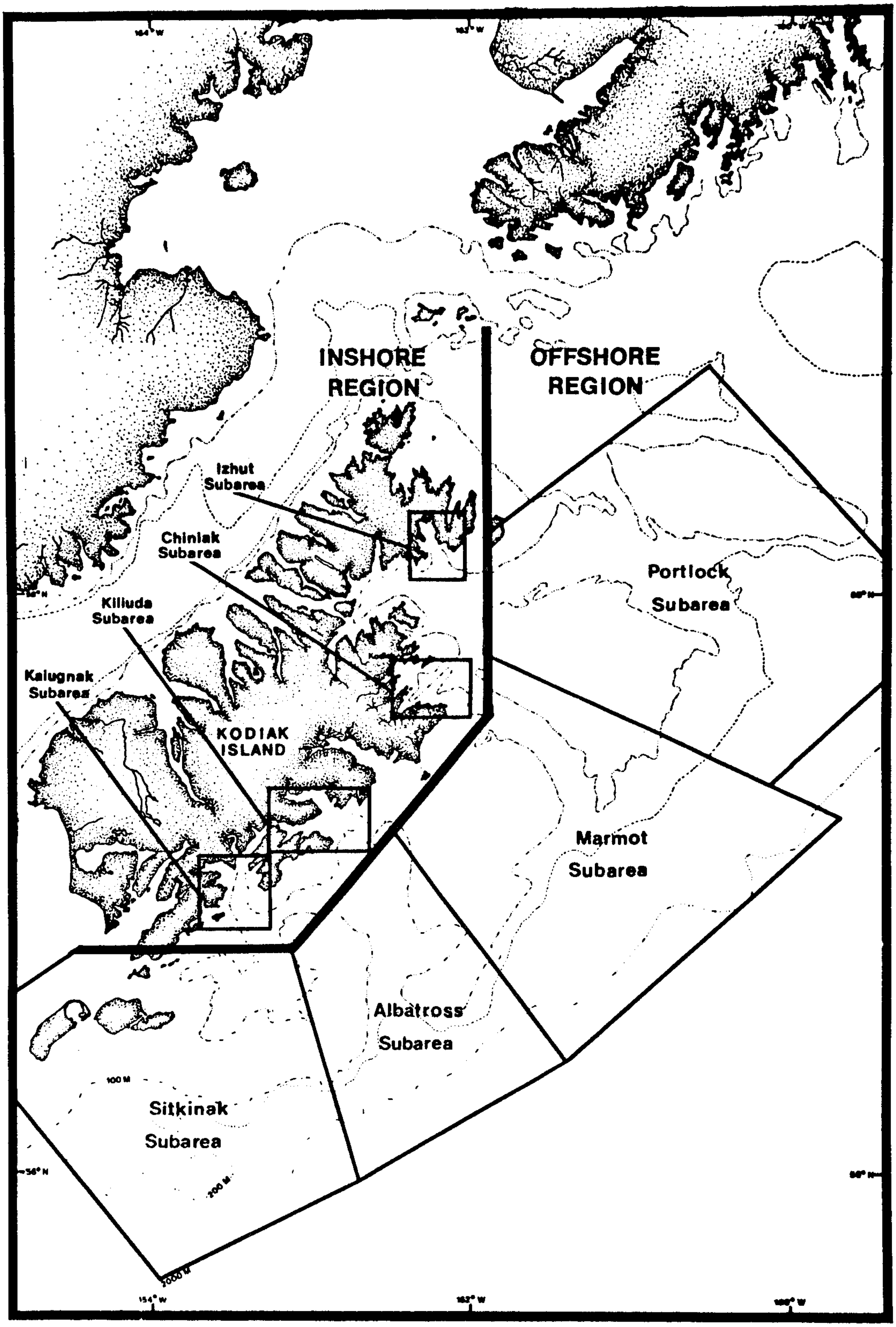


Figure 7.--Kodiak Island study area showing the two regions and corresponding subareas used in the comparative analysis of distribution and abundance.

151°20'; 57°13', 152°28'; 57°35', 151°55'; and including Chiniak Trough and Middle Albatross Bank.

Albatross subarea -- continental shelf regions offshore Kiliuda and Kaiugnak bays encompassed by 57°13', 152°28'; 56°27', 151°20'; 55°57', 152°41'; 56°46', 153°07'; and including Kiliuda Trough and the eastern arm of South Albatross Bank.

Sitkinak subarea -- continental shelf regions south of any inshore sampling area encompassed by 56°46', 153°07'; 55°57'; 152°41'; 55°39', 153°55'; 56°29', 155°20'; 56°46', 154°30'; including South Albatross Bank and stations near the Trinity Islands.

The significance of differences in time of occurrence, distribution, and/or abundance of each taxon of interest was determined through a series of analyses of variance on the bongo net information. For each taxon, data for each cruise within a subarea were pooled. This was done because data from the contract-sorted bongo net aliquots were adequate to represent amounts present only in data sets where observations by larval stage and station were combined (see Appendix A). Additionally, since depths fished and volumes of water filtered at the stations differed between cruises, it was necessary to standardize the subarea summaries. A standardized biomass per subarea was determined from the relationship:

$$\hat{B}_{\cdot jkl} = \frac{\left(\sum_{i=1}^{t} n_{ijkl} \cdot \sum_{i=1}^{t} d_{ijkl}/T\right) 10}{\frac{\sum_{i=1}^{t} s_{ijkl}}{T} \cdot \frac{\sum_{i=1}^{t} V_{ijkl}}{T}}$$

where:

i = station 1,2,...,t;
j = cruise 1,2,...,c;
k = subarea 1,2,3,4;
l = region 1,2;
n = the number of organisms of a taxon found in the aliquot at station "i", cruise "j", in subarea "k", of region "l";
s = the subsample fraction of bulk sample associated with station "i";
V = volume of water filtered at station "i";
d = depth fished at station "i";
T = the total number of stations sampled during cruise "j", in subarea "k", of region "l"; and
$\hat{B}$ = the standard biomass of a taxon during cruise "j" in subarea "k", of region "l".

The ANOVA tests were performed on natural log transformations of these biomass data ($ln\ (\hat{B}_{ijkl} + 1)$). Three main effects were considered: time (i.e. cruise), subarea, and region. Three separate factorial analyses of variance were performed for each taxon:

12 (inshore cruises) x 4 (inshore bays);
4 (offshore cruises) x 4 (offshore subareas); and
2 (regions) x 4 (cruise or seasons) x 4 (subareas).

The three separate tests were performed because of substantial differences in seasonal coverage for the inshore and offshore regions. The 10 surveys conducted inshore during spring and summer represented a level of detail for describing timing of inshore occurrence and abundance that was not possible when these surveys were combined by season for the 2 x 4 x 4 factorial analysis. This latter ANOVA was performed to identify possible regional significance in larval abundance or interactions between regions, seasons, and/or subareas.

The significance of main effects and interactions was tested at the a = 0.05 level. If a main effect was determined significant, a Scheffee's procedure (Steel and Torrie 1960) was used to identify significant subsets of data.

RESULTS

OCSEAP plankton surveys of the Kodiak Island shelf found approximately 19 different taxa of Natantia and Reptantia larvae (Table 3). These taxa included several species of current economic importance and other non-commercial taxa. Some of these latter taxa were substantially more prevalent in samples than the species of economic importance (Fig. 8). Consequently, they were included in the taxa analyzed in this report. The taxa studied were:

Hippolytid shrimps (Hippolytidae)
Sand shrimps (Crangonidae)
Northern or pink shrimp (*Pandalus borealis*)
Humpy shrimp (*P. goniurus*)
Anomuran crabs (Anomura)
Red king crab (*Paralithodes camtschatica*)
Dungeness crab (*Cancer magister*)
Cancer crab (*Cancer* sp.)
Tanner or snow crab (*Chionoecetes bairdi*)
Pea crabs (Pinnotheridae)

A summary of information follows for each decapod taxon of interest in the Kodiak Island study area. The limitations of the data base are analyzed and discussed in detail in Appendix A.

Table 3.—Decapod crustacea larvae found during OCSEAP inshore and offshore plankton cruises.

Taxonomic Classification	Species or Groups Encountered
Suborder Natantia	
Family Hippolytidae	unspecified hippolytid shrimp
Family Crangonidae	unspecified crangonid shrimp
Family Pandalidae	*Pandalopsis dispar* *Pandalus borealis* *P. goniurus* *P. hypsinotus* *P. montagui tridens* *P. platyceros* *P. stenolepis*
Family Pasiphaeidae	*Pasiphaea* sp.
Suborder Reptantia	
Section Anomura	unspecified anomuran crabs
Family Lithodidae	*Paralithodes camtschatica*
Section Brachyura	
Family Atelecyclidae	*Telemessus cheiragonus*
Family Cancridae	*Cancer magister* *Cancer* sp.
Family Majidae	*Chionoecetes bairdi* *Hyas* sp. *Oregonia* sp.
Family Pinnotheridae	unspecified pinnotherid crabs

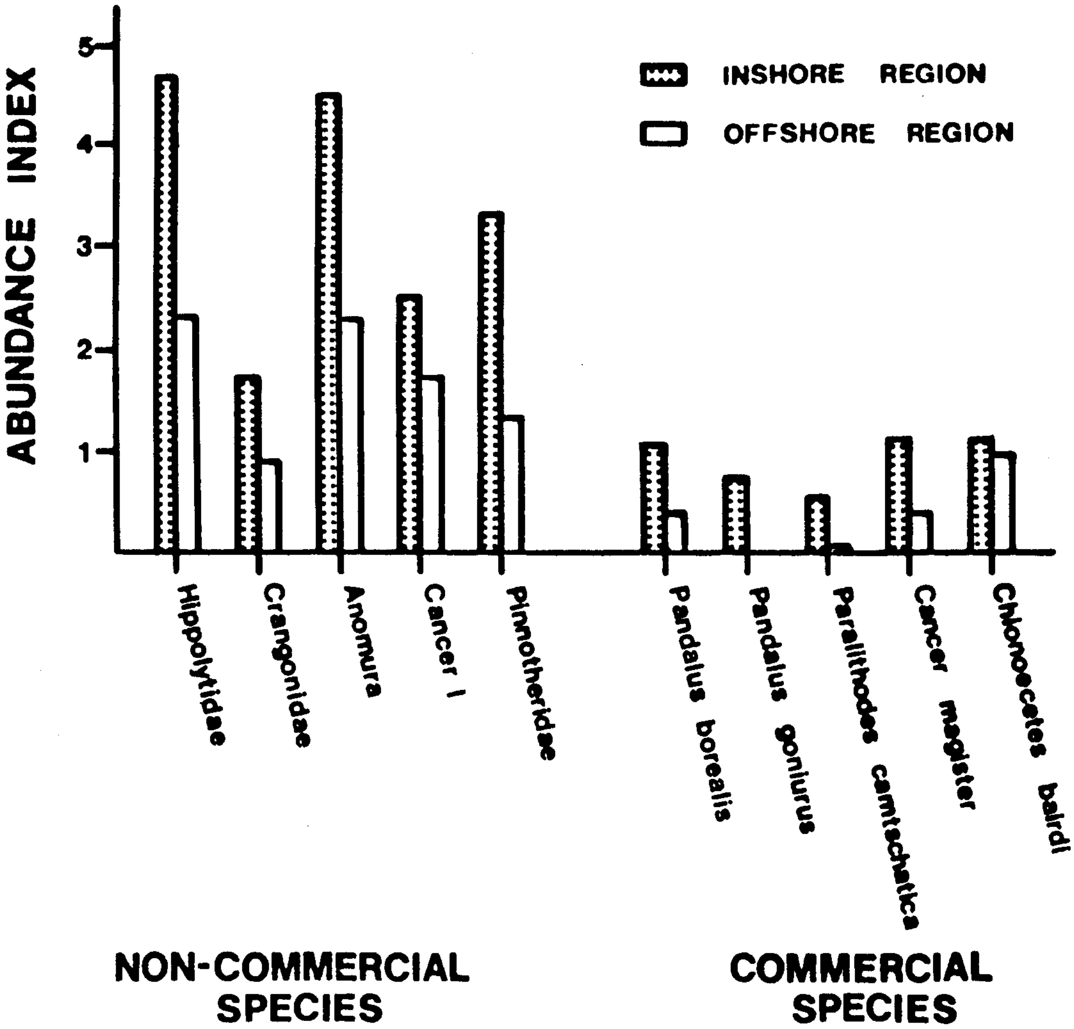


Figure 8.--Index of abundance for commercial and non-commercial species of importance found during OCSEAP inshore and offshore plankton cruises.

Results for Selected Taxa

Hippolytidae (hippolytid shrimps)

The hippolytid shrimp group comprises several species each with its own, often different, reproductive strategy. Because analysis could not be performed at the species level, the following reflects only gross aspects of larval distribution and abundance for this important and diverse group.

Larvae of hippolytid shrimp were found in the water column during all times of the year (Fig. 9) and in all areas sampled (Fig. 10). First stage zoeae were present from late winter through summer.

During the day most hippolytid zoeae were found in the upper and mid-portions of the water column (5-60 m) (Fig. 11), while at night their vertical distribution appeared even shallower. Highest night-time concentrations were at the surface in both bays sampled, and were greatest in Kiliuda Bay where neuston samples took over 90% of all zoeae.

Regions and seasons were identified in analysis of variance tests as having substantial effects on the distribution and abundance of hippolytid zoeae (Table 4). The abundance of this larval group was significantly greater in the inshore region and during spring and summer; however, a region x season interaction also was identified (Table 4). Estimated abundances of larvae per unit area were nearly identical in both regions during fall (Tables 5 and 6). During all other seasons, amounts in the inshore region were notably greater than amounts offshore (Fig. 10).

Separate tests of the inshore data determined that hippolytid larvae abundance in bays was significantly greater during June-August (Cruises VII-X) than during all other times surveyed. A significant bay effect was also identified, but no individual bay could be determined to have accounted for this significance.

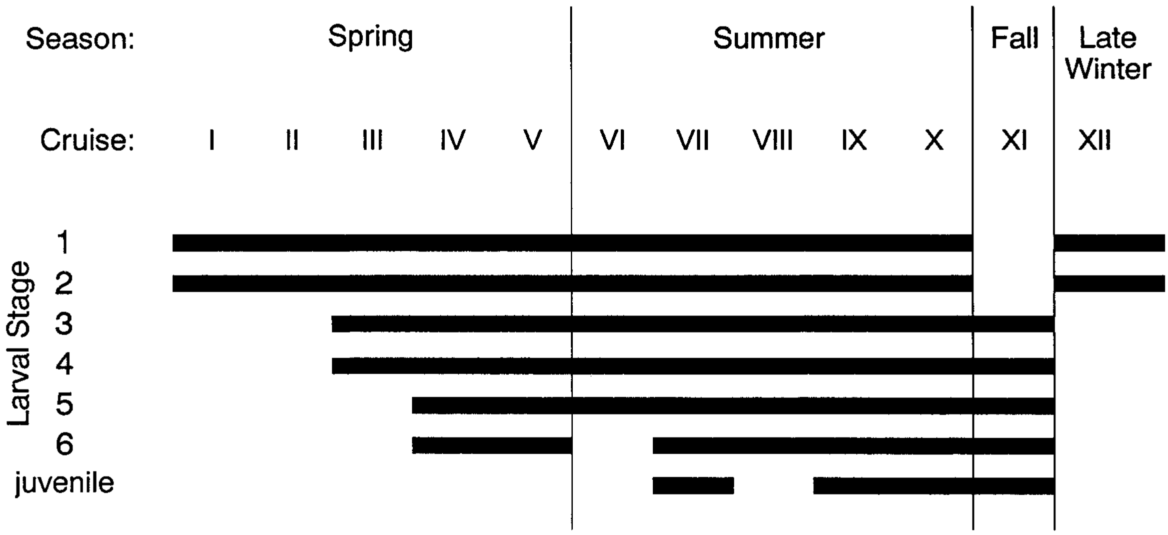


Figure 9.--Occurrence of larval stages of Hippolytidae by cruise and season from the OCSEAP inshore plankton cruises. Data from all gear types.

Table 4.—Summary of information derived from analysis of variance tests of bongo net data (ln(numbers per 10 m² + 1)) for hippolytid shrimp larvae.

Test	Source of Variability	Degrees of Freedom	Sum of Squares	Value of F
Inshore and offshore combined	Total	63	467.80	—
	Main effects			
	Region (R)	1	114.96	50.79**
	Subarea (A)	3	19.24	2.84
	Season (S)	3	101.59	14.97**
	Interactions			
	R X A	3	0.86	0.13
	R X S	3	31.87	4.70**
	A X S	9	9.35	0.46
	R X A X S	9	11.60	0.57
	Residual	32	72.36	—
Inshore	Total	47	236.06	—
	Main effects			
	Bays	3	20.02	3.94*
	Cruise	11	160.13	8.59**
	Residual	33	55.91	—
Offshore	Total	15	51.50	—
	Main effects			
	Subarea	3	2.12	1.91
	Cruise	3	46.06	41.51**
	Residual	9	3.33	—

* Denotes significance at = .05
** Denotes significance at = .01

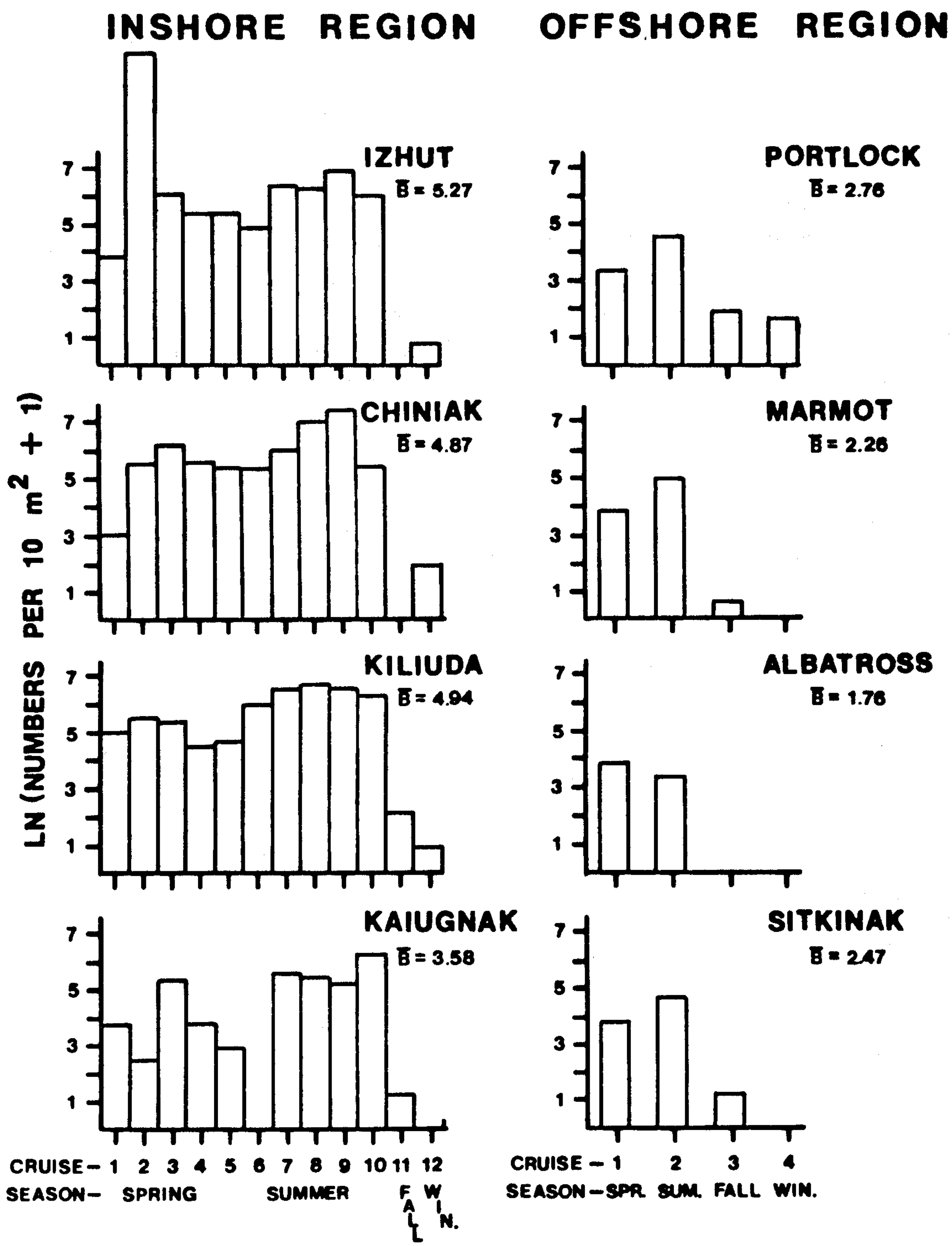


Figure 10.--Average density (ln(numbers per 10 m²)) by cruise, season, bay, subarea, and region for Hippolytidae in the Kodiak Island study area. Bongo net data.

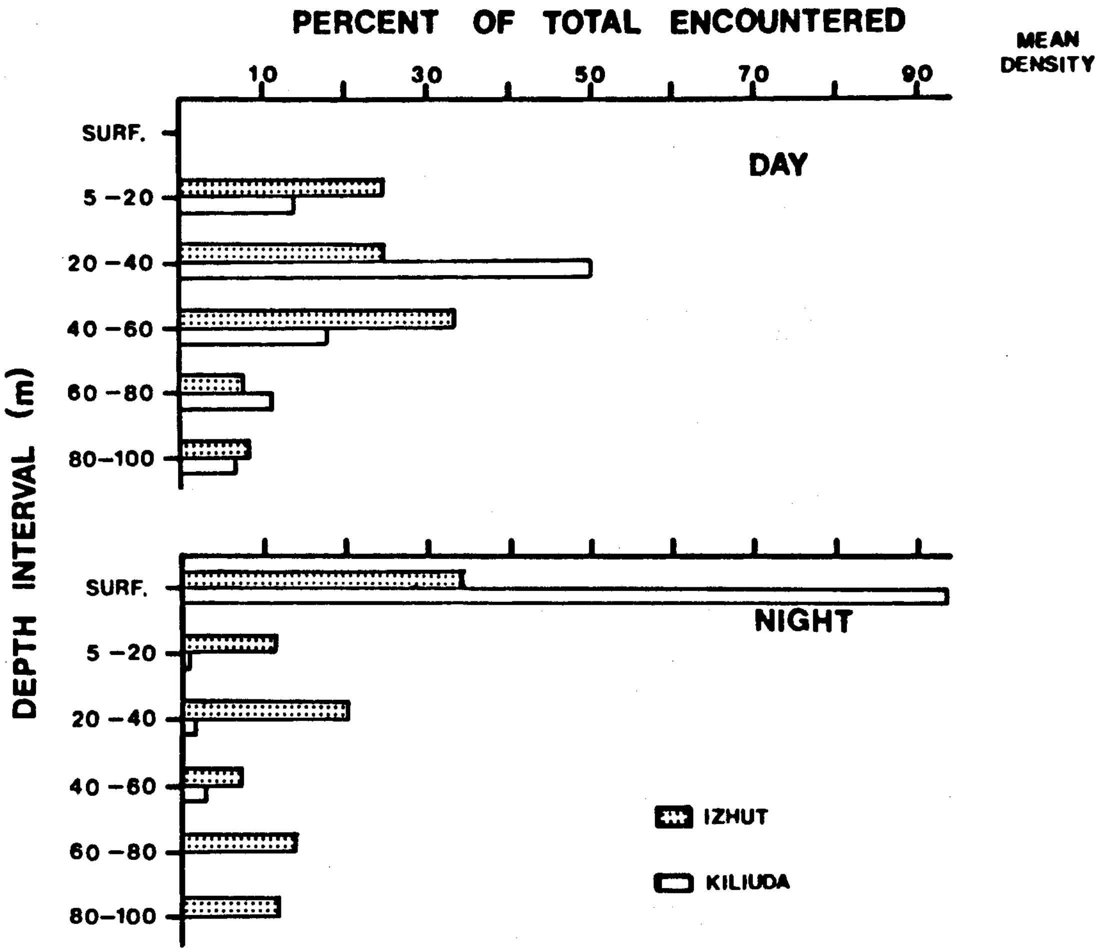


Figure 11.--Percentage of total Hippolytidae encountered during inshore OCSEAP plankton cruises by diel period and depth interval for Izhut and Kiliuda bays. Tucker trawl data.

Table 5.—Standardized biomass (ln (numbers per 10 m^2 + 1)) of hippolytid shrimp larvae by season, cruise, and subarea in the inshore region of the Kodiak Island study area, March 1978–March 1979. (Bongo net data.)

Season			Spring			Summer					Fall	Winter	Mean Biomass All Cruises
Cruise	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	
Subarea													
Izhut Bay	3.95	11.06	6.21	5.42	5.38	4.85	6.44	6.34	6.76	5.97	0	0.88	5.27
Chiniak Bay	2.97	5.52	6.16	5.48	5.40	5.27	6.02	6.92	7.31	5.45	0	1.98	4.87
Kiliuda Bay	4.91	5.41	5.20	4.30	4.53	5.69	6.28	6.55	6.40	6.17	2.08	1.74	4.94
Kaiugnak Bay	3.82	2.64	5.37	3.87	3.05	0	5.64	5.52	5.23	6.03	1.39	0.38	3.58
Mean Biomass Bays Combined	3.91	6.16	5.73	4.77	4.59	3.95	6.09	6.33	6.42	5.90	0.87	1.24	4.66

Table 6.—Standardized biomass (ln (numbers per 10 m² + 1)) of hippolytid shrimp larvae by season, cruise, and subarea in the offshore region of the Kodiak Island study area, March 1978–March 1979. (Bongo net data.)

Season	Spring	Summer	Fall	Winter	Mean Biomass All Cruises
Cruise	I	II	III	IV	
Subarea					
Portlock	3.21	4.49	1.68	1.67	2.76
Marmot	3.75	4.79	0.51	0	2.26
Albatross	3.73	3.33	0	0	1.76
Sitkinak	3.89	4.70	1.28	0	2.47
Mean Biomass Subareas Combined	3.64	4.33	0.87	0.42	2.31

Crangonidae (sand shrimps)

Crangonid shrimp larvae were found in the water column at all times of the year sampled (Fig. 12). Similar to Hippolytidae, first stage zoeae of this group were present in samples throughout the time periods sampled, except for fall.

During daylight, most larvae of this species group were encountered in mid and upper portions of the water column (Fig. 13), but at night, a trend in vertical distribution was not apparent. Previous analysis of only the Tucker trawl data suggested these larvae were concentrated in 40-100 m during the night (Kendall et al. 1980). Inclusion of the neuston samples in the vertical distribution data indicates that about 40% of all larvae were encountered at or near the surface (Fig. 13). Relatively substantial numbers were also found at 20-60 m in Kiliuda Bay and at depths below 60 m in Izhut Bay.

Analyses of variance of the bongo net samples indicated that crangonid larvae were notably more abundant in summer than during other seasons. There was no significant difference in abundance by region (Table 7). Various bays seemed to contain significantly greater numbers of crangonid shrimp zoeae than others, but the importance of a bay changed with time (Table 8 and Fig. 14). This apparent bay x cruise interaction masked the importance of abundance within a bay during multiple comparison tests.

A separate analysis of the offshore region data also failed to identify significant abundance differences between subareas, even though catches varied noticeably. For example, all samples obtained in the Sitkinak subarea contained no crangonid zoeae while samples from all other offshore subareas contained measurable amounts, at least during summer (Table 9).

The multi-species composition of the crangonid larvae group was a source of variation which could not be addressed in our sample analyses.

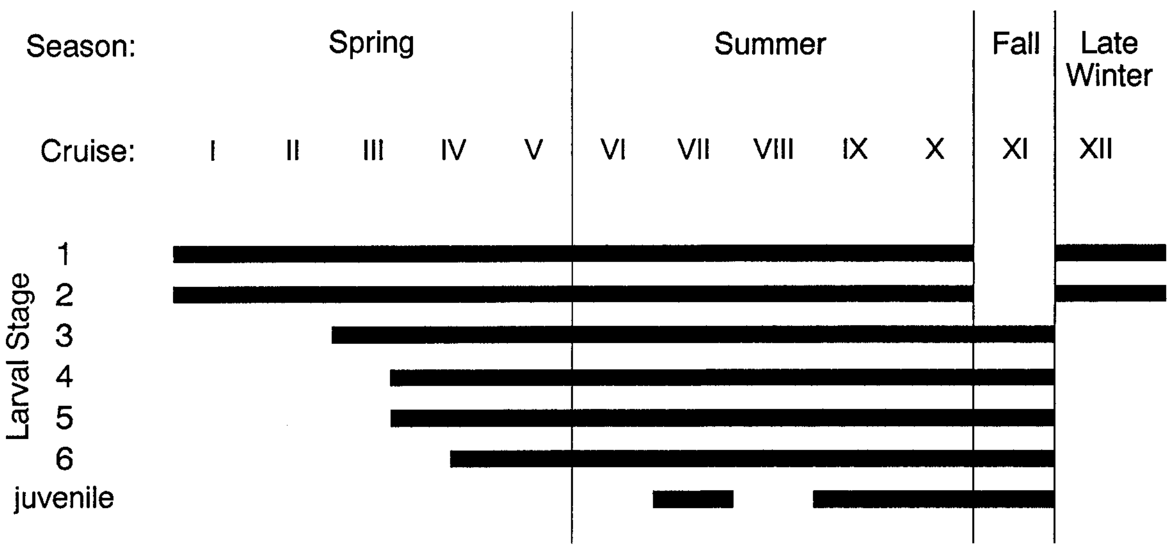


Figure 12.--Occurrence of larval stages of Crangonidae by cruise and season from the OCSEAP inshore plankton cruises. Data from all gear types.

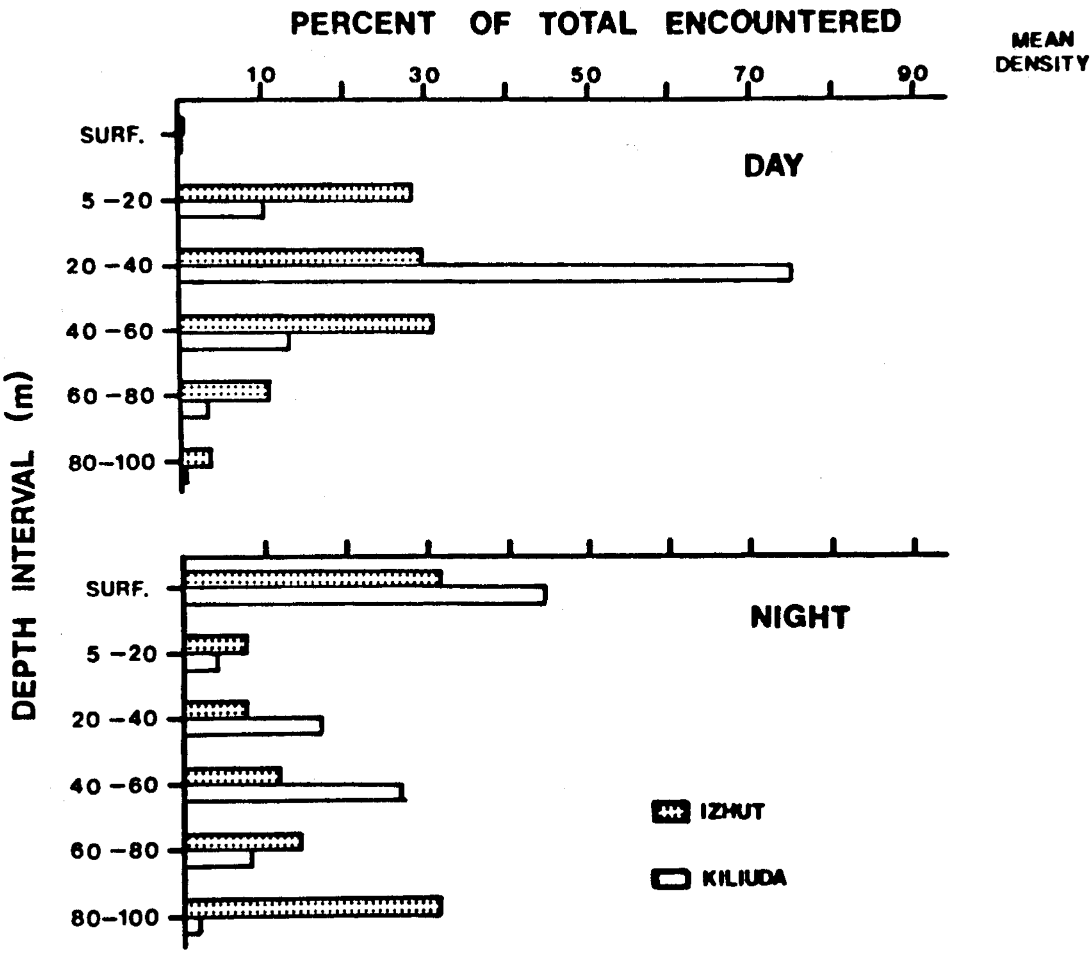


Figure 13.--Percentage of total Crangonidae encountered during inshore OCSEAP plankton cruises by diel period and depth interval for Izhut and Kiliuda bays. Tucker trawl data.

Table 7.—Summary of information derived from analysis of variance tests of bongo net data (ln (numbers per 10 m^2 + 1)) for sand shrimp (Crangonidae) larvae.

Test	Source of Variability	Degrees of Freedom	Sum of Squares	Value of F
Inshore and offshore combined	Total	63	212.182	—
	Main effects			
	Region (R)	1	0.722	0.32
	Subarea (A)	3	15.467	2.28
	Season (S)	3	66.963	9.88**
	Interactions			
	R X A	3	12.882	1.90
	R X S	3	1.811	0.27
	A X S	9	15.185	0.75
	R X A X S	9	14.536	0.71
	Residual	32	72.291	—
Inshore	Total	47	170.619	—
	Main effects			
	Bays	3	26.821	3.55*
	Cruise	11	60.788	2.20*
	Residual	33	83.010	—
Offshore	Total	15	31.709	—
	Main effects			
	Subarea	3	4.685	1.95
	Cruise	3	19.806	8.23**
	Residual	9	7.218	—

* Denotes significance at = .05

** Denotes significance at = .01

Table 8.—Standardized biomass (ln (numbers per 10 m² + 1)) of sand shrimp (Crangonidae) larvae by season, cruise, and subarea in the inshore region of the Kodiak Island study area, March 1978–March 1979. (Bongo net data.)

Season	Spring				Summer						Fall	Winter	Mean Biomass All Cruises
Cruise	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	
Subarea													
Izhut Bay	0	3.12	3.59	4.52	4.47	2.27	3.22	2.43	3.34	0	0	0	2.25
Chiniak Bay	0	0	0	0	0	3.39	3.69	0	0	4.53	0	0	0.97
Kiliuda Bay	1.59	3.94	0	2.60	3.01	4.54	4.92	3.71	4.74	4.21	0	0	2.77
Kaiugnak Bay	0	0	0	2.52	0	0	0	3.75	4.05	3.65	0	0	1.16
Mean Biomass Bays Combined	0.40	1.76	0.90	2.41	1.87	2.55	2.96	2.47	3.03	3.10	0	0	1.79

INSHORE REGION OFFSHORE REGION

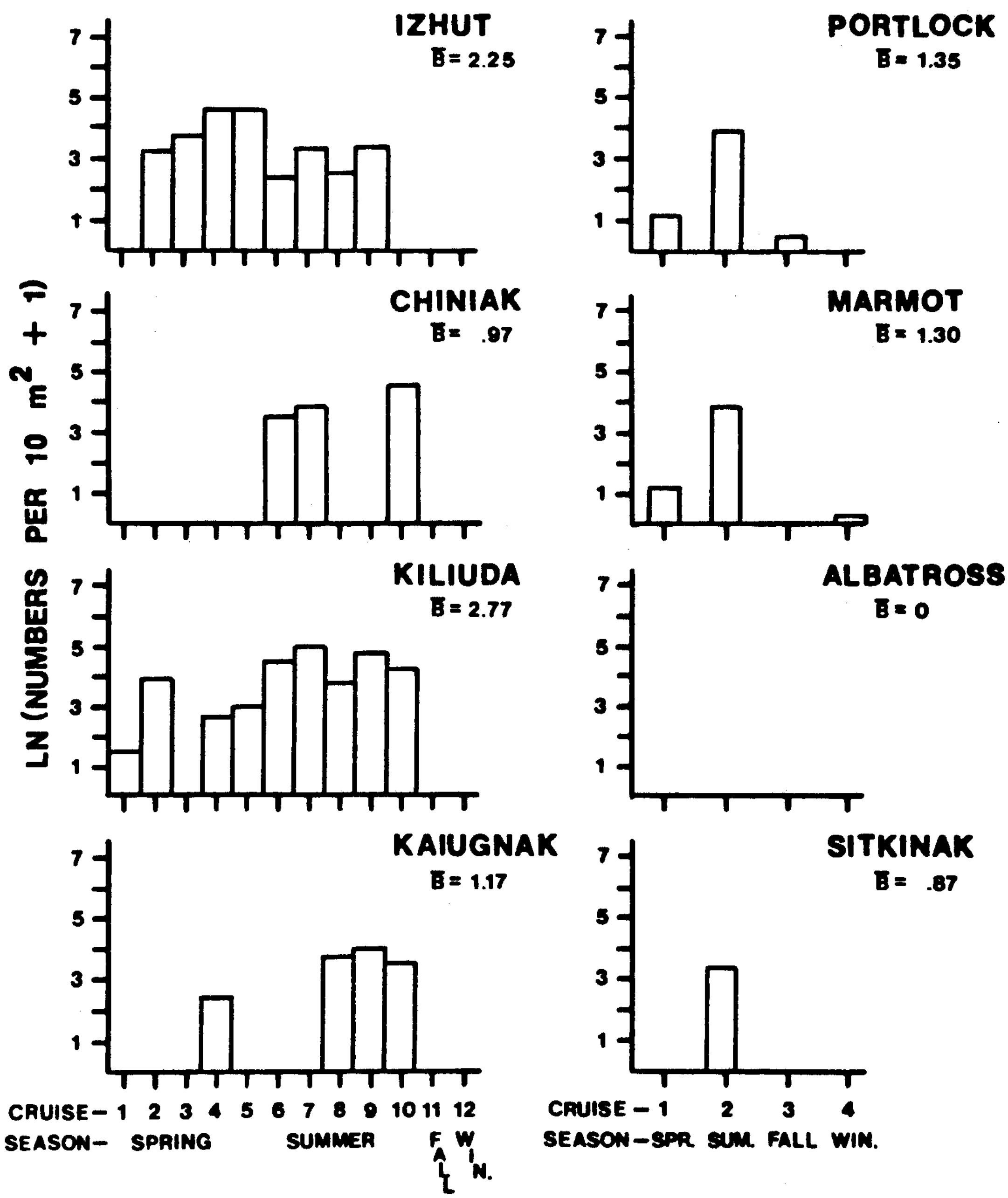


Figure 14.--Average density (ln(numbers per 10 m²)) by cruise, season, bay, subarea, and region for Crangonidae in the Kodiak Island study area. Bongo net data.

Table 9.—Standardized biomass (ln (numbers per 10 m² + 1)) of sand shrimp (Crangonidae) larvae by season, cruise, and subarea in the offshore region of the Kodiak Island study area, March 1978-March 1979. (Bongo net data.)

Season	Spring	Summer	Fall	Winter	Mean Biomass All Cruises
Cruise	I	II	III	IV	
Subarea					
Portlock	1.22	3.80	0.43	0	1.36
Marmot	1.19	3.79	0	0.16	1.28
Albatross	0	0	0	0	0
Sitkinak	0	3.49	0	0	0.88
Mean Biomass Subareas Combined	0.60	2.77	0.11	0.04	0.88

Pandalus borealis (pink shrimp)

Pandalus borealis zoeae were present in at least portions of the study area during all time periods sampled (Fig. 15). Stage I zoeae were found during late winter, spring, and early summer, suggesting protracted larval release; however, peak abundance of Stage I larvae occurred during mid-April (Cruise II).

Information from the standard Tucker trawl aliquots, re-sorted samples, and neuston tows indicated that daytime vertical distribution differed between the two bays where these samples were taken. Highest concentrations in Kiliuda Bay were found at 5-20 m, whereas zoeae found in Izhut Bay were concentrated in deeper waters, at 60-80 m (Fig. 16). At night most zoeae were found in the deeper strata sampled in both bays, with highest concentrations at 60-80 m. Very few *P. borealis* larvae were found in samples taken at the surface in both bays.

The detailed analyses of the daytime samples from Kiliuda Bay further suggest a change in vertical distribution of *P. borealis* zoeae with advancing stages of larval development. During Stages I-III, vertical distribution appeared to be associated with mid or upper portions of the water column, with only Stage I zoeae found in surface samples (Fig. 17). Notable amounts of *P. borealis* larvae started occurring in the deepest depths sampled (80-100 m) as Stage IV, while nearly all Stage VI and VII (juveniles) were found only in the deepest waters sampled.

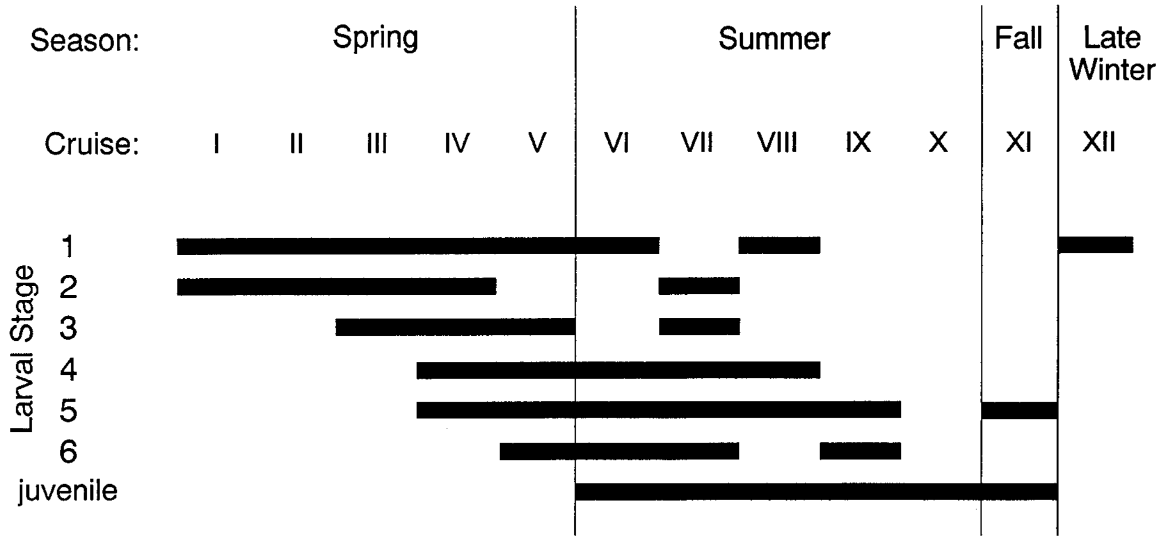


Figure 15.--Occurrence of larval stages of *Pandalus borealis* by cruise and season from the OCSEAP inshore plankton cruises. Data from all gear types.

No bays or offshore subareas displayed consistent trends in abundance for *P. borealis* larvae (Fig. 18 and Tables 10 and 11). Additionally, the ANOVA tests failed to identify any notable difference in abundance between the inshore and offshore regions of the Kodiak Island study area (Table 12).

Analysis of bongo data indicated *P. borealis* zoeae were significantly more abundant in spring than during other times surveyed throughout the study area. Separate tests on the inshore data identified mid-April through May (Cruises II-IV) as the period when inshore abundance was significantly higher than all other times sampled.

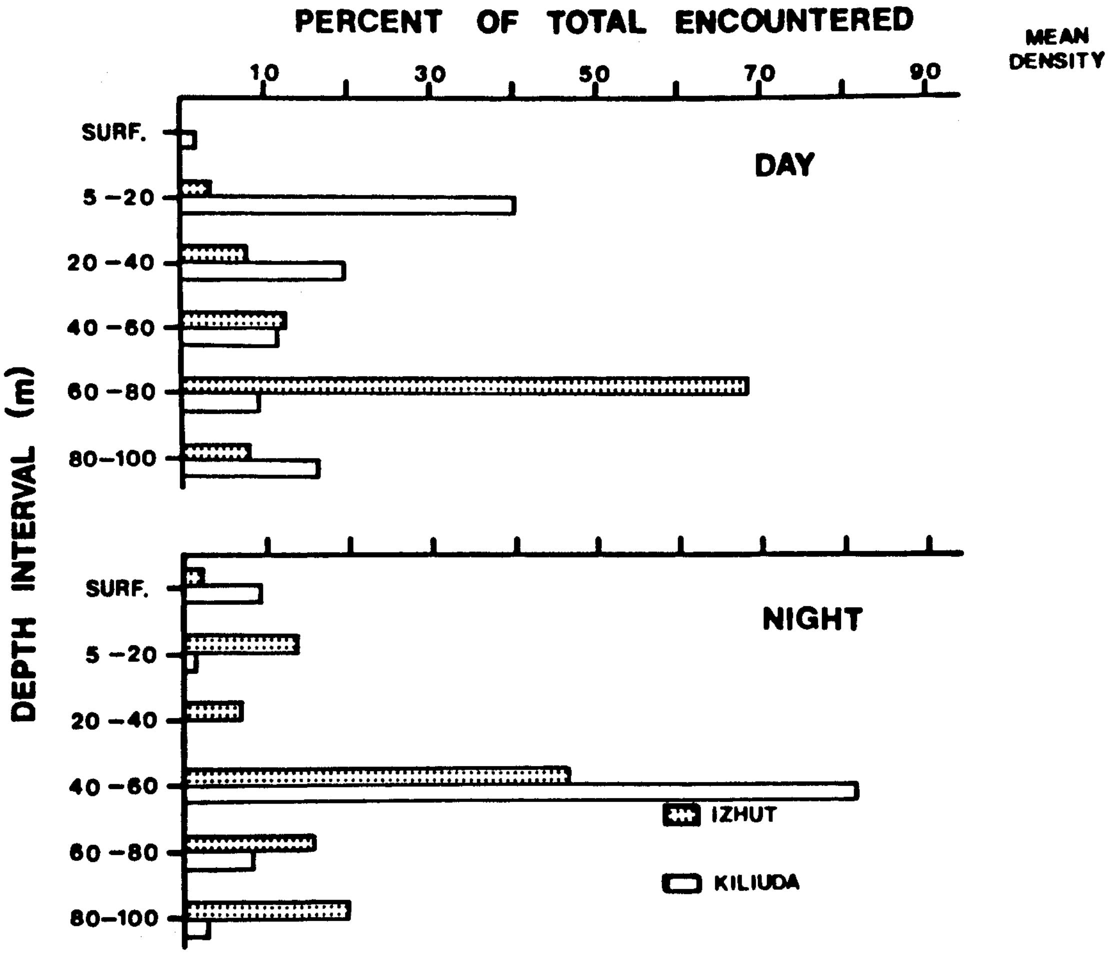


Figure 16.--Percentage of total *Pandalus borealis* encountered during inshore OCSEAP plankton cruises by diel period and depth interval for Izhut and Kiliuda bays. Tucker trawl data.

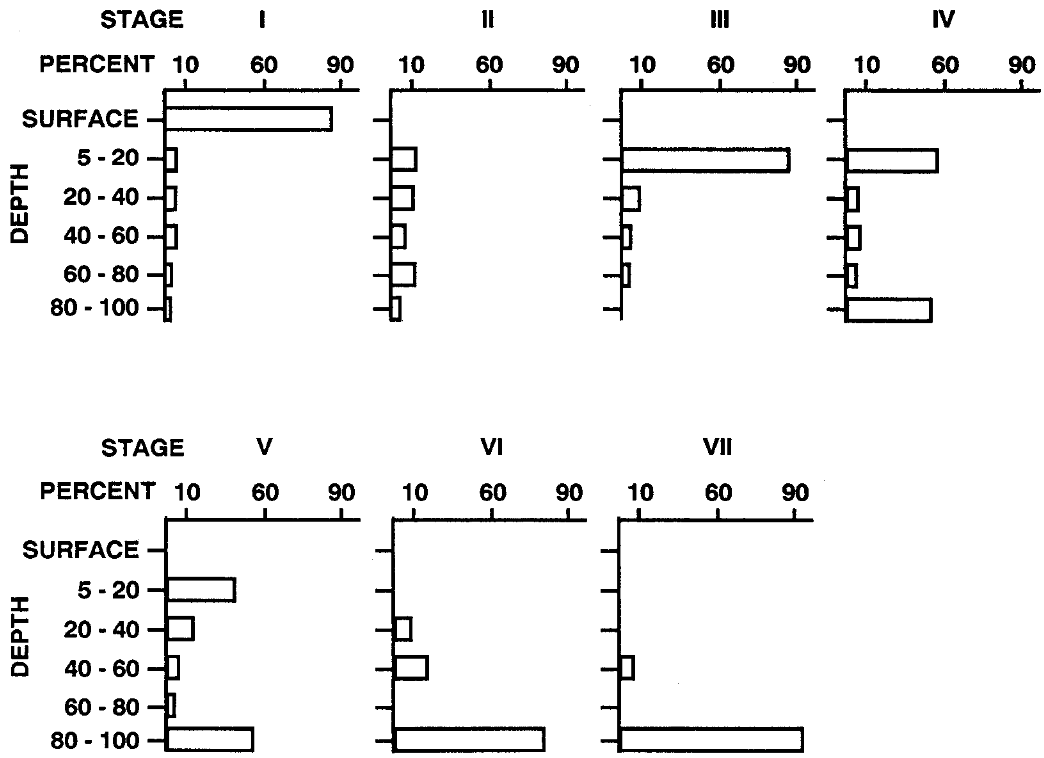


Figure 17.--Percentage of *Pandalus borealis* encountered by life stage and depth interval during inshore OCSEAP plankton cruises. Neuston sampler and Tucker trawl data.

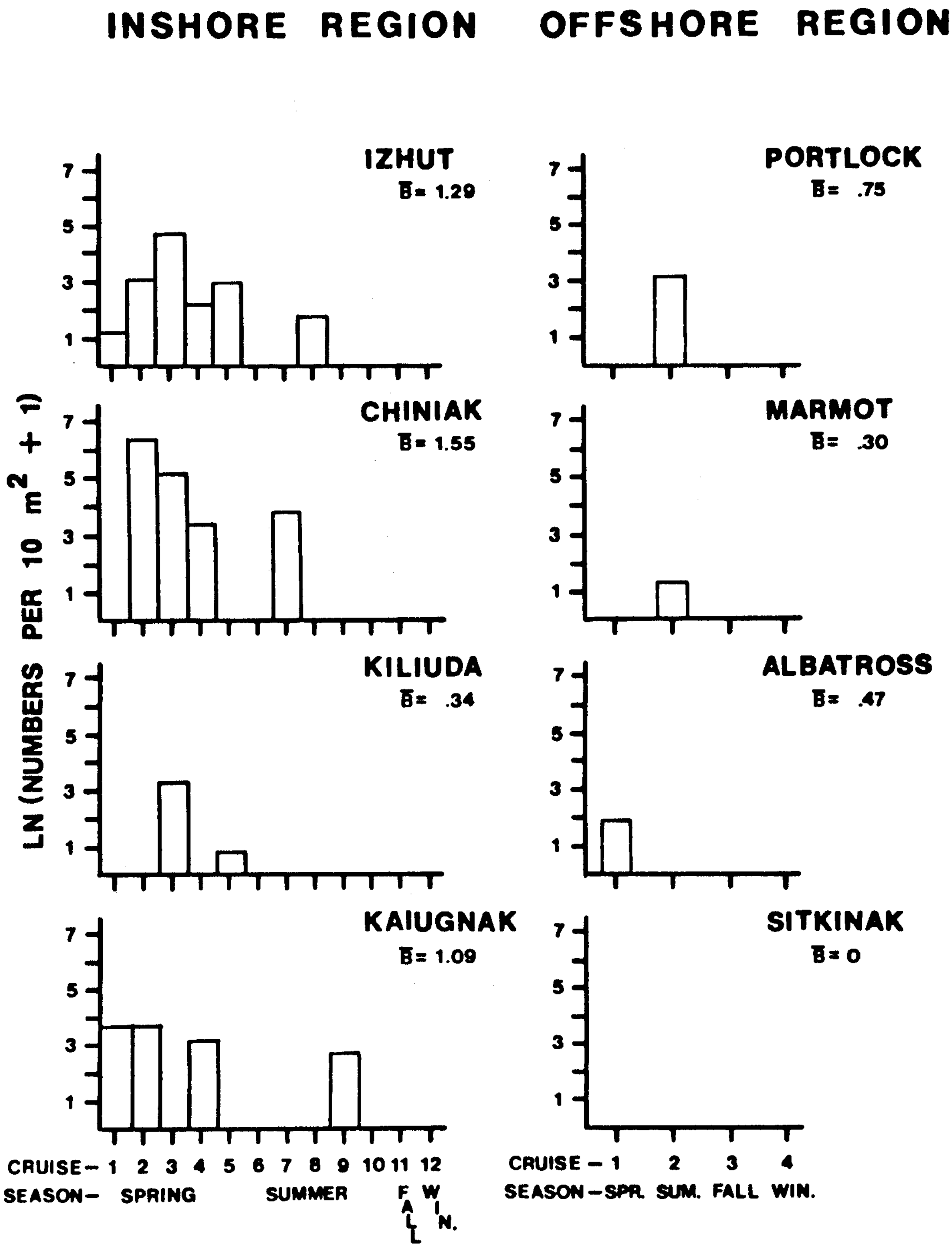


Figure 18.--Average density (ln(numbers per 10 m²)) by cruise, season, bay, subarea, and region for *Pandalus borealis* in the Kodiak Island study area. Bongo net data.

Table 10.—Standardized biomass (ln (numbers per 10 m^2 + 1)) of pink shrimp (*Pandalus borealis*) larvae by season, cruise, and subarea in the inshore region of the Kodiak Island study area, March 1978–March 1979. (Bongo net data.)

Season			Spring			Summer					Fall	Winter	Mean Biomass All Cruises
Cruise	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	
Subarea													
Izhut Bay	1.12	3.00	4.61	2.10	2.94	0	0	1.71	0	0	0	0	1.29
Chiniak	0	6.27	5.15	3.42	0	0	3.80	0	0	0	0	0	1.55
Kiliuda	0	0	3.22	0	0.84	0	0	0	0	0	0	0	0.34
Kaiugnak	3.64	3.59	0	3.18	0	0	0	0	2.68	0	0	0	1.09
Mean Biomass Bays Combined	1.19	3.21	3.24	2.17	0.94	0	0.95	0.43	0.67	0	0	0	1.07

Table 11.—Standardized biomass (ln (numbers per 10 m^2 + 1)) of pink shrimp (*Pandalus borealis*) larvae by season, cruise, and subarea in the offshore region in the Kodiak Island study area, March 1978–March 1979. (Bongo net data.)

Season	Spring	Summer	Fall	Winter	Mean Biomass All Cruises
Cruise	I	II	III	IV	
Subarea					
Portlock	0	3.04	0	0	0.76
Marmot	0	1.25	0	0	0.31
Albatross	1.87	0	0	0	0.47
Sitkinak	0	0	0	0	0
Mean Biomass Subareas Combined	0.47	1.07	0	0	0.385

Table 12.—Summary of information derived from analysis of variance tests of bongo net data (ln (numbers per 10 m^2 + 1)) for pink shrimp (*Pandalus borealis*) larvae.

Test	Source of Variability	Degrees of Freedom	Sum of Squares	Value of F
Inshore and offshore combined	Total	63	156.675	—
	Main effects			
	Region (R)	1	1.092	0.43
	Subarea (A)	3	7.518	0.98
	Season (S)	3	34.635	4.50**
	Interactions			
	R X A	3	2.589	0.34
	R X S	3	9.848	1.28
	A X S	9	2.324	0.10
	R X A X S	9	11.183	0.48
	Residual	32	82.080	—
Inshore	Total	47	139.139	—
	Main effects			
	Bays	3	9.795	1.62
	Cruise	11	62.946	2.84**
	Residual	33	66.397	—
Offshore	Total	15	11.929	—
	Main effects			
	Subarea	3	1.204	0.47
	Cruise	3	3.104	1.22
	Residual	9	7.622	—

* Denotes significance at = .05
** Denotes significance at = .01

***Pandalus goniurus* (humpy shrimp)**

The analysis presented by Kendall et al. (1980) did not address this species due to its low incidence. Surveys found larvae of *P. goniurus* in Kodiak Island waters only during spring and summer (Fig. 19 and Table 13) and Stage I zoeae only during spring.

Data resulting from the "extensive re-sort" subsamples (see Appendix A) were combined with the limited information previously available but this combination failed to show any consistent pattern in vertical distribution for *P. goniurus* zoeae. Larvae were found in only one daytime sample from Izhut Bay and those found in Kiliuda Bay appeared homogenously distributed at all depths (Fig. 20). During hours of darkness or low light levels, zoeae in Izhut Bay were heavily concentrated in depths shallower than 40 m but a ubiquitous vertical distribution was suggested in Kiliuda Bay. However, relatively few larvae were present at the surface in both bays.

Vertical distribution by stage of zoeal development was examined in the daytime Tucker samples from Kiliuda Bay. Nearly all *P. goniurus* Stage I larvae were found at the shallowest depths sampled (Fig. 21). No trends of depth preference were obvious for all other stages encountered. Stages II-V zoeae were present throughout the water column.

The analysis of variance tests on bongo samples for inshore, offshore, and combined regions failed to identify any significant region, area, or time effect on the distribution or abundance of *P. goniurus* zoeae (Table 14). Although these tests failed to identify statistically significant differences, there was an obvious "solely inshore" distribution of these larvae during the study (Fig. 22). None were encountered in any offshore subarea during any season.

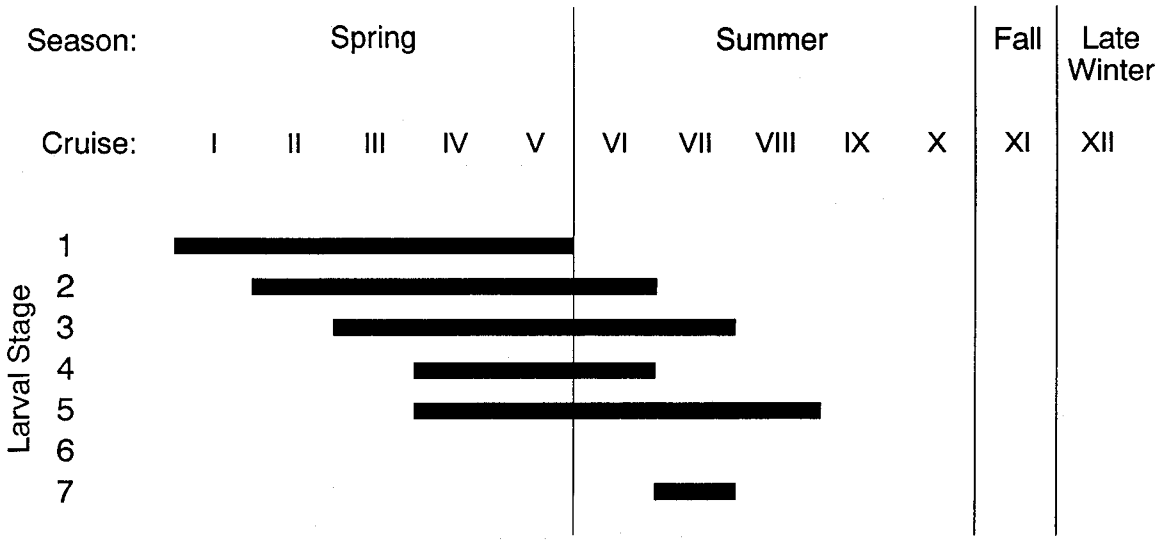


Figure 19.--Occurrence of larval stages of *Pandalus goniurus* by cruise and season from the OCSEAP inshore plankton cruises. Data from all gear types.

Table 13.—Standardized biomass (ln (numbers per 10 m² + 1)) of humpy shrimp (*Pandalus goniurus*) by season, cruise, and subarea in the inshore region of the Kodiak Island study area, March 1978–March 1979. (Bongo net data.)

Season	Spring				Summer						Fall	Winter	Mean Biomass All Cruises
Cruise	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	
Subarea													
Izhut	0	0	2.49	2.58	2.10	0	0	0	0	0	0	0	0.60
Chiniak	0	2.22	4.50	4.10	0	3.06	0	0	0	0	0	0	1.16
Kiliuda	2.91	0	2.57	0	1.60	2.28	4.38	0	0	0	0	0	1.14
Kaiugnak	0	0	0	1.74	0	0	0	0	0	0	0	0	0.14
Mean Biomass Bays Combined	0.73	0.55	2.39	2.10	0.92	1.33	1.09	0	0	0	0	0	0.76

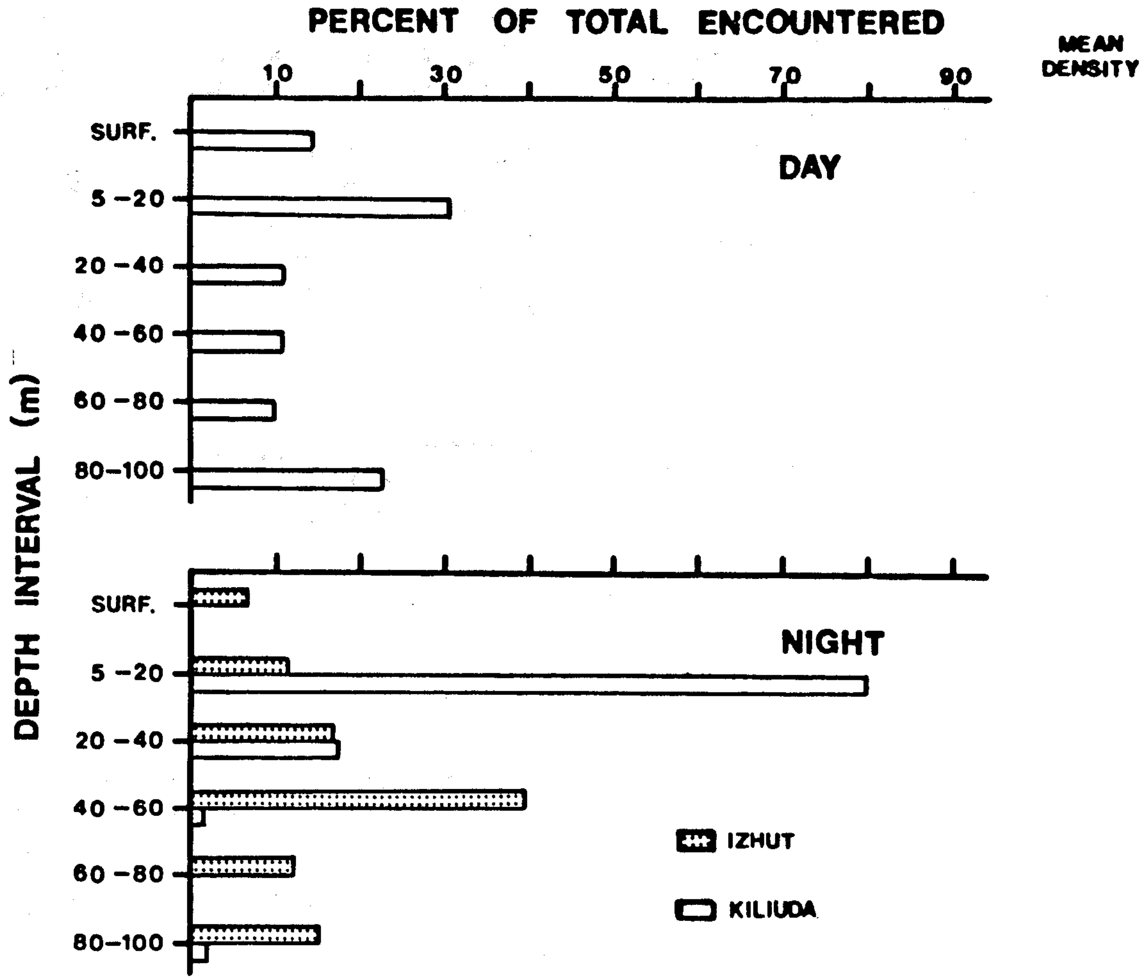


Figure 20.--Percentage of total *Pandalus goniurus* encountered during inshore OCSEAP plankton cruises by diel period and depth interval for Izhut and Kiliuda bays. Tucker trawl data.

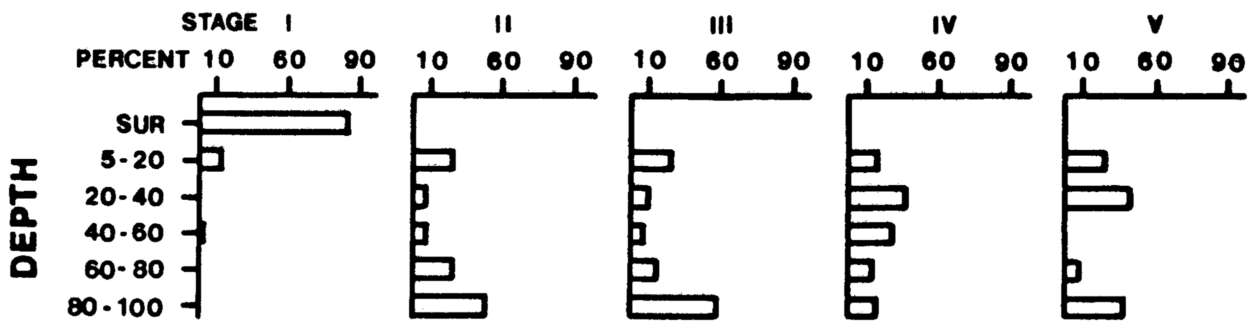


Figure 21.--Percentage of *Pandalus goniurus* encountered by life stage and depth interval during inshore OCSEAP plankton cruises. Neuston sampler and Tucker trawl data.

Table 14.—Summary of information derived from analysis of variance tests of bongo net data (ln (numbers per 10 m^2 + 1)) for humpy shrimp (*Pandalus goniurus*) larvae.

Test	Source of Variability	Degrees of Freedom	Sum of Squares	Value of F
Inshore and offshore combined	Total	63	92.861	—
	Main effects			
	Region (R)	1	3.478	1.90
	Subarea (A)	3	6.392	1.16
	Season (S)	3	9.567	1.74
	Interactions			
	R X A	3	1.065	0.19
	R X S	3	3.305	0.60
	A X S	9	4.556	0.28
	R X A X S	9	1.337	0.08
	Residual	32	58.618	—
Inshore	Total	47	85.905	—
	Main effects			
	Bays	3	8.522	2.04
	Cruise	11	31.486	2.06
	Residual	33	45.897	—
Offshore	Total	15	0	—
	Main effects			
	Subarea	3	0	0
	Cruise	3	0	0
	Residual	9	0	—

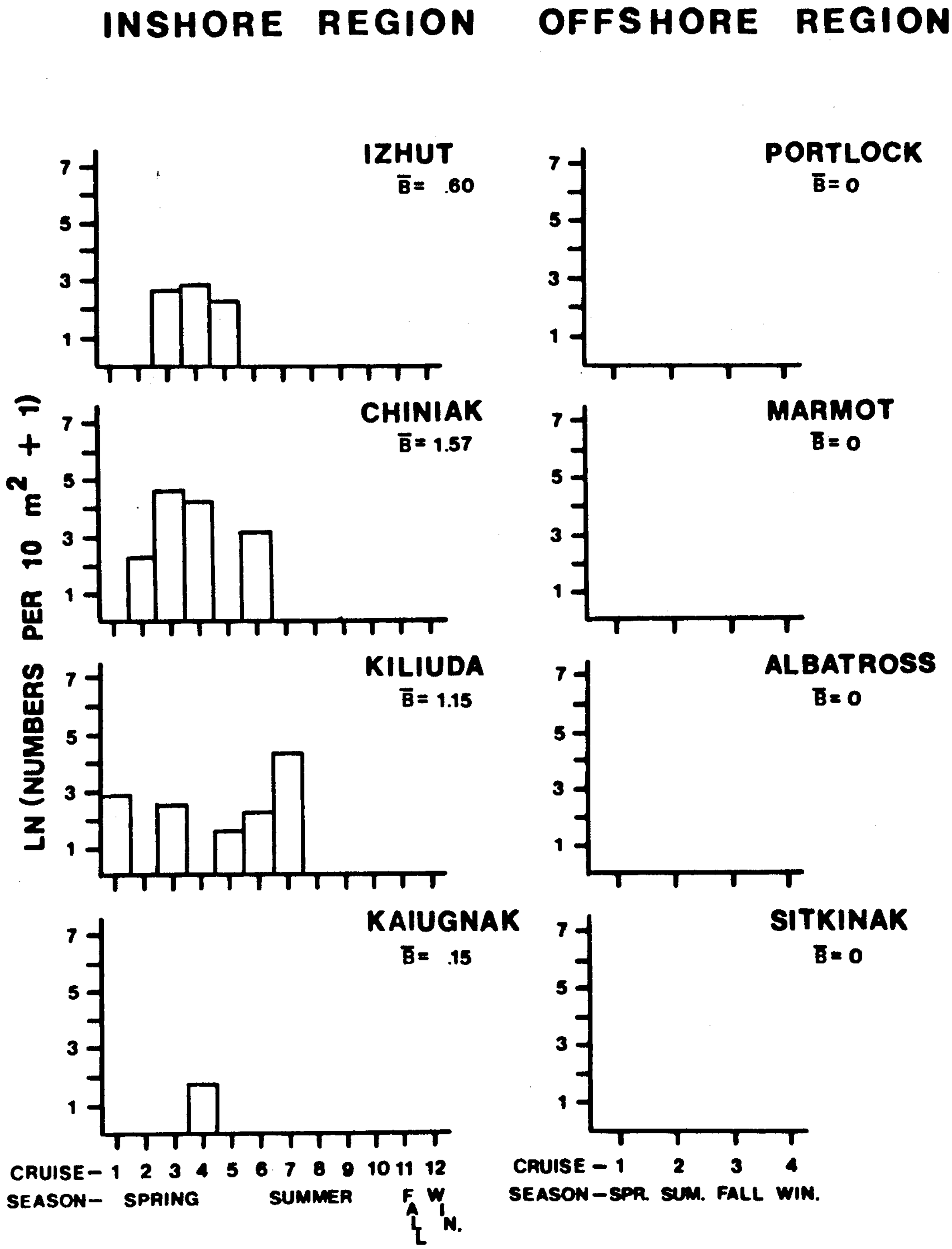


Figure 22.--Average density (ln(numbers per 10 m²)) by cruise, season, bay, subarea, and region for *Pandalus goniurus* in the Kodiak Island study area. Bongo net data.

Anomura (anomuran crabs, except *Paralithodes camtschatica*)

Similar to the hippolytid and crangonid shrimps in this report, the anomuran crab group is a multi-species assemblage. Larval forms of anomuran crabs were found in most areas at all times of the year sampled (Fig. 23 and Tables 15 and 16).

Analysis of vertical distribution data indicated that during the day most anomuran larvae concentrated at less than 40 m below the surface. Night-time data showed more larvae were present in the deeper intervals sampled than during the day. However, highest concentrations occurred at the surface in both bays (Fig. 24).

The abundance of anomuran crab zoeae was significantly affected by region and season (Table 17). The inshore region contained significantly more of these larvae than offshore, and spring and summer were more important than the other seasons. A region x season interaction was encountered, implying that the abundance of anomuran zoeae in each region changed seasonally.

When the inshore data were analyzed separately, both bay and cruise (time) effects on abundance were identified (Table 17). Significantly more anomuran larvae were present from early April through August (Cruises II-X) than during the remainder of the study period. Despite an apparent bay effect, no bay could be identified in multiple comparison tests as being more important than any other. All bays contained relatively substantial amounts of these zoeae (Fig. 25).

The separate analysis of the offshore data showed no significant subarea effect. There was a cruise effect, with spring and summer cruises encountering significantly greater numbers of larval anomurans than amounts encountered during fall or winter.

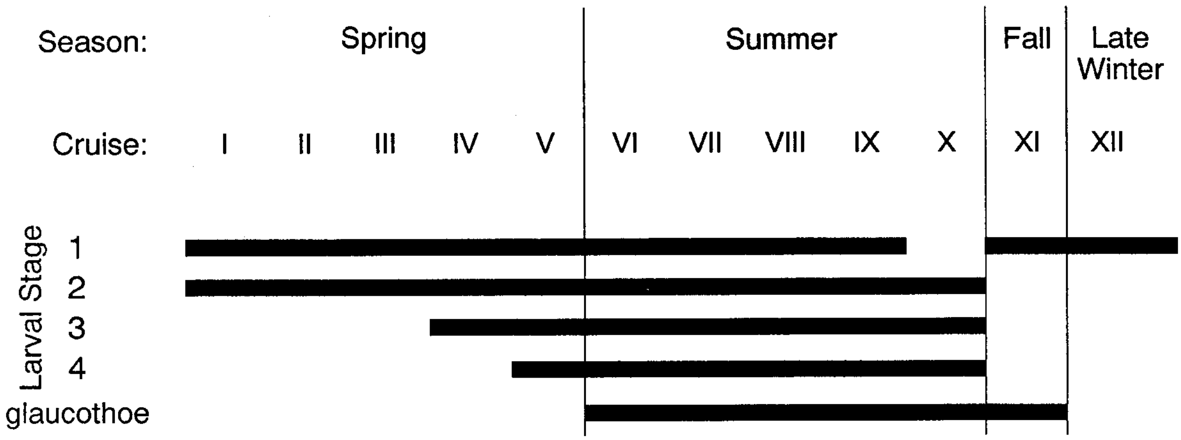


Figure 23.--Occurrence of larval stages of Anomura by cruise and season from the OCSEAP inshore plankton cruises. Data from all gear types.

Table 15.—Standardized biomass (ln (numbers per 10 m² + 1)) of anomuran crab larvae by season, cruise, and subarea in the inshore region of the Kodiak Island study area, March 1978–March 1979. (Bongo net data.)

Season			Spring		Summer						Fall	Winter	Mean Biomass All Cruises
Cruise	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	
Subarea													
Izhut	5.56	5.96	7.14	6.38	5.71	4.39	5.85	4.40	5.64	3.95	3.76	0.40	4.93
Chiniak	4.01	4.20	5.79	3.81	4.10	5.33	5.76	4.57	5.49	5.22	2.83	0.69	4.32
Kiliuda	5.11	5.14	5.49	6.56	6.21	6.34	4.70	4.21	5.04	5.34	4.45	1.20	4.98
Kaiugnak	0	4.94	3.49	5.78	4.84	5.89	2.41	5.24	5.44	3.99	2.20	0.96	3.76
Mean Biomass Bays Combined	3.67	5.06	5.48	5.63	5.21	5.49	4.68	4.60	5.40	4.62	3.31	0.81	4.50

Table 16.—Standardized biomass (ln (numbers per 10 m² + 1)) of anomuran crab larvae by season, cruise, and subarea in the offshore region of the Kodiak Island study area, March 1978-March 1979. (Bongo net data.)

Season	Spring	Summer	Fall	Winter	Mean Biomass All Cruises
Cruise	I	II	III	IV	
Subarea					
Portlock	3.96	5.35	0.04	1.16	2.62
Marmot	2.38	4.81	0	0.16	1.84
Albatross	3.69	4.10	0.26	0.21	2.06
Sitkinak	3.22	6.03	1.19	0	2.61
Mean Biomass Subareas Combined	3.31	5.07	0.37	0.38	2.28

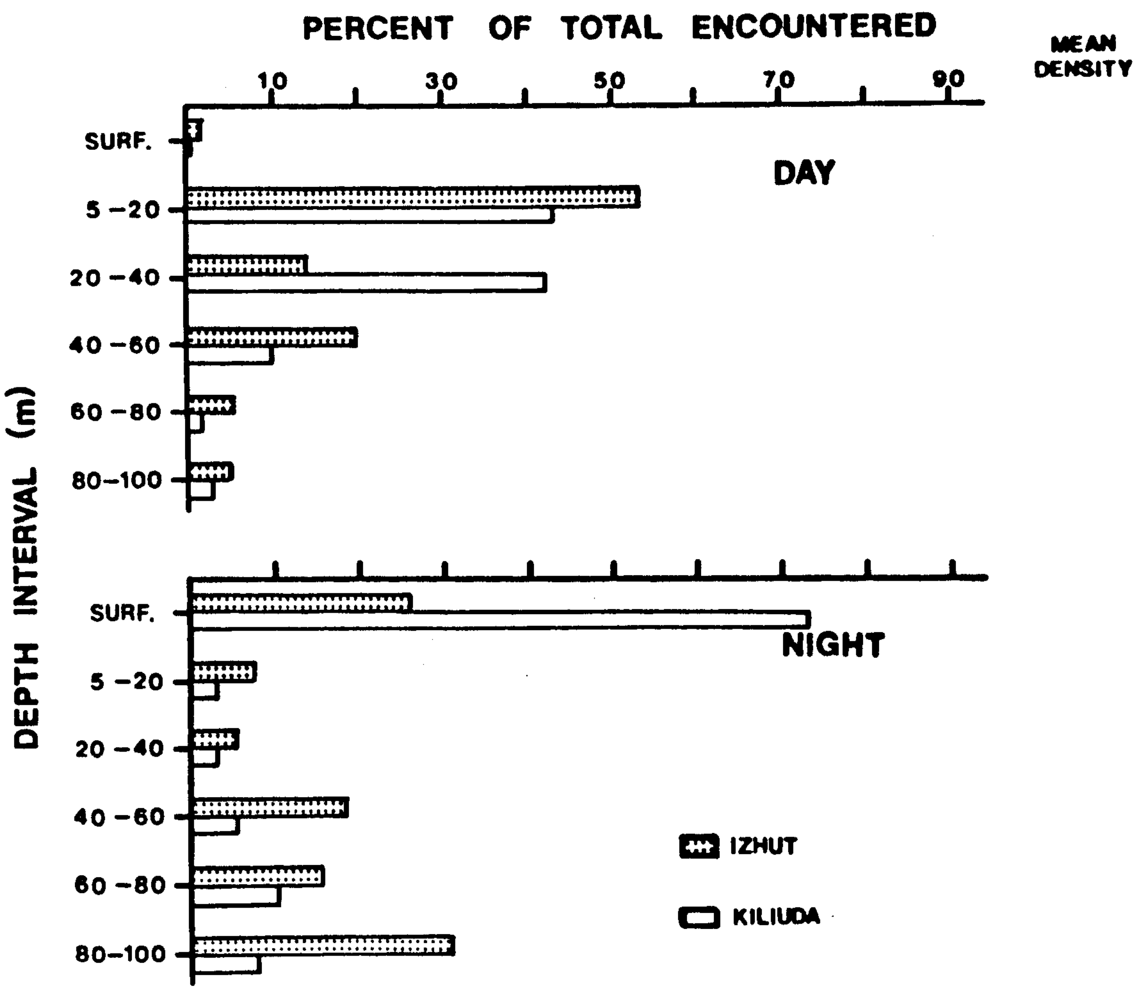


Figure 24.--Percentage of total Anomura encountered during inshore OCSEAP plankton cruises by diel period and depth interval for Izhut and Kiliuda bays. Tucker trawl data.

Table 17.—Summary of information derived from analysis of variance tests of bongo net data (ln (numbers per 10 m^2 + 1)) for anomuran crab larvae.

Test	Source of Variability	Degrees of Freedom	Sum of Squares	Value of F
Inshore and offshore combined	Total	63	261.543	—
	Main effects			
	Region (R)	1	13.546	10.60**
	Subarea (A)	3	8.684	2.26
	Season (S)	3	120.195	31.36**
	Interactions			
	R X A	3	4.665	1.22
	R X S	3	13.748	3.59*
	A X S	9	10.532	0.92
	R X A X S	9	3.638	0.32
	Residual	32	40.886	—
Inshore	Total	47	133.086	—
	Main effects			
	Bays	3	11.876	3.37*
	Cruise	11	82.461	6.38**
	Residual	33	38.749	—
Offshore	Total	15	69.621	—
	Main effects			
	Subarea	3	1.886	1.70
	Cruise	3	64.412	58.17**
	Residual	9	3.322	—

* Denotes significance at = .05

** Denotes significance at = .01

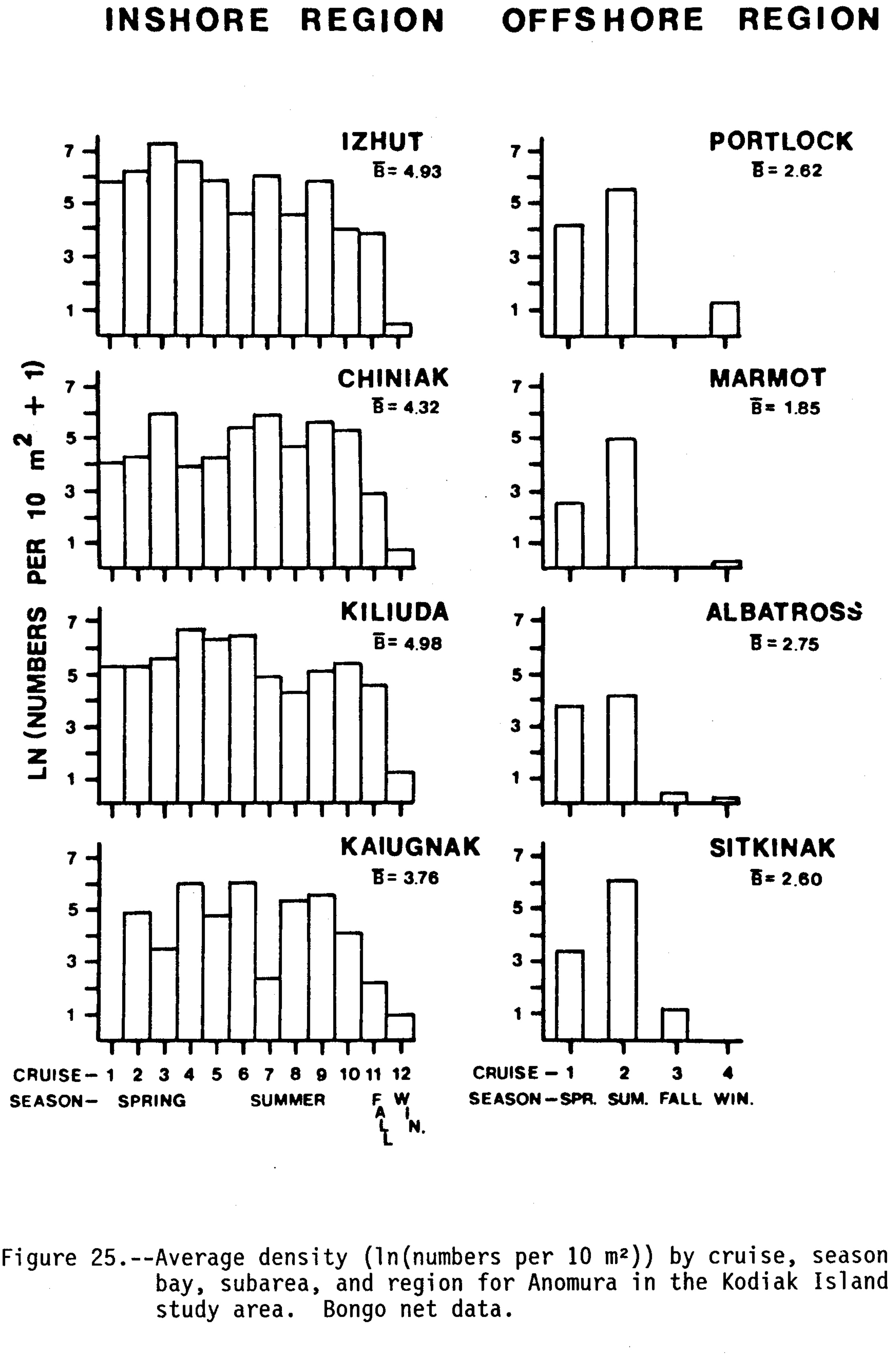


Figure 25.--Average density (ln(numbers per 10 m²)) by cruise, season, bay, subarea, and region for Anomura in the Kodiak Island study area. Bongo net data.

***Paralithodes camtschatica* (red king crab)**

The zoeae of *P. camtschatica* were present in the study area from late winter (inshore only) through spring and early summer (Fig. 26 and Tables 18 and 19) with Stage I larvae occurring March through May.

During the day, most larvae were found in the stratum 5-20 m below the surface in Kiliuda Bay and in the upper 60 m of the water column in Izhut Bay (Fig. 27). Relatively small numbers remained at or near the surface at night, and most zoeae appeared to move into deeper strata in both bays. *P. camtschatica* zoeae were concentrated in upper portions of the water column during daylight hours.

Detailed examination of the Kiliuda Bay daytime Tucker trawl samples indicates larval stages of *P. camtschatica* remain concentrated at very shallow depths until development into megalopae (Fig. 28). Stages I and II zoeae appeared somewhat dispersed throughout the upper 60 m, but very low amounts of these larvae in the samples place questionable value on this observation. Highest concentrations of megalopae were still encountered in shallow depth intervals and this stage was the only one found in measurable amounts at depths greater than 80 m.

There was no notable difference in abundance of *P. camtschatica* larvae by region or subarea during our study of the Kodiak Island shelf. Analysis of variance tests of the bongo data indicated that abundance differed significantly by season (Table 20); however, multiple comparison tests failed to identify which season was the most important. Inability to attach significance to seasonal abundance differences probably resulted from only small amounts of larvae being encountered in any area or time period (Tables 18 and 19). Although the statistical tests failed to substantiate seasonal abundance trends, *P. camtschatica* larvae were encountered primarily in late winter and spring. Zoeae were found sporadically in all inshore bays, but only in 2 of the 4 offshore subareas and in the offshore region only during spring and summer (Fig. 29).

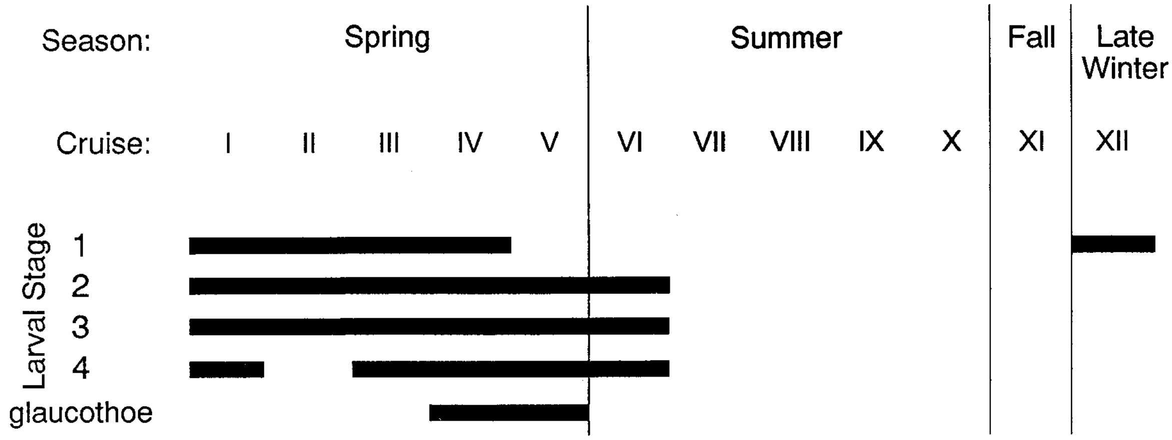


Figure 26.--Occurrence of larval stages of *Paralithodes camtschatica* by cruise and season from the OCSEAP inshore plankton cruises. Data from all gear types.

Table 18.—Standardized biomass (ln(numbers per 10 m^2 + 1)) of red king crab (*Paralithodes camtschatica*) larvae by season, cruise, and subarea in the inshore region of the Kodiak Island study area, March 1978–March 1979. (Bongo net data.)

Season	Spring				Summer						Fall	Winter	Mean Biomass All Cruises
Cruise	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	
Subarea													
Izhut	0	2.00	0	0	1.63	0	0	0	0	0	0	0.15	0.31
Chiniak	3.51	0	0	3.42	0	0	0	0	0	0	0	3.04	0.83
Kiliuda	0	2.08	3.11	2.90	1.44	0	0	0	0	0	0	0	0.79
Kaiugnak	0	0	2.70	0	0	0	0	0	0	0	0	0.80	0.29
Mean Biomass Bays Combined	0.88	1.02	0.70	1.58	0.77	0	0	0	0	0	0	1.00	0.55

Table 19.—Standardized biomass (ln (numbers per 10 m^2 + 1)) of red king crab (*Paralithodes camtschatica*) larvae by season, cruise, and subarea in the offshore region of the Kodiak Island study area, March 1978-March 1979. (Bongo net data.)

Season	Spring	Summer	Fall	Winter	Mean Biomass All Cruises
Cruise	I	II	III	IV	
Subarea					
Portlock	0.50	0	0	0	0.12
Marmot	0	0	0	0	0
Albatross	0	0	0	0	0
Sitkinak	0	0.65	0	0	0.16
Mean Biomass Subareas Combined	0.12	0.16	0	0	0.07

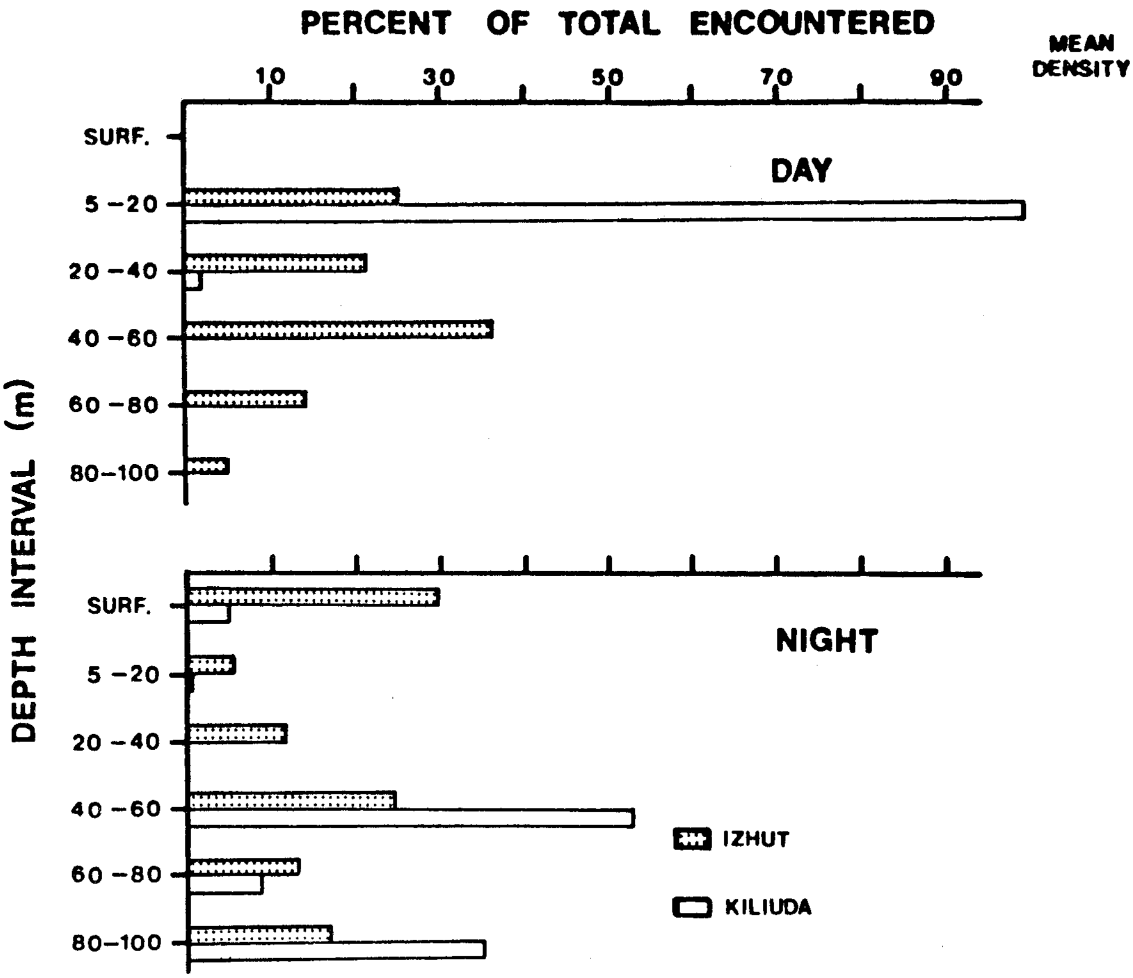


Figure 27.--Percentage of total *Paralithodes camtschatica* encountered during inshore OCSEAP plankton cruises by diel period and depth interval for Izhut and Kiliuda bays. Tucker trawl data.

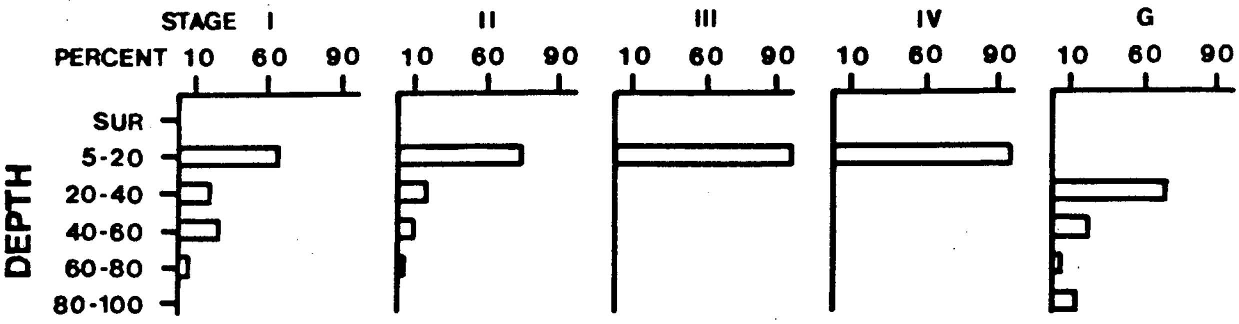


Figure 28.--Percentage of *Paralithodes camtschatica* encountered by life stage and depth interval during inshore OCSEAP plankton cruises. Neuston sampler and Tucker trawl data.

Table 20.—Summary of information derived from analysis of variance tests of bongo net data (ln(numbers per 10 m² + 1)) for red king crab (*Paralithodes camtschatica*) larvae.

Test	Source of Variability	Degrees of Freedom	Sum of Squares	Value of F
Inshore and offshore combined	Total	63	60.793	—
	Main effects			
	Region (R)	1	2.186	2.29
	Subarea (A)	3	1.921	0.67
	Season (S)	3	11.780	4.11*
	Interactions			
	R X A	3	1.503	0.52
	R X S	3	3.304	1.15
	A X S	9	5.901	0.69
	R X A X S	9	3.213	0.37
	Residual	32	30.556	—
Inshore	Total	47	57.371	—
	Main effects			
	Bays	3	3.124	0.92
	Cruise	11	17.042	1.37
	Residual	33	37.205	—
Offshore	Total	15	0.590	—
	Main effects			
	Subarea	3	0.085	0.61
	Cruise	3	0.085	0.61
	Residual	9	0.419	—

* Denotes significance at = .05

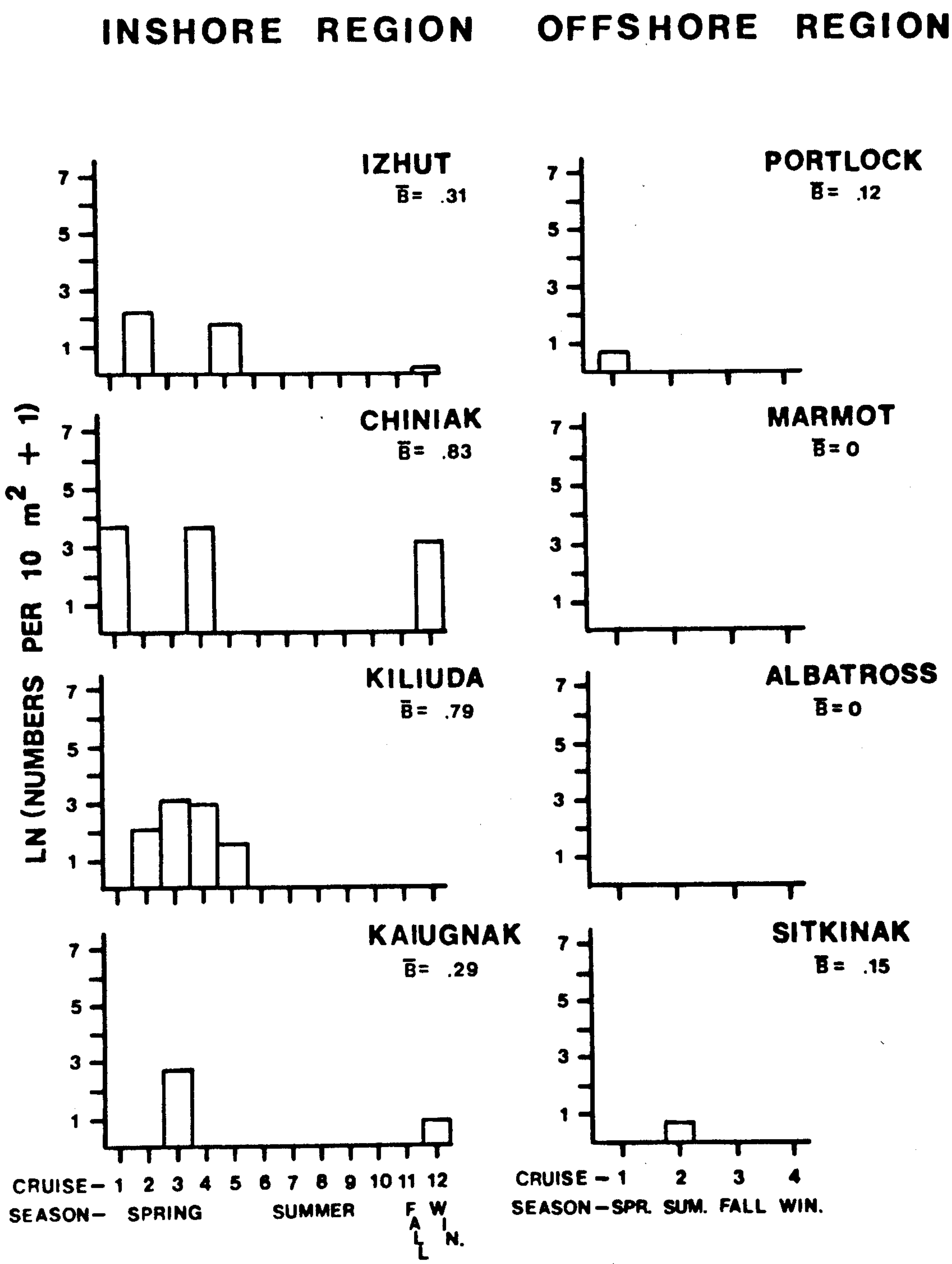


Figure 29.--Average density (ln(numbers per 10 m²)) by cruise, season, bay, subarea, and region for *Paralithodes camtschatica* in the Kodiak Island study area. Bongo net data.

***Cancer magister* (Dungeness crab)**

Larvae of *C. magister* were present in the water column in late winter, spring, and summer in the inshore region (Fig. 30 and Table 21), but only during summer offshore (Table 22). Stage I zoeae were present inshore throughout most of the study period; however, a time of peak release could not be discerned from our data.

Information from the diel vertical distribution data indicated most *C. magister* zoeae were present from the surface to depths of 60 m during the day (Fig. 31). At night they were encountered throughout the water column but in highest concentrations from the surface down to 20-40 m. A high percentage of *C. magister* zoeae were present at 80-100 m in Izhut Bay, but it should be noted that amounts found in samples from this bay were very low relative to concentrations encountered in Kiliuda Bay.

Analysis of variance tests of bongo net samples indicated no significant difference in the abundance of *C. magister* larvae between inshore and offshore regions of the study area (Table 23). Separate tests by region also failed to identify notable differences in offshore distribution or abundance by subarea or season but significant differences were apparent inshore. Multiple comparison tests determined that the abundance of *C. magister* zoeae in Kiliuda Bay (Fig. 32) was significantly higher than in any other bay during the study. An inshore cruise effect was also indicated; however, the greater importance of any single cruise or group of cruises was not discerned.

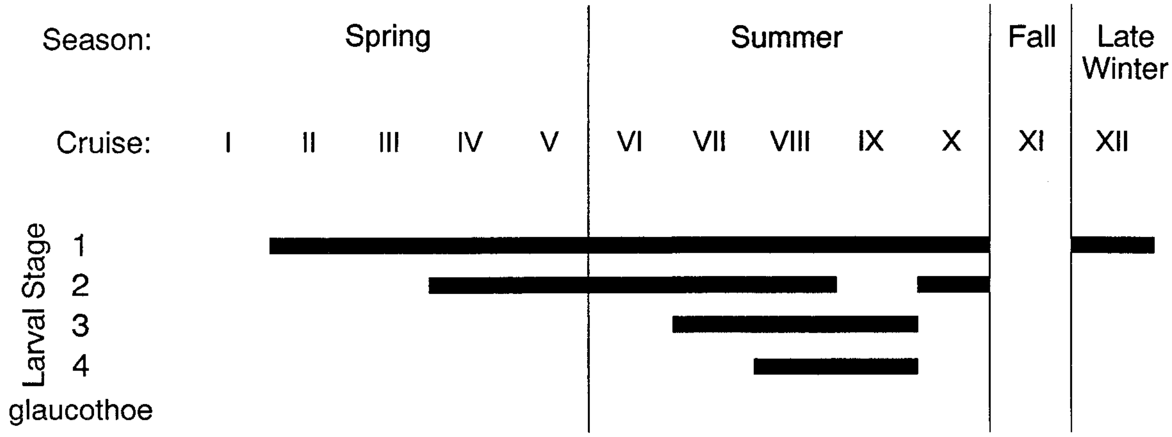


Figure 30.--Occurrence of larval stages of *Cancer magister* by cruise and season from the OCSEAP inshore plankton cruises. Data from all gear types.

Table 21.—Standardized biomass (ln(numbers per 10 m^2 + 1)) of Dungeness crab (*Cancer magister*) larvae by season, cruise, and subarea in the inshore region of the Kodiak Island study area, March 1978–March 1979. (Bongo net data.)

Season			Spring		Summer					Fall	Winter	Mean Biomass All Cruises
Cruise	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	
Subarea													
Izhut	0	0	0	2.35	0	1.24	3.32	0	0	0	0	0	0.56
Chiniak	0	0	0	0	0	3.96	0	0	0	0	0	0	0.33
Kiliuda	0	4.26	0	3.78	4.75	4.02	3.93	4.04	2.84	0	0	0	2.30
Kaiugnak	0	0	2.33	1.92	2.74	4.64	0	3.05	0	0	0	0.21	1.24
Mean Biomass Bays Combined	0	1.06	0.58	2.01	1.87	3.46	1.81	1.77	0.71	0	0	0.05	1.11

Table 22.—Standardized biomass (ln (numbers per 10 m^2 + 1)) of Dungeness crab (*Cancer magister*) larvae by season, cruise, and subarea in the offshore region of the Kodiak Island study area, March 1978–March 1979. (Bongo net data.)

Season	Spring	Summer	Fall	Winter	Mean Biomass All Cruises
Cruise	I	II	III	IV	
Subarea					
Portlock	0	0	0	0	0
Marmot	0	2.60	0	0	0.65
Albatross	0	0	0	0	0
Sitkinak	0	3.88	0	0	0.97
Mean Biomass Subareas Combined	0	1.62	0	0	0.40

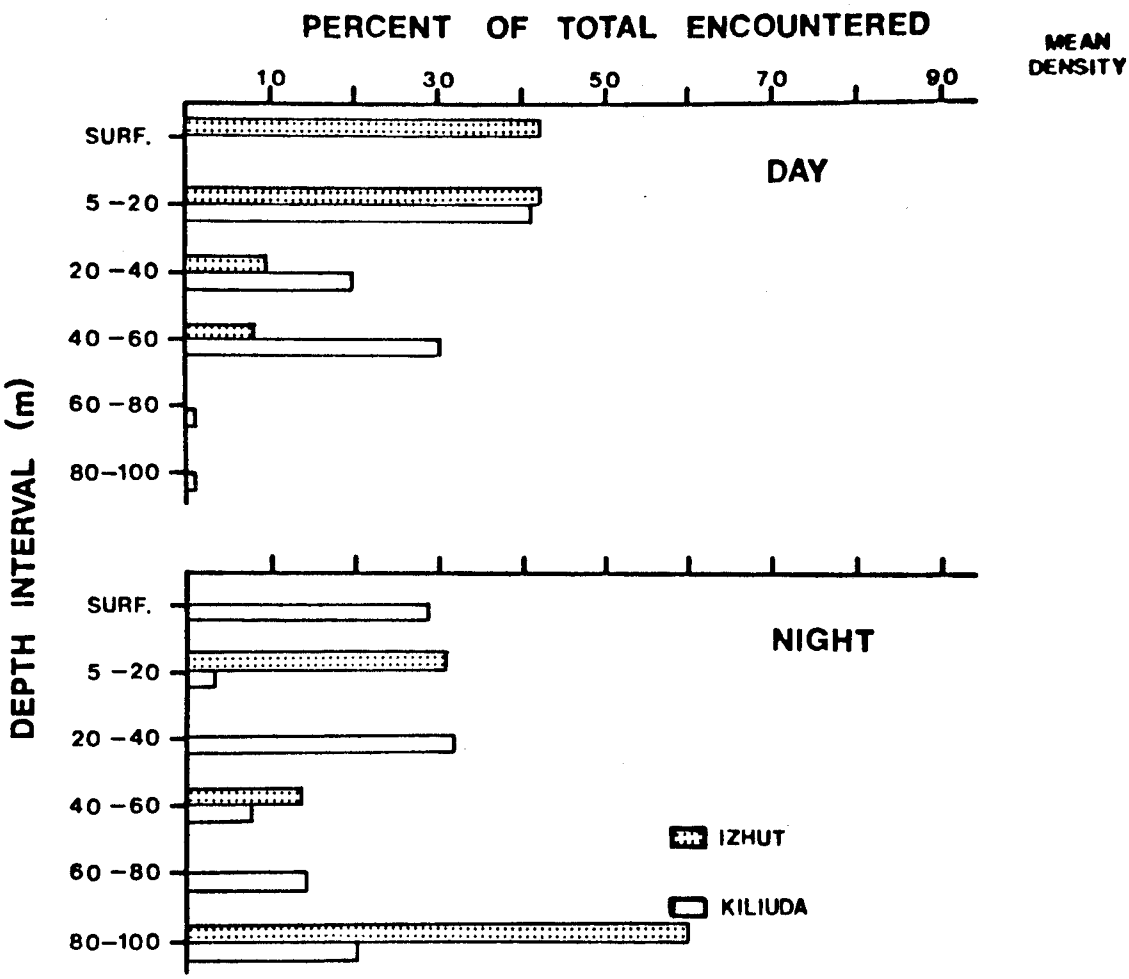


Figure 31.--Percentage of total *Cancer magister* encountered during inshore OCSEAP plankton cruises by diel period and depth interval for Izhut and Kiliuda bays. Tucker trawl data.

Table 23.—Summary of information derived from analysis of variance tests of bongo net data (ln (numbers per 10 m^2 + 1)) for Dungeness crab (*Cancer magister*) larvae.

Test	Source of Variability	Degrees of Freedom	Sum of Squares	Value of F
Inshore and offshore combined	Total	63	158.004	—
	Main effects			
	Region (R)	1	1.187	0.44
	Subarea (A)	3	19.350	2.41
	Season (S)	3	18.285	2.28
	Interactions			
	R X A	3	8.285	1.03
	R X S	3	2.911	0.36
	A X S	9	4.356	0.18
	R X A X S	9	10.232	0.43
	Residual	32	85.462	—
Inshore	Total	47	132.807	—
	Main effects			
	Bays	3	27.939	5.87**
	Cruise	11	52.508	3.01**
	Residual	33	52.361	—
Offshore	Total	15	19.190	—
	Main effects			
	Subarea	3	2.829	1.00
	Cruise	3	7.873	2.78
	Residual	9	8.488	—

** Denotes significance at = .01

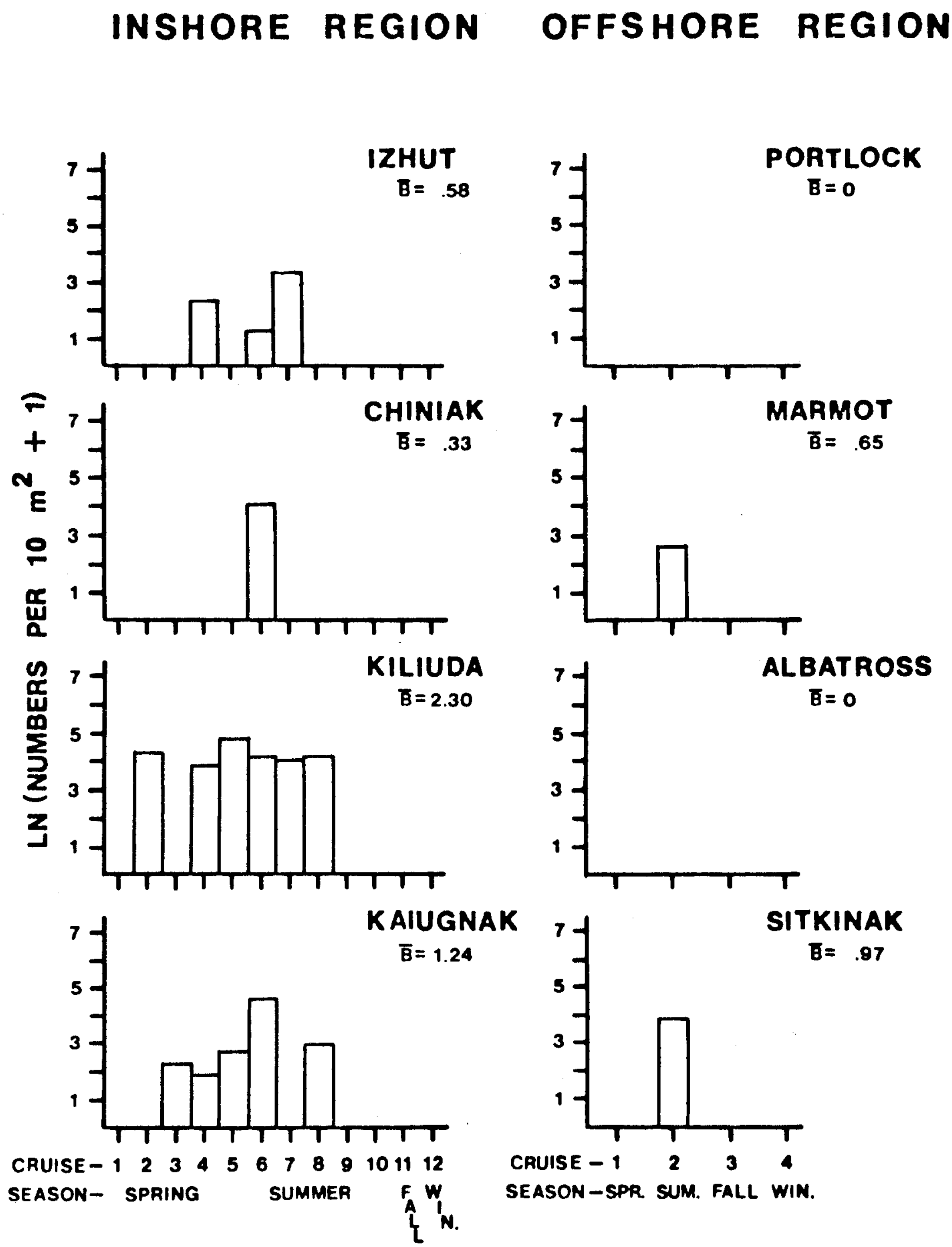


Figure 32.--Average density (ln(numbers per 10 m²)) by cruise, season, bay, subarea, and region for *Cancer magister* in the Kodiak Island study area. Bongo net data.

Cancer sp.

Occurrence of *Cancer* sp. larvae in the Kodiak Island study area was apparently limited to spring and summer (Figs. 33 and 34, Tables 24 and 25).

Nearly all larvae were found during the day in the 5- to 40-m interval and at or near the surface during the night (Fig. 35). The previous analysis by Kendall et al. (1980) suggested a deeper night-time distribution, but that analysis did not include neuston samples.

The analysis of variance test of combined inshore and offshore data indicated no notable region or area effects on distribution or abundance of *Cancer* sp. larvae (Table 26). There was a seasonal effect, with larval concentration in summer being significantly higher than amounts during other times of the year. These results were mirrored by separate analyses for the inshore and offshore data. The period of mid-June through early August (Cruises VI-IX) contained significantly greater amounts of *Cancer* sp. larvae inshore, while in the offshore region peak abundance occurred during the summer cruise.

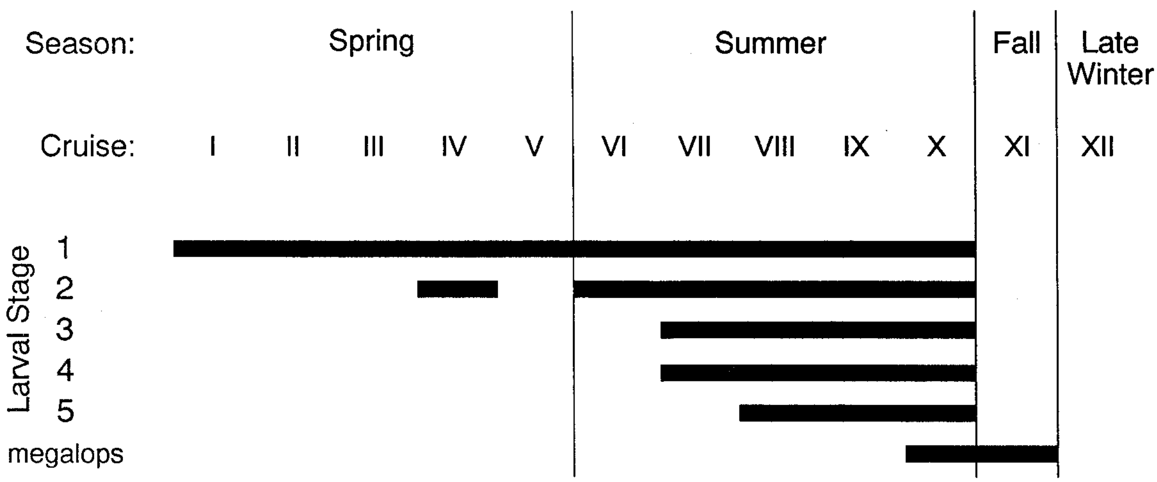


Figure 33.--Occurrence of larval stages of *Cancer* sp. by cruise and season from the OCSEAP inshore plankton cruises. Data from all gear types.

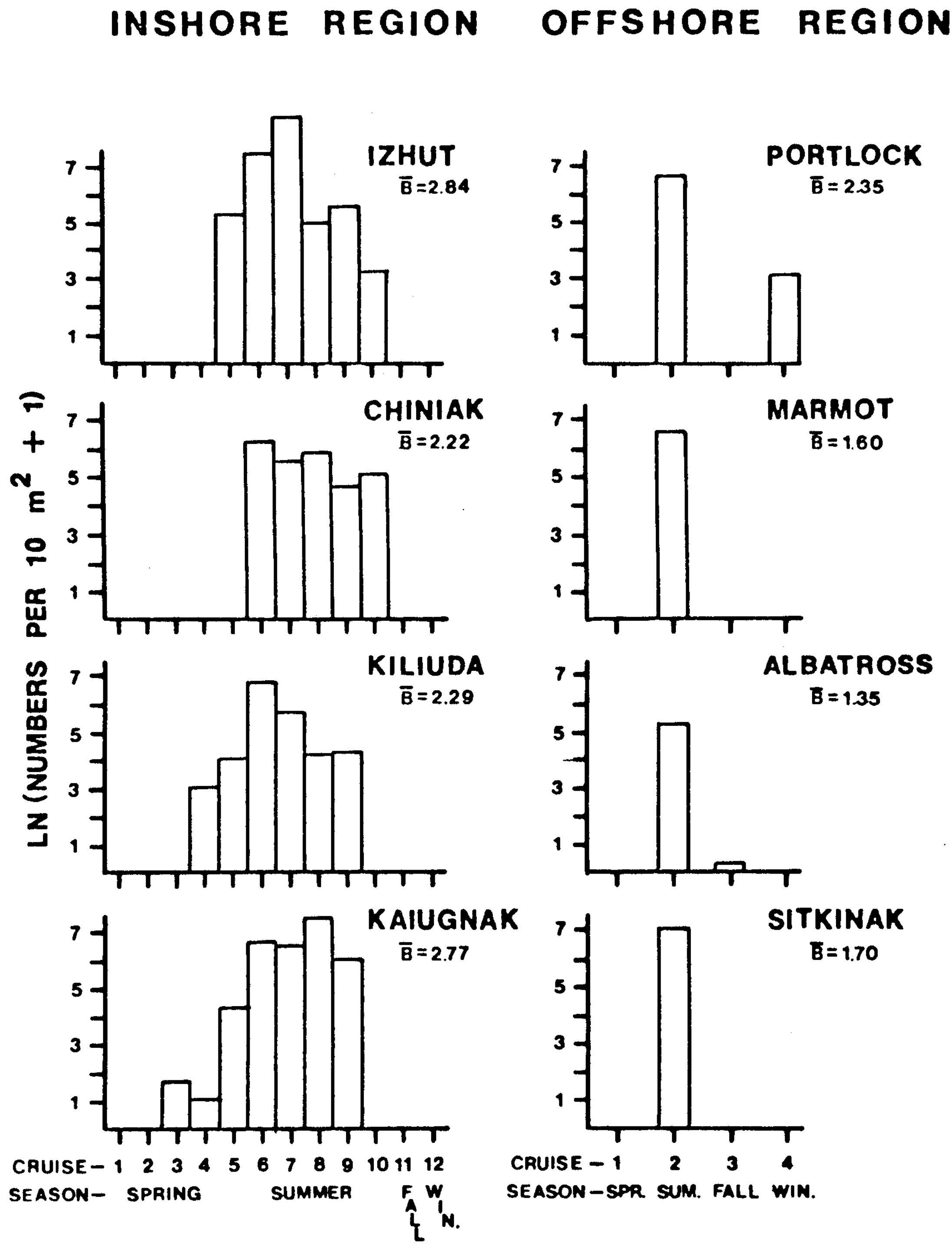


Figure 34.--Average density (ln(numbers per 10 m²)) by cruise, season, bay, subarea, and region for *Cancer* sp. in the Kodiak Island study area. Bongo net data.

Table 24.—Standardized biomass (ln(numbers per 10 m² + 1)) of cancer crab (*Cancer* sp.) larvae by season, cruise, and subarea in the inshore region of the Kodiak Island study area, March 1978–March 1979. (Bongo net data.)

Season			Spring		Summer						Fall	Winter	Mean Biomass All Cruises
Cruise	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	
Subarea													
Izhut	0	0	0	0	5.09	7.25	8.46	4.83	5.37	3.12	0	0	2.84
Chiniak	0	0	0	0	0	6.10	5.36	5.65	4.58	5.00	0	0	2.22
Kiliuda	0	0	0	3.00	4.00	6.61	5.57	4.08	4.18	0	0	0	2.29
Kaiugnak	0	0	1.73	1.14	4.30	6.52	6.40	7.18	5.93	0	0	0	2.77
Mean Biomass Bays Combined	0	0	0.43	1.03	3.35	6.62	6.45	5.43	5.01	2.03	0	0	2.53

Table 25.—Standardized biomass (ln (numbers per 10 m² + 1)) of cancer crab (*Cancer* sp.) larvae by season, cruise, and subarea in the offshore region of the Kodiak Island study area, March 1978–March 1979. (Bongo net data.)

Season	Spring	Summer	Fall	Winter	Mean Biomass All Cruises
Cruise	I	II	III	IV	
Subarea					
Portlock	0	6.37	0	3.02	2.35
Marmot	0	6.38	0	0	1.59
Albatross	0	5.08	0.30	0	1.34
Sitkinak	0	6.83	0	0	1.71
Mean Biomass Subareas Combined	0	6.16	0.07	0.75	1.74

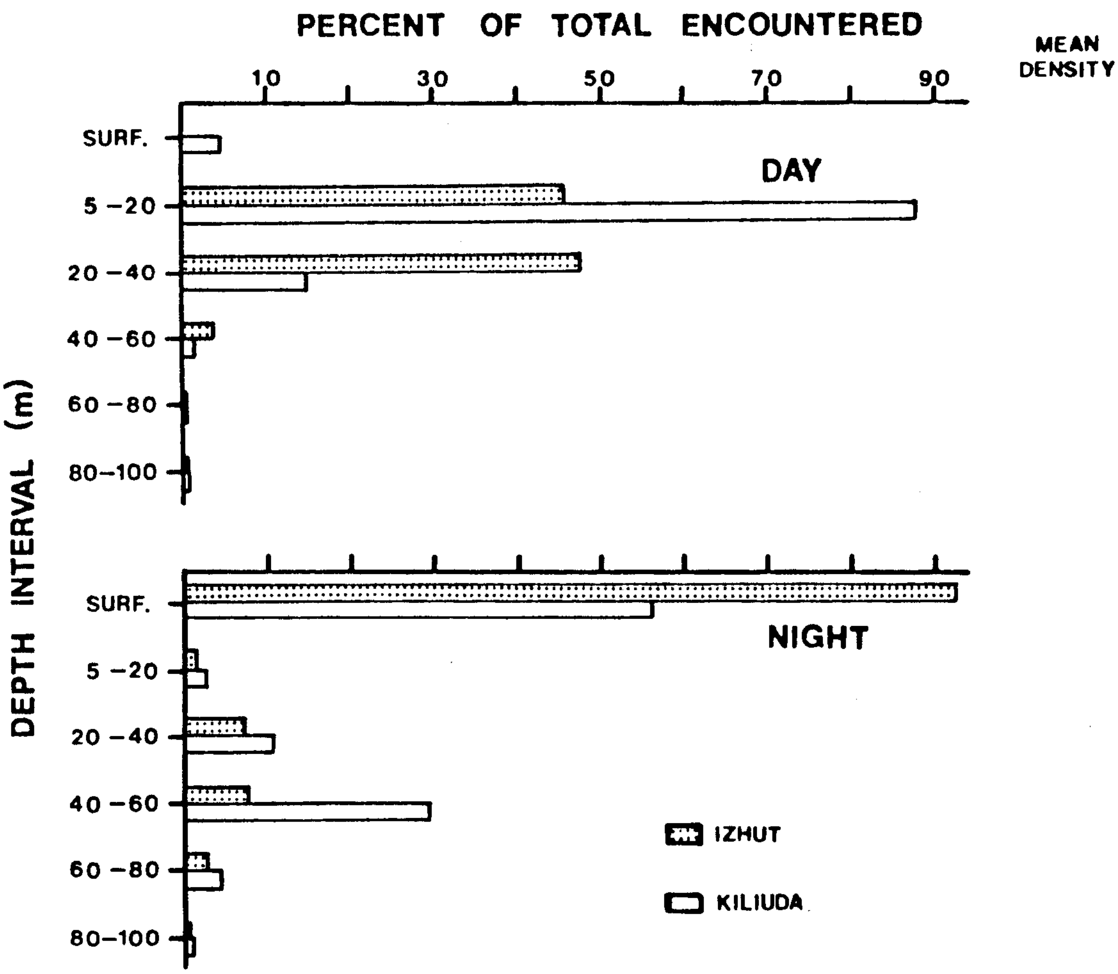


Figure 35.--Percentage of total *Cancer* sp. encountered during inshore OCSEAP plankton cruises by diel period and depth interval for Izhut and Kiliuda bays. Tucker trawl data.

Table 26.—Summary of information derived from analysis of variance tests of bongo net data (ln(numbers per 10 m² + 1)) for cancer crab (*Cancer* sp.) larvae.

Test	Source of Variability	Degrees of Freedom	Sum of Squares	Value of F
Inshore and offshore combined	Total	63	496.694	—
	Main effects			
	Region (R)	1	0.367	0.09
	Subarea (A)	3	5.250	0.44
	Season (S)	3	331.211	27.76**
	Interactions			
	R X A	3	0.425	0.04
	R X S	3	7.614	0.64
	A X S	9	12.799	0.36
	R X A X S	9	4.630	0.13
	Residual	32	127.252	—
Inshore	Total	47	575.260	—
	Main effects			
	Bays	3	3.679	0.77
	Cruise	11	319.351	18.34**
	Residual	33	52.229	—
Offshore	Total	15	114.017	—
	Main effects			
	Subarea	3	2.187	1.02
	Cruise	3	105.401	49.19**
	Residual	9	6.428	—

** Denotes significance at = .01

Chionoecetes bairdi (Tanner crab)

C. bairdi zoeae were present in plankton samples throughout the year (Figs. 36 and 37, Tables 27 and 28). Stage I larvae were encountered from late winter through midsummer (28 March-18 July 1978 and 4-16 March 1979), suggesting an asynchronous or protracted period of larval release. The data from the extensively re-sorted bongo samples in Chiniak Bay and Tucker trawl tows in Kiliuda Bay, however, indicate peak abundance of Stage I zoeae during late May-early June (Cruises IV and V), which implies that most hatching occurred during late spring.

Most larvae encountered during the day were found in depths to 60 m. Vertical distribution at night could not be clearly explained. Large numbers of *C. bairdi* zoeae were found near the surface, but equally substantial amounts were present from 40 m downward to 80-100 m. There was a notable lack of organisms at 20-40 m (Fig. 38).

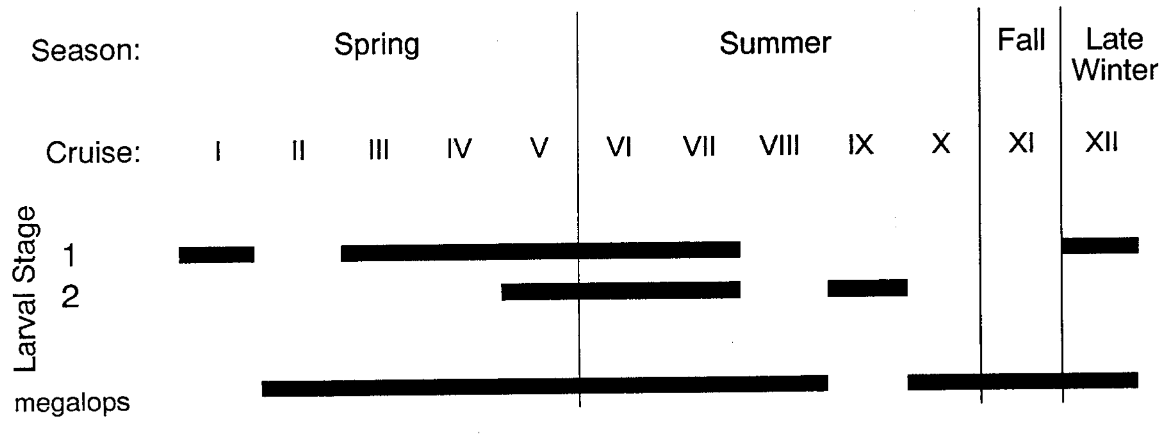


Figure 36.--Occurrence of larval stages of *Chionoecetes bairdi* by cruise and season from the OCSEAP inshore plankton cruises. Data from all gear types.

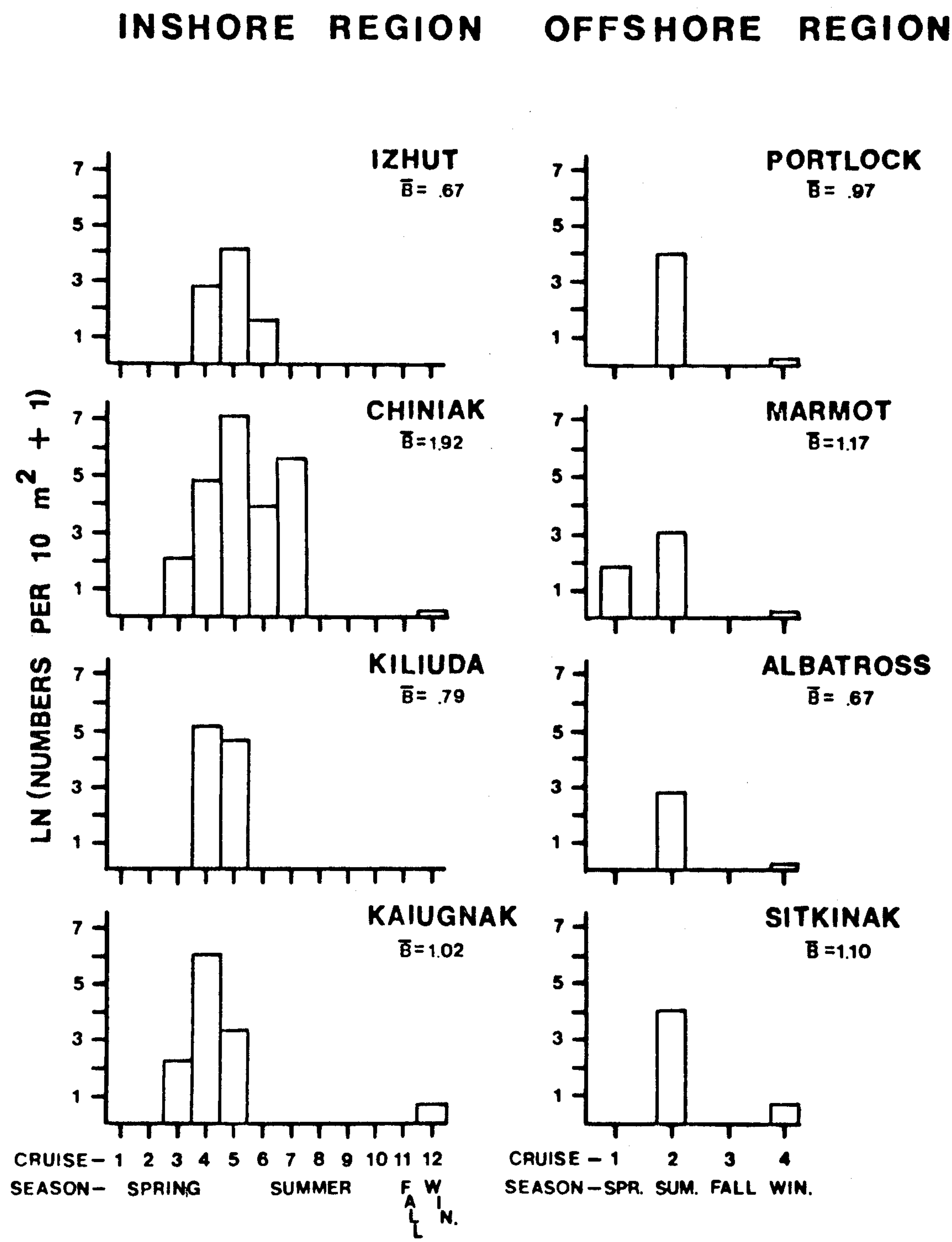


Figure 37.--Average density (ln(numbers per 10 m²)) by cruise, season, bay, subarea, and region for *Chionoecetes bairdi* in the Kodiak Island study area. Bongo net data.

Table 27.—Standardized biomass (ln (numbers per 10 m^2 + 1)) of Tanner crab (*Chionoecetes bairdi*) larvae by season, cruise, and subarea in the inshore region of the Kodiak Island study area, March 1978–March 1979. (Bongo net data.)

Season			Spring		Summer						Fall	Winter	Mean Biomass All Cruises
Cruise	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	
Subarea													
Izhut	0	0	0	2.58	3.96	1.50	0	0	0	0	0	0	0.67
Chiniak	0	0	1.99	4.66	6.99	3.78	5.53	0	0	0	0	0.07	1.92
Kiliuda	0	0	0	4.97	4.46	0	0	0	0	0	0	0	0.79
Kaiugnak	0	0	2.33	5.98	3.33	0	0	0	0	0	0	0.66	1.02
Mean Biomass Bays Combined	0	0	1.08	4.55	4.68	1.32	1.38	0	0	0	0	0.18	1.10

Table 28.—Standardized biomass (ln (numbers per 10 m² + 1)) of Tanner crab (*Chionoecetes bairdi*) larvae by season, cruise, and subarea in the offshore region of the Kodiak Island study area, March 1978-March 1979. (Bongo net data.)

Season	Spring	Summer	Fall	Winter	Mean Biomass All Cruises
Cruise	I	II	III	IV	
Subarea					
Portlock	0	3.83	0	0.10	0.98
Marmot	1.73	2.89	0	0.07	1.17
Albatross	0	2.65	0	0.06	0.68
Sitkinak	0	3.76	0	0.63	1.10
Mean Biomass Subareas Combined	0.43	3.28	0	0.21	0.98

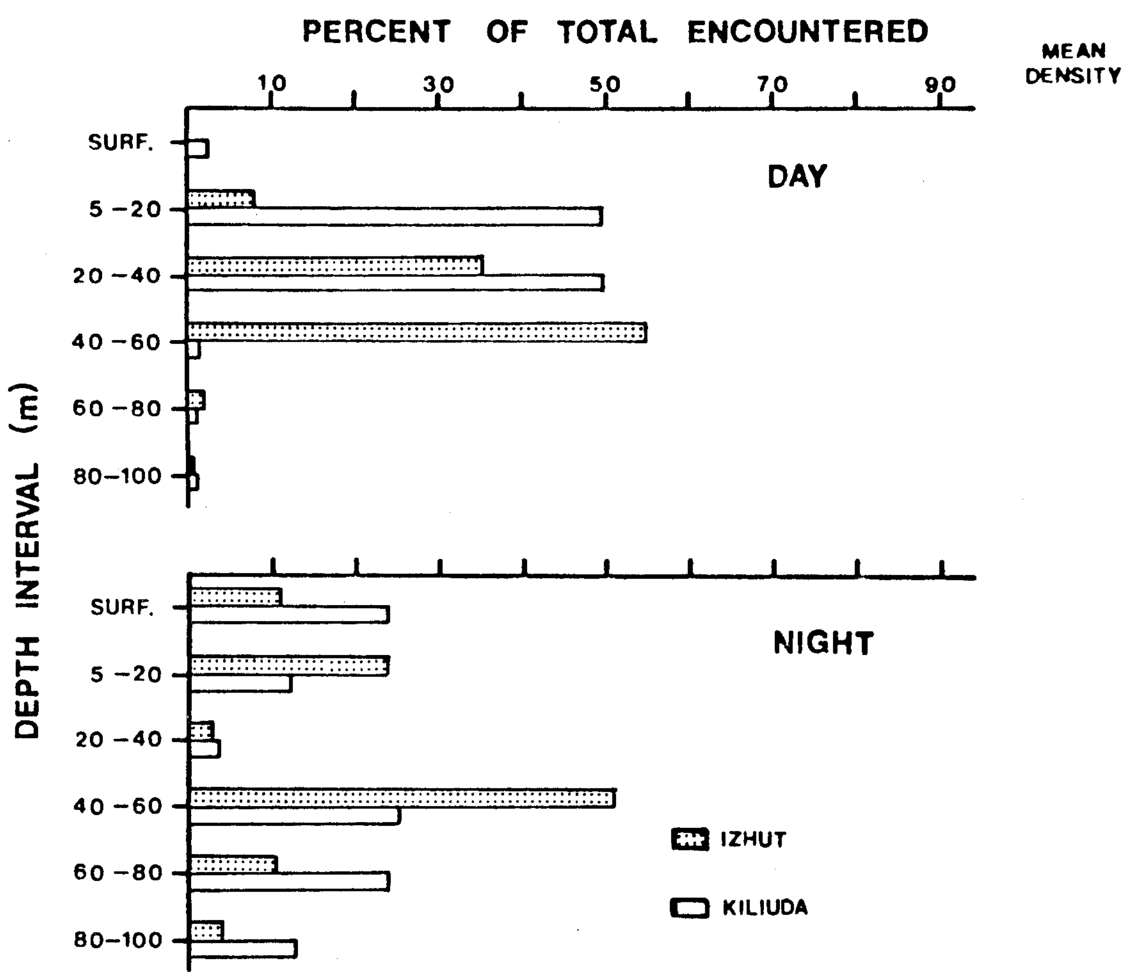


Figure 38.--Percentage of total *Chionoecetes bairdi* encountered during inshore OCSEAP plankton cruises by diel period and depth interval for Izhut and Kiliuda bays. Tucker trawl data.

Results from analysis of vertical distribution by larval stage indicated both Stage I and megalopae were present in highest concentrations in the upper portion of the water column (Kiliuda Bay, daytime data only). No stage II larvae were encountered in any of the 60 re-sorted samples used in this analysis by stage (Fig. 39).

Analysis of variance tests failed to discern a notable difference in the abundance of *C. bairdi* larvae between inshore and offshore regions of the study area (Table 29). Separate tests of each region identified significant time and/or area effects on amounts present. Multiple comparison tests determined that numbers of *C. bairdi* zoeae found inshore in May to early June (Cruises IV and V) and offshore during the summer cruise were significantly greater than those found in any other period sampled. A bay effect was also identified inshore, but an apparent bay x cruise interaction masked the importance of any bay.

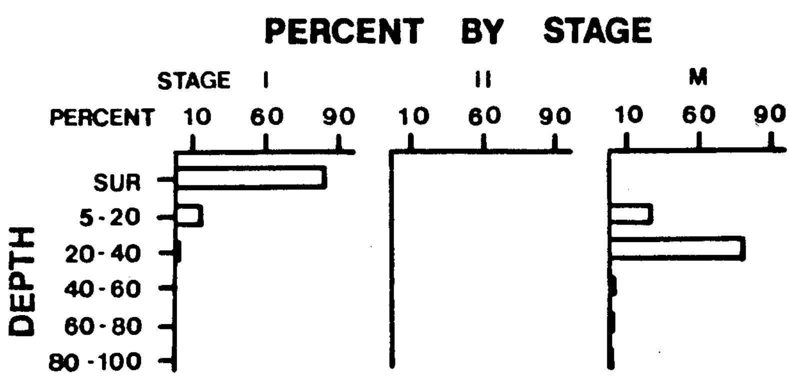


Figure 39.--Percentage of *Chionoecetes bairdi* encountered by life stage and depth interval during inshore OCSEAP plankton cruises. Neuston sampler and Tucker trawl data.

Table 29.—Summary of information derived from analysis of variance tests of bongo net data (ln (numbers per 10 m² + 1)) for Tanner crab (*Chionoecetes bairdi*) larvae.

Test	Source of Variability	Degrees of Freedom	Sum of Squares	Value of F
Inshore and offshore combined	Total	63	215.651	—
	Main effects			
	Region (R)	1	1.338	0.32
	Subarea (A)	3	10.212	0.82
	Season (S)	3	29.006	2.33
	Interactions			
	R X A	3	0.713	0.06
	R X S	3	32.619	2.63
	A X S	9	5.297	0.14
	R X A X S	9	3.998	0.11
	Residual	32	132.501	—
Inshore	Total	47	183.346	—
	Main effects			
	Bays	3	11.502	3.17*
	Cruise	11	131.980	9.93**
	Residual	33	39.865	—
Offshore	Total	15	32.144	—
	Main effects			
	Subarea	3	0.569	0.57
	Cruise	3	28.587	28.70**
	Residual	9	2.988	—

* Denotes significance at = .05
** Denotes significance at = .01

Pinnotheridae (pea crabs)

Pinnotherid crab larvae were found primarily from late spring through fall (Figs. 40 and 41, Tables 30 and 31). The presence of Stage I larvae from spring through summer suggests a fairly protracted period of larval release. Stages III through V were still prevalent in samples collected during the fall inshore cruise.

Pinnotherid zoeae were encountered mostly at midwater depths (Fig. 42). During the day, about 95% were found at 5-60 m; at night they appeared uniformly distributed throughout the water column. The largest proportion encountered during night-time was at 60-80 m. Few pinnotherids were found at the surface, and those only at night.

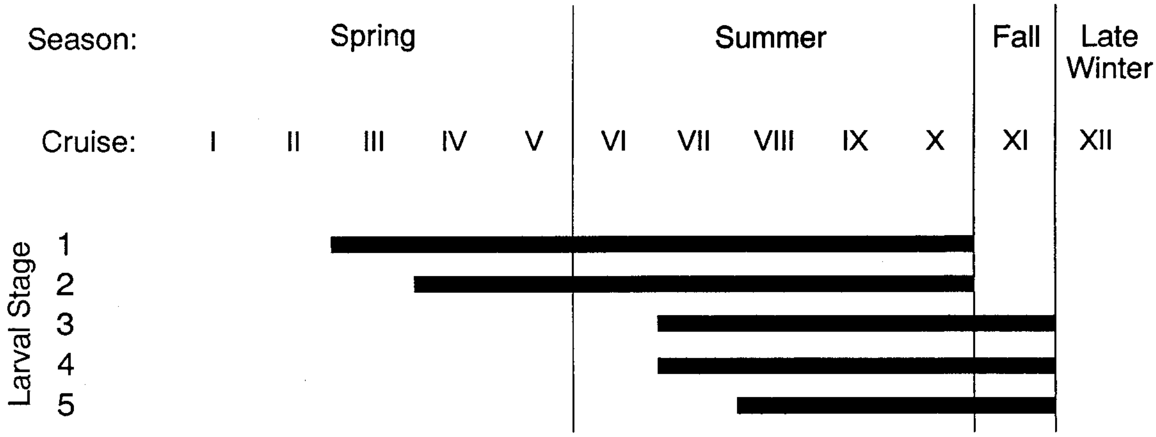


Figure 40.--Occurrence of larval stages of Pinnotheridae by cruise and season from the OCSEAP inshore plankton cruises. Data from all gear types.

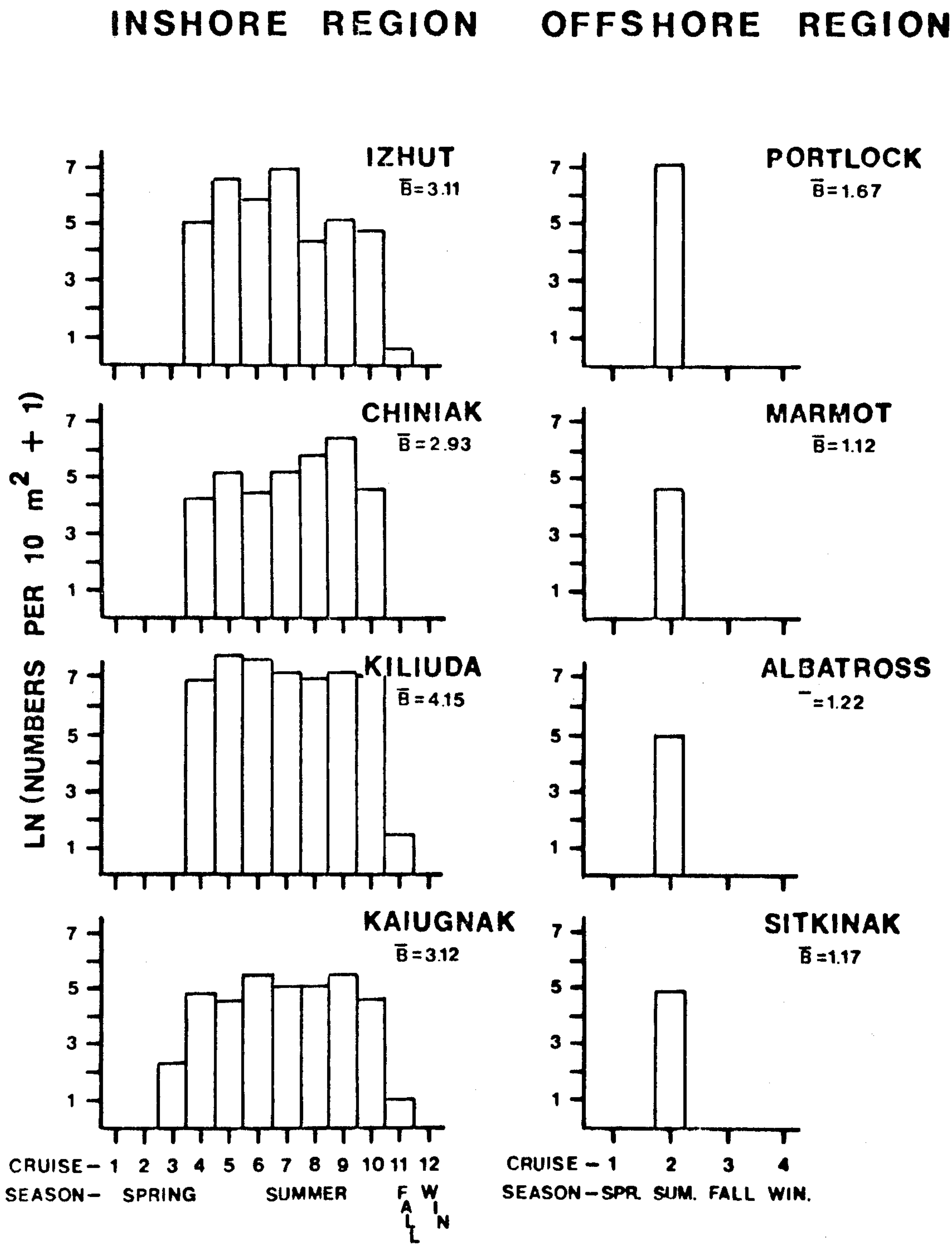


Figure 41.--Average density (ln(numbers per 10 m²)) by cruise, season, bay, subarea, and region for Pinnotheridae in the Kodiak Island study area. Bongo net data.

Table 30.—Standardized biomass (ln(numbers per 10 m² + 1)) of pea crab (Pinnotheridae) larvae by season, cruise, and subarea in the inshore region of the Kodiak Island study area, March 1978–March 1979. (Bongo net data.)

Season			Spring		Summer						Fall	Winter	Mean Biomass All Cruises
Cruise	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	
Subarea													
Izhut	0	0	0	4.77	6.26	5.57	6.75	4.17	4.94	4.47	0.41	0	3.11
Chiniak	0	0	0	4.08	5.09	4.44	5.06	5.66	6.34	4.53	0	0	2.93
Kiliuda	0	0	0	6.66	7.53	7.42	6.87	6.57	6.76	6.76	1.29	0	4.15
Kaiugnak	0	0	2.33	4.71	4.44	5.37	4.98	4.97	5.27	4.52	0.88	0	3.12
Mean Biomass Bays Combined	0	0	0.58	5.05	5.83	5.70	5.91	5.34	5.83	5.07	0.64	0	3.33

Table 31.—Standardized biomass (ln (numbers per 10 m² + 1)) of pea crab (Pinnotheridae) larvae by season, cruise, and subarea in the offshore region of the Kodiak Island study area, March 1978-March 1979. (Bongo net data.)

Season	Spring	Summer	Fall	Winter	Mean Biomass All Cruises
Cruise	I	II	III	IV	
Subarea					
Portlock	0	6.68	0	0	1.67
Marmot	0	4.52	0	0	1.13
Albatross	0	4.88	0	0	1.22
Sitkinak	0	4.74	0	0	1.81
Mean Biomass Subareas Combined	0	5.20	0	0	1.30

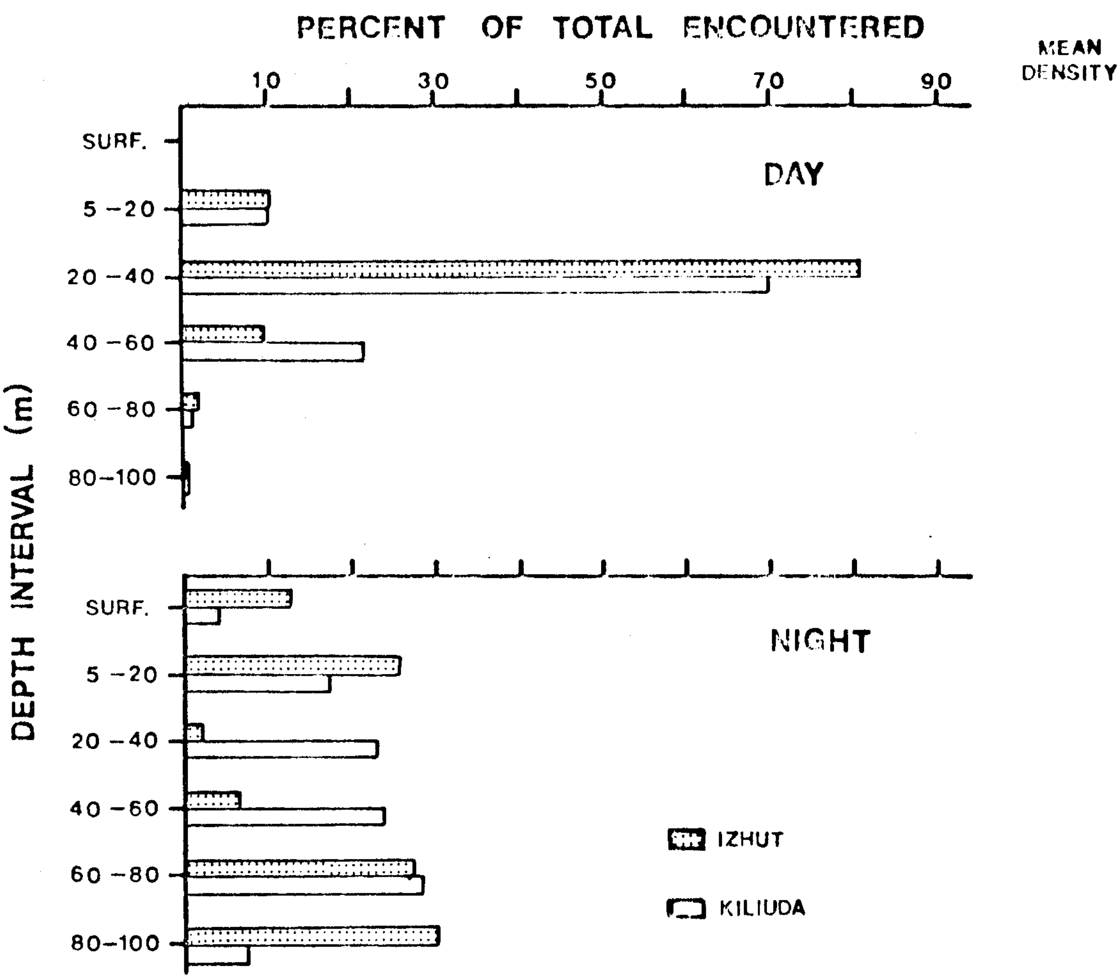


Figure 42.--Percentage of total Pinnotheridae encountered during inshore OCSEAP plankton cruises by diel period and depth interval for Izhut and Kiliuda bays. Tucker trawl data.

Analysis of variance tests for the inshore and offshore data combined identified a season effect on abundance of pinnotherid crab zoeae (Table 32). Numbers encountered during summer were significantly greater than other times of the year throughout the study area. A separate ANOVA and multiple comparison test of the inshore region further identified May through August (Cruises IV-X) as having significance over other time periods. Although a bay effect was also identified inshore, no bay could be determined to be more important than any other.

Table 32.—Summary of information derived from analysis of variance tests of bongo net data (ln(numbers per 10 m^2 + 1)) for pea crab (Pinnotheridae) larvae.

Test	Source of Variability	Degrees of Freedom	Sum of Squares	Value of F
Inshore and offshore combined	Total	63	496.460	—
	Main effects			
	Region (R)	1	9.672	2.03
	Subarea (A)	3	8.200	0.57
	Season (S)	3	267.239	18.66**
	Interactions			
	R X A	3	2.920	0.20
	R X S	3	9.141	0.64
	A X S	9	2.868	0.07
	R X A X S	9	3.174	0.07
	Residual	32	152.730	—
Inshore	Total	47	362.855	—
	Main effects			
	Bays	3	11.128	6.07**
	Cruise	11	331.562	49.33**
	Residual	33	20.165	—
Offshore	Total	15	84.243	—
	Main effects			
	Subarea	3	0.742	1.00
	Cruise	3	81.276	109.59**
	Residual	9	2.225	—

** Denotes significance at = .01

DISCUSSION AND SUMMARY

This report describes results from the Kodiak Island region OCSEAP plankton surveys which were not previously available and statistically examines trends suggested by earlier analyses in Kendall et al. (1980). The OCSEAP plankton surveys were meant to increase our understanding of three general aspects of the distribution and abundance of decapod larvae: (1) the areas within the survey region where larvae of a given species are most abundant; (2) the depths where they are found within the water column; and (3) the time of year they are present. An understanding of these parameters is necessary for a realistic assessment of the potential effects of oil and gas related development on larval populations.

Spatial Abundance

Distribution and abundance trends were suggested in the earlier report by Kendall et al. (1980), and an analysis of specific data sets was performed to substantiate or refute suggested trends. In most cases, statistical tests failed to identify significant abundance differences between subareas or between the regions. Significant regional abundance differences could only be determined for two taxa, Hippolytidae and Anomura. For both, abundance in the inshore region (i.e., bays and along the coast of Kodiak and Afognak islands) was significantly greater than offshore.

Statistical tests failed to identify other significant regional differences in larval abundance. However, supplemental information about adults indicates the inshore region to be more important than areas offshore for at least three additional taxa: *Pandalus goniurus*, *Paralithodes camtschatica*, and *Cancer magister*.

For example, adult *Pandalus goniurus* are found only in shallow water areas such as nearshore along the coasts of the Kodiak Island Archipelago or in shallow portions of bays within the study area. Consequently, mating and larval release should occur in these shallow, nearshore areas with resulting larvae likewise in this region. Lack of a net offshore directed current in the study area should then retain *P. goniurus* larvae in the inshore region. Data from the surveys suggest this inshore distribution--no *P. goniurus* larvae were found anywhere offshore. Unfortunately, small sample sizes and low densities of larvae obscured this obvious regional abundance difference. This taxon was the least abundant decapod studied. The few larvae found in samples from the bays and numerous "no catch" samples (stations) resulted in a relatively high variability for the inshore region. As a result, the inshore presence of *P. goniurus* larvae could not be determined significantly different from that in the offshore region.

A similar situation of low overall abundance masking significant regional differences was evident for the larvae of *Paralithodes camtschatica*. Adults of this commercially important crab species migrate inshore during late winter-early spring for larval release, molting, and mating. This shoreward movement sometimes extends into intertidal areas. Again, extremely low abundance or patchiness of catches precluded the determination that nearshore or inshore concentrations of *P. camtschatica* larvae were higher than amounts found offshore on the outer continental shelf.

A similar conclusion should be reached for *Cancer magister* larvae, but again, only very low concentrations of these zoeae were encountered.

While our statistical tests could not establish significant differences in regional abundance for most of the groups studied, summary averages for all 10 taxa (Tables 33 and 34) indicate decapod larvae are roughly 3 times more prevalent inshore than offshore.

Vertical Distribution

The data used for study of the vertical distribution and diel behavior of decapod larvae were only from the inshore surveys because sampling in the bays was more frequent and consistent than offshore. Limits imposed by subsample sizes (see Appendix A) caused diel observations from the 12 inshore cruises to be pooled and the resulting data set was not statistically analyzed. While a moderate degree of variability was noted between bays, we believe the averages presented reflect general depth preferences and day-night movements of the taxa studied.

The inclusion of neuston information into the data base studied by Kendall et al. (1980) noticeably altered vertical distribution trends

Table 33.—Summary of average biomass (natural log of biomass + 1) for the taxa in the various bays and their averages over all taxa and all bays.

	Izhut Bay	Chiniak Bay	Kiliuda Bay	Kaiugnak Bay	Taxa Averages
Hippolytidae	5.27	4.87	4.94	3.58	4.67
Crangonidae	2.25	0.97	2.77	1.17	1.79
Pandalus borealis	1.29	1.55	0.34	1.09	1.07
Pandalus goniurus	0.60	1.57	1.15	0.15	0.87
Anomura	4.93	4.32	4.98	3.76	4.50
Paralithodes camtschatica	0.31	0.83	0.79	0.29	0.55
Cancer magister	0.58	0.33	2.30	1.24	1.11
Cancer sp.	2.84	2.22	2.29	2.77	2.53
Chionoecetes bairdi	0.67	1.92	0.79	1.02	1.10
Pinnotheridae	3.11	2.93	4.15	3.12	3.33
Bay Averages	2.19	2.15	2.45	1.82	2.15

Table 34.—Summary of average biomass (natural log of biomass + 1) for the taxa in the various offshore subareas and their averages over all taxa and all bays.

	Portlock Subarea	Marmot Subarea	Albatross Subarea	Sitkinak Subarea	Taxa Averages
Hippolytidae	2.76	2.26	1.76	2.47	2.31
Crangonidae	1.35	1.30	0.00	0.87	0.88
Pandalus borealis	0.75	0.30	0.47	0.00	0.38
Pandalus goniurus	0.00	0.00	0.00	0.00	0.00
Anomura	2.62	1.85	2.75	2.60	2.45
Paralithodes camtschatica	0.12	0.00	0.00	0.15	0.07
Cancer magister	0.00	0.65	0.00	0.97	0.41
Cancer sp.	2.35	1.60	1.35	1.70	1.75
Chionoecetes bairdi	0.97	1.17	0.67	1.10	0.98
Pinnotheridae	1.67	1.12	1.22	1.17	1.29
Subarea Averages	1.26	1.03	0.82	1.10	1.05

suggested in their report. In their analysis many taxa, especially crabs, seemed positively phototaxic. Larvae appeared concentrated in shallow strata during the day and shifted downward into deeper water at night. Unfortunately, not knowing anything about larval presence in the near-surface regime complicated that interpretation. Our subsequent inclusion of neuston information indicates that although many taxa were present in upper portions of the water column during the day, their centers of abundance did not necessarily shift downward at night. Substantial amounts of larvae occurred during the night at the sea surfaces; up to 90% of the combined total from all samples for some taxa. Those larvae that were found extensively in the night neuston samples include: Hippolytidae, Crangonidae, Anomura, *Paralithodes camtschatica*, *Cancer magister*, *Cancer* sp., and *Chionoecetes bairdi*. However, night-time concentration at the surface is not wholly indicative of a negative phototaxis. Considerable proportions of some taxa (e.g., Crangonidae, *Cancer magister*, Anomura and *Paralithodes camtschatica*) were still present in deeper strata at night.

The following then is a revised general pattern of day-night vertical distribution for many taxa of decapod larvae studied in this report. During the day larvae appear concentrated at mid-depths (i.e., 10-50 m,) and at night these concentrations seem to shift both to the surface and to near the bottom. We do not know why this pattern occurs. It tends to lessen the apparent significance of light levels on diel movement and suggests other factors are involved. Unfortunately, we could not identify a correlation between larval vertical distribution and such factors as water temperature or salinity.

A possible reason for the above-mentioned trend may be different depth or food preferences at various stages of larval development. An extensive re-sort of Kiliuda Bay vertical distribution samples resulted in enough larvae for several species (*Pandalus borealis*, *P. goniurus*, *Paralithodes camtschatica*, and *Chionoecetes bairdi*) to look at vertical distribution by stage on a combined day-night basis. For each species there was an observed shift in distribution from at or near surface downward into mid or bottom strata with progressive stages of development. An example is seen in Figure 17, depicting vertical distribution by larval stage of *Pandalus borealis*. The early stages (I, II, III) were found primarily in the surface and 10-m strata; mid-stages (IV, V) had their largest numbers divided into near surface and near bottom modes; and later larval stages (VI, VII) were encountered almost entirely in the deepest depths sampled. The surface/near bottom pattern seen for stages IV and V is the same trend exhibited by a number of the other taxa at night. From the standpoint of a developing *P. borealis* larvae, stages IV and V might be considered transitional when they switch from feeding on one "type" of food to another (for example, phytoplankton to copepods). The food "types" might have different depth distributions which correspond to those chosen by the different stages of larvae.

Temporal Abundance

The biweekly cruises conducted in the inshore region during the spring and summer provided the best indication of changes in larval abundance with time. This sampling intensity, unfortunately, was not continued throughout the remainder of the year inshore, or at all offshore. Consequently, in the region and season analyses, all four offshore cruises and the latter two inshore (XI and XII) had to be considered representative of entire seasons. This is a very questionable assumption which must be considered when seasonal presence or absence of larvae is discussed.

Tests of a majority of the taxa showed significant differences in abundance by season. It is common knowledge that larvae of a given species are most abundant during certain gross times of the year (i.e., spring and summer); however, many of the cruise and season effects were highly significant and further multiple comparison tests determined more precisely the times of the year that were most important. For instance, multiple comparison tests of a significant inshore cruise effect on *P. borealis* larvae identified Cruises II through IV (i.e., mid-April to late May) as having distinctly higher abundances of this taxon than during any other cruises. This period of peak abundance is similar to that determined by Haynes and Wing (1976) during their 1972 study of pandalid larvae in Kachemak Bay, on the southcentral coast of Alaska. Those instances where no significant time effect was identified probably were the result of low overall abundance (i.e., *Pandalus goniurus*) or other problems.

Temporal analysis of *Paralithodes camtschatica* was hampered by small numbers of this taxon in the samples and also by the timing of the cruises. Stage IV zoeae were present in the inshore Cruise I samples, indicating that in 1978, larval release had commenced considerably earlier than April. Furthermore, Cruise XII was planned as the final inshore sampling period of the 1978-79 study. That cruise, however, occurred in very late winter and its samples only contained Stage I *Paralithodes camtschatica* zoeae (see Fig. 26). This implies that Cruise XII actually represented initial observations for progeny of the following year (1979-80).

Study Limitations and Recommendations for Future Work

There were a number of points we considered in qualifying our data and results, namely: the atypical environmental conditions encountered during the surveys; insufficient subsample size; differences in the timing and amounts of sampling performed between the inshore and offshore regions; and the multispecies nature of some of the taxonomic groups analyzed. A detailed analysis of some of these factors can be found in Appendix A; a discussion of the major conclusions as well as recommendations for future work are taken up here.

Environmental conditions during the time period the study took place differed noticeably from a long term average. How changes in these environmental parameters (especially water temperature) affect hatching times and abundance of larval decapods is not adequately understood. Substantially more than one season would be necessary to evaluate the affects these parameters have on larval distribution and abundance. Given these limitations, we can only assume that conclusions derived from this study reflect aspects of larval decapod distribution and abundance during "warm weather" time periods.

Decapod larvae were not the only group targeted in the OCSEAP zooplankton surveys and, consequently, sort rules were not designed with the diversity and low relative abundance of this group in mind. The overall conclusion from the subsampling test was that the 500-organism aliquots used as the standard subsample for the study were too small to provide detailed descriptions of larval abundance by time, area, and depth for the individual stages of zoeal development. The aliquots were sufficient, however, to describe vertical distributions or abundance with time in pooled data terms (i.e., all larval stages combined) for each species of decapod larvae tested. Future research directed at decapod larvae of commercially important species should have a subsampling intensity at least an order of magnitude larger (i.e., subsample aliquots averaging 40% of the bulk sample and not 4%) than that averaged in this study.

Sampling schemes for the two surveys differed substantially and restricted the comparisons which could be made between the inshore and offshore regions. Cruise intervals varied from 2 weeks to 3 months for inshore and offshore surveys, respectively. An average time in stage for some of the larval decapods encountered is 10 to 20 days. Scheduling of future cruises should take this into account if abundance by stage data is desired. Depending on the species of interest, sampling should be initiated earlier in the year. Cruise I of the inshore survey (29 March-8 April) found Stage II larvae of a majority of the species, and Stage I-IV larvae of *Paralithodes camtschatica*. This suggests that the onset of hatching is significantly earlier in the year.

The level of sampling attained during the surveys was also too limited to achieve the sample size necessary for testing relatively low larval concentrations. In many cases, statistical tests failed to identify significant abundance differences within both the inshore and offshore regions, and further, regional differences were rarely discerned. However, failure to identify significant differences in inshore-offshore larval abundance should not imply uniform or random distribution.

One more limiting aspect of the study which would benefit from further work was the multispecies nature of some (of our) taxonomic groups. Of the 10 taxa considered in our analysis, only 5 were individual species. The remaining (i.e., Hippolytidae, Crangonidae, Anomura, *Cancer* sp. and Pinnotheridae) were primarily composed of a number of species. We were unable to differentiate species within these taxa because of the lack of descriptive literature regarding their larval morphology. Since individual species within these groups occupy different habitats and possess different "reproductive strategies," our gross taxonomic combinations masked species-specific information in our samples. This was a probable reason for the region-season interactions observed in our ANOVA for hippolytid shrimp and anomuran crabs. A hypothetical example for this interaction would be one abundant inshore species spawning in spring and an abundant offshore species spawning during the summer.

Despite these limitations, it is our opinion that the OCSEAP-funded surveys still provided information which allows considerable insight into decapod larvae populations in the Kodiak Island region.

Oil Effects

The impact of toxic levels of oil on decapod larvae would be greatest from late winter through summer. The following list summarizes this study's findings on times of peak abundance for larvae of the five commercially important species:

Pandalus borealis	early April-early July
Pandalus goniurus	mid-April-early July
Paralithodes camtschatica	early March-early June
Cancer magister	late April-late July
Chionoecetes bairdi	late April-early July

A number of researchers have explored and documented the sensitivity of larval forms of various decapods to oil and its water soluble fraction (WSF). Caldwell et al. (1977) reported toxic effects on *Cancer magister* larvae from WSF (Cook Inlet crude) as low as 0.22 mg/l. Stage I larvae of *Pandalus hypsinotus* and *Paralithodes camtschatica* had 96-hr LC50's of 7.94 and 2.00 ppm (WSF Cook Inlet crude), respectively (Mecklenburg et al. 1977). Besides being more susceptible to the toxic effects of oil than are juveniles and adults (Wells and Sprague 1976), larval forms are also significantly more sensitive to exposure during the molting period (Mecklenburg et al. 1977). While the duration and number of larval stages varies between species, 5 molts over the course of 2 months might be considered an average for decapod larvae. This molting frequency and concurrent sensitivity makes this life stage particularly vulnerable.

Another factor which increases the susceptibility of decapod larvae to the effects of water soluble fractions of surface-borne oil is their proximity to the surface. The extent to which hydrocarbons dissolve into the water column is significantly affected by mixing (Gordon et al. 1973). Studies as well as measurements from actual spills (Boehm and Fiest 1980) show that such wave related mixing can occur at toxic concentrations to a depth of 20-30 m in summer and 75-100 m in winter. The vertical distribution and diel movement portion of this study found that, day or night, substantial numbers of all the taxa studied were well within depths which would be mixed during spring.

While extent varied from group to group, all taxa exhibited some form of diel migration. Bigford (1977) showed that both geotactic and phototactic behavior for *Cancer irroratus* was significantly affected by exposure to WSF of fuel oil. It follows that exposure to either castastrophic or chronic levels of dissolved hydrocarbons would have a disabling effect on a decapod larva's ability for diel migration. Most likely, daily vertical migration is an important part of a larva's feeding behavior and disruption of it would further diminish an animal's survivability under adverse conditions. These same adverse conditions also affect the phytoplankton, copepods, etc., upon which decapod larvae most likely feed.

In summary, this study suggests that decapod larvae would suffer significant direct and indirect mortality from relatively low (WSF) oil concentrations, especially in areas and at times of peak abundance. Combining the information from this study with our knowledge of life histories of commercially important decapods will provide an indication of the impact of oil development and/or accidents upon a year class, and the subsequent potential reduction of recruitment to a fishery.

REFERENCES CITED

Bigford, T. E. 1977. Effects of oil on behavioral responses to light, pressure and gravity in larvae of the rock crab *Cancer irroratus*. Mar. Biol. 43:137-148.

Boehm, P. D., and D. L. Fiest. 1980. Surface water column transport and weathering of petroleum hydrocarbons during the IXTOC-1 blowout in the Bay of Campeche and the relation to surface oil and microlayer compositions. Pages 267-340 *in* Proc. Symposium on Preliminary Results from the September 1979 Researcher/Pierce IXTOC-1 Cruise, Key Biscayne, Florida, June 9-10, 1980. NOAA/OMPA, Boulder, Colo.

Buck, E. H., W. J. Wilson, L. S. Lar, C. Liburd, and Harold W. Searby. 1975. Kadyak; a background for living. Arctic Environmental Information and Data Center, University of Alaska, Anchorage, Alaska.

Caldwell, R. S., E. M. Caldrone, and M. H. Mallon. 1977. Effects of a seawater-soluble fraction of Cook Inlet crude oil and its major aromatic components on larval stages of the Dungeness crab, *Cancer magister* Dana. *In:* D. A. Wolfe, ed., Fate and Effects of Petroleum Hydrocarbons in Marine Organisms and Ecosystems. Pergamon Press, New York. 428 pp.

Clarke, M. R. 1969. A new midwater trawl for sampling discrete depth horizons. J. Mar. Biol. Assoc. U.S. 49:945-960.

Environmental Data and Information Service. TD-1440 Airways Surface Observations-25501 Kodiak, Alaska, 11/1/45 to 12/31/80 (Data Tape). USDOC, NOAA, EDIS, National Climatic Center, Federal Building, Asheville, NC 28801.

Favorite, F., and W. T. Ingraham, Jr. 1977. On flow in the northwestern Gulf of Alaska, May 1972. J. Oceanogr. Soc. Japan 33:67-81.

Gordon, D. C., Jr., P. D. Keizer, and N. J. Prouse. 1973. Laboratory studies on the accommodation of some crude and residual fuel oils in sea water. J. Fish. Res. Board Can. 30:1611-1618.

Haynes, E. B., and B. L. Wing. 1977. Distribution of king crab, pandalid shrimp, and brachyuran crab larvae in Kachemak Bay, Alaska, 1972. NOAA, Natl. Mar. Fish. Serv., Northwest and Alaska Fisheries Center, Auke Bay Laboratory, Processed Report.

Ingraham, W., Jr. 1979. The anomalous surface salinity minima area across the northern Gulf of Alaska and its relation to fisheries. Mar. Fish. Rev.(May-June):8-19.

Ingraham, W. J., Jr., A. Bakun, and F. Favorite. 1976. Physical oceanography of the Gulf of Alaska. Unpubl. Final Report, OCSEAP, RU 357, 132 pp. NOAA, Natl. Mar. Fish. Serv., Northwest and Alaska Fisheries Center, 725 Montlake Blvd. E., Seattle, WA 98112.

Kendall, A. W., J. R. Dunn, and R. J. Wolotira, Jr. 1980. Zooplankton, including ichthyoplankton and decapod larvae of the Kodiak shelf. NOAA, Natl. Mar. Fish. Serv., NWAFC Processed Report 80-8.

Kramer, D. E., M. J. Kalin, E. G. Stevens, J. R. Thrailkill, and J. R. Zweifel. 1972. Collecting and processing data on fish eggs and larvae in the California current region. NOAA Tech. Rep. NMFS Circ. 370, 38 pp.

Mecklenburg, T. A., S. D. Rice, and J. F. Karinen. 1977. Molting and survival of king crab (*Paralithodes camtschatica*) and coonstripe shrimp (*Pandalus hypsinotus*) larvae exposed to Cook Inlet crude oil water-soluble fraction. *In:* D. A. Wolfe, ed., Fate and Effects of Petroleum Hydrocarbons in Marine Organisms and Ecosystems. Pergamon Press, New York. 428 pp.

Milne, A. A. 1959. The centric systematic area sample treated as a random sample. Biometrics 15:270-279.

Rogers, D. E., D. J. Rabin, B. J Rogers, K. J. Garrison, and M. E. Wangerin. 1979. Seasonal composition and food web relationships of marine organisms in the nearshore zone of Kodiak Island--including ichthyoplankton, meroplankton (shellfish), zooplankton, and fish. NOAA, OCSEAP, Environmental Assessment of the Alaskan Continental Shelf, Annu. Rep. 4:529-662.

Royer, T. C. 1978. Circulation and water masses in the Gulf of Alaska. NOAA, OCSEAP, Environmental Assessment of the Alaskan Continental Shelf, Annu. Rep. 10:292-323.

Sameoto, D. D,. and L. O. Jaroszynski. 1959. Otter surface sampler: a new neuston net. J. Fish. Res. Board Can. 25:2240-2244.

Schumacher, J. D., and R. K. Reed. 1979. Coastal flow in the northwest Gulf of Alaska: the Kenai Current. Unpubl. manuscr., 32 pp. NOAA, Pac. Mar. Environ. Lab., Environ. Res. Lab., 3711 - 15th Ave. N.E., Seattle, WA 98105.

Schumacher, J. D., R. Sillcox, D. Dreves, and R. D. Muench. 1978. Winter circulation and hydrography over the continental shelf of the Northwest Gulf of Alaska. U.S. Dep. Commer., NOAA Tech. Rep. ERL 404-PMEL31, 16 pp.

Seigel, S. 1956. Non-parametric Statistics for the Behavioral Sciences. McGraw-Hill, New York. 312 pp.

Smith, P. E., and S. L. Richardson. 1977. Standard techniques for pelagic fish egg and larva surveys. Food Agric. Organ. U.N. FAO Fish. Tech. Pap. 175, 100 pp.

Steel, R. G. D., and J. H. Torrie. 1960. Principles and Procedures of Statistics. McGraw-Hill, New York. 481 pp.

Wells, P. G., and J. B. Sprague. 1976. Effects of crude oil on American lobster (*Homarus americanus*) larvae in the laboratory. J. Fish. Res. Board Can. 33:1604-1614.

Appendix A
QUALIFICATION AND DATA LIMITATIONS

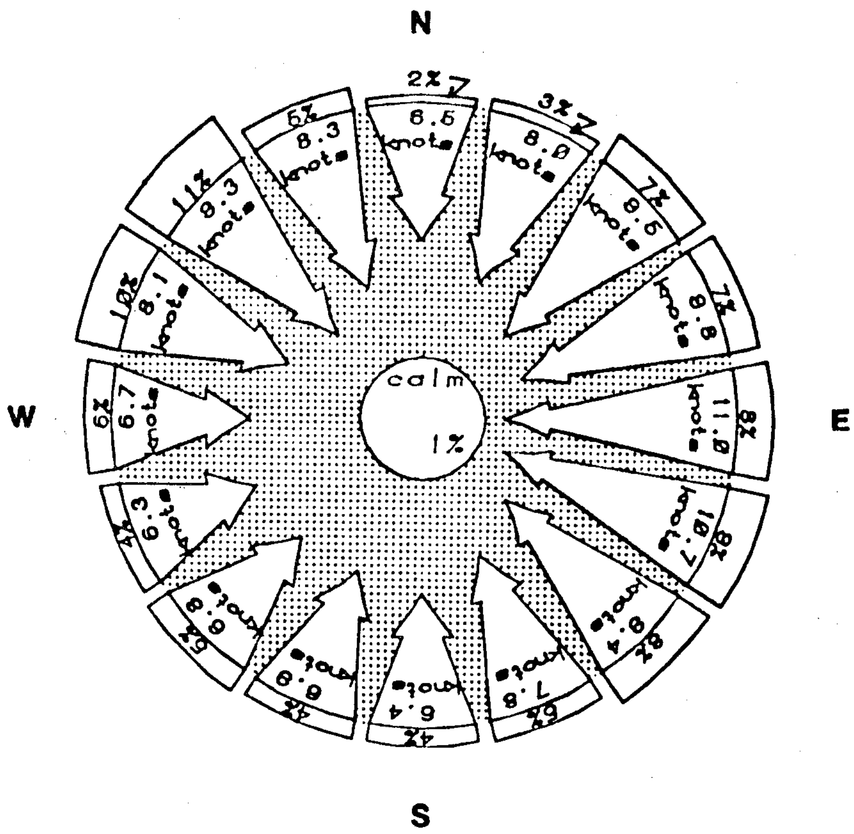
Three main questions must be considered regarding the analysis presented in this report. Were environmental conditions encountered during 1978 representative of normal or unusual occurrences? Was subsampling of the study's bulk plankton samples sufficient to accurately describe the number and types of organisms present? Was the level of sampling effort sufficient to accurately portray resource distribution and abundance?

Evaluation of Environmental Conditions

Seasonal weather information and water temperature data from the northeast coast of Kodiak Island were selected to show the study area's environment. Long-term measurements of these parameters were compared with observations obtained during the study period to evaluate how conditions during 1978 related to an average.

Observations of temperature and wind during 1978 suggest that weather and environmental conditions during the study period differed from long-term patterns. Surface winds were noticeably more frequent out of the east-northeast to east-southeast and the strongest average winds were associated with the northeast quadrant (Fig. A-1). Sea and air temperatures suggested warmer than usual conditions, especially during winter-early spring (Figs. A-2 and A-3). The most substantial of these temperature differences was observed for bottom water. February-April measurements at bottom were more than twice the levels averaged during several recent years (1971-1975).

Since this study focused on only one cycle of seasons it is impossible to determine how apparent anomalous environmental conditions may have affected larval decapod populations. Also, a lack of other data sets for the study area inhibits interpretation of observations during the period studied. Given these limitations, we can only assume that conclusions derived from this study reflect aspects of larval decapod distribution and abundance which occur in the Kodiak Island region during "warm weather" time periods.



Arrows indicate the average wind velocity. Arrow tails indicate the percent frequency of occurrence of wind direction.

Figure A-1.--Average wind velocity and percent frequency of occurrence of wind direction during 1978 in Kodiak Island study area. (Adapted from Buck et al. 1975.)

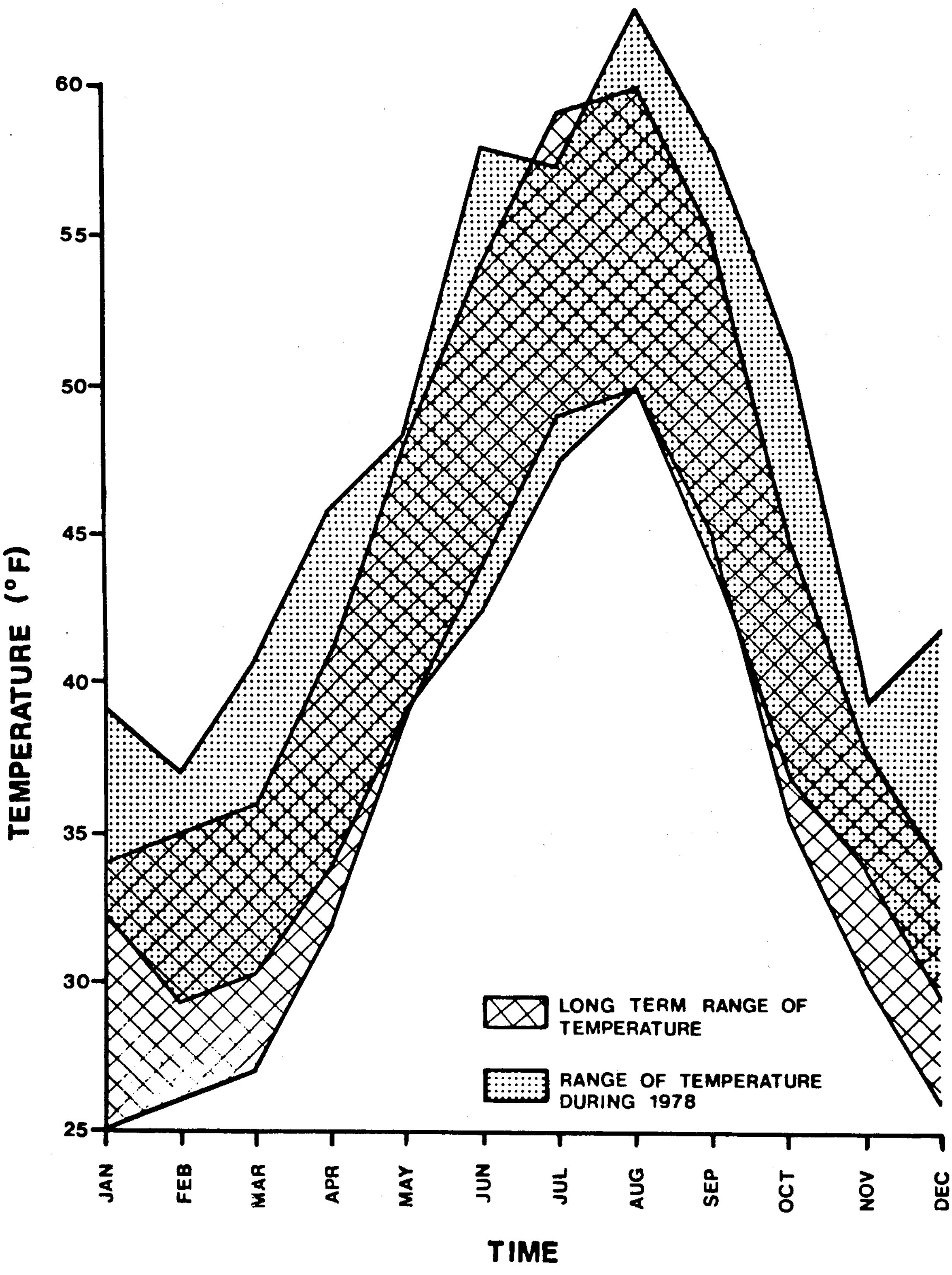


Figure A-2.--Average long term minimum and maximum air temperatures by month for the Kodiak Island region and monthly temperature ranges for 1978 (Buck et al. 1975).

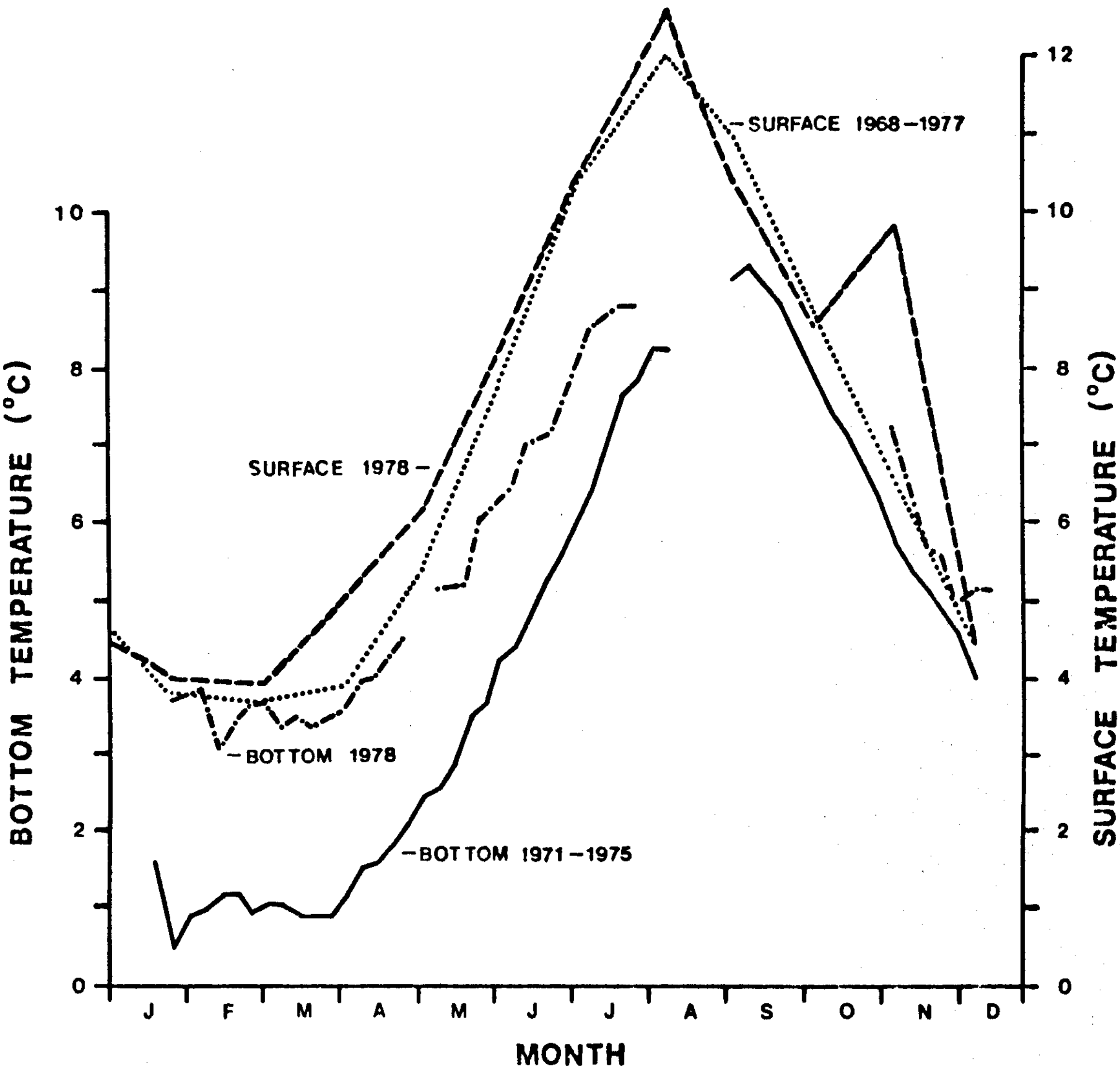


Figure A-3.--Surface and bottom water temperature in the vicinity of Kodiak, long term averages and measurements for 1978.

Evaluation of Subsampling Adequacy

Most information on larvae in this report was derived from analysis of 500-organism aliquots provided through the sorting contract with Texas Instruments, Inc. These subsamples were assumed adequate for indicating numbers of shrimp and crab larvae present in the bulk samples; however, this was a substantial assumption. The 500-organism subsamples often represented less than 1% and averaged only 4% of organisms present in a bulk sample.

The adequacy of the study subsamples was examined through a series of nonparametric Spearman rank correlation tests (Seigel 1956) on sets of inshore region bongo net and Tucker trawl information. Larval concentrations obtained from the aliquots of a selected set or series of bulk samples were ranked relative to each other and this ranking was compared to the ranks derived from extensive resampling of the same bulk samples. Calculations for each test are presented at the end of this appendix.

Data for four economically important decapod species were examined. These species were: pink shrimp (*Pandalus borealis*), humpy shrimp (*P. goniurus*), red king crab (*Paralithodes camtschatica*), and Tanner crab (*Chionoecetes bairdi*).

Analysis of the bongo net samples for individual stages of *Pandalus borealis* indicated that the original aliquots showed close association with the extensive subsamples for some zoeal stages but there was not a close correlation for every stage (Table A-1). When data for all larval stages were combined (by cruise for all stations in a bay) the test again indicated a high probability (P = .975) that the number of *P. borealis* zoeae derived from the original aliquot was closely correlated with the number present in the associated bulk sample. Similar results were obtained for all other species, except *Chionoecetes bairdi*; however, a graph comparing data for this species from the different subsamples (Fig. A-4) showed notable similarity in depicting abundance with time. Our conclusion followed that the standard subsampling used for the study was sufficient to accurately describe overall abundance of a species by time (i.e., all stages combined for all stations in a bay) but that determining abundance by larval stage was not possible.

Table A-1.--Summary of information on numbers of larvae removed from two different subsamples of bongo net catches obtained during larval distribution and abundance studies in the Chiniak Bay area of Kodiak Island, March-November 1978 and February 1979 (data for Stations 1-3 combined).

Species	Larval Stage	Number of cruises encountering larvae	Number found in 500-organism aliquot	Number found in "extensive resort" subsamples	Spearman rank correlation data: Σd_i^2 1/	r_s 2/	correlation or association between subsamples at a=0.25
Pandalus borealis	1	12	10	443	74.00	0.67	Yes
	2	4(1-4) 3/	2	240	1.00	0.90	No
	3	6(1-6)	0	98	16.50	0.00	No
	4	6(1-6)	0	43	15.50	0.00	No
	5	7(1-7)	0	40	23.00	0.00	No
	6	7(1-7)	1	3	0.00	1.00	Yes
	7	7(1-7)	0	1	0.00	0.00	No
	All stages combined	12	13	868	99.00	0.60	Yes
P. goniurus	All stages combined	8(1-8)	8	186	40.00	0.92	Yes
Chionoecetes bairdi	All stages combined	10(1-10)	2	41	57.50	0.53	No
Paralithodes camtschatica	All stages combined	5(1-5)	13	179	2.00	0.90	Yes

1/ Sum of squares of the differences between rankings within subsample sets

2/ Spearman rank correlation co-efficient

3/ Number in parentheses indicates cruises included in testing.

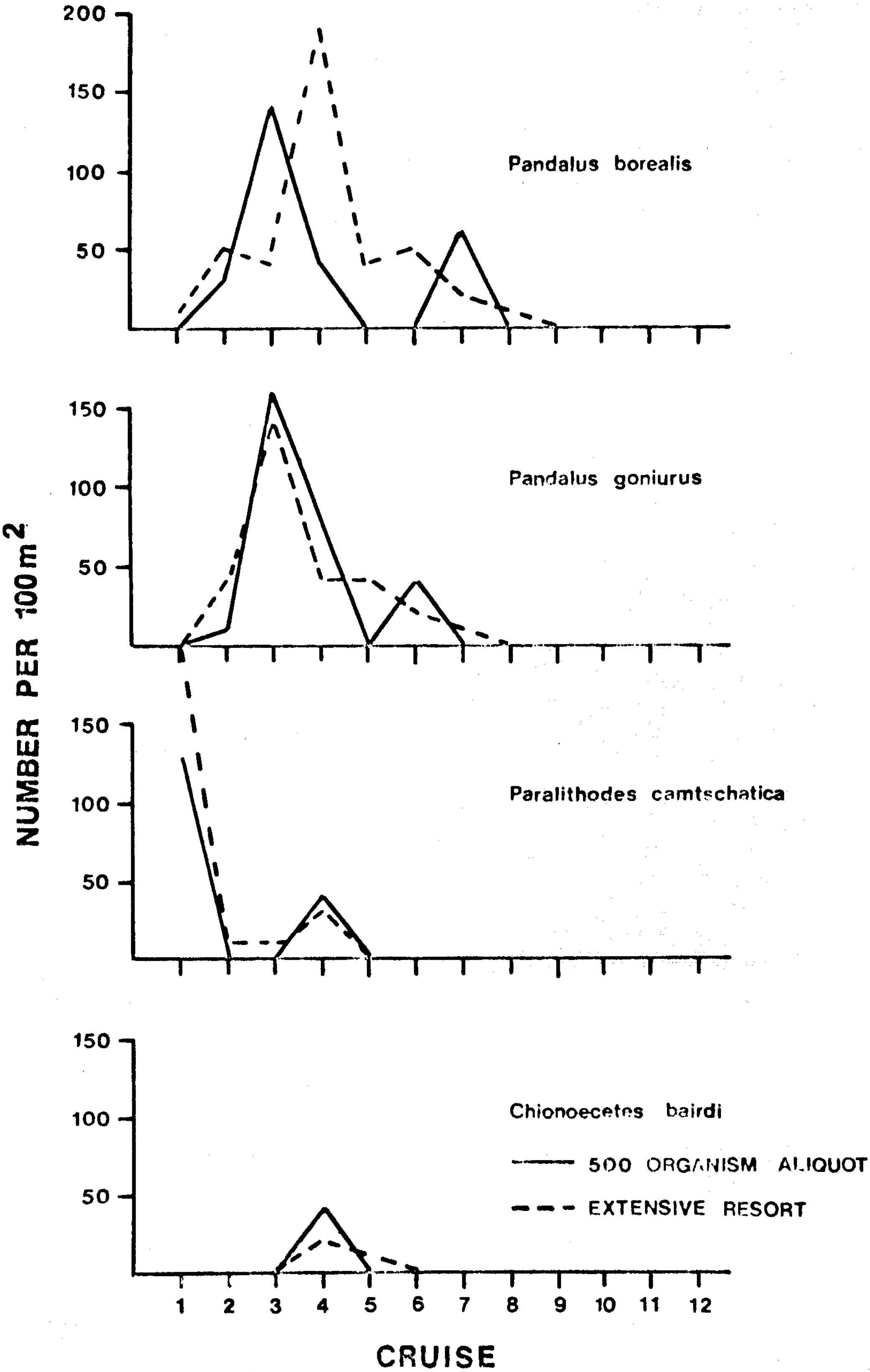


Figure A-4.--Comparison of accuracy of sample sorting by number per 100 m² and cruise from the inshore region of the Kodiak Island study area. Bongo net data.

Table A-2.--Summary of information on estimated densities of bairdi Tanner crab larvae from two different subsamples of Tucker trawl catches obtained during decapod larvae vertical distribution studies in the Kiliuda Bay area of Kodiak Island, March-November 1978 and February 1979.

Cruises	Average number of larvae per 1000 m^3 estimated present in Kiliuda Bay from original "500 organism" aliquot (all depths combined)	Average number of larvae per 1000 m^3 estimated present in Kiliuda Bay from the "estensive resort" subsamples (all depth combined)	Spearman Rank Correlation Information		
			d_i^2	r_s	Correlation of association between sub-samples at = .025
1	0	0	0	1.00	yes
2	48	51	6.00	0.70	no
3	0	180	10.00	0.50	no
4	738	1,297	0.50	0.98	yes
5	38	363	2.00	0.90	yes
6-12	0	0	0	1.00	yes
2-5 combined	206	473	0.50	0.98	yes

Spearman rank correlation tests on the vertical distribution information produced varying results. In general, there was a higher association between subsamples for larvae of crab species than shrimp. Aliquot data on *C. bairdi* zoeae were correlated closely with data produced from the extensive subsamples for nearly every cruise (Table A-5), but association between subsamples for *Paralithodes camtschatica* was not as extensive (Table A-3). For either species, however, there was a significant correlation between subsamples when data were combined for all cruises uncountering larvae. High correlation coefficients (r_S = 0.98) for the pooled data suggest that the 500-organism aliquot of Tucker trawl catches was adequate to describe the vertical distribution of crab larvae (all stages combined) over the entire study period but not for specific time (cruise) intervals.

Table A-3.--Summary of information on estimated densities of red king crab larvae from two different subsamples of Tucker trawl catches obtained during decapod larvae vertical distribution studies in the Kiliuda Bay area of Kodiak Island, March-November 1978 and February 1979.

Cruises	Average number of larvae per 1000 m^3 estimated present in Kiliuda Bay from original "500 organism" aliquot (all depths combined)	Average number of larvae per 1000 m^3 estimated present in Kiliuda Bay from the "estensive resort" subsamples (all depth combined)	Spearman Rank		
			d_i^2	r_s	Correlation of association between sub-samples at = .025
1	0	65	5.00	0.91	yes
2	76	41	2.00	0.90	yes
3	0	44	10.00	0.50	no
4	6	27	3.50	0.83	no
5	767	3,482	2.75	0.86	no
6-12	0	0	0	1.00	yes
1-5 combined	170	732	0.50	0.98	yes

Subsamples for shrimp zoeae appeared less correlated. Comparisons by cruise and with cruises combined, infrequently identified an association between numbers of shrimp larvae from the two types of subsamples (Tables A-4 and A-5). Despite a lack of significant correlation, data from both subsamples displayed similar trends in describing general vertical distribution (Fig. A-5). Most *Pandalus borealis* larvae in both data sets were found in samples from the upper 30 m of the water column, whereas the greatest proportion of *P. goniurus* larvae were observed for both subsample types in catches from near the surface.

The overall conclusion from the subsampling tests was that the 500-organism aliqouts used as the standard subsample for the study were too small to provide detailed descriptions of larval abundance by time, area, and depth for individual stages of zoeal development. The aliquots were sufficient, however, to describe vertical distributions or abundance with time in pooled-data terms (i.e., all larval stages combined) for each species of decapod larvae tested.

Evaluation of Sampling Adequacy

Detailed analysis of the adequacy of the study's sampling intensity by area or time was not attempted. There is not other data base for comparison. However, some comparisons were made between portions of the study's efforts. Larval populations in the offshore region were sampled once per season and station density never exceeded one station per

Table A-4.--Summary of information on estimated densities of pink shrimp larvae from two different subsamples of Tucker trawl catches obtained during decapod larvae vertical distribution studies in the Kiliuda Bay area of Kodiak Island, March-November 1978 and February 1979.

Cruises	Average number of larvae per 1000 m^3 estimated present in Kiliuda Bay from original "500 organism" aliquot (all depths combined)	Average number of larvae per 1000 m^3 estimated present in Kiliuda Bay from the "extensive resort" subsamples (all depth combined)	Spearman Rank Correlation Information		
			d_i^2	r_s	Correlation of association between subsamples at = .025
1	521	83	14.00	0.30	no
2	0	337	10.00	0.50	no
3	1,481	164	2.00	0.90	yes
4	33	391	5.00	0.75	no
5	0	168	8.00	0.97	yes
6	0	20	13.50	0.71	no
7	0	9	10.00	0.92	yes
8	0	5	9.50	----	no
9	0	1	5.00	0.91	yes
10-12	0	0	0	1.00	yes
1-9 combined	226	131	20.00	0.00	no

Table A-5.--Summary of information on estimated densities of humpy shrimp larvae from two different subsamples of Tucker trawl catches obtained during decapod larvae vertical distribution studies in the Kiliuda Bay area of Kodiak Island, March-November 1978 and February 1979

Cruises	Average number of larvae per 1000 m^3 estimated present in Kiliuda Bay from original "500 organism" aliquot (all depths combined)	Average number of larvae per 1000 m^3 estimated present in Kiliuda Bay from the "estensive resort" subsamples (all depth combined)	Spearman Rank Correlation Information: d_i^2	Spearman Rank Correlation Information: r_s	Spearman Rank Correlation Information: Correlation of association between subsamples at = .025
1	29	32	12.50	0.48	no
2	0	3	5.00	0.92	yes
3	0	5	8.00	0.97	yes
4	211	95	20.00	0.00	no
5	9	32	15.00	0.25	no
6	119	8	27.25	0.36	no
7-12	0	0	0	1.00	yes
1-6 combined	61	29	9.00	0.55	no

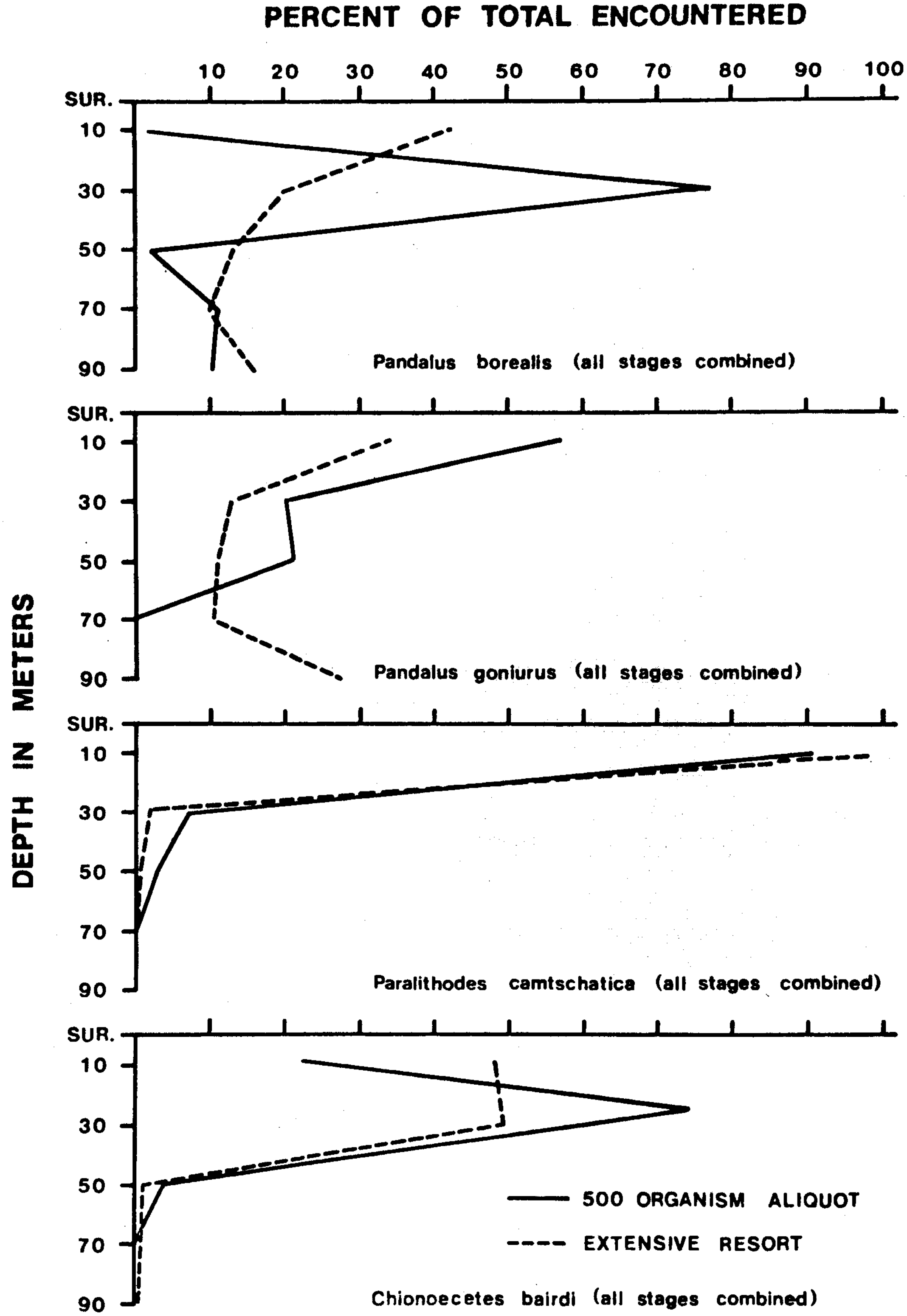


Figure A-5.--Comparison of accuracy of sample sorting by percentage of total organisms encountered and depth interval from the inshore region of the Kodiak Island study area. Neuston sampler and Tucker trawl data.

700 km^2. This coverage was limited in comparison to sampling of the inshore region. Inshore sampling density was as high as 5 cruises per season with station densities approaching one per 50 km^2. These regional sampling differences precluded integration of data from adjacent geographic areas and substantially complicated the analyses.

Summary of Report Limitations

This report presents a summary of data that were: (1) obtained during a year marked by weather conditions different from long-term averages; (2) derived from subsamples adequate only to describe relatively general distribution and abundance; and (3) gathered during two somewhat dissimilar sets of surveys.

It is most difficult to substantiate periods of larval occurrence or assess the relative magnitude of larval resources from the study's approximately one year of information. Further, it is impossible to identify how timing of larval occurrence during a year of apparently anomalous climate conditions relates to other years. Despite these limitations, this report represents the most comprehensive analysis available for shrimp and crab larvae in the study area. Information presented in the report provides a general description of the seasonal abundance and distribution of decapod larvae in inshore and offshore regions of the Kodiak Island shelf.

Spearman Rank Non-parametric Correlation Tests

Bongo Sampling

Table A-6	*Pandalus borealis*	Stage I
Table A-7	" "	Stage II
Table A-8	" '	Stage III
Table A-9	" "	Stage IV
Table A-10	" "	Stage V
Table A-11	" "	Stage VI
Table A-12	" "	Stage VII
Table A-13	*Pandalus borealis*	all stages combined
Table A-14	*P. goniurus*	all stages combined
Table A-15	*Paralithodes camtschatica*	all stages combined
Table A-16	*Chionoecetes bairdi*	all stages combined

Vertical Distribution Sampling

Table A-17	*Pandalus borealis*	Cruise I
Table A-18	" "	Cruise II
Table A-19	" "	Cruise III
Table A-20	" "	Cruise IV
Table A-21	" "	Cruise V
Table A-22	" "	Cruise VI
Table A-23	" "	Cruise VII
Table A-24	" "	Cruise VIII
Table A-25	" "	Cruise IX
Table A-26	*Pandalus borealis*	Cruises I thru IX combined
Table A-27	*P. goniurus*	Cruise I
Table A-28	" "	Cruise II
Table A-29	" "	Cruise III
Table A-30	" "	Cruise IV
Table A-31	" "	Cruise V
Table A-32	" "	Cruise VI
Table A-33	*P. goniurus*	Cruises I thru VI combined
Table A-34	*Paralithodes camtschatica*	Cruise I
Table A-35	" "	Cruise II
Table A-36	" "	Cruise III
Table A-37	" "	Cruise IV
Table A-38	" "	Cruise V
Table A-39	*Paralithodes camtschatica*	Cruises I through V combined
Table A-40	*Chionoecetes bairdi*	Cruise II
Table A-41	" "	Cruise III
Table A-42	" "	Cruise IV
Table A-43	" "	Cruise V
Table A-44	" "	Cruises II through V combined
Table A-45	" "	Cruises VI through XII combined

Table A-6.--Spearman rank non-parametric correlation tests on bongo net information for pink shrimp larvae in the Chiniak Bay area of Kodiak Island, 1978-79 (stations C1, C2, and C3 combined).

Stage 1

Cruise	Number found in original "500-organism" aliquots (x_i)	Rank of x_i	Number found in "extensive resort" subsamples (y_i)	Rank of y_i	Difference in ranks (d_i)	Squares of differences (d_i^2)
1	0	5.5	17	10	4.5	20.25
2	2	11.0	226	12	1	1
3	8	12.0	179	11	1	1
4	0	5.5	12	9	3.5	12.25
5	0	5.5	1	6.5	1	1
6	0	5.5	0	3	2.5	6.25
7	0	5.5	0	3	2.5	6.25
8	0	5.5	7	8	2.5	6.25
9	0	5.5	0	3	2.5	6.25
10	0	5.5	0	3	2.5	6.25
11	0	5.5	0	3	2.5	6.25
12	0	5.5	1	6.5	1	1
						$\Sigma d_i^2 = 74$

Test: H_0: x and y are independent, i.e., there is no correlation between subsamples.
H_a: x and y are dependent, i.e., there is correlation or association.

Test Statistic: $t = r_s\sqrt{\frac{N-2}{1-(r_s)^2}}$ ~ student's "t" with N-2 degrees of freedom

Rejection Rule: Reject H_0 if $t > t_{N-2}^{.975}$; $t_{10}^{.975} = 2.228$

Calculations:

Correction for ties: $x = \frac{\Sigma T_x^3 - T_x}{12} = \frac{10^3-10}{12} = \frac{1000-10}{12} = 82.5$; $\Sigma x^2 = \frac{N^3-N}{12} - T_x = \frac{12^3-12}{12} - 82.5 = 60.5$

$y = \frac{\Sigma T_y^2 - T_y}{12} = \frac{5^3-5}{12} + \frac{2^3-2}{12} = 10.5$; $\Sigma y^2 = \frac{N^3-N}{12} - T_y = \frac{12^3-12}{12} - 10.5 = 132.5$

$$r_s = \frac{\Sigma x^2+\Sigma y^2-\Sigma d_i^2}{2\sqrt{\Sigma x^2\cdot\Sigma y^2}} = \frac{60.5+132.5-74.0}{2\sqrt{60.5\cdot 132.5}} = \frac{119.00}{179.07} = 0.665$$

$$t = r_s\sqrt{\frac{N-2}{1-r_s^2}} = 0.655\sqrt{\frac{12-2}{1-.665^2}} = 0.665\sqrt{\frac{10}{.558}} = 2.816 > 2.228$$

Conclusion: Reject H_0. The subsamples are correlated with respect to the numbers of stage I larvae present.

Table A-7.--Spearman rank non-parametric correlation tests on bongo net information for pink shrimp larvae in the Chiniak Bay area of Kodiak Island, 1978 (stations C1, C2, and C3 combined).

Stage 2

Cruise 1/	Numbers found in original "500-organism aliquot (x_i)	Rank of x_i	Numbers found in "extensive resort" subsample (y_i)	Rank of y_i	Difference in ranks (d_i)	Squares of differences (d_i^2)
1	0	1.5	2	1	0.5	0.25
2	0	1.5	5	2	0.5	0.25
3	1	3.5	90	3	0.5	0.25
4	1	3.5	143	4	0.5	0.25
						$\Sigma d_i^2 = 1.00$

Test: H_0: x and y are independent, i.e., there is no correlation between subsamples.
H_a: x and y are dependent, i.e., there is correlation or association.

Test Statistic: $t = r_s\sqrt{\frac{N-2}{1-(r_s)^2}}$ ~ student's "t" with N-2 degrees of freedom

Rejection Rule: Reject H_0 if $t > t_{N-2}^{.975}$; $t_2^{.975} = 4.303$

Calculations:

$$r_s = 1 - \frac{6\Sigma d_i^2}{N^3-N} = 1 - \frac{6(1)}{64-4} = 0.900$$

$$t = r_s\sqrt{\frac{N-2}{1-r_s^2}} = 0.900\sqrt{\frac{2}{1-0.81}} = 2.920 \ngtr 4.303$$

Conclusion: Fail to reject H_0. The subsamples are not correlated.

1/ Cruises with zero catches in both subsamples (after occurrences) are omitted.

Table A-8.--Spearman rank non-parametric correlation tests on bongo net information for pink shrimp larvae in the Chiniak Bay area of Kodiak Island, 1978 (stations C1, C2, and C3 combined).

Stage 3

Cruise 1/	Numbers found in original "500-organism aliquot (x_i)	Rank of x_i	Numbers found in "extensive resort" subsample (y_i)	Rank of y_i	Difference in ranks (d_i)	Squares of differences (d_i^2)
1	0	3.5	0	1.5	2	4.00
2	0	3.5	0	1.5	2	4.00
3	0	3.5	1	3	0.5	0.25
4	0	3.5	91	6	2.5	6.25
5	0	3.5	3	4.5	1	1.00
6	0	3.5	3	4.5	1	1.00
						Σd_i^2 = 16.50

Test: H_0: x and y are independent, i.e., there is no correlation between subsamples.
H_a: x and y are dependent, i.e., there is correlation or association.

Test Statistic: $t = r_s\sqrt{\frac{N-2}{1-(r_s)^2}}$ ~ student's "t" with N-2 degrees of freedom

Rejection Rule: Reject H_0 if $t > t_{N-2}^{.975}$; $t_4^{.975} = 2.776$

Calculations:

Correction for ties: $x = \Sigma\frac{T_x^3-T_x}{12} = \frac{6^3-6}{12} = 17.5$; $\Sigma x^2 = \frac{N^3-N}{12} - T_x = \frac{6^3-6}{12} - 17.5 = 17.5 - 17.5 = 0$

$y = \Sigma\frac{T_y^3-T_y}{12} = \frac{2^3-2}{12} + \frac{2^3-2}{12} = 0.5 + 0.5 = 1.0$; $\Sigma y^2 = \frac{N^3-N}{12} - T_y = 17.5 - 1.0 = 16.5$

$r_s = \frac{\Sigma x^2 + \Sigma y^2 - \Sigma d_i^2}{2\sqrt{\Sigma x^2 \cdot \Sigma y^2}} = \frac{0+16.5-16.5}{2\sqrt{0 \cdot 16.5}} = 0$ $\quad t = 0\sqrt{\frac{4}{1-0}} = 0 \cdot 2 = 0 \not> 2.776$

Conclusion: Fail to reject H_0. The subsamples are not correlated.

1/ Cruises with zero catches in both subsamples (after occurrences) are omitted, i.e., all cruises after occurrence of larvae are omitted from the analysis.

Table A-9.--Spearman rank non-parametric correlation tests on bongo net information for pink shrimp larvae in the Chiniak Bay area of Kodiak Island, 1978 (stations C1, C2, and C3 combined).

Stage 4

Cruise 1/	Numbers found in original "500-organism aliquot (x_i)	Rank of x_i	Numbers found in "extensive resort" subsample (y_i)	Rank of y_i	Difference in ranks (d_i)	Squares of differences (d_i^2)
1	0	3.5	0	2	1.5	2.25
2	0	3.5	0	2	1.5	2.25
3	0	3.5	0	2	1.5	2.25
4	0	3.5	1	6	2.5	6.25
5	0	3.5	22	5	1.5	2.25
6	0	3.5	20	4	0.5	0.25

$\Sigma d_i^2 = 15.50$

Test: H_0: x and y are independent, i.e., there is no correlation between subsamples.
H_a: x and y are dependent, i.e., there is correlation or association.

Test Statistic: $t = r_s\sqrt{\frac{N-2}{1-(r_s)^2}}$ ~ student's "t" with N-2 degrees of freedom

Rejection Rule: Reject H_0 if $t > t_{N-2}^{.975}$; $t_4^{.975} = 2.776$

Calculations:

Correction for ties: $x = \Sigma\frac{T_x^3 - T_x}{12} = \frac{6^3-6}{12} = \frac{216-6}{12} = 17.5$; $\Sigma x^2 = \frac{N^3-N}{12} - T_x = \frac{6^3-6}{12} - 17.5 = 0$

$y = \Sigma\frac{T_y^3 - T_y}{12} = \frac{3^3-3}{12} = \frac{27-3}{12} = 2.0$; $\Sigma y^2 = \frac{N^3-N}{12} - T_y = \frac{6^3-6}{12} - 2.0 = 15.5$

$r_s = \frac{\Sigma x^2 + \Sigma y^2 - \Sigma d_i^2}{2\sqrt{\Sigma x^2 \cdot \Sigma y^2}} = \frac{0+15.5-15.5}{2\sqrt{0 \cdot 15.5}} = 0$ $\quad t = 0\sqrt{\frac{4}{1-0}} = 0 \cdot 2 = 0 \not> 2.776$

Conclusion: Fail to reject H_0. The subsamples are not correlated.

1/ Cruises with zero catches in both subsamples (after occurrences) are omitted.

Table A-10.--Spearman rank non-parametric correlation tests on bongo net information for pink shrimp larvae in the Chiniak Bay area of Kodiak Island, 1978 (stations C1, C2, and C3 combined).

Stage 5

Cruise 1/	Numbers found in original "500-organism aliquot (x_i)	Rank of x_i	Numbers found in "extensive resort" subsample (y_i)	Rank of y_i	Difference in ranks (d_i)	Squares of differences (d_i^2)
1	0	4	0	2.5	1.5	2.25
2	0	4	0	2.5	1.5	2.25
3	0	4	0	2.5	1.5	2.25
4	0	4	0	2.5	1.5	2.25
5	0	4	21	7	3.0	9.00
6	0	4	4	5	1.0	1.00
7	0	4	15	6	2.0	4.00
						$\Sigma d_i^2 = 23.00$

Test: H_0: x and y are independent, i.e., there is no correlation between subsamples.
H_a: x and y are dependent, i.e., there is correlation or association.

Test Statistic: $t = r_s\sqrt{\frac{N-2}{1-(r_s)^2}}$ ~ student's "t" with N-2 degrees of freedom

Rejection Rule: Reject H_0 if $t > t_{N-2}^{.975}$; $t_6^{.975} = 2.571$

Calculations:

Correction for ties: $x = \frac{T_x^3 - T_x}{12} = \frac{7^3-7}{12} = \frac{343-7}{12} = 28.0$; $\Sigma x^2 = \frac{N^3-N}{12} - T_x = \frac{7^3-7}{12} - 28.0 = 0$

$y = \frac{T_y^3 - T_y}{12} = \frac{4^3-4}{12} = \frac{64-4}{12} = 5.0$; $\Sigma y^2 = \frac{N^3-N}{12} - T_y = 28.0 - 5.0 = 23.0$

$r_s = \frac{\Sigma x^2 + \Sigma y^2 - \Sigma d^2}{2\sqrt{\Sigma x^2 \cdot \Sigma y^2}} = \frac{0+23-23}{2\sqrt{0 \cdot 23}} = 0$ $t = 0\sqrt{\frac{5}{1-0}} = 0 \not> 2.571$

Conclusion: Fail to reject H_0. The subsamples are not correlated.

1/ Cruises with zero catches in both subsamples (after occurrences) are omitted.

Table A-11.--Spearman rank non-parametric correlation tests on bongo net information for pink shrimp larvae in the Chiniak Bay area of Kodiak Island, 1978 (stations C1, C2, and C3 combined).

Stage 6

Cruise 1/	Numbers found in original "500-organism aliquot (x_i)	Rank of x_i	Numbers found in "extensive resort" subsample (y_i)	Rank of y_i	Difference in ranks (d_i)	Squares of differences (d_i^2)
1	0	3.5	0	3.5	0	0
2	0	3.5	0	3.5	0	0
3	0	3.5	0	3.5	0	0
4	0	3.5	0	3.5	0	0
5	0	3.5	0	3.5	0	0
6	0	3.5	0	3.5	0	0
7	1	7.0	3	7.0	0	0
					Σd_i^2 =	0.00

Test: H_0: x and y are independent, i.e., there is no correlation between subsamples.
H_a: x and y are dependent, i.e., there is correlation or association.

Test Statistic: $t = r_s\sqrt{\frac{N-2}{1-(r_s)^2}}$ ~ student's "t" with N-2 degrees of freedom

Rejection Rule: Reject H_0 if $t > t^{.975}_{N-2}$; $t^{.975}_{5} = 2.571$

Calculations:
Correction for ties:

$$x = \Sigma\frac{T_x^3 - T_x}{12} = \frac{6^3-6}{12} = \frac{216-6}{12} = 17.5;\ \Sigma x^2 = \frac{N^3-N}{12} - T_x = \frac{7^3-7}{12} - 17.5 = 28.0 - 17.5 = 10.5$$

$$y = \Sigma\frac{T_y^3 - T_y}{12} = \frac{6^3-6}{12} = \frac{216-6}{12} = 17.5;\ \Sigma y^2 = \frac{N^3-N}{12} - T_y = \frac{7^3-7}{12} - 17.5 = 28.0 - 17.5 = 10.5$$

$$r_s = \frac{\Sigma x^2 + \Sigma y^2 - \Sigma d_i^2}{2\sqrt{\Sigma x^2 \cdot \Sigma y^2}} = \frac{10.5+10.5-0}{2\sqrt{10.5 \cdot 10.5}} = \frac{21.0}{21.0} = 1.00 = \text{complete correlation}$$

Conclusion: Reject H_0. The subsamples are correlated.

1/ Cruises with zero catches in both subsamples (after occurrences) are omitted.

Table A-12.--Spearman rank non-parametric correlation tests on bongo net information for pink shrimp larvae in the Chiniak Bay area of Kodiak Island, 1978 (stations C1, C2, and C3 combined).

Stage 7

Cruise 1/	Numbers found in original "500-organism aliquot (x_i)	Rank of x_i	Numbers found in "extensive resort" subsample (y_i)	Rank of y_i	Difference in ranks (d_i)	Squares of differences (d_i^2)
1	0	4	0	3.5	0.5	0.25
2	0	4	0	3.5	0.5	0.25
3	0	4	0	3.5	0.5	0.25
4	0	4	0	3.5	0.5	0.25
5	0	4	0	3.5	0.5	0.25
6	0	4	0	3.5	0.5	0.25
7	0	4	1	7.0	3.0	9.00
						Σd_i^2 = 10.50

Test: H_0: x and y are independent, i.e., there is no correlation between subsamples.
H_a: x and y are dependent, i.e., there is correlation or association.

Test Statistic: $t = r_s\sqrt{\frac{N-2}{1-(r_s)^2}}$ ~ student's "t" with N-2 degrees of freedom

Rejection Rule: Reject H_0 if $t > t_{N-2}^{.975}$; $t_6^{.975} = 2.447$

Calculations:
Correction for ties:

$$x = \frac{T_x^3 - T_x}{12} = \frac{7^3-7}{12} = \frac{343-7}{12} = 28.0;\ \Sigma x^2 = \frac{N^3-N}{12} - T_x = \frac{343-7}{12} - 28.0 = 0$$

$$y = \frac{T\ \ -T}{12} = \frac{6^3-6}{12} = \frac{216-6}{12} = 17.5;\ \Sigma y^2 = \frac{N^3-N}{12} - T_y = \frac{343-7}{12} - 17.5 = 11.5$$

$$r_s = \frac{\Sigma x^2 + \Sigma y^2 - \Sigma d_i^2}{2\sqrt{\Sigma x^2 \cdot \Sigma y^2}} = \frac{0+11.5-10.5}{2\sqrt{0 \cdot 11.5}} = \frac{I}{-} = 0 \qquad t = 0\sqrt{\frac{5}{1-0}} = 0 = 0 \not> 2.447$$

Conclusion: Fail to reject H_0. The subsamples are not correlated.

1/ Cruises with zero catches in both subsamples (after occurrences) are omitted.

Table A-13.--Spearman rank non-parametric correlation tests on bongo net information for pink shrimp larvae in the Chiniak Bay area of Kodiak Island, 1978 (stations C1, C2, and C3 combined).

Stage 1-12 combined

Cruise	Numbers found in original "500-organism aliquot (x_i)	Rank of x_i	Numbers found in "extensive resort" subsample (y_i)	Rank of y_i	Difference in ranks (d_i)	Squares of differences (d_i^2)
1	0	4.5	2	5	1.5	2.25
2	33	9	49	11	2.0	4.00
3	138	12	42	9	3.0	9.00
4	38	10	185	12	2.0	4.00
5	0	4.5	35	8	3.5	12.25
6	0	4.5	46	10	5.5	30.25
7	65	11	20	7	4.0	16.00
8	0	4.5	5	6	1.5	2.25
9	0	4.5	0	2	2.5	6.25
10	0	4.5	0	2	2.5	6.25
11	0	4.5	0	2	2.5	6.25
12	0	4.5	1	4	0.5	0.25
					$\Sigma d_i^2 =$	99.00

Test: H_0: x and y are independent, i.e., there is no correlation between subsamples.
H_a: x and y are dependent, i.e., there is correlation or association.

Test Statistic: $t = r_s\sqrt{\frac{N-2}{1-(r_s)^2}}$ ~ student's "t" with N-2 degrees of freedom

Rejection Rule: Reject H_0 if $t > t_{N-2}^{.975}$; $t_{10}^{.975} = 2.228$

Calculations:
Correction for ties: $x = \Sigma\frac{T_x^3-T_x}{12} = \frac{8^3-8}{12} = \frac{512-8}{12} = 42.0$; $\Sigma x^2 = \frac{N^3-N}{12} - T_y = \frac{12^3-12}{12} - 42.0 = 143 - 42 = 101$

$y = \Sigma\frac{T_y^3-T_y}{12} = \frac{3^3-3}{12} = \frac{27-3}{12} = 2.0$; $\Sigma y^2 = \frac{N^3-N}{12} - T = \frac{12^3-12}{12} - 2 = 143-2 = 141$

$r_s = \frac{\Sigma x^2+\Sigma y^2-\Sigma d_i^2}{2\sqrt{\Sigma x^2\cdot\Sigma y^2}} = \frac{101+141-99}{2\sqrt{101\cdot 141}} = \frac{143}{238.67} = 0.599$ $\qquad t = 0.599\sqrt{\frac{10}{1-.359}} = 2.366 > 2.228$

Conclusion: Reject H_0. The subsamples are correlated.

Table A-14.--Spearman rank non-parametric correlation tests on bongo net information for humpy shrimp larvae in the Chiniak Bay area of Kodiak Island, 1978 (stations C1, C2, and C3 combined).

Stage - All stages combined

Cruise 1/	Numbers found in original "500-organism aliquot (x_i)	Rank of x_i	Numbers found in "extensive resort" subsample (y_i)	Rank of y_i	Difference in ranks (d_i)	Squares of differences (d_i^2)
1	0	2.5	0	1	1.5	2.25
2	10 2/	5	3	2	3.0	9.00
3	164	8	41	5	3.0	9.00
4	77	7	129	8	1.0	1.00
5	0	2.5	44	6.5	4.0	16.00
6	44	6	44	6.5	0.5	0.25
7	0	2.5	21	4	1.5	2.25
8	0	2.5	7	3	0.5	0.25
						$\Sigma d_i^2 = 40.00$

Test: H_0: x and y are independent, i.e., there is no correlation between subsamples.
H_a: x and y are dependent, i.e., there is correlation or association.

Test Statistic: $t = r_s\sqrt{\frac{N-2}{1-(r_s)^2}}$ ~ student's "t" with N-2 degrees of freedom

Rejection Rule: Reject H_0 if $t > t_{N-2}^{.975} = t_6^{.975} = 2.447$

Calculations:

$$r_s = 1 - \frac{\Sigma d_i^2}{N^3-N} = 1 - \frac{40}{8^3-8} = 1 - \frac{40}{512-8} = 0.921$$

$$t = 0.921\sqrt{\frac{6}{1-.848}} = 5.778 > 2.447$$

Conclusion: Reject H_0. There is correlation between subsamples.

1/ Cruises with zero catches in both subsamples (after occurrences) are omitted.
2/ Mean biomass per 100 m^2

Table A-15.--Spearman rank non-parametric correlation tests on bongo net information for red king crab shrimp larvae in the Chiniak Bay area of Kodiak Island, 1978 (stations C1, C2, and C3 combined).

Stage - All stages combined

Cruise 1/	Numbers found in original "500-organism aliquot (x_i)	Rank of x_i	Numbers found in "extensive resort" subsample (y_i)	Rank of y_i	Difference in ranks (d_i)	Squares of differences (d_i^2)
1	125 2/	5	209	5	0	0
2	0	2	9	2	0	0
3	0	2	13	3	1	1
4	38	4	36	4	0	0
5	0	2	5	1	1	1
						$\Sigma d_i^2 = 2.00$

Test: H_0: x and y are independent, i.e., there is no correlation between subsamples.
H_a: x and y are dependent, i.e., there is correlation or association.

Test Statistic: $t = r_s\sqrt{\frac{N-2}{1-(r_s)^2}}$ ~ student's "t" with N-2 degrees of freedom

Rejection Rule: Reject H_0 if $t > t_{N-2}^{.975}$; $t_3^{.975} = 3.182$

Calculations:

$$r_s = 1 - \frac{6\Sigma d_i^2}{N^3-N} = 1 - \frac{6(2)}{5^3-5} = 1 - \frac{12}{120} = 0.900$$

$$t = 0.90\sqrt{\frac{3}{1-.81}} = 3.476 > 3.182$$

Conclusion: Reject H_0. The two sets of subsamples are correlated.

1/ Cruises with zero catches in both subsamples (after occurrences) are omitted.
2/ Mean biomass per 100 m^2.

Table A-16.--Spearman rank non-parametric correlation tests on bongo net information for bairdi Tanner crab larvae in the Chiniak Bay area of Kodiak Island, 1978 (stations C1, C2, and C3 combined).

Stage - All stages combined

Cruise 1/	Numbers found in original "500 organism" aliquot (x_i)	Rank of x_i	Numbers found in "extensive resort" subsample (y_i)	Rank of Y_i	Difference in ranks (d_i)	Squares of differences (d_i^2)
1	0	5	1 2/	5	0.0	0
2	0	5	3	8	3.0	9.00
3	0	5	1	5	0.0	0
4	2	10	23	10	0.0	0
5	0	5	10	9	4.0	16.00
6	0	5	2	7	2.0	4.00
7	0	5	0	2	3.0	9.00
8	0	5	0	2	3.0	9.00
9	0	5	0	2	3.0	9.00
10	0	5	<1	5	0.0	0

$\Sigma d_i^2 = 5$

Test: H_0: x and y are independent, i.e., there is no correlation between subsamples.
H_a: x and y are dependent, i.e., there is correlation or association.

Test Statistic: $t = r_s \sqrt{\frac{N-2}{1-(r_s)^2}}$ ~ student's "t" with N-2 degrees of freedom

Rejection Rule: Reject H_0 if $t > t^{.975}_{N-2}$; $t^{.975}_{8} = 2.306$

Calculations:

Correction for ties: $x = \Sigma\frac{T_x^3 - T_x}{12} = \frac{9^3-9}{12} = \frac{729-9}{12} = 60$; $\Sigma x^2 = \frac{N^3-N}{12} - T_x = \frac{10^3-10}{12} - 60 = \frac{1000-10}{12} - 60 = 22.5$

$y = \Sigma\frac{T_y^3-T_y}{12} = \left[\frac{3^3-3}{12} + \frac{3^3-3}{12}\right] = \left[\frac{27-3}{12} + \frac{27-3}{12}\right] = 4.0$; $\Sigma y^2 = \frac{N^3-N}{12} - T_y = \frac{10^3-10}{12} - 4.0 = \frac{1000-10}{12} - 4.0 =$

$r_s = \frac{\Sigma x^2 + \Sigma y^2 - \Sigma d_i^2}{2\sqrt{\Sigma x^2 \cdot \Sigma y^2}} = \frac{22.5+78.5-56.0}{2\sqrt{78.5 \cdot 22.5}} = \frac{45.00}{84.05} = 0.535$

$t = r_s\sqrt{\frac{N-2}{1-r_s^2}} = 0.535\sqrt{\frac{8}{1-.281}} = 1.762 \not> 2.306$

Conclusion: Fail to reject H_0. There is no correlation between subsamples.

1/ Cruises with zero catches in both subsamples (after occurrences) are omitted.

2/ Mean biomass per 100 m^2.

Table A-17.--Spearman rank non-parametric correlation tests on vertical distribution for pink shrimp larvae in the Kiliuda Bay area of Kodiak Island, 1978.

Cruise 1

Sample Depth$_i$ (m)	Density estimated from original "500 organism" aliquot (x_i)	Rank of X_i	Density estimated from "extensive resort" subsample (y_i)	Rank of Y_i	Difference in ranks (d_i)	Squares of differences (d_i^2)
10	80 1/	2	378	5	3	9
30	366	3	12	3	0	0
50	0	1	0	1	0	0
70	1100	5	18	4	1	1
90	1059	4	9	2	2	4

$\Sigma d_i^2 = 14.00$

Test: H_0: x and y are independent, i.e., there is no correlation between subsamples.
H_a: x and y are dependent, i.e., there is correlation or association.

Test Statistic: $t = r_s\sqrt{\frac{N-2}{1-(r_s)^2}}$ ~ student's "t" with N-2 degrees of freedom

Rejection Rule: Reject H_0 if $t > t_{N-2}^{.975}$; $t_3^{.975} = 3.182$

Calculations:

$$r_s = 1 - \frac{6\sum_{i=10}^{90} d_i^2}{N^3-N}$$

$$= 1 - \frac{6(14)}{125-5}$$

$$= 1 - \frac{84}{120} = 0.30$$

$$t = 0.30\sqrt{\frac{N-2}{1-r_s^2}} = 0.30\sqrt{\frac{3}{1-.09}} = 0.544 \not> 3/182$$

Conclusion: Fail to reject H_0. These subsamples are not correlated.

1/ Number of larvae per 1000 m³.

Table A-18.--Spearman rank non-parametric correlation tests on vertical distribution for pink shrimp larvae in the Kiliuda Bay area of Kodiak Island, 1978.

Cruise 2

Sample Depth$_i$ (m)	Density estimated from original "500 organism" aliquot (x_i)	Rank of X_i	Density estimated from "extensive resort" subsample (y_i)	Rank of Y_i	Difference in ranks (d_i)	Squares of differences (d_i^2)
10	0	3	160	2	1	1
30	0	3	361	3	0	0
50	0	3	566	5	2	4
70	0	3	468	4	1	1
90	0	3	140	1	2	4

<u>Test</u>: H_0: x and y are independent, i.e., there is no correlation between subsamples. $\Sigma d_i^2 = 10$
H_a: x and y are dependent, i.e., there is correlation or association.

<u>Test Statistic</u>: $t = r_s\sqrt{\frac{N-2}{1-(r_s)^2}}$ ~ student's "t" with N-2 degrees of freedom

<u>Rejection Rule</u>: Reject H_0 if $t > t_{N-2}^{.975}$; $t_3^{.975} = 3.182$

<u>Calculations</u>:

$$r_s = 1 - \frac{6\sum_{i=10}^{90} d_i^2}{N^3 - N}$$

$$= 1 - \frac{6(10)}{125-5}$$

$$= 1 - \frac{60}{120} = 0.500$$

$$t = 0.500\sqrt{\frac{3}{1-0.250}} = 1.00 \not> 3.182$$

<u>Conclusion</u>: Fail to reject H_0. These subsamples are not correlated.

Table A-19.--Spearman rank non-parametric correlation tests on vertical distribution for pink shrimp larvae in the Kiliuda Bay area of Kodiak Island, 1978.

Cruise 3

Sample Depth$_i$ (m)	Density estimated from original "500 organism" aliquot (x_i)	Rank of X_i	Density estimated from "extensive resort" subsample (y_i)	Rank of Y_i	Difference in ranks (d_i)	Squares of differences (d_i^2)
10	0	2	70	3	1	1
30	7246	5	632	5	0	0
50	158	4	90	4	0	0
70	0	2	30	2	0	0
90	0	2	10	1	1	1

$\Sigma d_i^2 = 2$

Test: H_0: x and y are independent, i.e., there is no correlation between subsamples.
H_a: x and y are dependent, i.e., there is correlation or association.

Test Statistic: $t = r_s\sqrt{\frac{N-2}{1-(r_s)^2}}$ ~ student's "t" with N-2 degrees of freedom

Rejection Rule: Reject H_0 if $t > t^{.975}_{N-2}$; $t^{.975}_3 = 3.182$

Calculations:

$$r_s = 1 - \frac{6\sum_{i=10}^{90} di^2}{N^3-N}$$

$$= 1 - \frac{6(2)}{125-5}$$

$$= 1 - \frac{12}{120} = 0.90$$

$$t = 0.90\sqrt{\frac{3}{1-0.9^2}} = 3.576 > 3.182$$

Conclusion: Reject H_0. These subsamples are correlated.

Table A-20.--Spearman rank non-parametric correlation tests on vertical distribution for pink shrimp larvae in the Kiliuda Bay area of Kodiak Island, 1978.

Cruise 4

Sample $Depth_i$ (m)	Density estimated from original "500 organism" aliquot (x_i)	Rank of X_i	Density estimated from "extensive resort" subsample (y_i)	Rank of Y_i	Difference in ranks (d_i)	Squares of differences (d_i^2)
10	166	5	1760	5	0	0
30	0	2.5	130	4	1.5	2.25
50	0	2.5	27	2	0.5	0.25
70	0	2.5	4	1	1.5	2.25
90	0	2.5	33	3	0.5	0.25

$\Sigma d_i^2 = 5.00$

Test: H_0: x and y are independent, i.e., there is no correlation between subsamples.
H_a: x and y are dependent, i.e., there is correlation or association.

Test Statistic: $t = r_s\sqrt{\frac{N-2}{1-(r_s)^2}}$ ~ student's "t" with N-2 degrees of freedom

Rejection Rule: Reject H_0 if $t > t_{N-2}^{.975}$; $t_3^{.975} = 3.182$

Calculations:

$$r_s = 1 - \frac{6\sum_{i=10}^{90} d_i^2}{N^3-N}$$

$$= 1 - \frac{6(5)}{125-5}$$

$$= 1 - \frac{30}{120} = 0.750$$

$$t = 0.750\sqrt{\frac{3}{1-.75^2}} = 1.965 \ngtr 3.182$$

Conclusion: Fail to reject H_0. These subsamples are not correlated.

Table A-21.--Spearman rank non-parametric correlation tests on vertical distribution for pink shrimp larvae in the Kiliuda Bay area of Kodiak Island, 1978.

Cruise 5

Sample Depth$_i$ (m)	Density estimated from original "500 organism" aliquot (x_i)	Rank of X_i	Density estimated from "extensive resort" subsample (y_i)	Rank of Y_i	Difference in ranks (d_i)	Squares of differences (d_i^2)
10	0	3	64	4	1	1
30	0	3	20	2	1	1
50	0	3	20	2	1	1
70	0	3	20	2	1	1
90	0	3	718	5	2	4

$\Sigma d_i^2 = 8.00$

Test: H_0: x and y are independent, i.e., there is no correlation between subsamples.
H_a: x and y are dependent, i.e., there is correlation or association.

Test Statistic: $t = r_s\sqrt{\frac{N-2}{1-(r_s)^2}}$ ~ student's "t" with N-2 degrees of freedom

Rejection Rule: Reject H_0 if $t > t_{N-2}^{.975}$; $t_3^{.975} = 3.182$

Calculations:

Correction for ties - $T_x = \frac{T_x^3 - T_x}{12} = \frac{5^3-5}{12} = \frac{125-5}{12} = 10$; $\Sigma x^2 = \frac{N^3-N}{12} - T_x = \frac{125-5}{12} - 10 = 0$

$$T_y = \frac{T_y^3 - T_y}{12} = \frac{3^3-3}{12} = \frac{27-3}{12} = 2;\ \Sigma y^2 = \frac{N^3-N}{12} - T_x = \frac{125-5}{12} - 2 = 8$$

$$r_s = \frac{\Sigma x^2 + \Sigma y^2 - \Sigma d_i^2}{2\sqrt{\Sigma x^2 \cdot \Sigma y^2}} = \frac{0+8-8}{2\sqrt{0 \cdot 8}} = 0$$

$$t = 0\sqrt{\frac{3}{1-0}} = 0 \not> 3.182$$

Conslusion: Fail to reject H_0. These subsamples are not significantly correlated.

Table A-22.--Spearman rank non-parametric correlation tests on vertical distribution for pink shrimp larvae in the Kiliuda Bay area of Kodiak Island, 1978.

Cruise 6

Sample Depth$_i$ (m)	Density estimated from original "500 organism" aliquot (x_i)	Rank of X_i	Density estimated from "extensive resort" subsample (y_i)	Rank of Y_i	Difference in ranks (d_i)	Squares of differences (d_i^2)
10	0	3	3	1	2	4
30	0	3	10	2.5	1.5	2.5
50	0	3	41	5	2	4
70	0	3	10	2.5	1.5	2.25
90	0	3	36	4	1	1

$\Sigma d_i^2 = 13.50$

Test: H_0: x and y are independent, i.e., there is no correlation between subsamples.
H_a: x and y are dependent, i.e., there is correlation or association.

Test Statistic: $t = r_s\sqrt{\frac{N-2}{1-(r_s)^2}}$ ~ student's "t" with N-2 degrees of freedom

Rejection Rule: Reject H_0 if $t > t_{N-2}^{.975}$; $t_3^{.975} = 3.182$

Calculations:

Correction for ties - $T_x = \frac{Tx^3-Tx}{12} = \frac{5^3-5}{12} = \frac{125-5}{12} = 10$; $\Sigma x^2 = \frac{N^3-N}{12} - T_x = \frac{125-5}{12} - 10 = 0$

$T_y = \frac{Ty^3-Ty}{12} = \frac{3^3-3}{12} = \frac{27-3}{12} = 2$; $\Sigma y^2 = \frac{N^3-N}{12} - T_y = \frac{125-5}{12} - 2 = 8$

$$r_s = \frac{\Sigma x^2+\Sigma y^2-\Sigma d_i^2}{2\sqrt{\Sigma x^2\cdot\Sigma y^2}} = \frac{0+8-13.5}{2\sqrt{0\cdot 8}} = 0$$

$$t = 0\sqrt{\frac{3}{1-0}} = 0 \not> 3.182$$

Conclusion: Fail to reject H_0. These subsamples are not correlated.

Table A-23.--Spearman rank non-parametric correlation tests on vertical distribution for pink shrimp larvae in the Kiliuda Bay area of Kodiak Island, 1978.

Cruise 7

Sample Depth$_i$ (m)	Density estimated from original "500 organism" aliquot (x_i)	Rank of X_i	Density estimated from "extensive resort" subsample (y_i)	Rank of Y_i	Difference in ranks (d_i)	Squares of differences (d_i^2)
10	1	3	16	5	2	4
30	0	3	4	2	1	1
50	0	2	14	4	1	1
70	0	3	12	3	0	0
90	0	3	--	1	2	4

Test: H_0: x and y are independent, i.e., there is no correlation between subsamples. $\Sigma d_i^2 = 10.00$
H_a: x and y are dependent, i.e., there is correlation or association.

Test Statistic: $t = r_s\sqrt{\frac{N-2}{1-(r_s)^2}}$ ~ student's "t" with N-2 degrees of freedom

Rejection Rule: Reject H_0 if $t > t^{.975}_{N-2}$; $t^{.975}_{3} = 3.182$

Calculations:

$$r_s = \sum_{i=10}^{90} \frac{d_i^2}{N^3-N}$$

$$= 1 - \frac{10}{125-5}$$

$$= 0.917$$

$$t = 0.917\sqrt{\frac{3}{1-.917^2}} = 3.974 > 3.182$$

Conclusion: Reject H_0. There is correlation between these subsamples.

Table A-24.--Spearman rank non-parametric correlation tests on vertical distribution for pink shrimp larvae in the Kiliuda Bay area of Kodiak Island, 1978.

Cruise 8

Sample Depth$_i$ (m)	Density estimated from original "500 organism" aliquot (x_i)	Rank of X_i	Density estimated from "extensive resort" subsample (y_i)	Rank of Y_i	Difference in ranks (d_i)	Squares of differences (d_i^2)
10	0	3	0	1.5	1.5	2.25
30	0	3	0	1.5	1.5	2.25
50	0	3	3	3	0	0
70	0	3	13	5	2	4
90	0	3	7	4	1	1

Test: H_0: x and y are independent, i.e., there is no correlation between subsamples. $\Sigma d_i^2 = 9.50$
H_a: x and y are dependent, i.e., there is correlation or association.

Test Statistic: $t = r_s\sqrt{\frac{N-2}{1-(r_s)^2}}$ ~ student's "t" with N-2 degrees of freedom

Rejection Rule: Reject H_0 if $t > t^{.975}_{N-2}$; $t^{.975}_{3} = 3.182$

Calculations:

Correction for ties - $T_x = \frac{T_x^3 - T_x}{12} = \frac{5^3-5}{12} = \frac{125-5}{12} = 10$; $\Sigma x^2 = \frac{N^3-N}{12} - T_x = \frac{125-5}{12} - 10 = 0$

$$T_y = \frac{T_y^3 - T_y}{12} = \frac{2^3-2}{12} = \frac{8-2}{12} = 0.5;\ \Sigma y^2 = \frac{N^3-N}{12} - T_y = 9.5$$

$$r_s = \frac{\Sigma x^2 + \Sigma y^2 - \Sigma d_i^2}{2\sqrt{\Sigma x^2 \cdot \Sigma y^2}} = \frac{0+9.5-9.5}{2\sqrt{0 \cdot 9.5}} = 0$$

$$t = 0\sqrt{\frac{3}{1-0}} = 0 \not> 3.182$$

Conclusion: Fail to reject H_0. There is no correlation between these subsamples.

Table A-25.--Spearman rank non-parametric correlation tests on vertical distribution for pink shrimp larvae in the Kiliuda Bay area of Kodiak Island, 1978.

Cruise 9

Sample Depth$_i$ (m)	Density estimated from original "500 organism" aliquot (x_i)	Rank of X_i	Density estimated from "extensive resort" subsample (y_i)	Rank of Y_i	Difference in ranks (d_i)	Squares of differences (d_i^2)
10	0	3	0	2.5	0.5	0.25
30	0	3	0	2.5	0.5	0.25
50	0	3	6	5	2	4.00
70	0	3	0	2.5	0.5	0.25
90	0	3	0	2.5	0.5	0.25

$\Sigma d_i^2 = 5.00$

Test: H_0: x and y are independent, i.e., there is no correlation between subsamples.
H_a: x and y are dependent, i.e., there is correlation or association.

Test Statistic: $t = r_s\sqrt{\frac{N-2}{1-(r_s)^2}}$ ~ student's "t" with N-2 degrees of freedom

Rejection Rule: Reject H_0 if $t > t^{.975}_{N-2}$; $t^{.975}_{3} = 3.182$

Calculations:

Correction for ties - $T_x = \frac{Tx^3 - Tx}{12} = \frac{5^3-5}{12} = \frac{120}{12} = 10$; $\Sigma x^2 = \frac{N^3-N}{12} - T_x = \frac{125-5}{12} - 10 = 0$

$T_y = \frac{Ty^3 - Ty}{12} = \frac{4^3-4}{12} = \frac{60}{12} = 5$; $\Sigma y^2 = \frac{N^3-N}{12} - T_y = \frac{125-5}{12} - 5 = 5$

$$r_s = \frac{\Sigma x^2 + \Sigma y^2 - \Sigma d_i^2}{2\sqrt{\Sigma x^2 \cdot \Sigma y^2}} = \frac{0+5-5}{2\sqrt{0 \cdot 5}} = 0$$

$$t = 0\sqrt{\frac{3}{1-0}} = 0 \not> 3.182$$

Conclusion: Fail to reject H_0. There is no significant correlation between these subsamples.

Table A-26.--Spearman rank non-parametric correlation tests on vertical distribution for pink shrimp larvae in the Kiliuda Bay area of Kodiak Island, 1978.

Cruise 1-9

Sample Depth$_i$ (m)	Density estimated from original "500 organism" aliquot (x_i)	Rank of X_i	Density estimated from "extensive resort" subsample (y_i)	Rank of Y_i	Difference in ranks (d_i)	Squares of differences (d_i^2)
10	27 1/	2	272	5	3	9
30	846	5	130	4	1	1
50	18	1	84	2	1	1
70	122	4	64	1	3	9
90	118	3	106	3	0	0

$\Sigma d_i^2 = 20.00$

Test: H_0: x and y are independent, i.e., there is no correlation between subsamples.
H_a: x and y are dependent, i.e., there is correlation or association.

Test Statistic: $t = r_s\sqrt{\frac{N-2}{1-(r_s)^2}}$ ~ student's "t" with N-2 degrees of freedom

Rejection Rule: Reject H_0 if $t > t_{N-2}^{.975}$; $t_3^{.975} = 3.182$

Calculations:

$$r_s = 1 - \frac{6\left(\sum_{i=10}^{90} d_i^2\right)}{N^3 - N}$$

$$= 1 - \frac{6(20)}{125-5}$$

$$= 0$$

$$t = 0\sqrt{\frac{3}{1}} = 0 \not> 3.182$$

Conclusion: Fail to reject H_0. These subsamples are not correlated.

1/ Mean density per 1000 m³ for Cruises 1-9.

Table A-27.--Spearman rank non-parametric correlation tests on vertical distribution for humpy shrimp larvae in the Kiliuda Bay area of Kodiak Island, 1978.

Cruise 1

Depth (m)	Density estimated from original "500 organism" aliquot (x_i)	Rank of x_i	Density estimated from "extensive resort" subsample (y_i)	Rank of y_i	Difference in ranks (d_i)	Squares of differences (d_i^2)
10	0	2.5	156	5	2.5	6.25
30	0	2.5	0	2.5	0	0
50	145 1/	5	0	2.5	2.5	6.25
70	0	2.5	0	2.5	0	0
90	0	2.5	0	2.5	0	0
						$\Sigma d_i^2 = 12.50$

Test: H_0: x and y are independent, i.e., there is no correlation between subsamples.
H_a: x and y are dependent, i.e., there is correlation or association.

Test Statistic: $t = r_s\sqrt{\frac{N-2}{1-(r_s)^2}}$ ~ student's "t" with N-2 degrees of freedom

Rejection Rule: Reject H_0 if $t > t_{N-2}^{.975}$; $t_3^{.975} = 3.182$

Calculations:

Correction for ties - $T_x = \frac{T_x^3 - T_x}{12} = \frac{4^3-4}{12} = \frac{60}{12} = 5$; $\Sigma x^2 = \frac{N^3-N}{12} - T_x = \frac{125-5}{12} - 5 = 5$

$T_y = \frac{T_y^3 - T_y}{12} = \frac{4^3-4}{12} = \frac{60}{12} = 5$; $\Sigma y^2 = \frac{N^3-N}{12} - T_y = \frac{125-5}{12} - 5 = 5$

$$r_s = \frac{\Sigma x^2 + \Sigma y^2 - \Sigma d_i^2}{2\sqrt{\Sigma x^2 \cdot \Sigma y^2}} = \frac{5+5-12.5}{2\sqrt{25}} = \frac{-2.5}{10} = -0.250$$

$$t = -.250\sqrt{\frac{3}{1-.063}} = -0.447 \not> 3.182$$

Conclusion: Fail to reject H_0. These subsamples are not correlated.

1/ Number of larvae per 1000 m^3.

Table A-28.--Spearman rank non-parametric correlation tests on vertical distribution for humpy shrimp larvae in the Kiliuda Bay area of Kodiak Island, 1978.

Cruise 2

Depth (m)	Density estimated from original "500 organism" aliquot (x_i)	Rank of x_i	Density estimated from "extensive resort" subsample (y_i)	Rank of y_i	Difference in ranks (d_i)	Squares of differences (d_i^2)
10	0	3	0	2.5	0.5	0.25
30	0	3	0	2.5	0.5	0.25
50	0	3	16	5	2.0	4.00
70	0	3	0	2.5	0.5	0.25
90	0	3	0	2.5	0.5	0.25

$\Sigma d_i^2 = 5.00$

Test: H_0: x and y are independent, i.e., there is no correlation between subsamples.
H_a: x and y are dependent, i.e., there is correlation or association.

Test Statistic: $t = r_s\sqrt{\frac{N-2}{1-(r_s)^2}}$ ~ student's "t" with N-2 degrees of freedom

Rejection Rule: Reject H_0 if $t > t_{N-2}^{.975}$; $t_3^{.975} = 3.182$

Calculations:

Correction for ties - $T_x = \Sigma \frac{T_x^3 - T_x}{12} = \frac{5^3-5}{12} = \frac{125-5}{12} = 10;\ \Sigma x = \frac{N^3-N}{12} - T_x = 10 - 10 = 0$

$$T_y = \Sigma \frac{T_y^3 - T_y}{12} = \frac{4^3-4}{12} = \frac{60}{12} = 5;\ \Sigma y^2 = \frac{N^3-N}{12} - T_y = 10 - 5 = 5$$

$$r_s = \frac{\Sigma x^2 + \Sigma y^2 - \Sigma d_i^2}{2\sqrt{\Sigma x^2 \cdot \Sigma y^2}} = \frac{0+5-5}{2\sqrt{0.5}} = 0$$

$$t = r_s\sqrt{\frac{N-3}{1-r_s^2}} = 0\sqrt{\frac{3}{0}} = 0 \not> 3.182$$

Conclusion: Fail to reject H_0. There is no correlation between the subsamples.

Table A-29.--Spearman rank non-parametric correlation tests on vertical distribution for humpy shrimp larvae in the Kiliuda Bay area of Kodiak Island, 1978.

Cruise 3

Depth (m)	Density estimated from original "500 organism" aliquot (x_i)	Rank of x_i	Density estimated from "extensive resort" subsample (y_i)	Rank of y_i	Difference in ranks (d_i)	Squares of differences (d_i^2)
10	0	3	20	5	2.00	4.00
30	0	3	0	2	1.00	1.00
50	0	3	0	2	1.00	1.00
70	0	3	4	4	1.00	1.00
90	0	3	0	2	1.00	1.00
						$\Sigma d_i^2 = 8.00$

Test: H_0: x and y are independent, i.e., there is no correlation between subsamples.
H_a: x and y are dependent, i.e., there is correlation or association.

Test Statistic: $t = r_s\sqrt{\frac{N-2}{1-(r_s)^2}}$ ~ student's "t" with N-2 degrees of freedom

Rejection Rule: Reject H_0 if $t > t_{N-2}^{.975}$; $t_3^{.975} = 3.182$

Calculations:

Correction for ties - $T_x = \Sigma \frac{T_x^3 - T_x}{12} = \frac{5^3-5}{12} = \frac{120}{12} = 10; \ \Sigma x^2 = \frac{N^3-N}{12} - T_x = \frac{125-5}{12} - 10 = 10 - 10 = 0$

$$T_y = \Sigma \frac{T_y^3 - T_y}{12} = \frac{3^3-3}{12} = \frac{27-3}{12} = 2; \ \Sigma y^2 = \frac{N^3-N}{12} - T_y = 10 - 2 = 8$$

$$r_s = \frac{\Sigma x^2 + \Sigma y^2 - \Sigma d}{2\sqrt{\Sigma x^2 \cdot \Sigma y^2}} = \frac{0+8-8}{2\sqrt{0 \cdot 8}} = 0$$

$$t = r_s\sqrt{\frac{N-3}{1-r_s^2}} = 0\sqrt{\frac{3}{1-0}} = 0 \not> 3.182$$

Conclusion: Fail to reject H_0. There is no correlation between subsamples.

Table A-30.--Spearman rank non-parametric correlation tests on vertical distribution for humpy shrimp larvae in the Kiliuda Bay area of Kodiak Island, 1978.

Cruise 4

Depth (m)	Density estimated from original "500 organism" aliquot (x_i)	Rank of x_i	Density estimated from "extensive resort" subsample (y_i)	Rank of y_i	Difference in ranks (d_i)	Squares of differences (d_i^2)
10	1055 1/	5	79	2	3	9.00
30	0	2.5	97	4	1.5	2.25
50	0	2.5	11	1	1.5	2.25
70	0	2.5	82	3	0.5	0.25
90	0	2.5	203	5	2.5	6.25
						$\Sigma d_i^2 = 20.00$

Test: H_0: x and y are independent, i.e., there is no correlation between subsamples.
H_a: x and y are dependent, i.e., there is correlation or association.

Test Statistic: $t = r_s\sqrt{\frac{N-2}{1-(r_s)^2}}$ ~ student's "t" with N-2 degrees of freedom

Rejection Rule: Reject H_0 if $t > t_{N-2}^{.975}$; $t_3^{.975} = 3.182$

Calculations:

$$r_s = 1 - \frac{6\sum_{i=10}^{N} d_i^2}{N^3 - N}$$

$$= 1 - \frac{6(20)}{125-5}$$

$$= 1 - \frac{120}{120} = 0$$

$$t = 0\sqrt{\frac{3}{1}} = 0 \not> 3.182$$

Conclusion: Fail to reject H_0, there is no correlation.

1/ estimated number per 1000 m³.

Table A-31.--Spearman rank non-parametric correlation tests on vertical distribution for humpy shrimp larvae in the Kiliuda Bay area of Kodiak Island, 1978.

Cruise 5

Depth (m)	Density estimated from original "500 organism" aliquot (x_i)	Rank of x_i	Density estimated from "extensive resort" subsample (y_i)	Rank of y_i	Difference in ranks (d_i)	Squares of differences (d_i^2)
10	0	2.5	51	4	1.5	2.25
30	47	5	21	3	2.0	4.00
50	0	2.5	82	5	2.5	6.25
70	0	2.5	8	2	0.5	0.25
90	0	2.5	0	1	1.5	2.25

$\Sigma d_i^2 = 15.00$

Test: H_0: x and y are independent, i.e., there is no correlation between subsamples.
H_a: x and y are dependent, i.e., there is correlation or association.

Test Statistic: $t = r_s\sqrt{\frac{N-2}{1-(r_s)^2}}$ ~ student's "t" with N-2 degrees of freedom

Rejection Rule: Reject H_0 if $t > t_{N-2}^{.975}$; $t_3^{.975} = 3.182$

Calculations:

$$r_s = 1 - \frac{6\sum_{i=1}^{N} d_i^2}{N^3 - N}$$

$$= 1 - \frac{6(15)}{120}$$

$$= 1 - \frac{90}{120} = 0.250$$

$$t = 0.250\sqrt{\frac{3}{1-.25^2}} = 0.447 \ngtr 3.182$$

Conclusion: Fail to reject H_0. There is no correlation.

Table A-32.--Spearman rank non-parametric correlation tests on vertical distribution for humpy shrimp larvae in the Kiliuda Bay area of Kodiak Island, 1978.

Cruise 6

Depth (m)	Density estimated from original "500 organism" aliquot (x_i)	Rank of x_i	Density estimated from "extensive resort" subsample (y_i)	Rank of y_i	Difference in ranks (d_i)	Squares of differences (d_i^2)
10	0	25	6	3	0.5	0.25
30	334 1/	5	0	1.5	3.5	12.25
50	262	4	0	1.5	2.5	6.25
70	0	2.5	7	4	1.5	2.25
90	0	2.5	27	5	2.5	6.25

$\Sigma d_i^2 = 27.25$

Test: H_0: x and y are independent, i.e., there is no correlation between subsamples.
H_a: x and y are dependent, i.e., there is correlation or association.

Test Statistic: $t = r_s\sqrt{\frac{N-2}{1-(r_s)^2}}$ ~ student's "t" with N-2 degrees of freedom

Rejection Rule: Reject H_0 if $t > t_{N-2}^{.975}$; $t_3^{.975}$ =3.182

Calculations:

$$r_s = 1 - \frac{6\sum_{i=10}^{N} d_i^2}{N^3-N}$$

$$= 1 - \frac{6(27.25)}{5^3-5} = 1 - \frac{163.5}{120} = -0.363$$

$$t = -0.363\sqrt{\frac{3}{1-(-0.363)^2}} = -0.591 \not> 3.182$$

Conclusion: Fail to reject H_0. There is no correlation.

1/ Number of organisms per 1000 m^3.

Table A-33.--Spearman rank non-parametric correlation tests on vertical distribution for humpy shrimp larvae in the Kiliuda Bay area of Kodiak Island, 1978.

Cruises 7-12 -- no organisms found at any depth in either subsamples.
Cruises 1-6 combined.

Depth (m)	Density estimated from original "500 organism" aliquot (x_i)	Rank of x_i	Density estimated from "extensive resort" subsample (y_i)	Rank of y_i	Difference in ranks (d_i)	Squares of differences (d_i^2)
10	176 1/	5	52	5	0	0
30	64	3.5	20	3	0.5	0.25
50	68	3.5	18	2	1.5	2.25
70	0	1.5	16	1	0.5	0.25
90	0	1.5	41	4	2.5	6.25
						$\Sigma d_i^2 = 9.00$

<u>Test:</u> H_0: x and y are independent, i.e., there is no correlation between subsamples.
H_a: x and y are dependent, i.e., there is correlation or association.

<u>Test Statistic:</u> $t = r_S\sqrt{\frac{N-2}{1-(r_S)^2}}$ ~ student's "t" with N-2 degrees of freedom

<u>Rejection Rule:</u> Reject H_0 if $t > t_{N-2}^{.975}$; $t_3^{.975} = 3.182$

<u>Calculations:</u>

$$r_S = 1 - \frac{6\sum_{i=10}^{N} d_i^2}{N^3 - N}$$

$$= 1 - \frac{6(9)}{120} = 1 - \frac{54}{120} = .550$$

$$t = r_S \frac{N-2}{1-r_S^2} = .550\sqrt{\frac{3}{1-.303}} = 1.141 \not> 3.182$$

<u>Conclusion:</u> Fail to reject H_0. The subsamples are not correlated.

1/ Mean density per 1000 m^3 for cruises 1-6.

Table A-34.--Spearman rank non-parametric correlation tests on vertical distribution for red king crab larvae in the Kiliuda Bay area of Kodiak Island, 1978.

Cruise 1

Depth (m)	Density estimated from original "500 organism" aliquot (x_i)	Rank of x_i	Density estimated from "extensive resort" subsample (y_i)	Rank of y_i	Difference in ranks (d_i)	Squares of differences (d_i^2)
10	0	3	323 1/	5	2	4.00
30	0	3	0	2.5	0.5	0.25
50	0	3	0	2.5	0.5	0.25
70	0	3	0	2.5	0.5	0.25
90	0	3	0	2.5	0.5	0.25
						$\Sigma d_i^2 = 5.00$

Test: H_0: x and y are independent, i.e., there is no correlation between subsamples.
H_a: x and y are dependent, i.e., there is correlation or association.

Test Statistic: $t = r_s\sqrt{\frac{N-2}{1-(r_s)^2}}$ ~ student's "t" with N-2 degrees of freedom

Rejection Rule: Reject H_0 if $t > t_{N-2}^{.975}$; $t_3^{.975} = 3.182$

Calculations:

Correction for ties - $T_x = \Sigma \frac{Tx^3 - Tx}{12} = \frac{5^3-5}{12} = \frac{125-5}{12} = 10;\ \Sigma x^2 = \frac{N^3-N}{12} - T_x = \frac{125-5}{12} - 10 = 0$

$$T_y = \Sigma \frac{Ty^3 - Ty}{12} = \frac{4^3-4}{12} = \frac{60}{12} = 5;\ \Sigma y^2 = \frac{N^3-N}{12} - T_y = 10 - 5 = 5$$

$$r_s = \frac{\Sigma x^2 + \Sigma y^2 - \Sigma d}{2\sqrt{\Sigma x^2 \cdot \Sigma y^2}} = \frac{0+5-5}{2\sqrt{0.5}} = 0$$

$$t = 0\sqrt{\frac{3}{1-0}} = 0 \not> 3.182$$

Conclusion: Fail to reject H_0. The two types of subsamples are not correlated for king crab larvae during Cruise 1.

1/ Number of larvae per 1000 m^3.

Table A-35.--Spearman rank non-parametric correlation tests on vertical distribution for red king crab larvae in the Kiliuda Bay area of Kodiak Island, 1978.

Cruise 2

Depth (m)	Density estimated from original "500 organism" aliquot (x_i)	Rank of x_i	Density estimated from "extensive resort" subsample (y_i)	Rank of y_i	Difference in ranks (d_i)	Squares of differences (d_i^2)
10	0	2	23	3	1	1
30	286	5	100	5	0	0
50	95	4	65	4	0	0
70	0	2	19	2	0	0
90	0	2	0	1	1	1
						$\Sigma d_i^2 = 2.00$

Test: H_0: x and y are independent, i.e., there is no correlation between subsamples.
H_a: x and y are dependent, i.e., there is correlation or association.

Test Statistic: $t = r_s\sqrt{\frac{N-2}{1-(r_s)^2}}$ ∼ student's "t" with N-2 degrees of freedom

Rejection Rule: Reject H_0 if $t > t^{.975}_{N-2}$; $t^{.975}_{3} = 3.182$

Calculations:

$$r_s = 1 - \frac{6\Sigma(d_i^2)}{N^3-N} = 1 - \frac{6(2)}{120} = 1 - 0.10 = 0.90$$

$$t = .90\sqrt{3/1-0.81} = 3.576 > 3.182$$

Conclusion: There is correlation between two types of subsamples.
Reject H_0.

Table A-36.--Spearman rank non-parametric correlation tests on vertical distribution for red king crab larvae in the Kiliuda Bay area of Kodiak Island, 1978.

Cruise 3

Depth (m)	Density estimated from original "500 organism" aliquot (x_i)	Rank of x_i	Density estimated from "extensive resort" subsample (y_i)	Rank of y_i	Difference in ranks (d_i)	Squares of differences (d_i^2)
10	0	3	161	5	2	4
30	0	3	44	4	1	1
50	0	3	12	3	0	0
70	0	3	4	2	1	1
90	0	3	0	1	2	4
						$\Sigma d_i^2 = 10.00$

Test: H_0: x and y are independent, i.e., there is no correlation between subsamples.
H_a: x and y are dependent, i.e., there is correlation or association.

Test Statistic: $t = r_s\sqrt{\frac{N-2}{1-(r_s)^2}}$ ~ student's "t" with N-2 degrees of freedom

Rejection Rule: Reject H_0 if $t > t_{N-2}^{.975}$; $t_3^{.975} = 3.182$

Calculations:

$$r_s = 1 - \frac{6\Sigma d_i^2}{N^3-N} = 1 - \frac{6(10)}{120} = 0.50$$

$$t = 0.50\sqrt{\frac{3}{1-.25}} = 1.00 \not> 3.182$$

Conclusion: Fail to reject H_0. There is no correlation between the two subsamples.

Table A-37.--Spearman rank non-parametric correlation tests on vertical distribution for red king crab larvae in the Kiliuda Bay area of Kodiak Island, 1978.

Cruise 4

Depth (m)	Density estimated from original "500 organism" aliquot (x_i)	Rank of x_i	Density estimated from "extensive resort" subsample (y_i)	Rank of y_i	Difference in ranks (d_i)	Squares of differences (d_i^2)
10	0	2.5	0	1	1.5	2.25
30	0	2.5	119	5	0.5	0.25
50	30	5	8	4	1.0	1.00
70	0	2.5	4	2.5	0	0
90	0	2.5	4	2.5	0	0
						$\Sigma d_i^2 = 3.50$

Test: H_0: x and y are independent, i.e., there is no correlation between subsamples.
H_a: x and y are dependent, i.e., there is correlation or association.

Test Statistic: $t = r_s\sqrt{\frac{N-2}{1-(r_s)^2}}$ ~ student's "t" with N-2 degrees of freedom

Rejection Rule: Reject H_0 if $t > t_{N-2}^{.975}$; $t_3^{.975} = 3.182$

Calculations:

Correction for ties - $T_x = \frac{T_x^3 - T_x}{12} = \frac{4^3-4}{12} = \frac{60}{12} = 5$; $\Sigma x^2 = \frac{N^3-N}{12} - T_x = 10 - 5 = 5$

$$T_y = \frac{T_y^3 - T_y}{12} = \frac{2^3-2}{12} = \frac{6}{12} = 0.5; \ \Sigma y^2 = \frac{N^3-N}{12} - T_y = 10 - 0.5 = 9.5$$

$$r_s = \frac{\Sigma x^2 + \Sigma y^2 - \Sigma d_i^2}{2\sqrt{\Sigma x^2 \cdot \Sigma y^2}} = \frac{5+9.5-3.5}{2\sqrt{47.5}} = 0.798$$

$$t = r_s\sqrt{\frac{N-2}{1-r_s^2}} = 0.80\sqrt{\frac{3}{1-(.80)^2}} = 2.294 \not> 3.182$$

Conclusion: Fail to reject H_0. No correlation for Cruise 4.

Table A-38.--Spearman rank non-parametric correlation tests on vertical distribution for red king crab larvae in the Kiliuda Bay area of Kodiak Island, 1978.

Cruise 5
Cruises 6-12 - No catches either subsample -- Correlation

Depth (m)	Density estimated from original "500 organism" aliquot (x_i)	Rank of x_i	Density estimated from "extensive resort" subsample (y_i)	Rank of y_i	Difference in ranks (d_i)	Squares of differences (d_i^2)
10	3813	5	17357	5	0	0
30	24	4	24	4	0	0
50	0	2.5	11	2	0.5	0.25
70	0	2.5	6	1	1.5	2.25
90	0	2.5	12	3	0.5	0.25
						$\Sigma d_i^2 = 2.75$

Test: H_0: x and y are independent, i.e., there is no correlation between subsamples.
H_a: x and y are dependent, i.e., there is correlation or association.

Test Statistic: $t = r_s\sqrt{\frac{N-2}{1-(r_s)^2}}$ ~ student's "t" with N-2 degrees of freedom

Rejection Rule: Reject H_0 if $t > t_{N-2}^{.975}$; $t_3^{.975} = 3.182$

Calculations:

$$r_s = 1 - \frac{6\Sigma d_i^2}{N^3-N} = 1 - \frac{6(2.75)}{120} = 0.863$$

$$t = r_s\sqrt{\frac{N-2}{1-r_s^2}} = 0.86\sqrt{\frac{3}{1-.74}} = 2.954 \not> 3.182$$

Conclusion: Fail to reject H . No correlation between subsamples for cruise 5.

Table A-39.--Spearman rank non-parametric correlation tests on vertical distribution for red king crab larvae in the Kiliuda Bay area of Kodiak Island, 1978.

Cruise 1-5 combined

Depth (m)	Density estimated from original "500 organism" aliquot (x_i)	Rank of x_i	Density estimated from "extensive resort" subsample (y_i)	Rank of y_i	Difference in ranks (d_i)	Squares of differences (d_i^2)
10	953 1/	5	4466	5	0	0
30	78	4	72	4	0	0
50	31	3	24	3	0	0
70	0	1.5	8	2	0.5	0.25
90	0	1.5	4	1	0.5	0.25

$\Sigma d_i^2 = 0.50$

Test: H_0: x and y are independent, i.e., there is no correlation between subsamples.
H_a: x and y are dependent, i.e., there is correlation or association.

Test Statistic: $t = r_s\sqrt{\frac{N-2}{1-(r_s)^2}}$ ~ student's "t" with N-2 degrees of freedom

Rejection Rule: Reject H_0 if $t > t_{N-2}^{.975}$; $t_3^{.975} = 3.182$

Calculations:

$$r_s = 1 - \frac{6\Sigma d_i^2}{N^3-N} = 1 - \frac{6(.5)}{120} = 0.975$$

$$t = r_s\sqrt{\frac{N-2}{1-r_s^2}} = 0.975\sqrt{\frac{3}{1-.951}} = 7.600 > 3.182$$

Conclusion: Reject H . There is correlation between the subsamples when the data for several cruises are combined.

1/ Mean density per 1000 m^3 for cruises 1-5.

Table A-40.--Spearman rank non-parametric correlation tests on vertical distribution for bairdi Tanner crab larvae in the Kiliuda Bay area of Kodiak Island, 1978.

Cruise 1 -- No catches in either subsample. Correlation--yes.

Cruise 2

Depth (m)	Density estimated from original "500 organism" aliquot (x_i)	Rank of x_i	Density estimated from "extensive resort" subsample (y_i)	Rank of y_i	Difference in ranks (d_i)	Squares of differences (d_i^2)
10	0	2	23	2	0	0
30	143 1/	5	133	5	0	0
50	95	4	33	3	1	1
70	0	2	19	1	1	1
90	0	2	47	4	2	4
						$\Sigma d_i^2 = 6$

Test: H_0: x and y are independent, i.e., there is no correlation between subsamples.
H_a: x and y are dependent, i.e., there is correlation or association.

Test Statistic: $t = r_s\sqrt{\frac{N-2}{1-(r_s)^2}}$ ~ student's "t" with N-2 degrees of freedom

Rejection Rule: Reject H_0 if $t > t_{N-2}^{.975}$; $t_3^{.975} = 3.182$

Calculations:

$$r_s = 1 - \frac{6\Sigma d_i^2}{N^3 - N} = 1 - \frac{6(6)}{120} = 0.70$$

$$t = 0.70\sqrt{\frac{3}{1-0.49}} = 1.70 \ngtr 3.182$$

Conclusion: Fail to reject H_o. No correlation between subsamples.

1/ Number per 1000 m^3.

Table A-41.--Spearman rank non-parametric correlation tests on vertical distribution for bairdi Tanner crab larvae in the Kiliuda Bay area of Kodiak Island, 1978.

Cruise 3

Depth (m)	Density estimated from original "500 organism" aliquot (x_i)	Rank of x_i	Density estimated from "extensive resort" subsample (y_i)	Rank of y_i	Difference in ranks (d_i)	Squares of differences (d_i^2)
10	0	3	723 1/	5	2	4
30	0	3	131	4	1	1
50	0	3	12	1	2	4
70	0	3	16	2	1	1
90	0	3	17	3	0	0
						$\Sigma d_i^2 = 10.00$

Test: H_0: x and y are independent, i.e., there is no correlation between subsamples.
H_a: x and y are dependent, i.e., there is correlation or association.

Test Statistic: $t = r_s\sqrt{\frac{N-2}{1-(r_s)^2}}$ ~ student's "t" with N-2 degrees of freedom

Rejection Rule: Reject H_0 if $t > t_{N-2}^{.975}$; $t_3^{.975} = 3.182$

Calculations:

$$r_s = 1 - \frac{6\Sigma di^2}{N^3-N} = 1 - \frac{6(10)}{120} = 0.50$$

$$t = 0.50\sqrt{\frac{3}{1-.25}} = 1.00 \not> 3.182$$

Conclusion: Fail to reject H_0. No correlation between subsamples.

1/ Number of larvae per 1000 m^3.

Table A-42.--Spearman rank non-parametric correlation tests on vertical distribution for bairdi Tanner crab larvae in the Kiliuda Bay area of Kodiak Island, 1978.

Cruise 4

Depth (m)	Density estimated from original "500 organism" aliquot (x_i)	Rank of x_i	Density estimated from "extensive resort" subsample (y_i)	Rank of y_i	Difference in ranks (d_i)	Squares of differences (d_i^2)
10	792 1/	4	2101	4	0	0
30	2837	5	4337	5	0	0
50	60	3	30	3	0	0
70	0	1.5	16	2	.5	.25
90	0	1.5	1	1	.5	.25
						$\Sigma d_i^2 = 0.50$

Test: H_0: x and y are independent, i.e., there is no correlation between subsamples.
H_a: x and y are dependent, i.e., there is correlation or association.

Test Statistic: $t = r_s\sqrt{\frac{N-2}{1-(r_s)^2}}$ ~ student's "t" with N-2 degrees of freedom

Rejection Rule: Reject H_0 if $t > t_{N-2}^{.975}$; $t_3^{.975} = 3.182$

Calculations:

$$r_s = 1 - \frac{6\Sigma di^2}{N^3-N} = 1 - \frac{6(0.5)}{120} = 0.98$$

$$t = 0.98\sqrt{\frac{3}{1-.95}} = 7.65 > 3.182$$

Conclusion: Reject H_0. There is correlation between the subsamples.

1/ Number of larvae per 1000 m³.

Table A-43.--Spearman rank non-parametric correlation tests on vertical distribution for bairdi Tanner crab larvae in the Kiliuda Bay area of Kodiak Island, 1978.

Cruise 5

Depth (m)	Density estimated from original "500 organism" aliquot (x_i)	Rank of x_i	Density estimated from "extensive resort" subsample (y_i)	Rank of y_i	Difference in ranks (d_i)	Squares of differences (d_i^2)
10	166 1/	5	1736	5	0	0
30	24	4	47	4	0	0
50	0	2	23	3	1	1
70	0	2	6	2	0	0
90	0	2	0	1	1	1

$\Sigma d_i^2 = 2.0$

Test: H_0: x and y are independent, i.e., there is no correlation between subsamples.
H_a: x and y are dependent, i.e., there is correlation or association.

Test Statistic: $t = r_s\sqrt{\frac{N-2}{1-(r_s)^2}}$ ~ student's "t" with N-2 degrees of freedom

Rejection Rule: Reject H_0 if $t > t_{N-2}^{.975}$; $t_3^{.975}$ =3.182

Calculations:

$$r_s = 1 - \frac{6\Sigma d_i^2}{N^3-N} = 1 - \frac{6(2)}{120} = 0.90$$

$$t = 0.90\sqrt{\frac{3}{1-0.81}} = 3.674 > 3.182$$

Conclusion Reject H_0. There is correlation between subsamples.

1/ Number of larvae per 1000 m^3.

Table A-44.--Spearman rank non-parametric correlation tests on vertical distribution for bairdi Tanner crab larvae in the Kiliuda Bay area of Kodiak Island, 1978.

Cruise 2-5 combined.

Depth (m)	Density estimated from original "500 organism" aliquot (x_i)	Rank of x_i	Density estimated from "extensive resort" subsample (y_i)	Rank of y_i	Difference in ranks (d_i)	Squares of differences (d_i^2)
10	240 1/	4	1146	4	0	0
30	751	5	1162	5	0	0
50	39	3	25	3	0	0
70	0	1.5	14	1	0.5	0.25
90	0	1.5	16	2	0.5	0.25
						$\Sigma d_i^2 = 0.50$

Test: H_0: x and y are independent, i.e., there is no correlation between subsamples.
H_a: x and y are dependent, i.e., there is correlation or association.

Test Statistic: $t = r_s\sqrt{\frac{N-2}{1-(r_s)^2}}$ ∿ student's "t" with N-2 degrees of freedom

Rejection Rule: Reject H_0 if $t > t_{N-2}^{.975}$; $t_3^{.975} = 3.182$

Calculations:

$$r_s = 1 - \frac{6\Sigma d_i^2}{N^3 - N} = 1 - \frac{6(0.5)}{120} = 0.98$$

$$t = 0.98\sqrt{\frac{3}{1-0.95}} = 7.65 > 3.182$$

Conclusion: H_0 is rejected, correlation between subsamples.

1/ Mean density per 1000 m^3 for cruises 2-5.

Table A-45.--Spearman rank non-parametric correlation tests on vertical distribution for bairdi Tanner crab larvae in the Kiliuda Bay area of Kodiak Island, 1978.

Cruise 6-12

Depth (m)	Density estimated from original "500 organism" aliquot (x_i)	Rank of x_i	Density estimated from "extensive resort" subsample (y_i)	Rank of y_i	Difference in ranks (d_i)	Squares of differences (d_i^2)
10	0	3	0	3	0	0
30	0	3	0	3	0	0
50	0	3	0	3	0	0
70	0	3	0	3	0	0
90	0	3	0	3	0	0
						$\Sigma d_i^2 = 0$

Test: H_0: x and y are independent, i.e., there is no correlation between subsamples.
H_a: x and y are dependent, i.e., there is correlation or association.

Test Statistic: $t = r_s\sqrt{\frac{N-2}{1-(r_s)^2}}$ ~ student's "t" with N-2 degrees of freedom

Rejection Rule: Reject H_0 if $t > t_{N-2}^{.975}$; $t_3^{.975} = 3.182$

Calculations:

$$r_s = 1 - \frac{6\Sigma d_i^2}{N^3-N} = 1.0 = \text{correlation}$$

Appendix B

LITERATURE REFERENCES FOR DECAPOD LARVAE IDENTIFICATION

1. Ally, J. R. R. 1975. A description of the laboratory-reared larvae of *Cancer gracilis* Dana, 1852 (Decapoda, Brachyura). Crustaceana 28(3):231-246.

2. Berkeley, A. A. 1930. The postembryonic development of the common pandalids of British Columbia. Contr. Canad. Biol. (new Ser.) 6:79-163.

3. Buchanan, D. V., and R. E. Milleman. 1969. The prezoeal stage of Dungeness crab *Cancer magister* Dana. Biol. Bull. 137(2):250-255.

4. Hart, J. F. L. 1935. The larval development of British Columbia Brachyura I. Zanthidae, Pinnotheridae (in part) and Grapsidae. Can. J. Res. 12(4):411-432.

5. Hart, J. F. L. 1937. Larval and adult stages of British Columbia Anomura. Can. J. Res. 10(D):179-220.

6. Hart, J. F. L. 1960. The larval development of British Columbia Brachyura II. Majidae, subfamily Oregoninae. Can. J. Zool. 38:539-546.

7. Hart, J. F. L. 1971. Key to planktonic larvae of families of decapod crustacea of British Columbia. Syesis 4:227-234.

8. Haynes, E. 1973. Descriptions of prezoeae and stage I zoeae of *Chionoecetes bairdi* and *C. opilio* (Oxyrhyncha, Oregoninae). Fish. Bull. 71(3):769-775.

9. Haynes, E. 1976. Description of zoeae of coonstripe shrimp, *Pandalus hypsinotus*, reared in the laboratory. Fish. Bull. 74(2):323-342.

10. Haynes, E. 1978. Description of larvae of a hippolytid shrimp, *Lebbeus groenlandicus*, reared in situ in Kachemak Bay, Alaska. Fish. Bull. 76(2):457-465.

11. Haynes, E. 1978. Description of larvae of the humpy shrimp, *Pandalus goniurus*, reared in situ in Kachemak Bay, Alaska. Fish. Bull. 76(1):235-248.

12. Haynes, E. 1979. Description of larvae of the northern shrimp, *Pandalus borealis*, reared in situ in Kachemak Bay, Alaska. Fish. Bull. 77(1):157-173.

13. Haynes, E. 1980. Larval morphology of *Pandalus tridens* and a summary of the principal morphological characteristics of North Pacific pandalid shrimp larvae. Fish. Bull. 77(3):625-640.

14. Haynes, E. 1980. Stage I zoeae of crangonid shrimp, *Crangon franciscorum angustimana*, hatched from ovigerous females collected in Kachemak Bay, Alaska. Fish. Bull. 77(4):991-995.

15. Ivanov, B. G. 1965. A description of the first larvae of the far-eastern shrimp *Pandalus goniurus* (in Russian, English summary). Zool. Zh. 44:1255-1257.

16. Ivanov, B. G. 1971. The larvae of some eastern shrimps in relation to their taxonomic status. Zool. Zh. 50(5):657-665.

17. Kurata, H. 1963. Larvae of Decapoda Crustacea of Hokkaido 1. Atelecyclidae (Atelecyclinae). Bull. Hokkaido Reg. Fish. Res. Lab. 27:13-24.

18. Kurata, H. 1964. Larvae of Decapod Crustacea of Hokkaido 4. Crangonidae and Glyphocrangonidae. Bull. Hokkaido Reg. Fish. Res. Lab. 28:35-50.

19. Makarov, R. R. 1967. Larvae of the shrimps and crabs of the West Kamchatkan shelf and their distribution.

20. Mir, R. D. 1961. The external morphology of the first zoeal stages of the crabs *Cancer magister* Dana, *Cancer antennarius* Stimpson, and *Cancer anthonyi* Rathbun. Calif. Fish and Game 47(1):103-111.

21. Morton, H. 1973. Laboratory-reared zoeae and megalopae of Zuwai crab from the Sea of Japan. Bull. Jap. Soc. Sci. Fish. 39(12):1223-1230.

22. Needler, A. B. 1934. Larvae of some British Columbian Hippolytidae. Contrib. Can. Biol. Fish. 8(18-20):239-242.

23. Needler, A. B. 1938. The larval development of *Pandalus stenolepis*. J. Fish. Res. Board Can. 4(2):88-95.

24. Needler, A. B. 1941. Larval stages of Crangon septemspinosus Say. Trans. Roy. Canadian Inst. 23:193-199.

25. Pike, R. B., and D. I. Williamson. 1964. The larvae of some species of Pandalidae (Decapoda). Crustaceana 6(4):1964.

26. Poole, R. L. 1966. A description of laboratory-reared zoeae of *Cancer magister* Dana, and megalopae taken under natural conditions (Decapoda, Brachyura). Crustaceana 11(1):83-97.

27. Price, V. A. 1969. The post-embryonic development of laboratory-reared "spot" shrimp, *Pandalus platyceros* Brandt.

28. Price, V. A., and K. K. Chew. 1972. Laboratory rearing of spot shrimp larvae (*Pandalus platyceros*) and descriptions of stages. J. Fish. Res. Board Can. 29:413-422.

29. Sato, S. 1958. Studies on larval development and fishery biology of king crab, *Paralithodes camtschatica* (Tilesius). Bull. Hokkaido Reg. Fish. Res. Lab. 17.

30. Sato, S., and S. Tanaka. 1949. Study on the larval stage of *Paralithodes camtschatica* (Tilesius) I. Morphological Research. Hokkaido Fish. Exper. St. Res. Rep. 1:7-24.

31. Tesmer, C. A., and A. C. Broad. 1964. The larval development of *Crangon septemspinosa* (Say). Ohio J. Sci. 64(4):239-250.

32. Trask, T. 1970. A description of laboratory-reared larvae of *Cancer productus* Randall (Decapoda, Brachyura) and a comparison to larvae of *Cancer magister* Dana. Crustaceana 18(2):133-146.

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