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

by

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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 multiparous 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.

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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
/00	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
1	Liters
m	Meters
ml	Mililiters
mm	Millimeters
urn	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 aria, 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 (O+), 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 kmwest 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

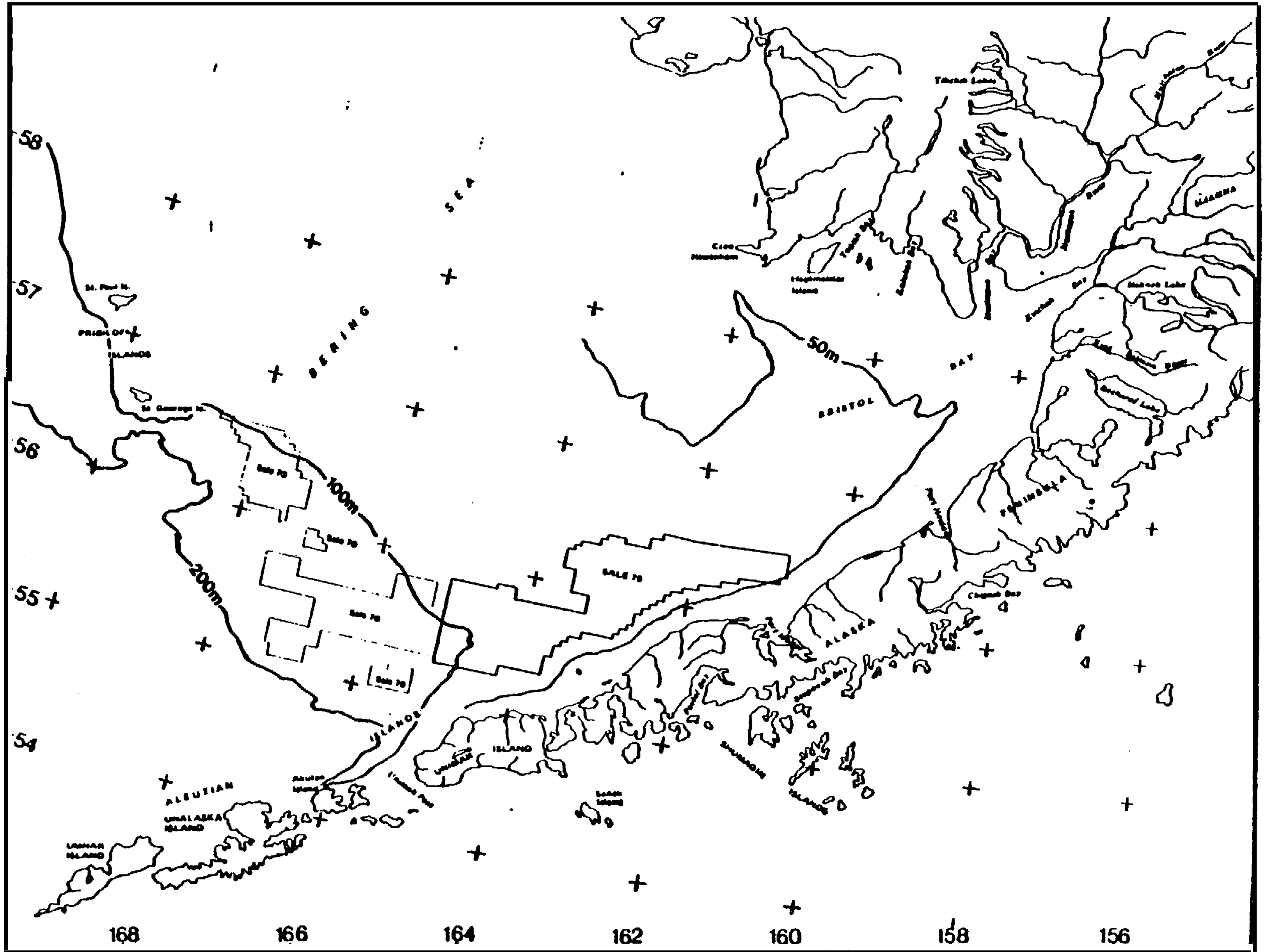


Figure 1.1 Map of the southeastern Bering Sea showing the Pribilof Islands, isobaths, and St. George oil leases.

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. Minter 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/see) over the middle shelf proper, but relatively strong flows of 1-10 cm/sec to the northwest in the vicinity of the Pribilof Islands

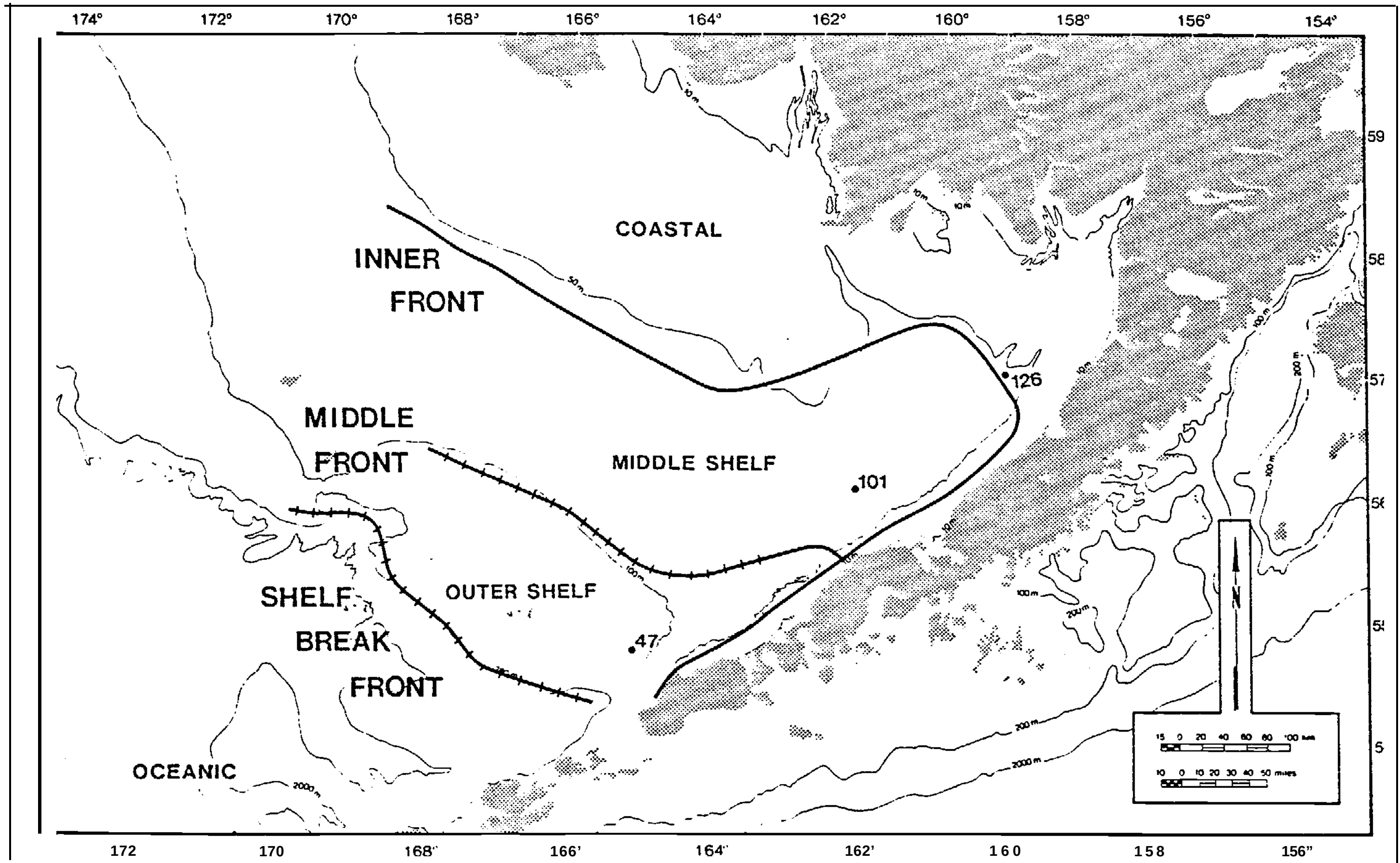


Figure 1.2 Approximate boundaries separating the three shelf (coastal, middle, outer) and the oceanic hydrographic domains. The boundaries are three fronts: inner, middle, and shelf break. These fronts roughly coincide with the 50 m isobath, the 100 m isobath, and the 200 m isobath (shelf break) (from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

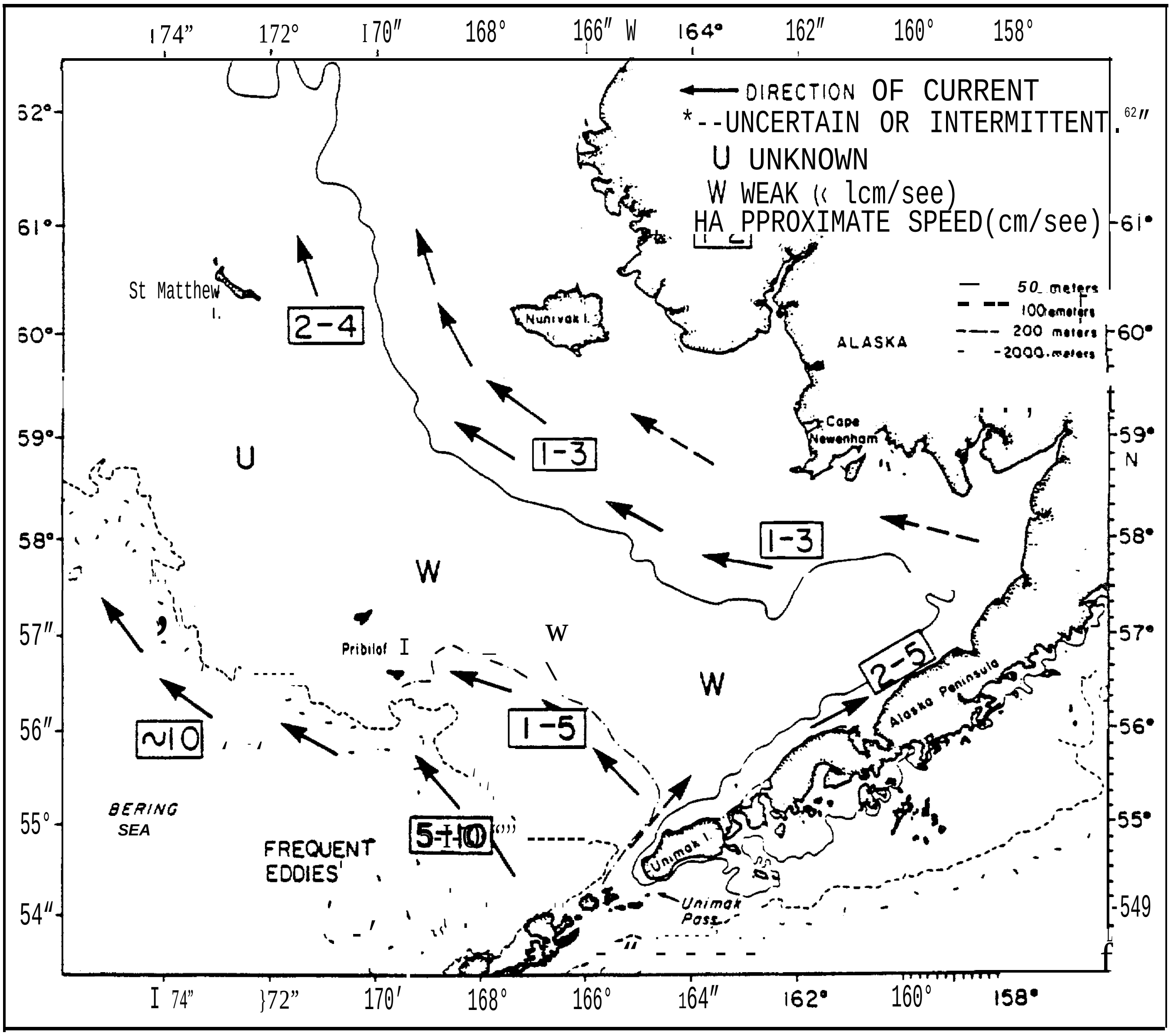


Figure 1.3 Current directions and net speed over the southeastern Bering Sea shelf (from Kinder and Schumacher 1981a).

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 fisher"ies) 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

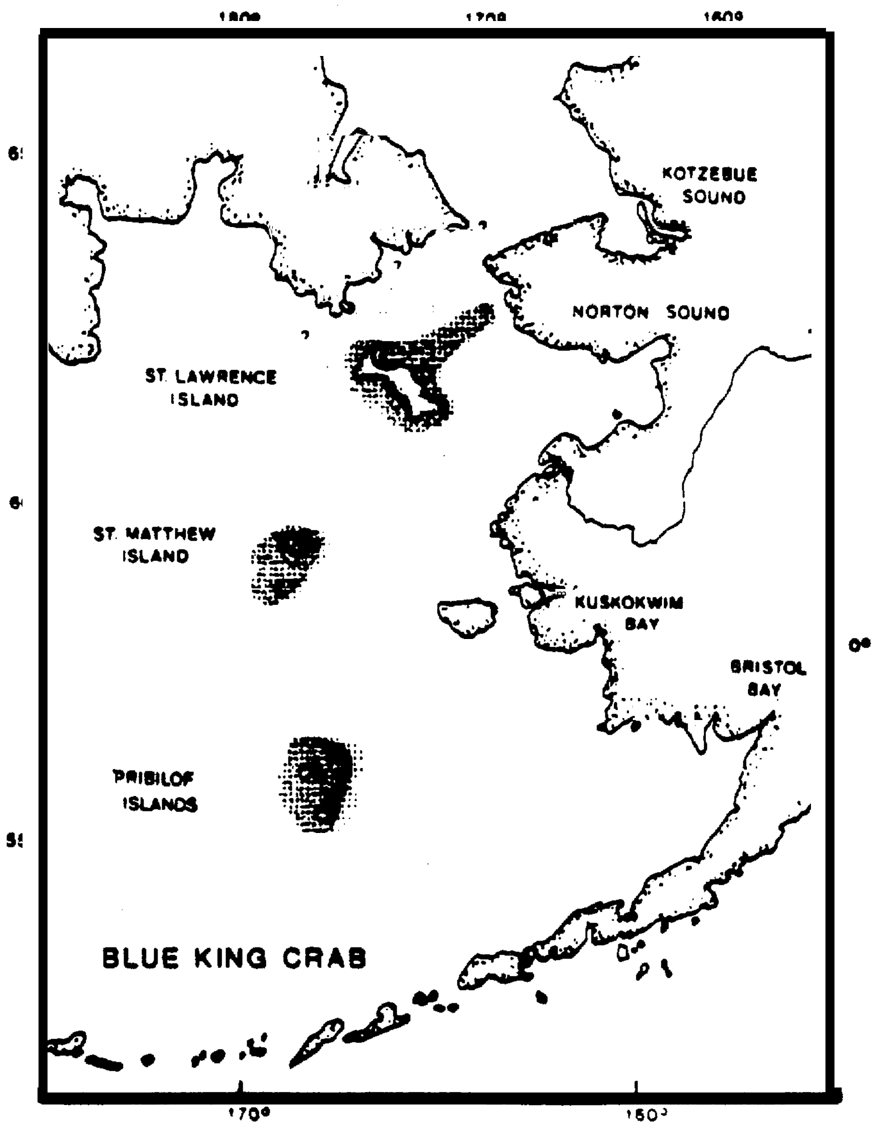


Figure 1.4 Distribution of blue king crab (*Paralithodes platypus*) in the eastern Bering Sea. Darkly shaded portions indicate areas of consistent abundance (from Otto 1981).

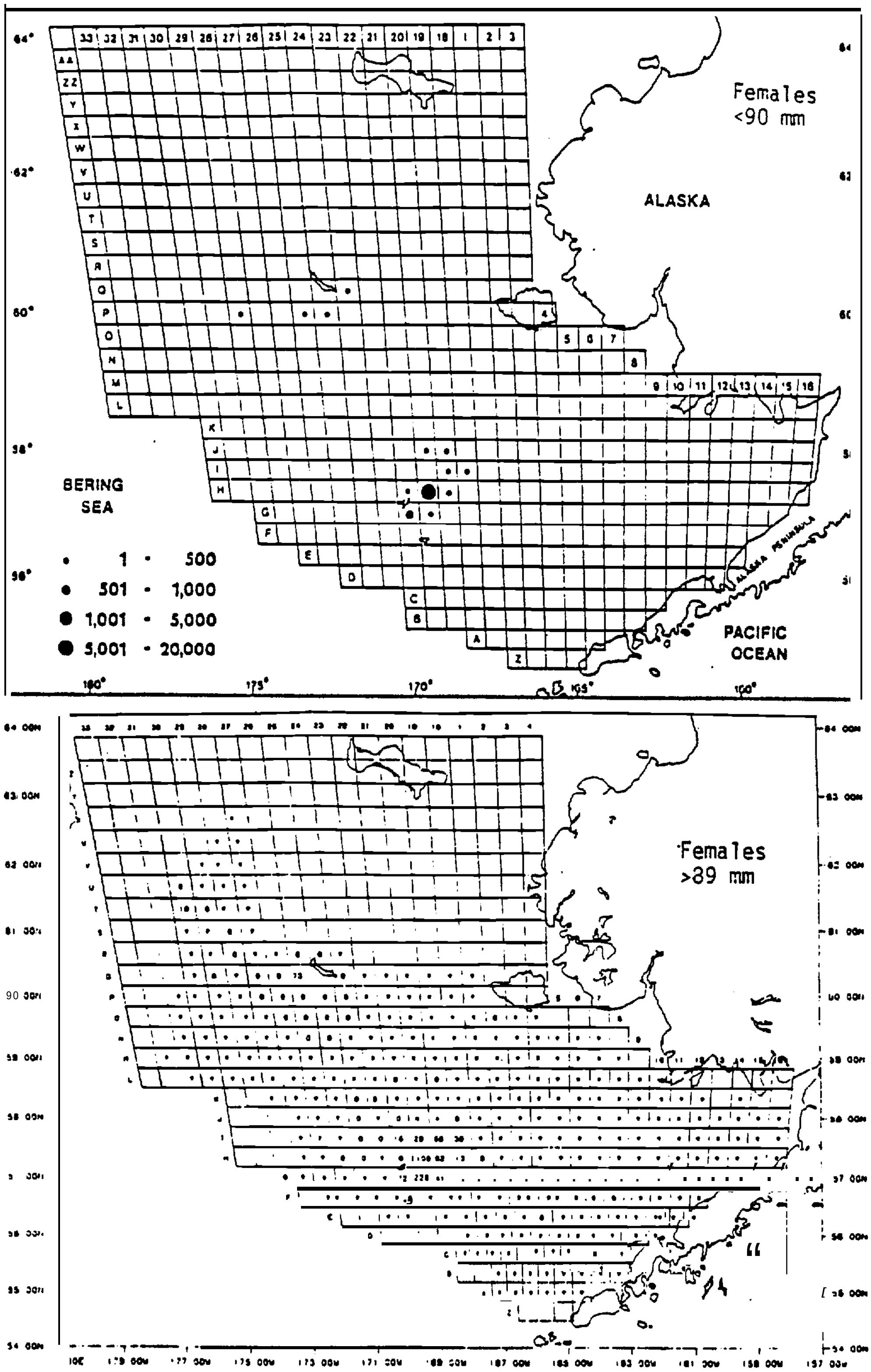


Figure 1.5 Distribution and abundance (numbers per mile²) of female blue king crab less than 90 mm carapace length in the eastern Bering Sea during May-July 1981 (above) and females greater than 89 mm in 1982 (below) (from Otto et al. 1981, 1982).

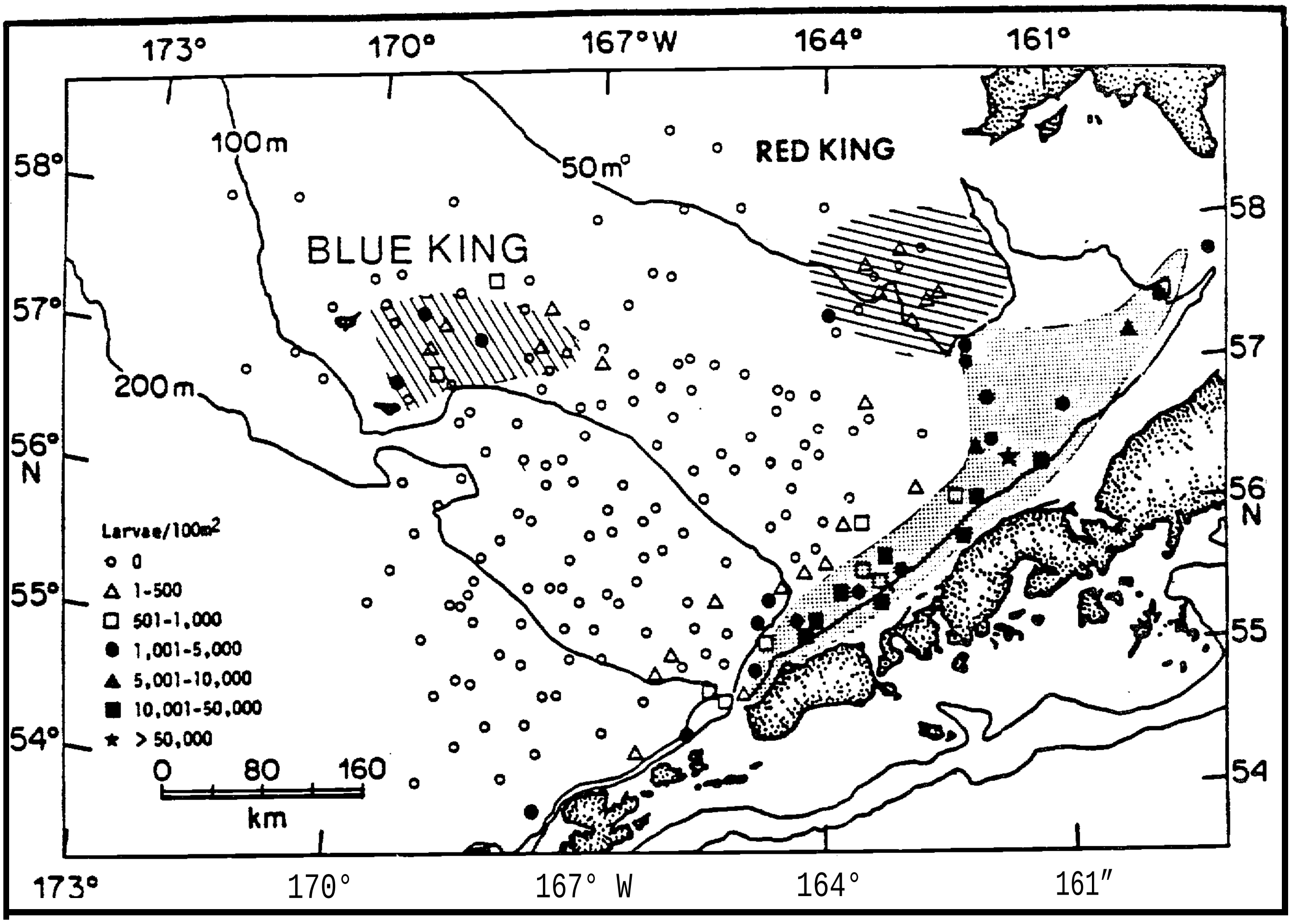


Figure 1.6 Larval king crab distribution in the southeastern Bering Sea. Data summarized from 1976 to 1981. Blue king crab larvae only at the Pribilofs (Armstrong et al. 1981). Shading highlights major aggregations of larvae.

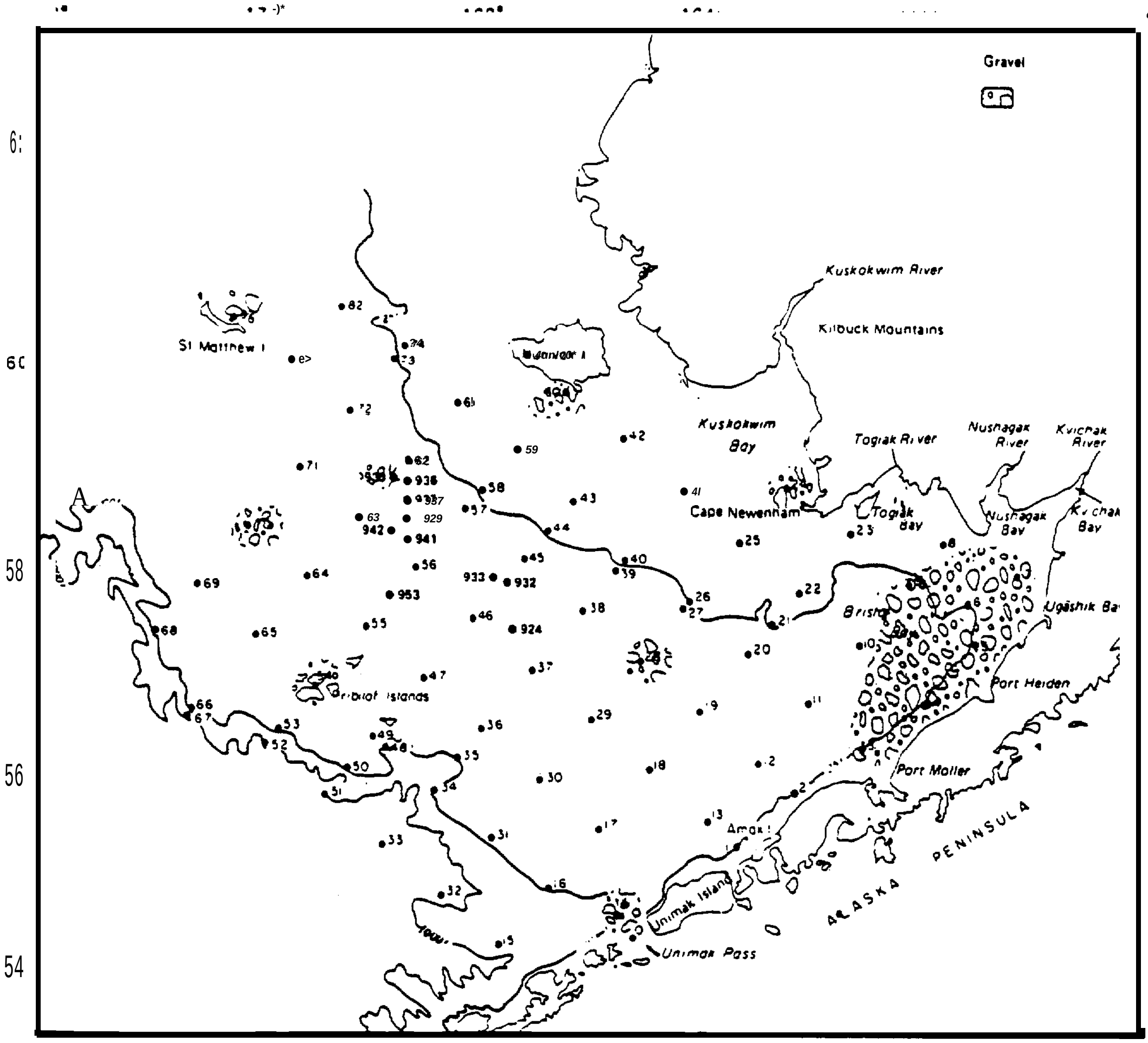


Figure 1.7 Distribution of gravel in the southeastern Bering Sea (McDonald et al. 1981).

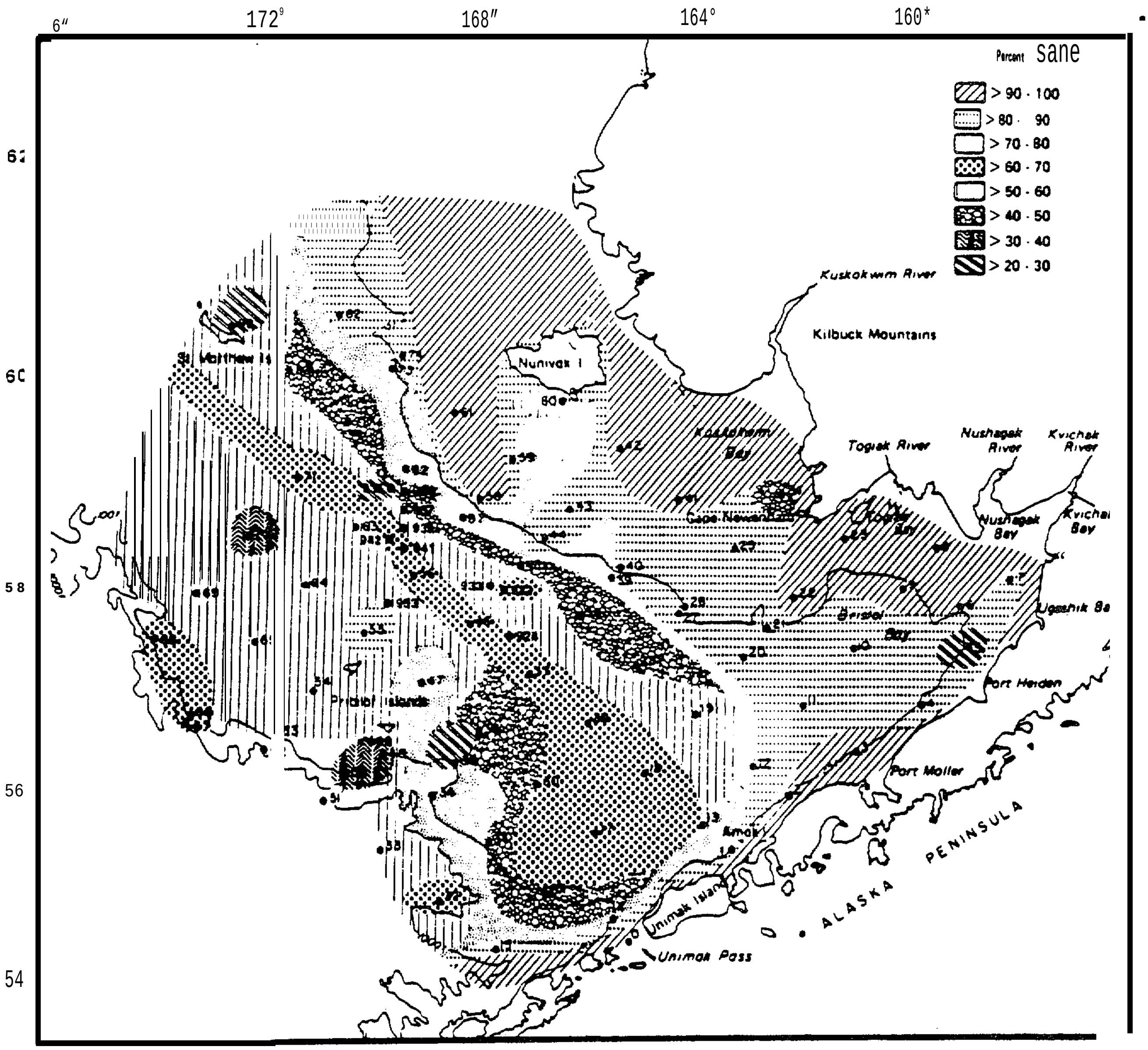


Figure 1.8 Distribution of sand in the southeastern Bering Sea (McDonald et al. 1981).

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 mmCL 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).

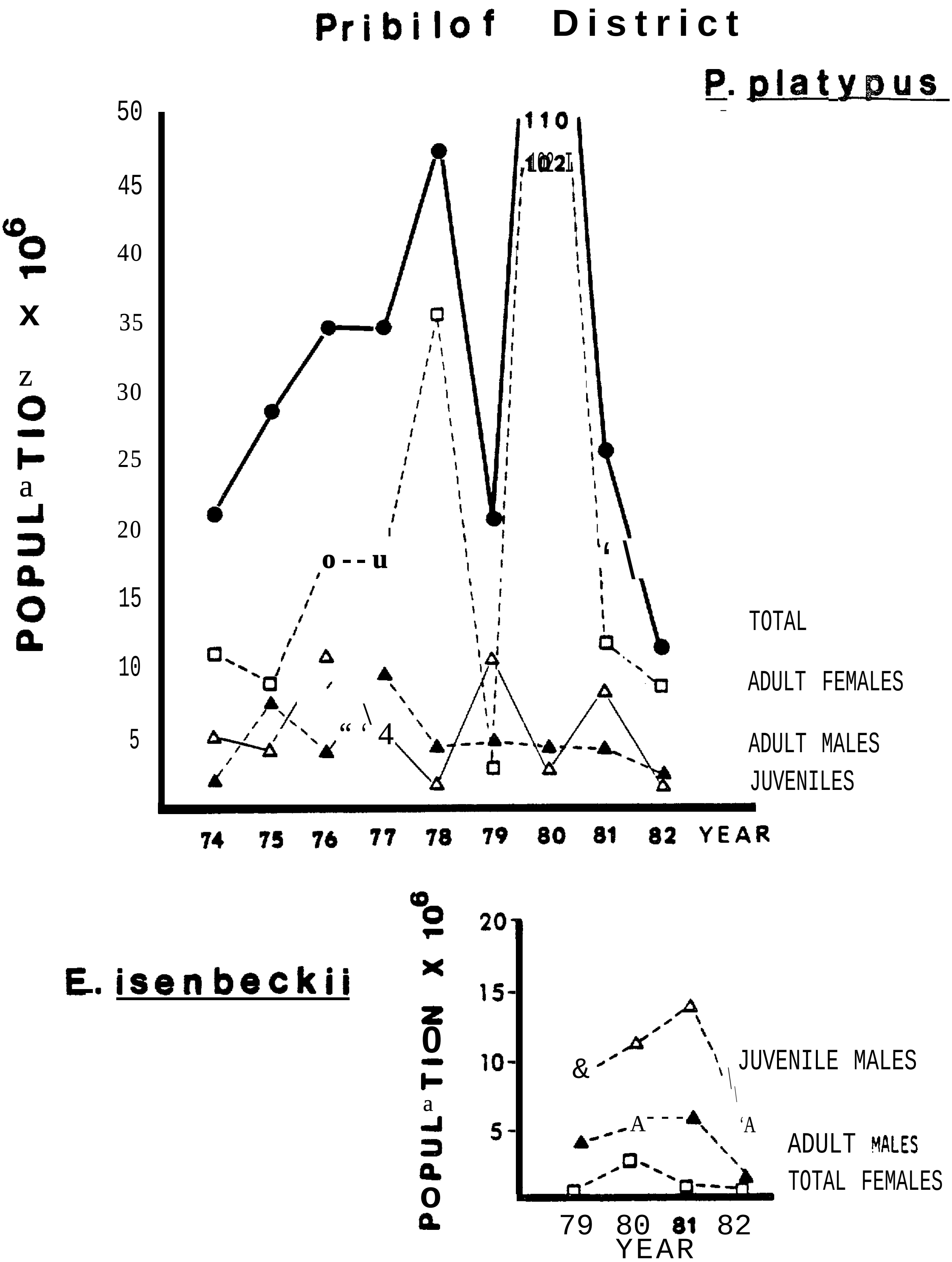


Figure 1.9 Estimates of annual abundance of *Paralithodes platypus* (above) and *Erimacrus isenbeckii* (below) over several NMFS survey years (modified from Otto et al. 1982).

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

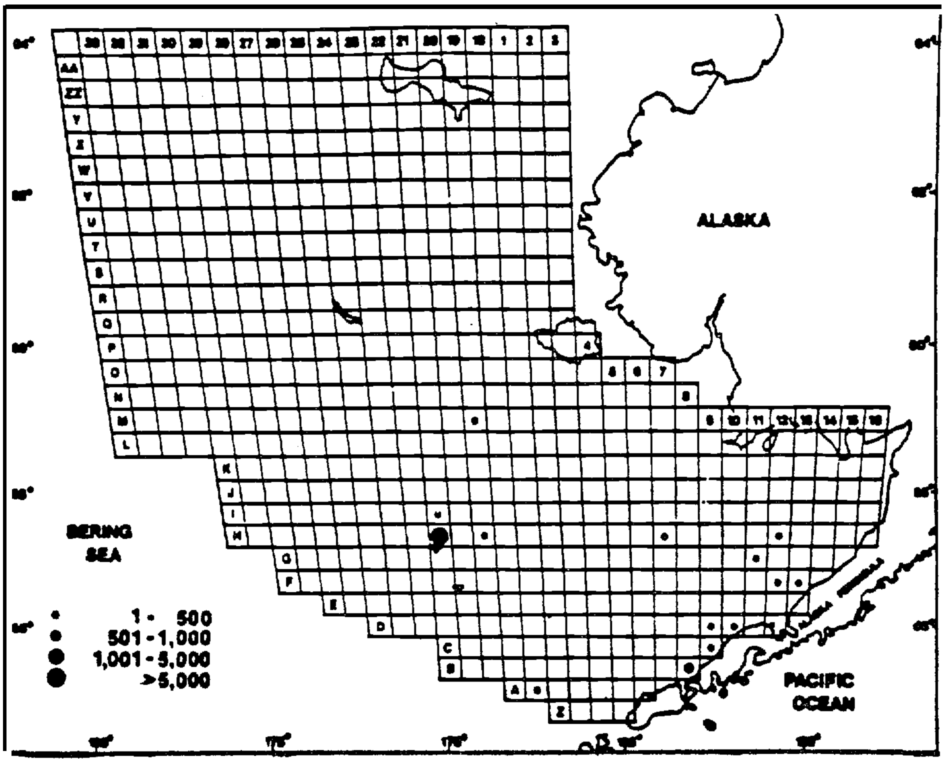


Figure 1.10 Distribution of female *Erimacrus isenbeckii* in the eastern Bering Sea during May-July 1980. Numbers per NM^2 (Otto et al. 1980).

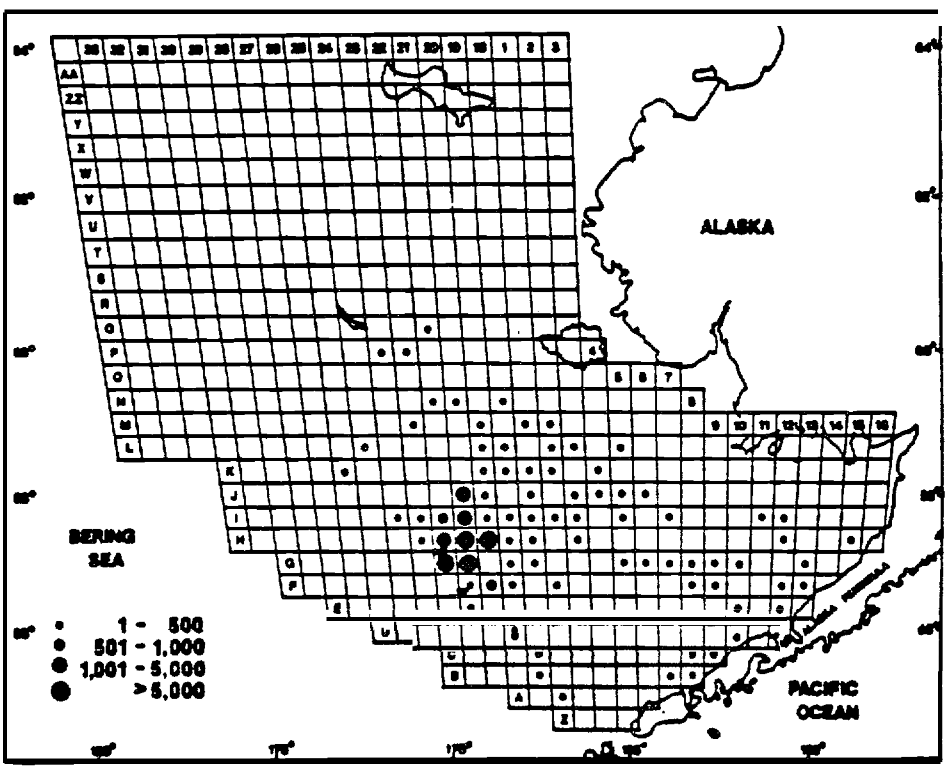


Figure 1.11 Distribution of male *Erimacrus isenbeckii* in the eastern Bering Sea during May-July 1980 (Otto et al. 1980).

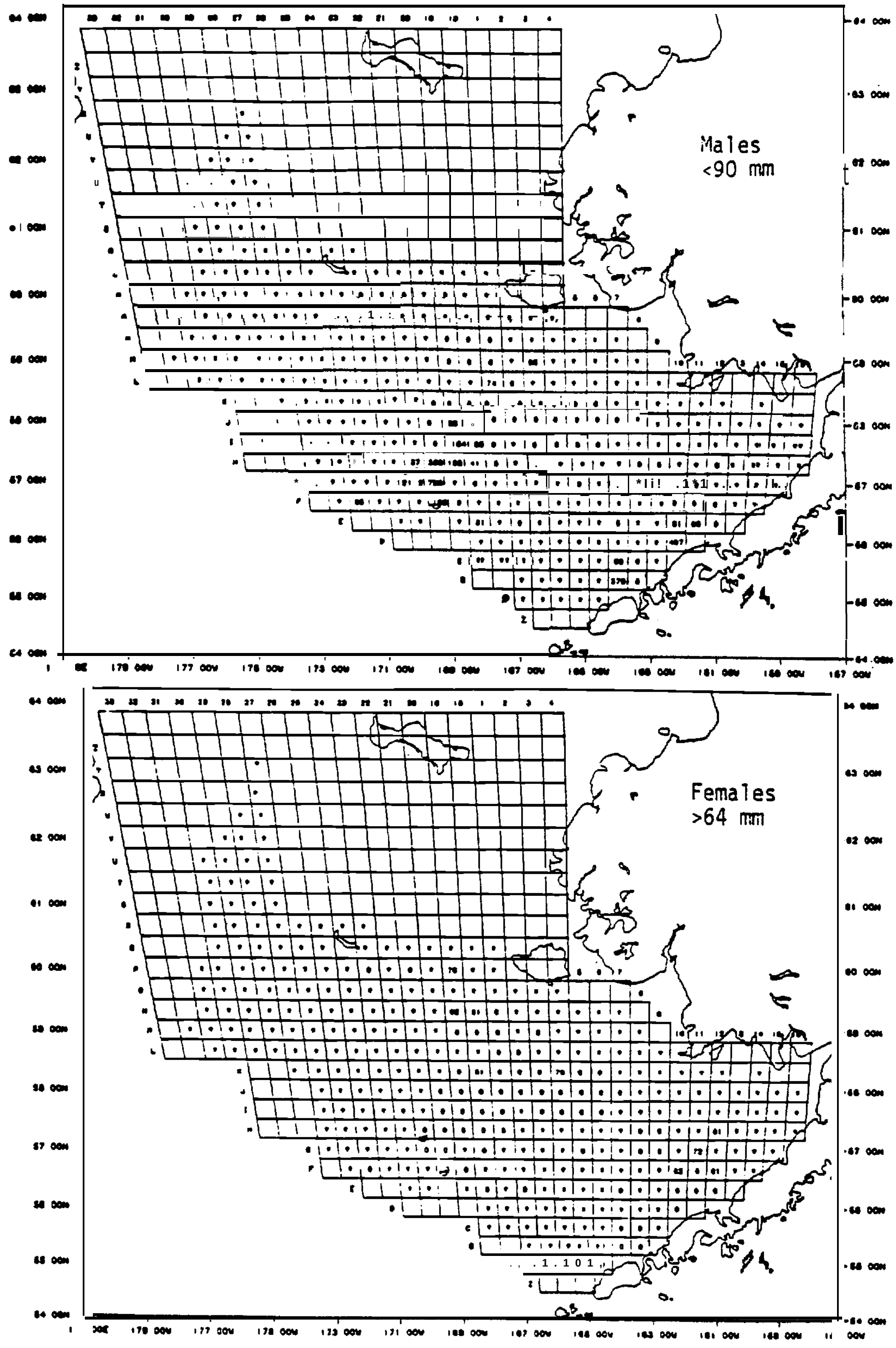


Figure 1.12 Distribution and relative abundance (no. /mile²) of male Korean hair crab less than 90 mm carapace length in the eastern Bering Sea during May-July 1982 (above) and females greater than 64 mm (below) (Otto et al. 1982).

(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 <u>Erimacrus</u> 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

<u>Blue King Crab</u>: 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

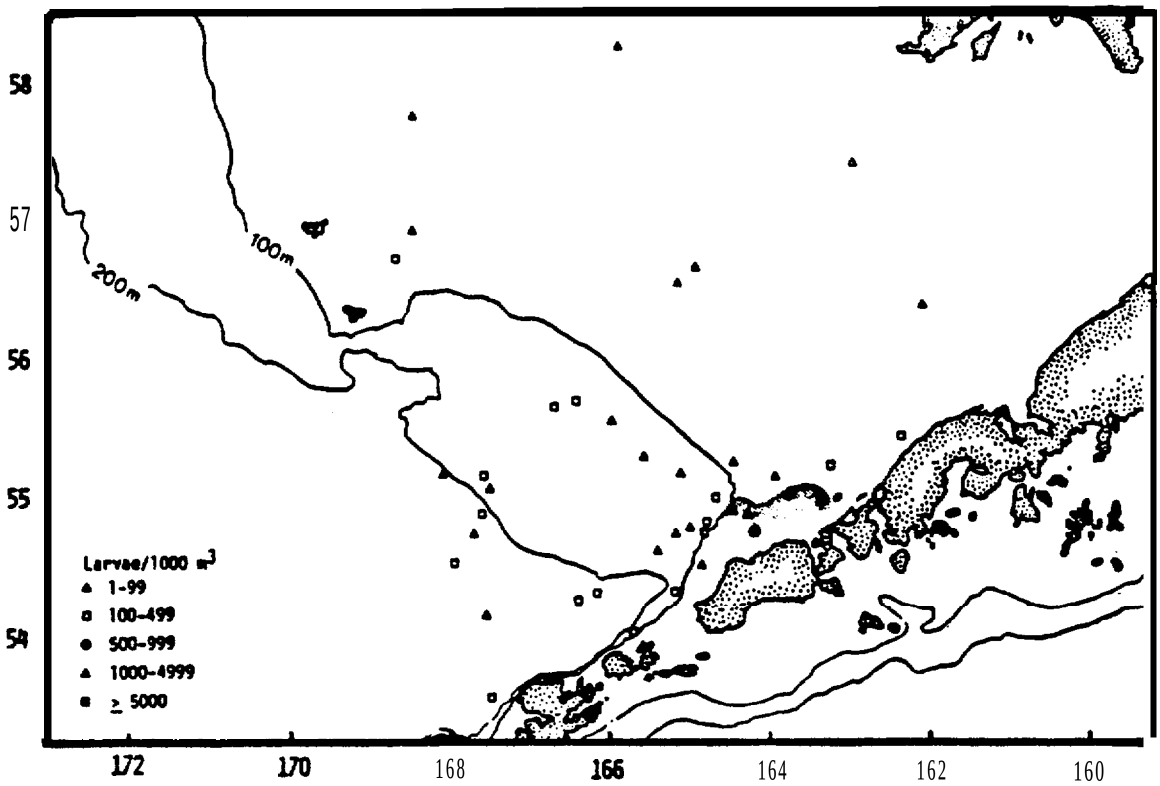


Figure 1.13 Locations and density of Erimacrus isenbeckii larvae collected in the southeastern Bering Sea from 1976 to 1980. Densities of larvae were corrected for the upper 60 m (Armstrong et al. 1981).

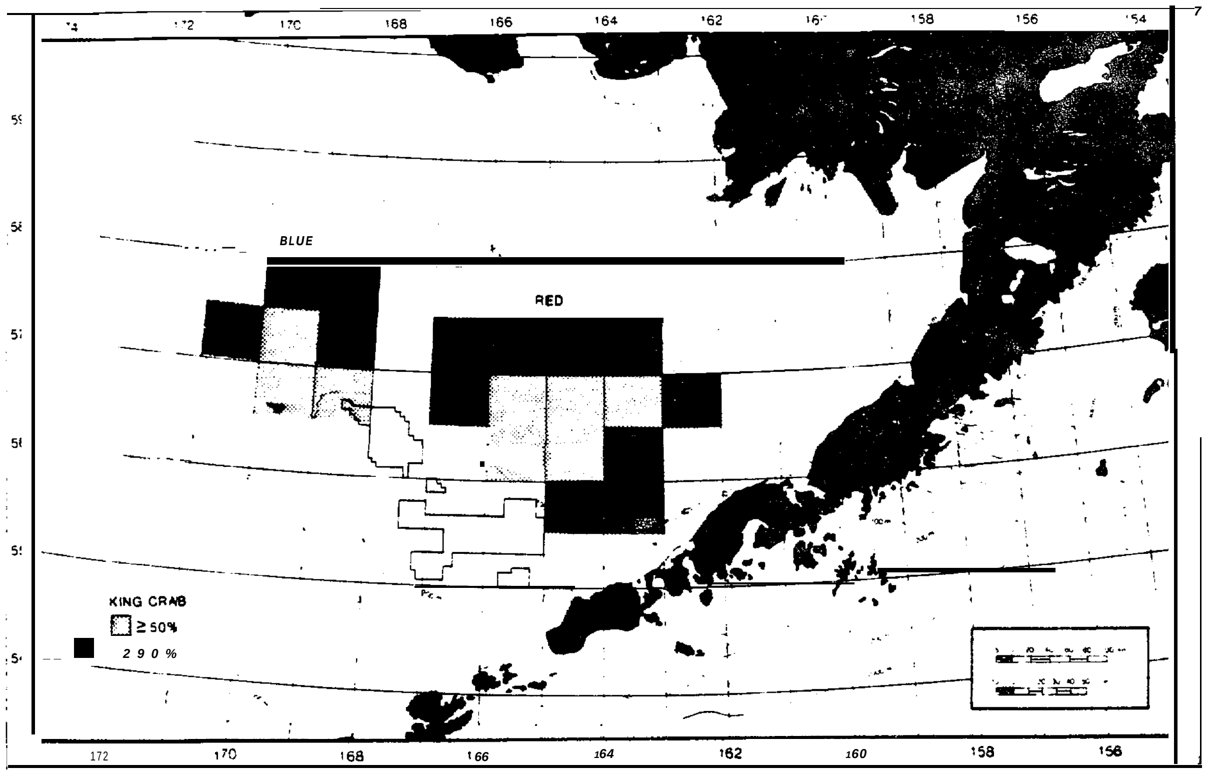


Figure 1.14 Major king crab catch areas re" ative to St. George Basin lease area (Otto 1981 in Curl and Manen 1982). Light shading represents ADF&G statistical areas from which 50% or more of commercial landings come. Dark shading represents 90% or more of commercial landings.

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 hay 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

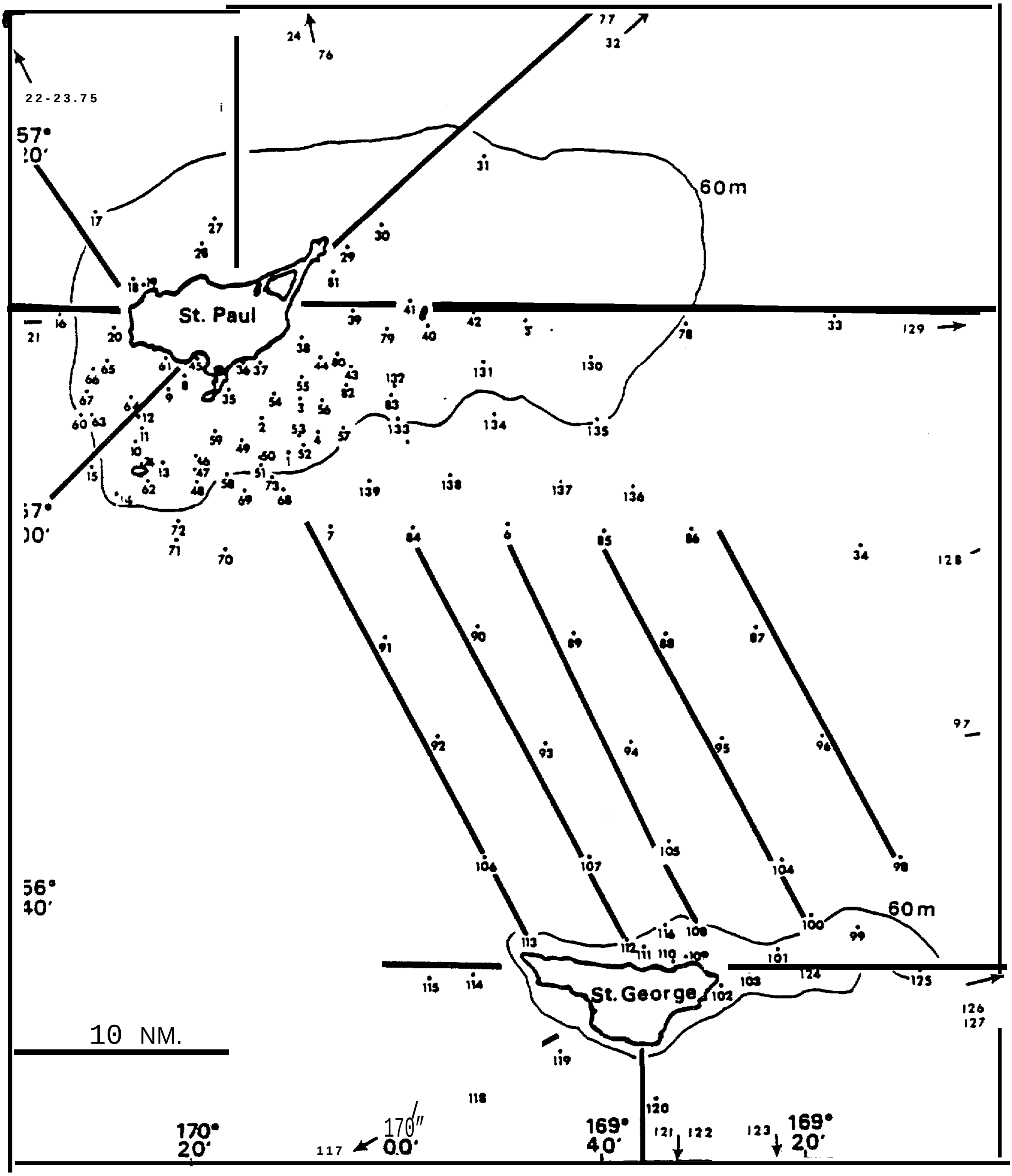


Figure 2.1 Station locations for zooplankton and benthic samples, May 1983. Stations were located up to 40 NM offshore of both islands as indicated. The original transect array emanated as spokes from the islands with coverage between the islands extended westward toward the 80-m isobath. Additional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

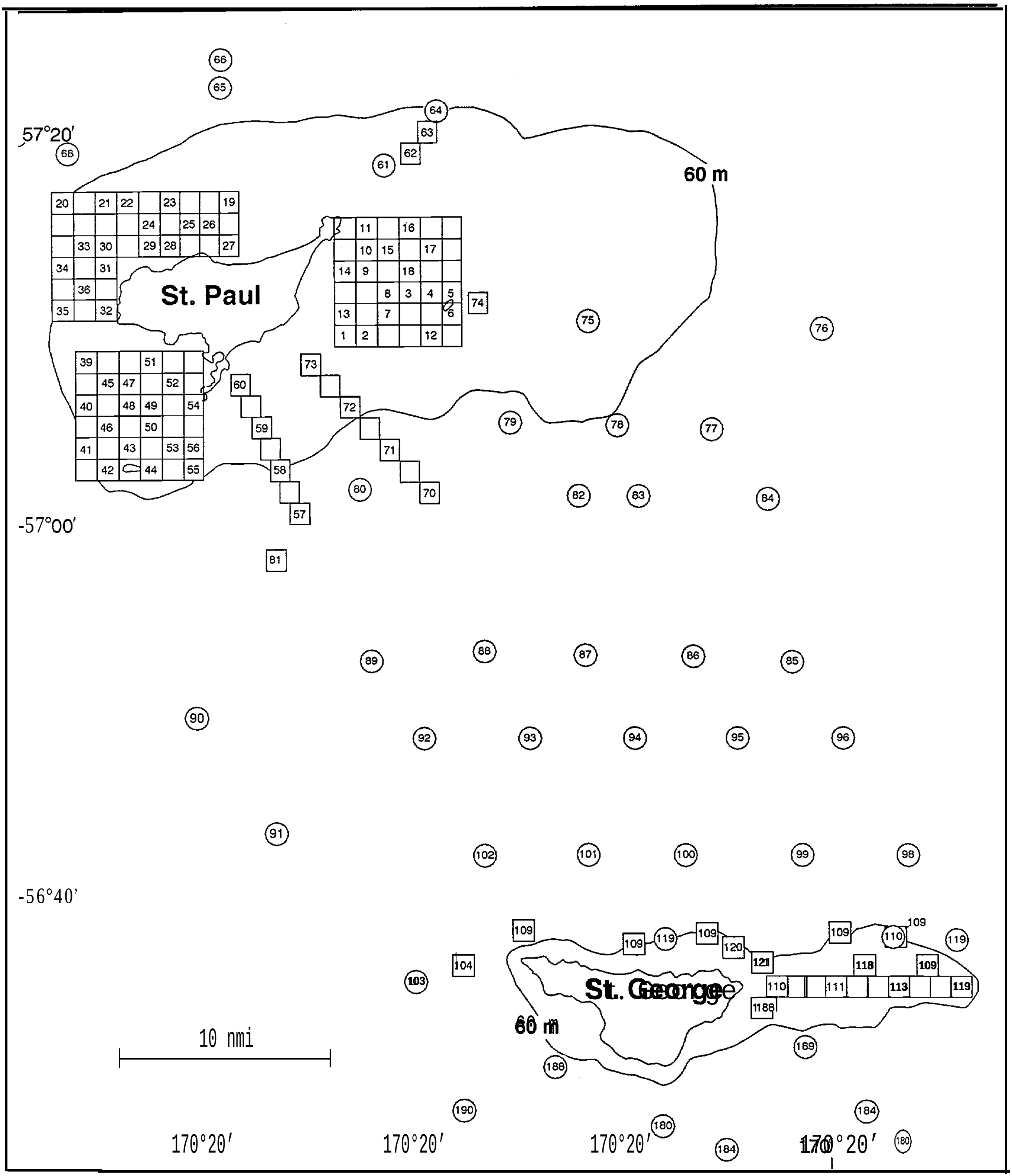


Figure 2.2 Side scan sonar (SSS) grid and regular stations, August 1983. Depicted as squares are grids in which random number selection was used to locate SSS stations around St. Paul and isolated SSS stations elsewhere. Circles show the location of stations where no SSS was used.

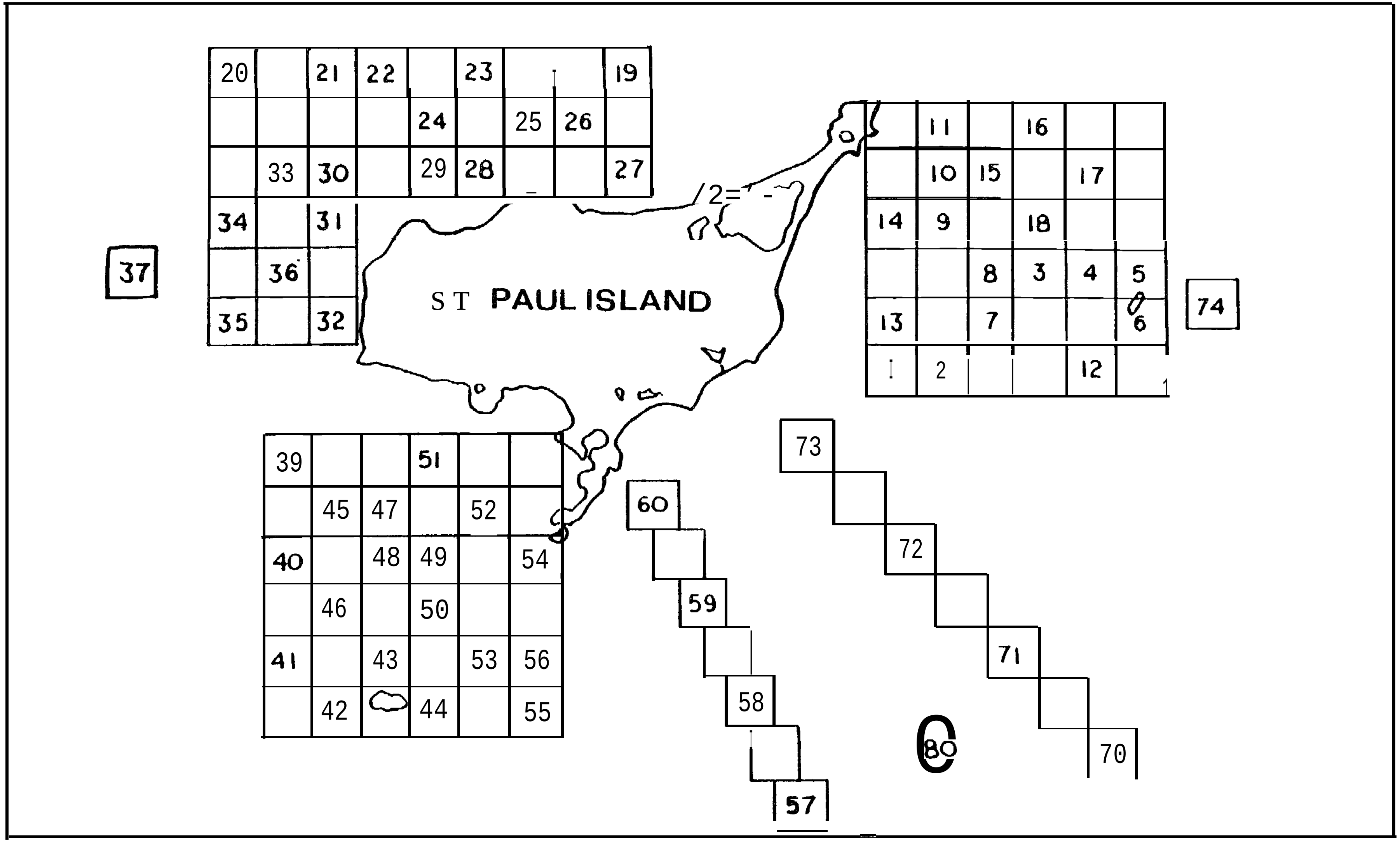


Figure 2.3 St. Paul side scan sonar grids, August 1983. Each square is 1 NM on a side and was selected by a random number process. The side scan sonar survey was conducted for a complete mile in a variable direction dictated by currents and winds. The bottom width covered during each survey varied from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

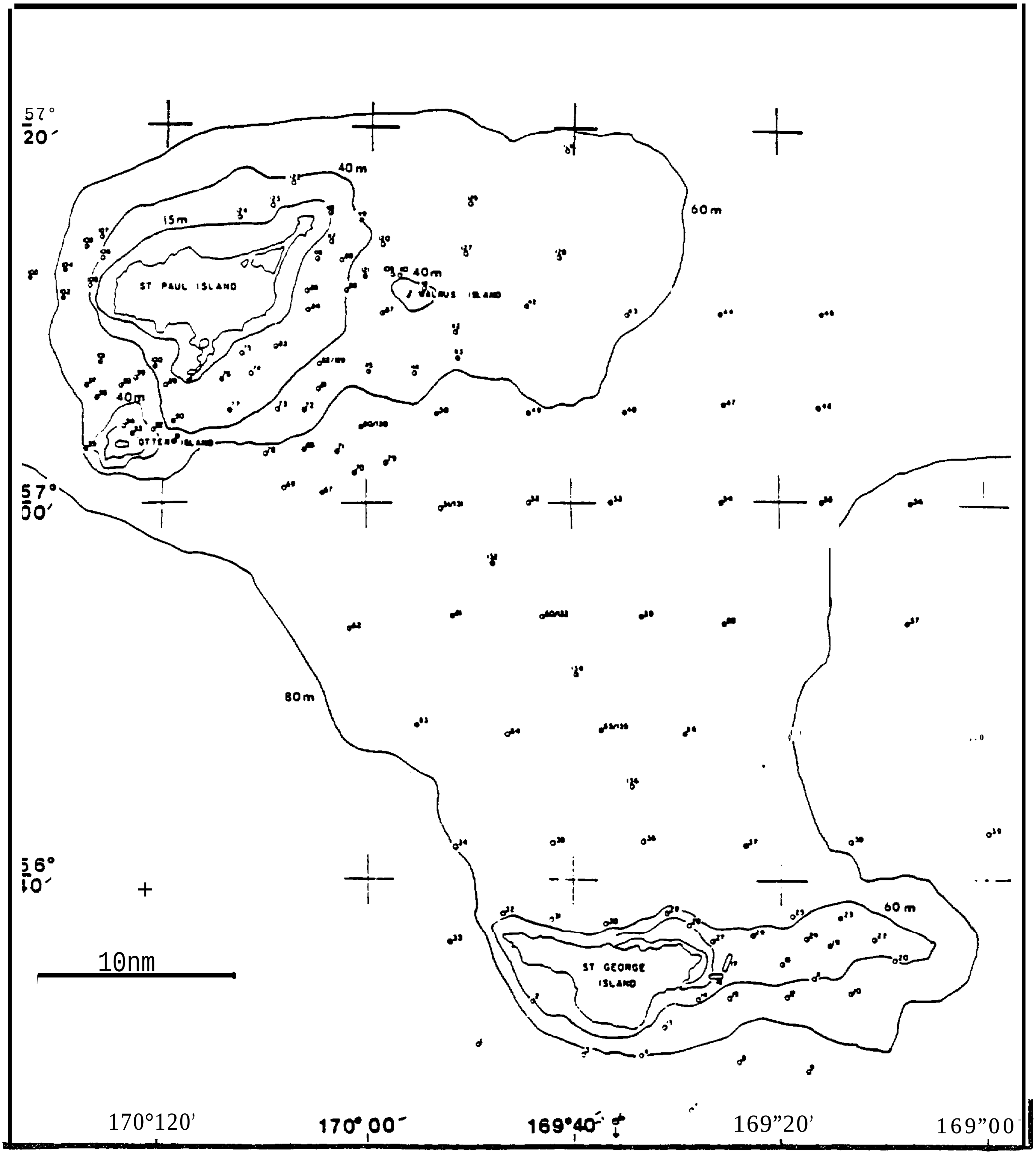


Figure 2.4 April 1984 station locations.

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:

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

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 monographs. 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.

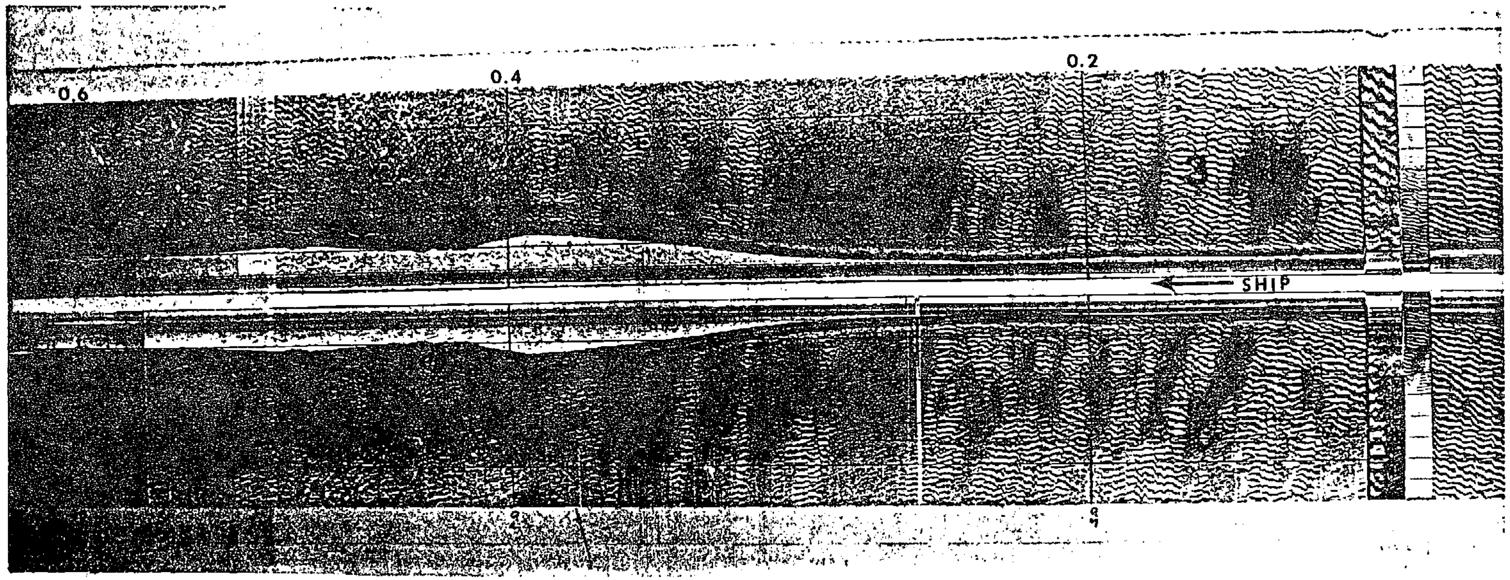


Figure 2.5 Side scan sonar trace showing several bottom features interpreted by ground-truthing with a Shipek grab and dredge. This station occurred 4 NM southwest of St. Paul in 58 m of water (Station 48, Fig. 2.3). The ship traveled down the mid course and the sonar fish scanned 75 m to port and starboard (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.

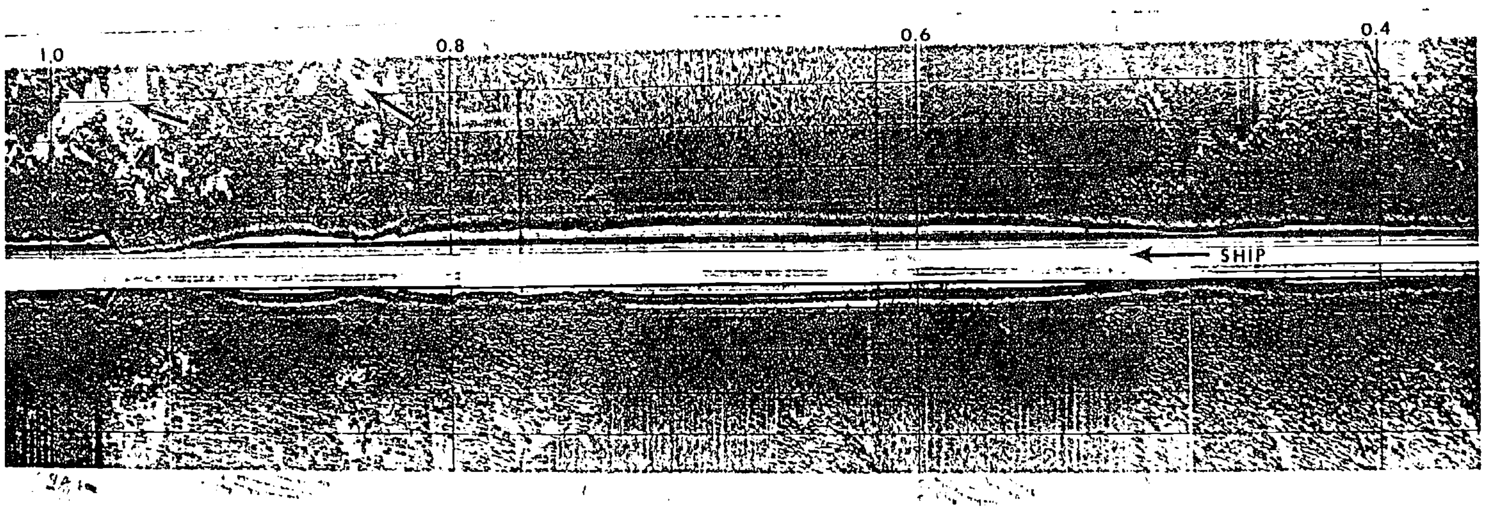


Figure 2.6 Side scan sonar trace over 1 NM about 5 NM southwest of St. Paul Island in 66 m of water (Station 43, Fig. 2.3). This example highlights the variability of substrates over short distances and resultant sampling problems. On the left, substrate No. 4 is large rock (note shadowing) with pockets 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.

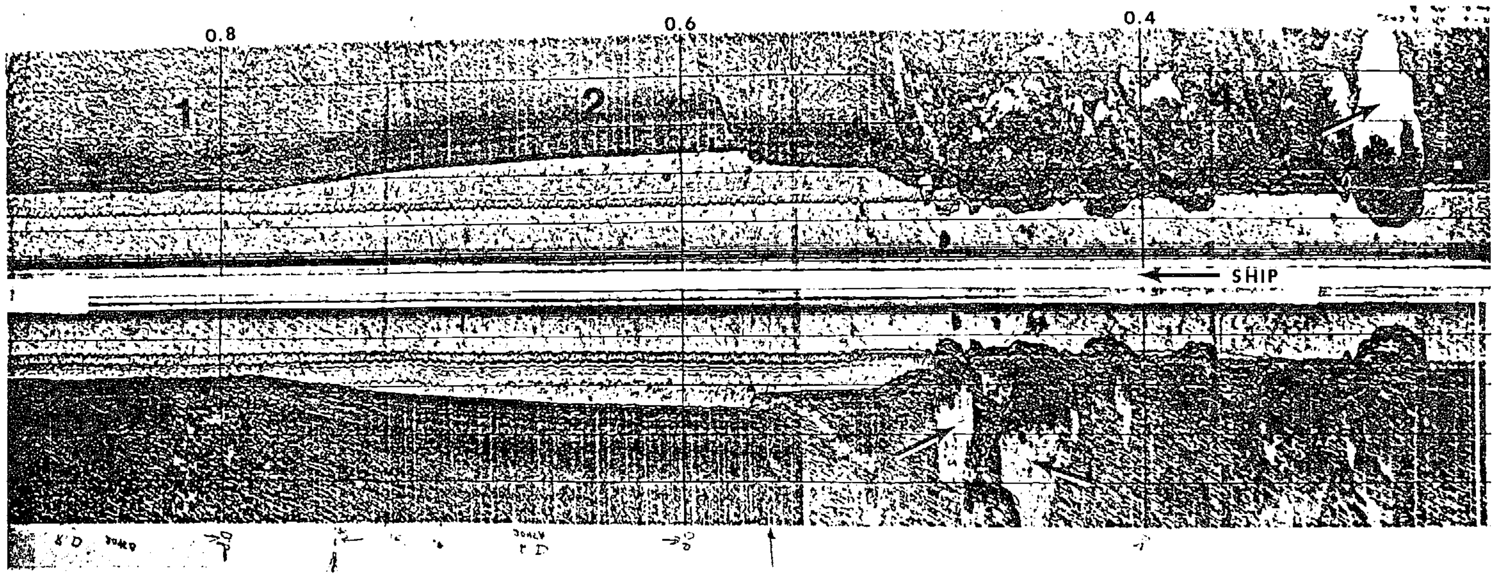


Figure 2.7 Side scan sonar trace over 1 NM about 6 NM southeast of St. Paul (near Otter Rock) at a depth of 62 m (Station 42, Fig. 2.3). Two types of rock formations are shown: (1) Low relief rock beds with associated pockets of shell hash (intact or large pieces with epiphytic growth; see Section 3.2.3). (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 urn 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 Al). 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 Al, 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 Al, 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, and8 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.

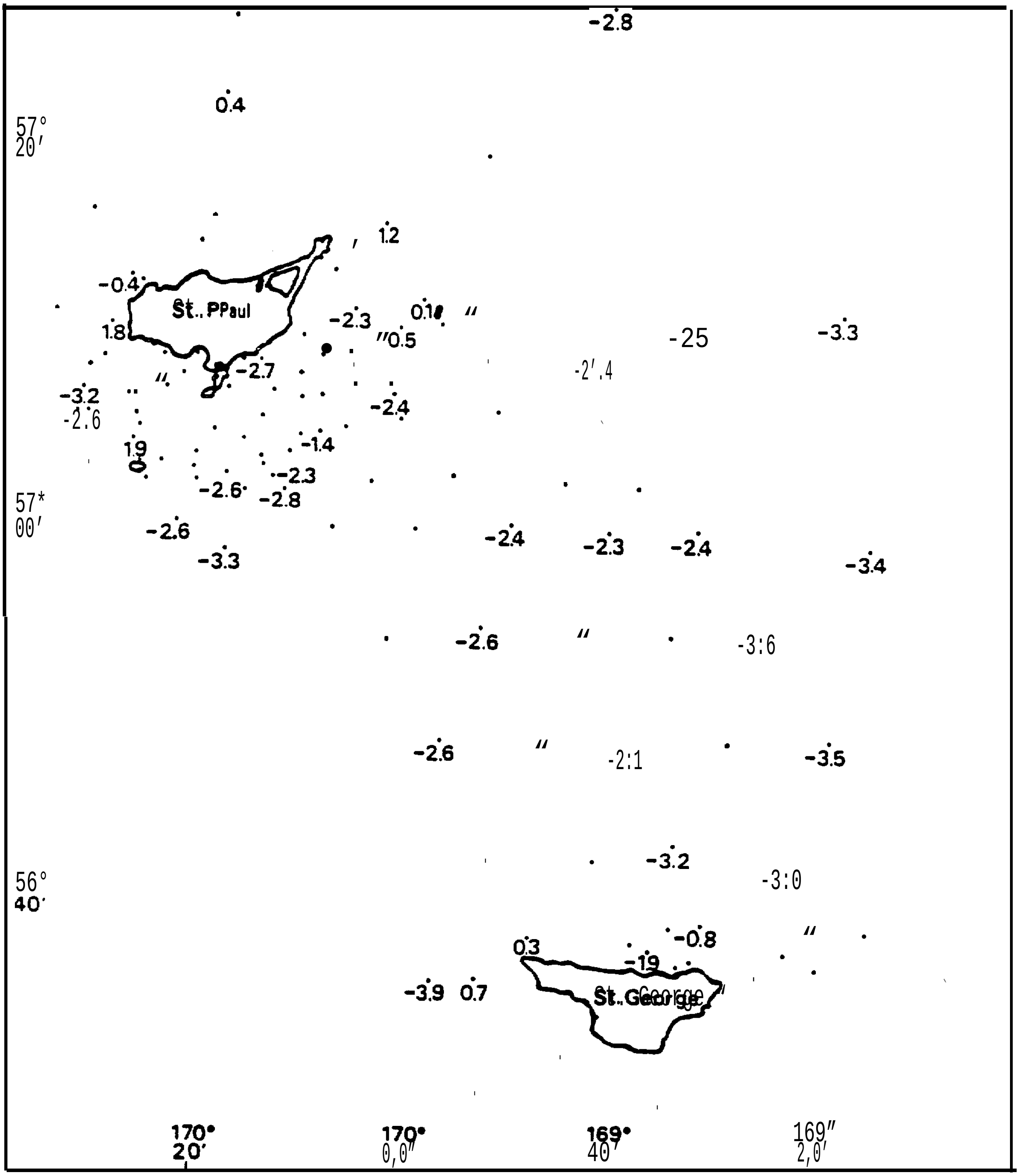
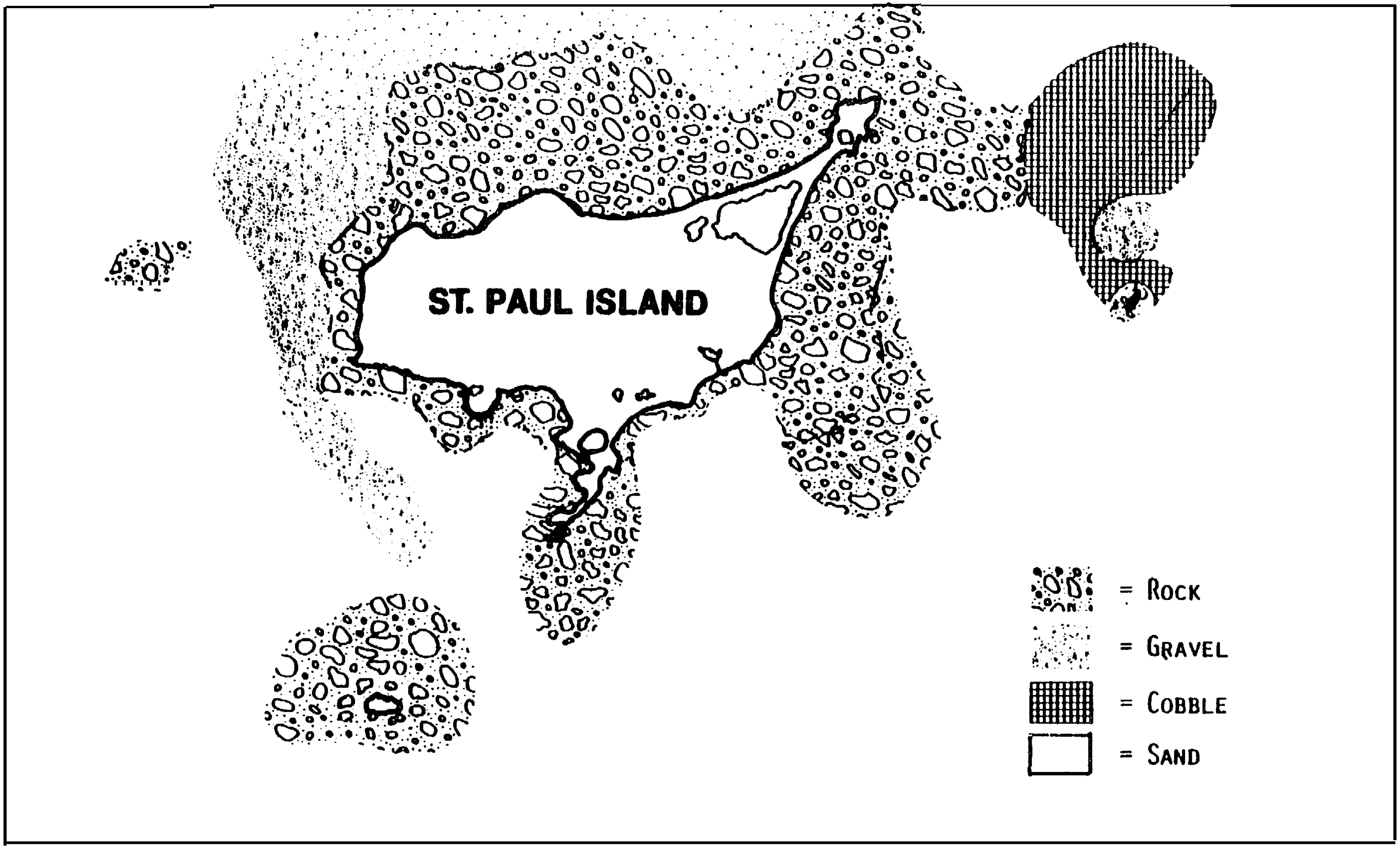


Figure 2.8 Mean phi values and location of the May 1983 stations chosen for sediment analysis.

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 heterogeneity 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 outcropping. 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 monographs 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



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

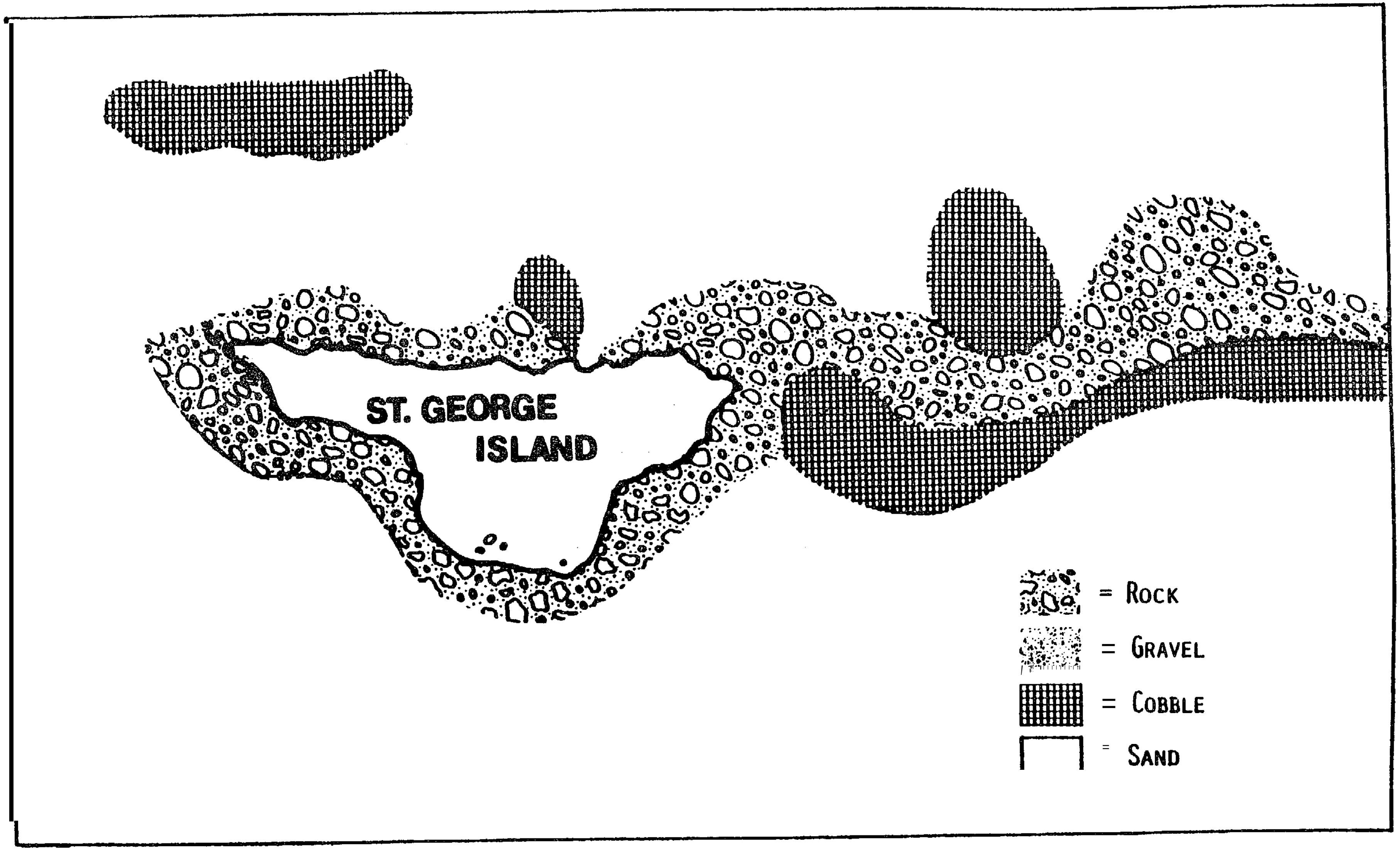


Figure 2.10 Summary map of substrate types around St. George Island compiled from side scan sonar, Shipek grabs, and rock dredge data.

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 assemblages 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 gastropod (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.

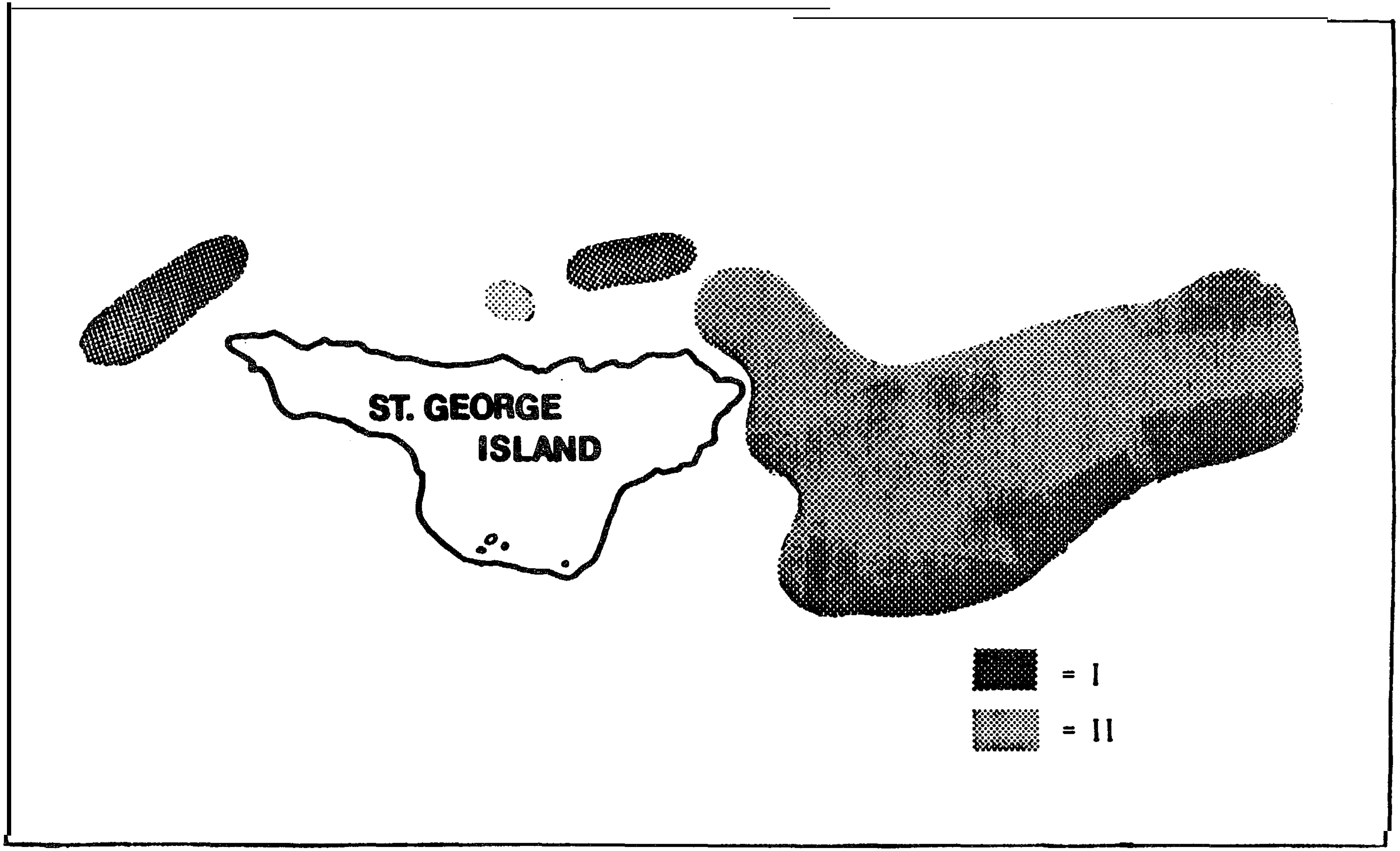


Figure 2.12 Extent of shellhash deposits around St. George Island. Shellhash type I is, for the most part, intact and covered with animal and plant growth. Type II is pulverized shellhash, very small pieces, with no epiphytic covering; typifies areas of low invertebrate numbers and biomass.

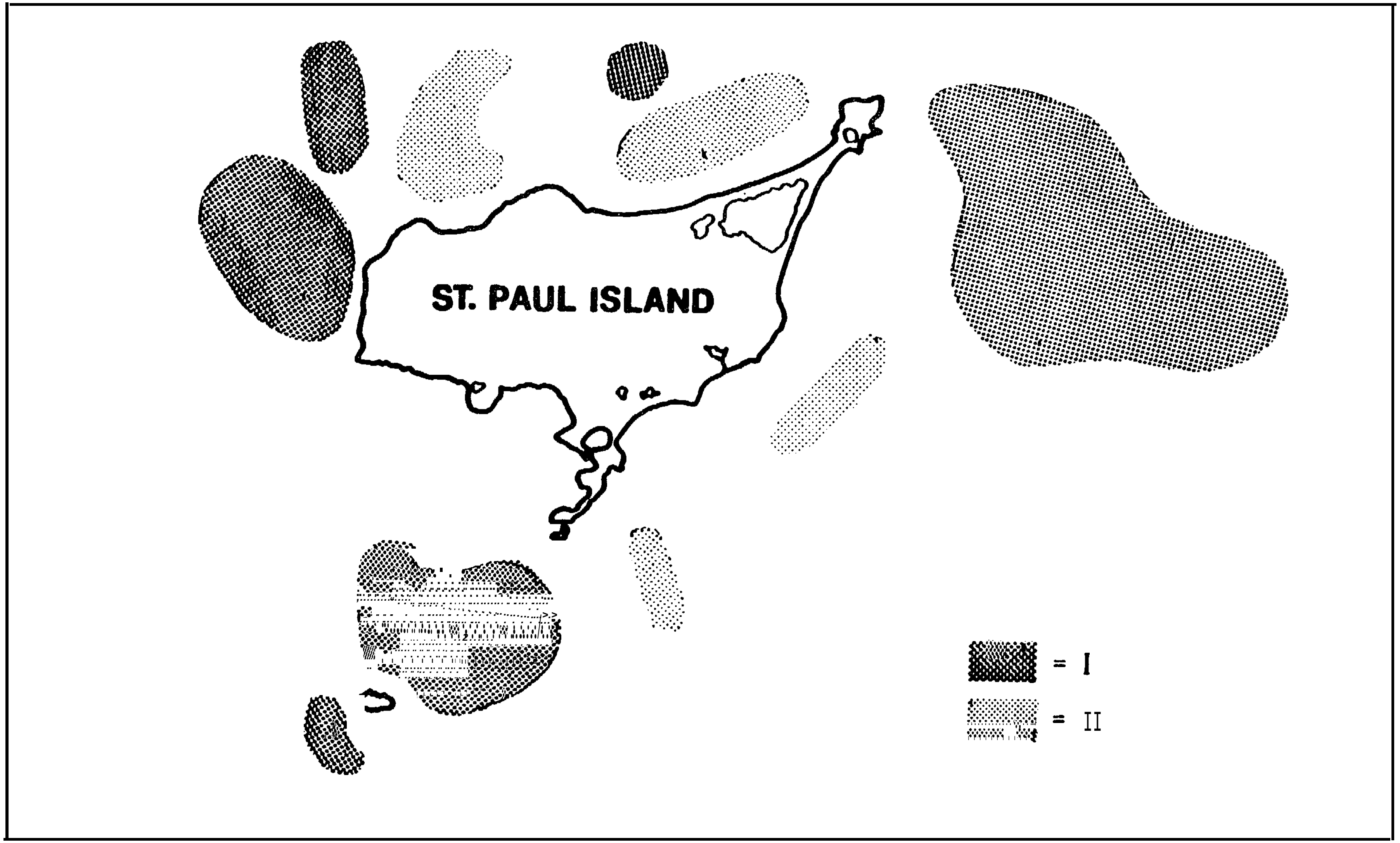


Figure 2.13 Extent of shellhash deposits around St. Paul Island. Shellhash type I is, for the most part, intact and covered with animal and plant growth. Type II is pulverized shellhash, very small pieces, with no epiphytic covering; typifies areas of low invertebrate numbers and biomass.

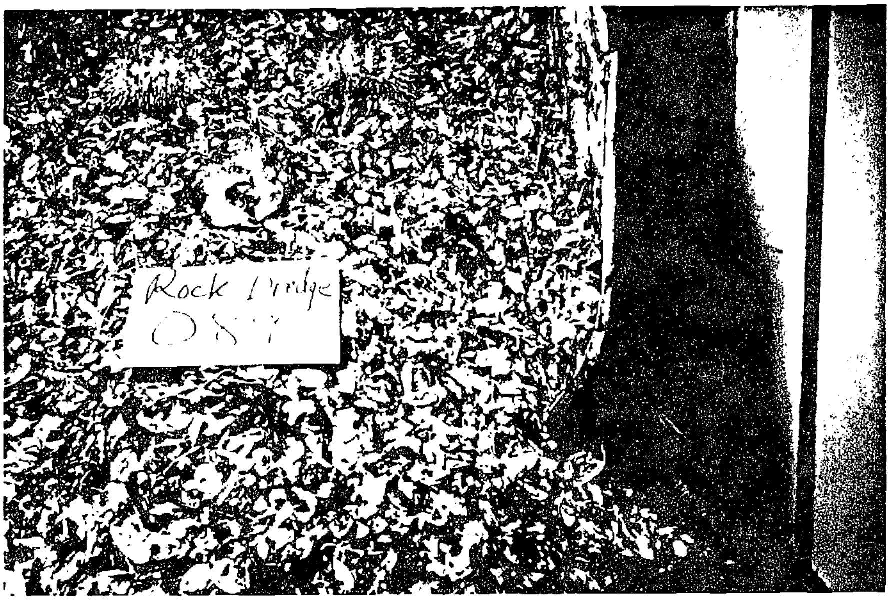


Figure 2.14 Shellhash type II, consisting of pulverized, well-washed shell material, associated with low numbers and biomass of blue king crab.

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

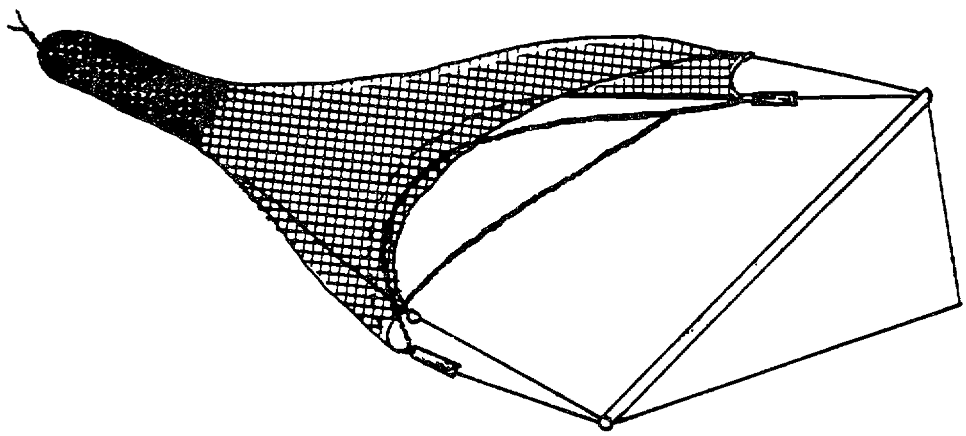
The above descriptions of SH I and SH II are the extreme cases, whereas a wide range of intact to broken shell with various amounts of attached epiphytic growth was taken. For this reason only a single shellhash (SH I) was considered when grouping stations for sediment classification. Those few stations 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 (O-8 km), Rock dredge tows were usually 5 minutes over a distance of 0.2 NM (0.4 km).



A

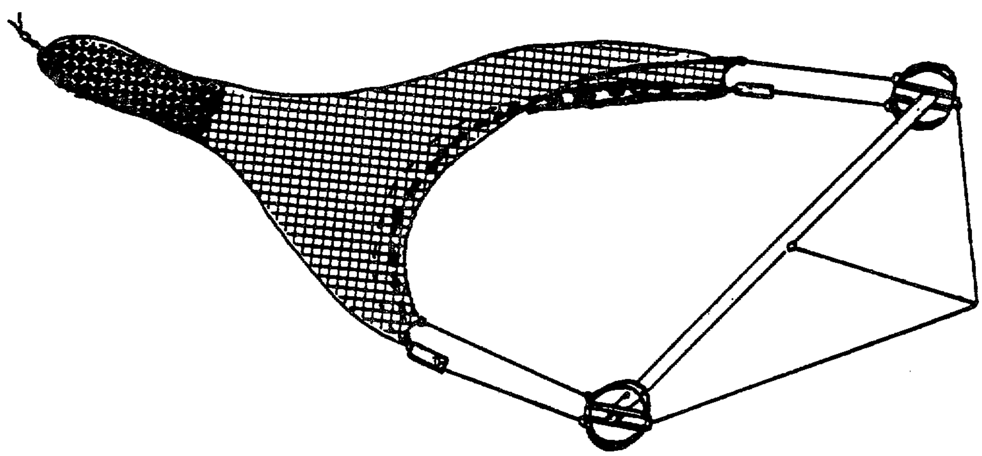


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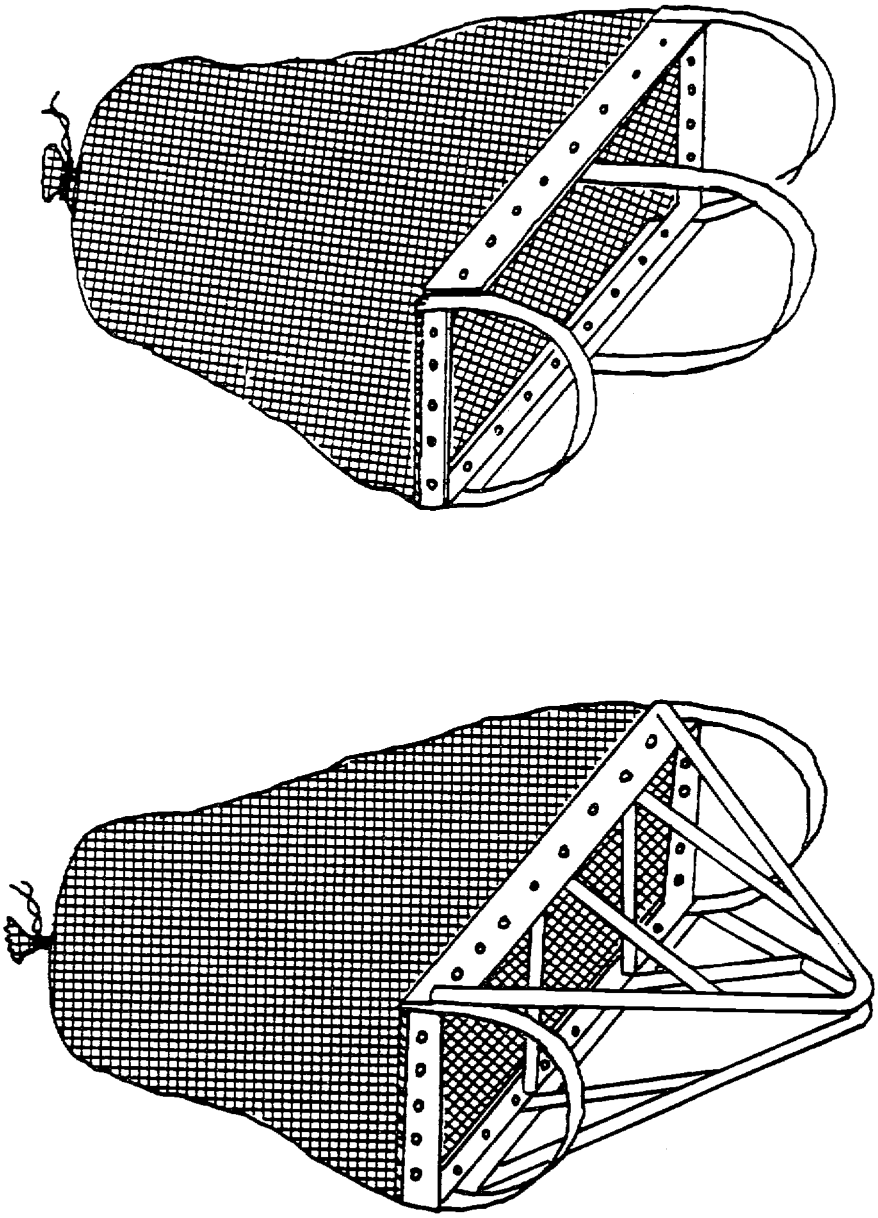
Figure 3.1 The original beam trawl (A) had an aluminum beam with double bridle and lightweight tickler chain. The modified beam trawl (B) employed a reinforced steel beam with steel runners, heavier (5/16″) tickler chain, and a triple bridle.



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 X_{1j} and X_{2j} 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.

Glass 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.

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

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 ‰. 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).

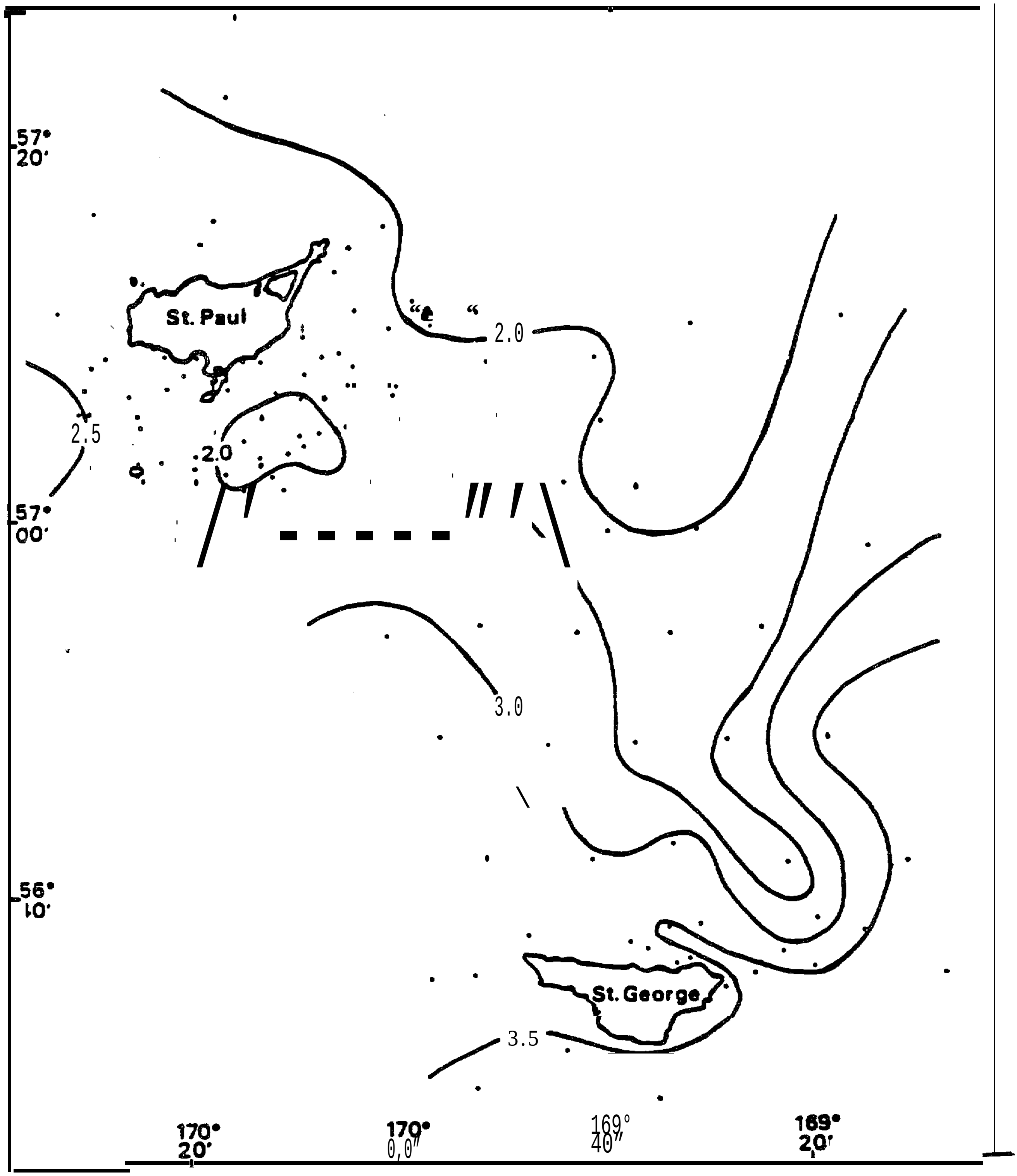


Figure 3.3 Bottom temperatures (“C), May 1983.

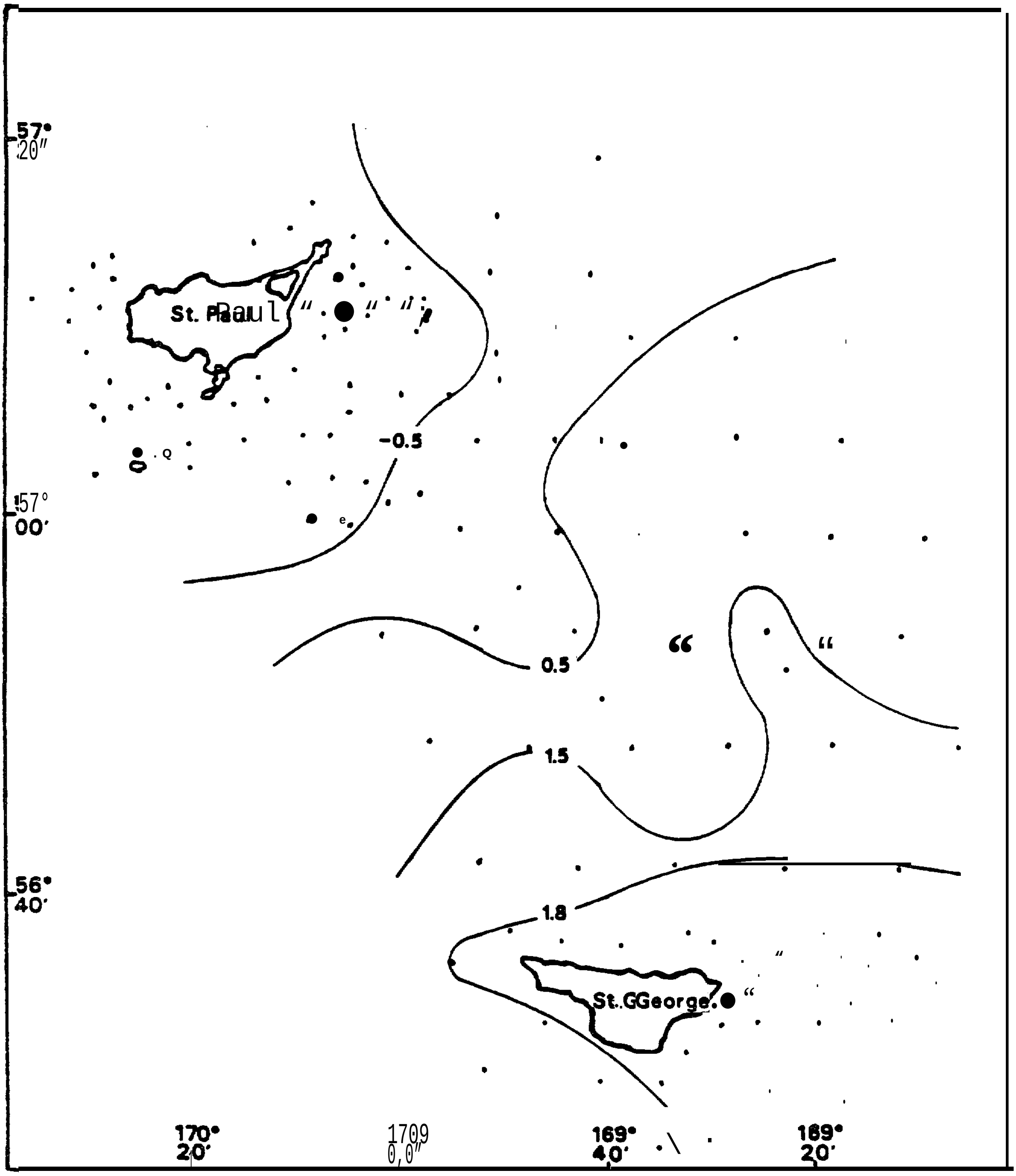


Figure 3.4 Bottom temperatures (°C), April 1984.

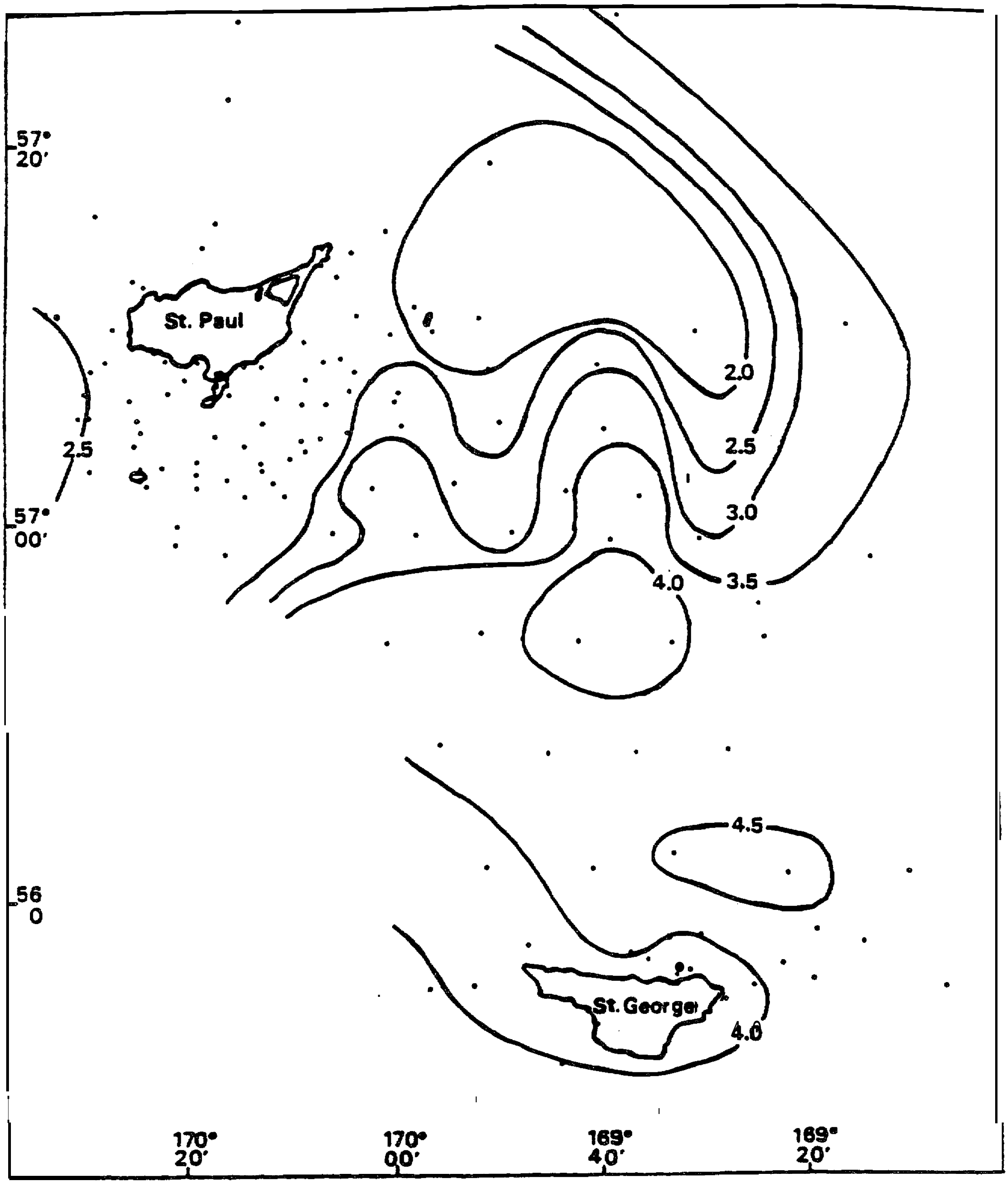


Figure 3.5 Surfaces temperatures (°C), May 1983.

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

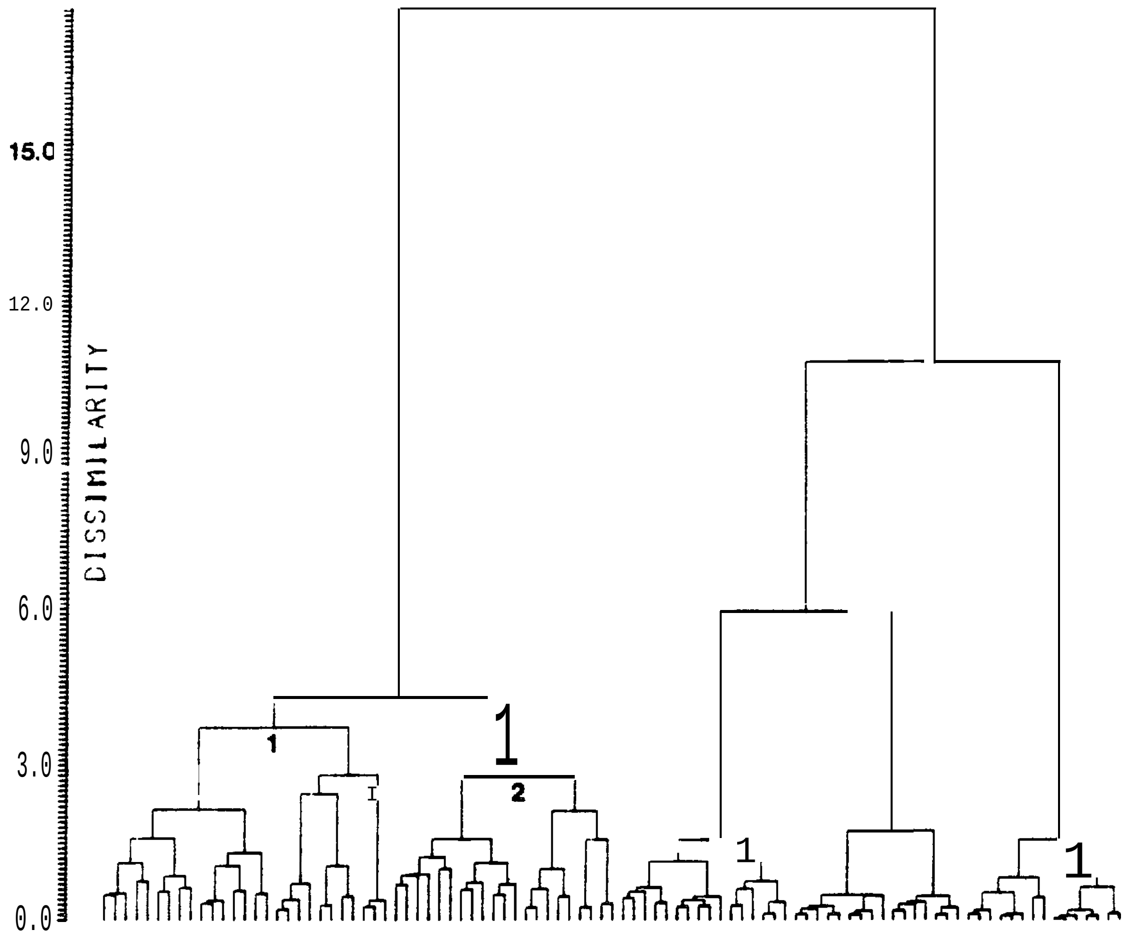


Figure 3.6 Dendrogram showing the relationship between the stations of the May 1983 cruise, beam trawls and rock dredges combined. Numbers 1, 2, and 3 indicate cluster groups common to all cruises (see Appendices B.4-6).

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

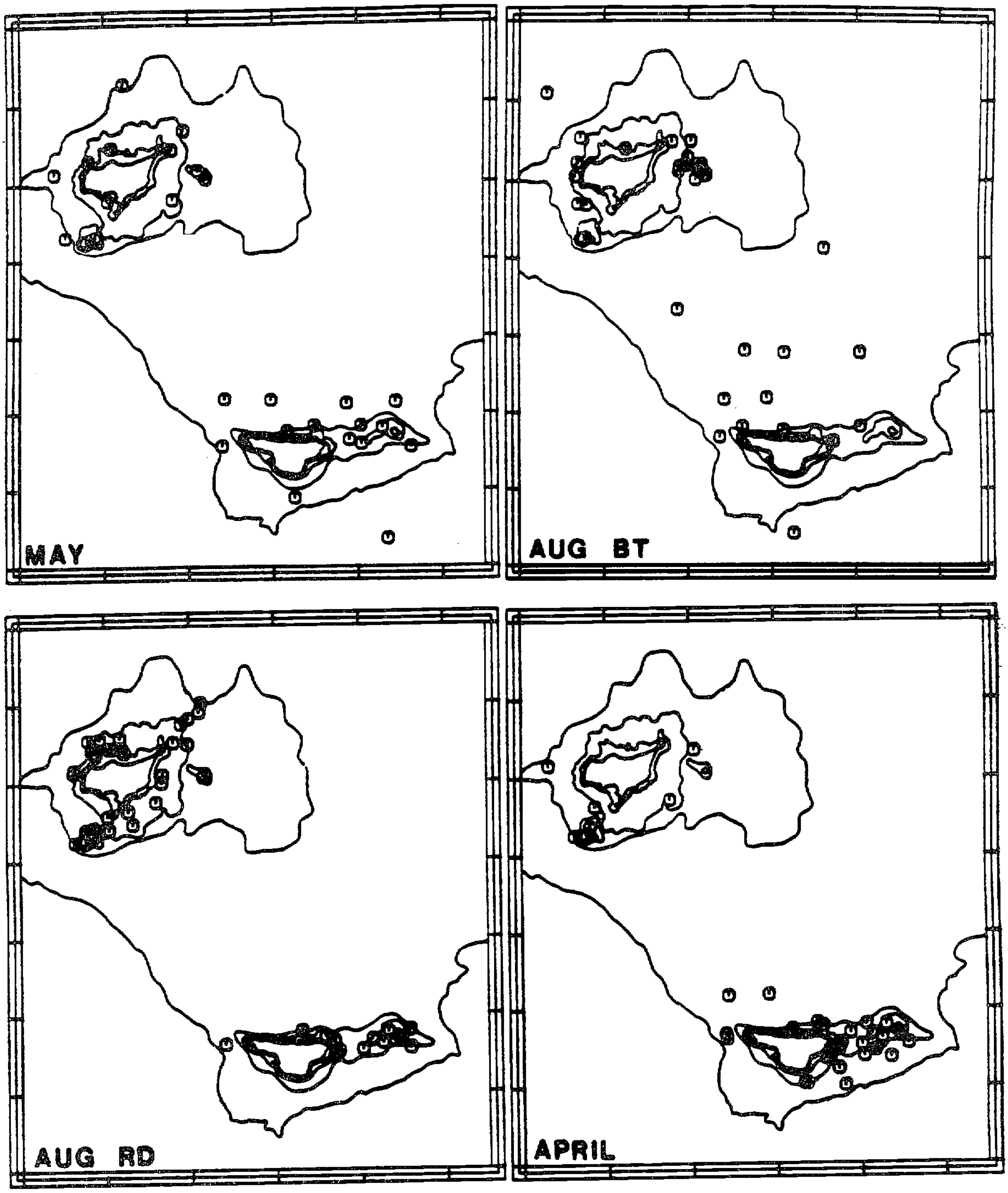


Figure 3.7 Geographical locations of stations in Cluster Group 1 formed for each cruise and rock dredge and beam trawl data separately in August 1983. Substrate at these stations is composed primarily of cobble and rock and extensive shell hash (type I), and is an area of high density of juvenile blue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

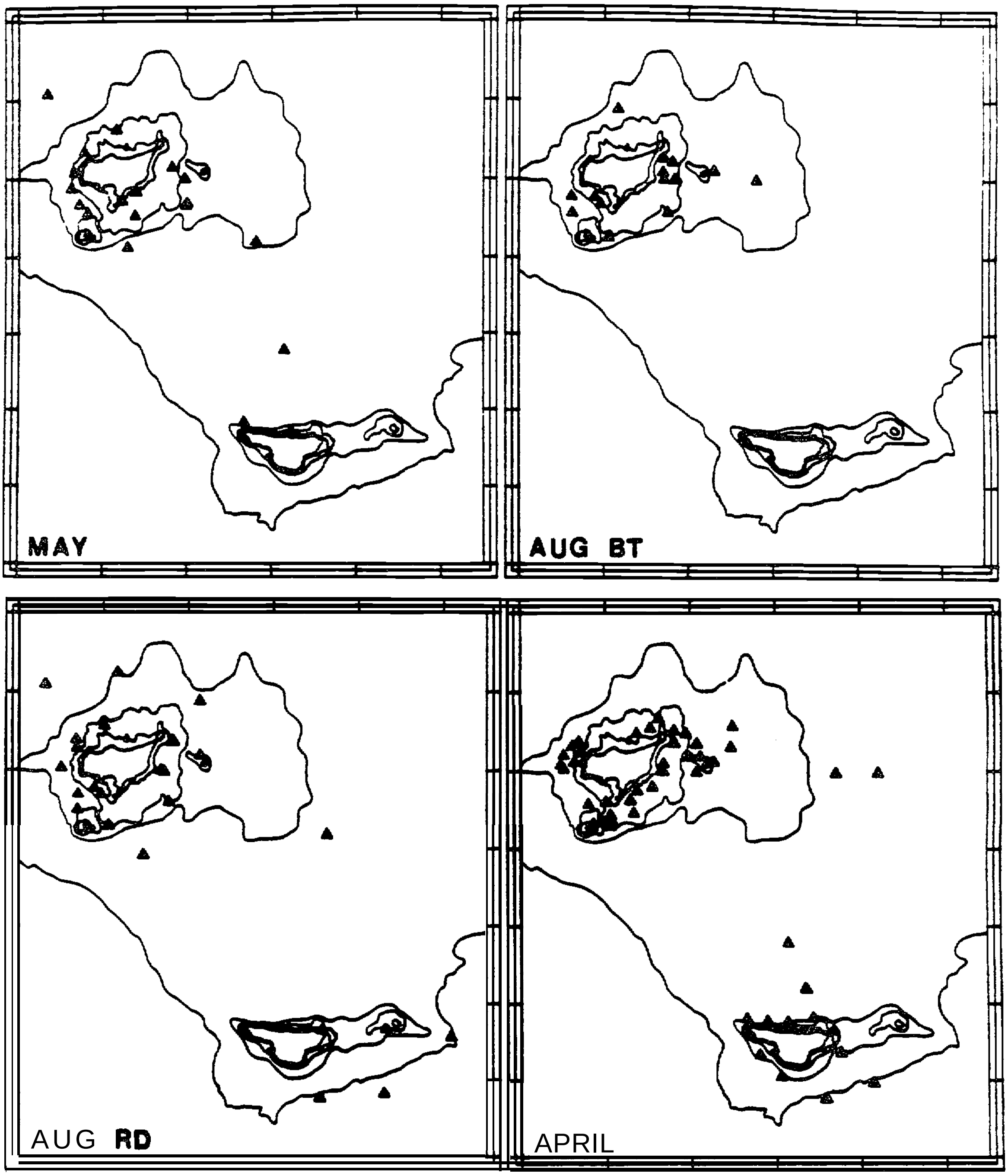


Figure 3.8 Geographical locations of stations in Cluster Group 2. Here, the substrate was a mixture of sand, cobble, rock and shell, and is viewed as transitional between Cluster Groups 1 and 3.

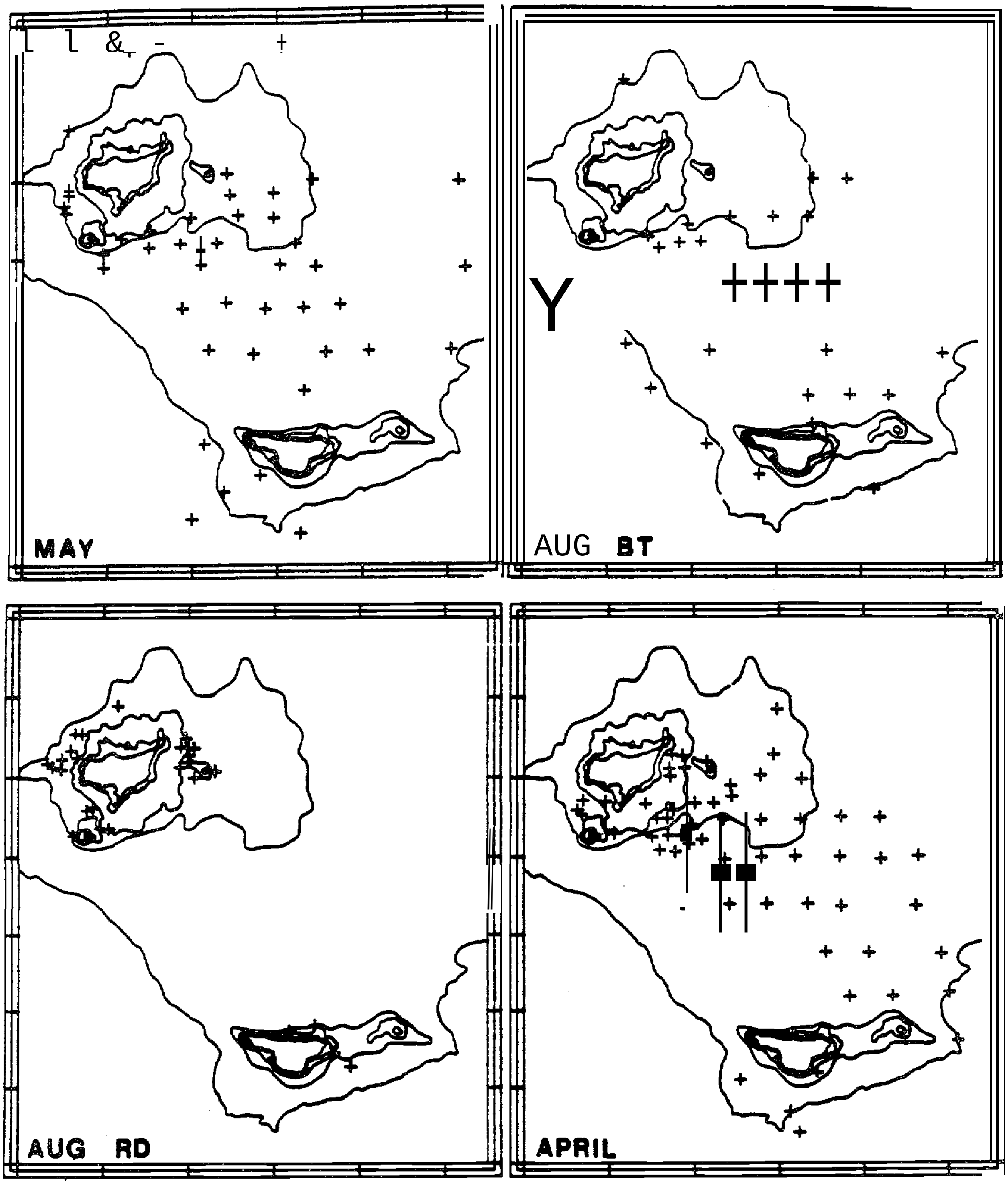


Figure 3.9 Geographical locations of stations in Cluster Group 3. Substrate is mainly mud and sand and very little shellhash. Adult blue king crab were typically located at stations in this cluster group.

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 m). 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															
Cluster	Substrate* / Average depth (m)	1	2	3	4	T	1	2	3	4	T	1	2	3	4
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															
Cluster	Substrate* / Average depth (m)	1	2	3	4	T	1	2	3	4	T	1	2	3	4
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															
Cluster	Substrate* / Average depth (m)	1	2	3	4	T	1	2	3	4	T	1	2	3	4
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															
Cluster	Substrate* / Average depth (m)	1	2	3	4	T	1	2	3	4	T	1	2	3	4
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 I-10 is true.

May 1983

Substrate type

cluster	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)	o (5.4)	1 (7.0)	o (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)	O (0.8)	1 (303)	O (0.2)	14	3.79
3	25 (18.6)	O (1.5)	2 (6.5)	O (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	

Aprf 1 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	S2 (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 (9)
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.O	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	84.0S	14328.4S	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	O*9S	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
	. 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	200
		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	192.8	1.3
		2	28.6	8.0	26.4	3.3
		3	19.1	4.9 S	1905	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	000 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 anti 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

Gastropod 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 ofCG 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 significantly 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 inc' udes 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

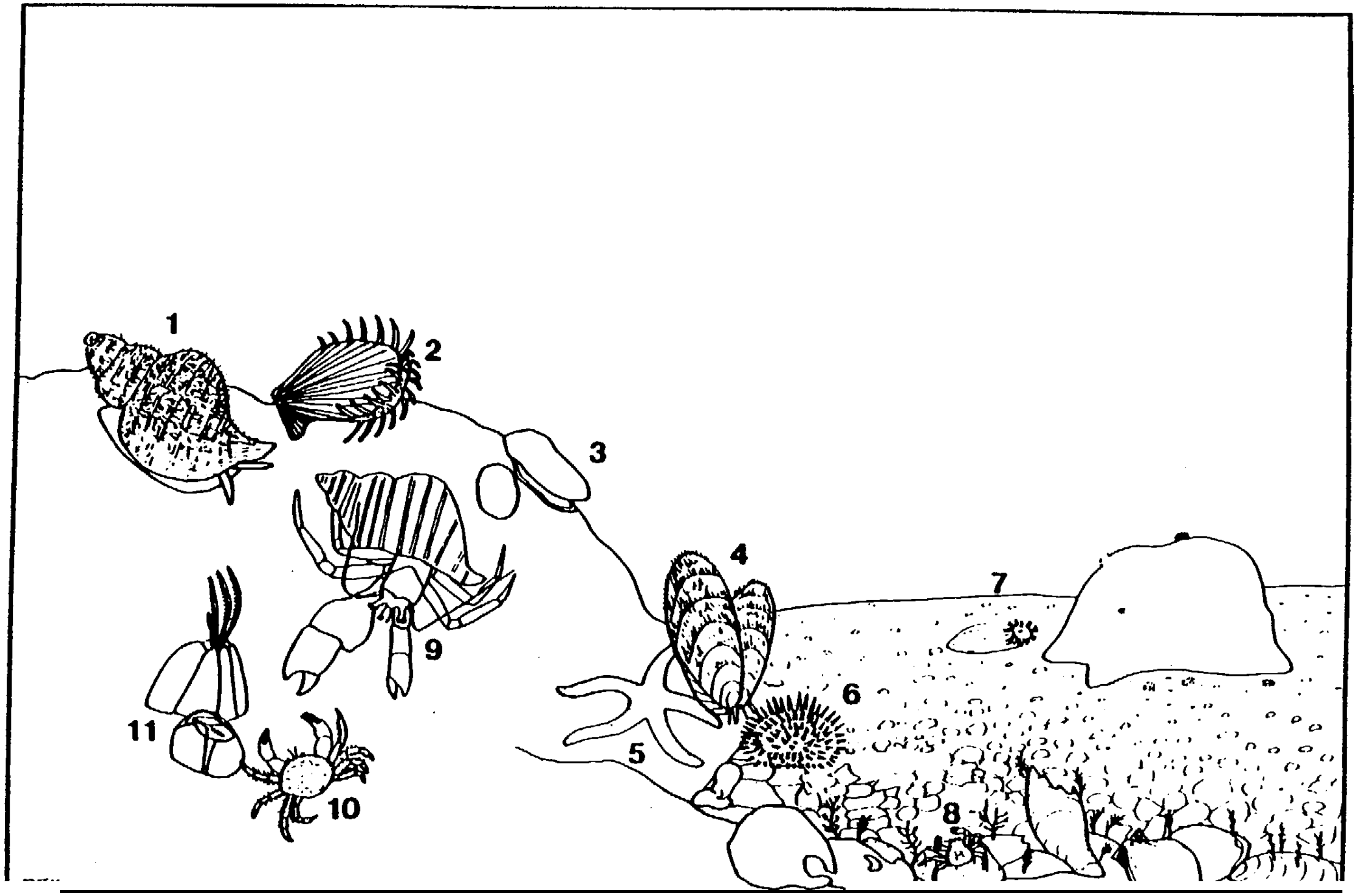


Figure 3.10 Sea urchin community, typical of rock and cobble habitat nearshore of St. Paul and St. George islands. 1, *Fusitriton oregonensis*; 2, *Chlamys* spp.; 3, *Pododesmus macrochisma*; 4, Mytilidae; 5, *Henricia* spp.; 6, *Strongylocentrotus droebachiensis*; 7, *Cucumaria* spp.; 8, juvenile *Paralithodes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

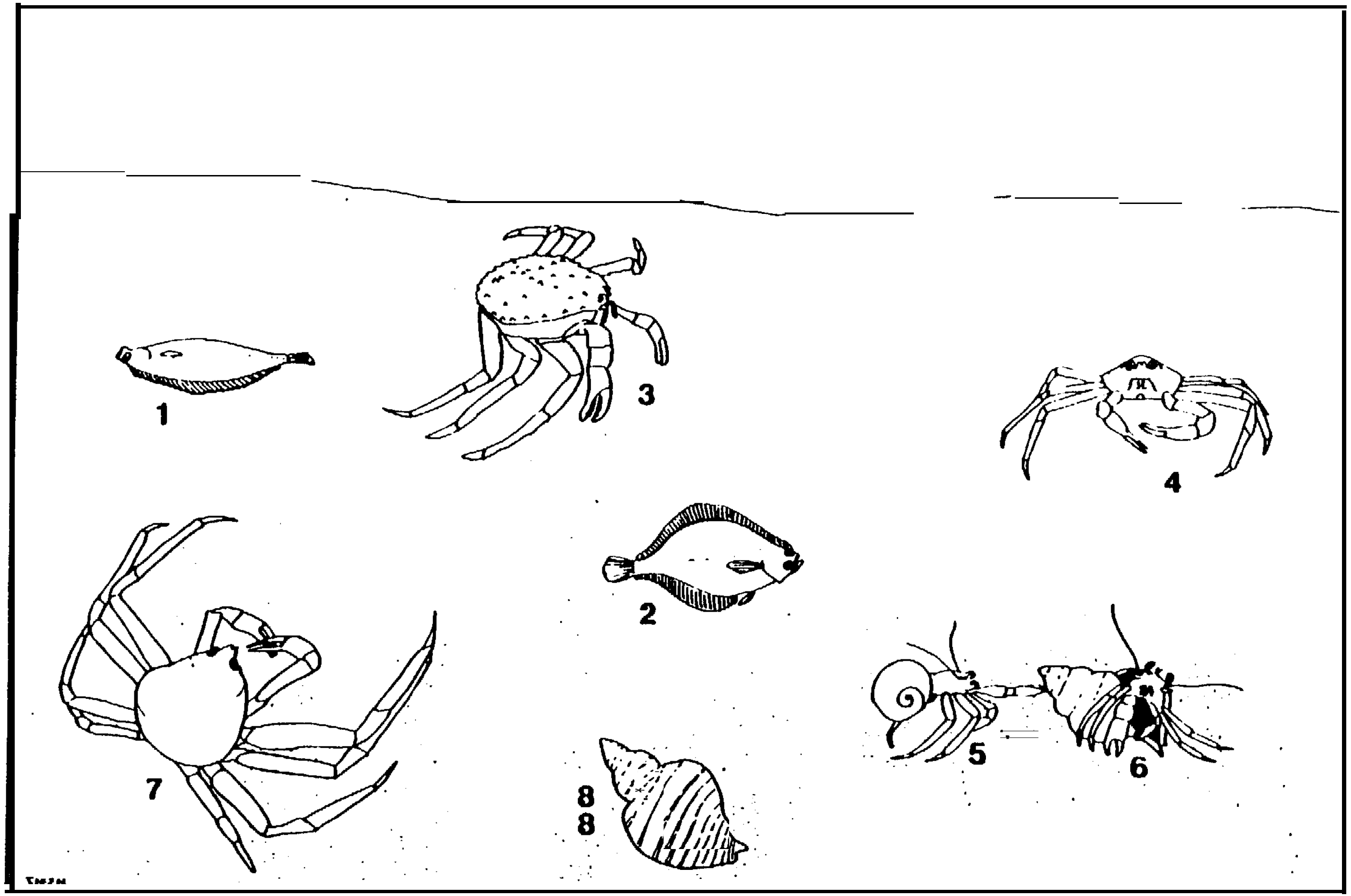


Figure 3.11 Tanner crab community, characteristic of sand/mud substrate between St. Paul and St. George islands. 1, *Lepidopsetta bilineata*; 2, *Hippoglossoides elassodon*; 3, *Paralithodes platypus*; 4, *Chionoecetes opilio*; 5, *Labidochirus splendescens*; 6, *Pagurus ochotensis*; 7, *Chionoecetes 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 Cl, C.2 and C.3 show station locations during the three cruises relative to these strata.

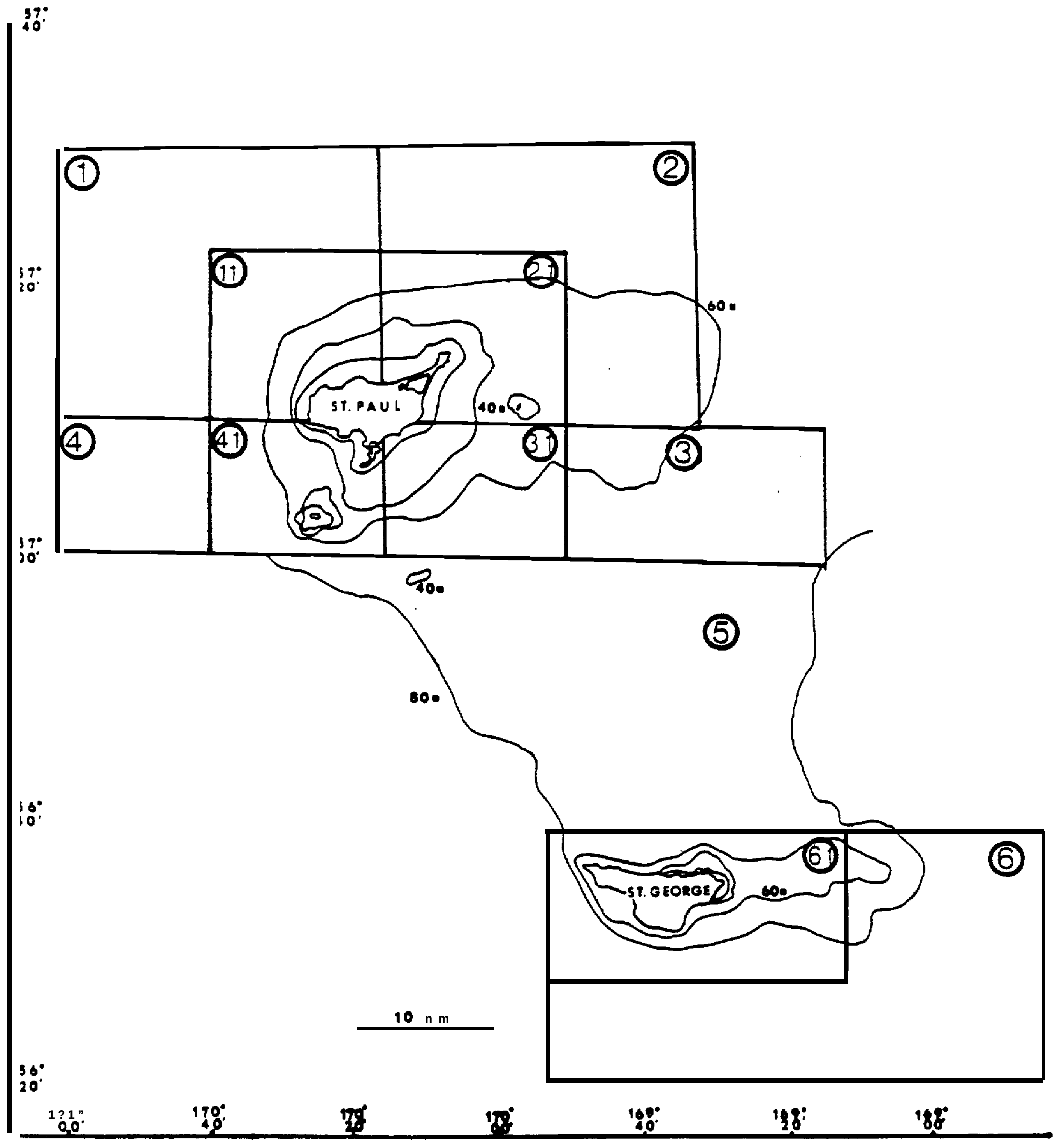


Figure 4.1 Stratum configuration of geographical areas. Inshore areas (strata 11-41 and 61) are included within the boundaries of large blocks, strata 1-4 and 6.

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 urn 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 11) 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 23 BKC occurred in the plankton. Z1 larvae were collected at 63% of all stations, Z2 at 68%, and 23 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 22 during the second week (5/16 to 5/21), and mostly 22 and 23 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

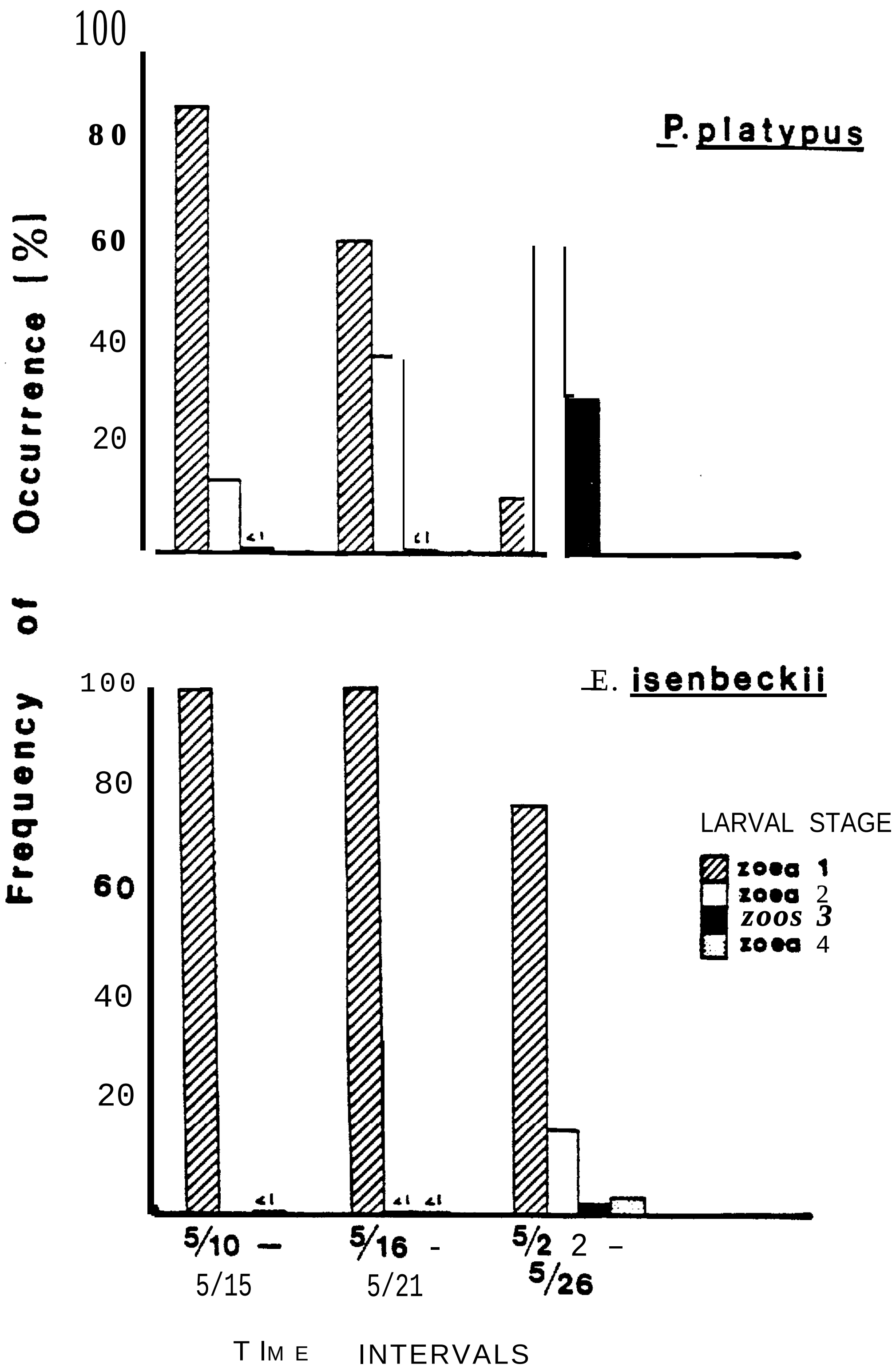


Figure 4.2 Percent stage frequency of *Paralithodes platypus* and *Erimacrus isenbeckii* larvae during Leg I, May 1983.

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 22 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 (" able 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 exoske eton is about 41% for Z1 and 26% for Z2. (Table 4.1).

4.1.3 Distribution and Abundance

BKC larvae occurred at82% 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 ± 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 111
Whole Body			
Dry weight	.443 ± .039 n = 10	.533 ± .104 n=ll	.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.

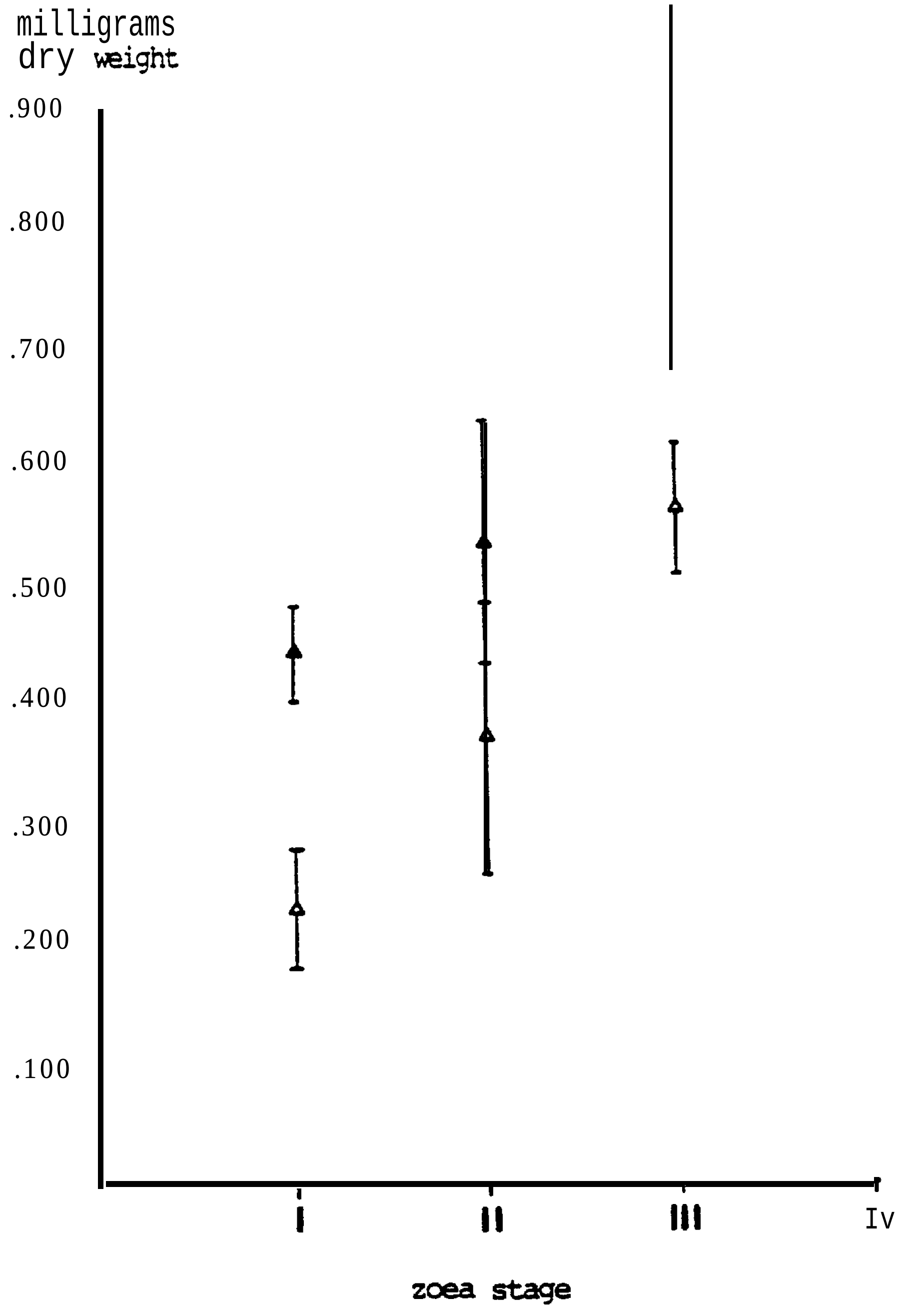


Figure 4.3 Comparison of *Paralithodes camtschatica* ( ) and *P. platypus* ( ) zoeal weight/stage growth. Shown are means ± 1 SD.

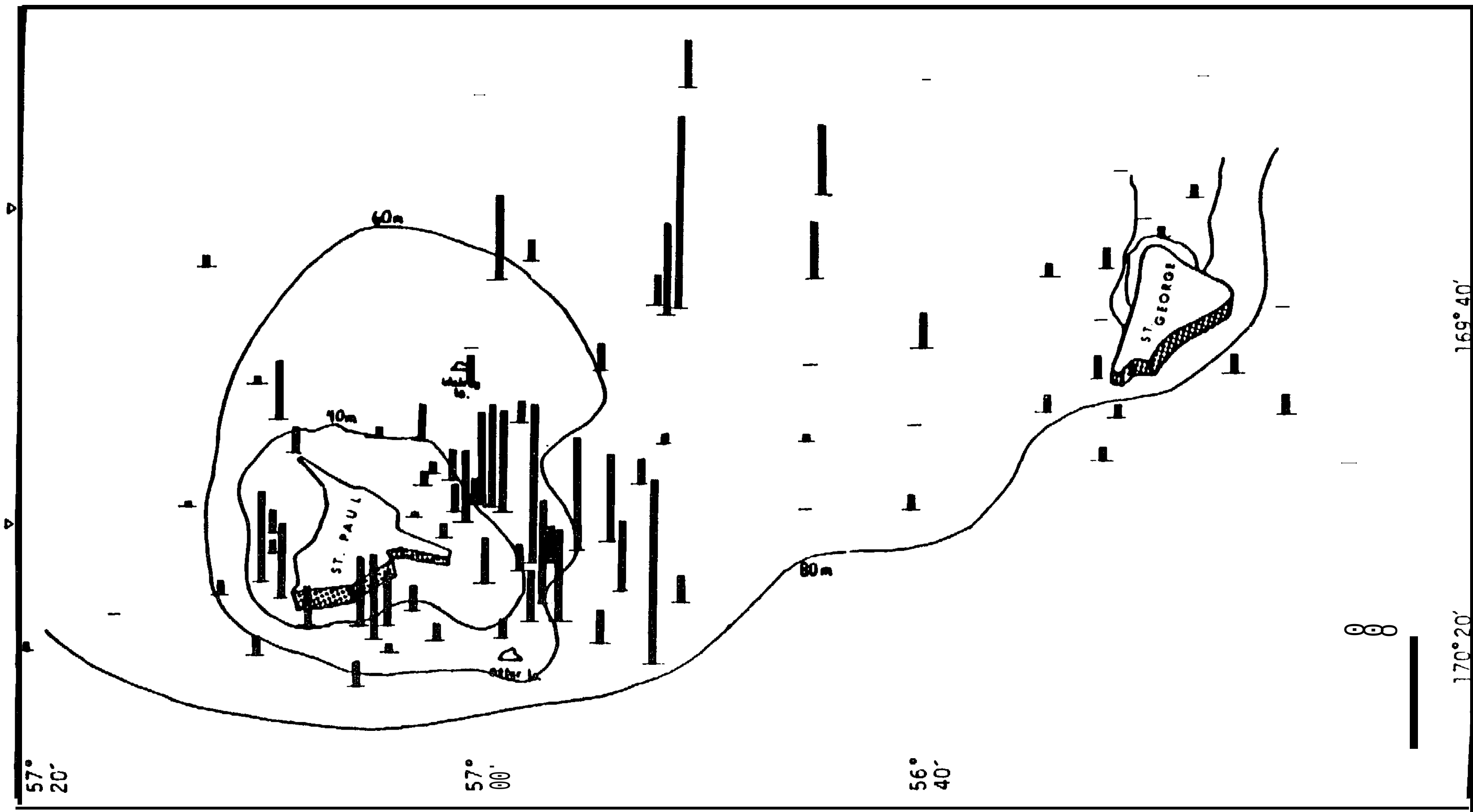


Figure 4.4 Paralithodes platypus larvae, May 983, number of zoeae/ ∞ m^2.

Paralithodes platypus larvae

May 1983

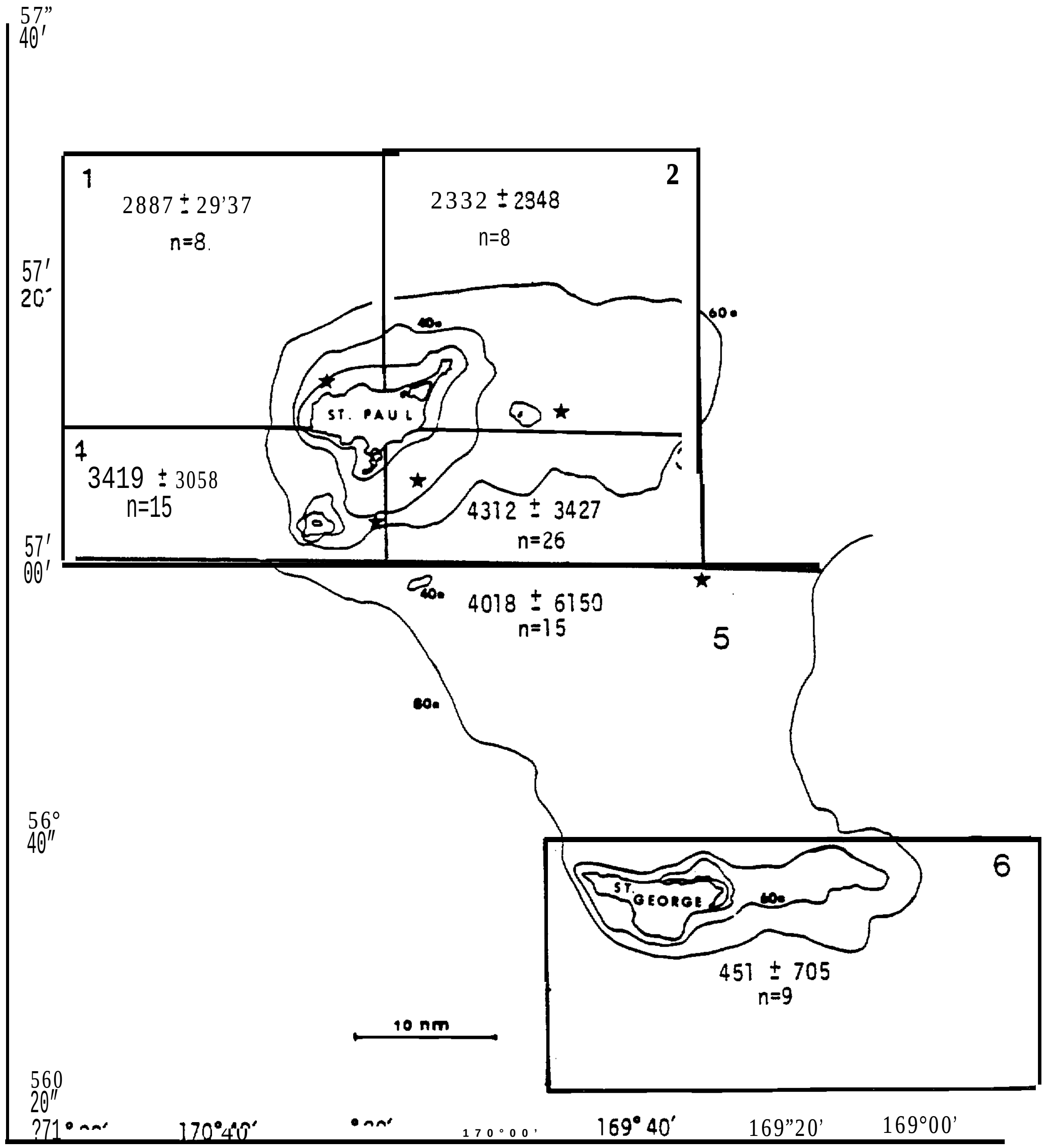


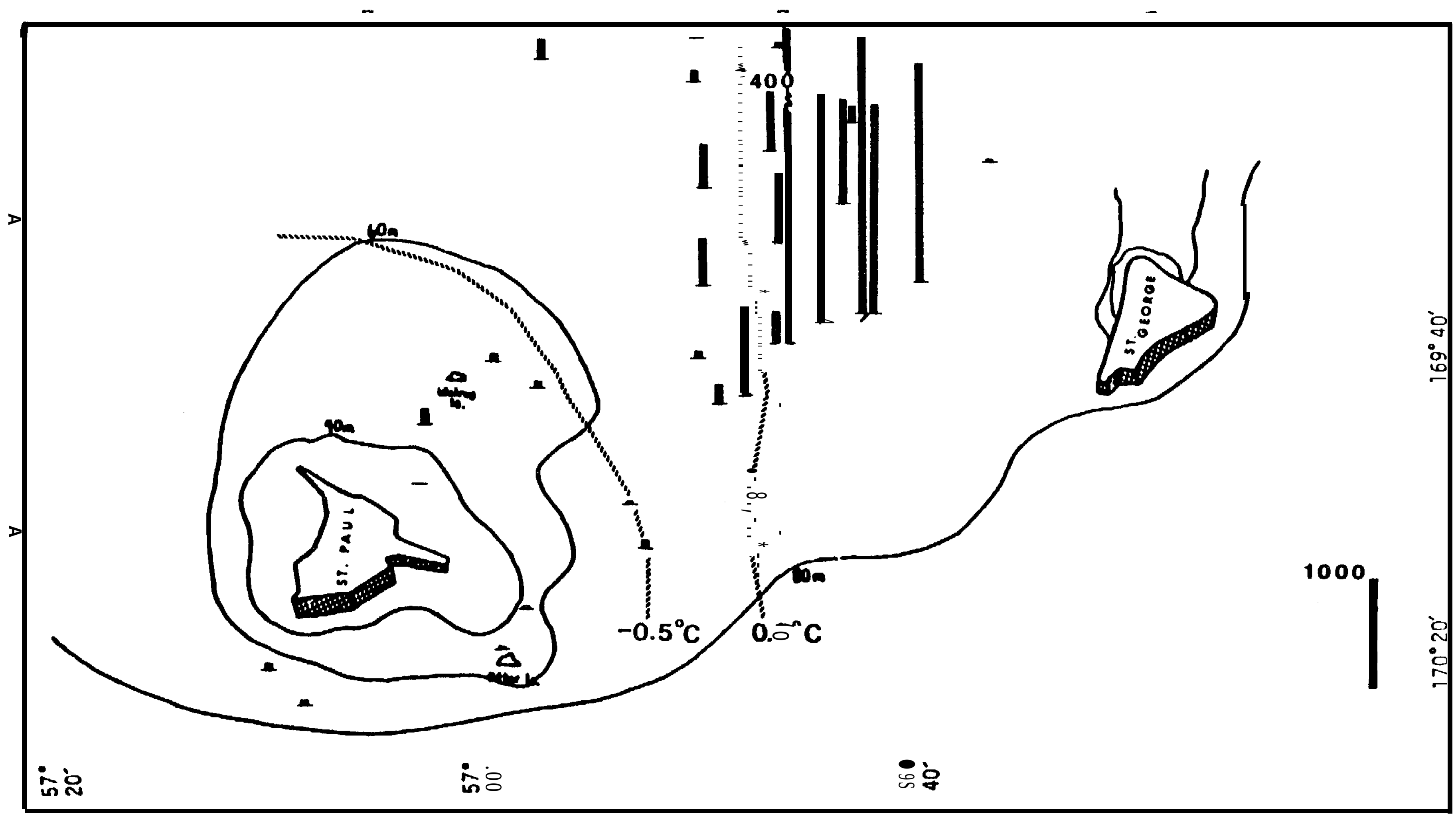
Figure 4.5 Paralithodes platypus larval abundance (no. larvae/100 m^2) by strata, May 1983. Shown are mean ± 1 SD and number of stations with larvae; stars indicate stations with the highest abundance per stratum.

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).

<u>Vertical Distribution and Abundance</u>: 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



Fi 4.6 Paralithodes platypus arvae, April 1984, number of zoeae/100 m².

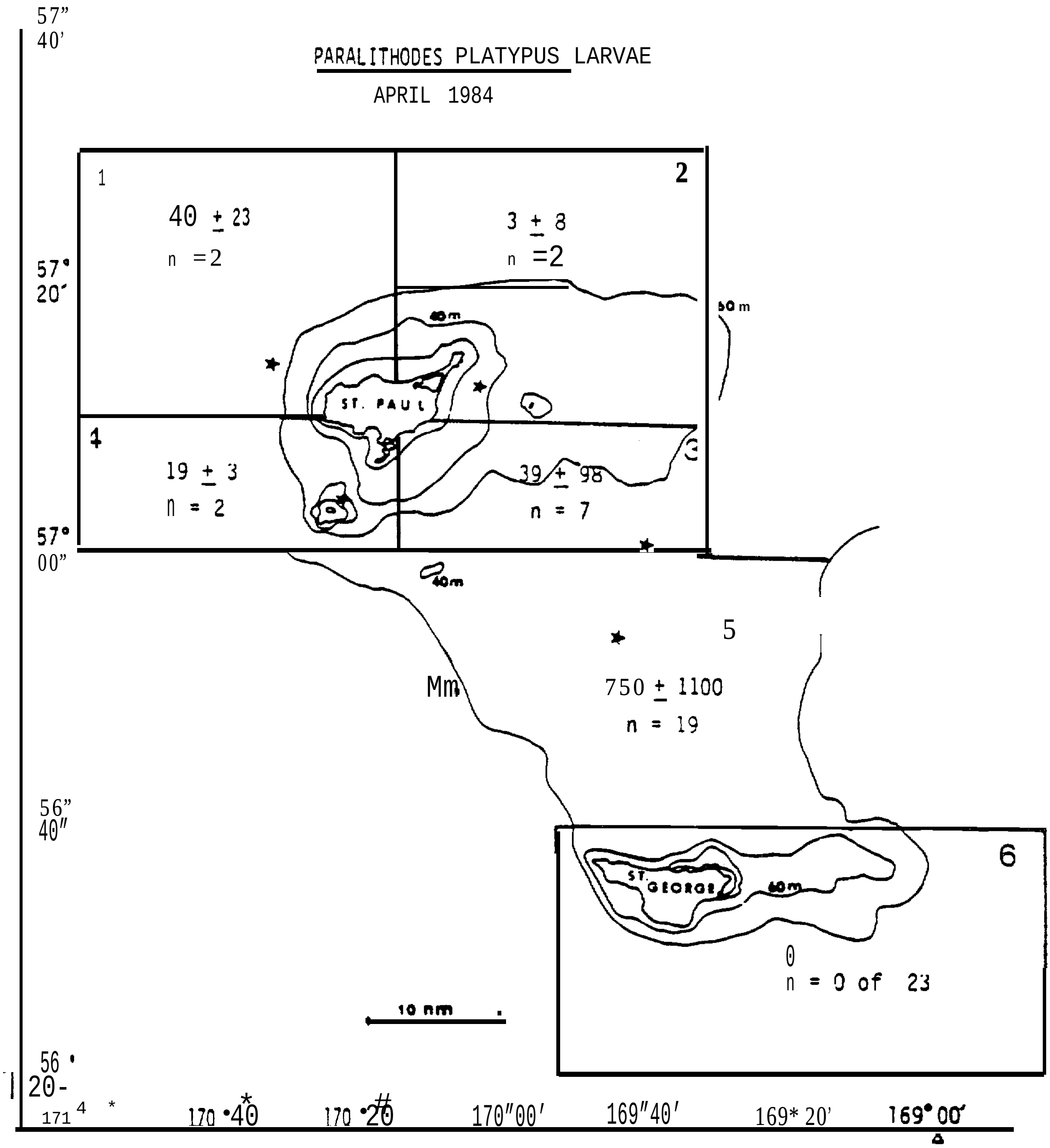


Figure 4.7 Paralithodes platypus larval abundance (no. larvae/100 m²) by strata, April 1984. Shown are mean ± 1 SD and number of stations with larvae; stars indicate stations with the highest abundance per stratum.

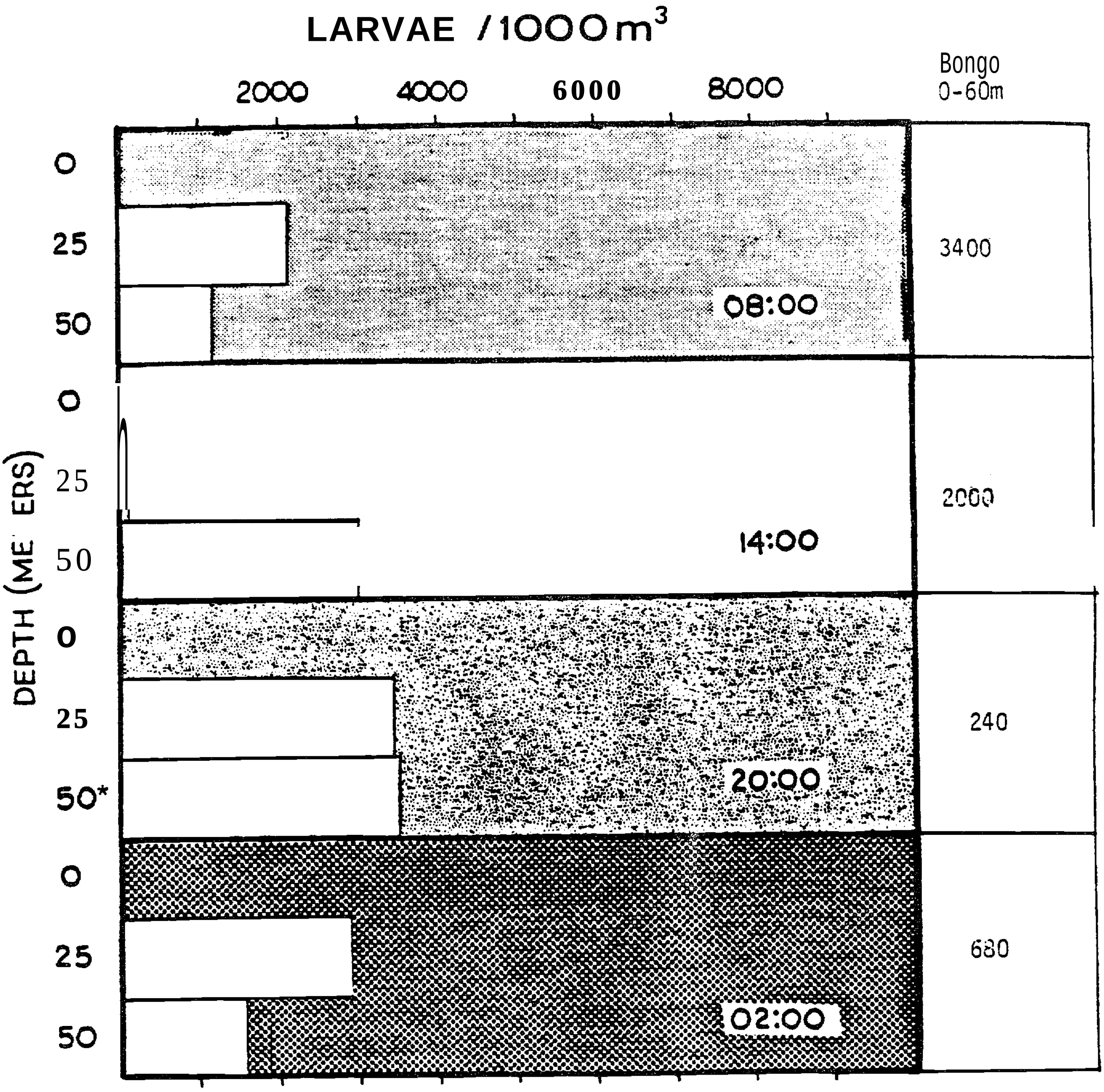


Figure 4.8 Larval Paralithodes platypus depth distribution, May 1983. Diel station was sampled by neuston, Tucker, and bongo tows. Times on right are local mean time.
*Poor tow--neuston net fished 50 m-surface.

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

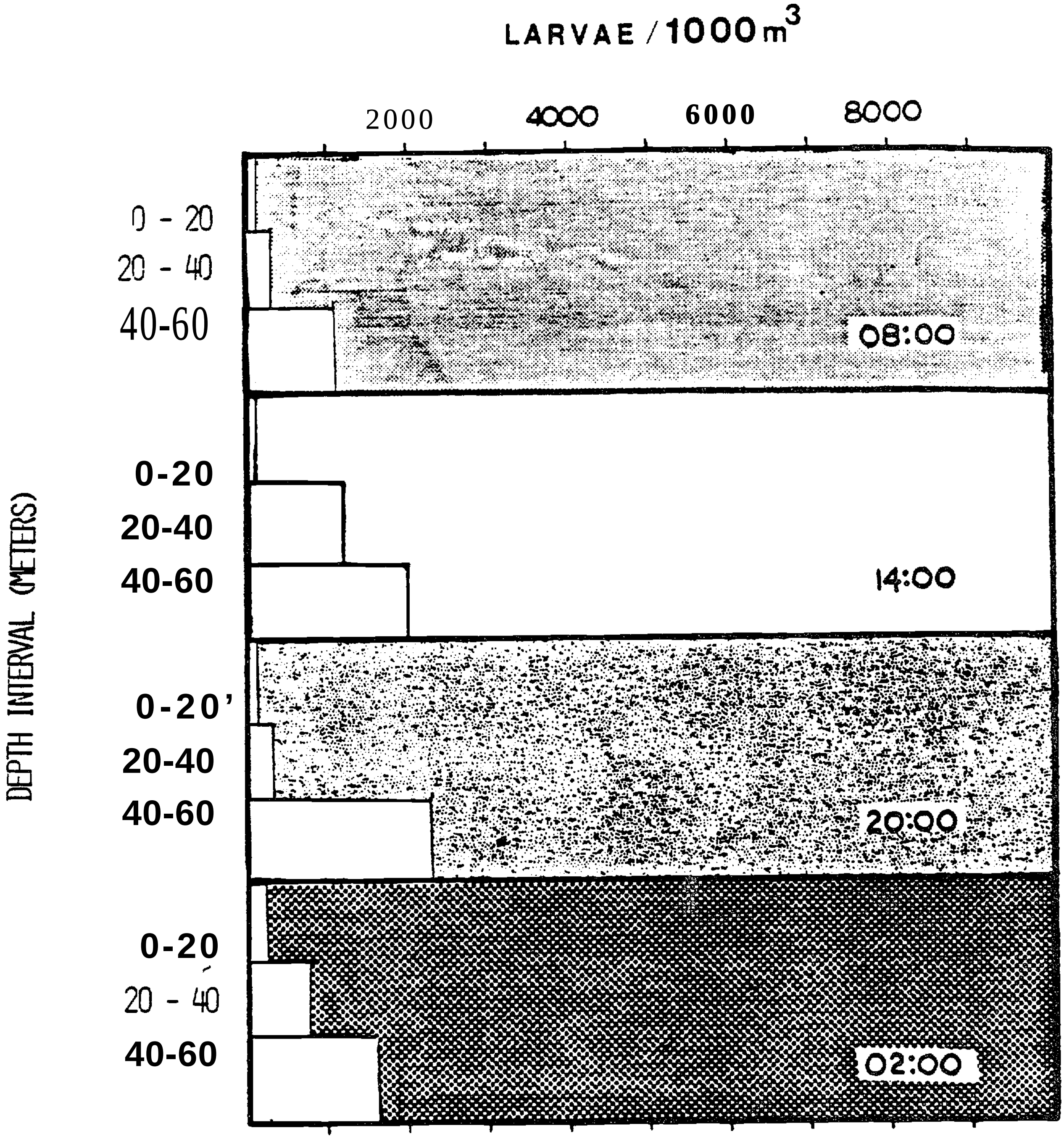


Figure 4.9 Paralithodes platypus larvae, April 1984, number of zoeae/1,000 m^3, diel vertical distribution, Tucker trawls only.

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 covers 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	N M^2	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	

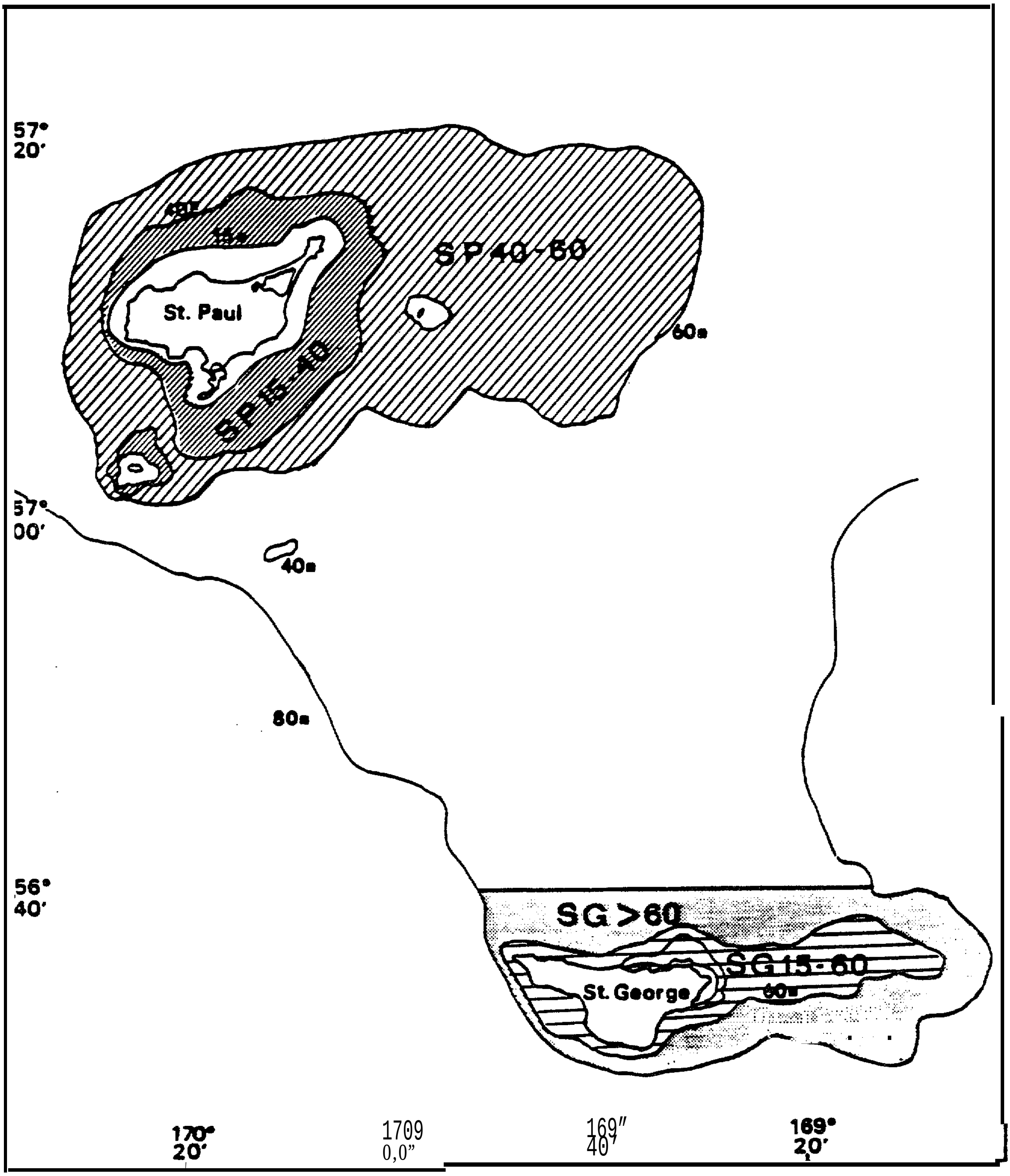


Figure 4.10 Depth strata around St. Paul (SP) and St. George (SG) islands; intervals in meters (see Table 4.4 for areas).

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 O+ and 1+

SHELLHASH, ST. PAUL, BT

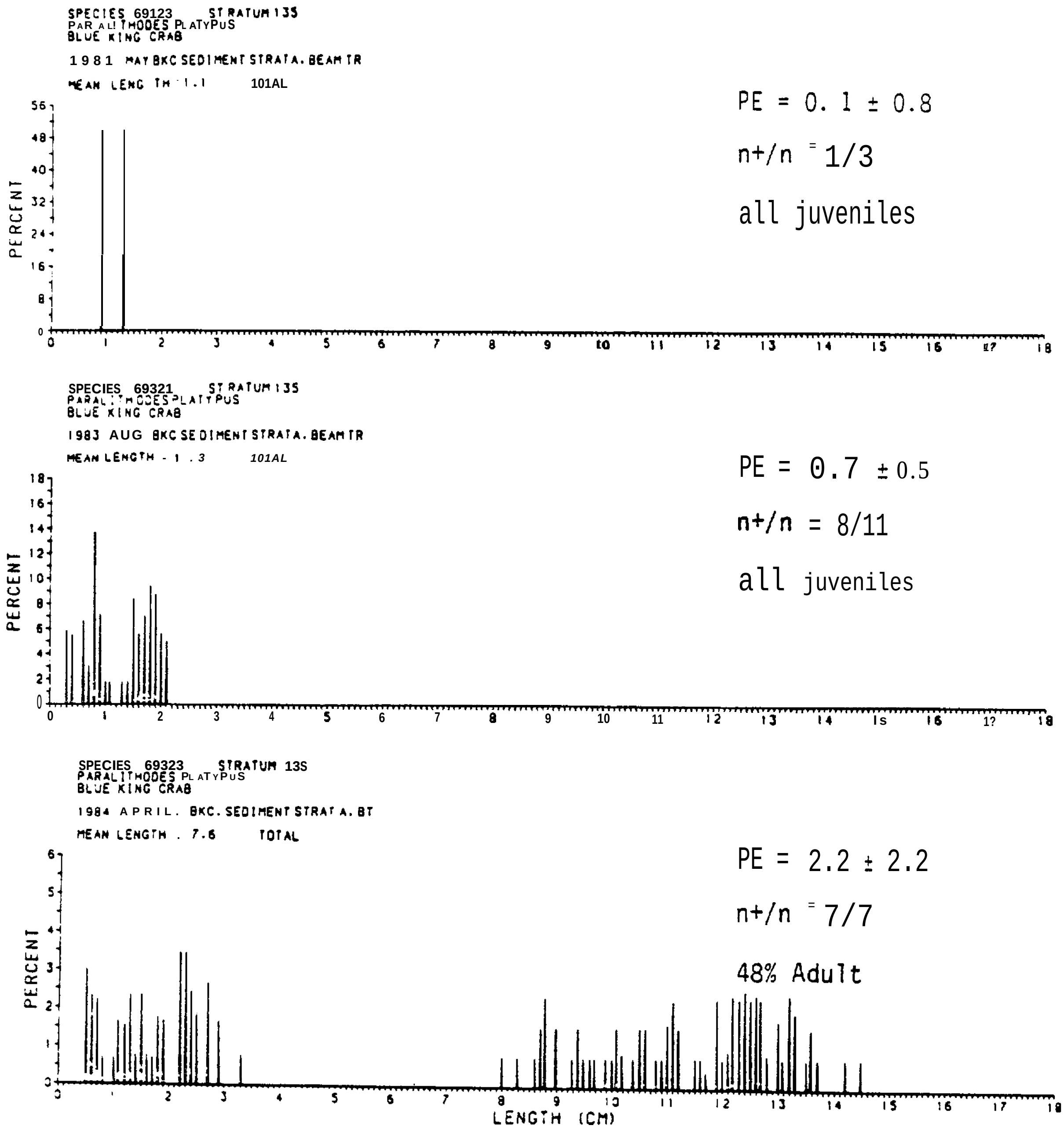


Figure 4.11 Carapace length frequencies of blue king crab collected in May and August 1983 and April 1984 by beam trawls from stratum 135, the shellhash stratum of the sediment strata configuration. Populations estimate (PE) in millions of crab, number of stations with crab/total number of stations sampled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

SAND, ST. PAUL, BT

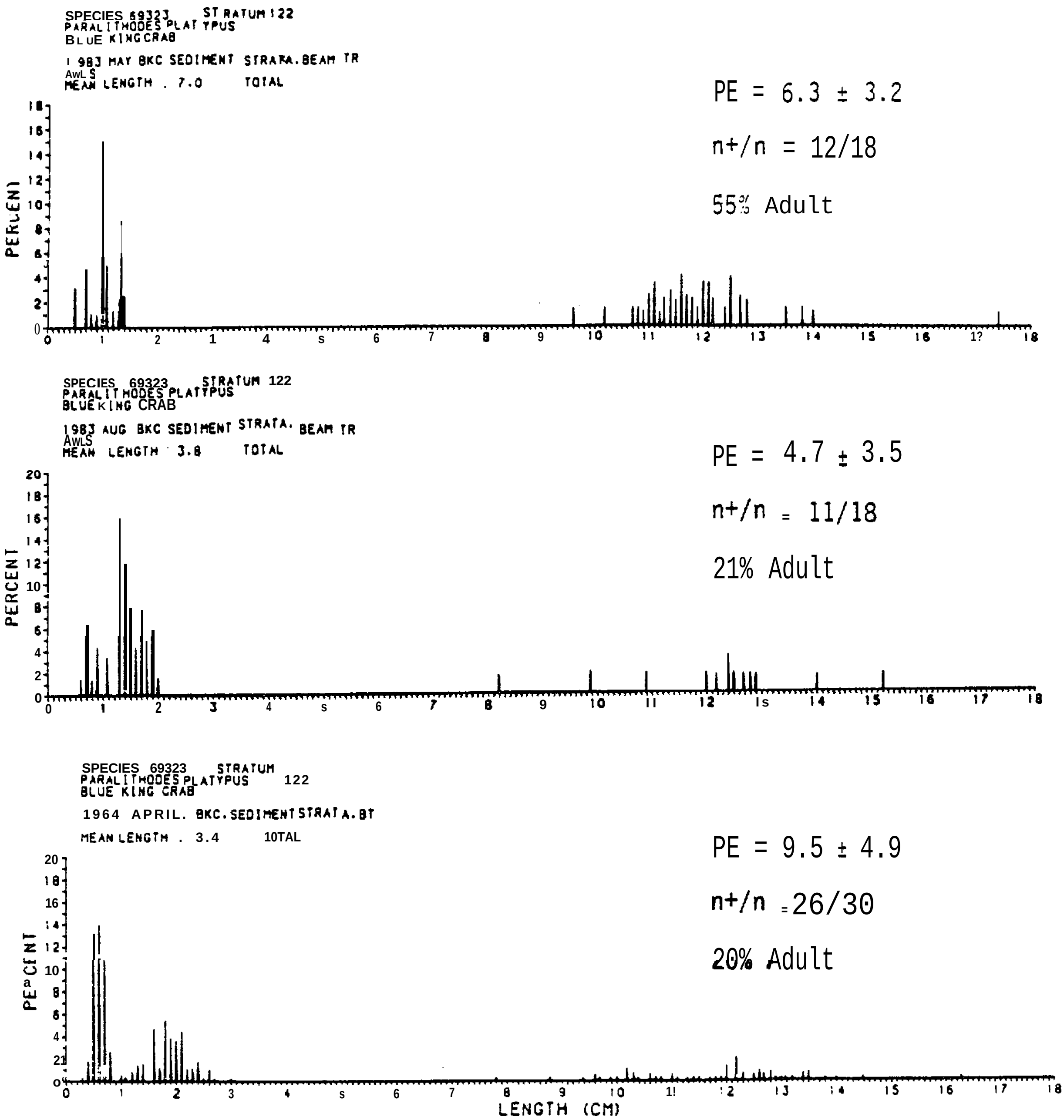


Figure 4.12 Carapace length frequencies of blue king crab collected in May and August 1983 and April 1984 by beam trawls from stratum 122, the sand substrate stratum to the east of St. Paul Island. Population estimate (PE) in millions of crab, number of stations with crab/total number of stations sampled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

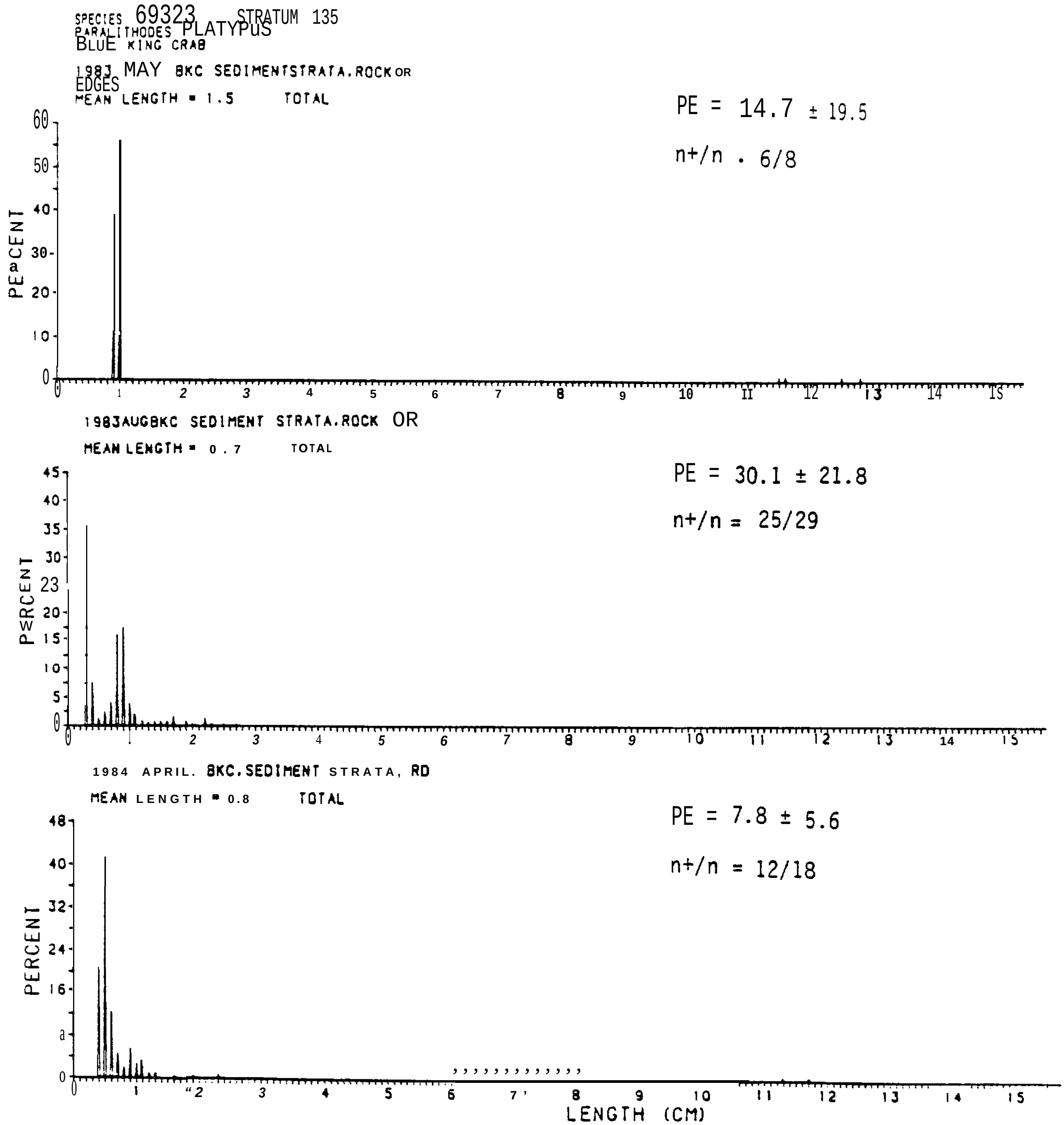


Figure 4.13 Carapace length frequencies of blue king crab collected in May and August 1983 and April 1984 by rock dredges in shellhash stratum 135 (sediment strata configuration). Population estimate (PE) in millions of crab, number of stations with crab/total number of stations sampled (n+/n), and percentage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

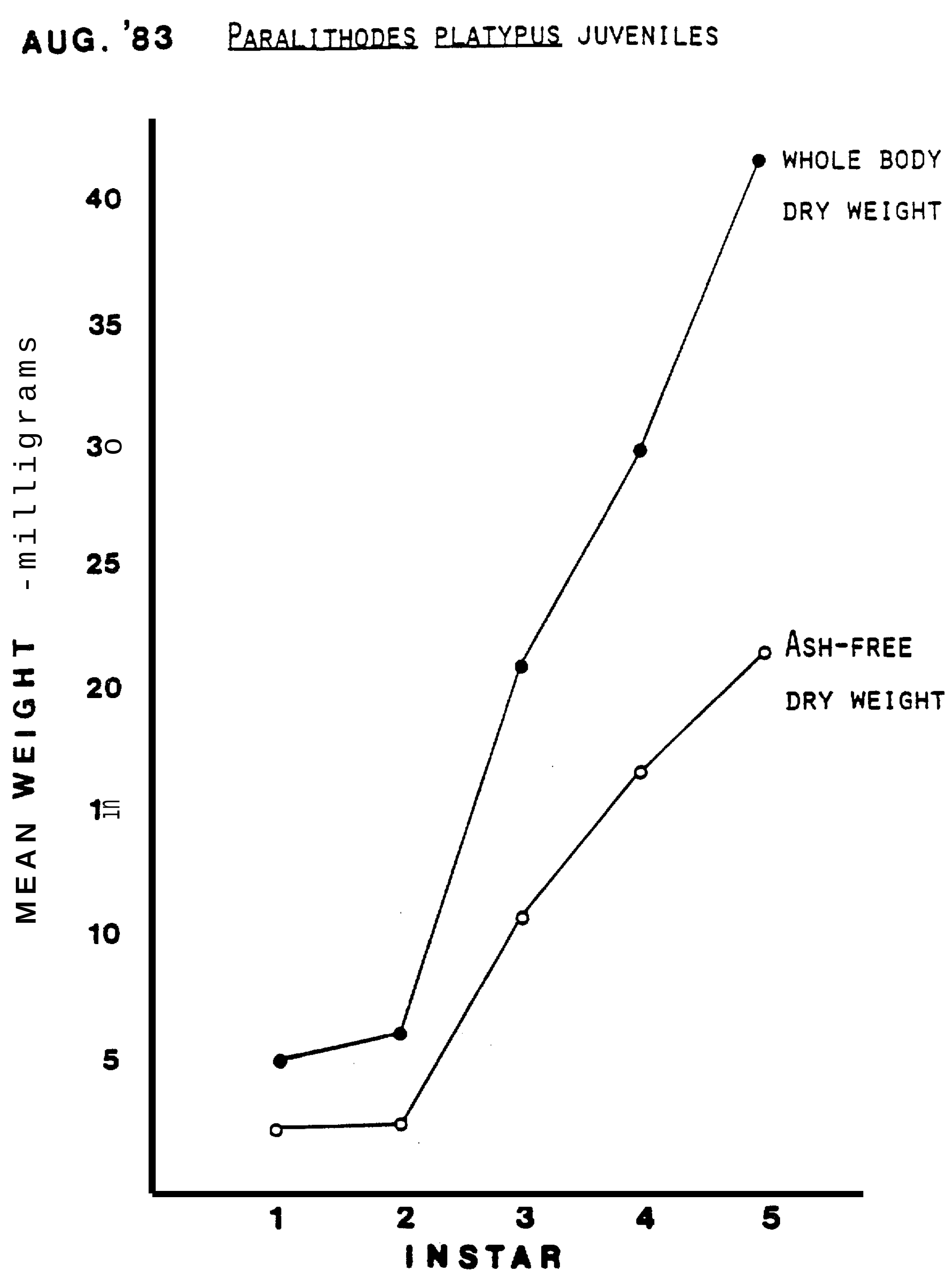


Figure 4.14 Paralithodes platypus juveniles, whole body dry weights vs. ash-free dry weights for 1st-5th instars, August 1983.

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.

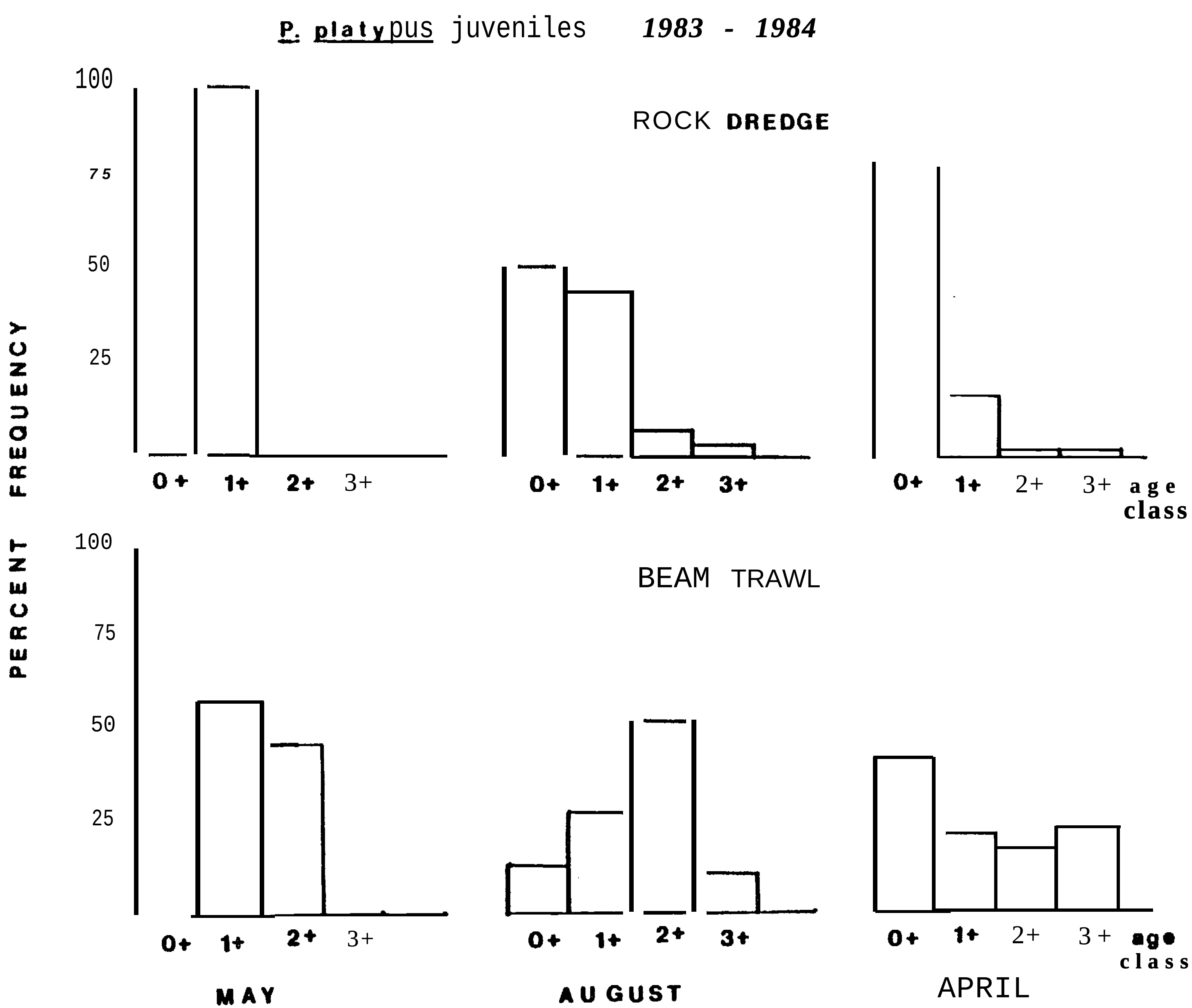


Figure 4.15 Percent frequency of age classes (0+ to 3+) of the Paralithodes platypus juvenile population taken by gear and by month from-the inshore area (strata 11-41) around St. Paul Island, 1983-84.

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.S). 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 from37 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

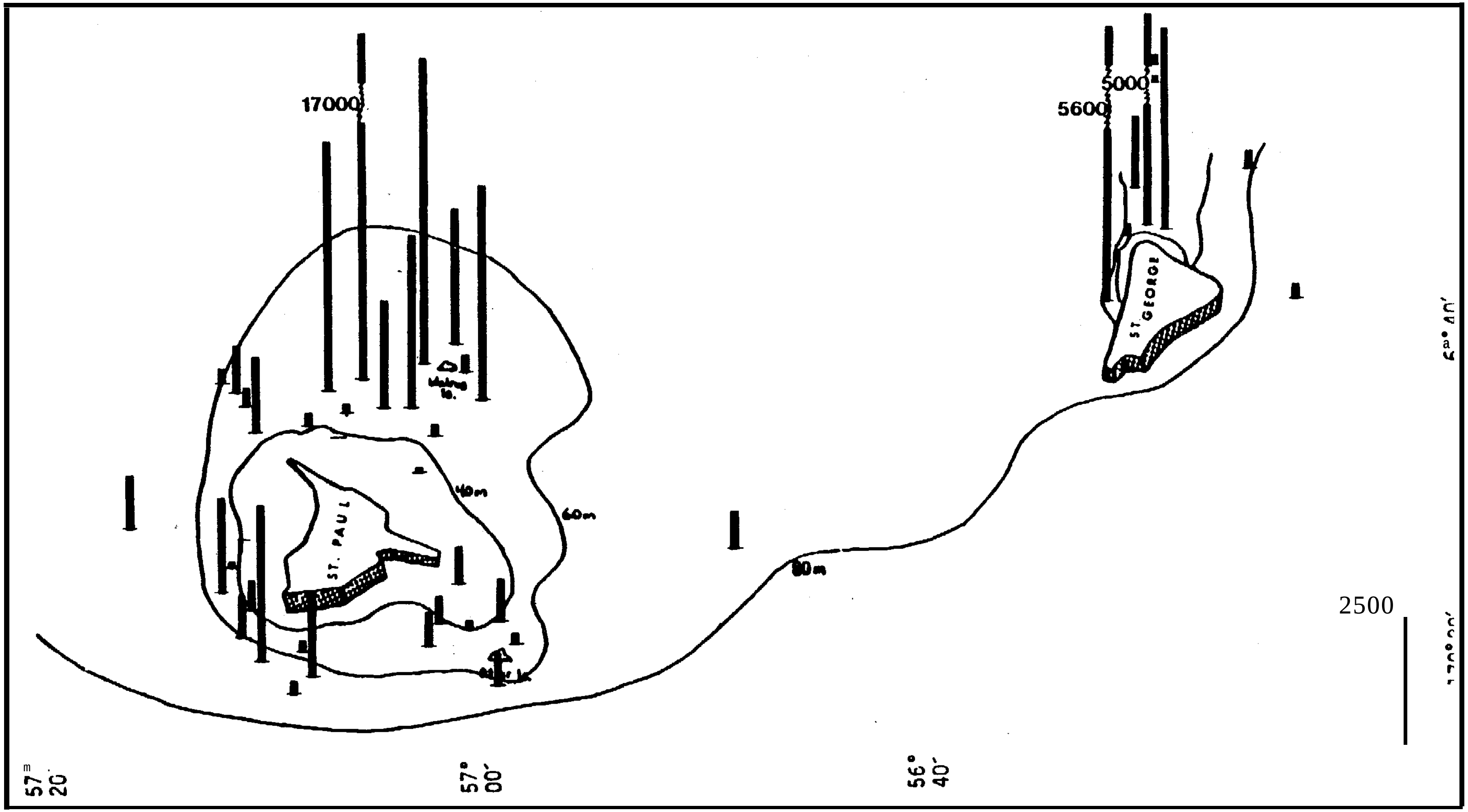


Figure 4.16 Juvenile *Paralithodes platypus* distribution and abundance, August 1983, expressed as number of juvenile crab/hectare caught by rock dredges only.

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 (± 692) crab/ha at St. Paul island and a mean of 425 (± 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 (± 57) crab/ha around St. Paul Island and a mean of 32 (± 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 Sample size	May 1983 Density	August 1983 Sample size	August 1983 Density	April 1984 Sample size	April 1984 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).

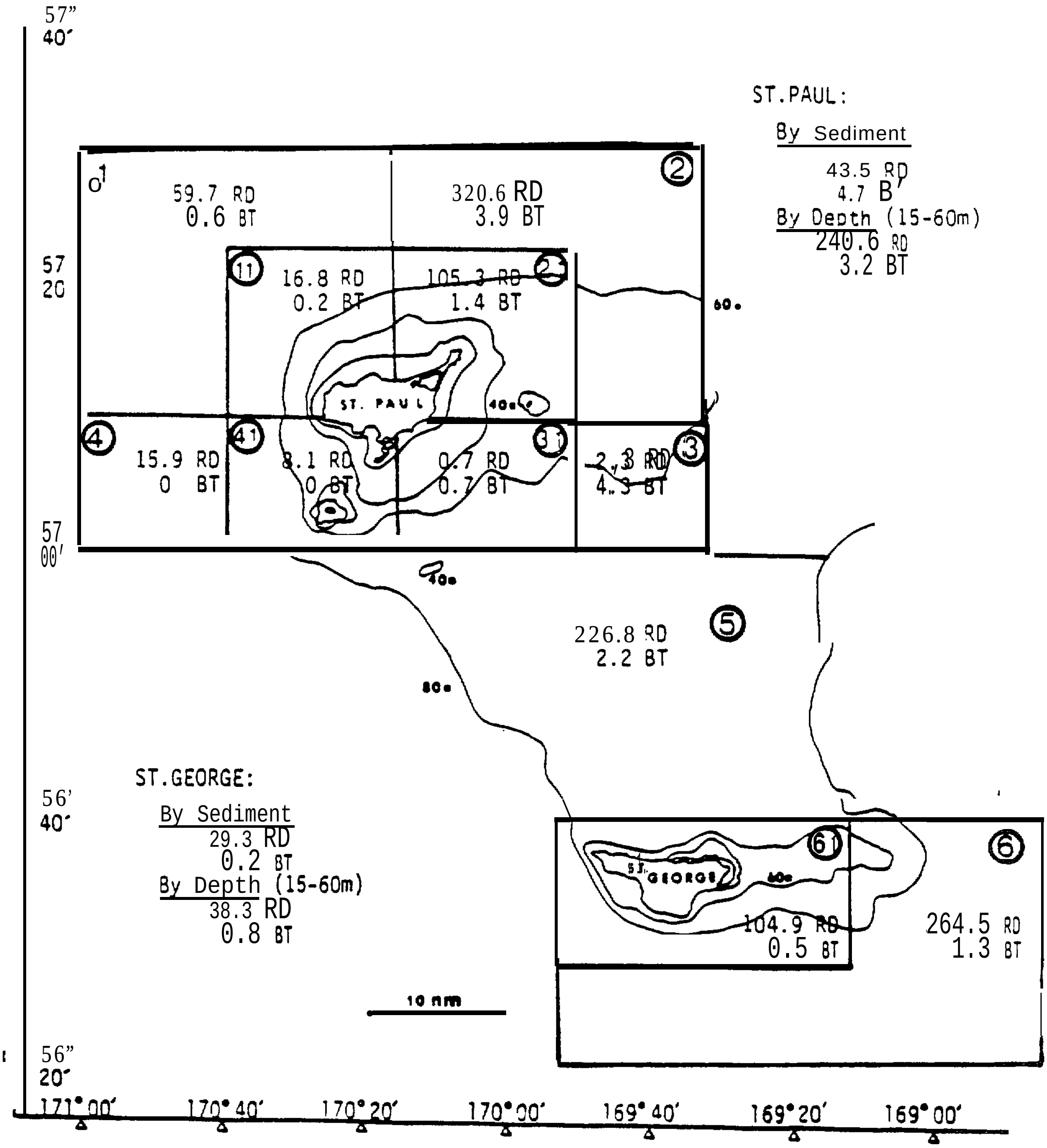


Figure 4.17 Population estimates for *Paralithodes platypus* juveniles in August 1983 by strata. Separate estimates, expressed as number of crab x 10^6, are given for each gear; RD = rock dredge, BT = beam trawl. Estimates for nearshore strata 11-41 and 61 can be compared to the island totals figured 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 to43.5 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 O+. 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.

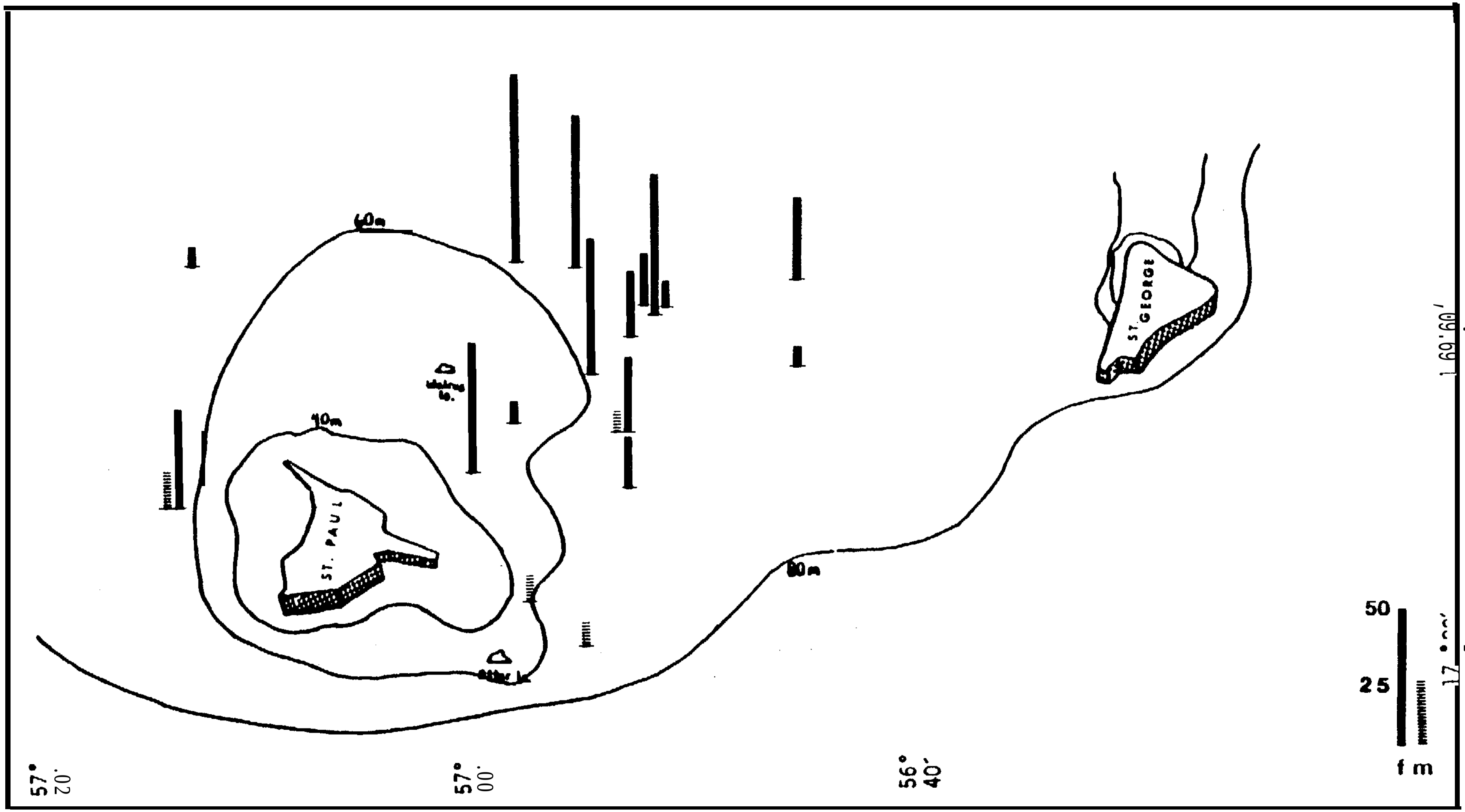
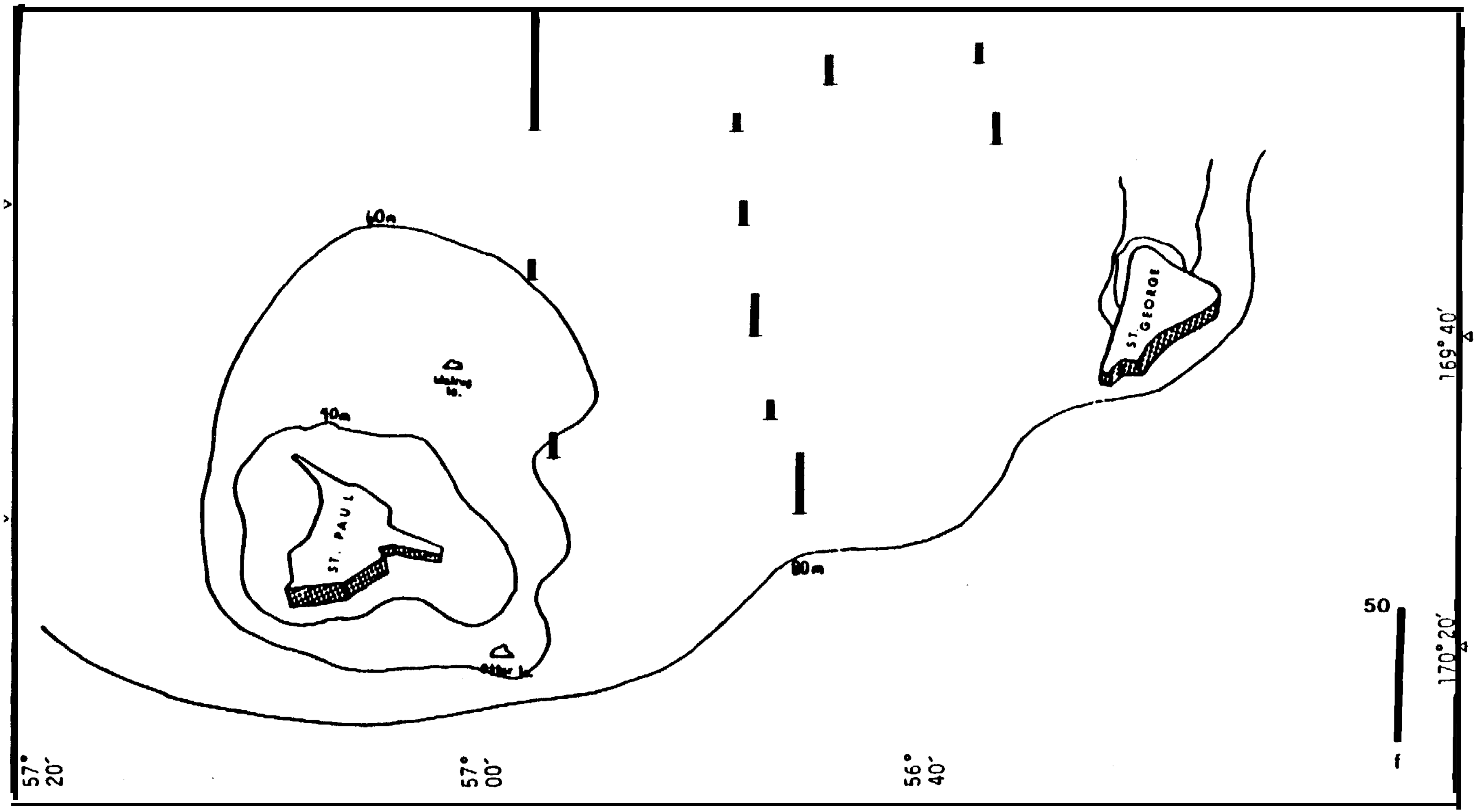


Figure 4. 8 Paralithodes platypus adults, May 1983, expressed as number of crab/hectare taken by beam trawls, females (solid bars) and males (striped bars).



F gure 4. 9 Para ithodes platypus adult distribution and abundance, August 1983, expressed as numDer oT crab/hectare taken by beam trawls, females only. No males were taken during this cruise.

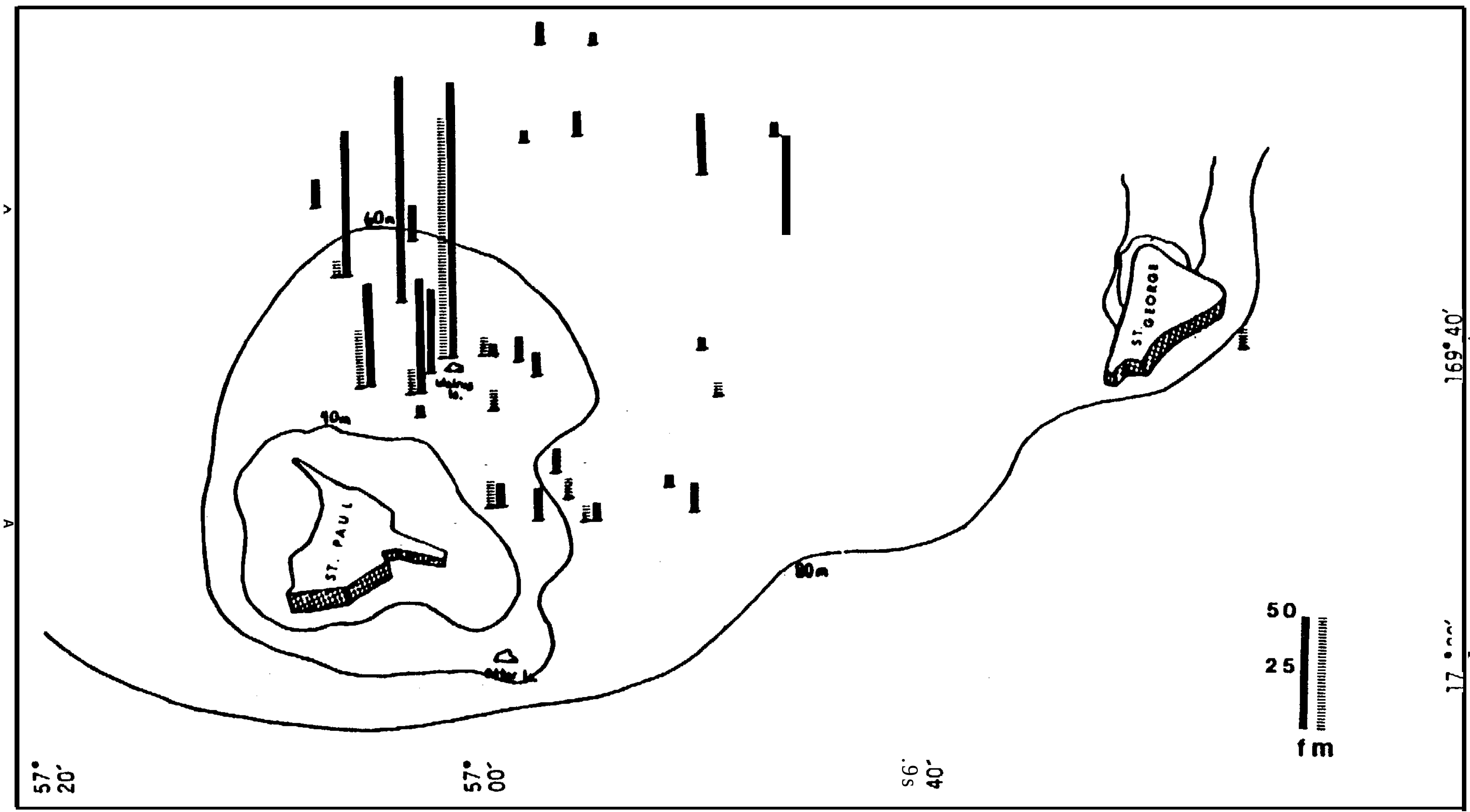


Figure 4.20 Paralithodes platypus adult distribution and abundance, April 1984, expressed as number of crab/hectare taken by beam trawls, females (solid bars) and males (striped bars).

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

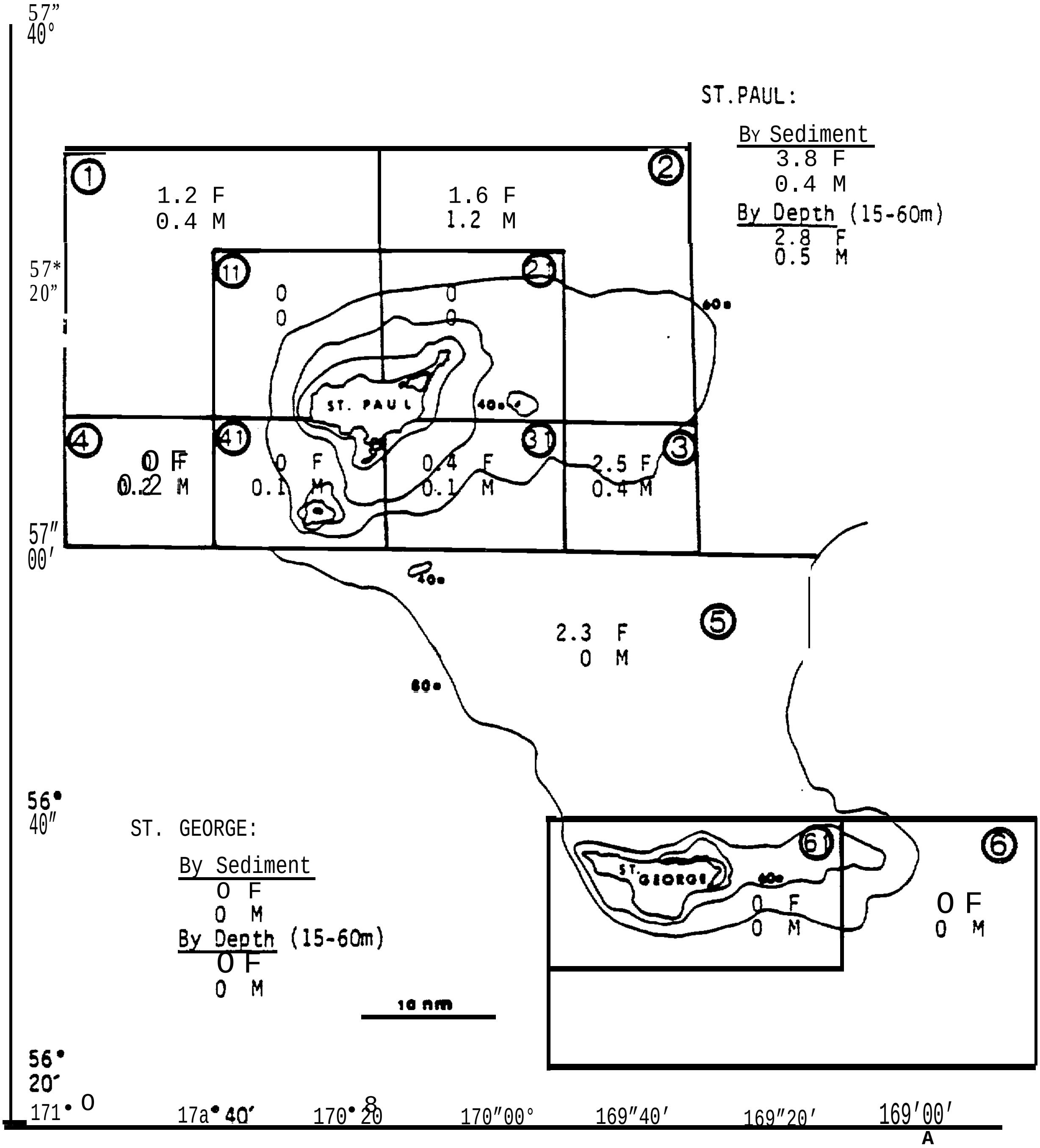


Figure 4.21 Population estimates for Paralithodes platypus adults by sex and strata for beam trawl data in May 1983. Estimates are expressed as millions of crab.

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 urn, 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 calculatedly dividing the ash-free egg weight by the ash-free weight of the remaining body.

4.5.2 Gametogenesis and Embryonic Development

Mav 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 urn (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 urn (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.

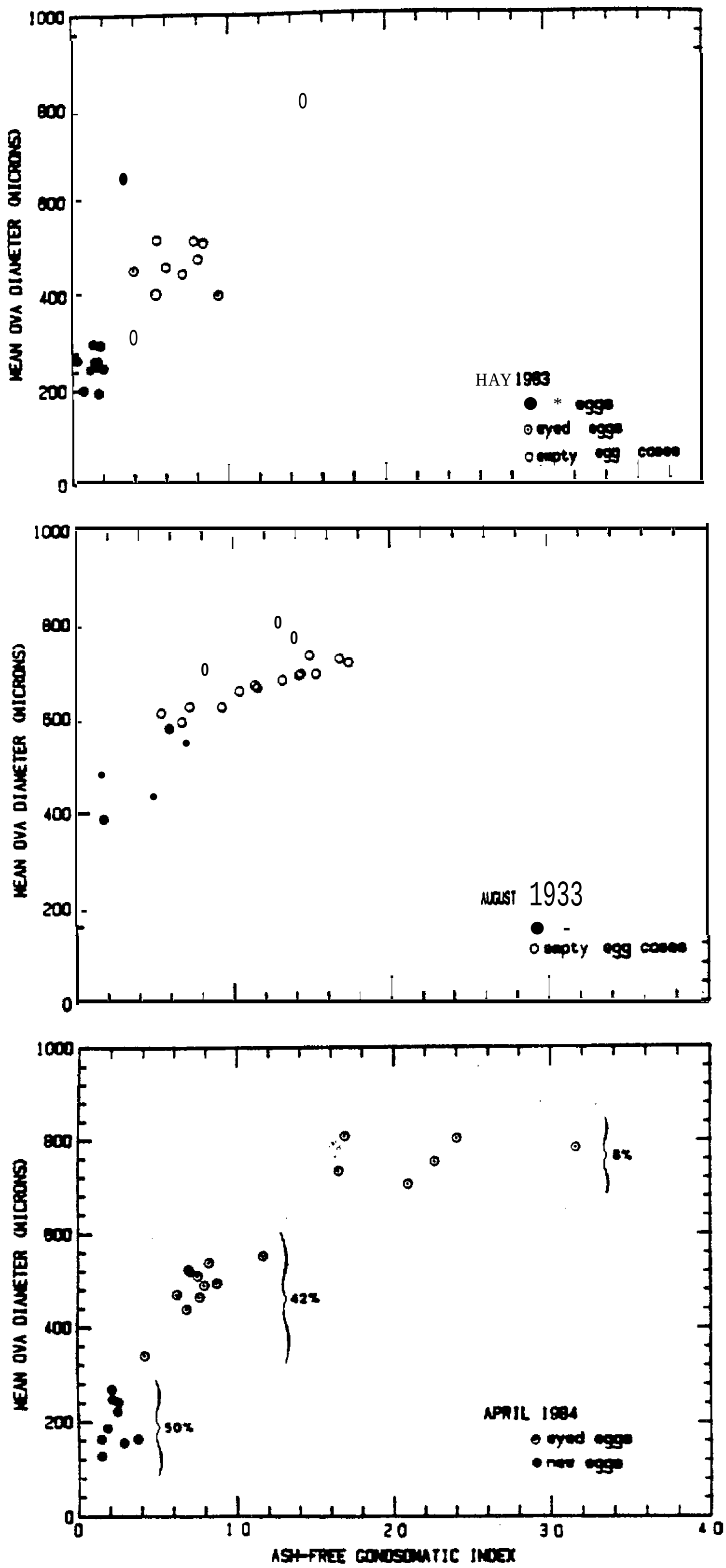


Figure 4.24 Mean ova diameters and ash-free gonosomatic indices for female blue king crab, 1983-84.

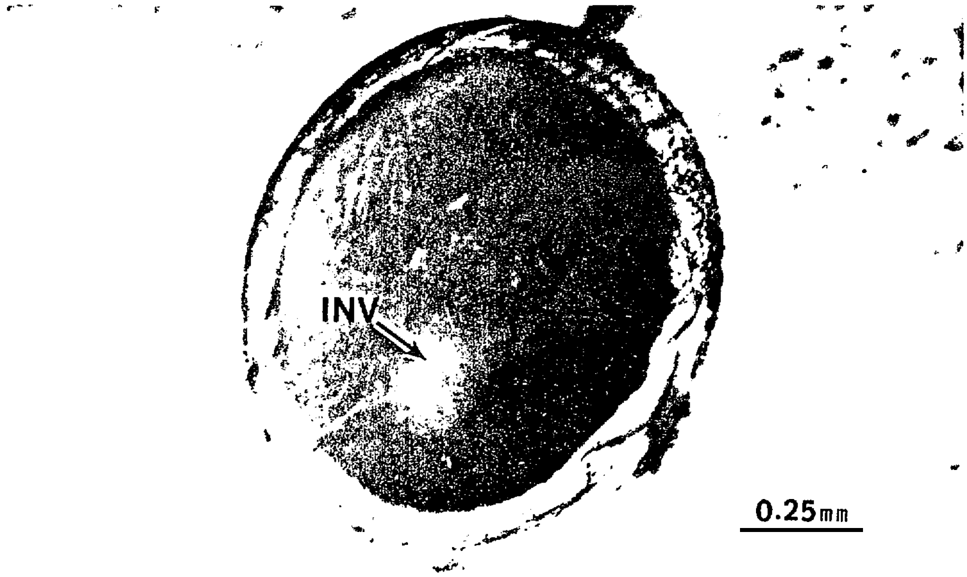


Figure 4.25 Egg from a new shell female blue king crab taken in May 1983, showing initial invagination. INV, invagination.

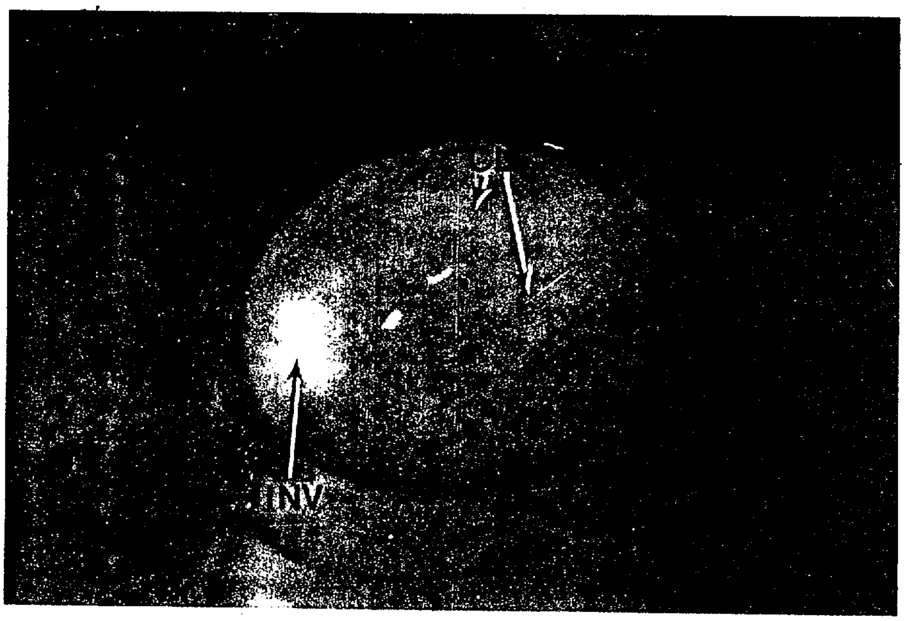


Figure 4.26 Egg from a new shell female blue king crab taken in May 1983, with cephalic lobes beginning to appear. CL, cephalic lobes; INV, invagination.

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 urn 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. Pau'), 46% had new shells (SC 1,2") and newly extruded egg masses and 43% were o' d 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 urn; 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.

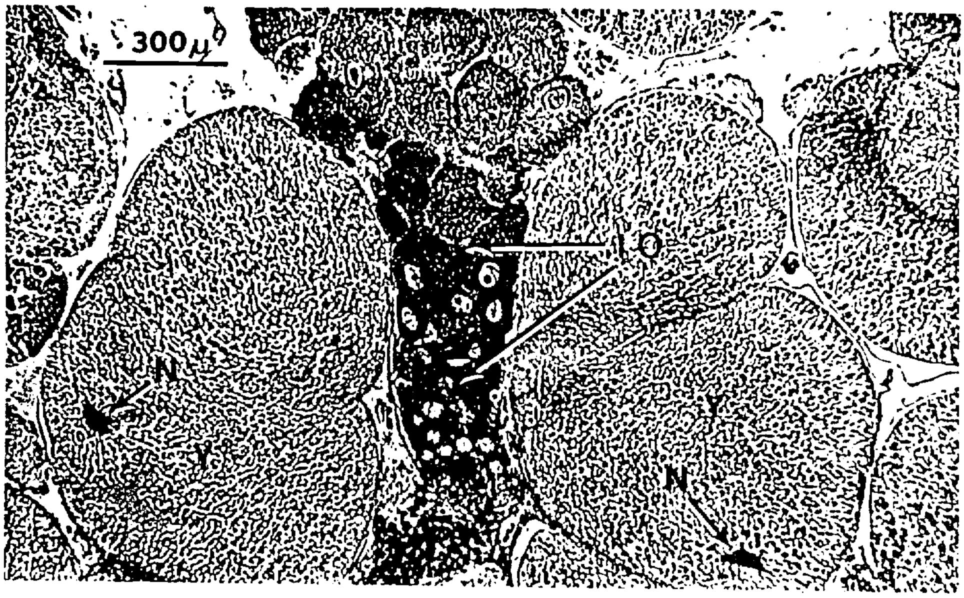


Figure 4.27 Section from a developing female blue king crab ovary showing large, well developed ova with yolk and small, non-vittelogenic ova. IO, immature ova; N, nucleus; Y, yolk.

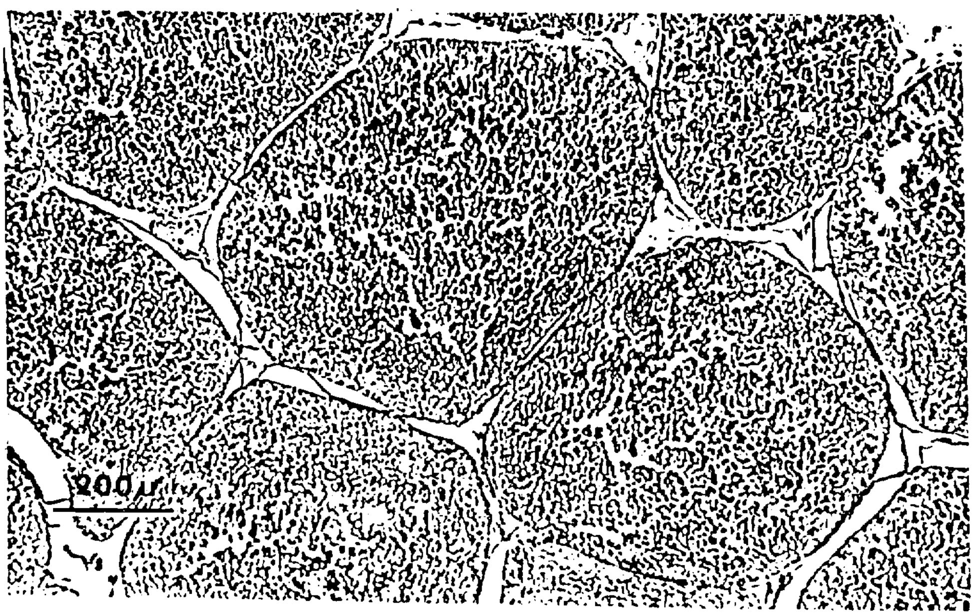


Figure 4.28 Example of a large, fully developed ovary from a blue king crab, August 1983.

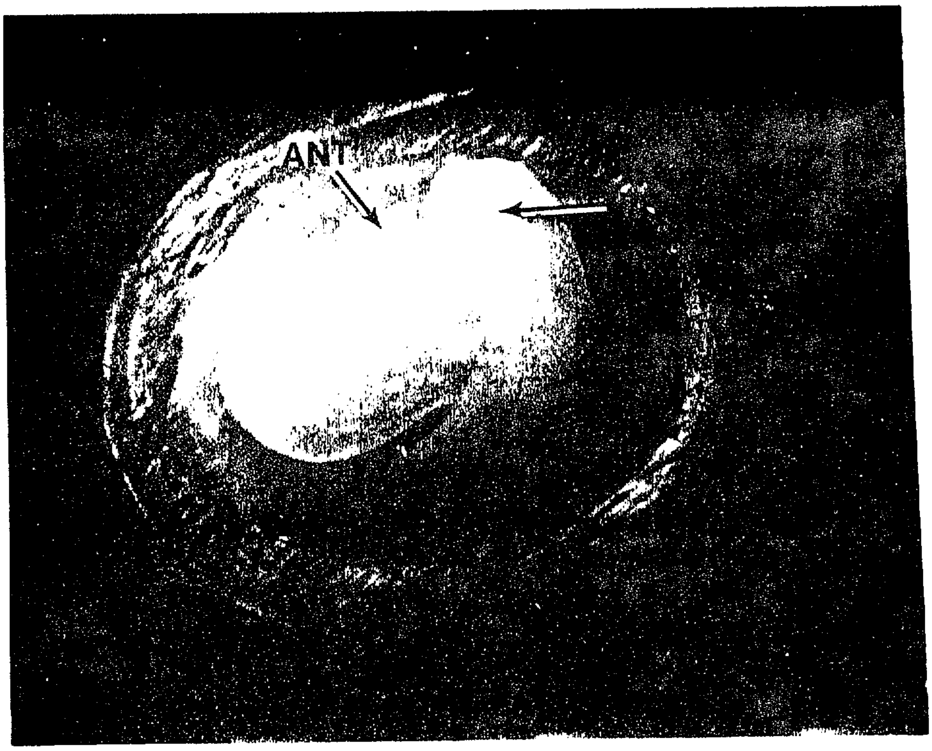


Figure 4.29 Egg from a female blue king crab caught in August 1983 showing embryo with prominent eyestalks and antennae. ANT, antennae; ES, eyestalk.

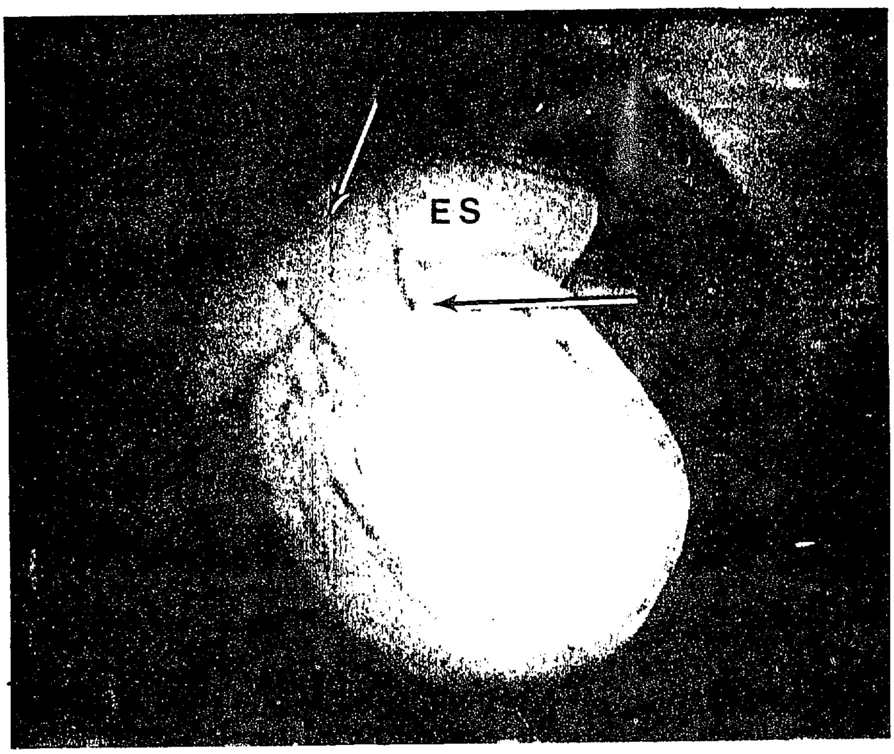


Figure 4.30 Egg from a female blue king crab taken in August 1983; large embryo with a well-developed telson. ES, eyestalk; T, telson; MXP, maxilliped.

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 urn 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 urn 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 urn in diameter, approaching the cross sectional width of external eggs reported to be about 1000 urn 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.

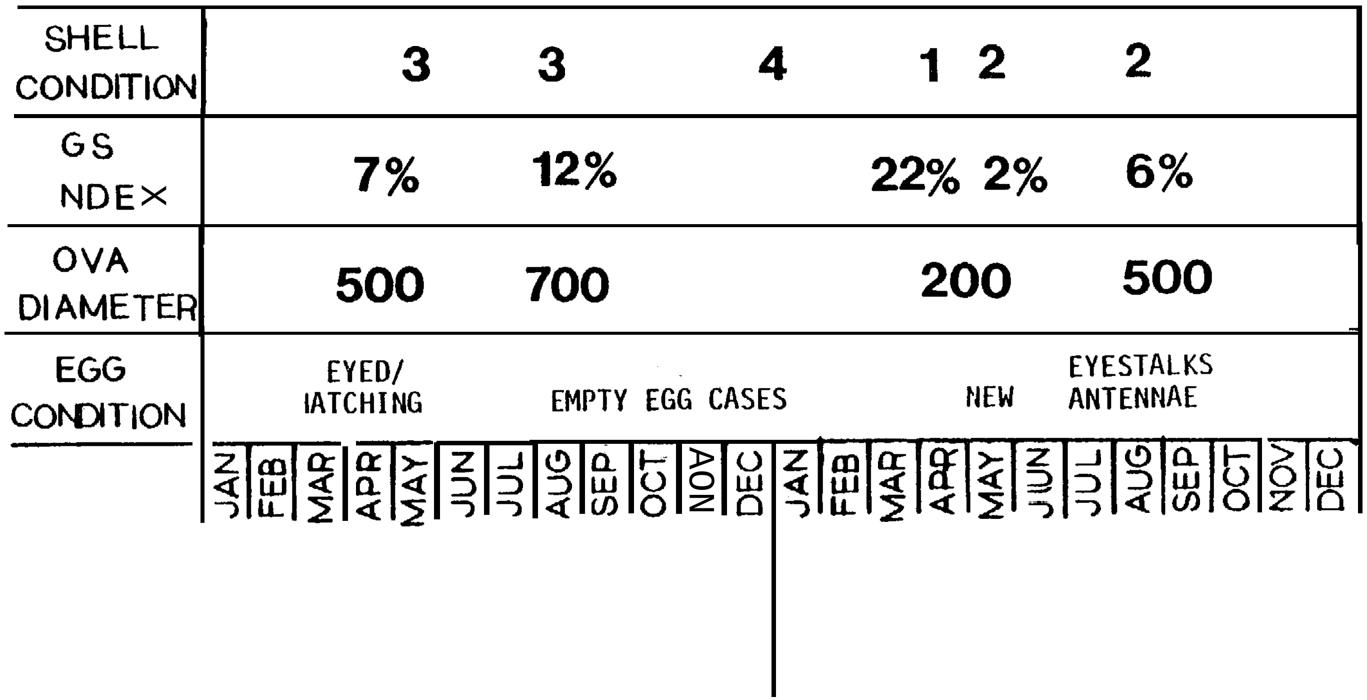


Figure 4.31 Timing of reproductive events and ovarian deve[illegible] for female blue king crab over a 2-year period.

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 neeaed 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 (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 islands 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 O+ 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 shell hash 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 (Zl) (Fig. 5.1). Near the end of May (5/22-5/26) larvae were still predominantly Zl, 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 24. 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

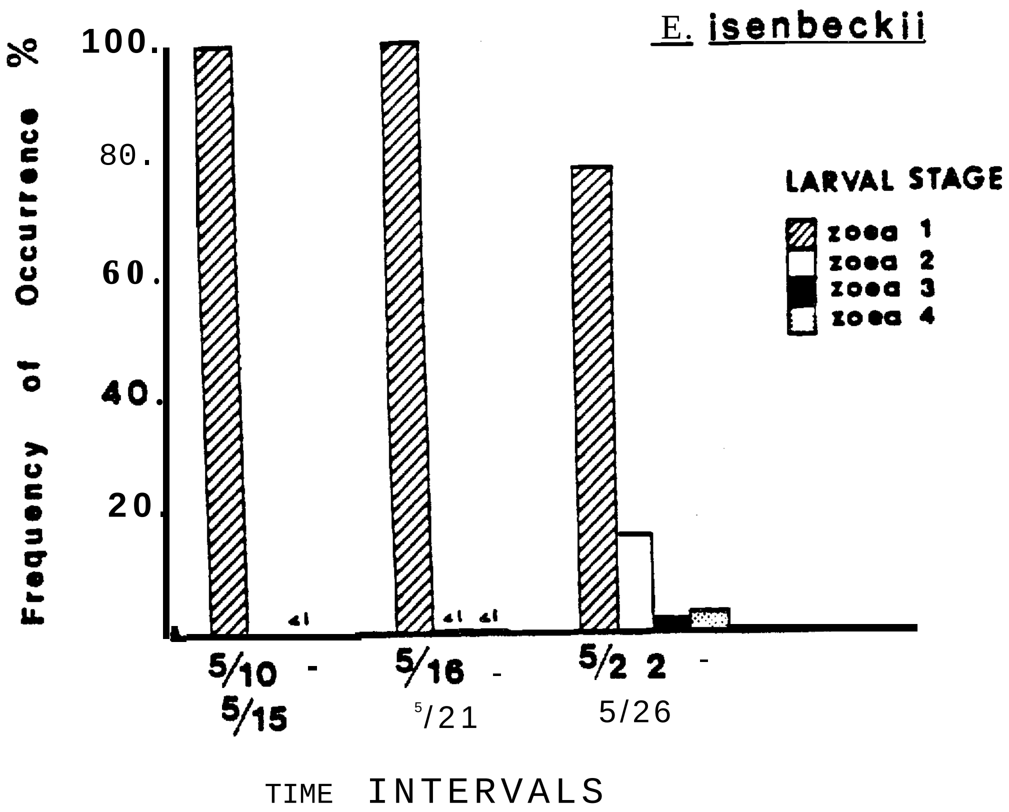


Figure 5.1 Percent stage frequency of Erimacrus isenbeckii larvae, May 1983.

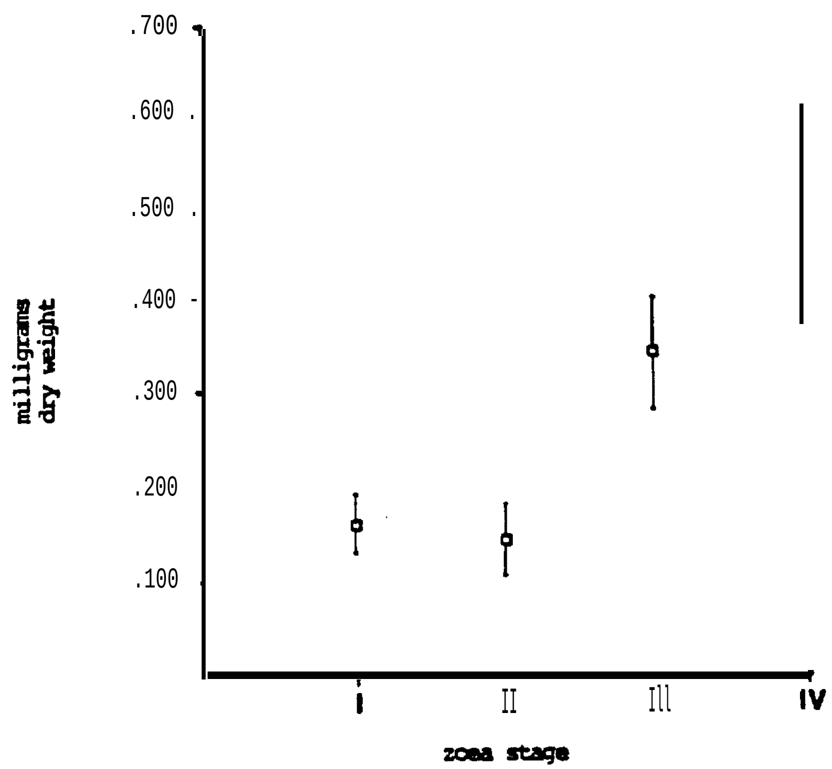
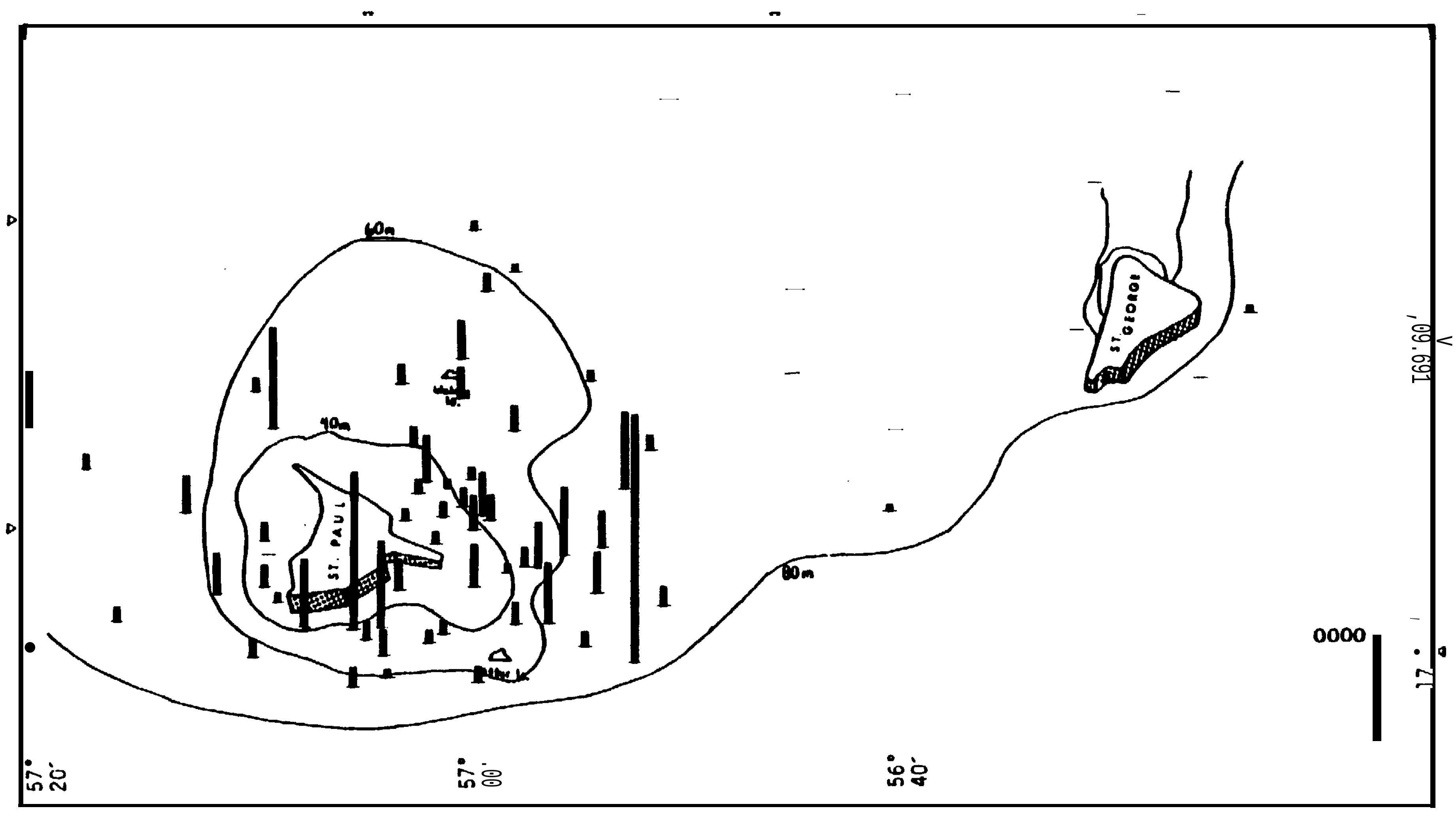


Figure 5.2 Erimacrus isenbeckii zoeal weight/stage growth.



gure 5.3 Erimacrus isenbeckii larvae, May 983, 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

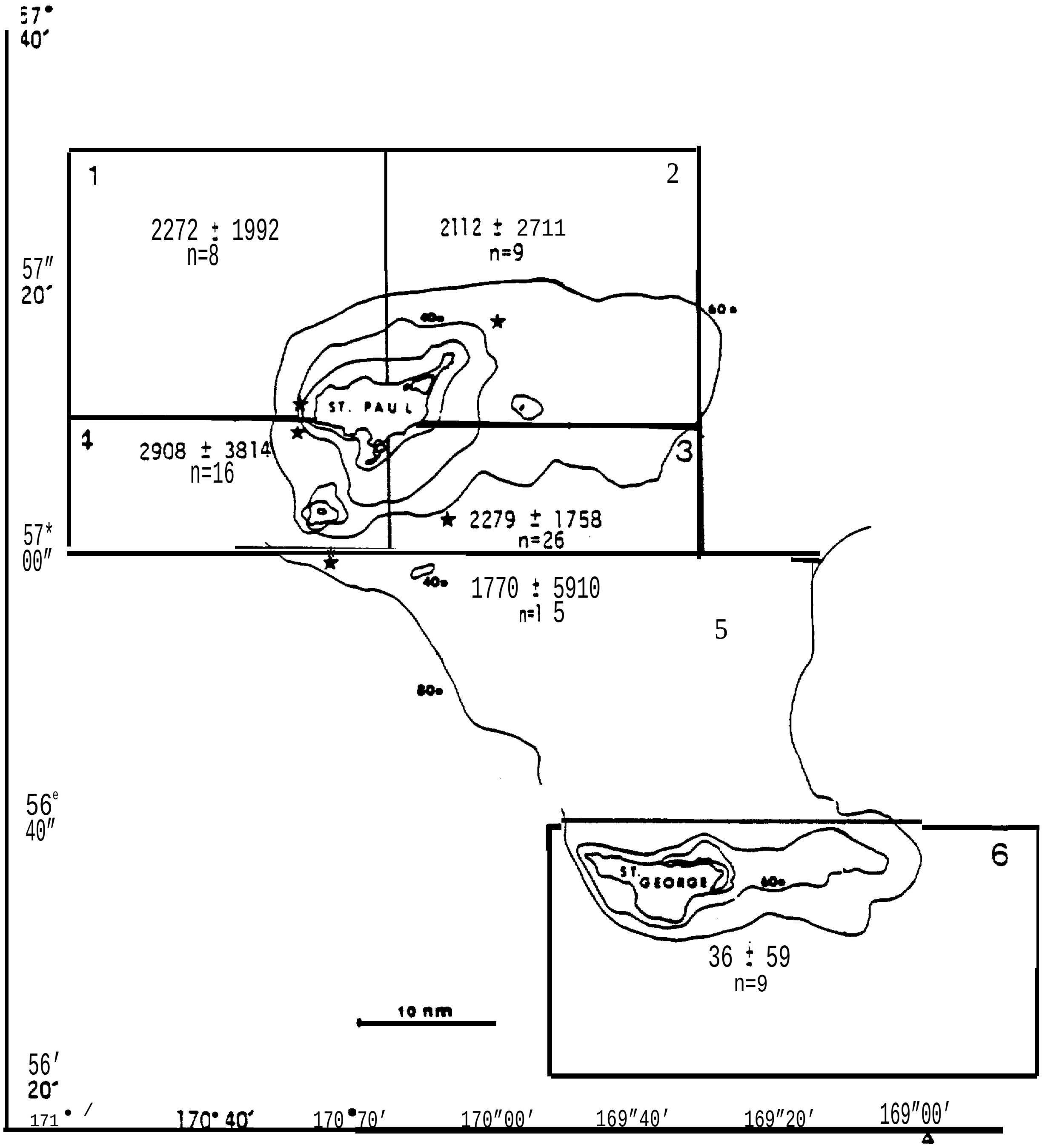


Figure 5.4 *Erimacrus isenbeckii* larval abundance (no. larvae/100 m²) by strata, May 1983. Shown are mean ± 1 SD and number of stations with larvae; stars indicate stations with the highest abundance per stratum.

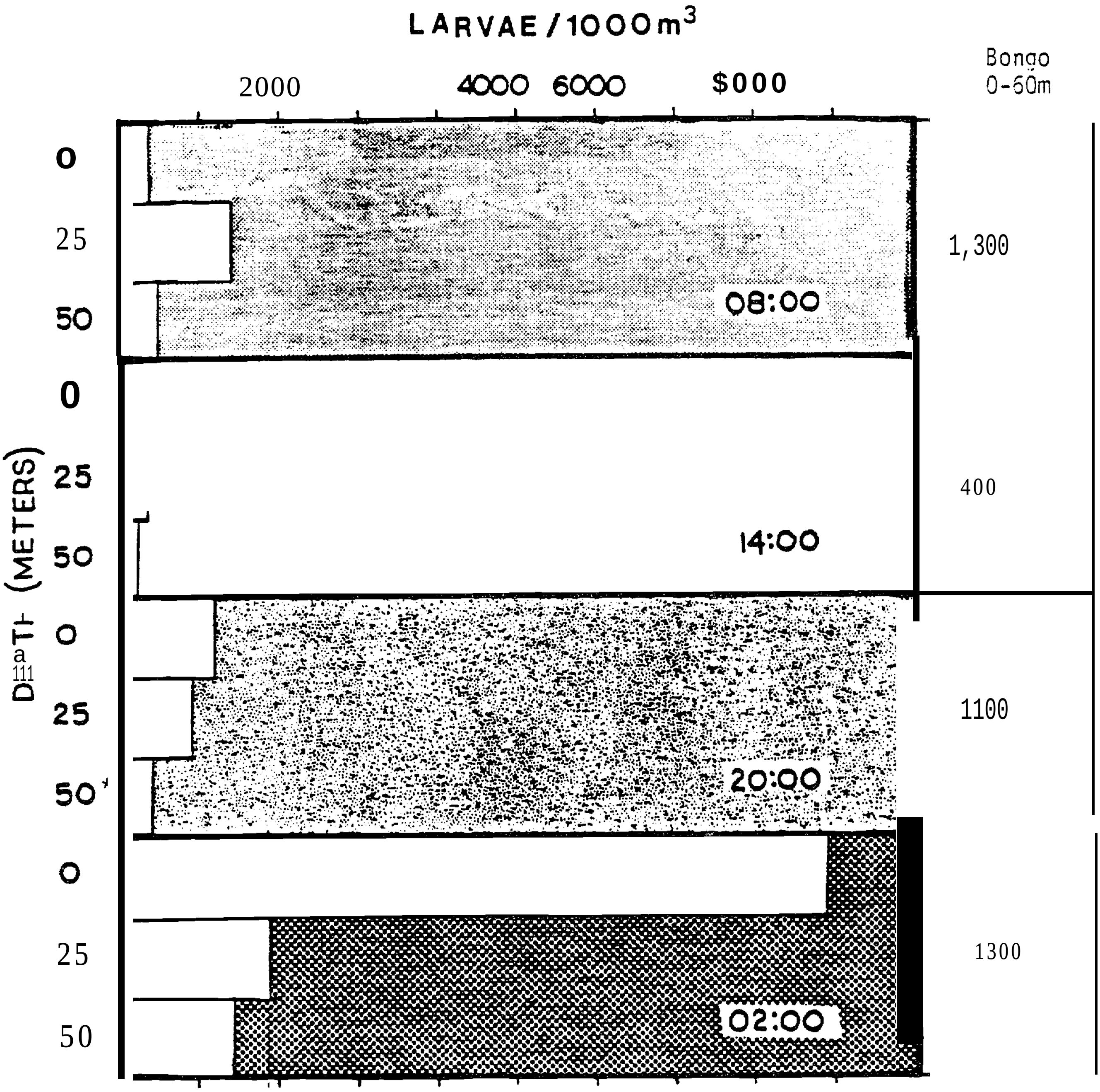


Figure 5.5 Larval _Erimacrus isenbeckii_ depth distribution, May 1983. Diel station was sampled by neuston, Tucker, and bongo tows. Times on right are local mean time.
*Poor tow--neuston net fished 50 m-surface.

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. 0.2, 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 3930313,015 (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 + 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

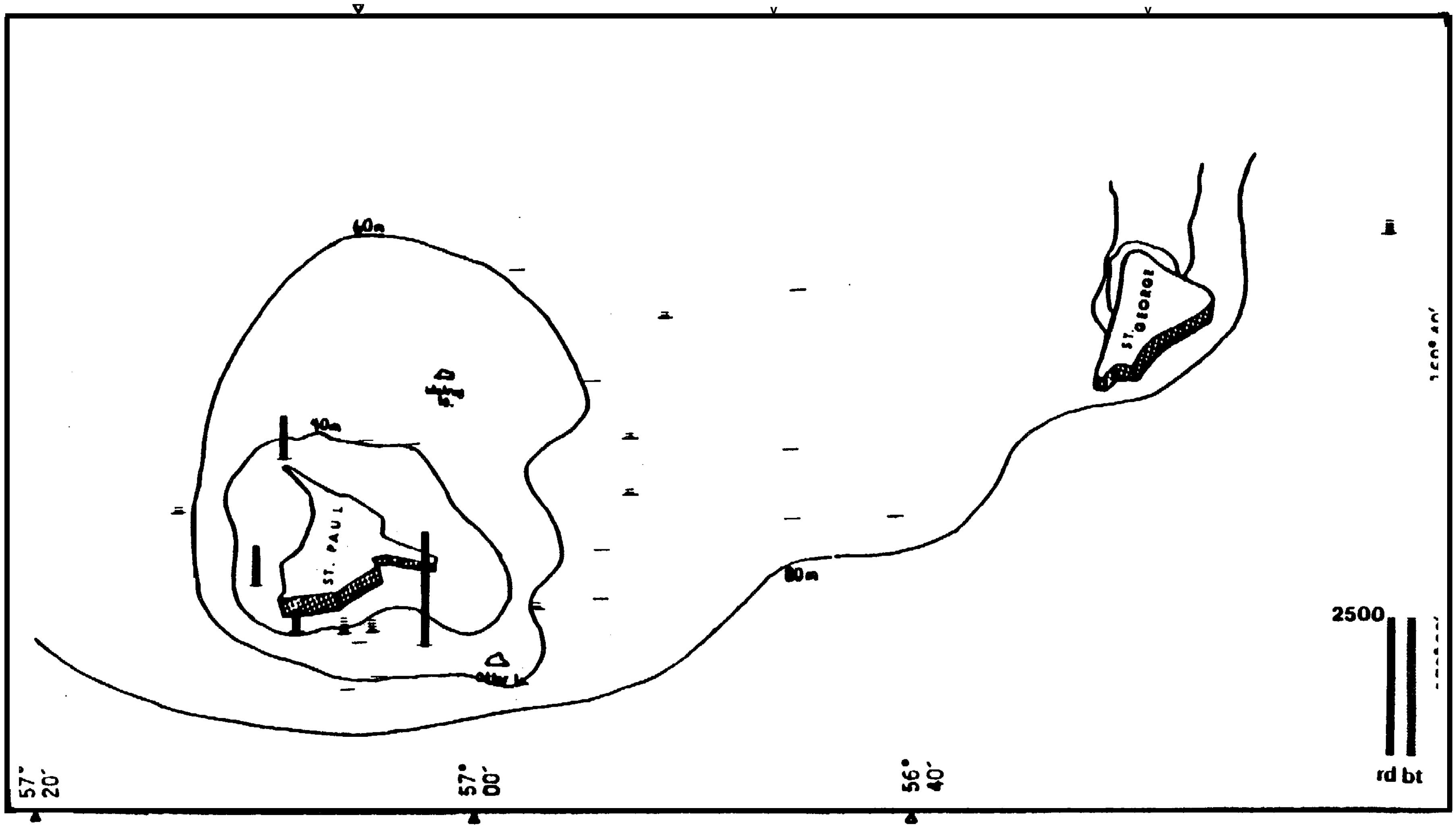


Figure 5.6 *Erimacrus isenbeckii* juvenile distribution and abundance, May 1983, expressed as number of juveniles/hectare taken by rock dredges (solid bars) and beam trawls (striped bars).

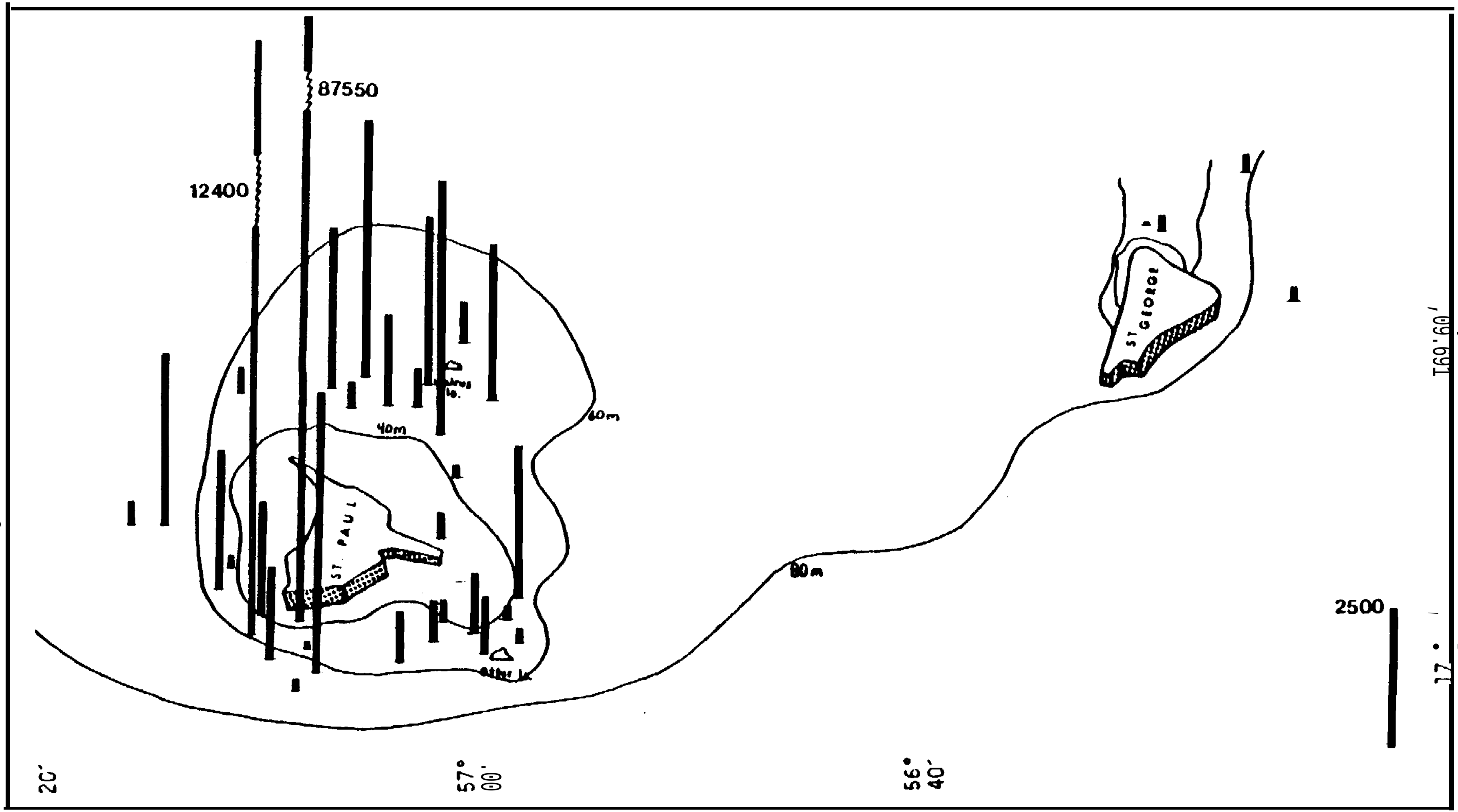


Figure 5.7 Erimacrus isenbeckii juvenile distribution and abundance, August 1983, expressed as number of juveniles/hectare taken by rock dredges. The size limit of 3.0-12.5 mm carapace width on this group denoted these as young-of-the-year and 1+ age classes.

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 + 2080 (range 90-9020) crab/ha, compared to a mean of 19 + 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).

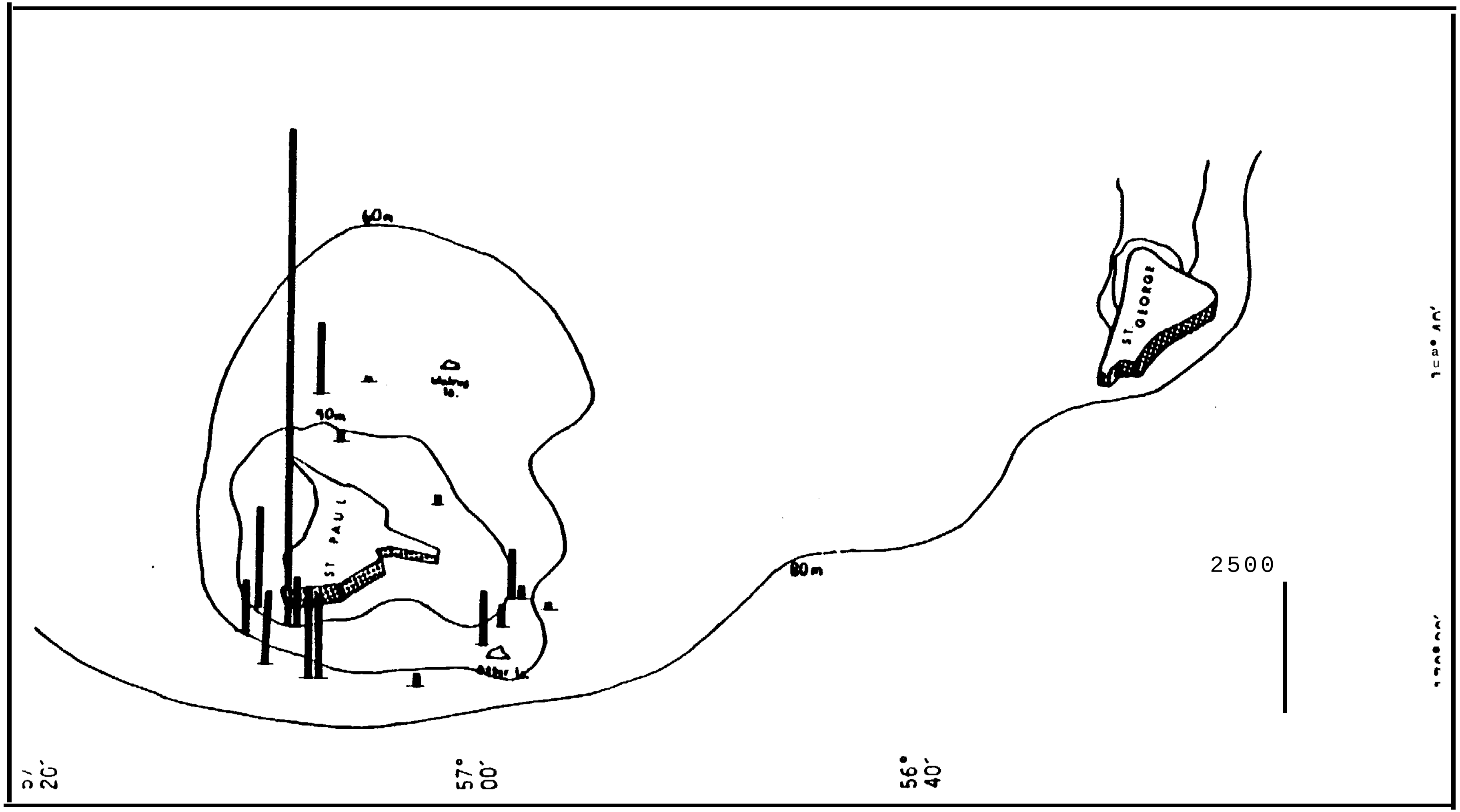


Figure 5.8 Erimacrus isenbeckii juveniles distribution and abundance, April 1984, expressed as number of juveniles/hectare taken by rock dredges.

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)
O+	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).

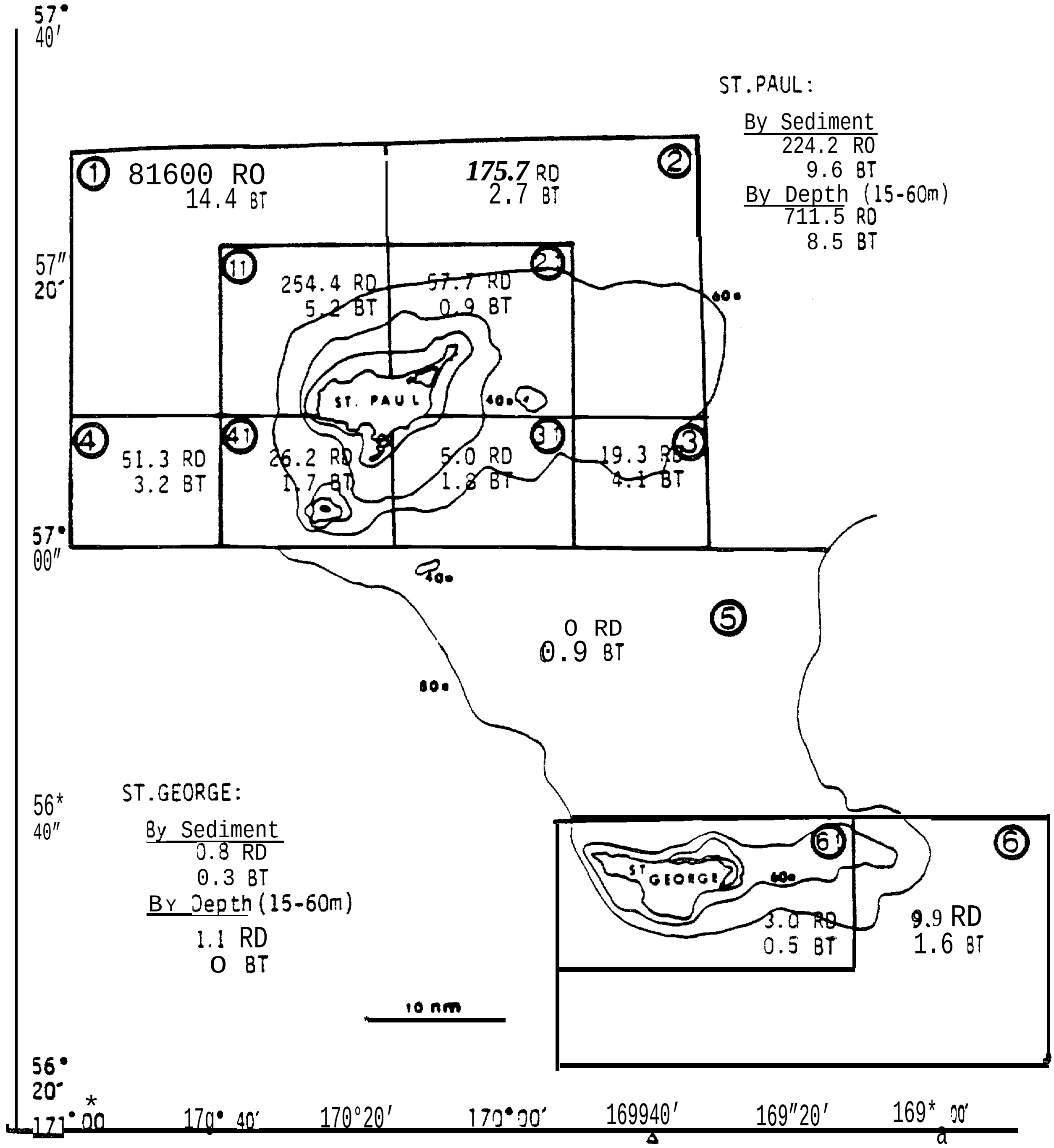


Figure 5.9 Population estimates for *Erimacrus isenbeckii* juveniles in August 1983 by strata. Separate estimates, expressed as number of juveniles x 10^6, are given for each gear; RD = rock dredge, BT = beam trawl. Estimates for nearshore strata 11-41 and 61 can be compared to the island totals figured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

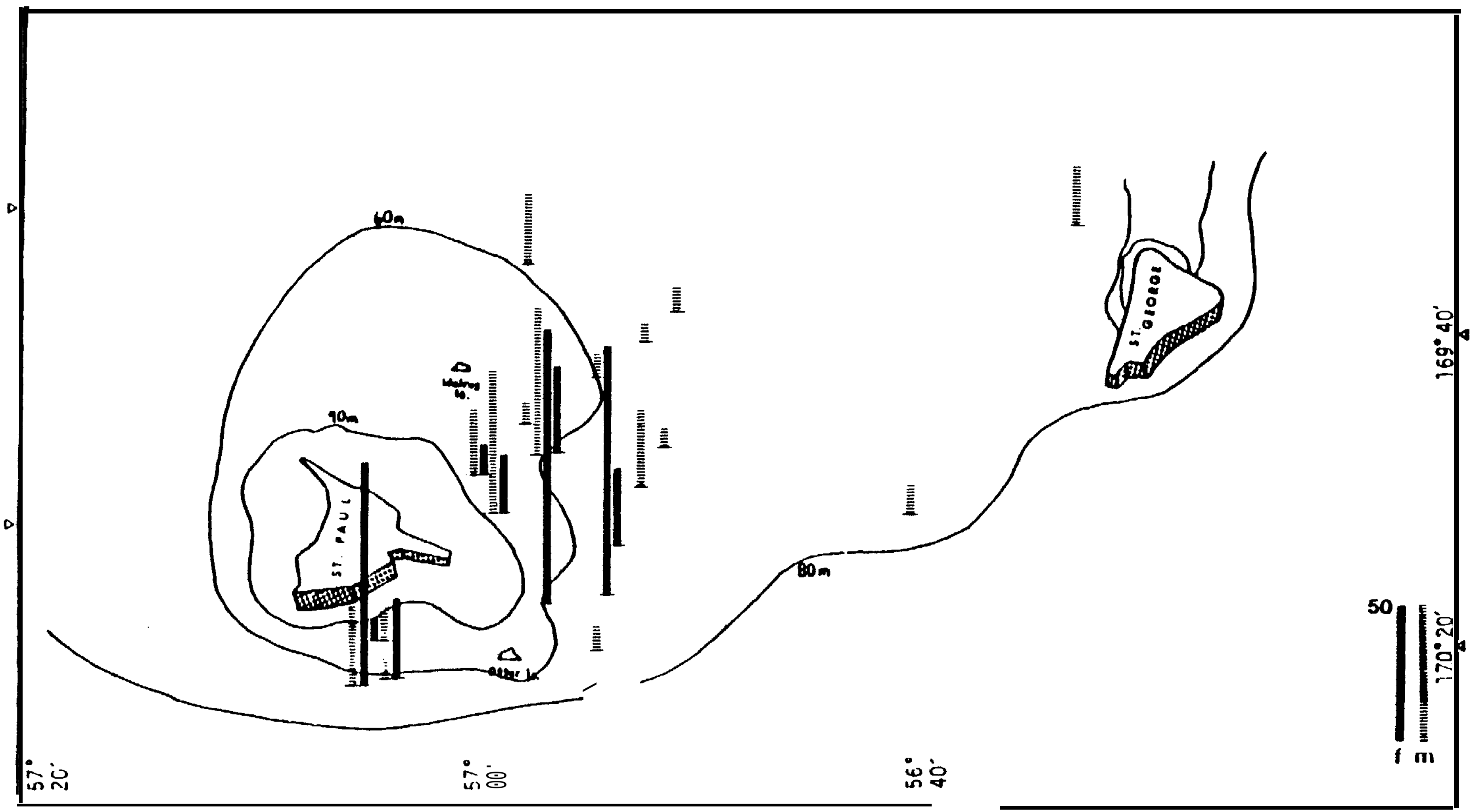


Figure 5. o *Erimacrus isenbeckii* adult distribution and abundance, May 1983, expressed as number of crab/hectare taken by beam trawls, females (solid bars) and males (striped bars).

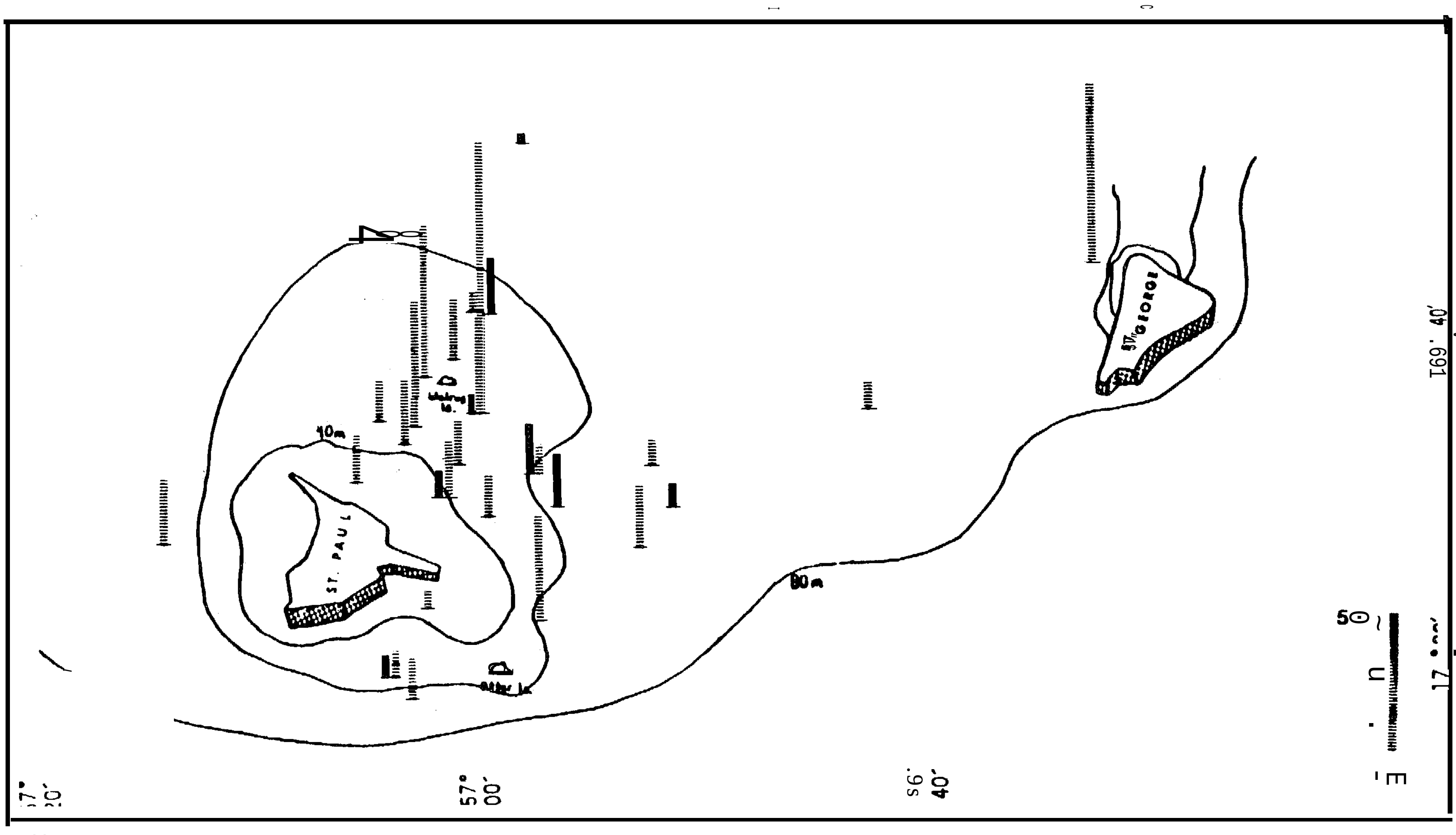


Figure 5.11 Erimacrus isenbeckii adult distribut·on and abundance, August 1983, expressed as number of crab/hectare taken by beam trawls, females (solid bars) and males (striped bars).

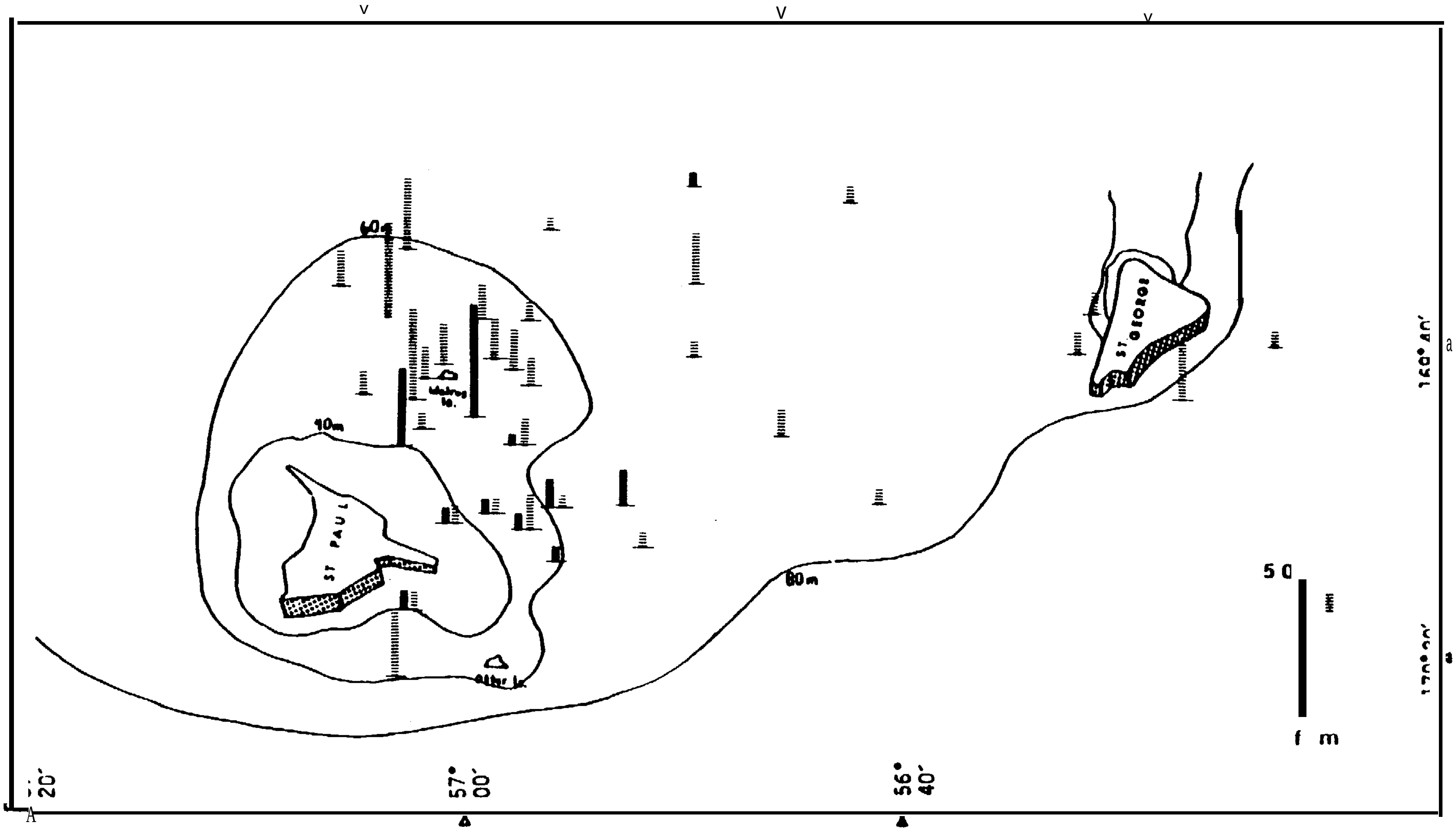


Figure 5.12 Erimacrus isenbeckii adult distribution and abundance, April 1984, expressed as number of crab/hectare taken by beam trawls, females (solid bars) and males (striped bars).

5.3.2 Estimated Population Abundance

An adult population of 8.1 million KHC was calculate 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.

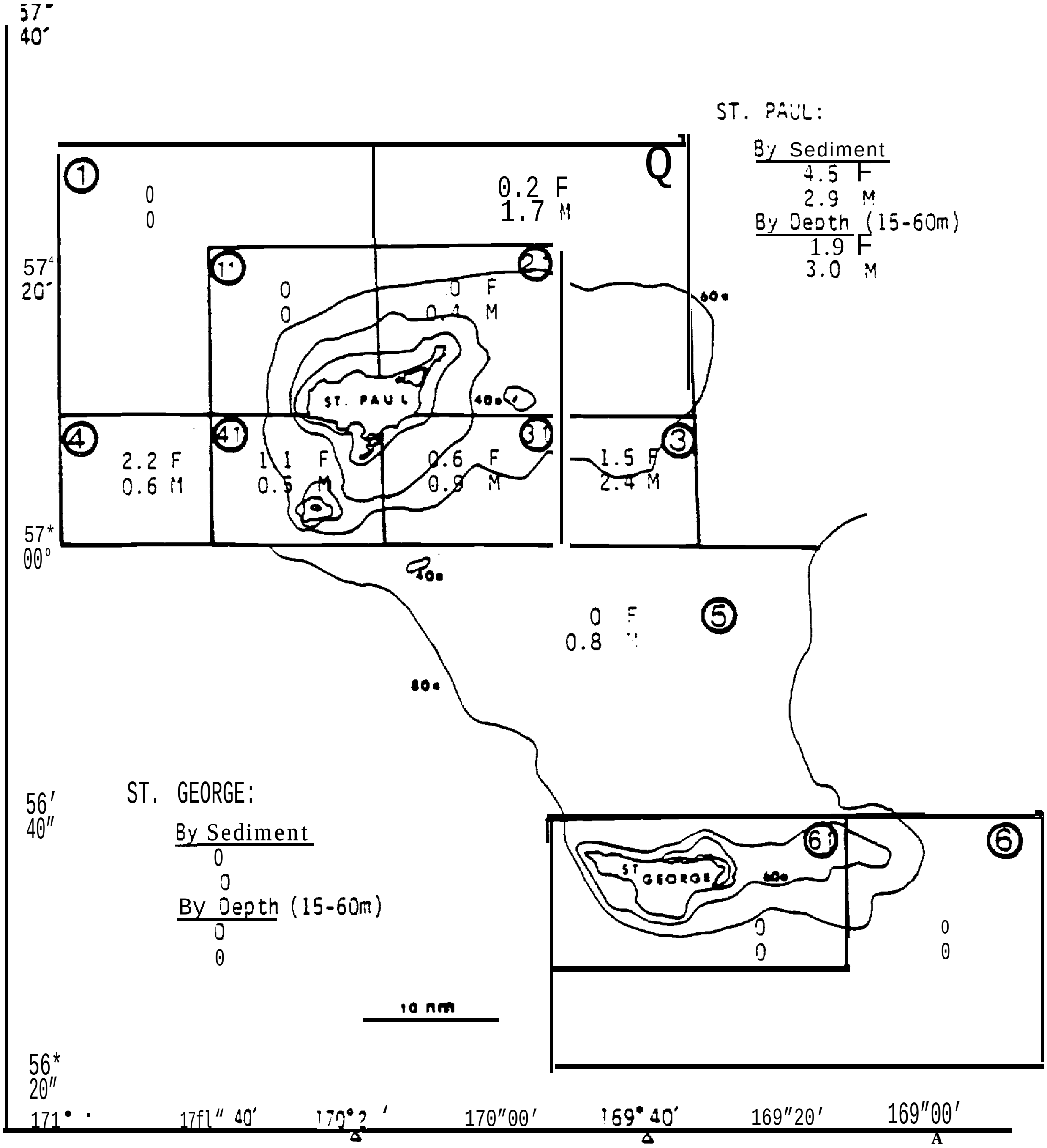


Figure 5.13 Population estimates for Erimacrus isenbeckii adults by sex and strata for beam trawls in May 1983. Estimates are expressed as number of crab x 10^6 for adult females and males.

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 (+ 5.2) compared to 57 mm (+ 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 ± 10.9 mm CW) than the new shell animals (43.8 mm

+ 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. ohs.); which if true for female KHC would mean very low matchability 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 shell hash 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)

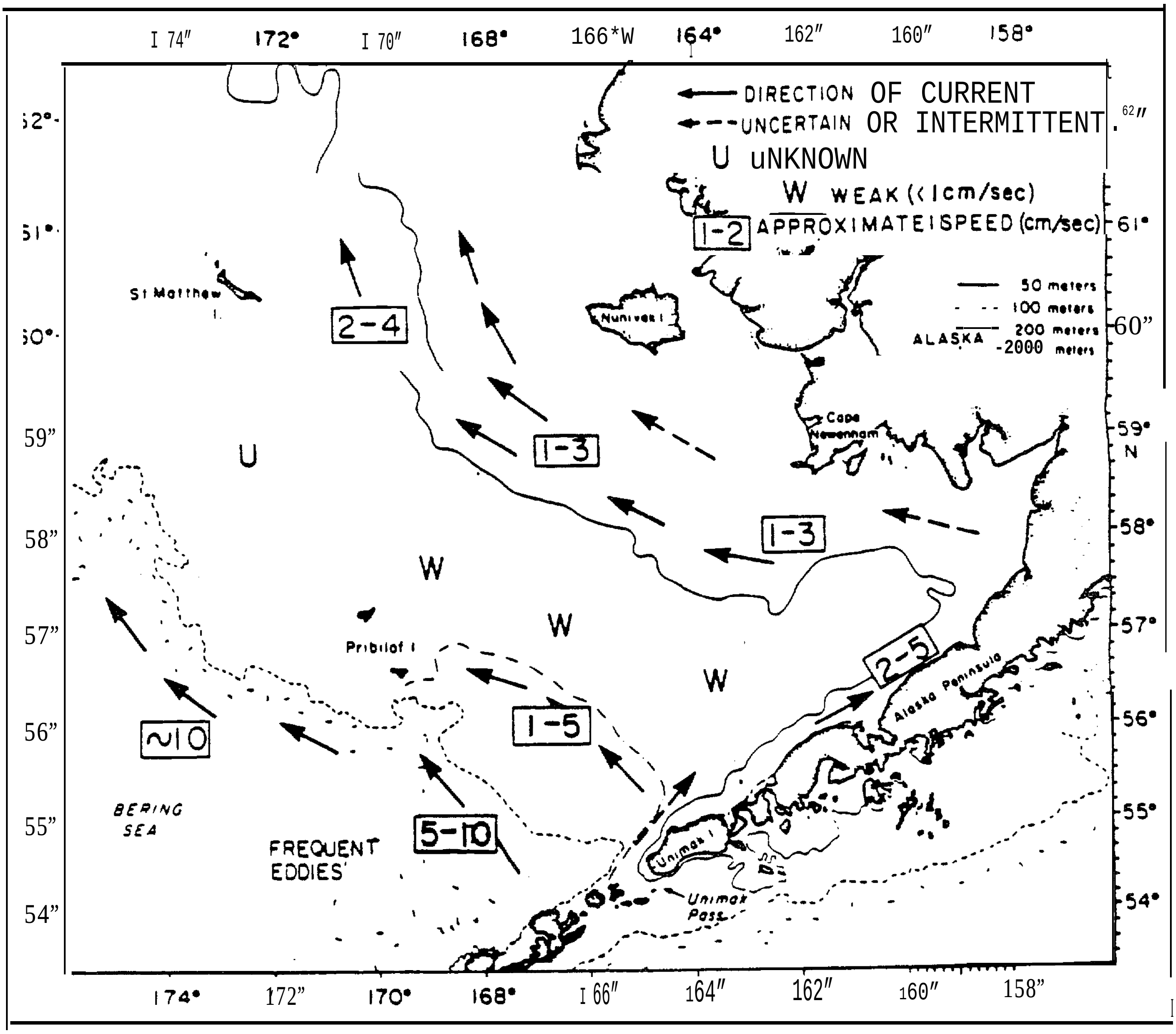
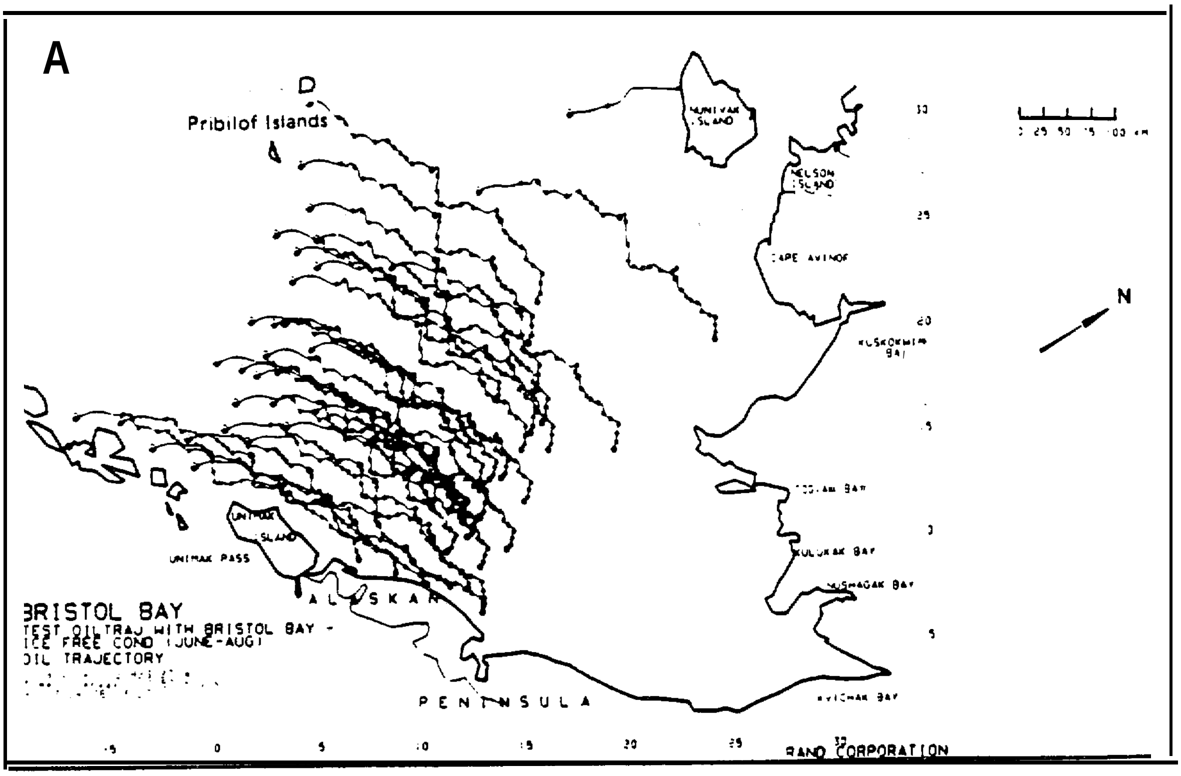


Figure 6.1 Current directions and net speed over the southeastern Bering Sea shelf (from Kinder and Schumacher 1981a).

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/1 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.



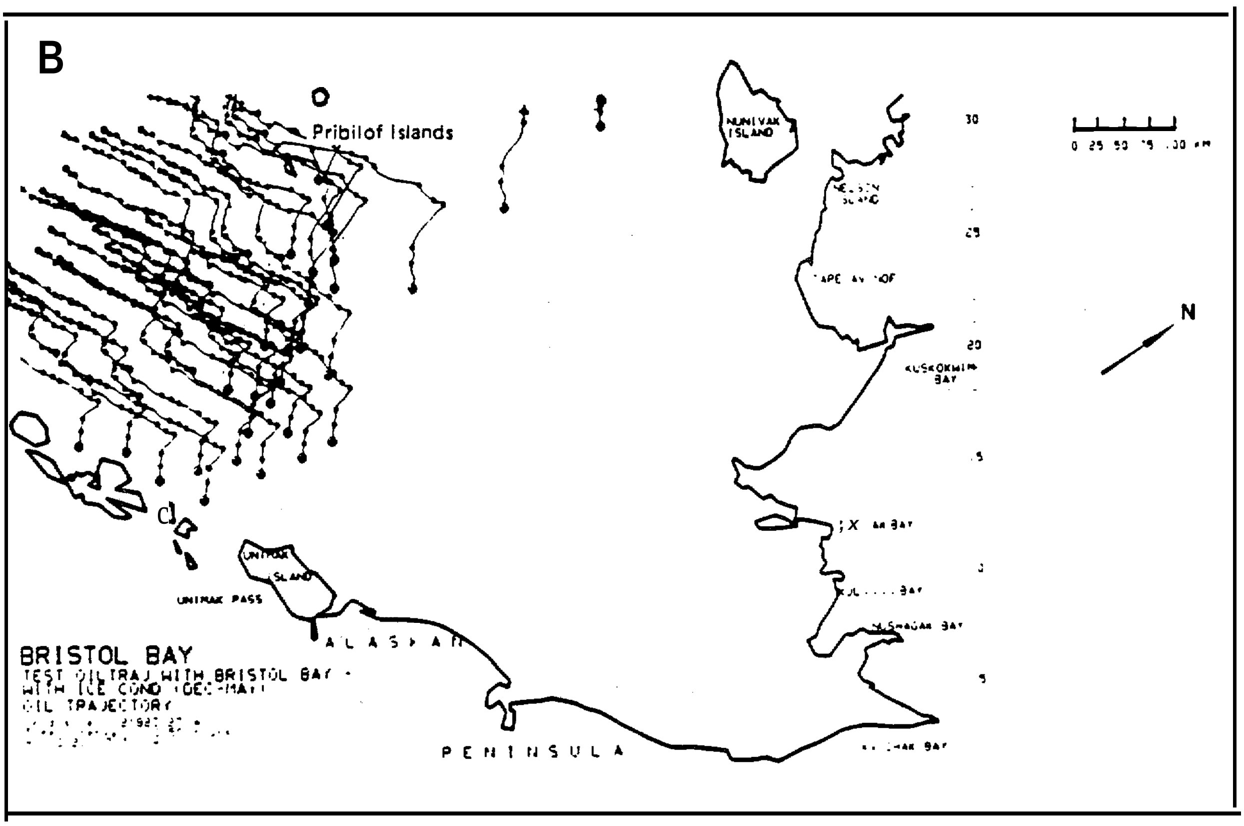


Figure 6.2 Surface oil trajectories during summer (A) and winter (B) in the southeastern Bering Sea (from Leendertse and Liu 1981).

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/1 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.

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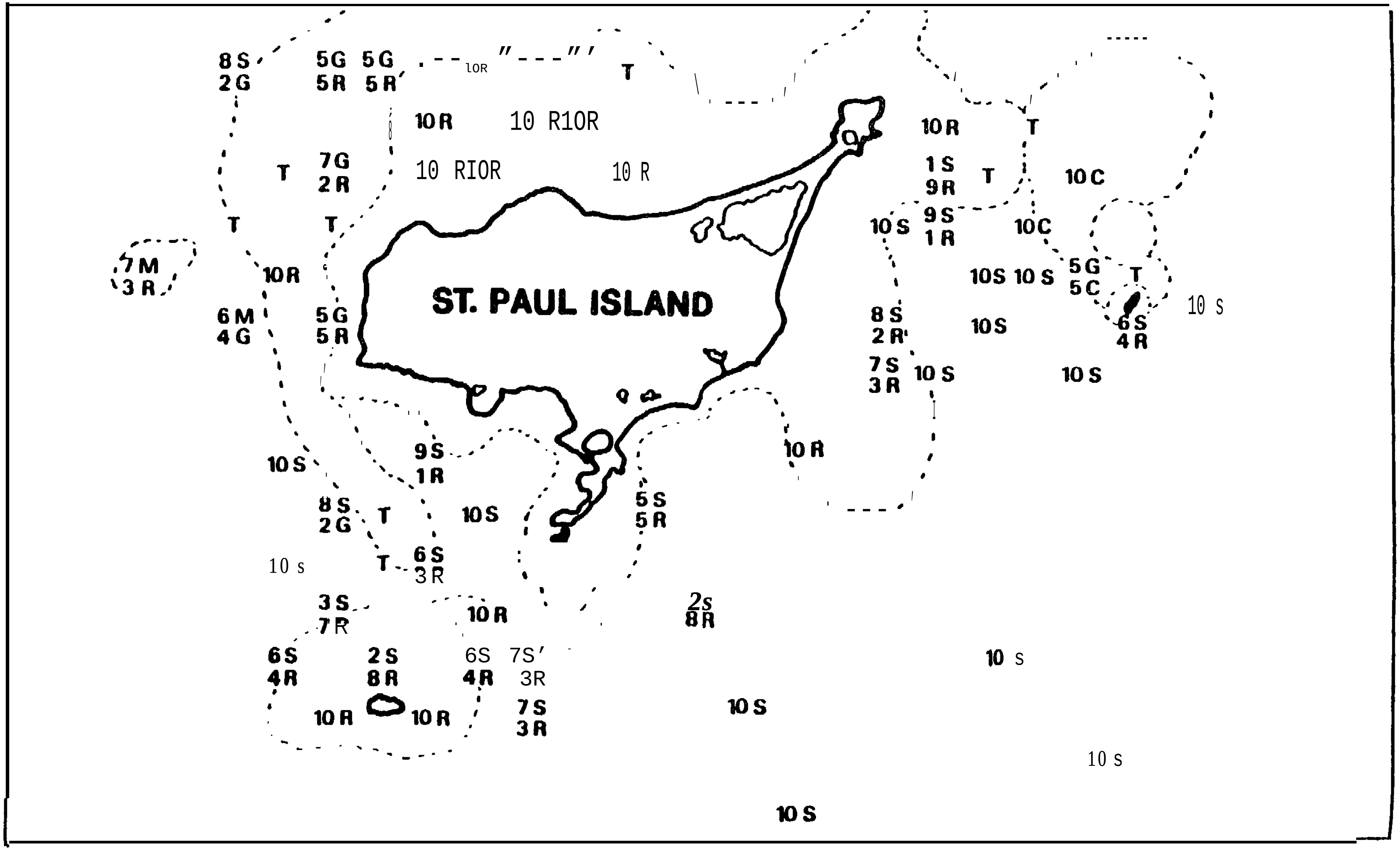
Appendix A.1 Sediment composition (%) of 80 selected stations from the May 1983 cruise.

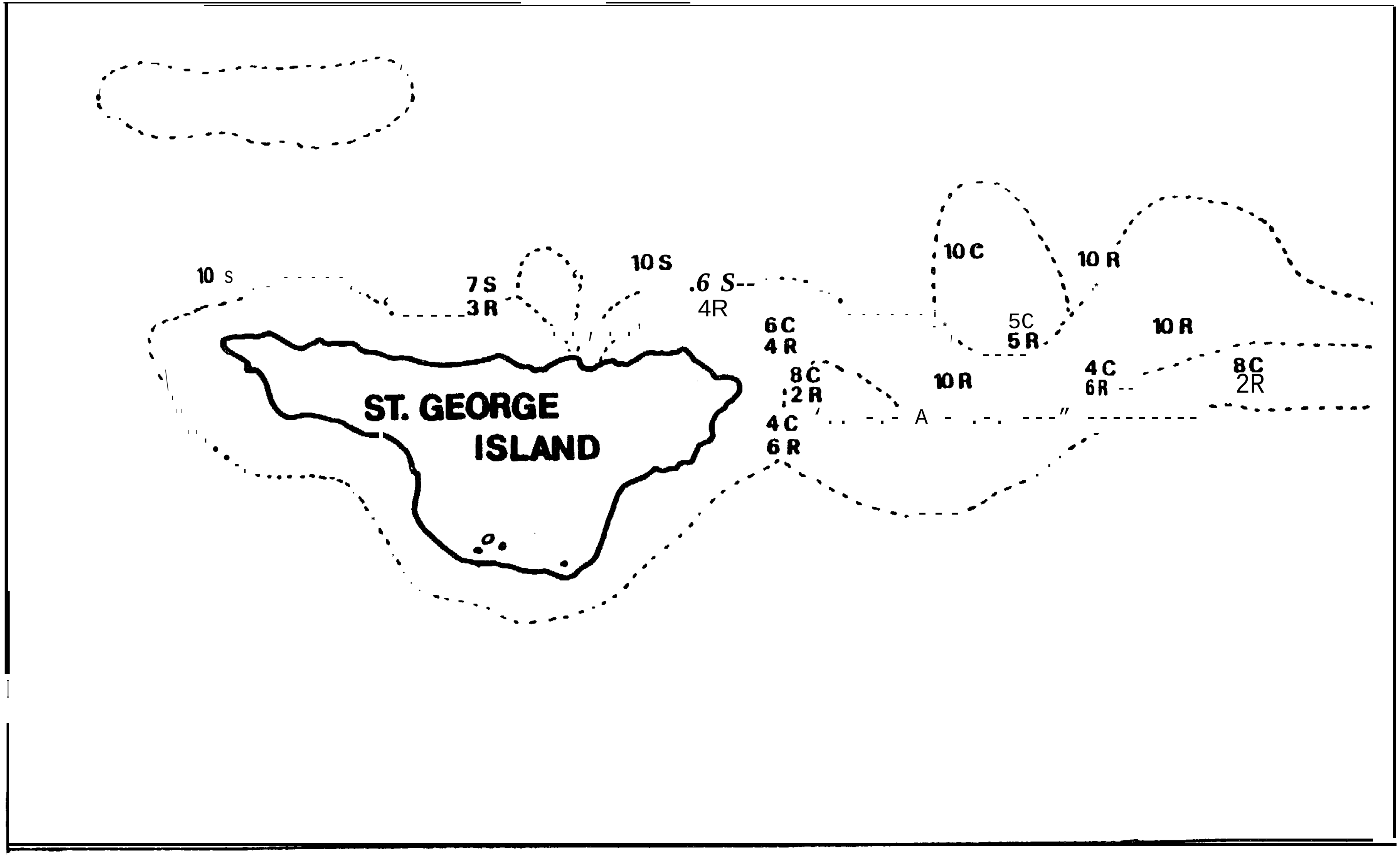
	PEBBLE	GRANULE	VERY COARSE SAND	COARSE SAND	MEDIUM SAND	VERY FINE SAND	FINE SAND	SILT AND CLAY
Grain	> 2	2 to 1	1 to o	0 to-l	-1 to-2	-2 to-3	-3 to -4 <	-4
size mm >	4	4 - 2	2 - 1	1-0 s	s-o 25	'25. 125	125- 063 <	063
STATION								
1	05	41	34	24	47	7 49	61 46	29 54
2	50	1 44	se	28	3S S6	55. 7s	2 42	3 48
3	10	41	68	40	2 60	90 81	2 81	1 99
4	69	7 09	20 81	15 23	6 62	31 98	11 S8	3 99
s	0 0	1.18	48	16	10 69	82.43	1 28	2 98
6	23	18	22	31	9 48	7S 84	11 03	1 72
9	00	0 6	0 7	0 6	1 13	86 6S	9.77	2.07
10	67 22	23 94	4 81	54	26	58	69	1 9s
12	00	18	l a	92	40 98	48 1s	1.47	8 12
1s	4 99	1 01	1 13	93	2 13	SO 32	21 12	1s 37
16	s.6 63	1s 12	10 87	8 09	3.23	84	9s	4 27
17	26	3.18	3s 90	3s 69	10 34	1 89	1 37	11 38
18	17	58	20.42	71 42	5.78	66	28	73
20	61 39	24 22	9 0 0	2 31	SO	75	93	92
21	11 11	16	23	0 3	34	S 12	12 48	70 53
22	12	22	17	10	99	77 20	10. S7	10 63
23	00	0 0	0 0	06	43	9 27	16 58	71 66
24	00	.13	13	09	1.11	49 57	31 99	16.96
2s	00	18	91	2 45	2.40	74.72	11.44	7 89
26	10 32	2s 81	30 36	21 04	6 4S	1 61	86	3 3s
27	0 0	00	14	1 2s	33 68	58 54	6.63	1.7s
30	45 12	23 89	12 29	7 03	3.72	4.90	1 28	1.77
31	24 13	s 37	10 10	12 03	21.31	22.68	1 16	3 22
32	17 39	6 7?	4 50	s 3s	12.71	24 17	14 98	14.12
33	00	14	06	45	4 69	26.80	44 23	23 63
34	Do	02	10	38	2.9S	24 97	41 91	29 67
3s	88	46	61	2.14	11. s2	77 37	4 76	2 26
37	97	0 s	26	32	1.47	74 SO	19 22	3.22
39	90	7 s	32	1 30	13 38	76 29	5.17	1 98
40	59 81	4 88	4 36	21	309	9 36	8 38	9 93
41	7 92	22.37	28 3s	18 26	9 69	10 43	1.01	1 98
58	1 09	1 76	1 17	2 61	22 51	58 S7	8 23	4 07
60	0 0	0 0	7s	1 78	3 24	63 61	26 94	3 68
63	51	28	21	17	4 33	72 24	19 66	2 11
67	0 0	83	43	47	2 07	37 19	38.13	20.88
68	1.46	42	17	10	45	66 03	26.20	6.17
69	3 04	1 713	59	19	34	66 1 4	23 S2	369
70	41	27	13	10	46	26 98	S7 3s	14 30
72	23	2 32	1 33	87	2 52	71 22	17.63	3.6a
73	3.88	2 30	1 04	44	4 34	71.16	12.74	4 10
7s	0 0	0 7	15	13	1 54	19 94	20.66	57 51
76	58	00	0 7	0 9	1 04	51 22	33.73	13 26
77	.0 0	0 3	0 s	0 9	2 48	72 96	18.06	6 33
78	77	51	47	79	5.80	78 69	11.30	1 67
79	● o .43	14 33	7 83	s 37	9 61	17 91	2.68	1 8s
83	2 2	1 18	68	31	3 es	81 70	S 76	130
04	00	0 7	10	12	1 0s	78 32	15. 71	4 64
es	2 80	66	25	20	3 50	97 55	4 26	77
86	20	51	58	1 48	1S 86	7s 16	3 44	2.77
87	00	00	0 0	04	97	16 9s	57 73	24 30
88	1 04	19	:0	57	10 13	64 41	16 60	5 87
89	1 09	17	19	22	3 73	07 47	4 26	2 88
90	0 0	0 6	0 4	06	70	24 S7	2 16	72 41
91	0 0	12	14	19	1 83	82 39	1174	3 se
92	2 0	07	19	30	4 02	75 34	14 41	3 57
94	1 55	13	2 3	1 75	28 22	64 413	2 09	1 S6
95	00	19	13	11	77	27 39	53 4a	17 94
96	16	31	12	1s	1 15	18 12	5s.71	24 27
97	0 0	0 4	0 s	19	3 73	53 08	29 63	13 28
98	00	13	3 3	1 39	13 3s	74 94	5.71	4 14
104	0 0	0 0	10	22	3 10	51 77	20 19	14 62
10s	00	2 6	05	04	56	37 93	S2 85	8 30
106	1 22	2 57	3 90	6 09	31 40	45 79	4 6 0	4 43
108	26.54	6 21	4 23	3 19	11 53	39 1s	3 55	s 60
111	0 0	0 4	19	96	54 81	43 12	62	27
112	1 76	s 21	S 87	8 54	11 9s	49 72	10.05	5 91
113	14 e?	29 49	9 84	17 37	23 07	3 01	39	1 16
114	S7 .93	8 94	4 57	2 14	2 75	10 34	5 07	9 36
11s	0 0	07	09	08	31	12 0s	32 S4	54 86
119	0 0	08	08	08	47	79 86	11 49	7 93
120	13 61	S 27	6 28	7 10	1s 74	31 3s	4 92	15 73
121	00	0 0	07	2 4	3 00	s2 5s	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	3s 49	S 07	10 13
127	0 0	0 0	00	01	3 60	14 97	45 94	3s 49
12a	0 0	0 0	04	16	S 55	67 80	18 91	7 5s
129	w	0 0	17	37	6 34	46 74	29 99	16 3a
130	16	1 84	90	45	21 40	70 30	2 81	2 2s
136	05	71	32	14	S 91	63 46	S 02	3.S8
137	04	10	12	09	1 07	80 02	12 54	5 91
139	2 60	60	23	0 9	90	72 99	16 1S	6 S4

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

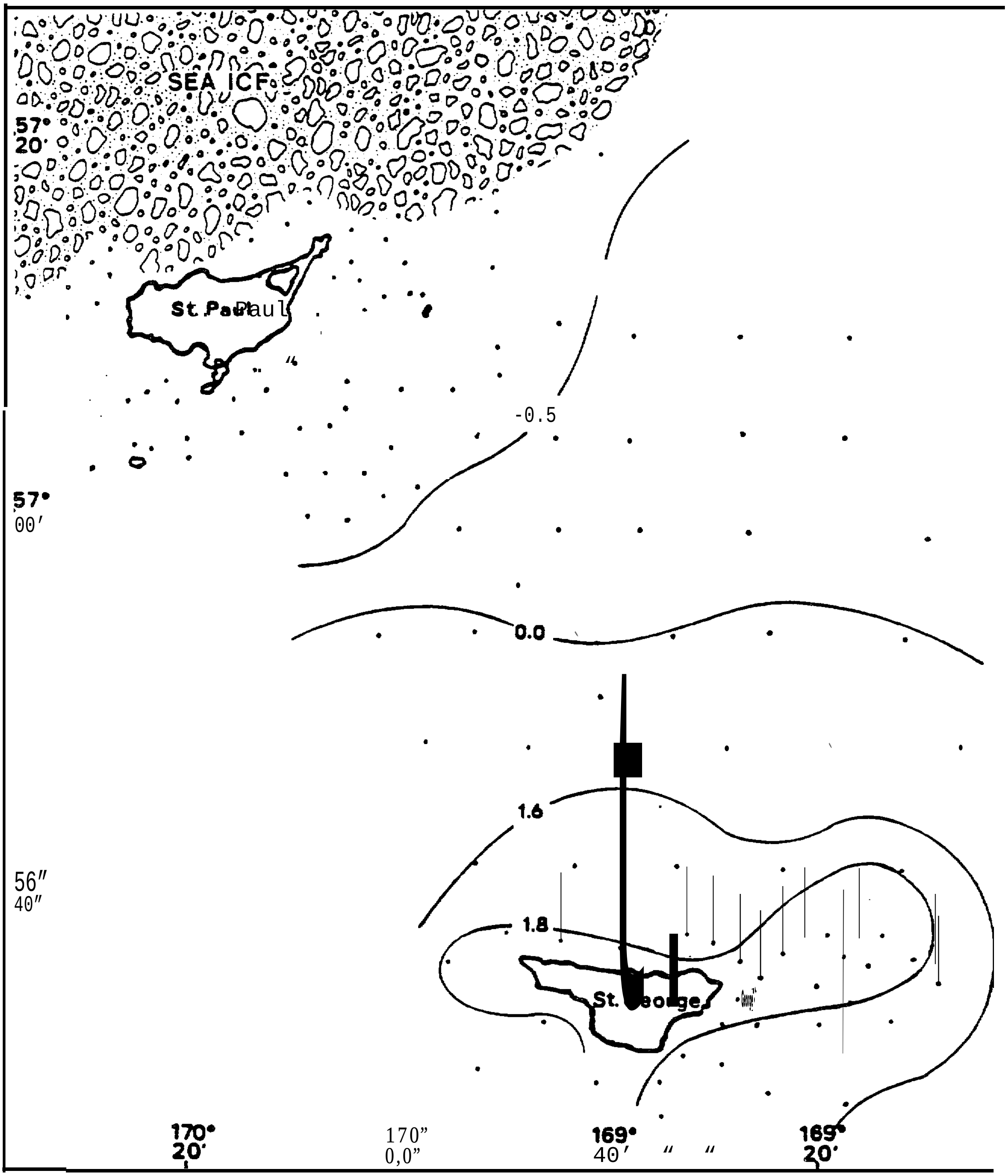
ST	MEAN PHI VALUE	S.D.	SKEW	KURT	ST	MEAN PHI VALUE	S.D.	SKEW	KURT
1	-3.67	.75	2.43	17.16	75	-3.83	.88	1.14	4.08
2	-2.13	.90	1.18	9.87	76	-3.06	.85	1.22	12.29
3	-2.49	.55	2.59	28.70	77	-2.78	.63	-1.12	5.45
4	-1.36	1.69	.14	1.92	78	-2.50	.77	2.88	20.56
5	-2.36	.81	2.77	18.79	79	,47	2.17	-.58	1.83
6	-2.52	.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	1.70	-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	9 6	-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	4.9a	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. 2"1	.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



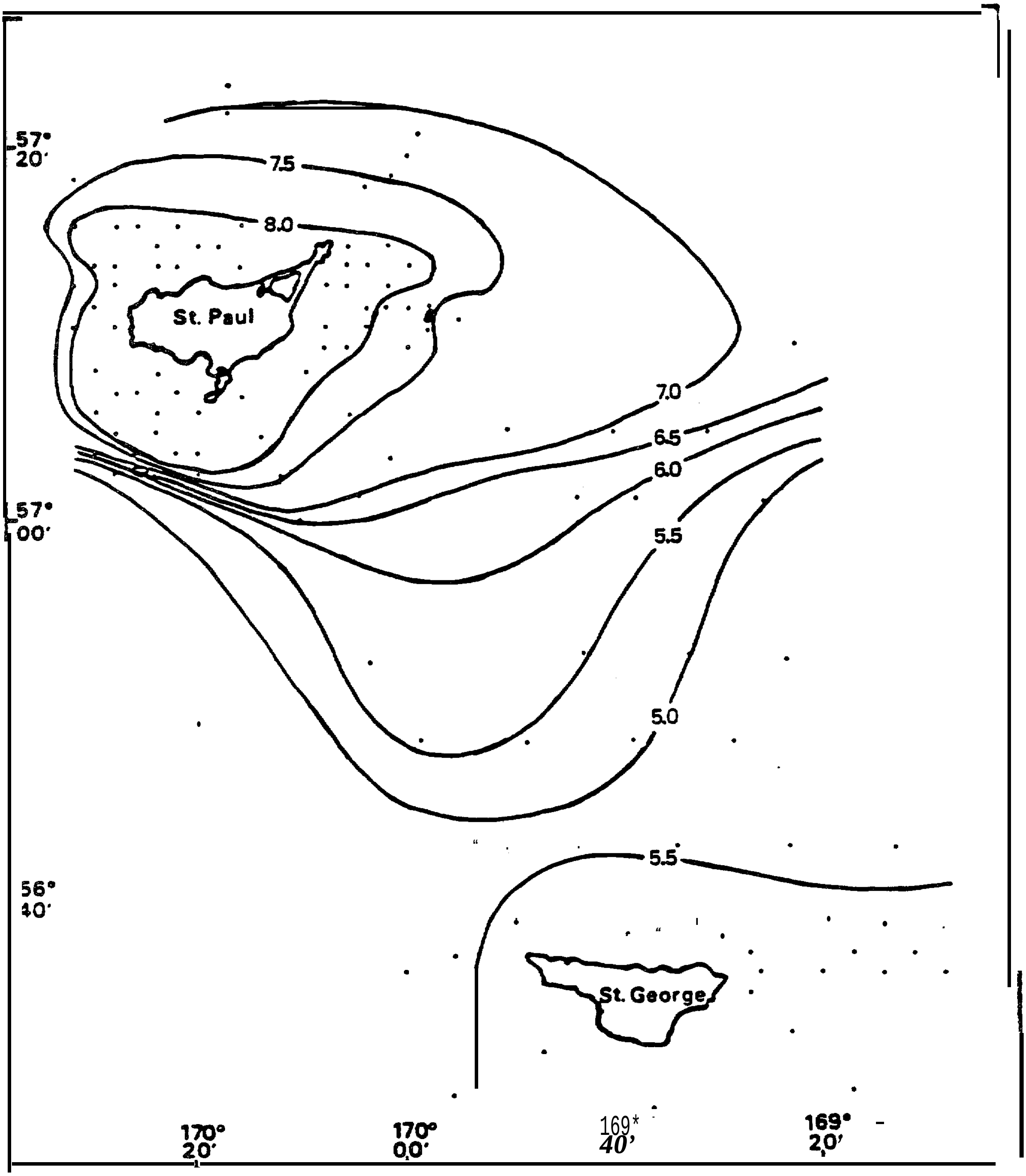
Appendix A.3 Summary of side scan sonar data on substrate type at each station, St. Paul Island. Over the linear distance of 1 NM at each station, the percent bottom type of each category present was summed and set on a scale of 10. R = rock, S = sand, M = mud, G = gravel , C = cobble, T = transition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



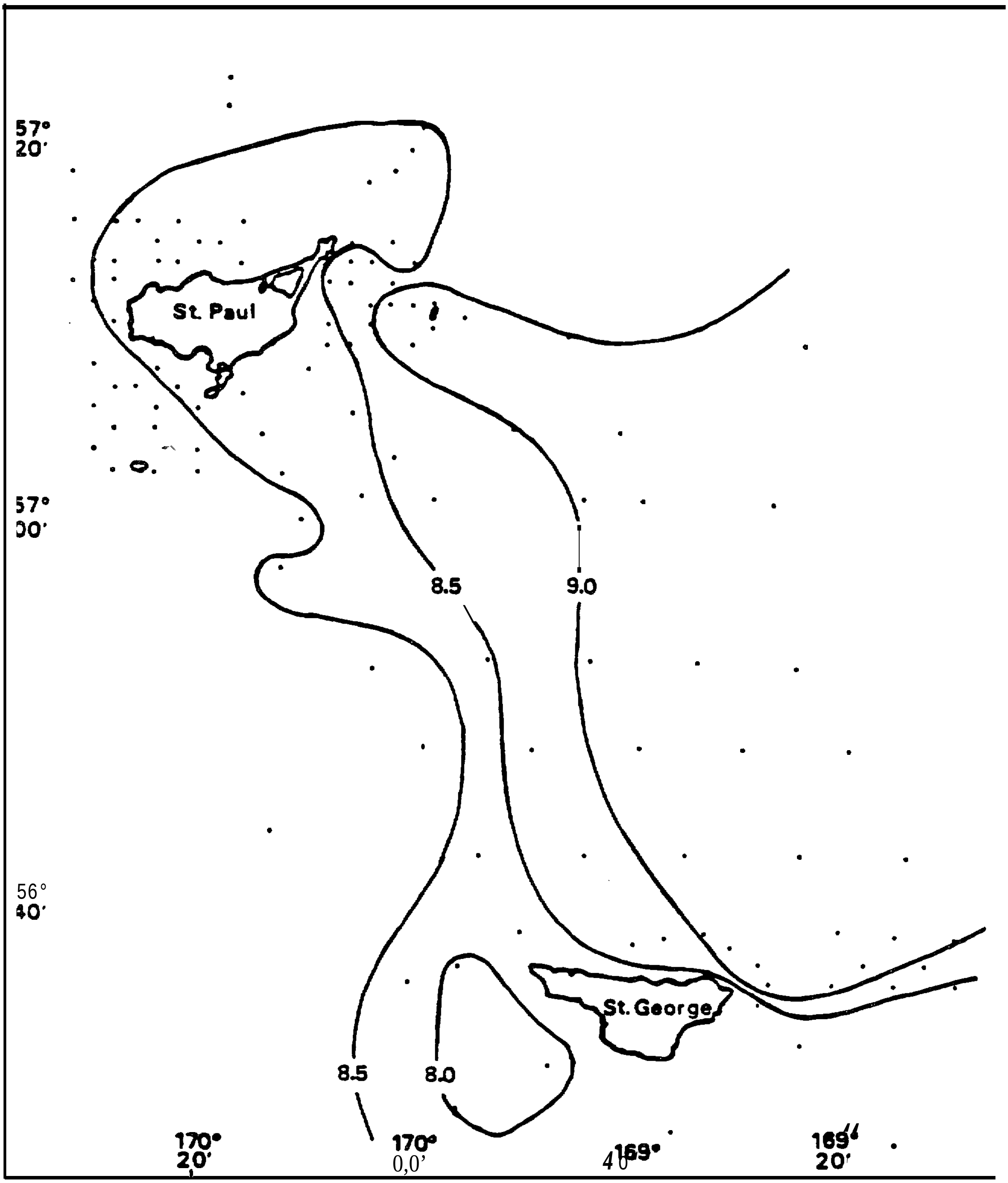
Appendix A.4 Summary of side scan sonar data on substrate type at each station, St. George Island. Over the linear distance of 1 NM at each station, the percent bottom type of each category present was summed and set on a scale of 10. R = rock, S = sand, C = cobble.



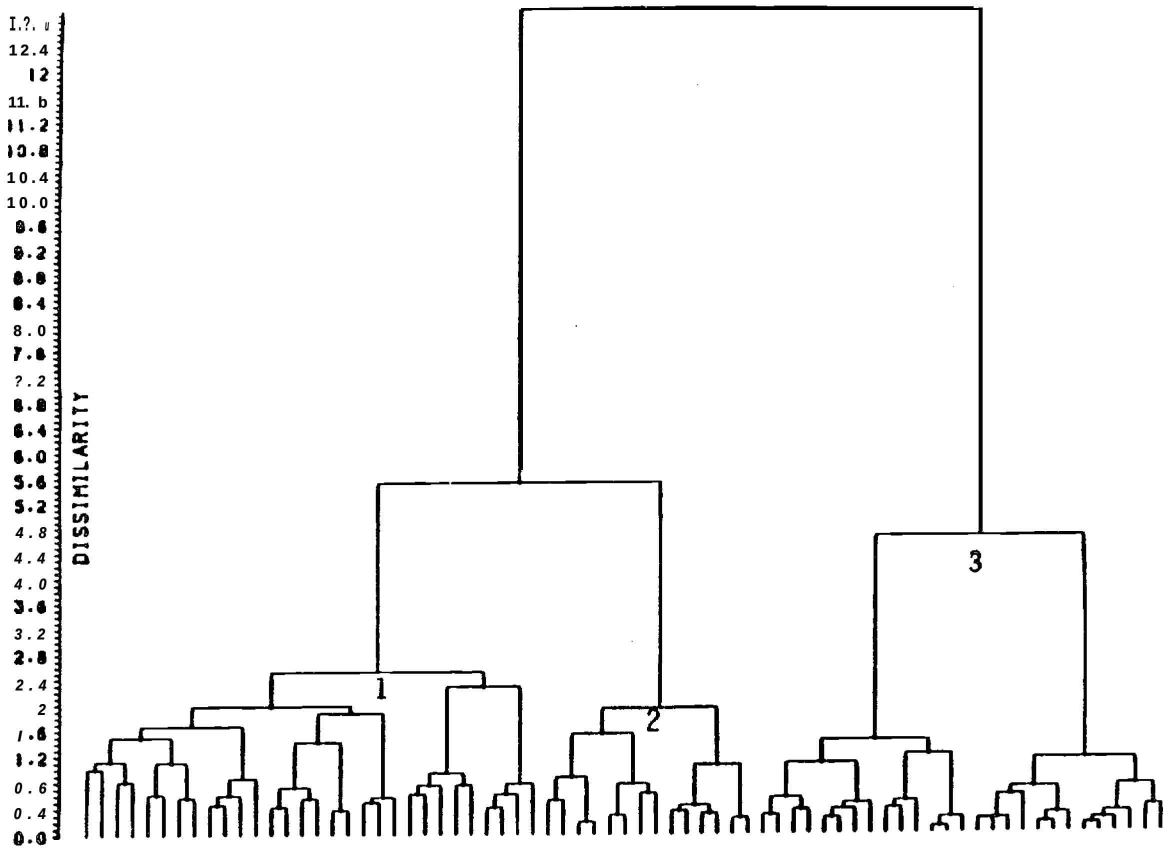
Appendix B.1 Surface temperatures (°C), April 1984.



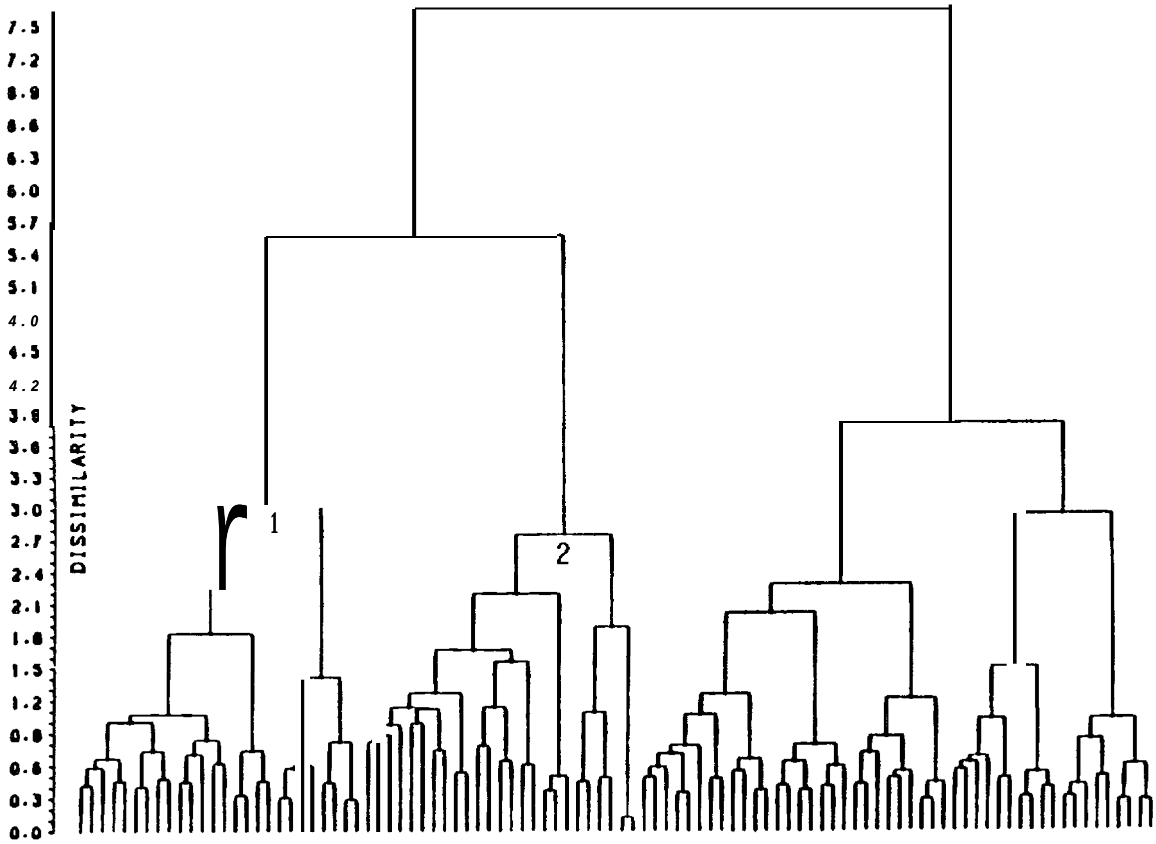
Appendix B.2 Bottom temperatures (°C), August 1983.



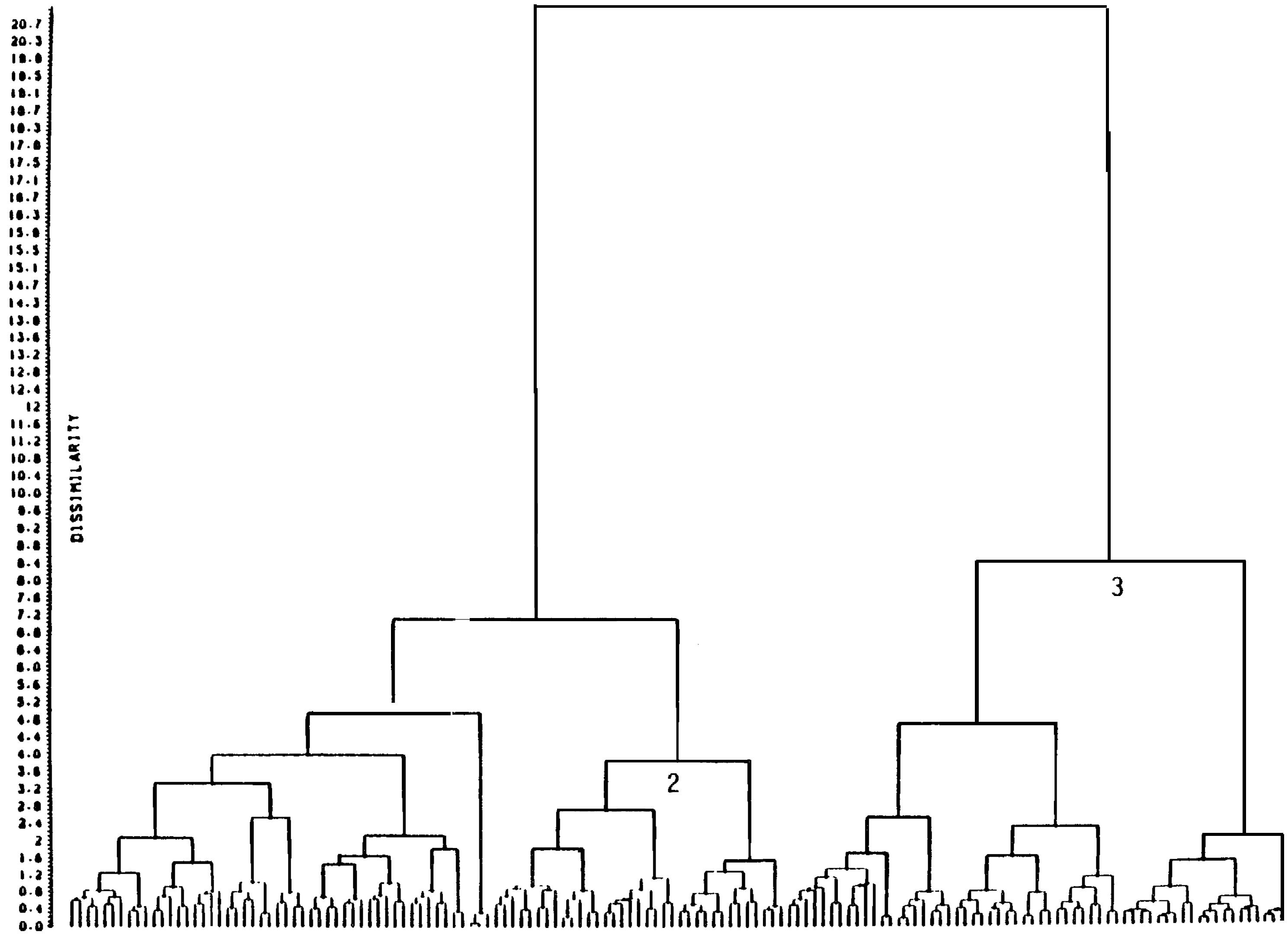
Appendix B.3 Surface temperatures (°C), August 1983.



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 (9)
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	16745.8S	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	1806	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	305.4S	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

Appendix B.7 (continued)

General Taxonomic Group	Species	Cluster number	Freq (%)	N (no/ha)	W (g/ha)	W/N (9)
	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.R	3.7	1.3
		3	22.2	4.2	11.6	2.8
	Chionocetes spp.	1	43*3	73.7	155007	21.0
		2	71.4	301.1	1331.8	4.4
		3	100.0	3216.7 *	1S969.3 *	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	15S4.6	91.4
		2	14.3	S.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.S	4.6
		2	71.4	S2.6	114.5	2.2
		3	70.4	8S.3	492.1	S.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 occurrences 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 (9)
Coelenterata	Sea Anemones	1	42.6	85.0	3715.2	43.7
		2	65.4	814.5 *		1904
		3	32.0	157.1	15799.7 / 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	38s9	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

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)	id/N (9)
	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 *	1509
	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)

Genera / 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	Overal 1
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	2000	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	1600	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 monographs 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 ana 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 ana 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 a?, 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.

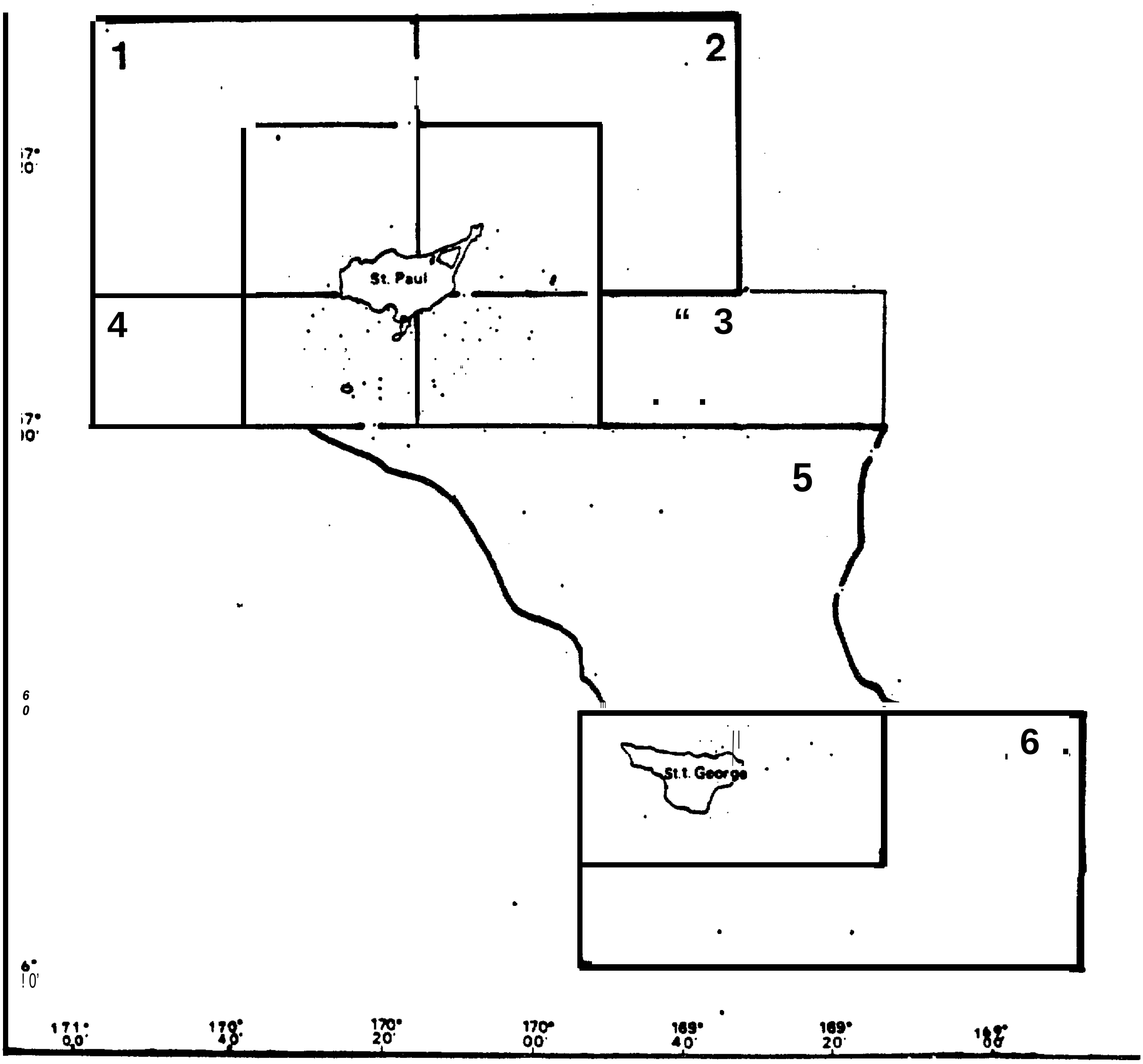
Extrinsic characteristics, like geographical distribution and substrate characteristics of the stations within different clusters must be carefully considered. When a method produces groups with mixed geographical distributions, the results must be viewed with skepticism unless other environmental factors 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

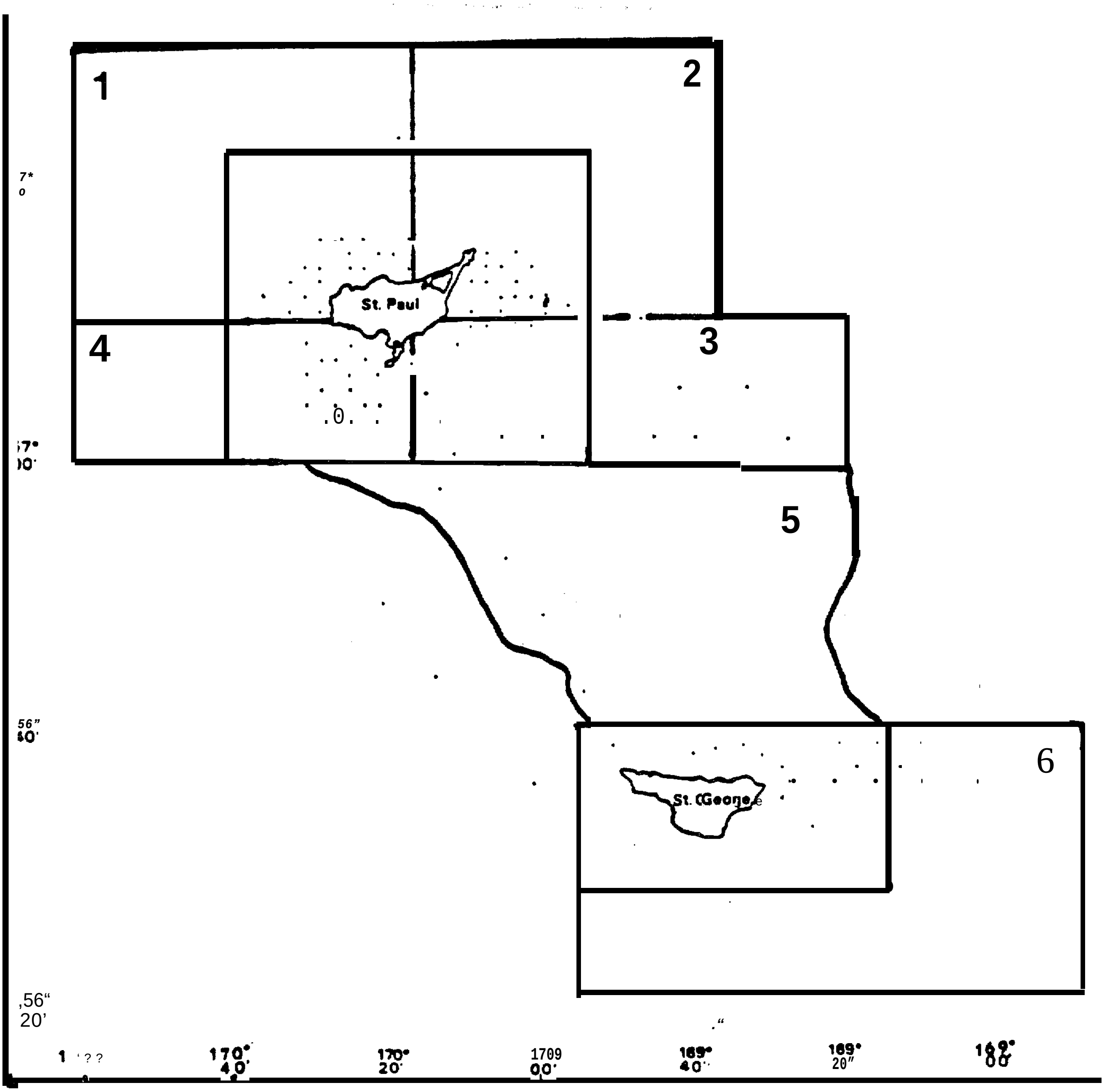
Examination of Table 3.4 and Appendices B.7 to B.9 show that while some species were caught almost exclusively at the stations in one of the clusters, others were more uniformly distributed across two or all three clusters and at comparable densities or frequencies. Whether these numbers are due to sampling 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).

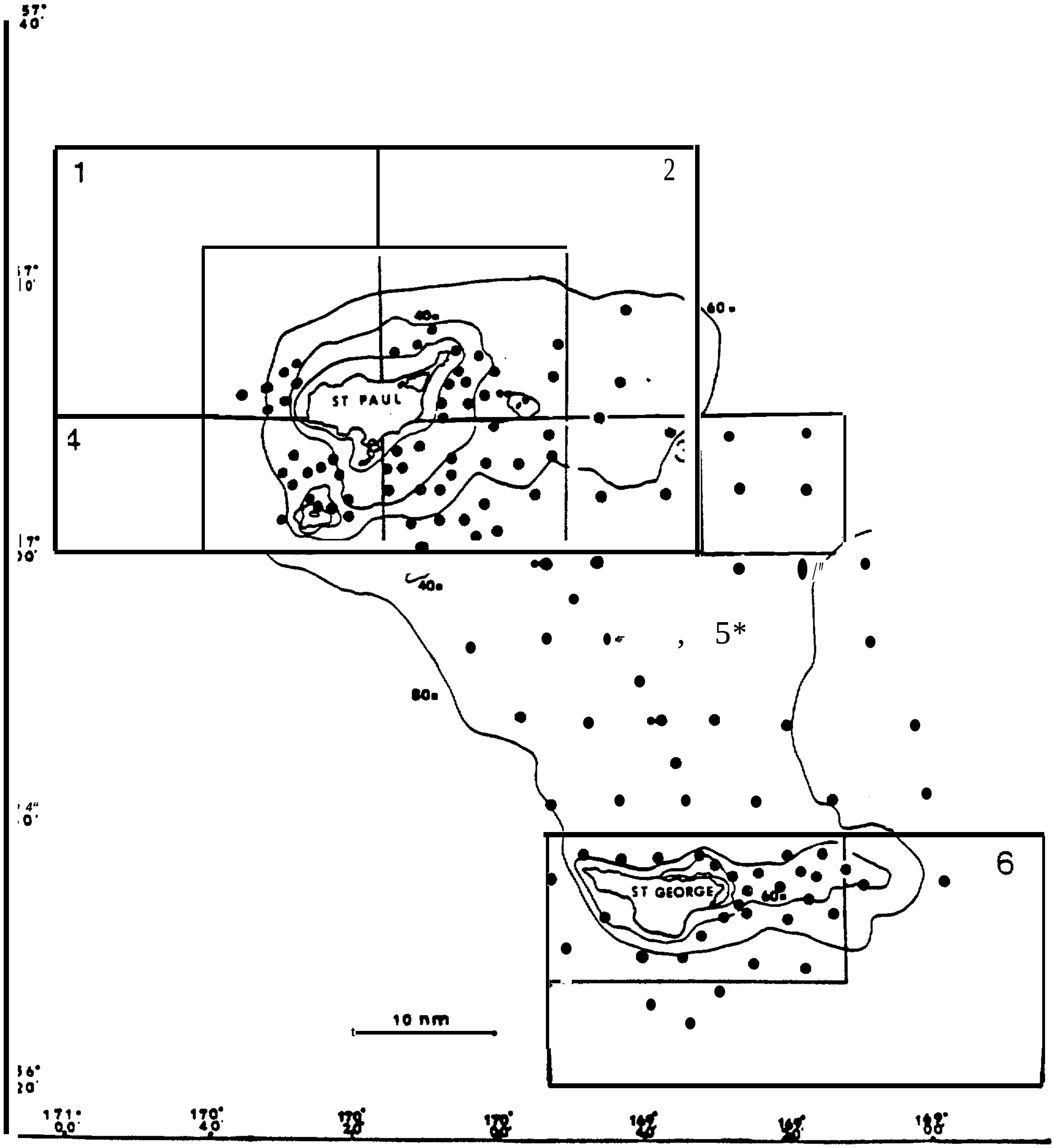
For these reasons, probability values given by the test are biased and they must be regarded carefully. Significant differences showed in Table 3.4 and Appendices B.7 to B.9 must be considered as showing values with a low (but unknown) probability of occurrence and therefore are useful as an indicator 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.

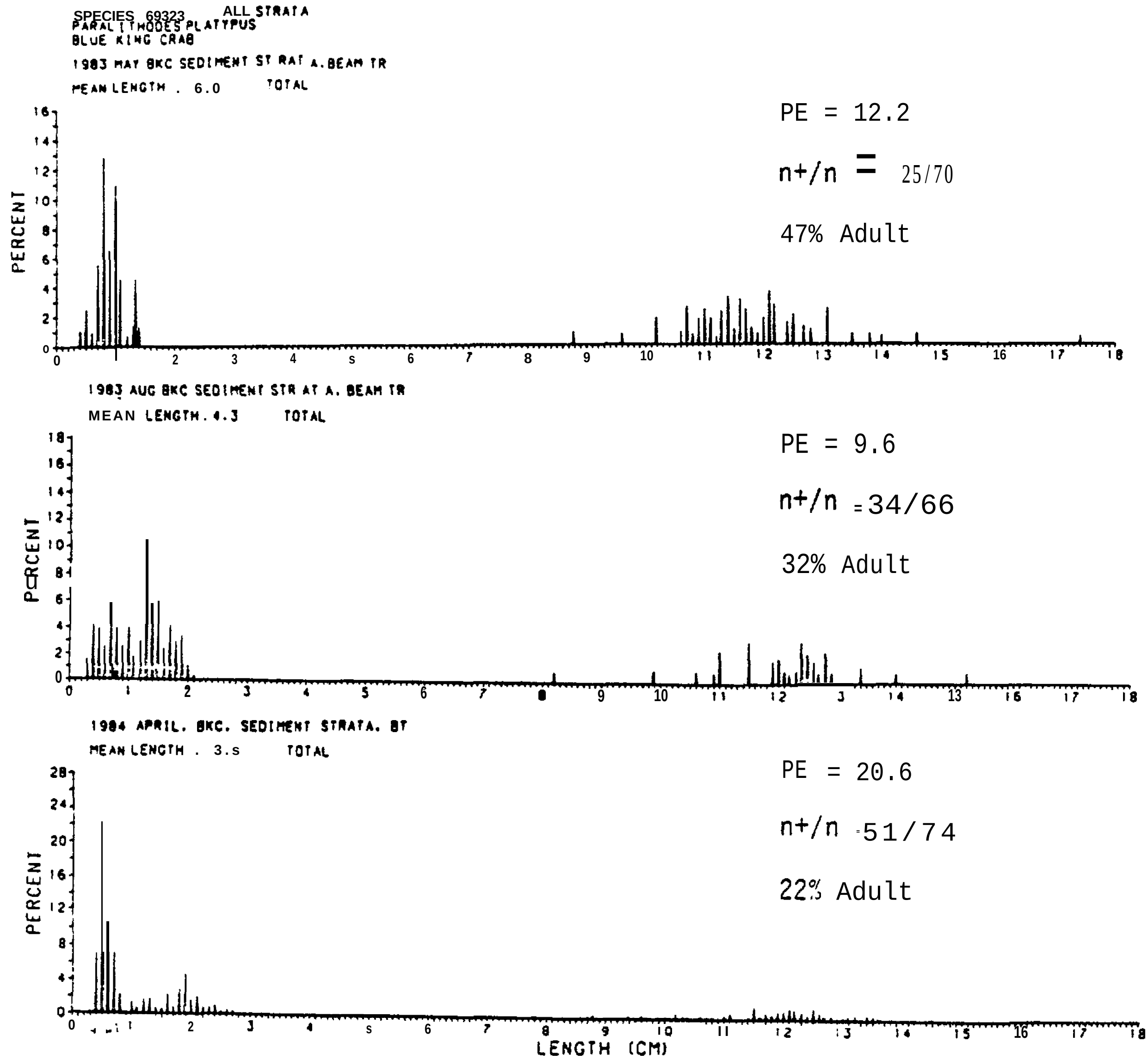
Appendix C.4 Strata groupings, areas, and sample sizes for blue king crab population estimates by rock dredge and beam trawl gear for three cruises. Numbers given are tows with crab/total tows.

Blue King Crab Population Estimate

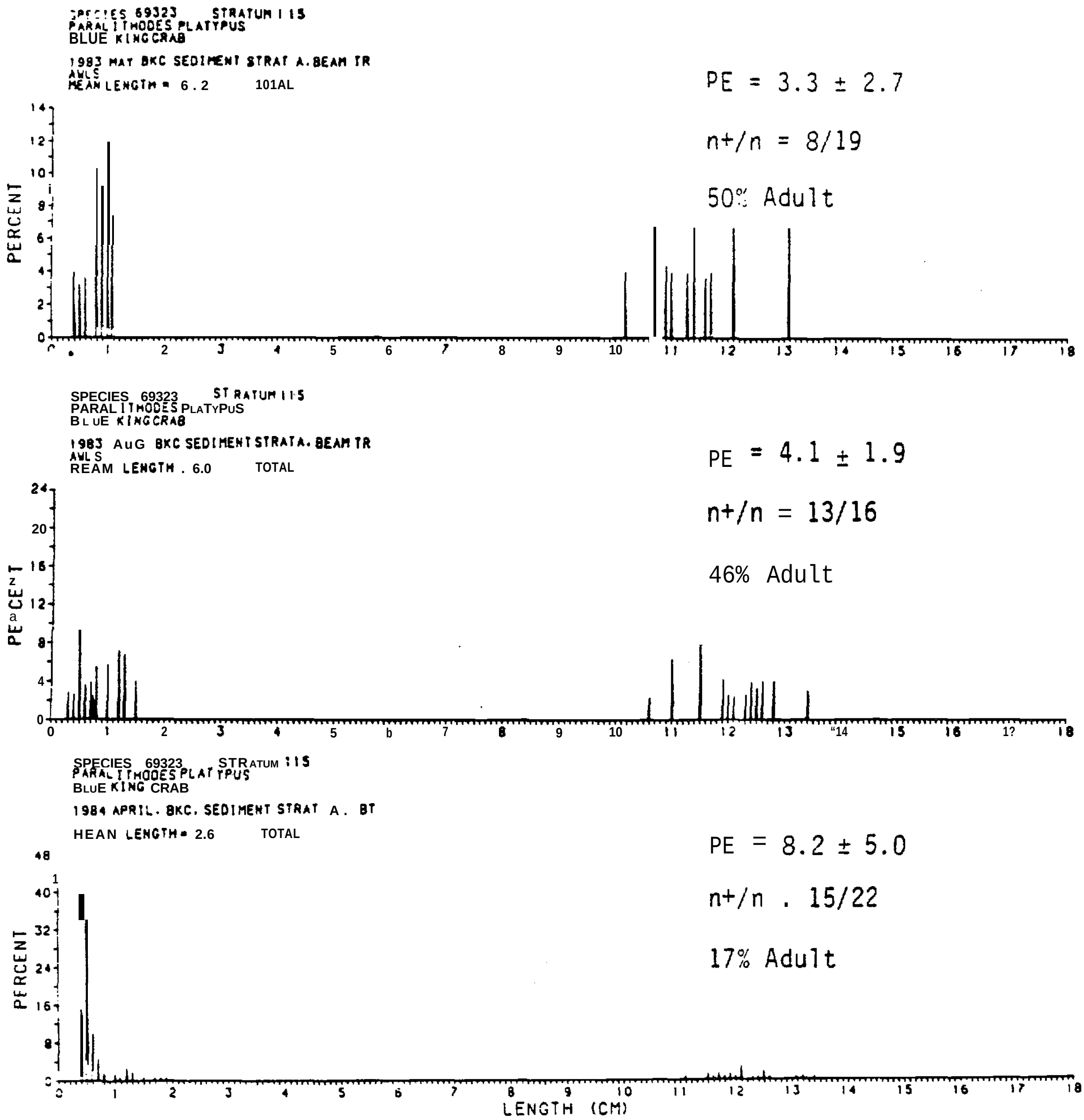
Stratum	Total Area (NM 2,	Rock Dredges May	Rock Dredges Aug	Rock Dredges Apri 1	Beam Trawls May	Beam Trawls Aug	Beam Trawls Apri 1
		Positive Tows / Total Tows			Positive Tows / Total Tows		
1	480	l/6*	13/28	4/9	l/5*	l/6*	NS
2	449	3/5	19/23	4/11	4/6	8/18	13/17
3	499	0/1	l/5*	2/5	17/24	11/12	21/23
4	232	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	l/2*	I/l*	0/2	9/23	14/17	14/20
SG Sub 6	808	3/6	13/24	10/27	l/n*	2/11	3/16
Total	3446	10/25	55/98	25/66	34/77	36/71	51/79
			12/27	4/9	0/2	l/5*	NS
21 .	147	3/5	19/23	4/11	l/2*	8/17	8/11
31	120	0/1	l/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	l/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
12'8	23	0/1	6/9	0/2	l/1*	0/5	0/1
135	48	6/8	25/29	12/18	l/3*	8/11	7/7
SP Sub	904	6/17	41/73	1 5/37	16/29	20/43	33/40
115	976	l/2*	I/l*	0/2	8/19	13/16	15/22
102	260	0/1	NS	0/3	0/3	0/1	3/5
105	33	l/1*	0/2	l/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	113*	2/5	0/5
SG Sub	373	3/6	13/21	10/25	l/7*	2/7	3/12
Total	2253	10/25	55/95	25/64	25/55	35/66	51/74
SP 15-40 M	83	l/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	l/6*	2/5	3/8
Total	830	8/19	49/87	21/52	17/38	12/38	20/34

* Low sample size

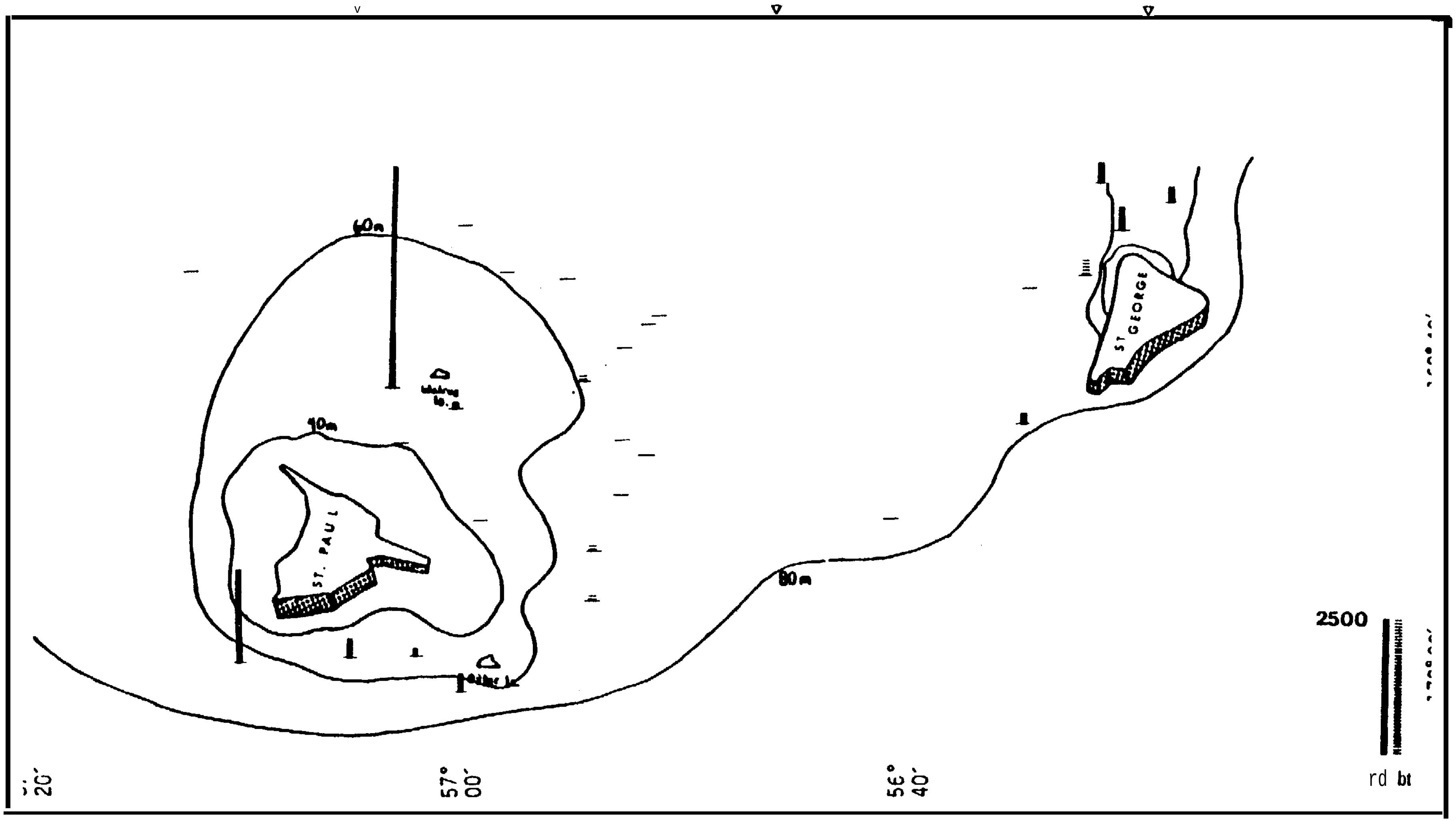
ALL SEDIMENT STRATA, BEAM TRAWL



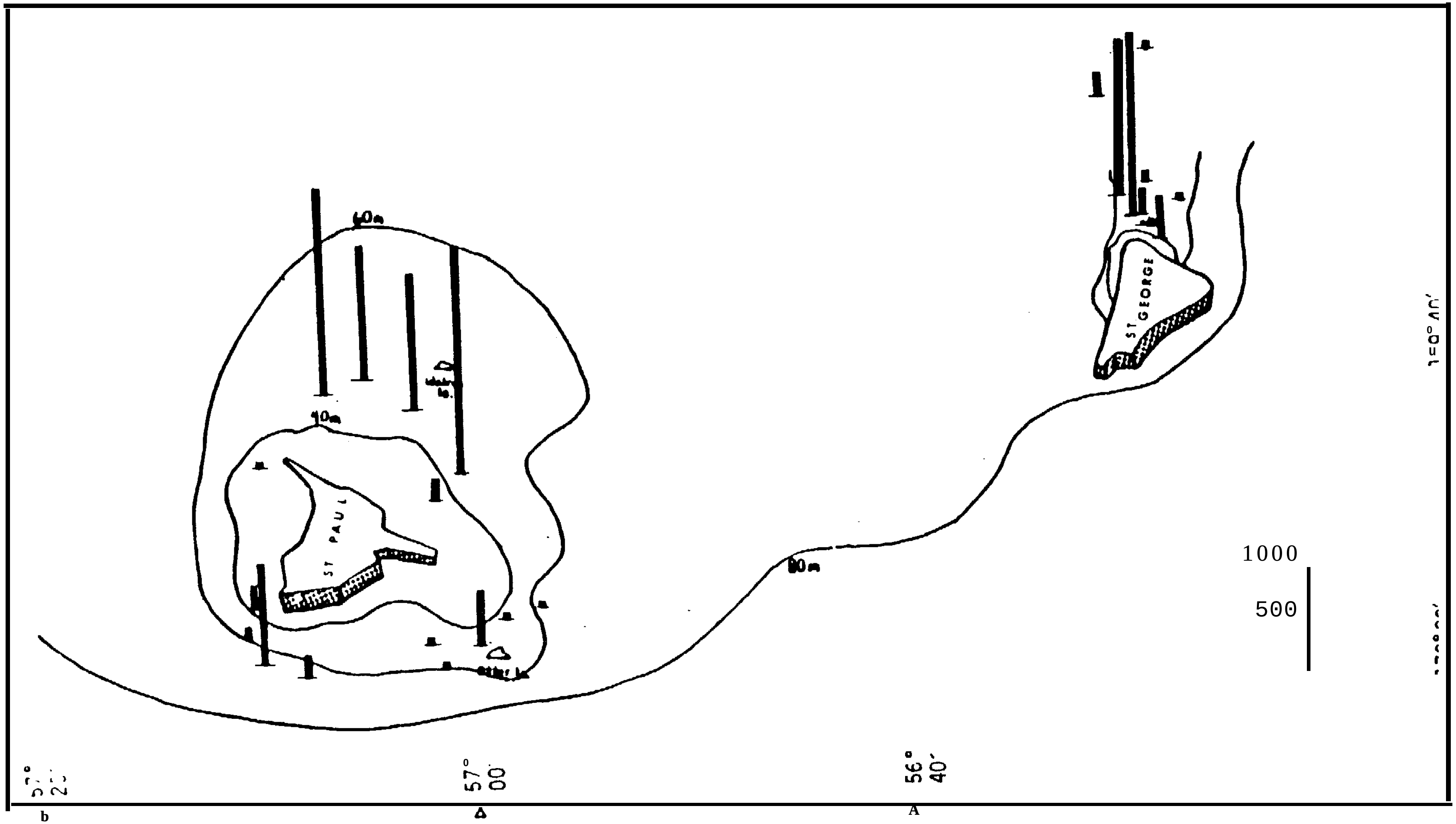
Appendix C.5 Carapace length frequencies of blue king crab collected in May and August 1983 and April 1984 by beam trawls within all strata of the sediment strata configuration. Population estimate (PE) in millions of crab, number of stations with crab/total number of stations sampled (n+/n), and percentage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



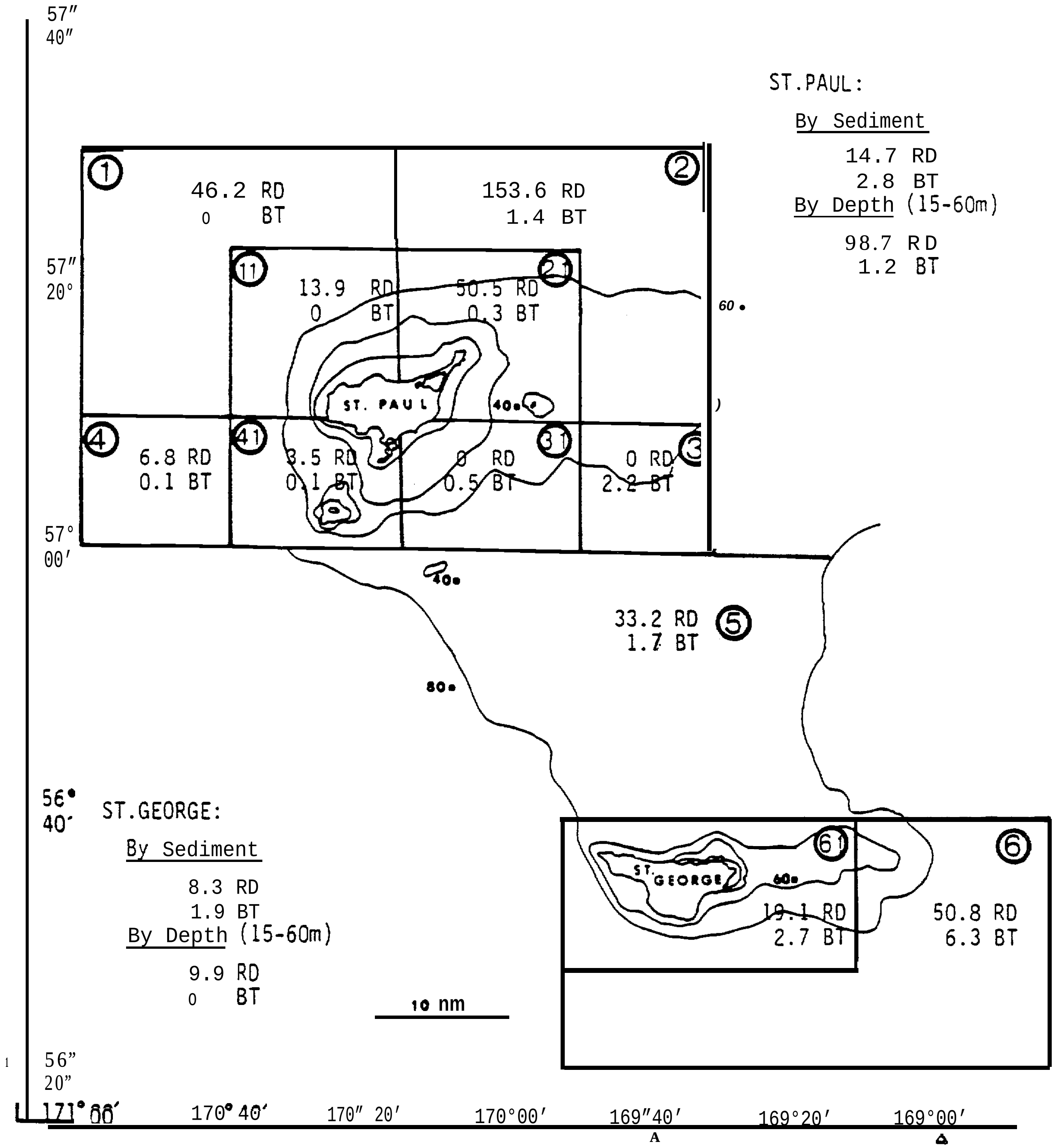
Appendix C.6 Carapace length frequencies of blue king crab collected in May and August 1983 and April 1984 by beam trawls from Stratum 115, the inter-island sandy plain. Population estimate (PE) in millions of crab, number of stations with crab/total number of stations sampled (n+/n), and percentage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



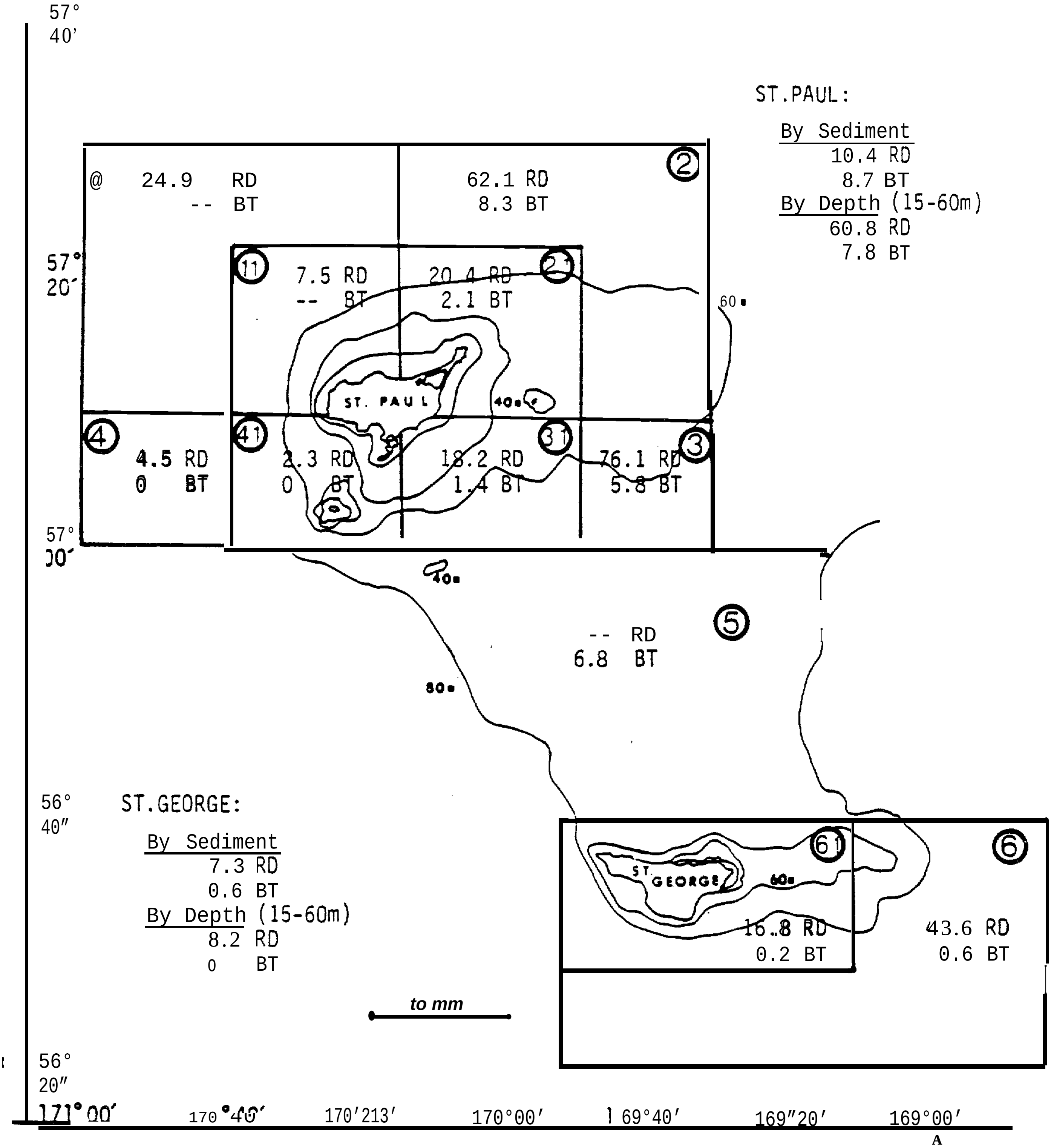
Appendix C.7 Juvenile Paralithodes platypus distribution and abundance, May 1983, expressed as number of juvenile crab/hectare. Solid bars indicate rock dredge and stiped bars are beam trawl catches.



Appendix C.8 Juveniles Paralithodes platypus 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.

	Mav		August		April	
Stratum	Pop. Estimate	± 2SE	Pop. Estimate	± 2SE	Pop. Estimate	± 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		7.5	8.1	6.5	2.3	3.4
Sub Total SP	'6$:;		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.

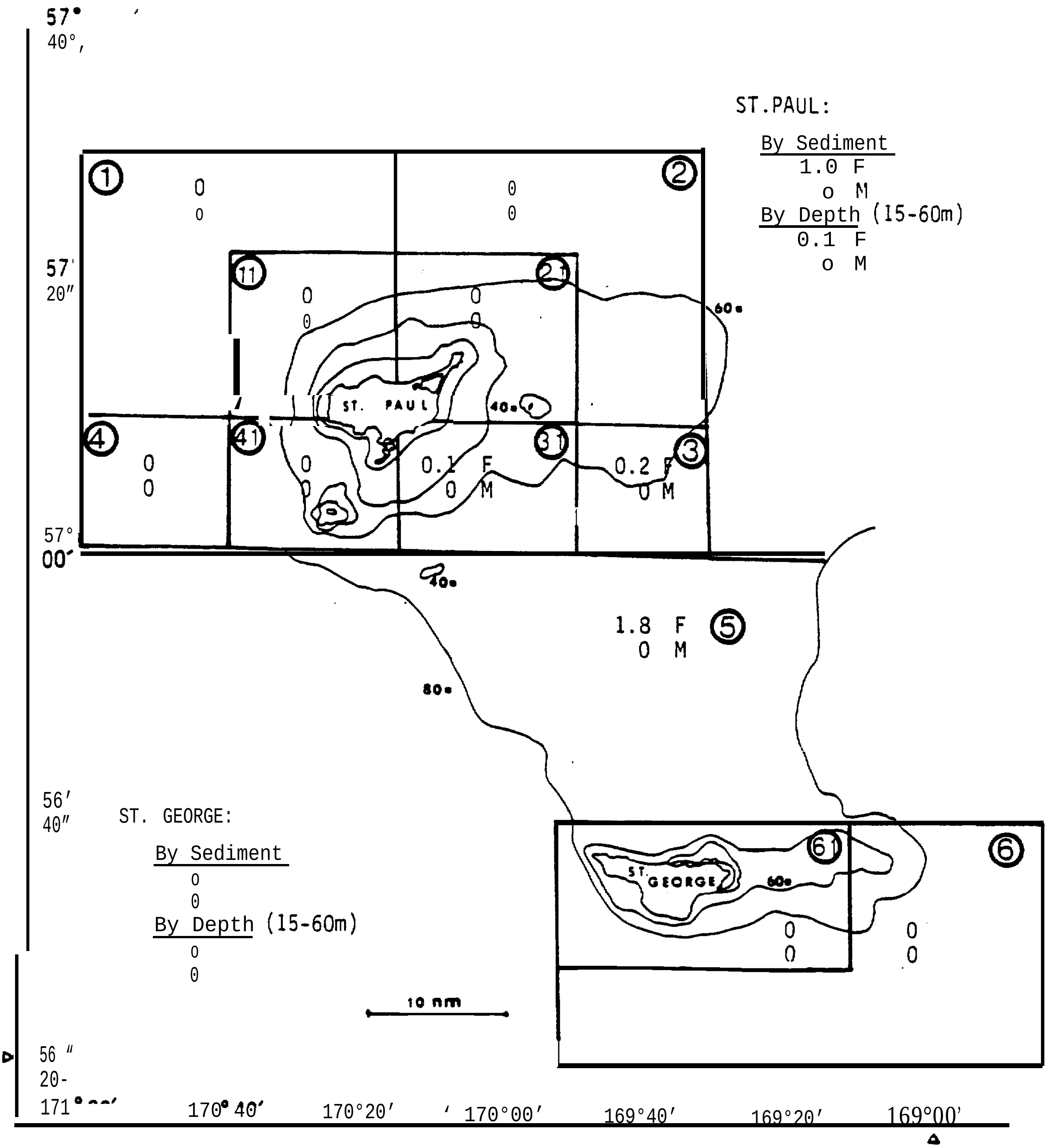
	May		August		April	
Stratum	Pop. Estimate	± 2SE	Pop. Estimate	± 2SE	Pop. Estimate	± 2SE
122	--		4.2	18.3	2.1	6.6
123	--		1.5	3,7	--	
125	--		2.7	3.5	0.5	0.9
128	--		5.0	3.7	--	
135	14.7	19.5	30.1	21.8	7.8	5.6
SP Sub Total	14.7	19.5	43.5	28.9	10.4	
115	33.1		226.9		--	
102	--		NS		--	
105	4.0		--		2.7	
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.

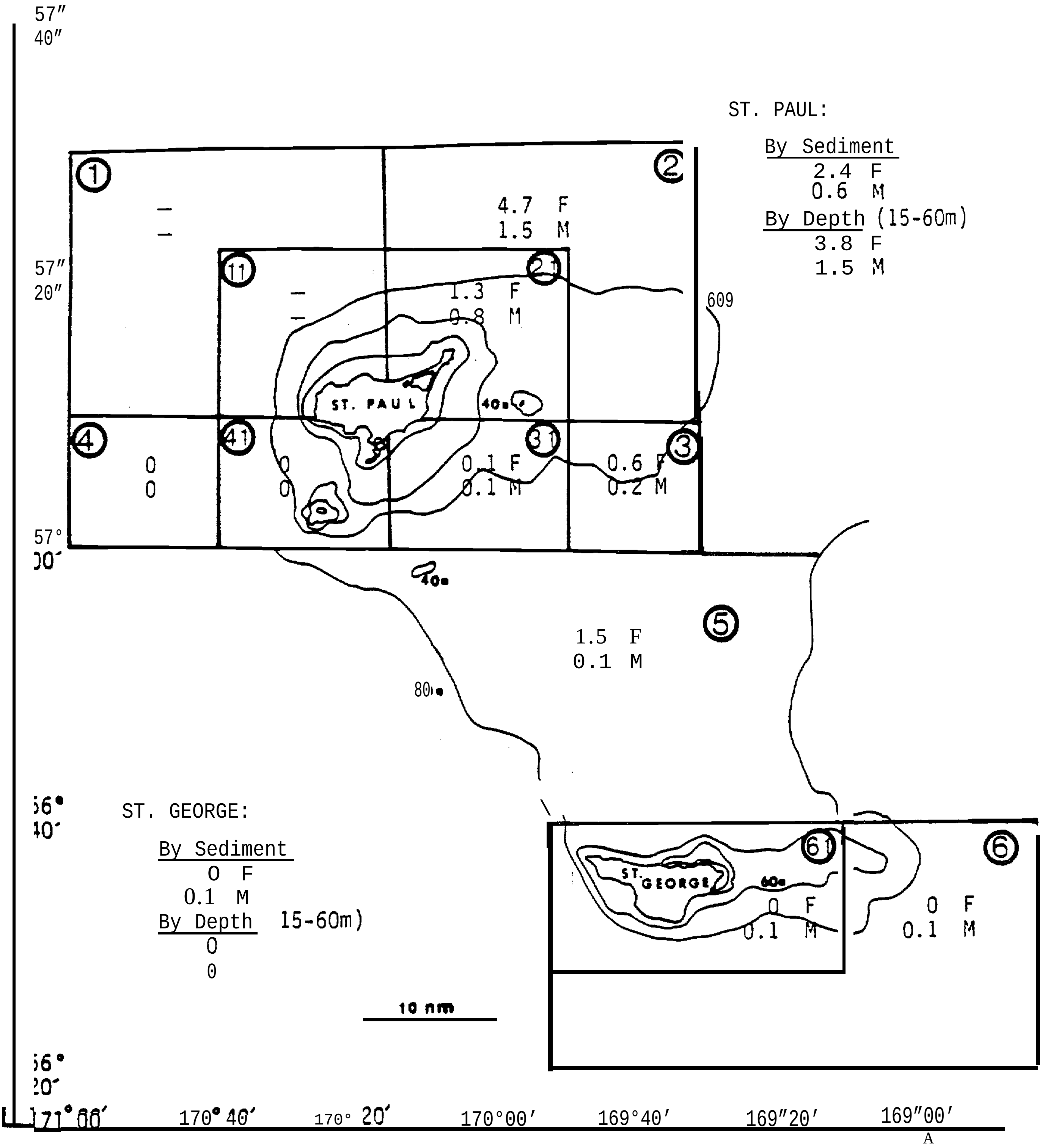
Stratum	May			August			April		
	Pop. Estimate	± 2SE	Proportion Adults	Pop. Estimate	± 2SE	Proportion Adults	Pop. Estimate	± 2SE	Proportion Adults
1	1.6	4.3	1.0	0.6	1.8	0	NS	-	
2	4.0	5.0	0.67	3,9	3.0	0	14.5	9.9	0.43
3	5.7	2.3	0.61	4.6	3.8	0.07	6.6	2.7	0.12
4	0.3	0.4	0.63	0			0	-	
SP Sub Total	11.6	6.0		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.

Stratum	May Pop. Estimates	May ± 2SE	May Proportion Adults	August Pop. Estimate	August ± 2SE	August Proportion Adults	April Pop. Estimate	April ± 2SE	April 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	(-).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.

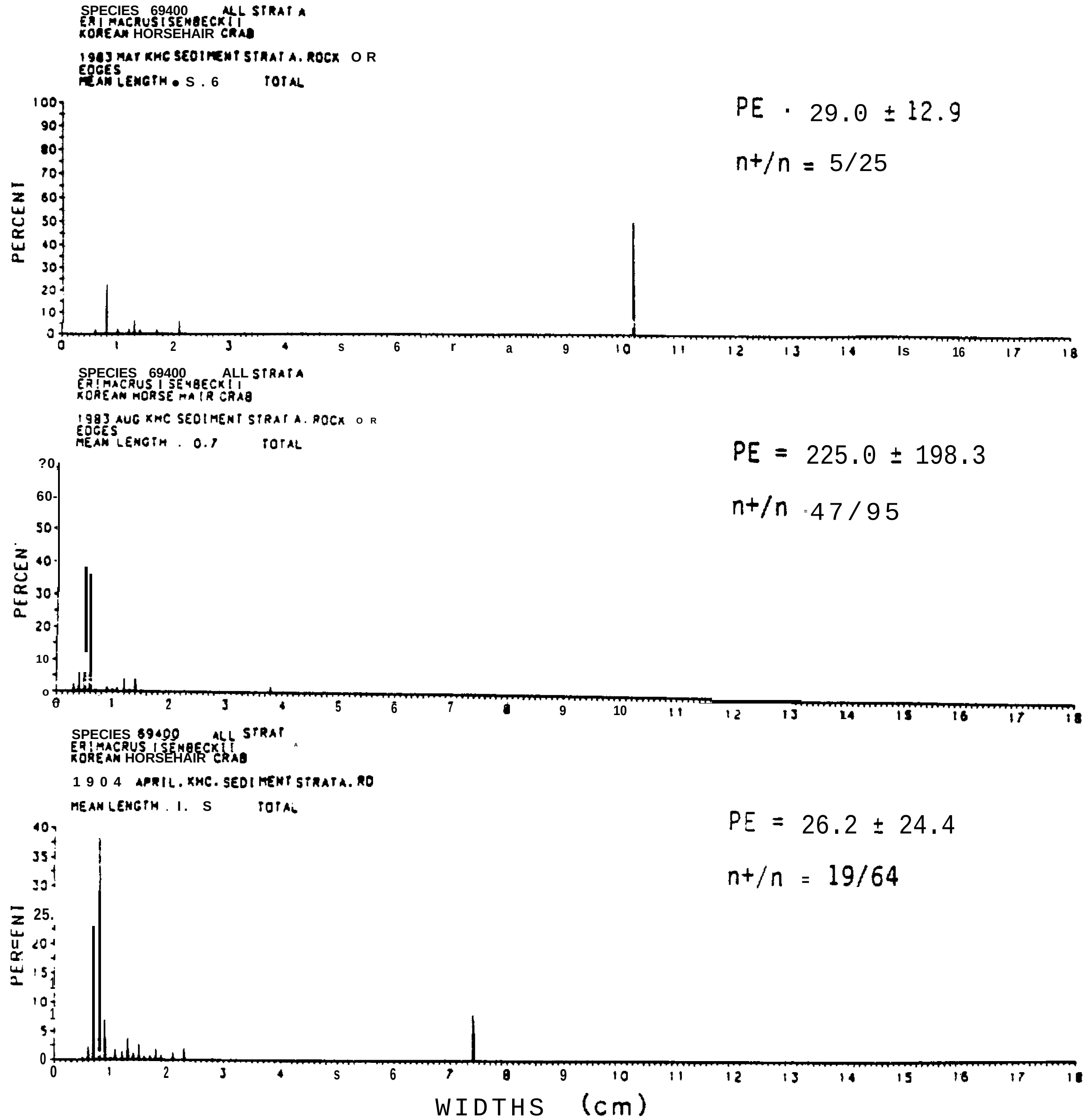
Appendix C.17 Adult blue king crab population estimates from sediment and depth strata, 1983-84, by sex, as taken by beam trawls. Values given are millions of crab.

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

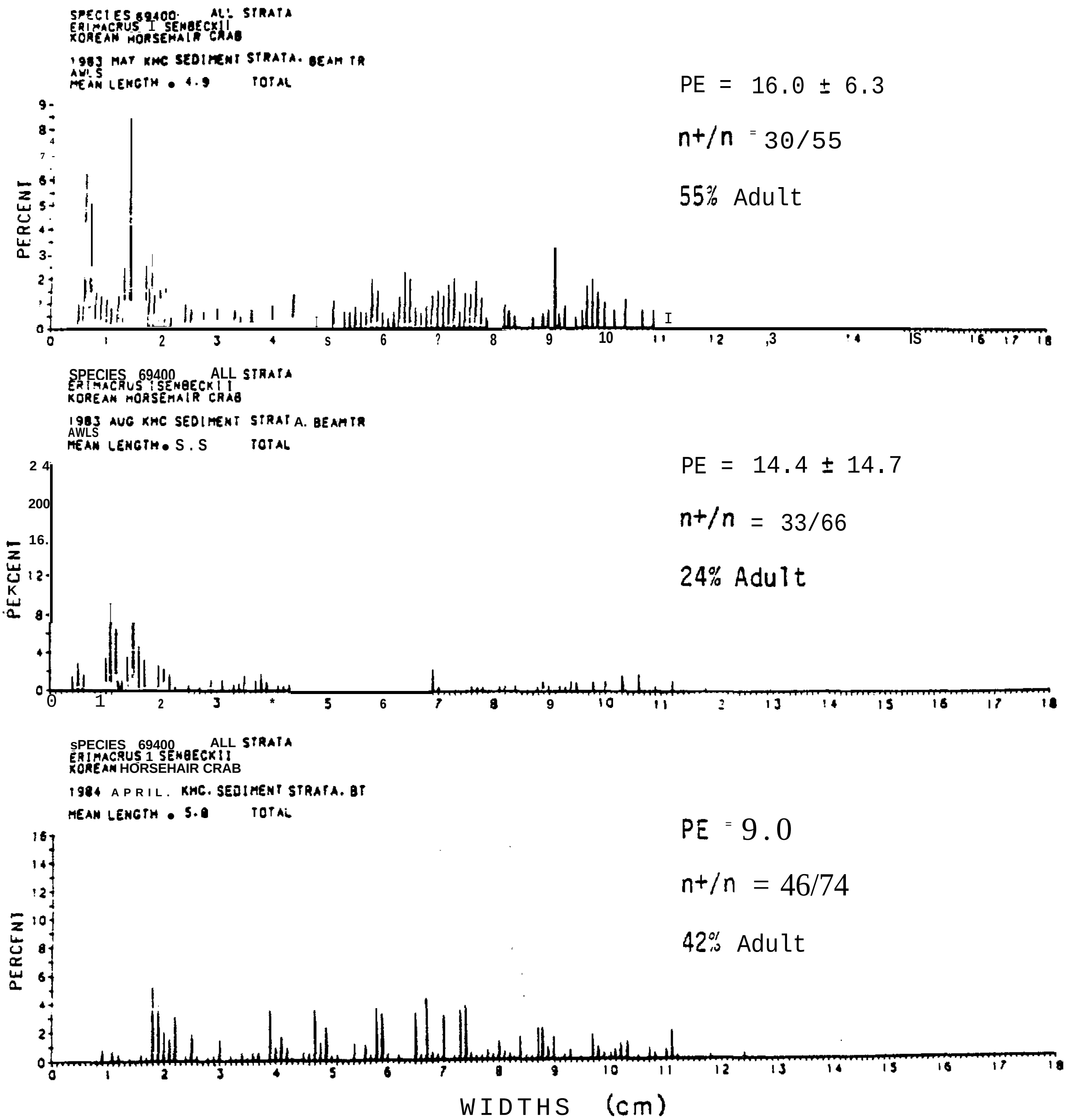
Appendix D.1 Larval Korean hair crab whole body dry weight analysis, May 1983. Mean values reported in milligrams (mean ± 1 SD).

	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.



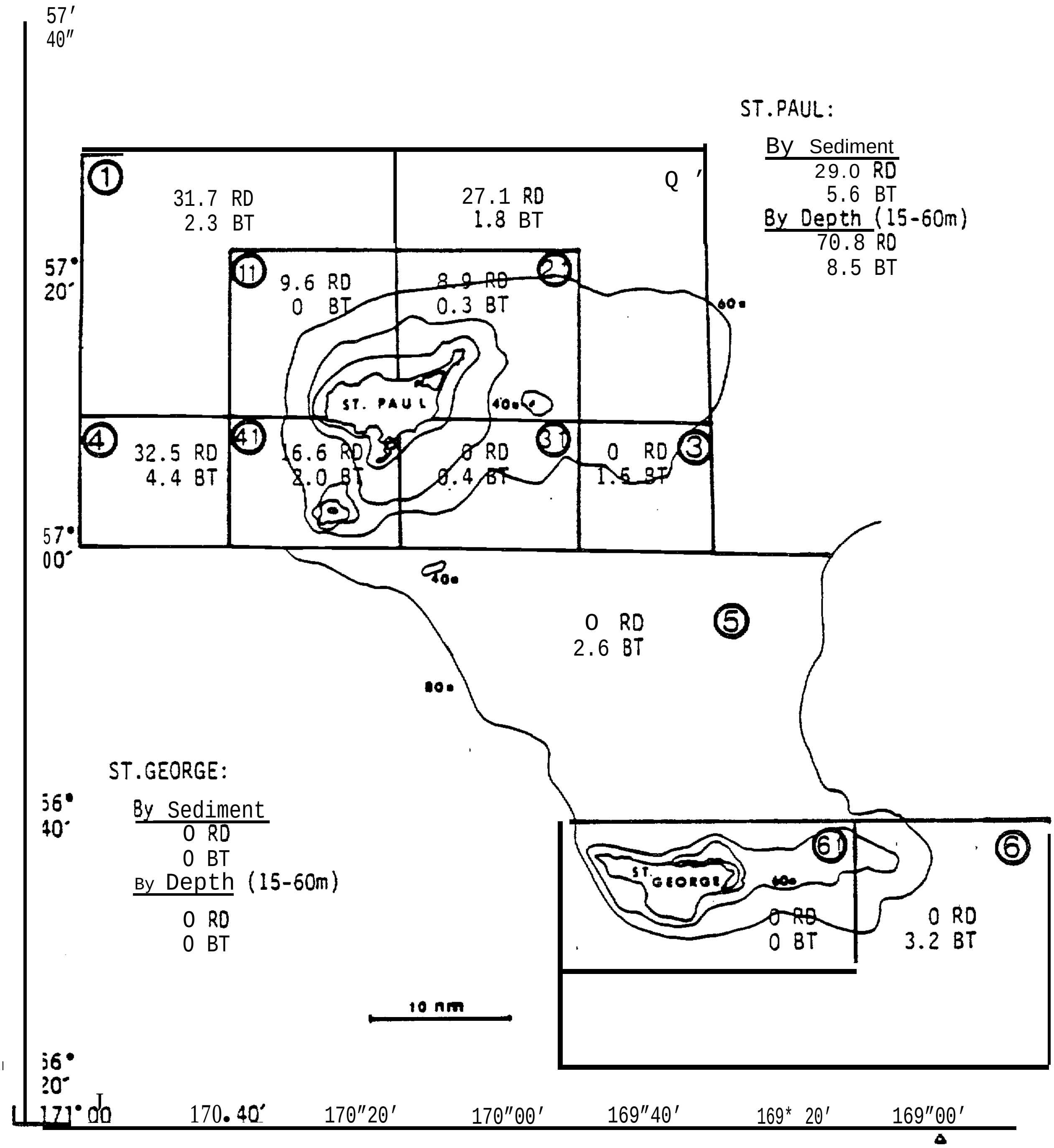
Appendix D.2 Carapace length frequencies of Korean hair crab collected in May and August 1983 and April 1984 by rock dredges within all strata of the sediment strata configuration. Population estimate (PE) in millions of crab and number of stations with crab/total number of stations sampled (n+/n) are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



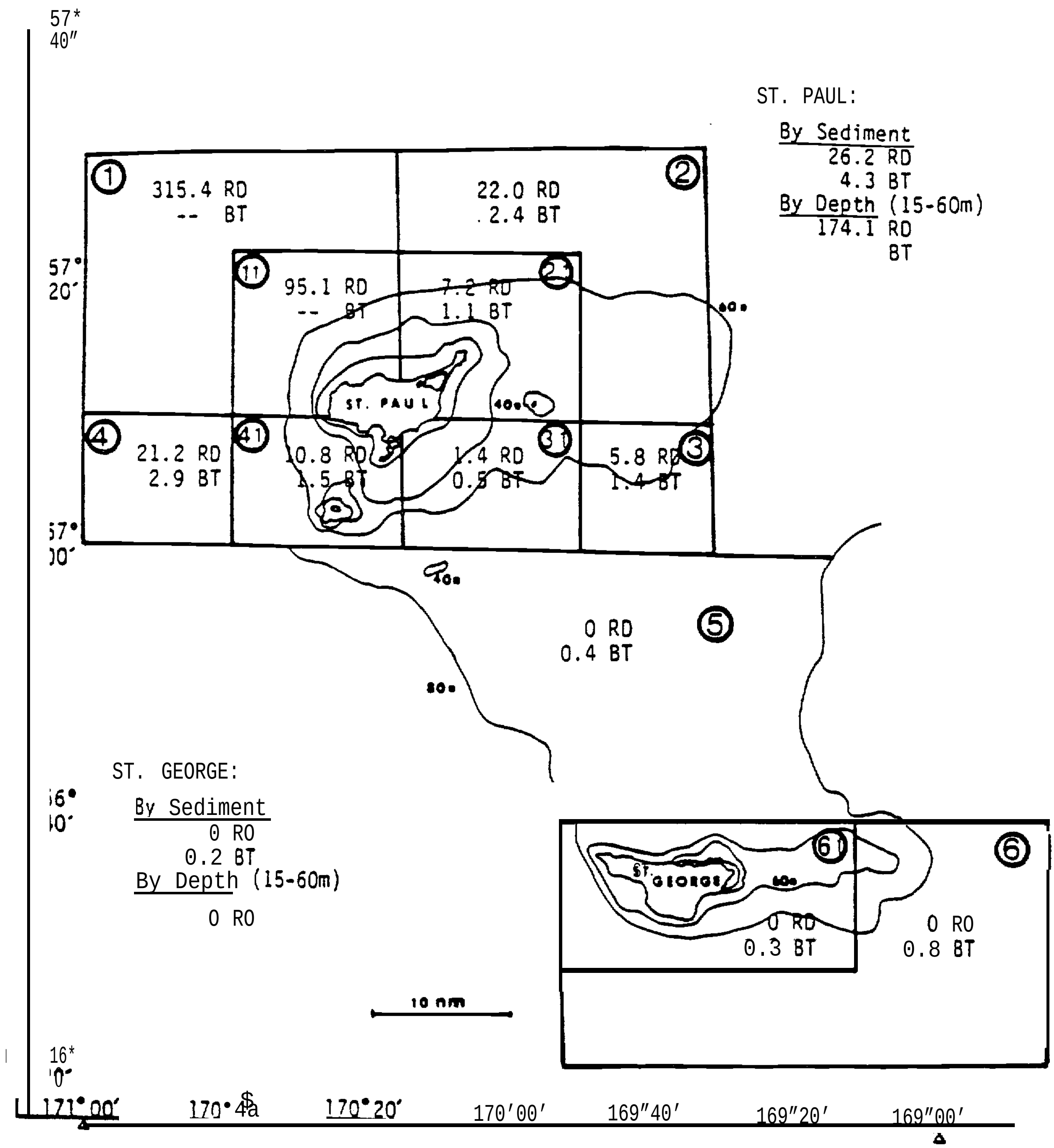
Appendix D.3 Carapace length frequencies of Korean hair crab collected in May and August 1983 and April 1984 by beam trawls within all strata of the sediment strata configuration. Population estimate (PE) in millions of crab, number of stations with crab/total number of stations sampled (n+/n), and percentage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

	May 1983		August 1983		April 1984	
Sediment Type (Stratum Number)	Sample size	Density	Sample size	Density	Sample size	Density
Sand (122 + 123)	0/3	o	.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; RO = 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	l/5*	2/6	NS
2	449	2/5	14/23	4/11	4/6	13/18	14/17
3	499	0/1	3/5	l/5*	19/24	8/12	18/23
4	232	l/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	34$6	5/25	48/98	1 9/66	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	4/1 1	2/2	12/17	9/11
31	120	0/1	2/4	l/5*	12/14	5/6	13/15
41	118	l/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	l/5*	13/18	15/18	24/30
123	200	0/2	3/7	0/2	5/6	3/6	1/2*
125	70	l/5*	6/25	2/10	0/1	0/3	Ns
128	23	l/1*	9/9	2/2	l/1*	2/5	l/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	l/2*
1 1 4	67	0/4	3/18	0/20	0/3	l/5*	1/5*
SG Sub Total	373	0/6	3/21	0/25	0/7	l/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	l/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.

Stratum	May		August		Apri 1	
	X 10^6 crab	± 2SE	X 10^6 crab	± 2SE	X 106 crab	± 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		August		April	
	Pop. Estimate X 10^6 crab	± 2SE	Pop. Estimate (10^6 crab	± 2SE	Pop. Esti ate (10^2 crab	± 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		0	
Total	29.0	12.9	225 ::	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.

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
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	.2a	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.

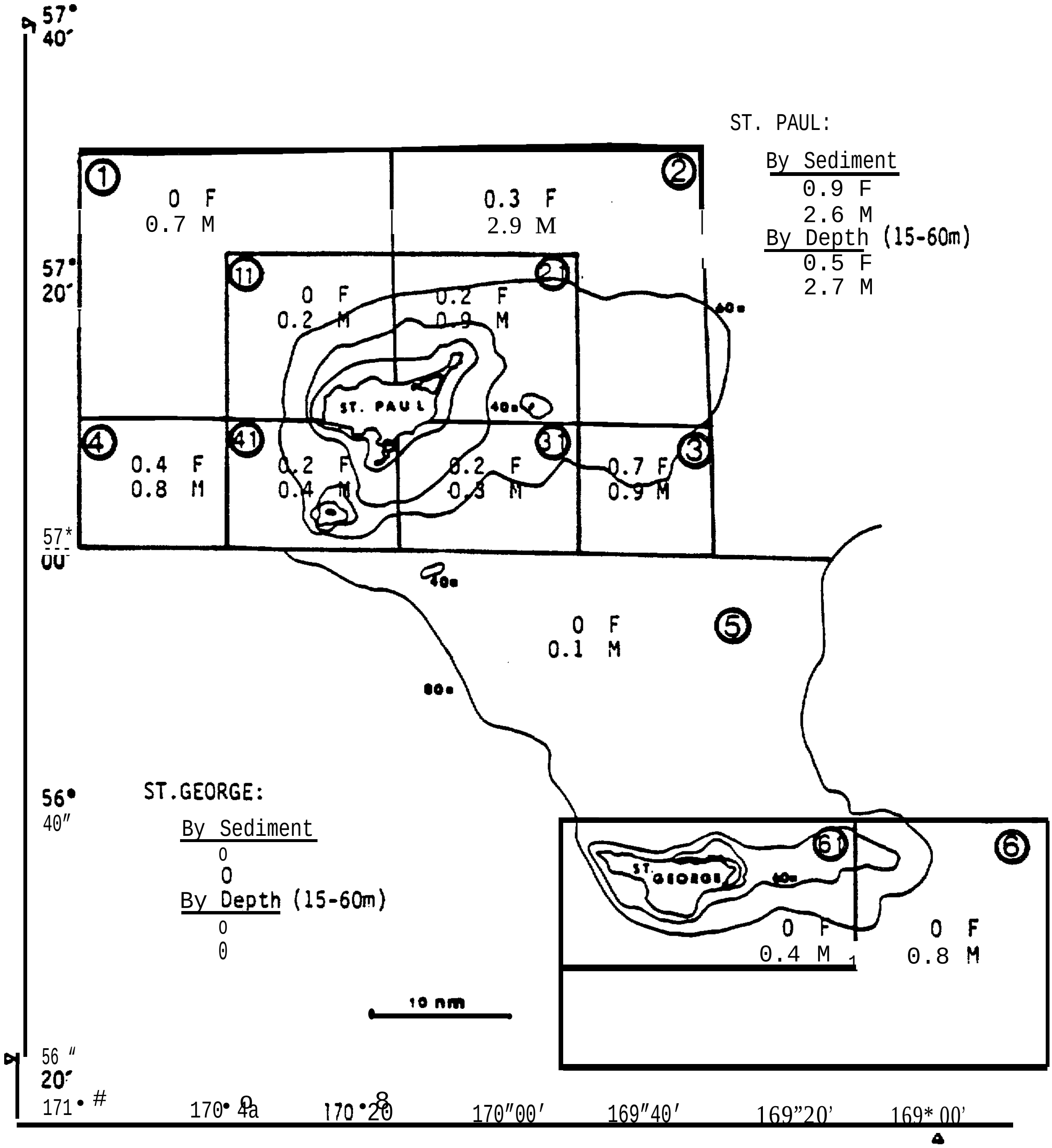
	Flay			August			April		
Stratum	Pop. Estimate K 10^6 crab	± 2SE	Proportion Adults	Pop. Estimate (10^6 crab	± 2SE	Proportion Adults	Pop. Estimate 10^6 crab	± 2SE	Proportion Adults
122	6.2	3.4	.67	5.8	3.9	.43	2.9	0.9	.49
123	4.1	4.7	.78	5.8	13.6	.08	2.8		.30
125	0			0			NS		
128	0.6		0	0.2	0.3	.13	0.5		.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.

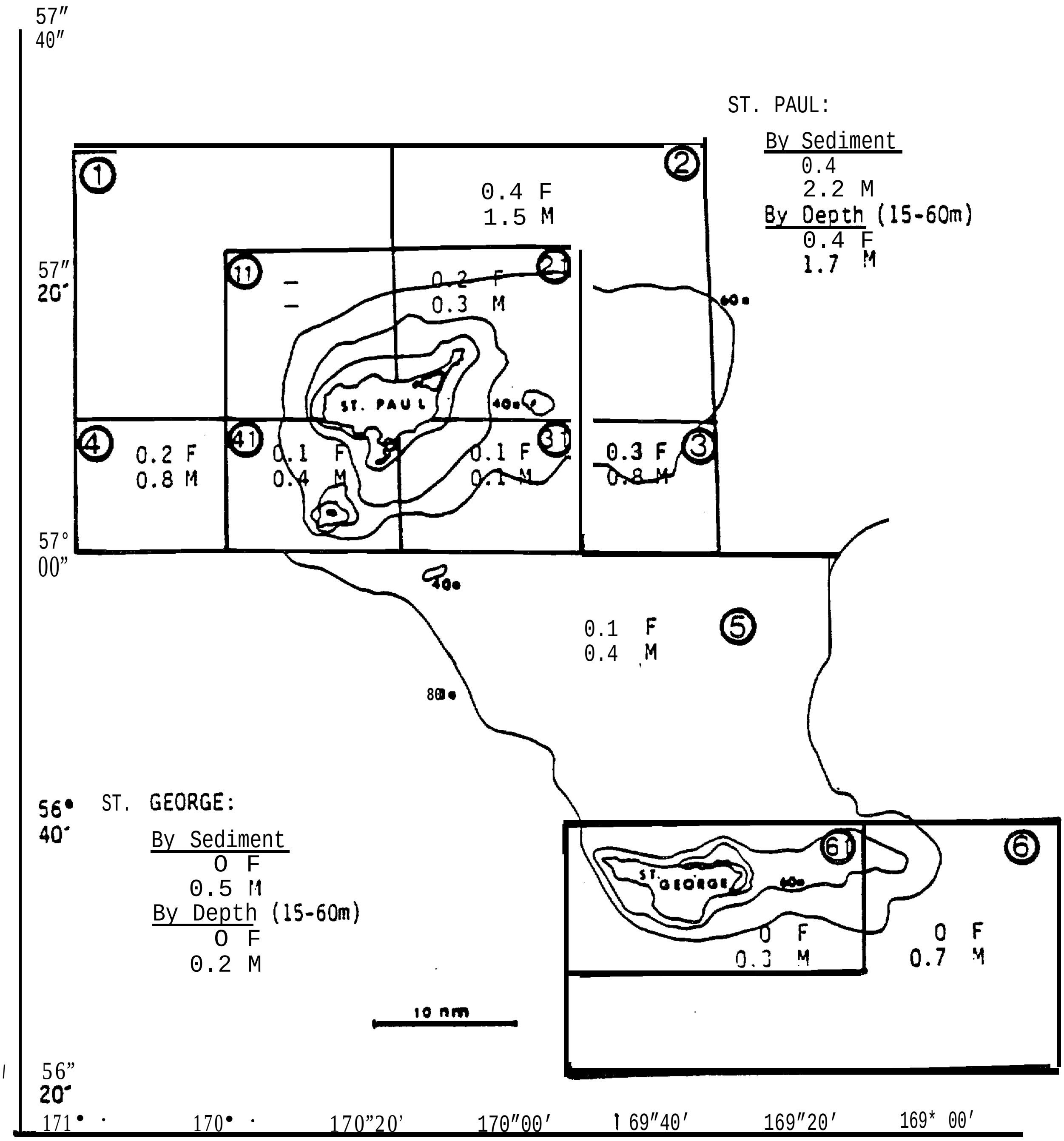
Stratum	May			August			April		
	Total Adult	Adult Female	Adult Hale	Total Adult	Adult Female	Adult Male	Total Adult	Adult Female	Adult Male
122	4.2	2.0	2.2	2.4	0.8	1.6	1.4	0.3	1.1
123	3.2	2.5	0.7	0.5	0	0.5	0.8	0	0.8
125	0	0	0	0	0	0	NS	NS	NS
128	0	0	0	trace	trace	trace	0.1	.05	.05
135	0	0	0	0.6	0.1	0.5	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 15-60111	0	0	0	0	0	0	0.2	0	0.2
60-90m	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.

Stratum	May			August			April		
	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.