DISTRIBUTION AND ABUNDANCE OF DECAPOD CRUSTACEAN LARVAE IN THE SOUTHEASTERN BERING SEA WITH EMPHASIS ON COMMERCIAL SPECIES

by

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1.0 GENERAL INTRODUCTION

1.1 Justification of the Study

The southeastern Bering Sea is characterized by rich water column productivity of both phytoplankton and zooplankton (McRoy and Goering 1974; Goering and Iverson 1978; Goering and McRoy 1981, Cooney 1981) which, in turn, supports an extensive and productive benthic community over much of the shelf (Feder and Jewett 1981; McDonald et al. 1981; Jewett and Feder 1981). Some of the most abundant epifaunal organisms quantified in these studies are several species of crab that constitute lucrative invertebrate fisheries for the United States (Otto 1981). Distribution of these species, particularly gravid females and sensitive larvae and Juveniles, in relation to areas of future oil and gas development of the St. George Basin and North Aleutian Shelf (NAS), make them particularly vulnerable to oil mishaps that could have ultimate repercussions on the general benthic community and commercial fishery (Curl and Manen 1982; Armstrong et al. 1983).

Minerals Management Service (MMS) has established six outer continental shelf planning units in the Bering Sea. Three of these units have been through tract selection stages and include the St. George Basin and the North Aleutian Shelf, which together encompass virtually all of the southeastern Bering Sea crab fishering grounds. Two synthesis meetings have been held to consider the impact of Outer Continental Shelf (OCS) oil and gas development on biota and habitats in both units in order to aid in development of management plans that mitigate perturbations on resources. Proceedings of tne St. George Basin meeting have been published prior to an anticipated lease sale in mid-1983 (Hameedi 1982), and reports of the NAS meeting are in review and expected by summer 1983. Data and interpretations from the present study on decapod larvae were included in proceedings from both meetings (Curl and Manen 1982; Armstrong et al. 1983), and served to extend knowledge on the biology and ecology of commercial crabs that was used to predict vulnerability of the species.

Crabs in the southeastern Bering Sea constitute one of the most valuable crustacean fisheries in the world. Two principle groups, king crab (*Paralithodes camtschatica* and *P. platypus*) and Tanner crab (*Chionoecetes bairdi* and *C. opilio*) comprised 35.4% and 23%, respectively, of total U.S. crab landings in 1980. Their respective dollar values were 60% and 11.7% of total ex-vessel U.S. crab revenues of $291,350,000 (NOAA 1981; Pacific Packers 1981; Sections 3.0 and 4.0 of this report give extensive literature reviews of general biology and fishery information on king and Tanner crab). Since the beginning of this project in January 1981, commercial fishing has suffered two years of depressed landings in 1981 and 1982, particularly of red king crab. Landings declined from 131 x 10^6 lb in 1980 to about 35 x 10^6 in 1981 (INPFC 1982), and the fishery was closed at about 3.5 x 10^6 in 1982 (M. Hayes, NMFS, Seattle, pers. communication). Such severe reductions in landings are in accord with NMFS predictions of decreased abundance (5-fold decrease from 1979 to 82: Otto et al. 1982), and reflect a substantial, but unexplained, variation in success of year-classes.

Larval stages are generally considered more sensitive to environmental stresses than adults or juveniles of aquatic species (Anger et al. 1981; Bakun et al. 1982; May 1974; Vernberg and Vernberg 1972). Studies of larval crab and shrimp biology in the southeastern Bering Sea are timely for insights behind the vagaries of adult abundance that might be traced to relative success of pelagic larval year-classes. An important consideration for predictions of impact is whether oil mishaps could further diminish populations already reduced by natural stresses on their larvae.

Forthcoming development of petroleum and gas reserves in the reproductive and fishing grounds of commercially important Crustacea led to the study outlined in this report. While extensive literature exists on the distribution and abundance of juvenile and adult decapod Crustacea in the southeastern Bering Sea (Jewett and Feder 1981; Otto 1981a; provided by NMFS as part of the commercial fisheries survey; Somerton 1981), little data on the general ecology, distribution, and abundance. . of their pelagic larvae are published. Larvae are considered extremely susceptible to oil pollution because:

1. This life-history stage is pelagic, usually in the upper 20 m of the water column and, for some species and stages, largely in the neuston (e.g., Smyth 1980). Given the tendency of the various molecular fractions of petroleum to either dissolve or form colloids and particles in water and disperse as a surface film or sink slowly (Shaw 1977; McAuliffe 1977}, crustacean larvae are more likely to be exposed to oil on a broader scale than are their benthic parents.

2. Larval crustaceans are more sensitive to any group of pollutants (including oil) than are juvenile or adult stages (Armstrong et al. 1976; Johnson 1977).

3. Larvae grow rapidly in the water column and molt up to five times in three to four months, whereas adults molt only once annually. Molting is the physiological event in crustacean life cycles most sensitive to ambient perturbations such as oil pollution. During an oil mishap, larvae will be exposed for a greater portion of their abbreviated molt cycle than will adults.

4. Recruitment of legal crabs to a fishery may be largely dependent on the larval survival of a given year-class (McKelvey et al. 1980; Somerton 1981). Annual variations of high or low abundance indicate differential mortality caused by physical and biological factors that vary in intensity and effect year to year (Incze 1983). Extensive oil pollution in critical seasons could increase larval mortality in years when natural causes are relatively benign, or act synergistically with severe natural events to decimate larval cohorts and, in turn, curtail the fishery years later.

1.2 The Data Base

Zooplankton samples sorted for this study of larval decapod distribution and abundance have come from several collections made in different years and areas with varying degrees of temporal/spatial thoroughness and continuity (Section 2.0, Methods and Materials, gives details of the data base). Only in the years 1980 and 1981 (and to a limited extent in 1982) did we have the opportunity to plan systematic collections related to hypotheses of species biology. Even in those years our program *was* a small, opportunistic portion of larger missions that limited that scope of work accomplished. Samples from years 1976-1979 came from several ichthyoplankton and zooplankton surveys that were, in cases, extremely helpful and relevant to our decapod study. But some collections were meager or far removed from areas of principal king and Tanner crab distribution and, consequently, only partially contributed to analyses of annual and regional differences in larval population dynamics.

The majority of collections were made during May and June of each year. The study suffered somewhat from lack of thorough collections in April to characterize time and area of hatch (more so for king crab), and also from few samples through July and August to better fix the period of metamorphosis to the benthos. Spatial representation was best over the middle, and outer shelf where the PROBES study was conducted for several years (see Section 2.0), and thus both species of Tanner crab and pandalid shrimp are the taxa where larval biology is best documented (Sections 4.0 and 6.0, respectively). Since very few samples were taken near the Pribilof Islands, nearshore along the North Aleutian Shelf and also in Bristol Bay from 1976 to 1981, a somewhat incomplete picture of both blue and red king crab larval ecology and biology has emerged, although collections in 1982 nearshore along the NAS have improved knowledge of the latter species (Section 3.0).

Despite these shortcomings, the sum of data presented in this report is the most comprehensive study of larval decapods in the southeastern Bering Sea to date and, for many taxa, over their entire range from the Bering Sea through the Gulf of Alaska and farther south. In reviewing the literature on shrimp and crabs, we were struck by the paucity of studies on the population dynamics and general ecology of larval decapod stages along the west coast of the United States and Canada. Investigations such as Lough's (1976) along Oregon that focus on decapod larvae are rare (see literature reviews in Section 3.0-7.0). Rather, such larval stages are studied in laboratories while field investigations tend to deal more with juvenile and adult populations. Zooplankton investigations tend to focus on holoplanktonic taxa such as copepods without much attention given meroplanktonic groups. Yet factors such as species distribution, ranges and flactuations in abundance of benthic adult populations may largely be explained by responses and survival of pelagic larvae (Bakun et al. 1982; Incze 1983; Young and Hazlett 1978). A notable exception in the pattern of few, comprehensive studies of larval crab populations are those done over the last several years on the eastern U.S. coast (Grant 1977; Johnson 1982, McConaugh et al. in press; Smyth 1980), which have greatly increased knowledge of estuarine and nearshore larval crab biology. Such information increases the accuracy of environmental impact predictions stemming from numerous projects in that region.

1.3 Format of this Report

This contract was established to provide information on larval decapods to federal agencies considering ramifications of oil and gas develop- and to aid them in devising management policy to mitigate possible impacts.

The sections of this report describe firstly the general methods and materials used in the program (Section 2.0). Next are several sections (3.0-7.0) that review pertinent literature on the biology and fishery (if applicable) of major decapod groups and then present results of this study. The commercial king and Tanner crabs are discussed in Sections 3.0 and 4.0, respectively, followed by other crabs (5.0), shrimp (6.0) and hermit crabs (7.0). While the latter three groups are not commercially important (an exception is the horsehair crab, *Erimacrus isenbeckii*), they may be of major ecological importance as predators and prey within benthic communities and must not be overlooked in predictions of oil impact.

Data on larval distribution and abundance, relationships to benthic adult stocks, molt frequency, annual variations in physiological and biological factors, etc., are considered in light of possible oil impacts in Section 8.0. Literature on oil toxicity to Crustacea is reviewed and previous models of oil impact are studied and criticized as a preface to discussion of decapod species/taxa vulnerability to oil in the southeastern Bering Sea. Data gaps are identified and future research on decapods in that area is suggested in the conclusion.

2.0 MATERIALS AND METHODS

2.1 Sample Sources and Station Locations

Zooplankton samples used for enumeration of decapod larvae were obtained from several sources. Four series of samples were retrieved from storage and loaned to us by the principal investigators of earlier zooplankton studies conducted in the southeastern Bering Sea under OCSEAP support. These samples had not been examined previously for decapod larvae. In addition to these past samples, participation in the 1980 and 1981 PROBES cruises enabled purposeful sampling for this study. In addition to our own sampling, a large number of depth-stratified samples were shared by the PROBES zooplankton working group, and samples were collected by National Marine Fisheries Services (NMFS) personnel during two cruises in 1981. Table 2.1 lists cruise and station information for the zooplankton samples analyzed in this study. The locations of sampling stations for each year and cruise are illustrated in Figures 2.1-2.18 at the end of this Chapter. Specific information regarding the location of stations as well as the sampling gear used and all results are available through the National Oceanography Data Center, Washington, D.C. under project title "Decapod Larvae," File Type 124 (zooplankton data).

A study of distribution and abundance of red king crab larvae along the North Aleutian Shelf was supported by NMFS and OCSEAP in 1982 and findings are briefly presented in this report for comparative purposes. Station locations are shown in Figs. 2.19 and 2.20 for collections made during June 16-29 and August 3-10, respectively, that totalled 131 samples (Table 2.1).

Table 2.1. Dates and sources of zooplankton samples searched for **decapod** larvae in this study.

Year	Temporal coverage of zooplankton samples	Cruise	Cruise sponsor*	Vessel	No. of stations	No. of stations
1976	26 April-31 May	MF-76A	OCSEAP	Miller Freeman	27	30
1977	16 April-17 May	RP-4-MF-77B	OCSEAP	Miller Freeman	80	112
1978	11 Feb-16 March	MF-78-1	OCSEAP	Miller Freeman	21	29
	11 April-29 June	TT-131	PROBES	T. G. Thompson	186	225
1979	1-27 June	3MF-70	OCSEAP	Miller Freeman	32	36
1980	6 April-8 June	TT-149	PROBES	T. G. Thompson	68	317
	4-5 October	AX-9	PROBES	Alpha Helix	4	21
1981	16 April-20 July	TT-159	PROBES	T. G. Thompson	165	610
	14-31 May	RP-4-DI-81A	NMFS	Discoverer	16	16
	24 May-20 July	AL/81 1	NMFS	Alaska	23	23
TOTAL					622	1,419
1982**	6-29 June		OCSEAP/ NMFS	Miller Freeman		83
	3-10 August			Miller Freeman		48

*OCSEAP, within National Oceanic and Atmospheric Administration. OCSEAP samples 1976-1979 collected under contract by National Marine Fisheries Service.

PROBES: National Science Foundation (Processes and Resources of the Bering Sea Shelf)

**Only samples through 1981 were supported on this contract. 1982 samples were collected with NMFS support and OCSEAP logistics.

However, the data are not included in File Type 124, "Decapod Larvae" as of this writing.

2.2 Sample Collection

Zooplankton samples were collected with Bongo nets on a 60 cm (diameter) Bongo frame, a MOCNESS (Multiple Opening/Closing Nets and Environmental Sampling System, Wiebe et al. 1976), a NORPAC net (Motoda et al. 1957) and an MTD net (Motoda, 1969). The mesh size on the nets deployed with each piece of gear varied, but all were fine enough to retain even the smallest of the decapod larvae of this region.*

During OCSEAP and NMFS cruises in 1976-1979, Bongo frames were deployed with one 333 µm and one 505 µm mesh net attached. The samples analyzed in this study depended exclusively upon availability and included collections from both mesh sizes. Bongo nets used during the 1978 PROBES cruise were 333 µm during Leg I and 505 µm during Legs II-IV (the investigators resorted to the larger mesh to reduce net clogging). A 505 µm net was used during the 1980-1982 PROBES and NMFS cruises. The NORPAC and MTD nets used both 333 and 505 µm mesh, and the MOCNESS was equipped with 149 µm mesh nets

Flow meters attached in front of the opening of Bongo, NORPAC, and MTD nets and near the top of the MOCNESS were used to estimate the volume of water filtered by each net. Bongo tows were made using standard

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*The smallest larvae were stage I zoeae (SI) of the Brachyuran family Pinnotheridae: minimum dimension of smallest individual collected with 149 µm nets was approximately 1.5 mm. The largest mesh used was 550 µm.

techniques which attempt to equally sample all depths involved in the tow (Smith and Richardson, 1977). The MTD and MOCNESS nets had discrete flow data for each depth interval sampled. The only samples for which flow data were not available are those from PROBES 1978; the average flow (250 m^3) computed for other processed zooplankton data from that cruise was used. Since every effort was made to keep those tows uniform, the error introduced by this estimation is probably small compared to real differences in decapod abundance.

The depth of sampling varied with the gear and cruise objectives. The depth of Bongo tows from OCSEAP and NMFS cruises generally reflected changes in the depth of water at various stations, whereas PROBES Bongo tows usually sampled only the upper 60 m of water, even at the deeper stations. MOCNESS was operated to sample the following depth intervals: 1200-600, 600-300, 300-120, 120-80, 80-60, 60-40, 40-20 and 20-0 m (sometimes 20-10 and 10-0 m). These depth intervals were modified slightly or deleted as station depth or equipment malfunction dictated. The MTD net used to collect samples examined in this study was deployed at fixed depths (e.g., 10 m, 30 m, etc.) rather than hauled obliquely through larger depth intervals.

Samples were preserved in 3-5% formal in:seawater.

2.3 Sample Processing

Initial zooplankton samples obtained for this study varied from 20% (our share of the MOCNESS samples) to 100% (most Bongo samples) of the original tow. This sample was then either examined entirely or was subsampled before removal of decapod larvae. The decision of whether or not to subsample depended on the size of the sample and required some subjective judgment. The general rules governing this decision follow:

1. Subsampling was done only if the settled volume of zooplankton in a clean sample exceeded approximately 0.15 1. The desired settled volume of a clean sample from which decapod larvae would be removed was approximately half the above, or 75 ml. A Folsom plankton splitter was used to split samples.

2. Subsampling was not done if the original sample contained a large volume of gelatinous zooplankton or aggregating phytoplankton (e.g., palmelloid form of Phaeocyctis poucheti) which interfered with the subsampling (splitting) process.

3. Subsampling was not done if the original sample contained a large number of large organisms (euphausiids, chaetognaths, etc.) but relatively few smaller animals.

4. A sample was not subdivided into a fraction containing less than 1/80 (MOCNESS) or 1/16 (Bongo) of the original tow.

The above guidelines were followed to ensure that subsampling yielded representative samples of the plankton. The adequacy of this approach was checked on several occasions with samples representing a variety of plankton conditions. These results are reported in the Data Sensitivity and Accuracy section that follows.

In all cases where at least one split was possible, one of the final pair of samples was archived for possible future needs, including verification of results or examination of subsampling error. Decapod larvae were removed from the remaining subsample for identification. Occasionally, a subsample yielded hundreds of decapod larvae of a genus. When such numbers were found, these larvae were further sub-sampled using a small plankton splitter before taxonomic work was begun.

2.4 Taxonomy

Once removed from the raw plankton sample, decapod larvae were stored in a 95% ethanol, 2% glycerol solution until they could be identified and counted. The principal objective of this program was enumeration of the larvae of the commercially important king and Tanner crabs, as well as general categories to include all "other" crab and shrimp larvae. However, in the process of distinguishing king and Tanner crab larvae from other Anomura and Brachyura, several additional identifications are made simultaneously. The result is that, with a little extra effort, all other Anomurans and Brachyurans could be identified to some finer taxonomic level within these two sections. The enumeration of larvae of the Korean horse-hair crab, for which there is a developing fishery, was one advantage of this extra effort. Among the shrimp, identification to family can ordinarily be accomplished without much difficulty, so this was routinely done. This has the advantage of separating out the pandalid shrimp (Family Pandalidae) for which there was once, and may be again, a commercial fishery. Identification of the pandalids was done to species level.

A hierarchical list of taxonomic levels identified from our zooplankton samples is provided in Table 2.2. References for the identifi-

Table 2.2. List of taxonomic levels of decapod crustacean larvae identified in this study.

- Order Decapoda
  - Suborder Reptantia
    - Section Brachyura
      - Family Majidae
        - Subfamily Oregoniinae
          - *Chionoecetes* spp.
          - *C. bairdi*
          - *C. opilio*
          - Non-*Chionoecetes* Oregoniinae
            (Includes *Hyas* spp. and *Oregonia* sp.)
        - Subfamily Acanthonychinae and/or Pisinae
      - Family Atelecyclidae
        - *Erimacrus isenbeckii*
        - *Telmessus cheiragonus*
      - Family Cancridae
      - Family Pinnotheridae
    - Section Anomura
      - Family Lithodidae
        - *Paralithodes camtschatica*
        - *P. platypus*
        - Non-*Paralithodes* Lithodidae
      - Family Paguridae
        - *Pagurus* spp.
  - Suborder Natantia
    - Section Penaeidea
      - Family Penaeidae
        - *Penaeus* spp.
    - Section Caridea
      - Family Pandalidae
        - *Pandalus borealis*
        - *P. tridens*
        - *P. hypsinotus*
        - *P. stenolepis*
        - *Pandalopsis dispar*
      - Family Crangonidae
        - *Crangon* spp.
        - *Argis dentata*
      - Family Hippolytidae
      - Family Pasiphaeidae
        - *Pasiphaea* spp.

cation of these larvae and the various larval stages are included in the text sections for each major larval group.

2.5 Data Reporting

The larvae of commercial decapod crustaceans are the focus of this report; they include the larval stages (zoeae and megalopae) of king crab (Paralithodes camtschatica, P. platypus), Tanner crab (Chionoecetes bairdi, C. opilio), korean horse-hair crab (Erimacrus isenbeckii), and pandalid shrimp (Pandalus borealis). In most cases, larvae of all other taxonomic divisions enumerated in our laboratory work are discussed in general categories as the larvae of "other anomuran crabs," "other brachyuran crabs" and "other shrimp." The pagurid crabs (Anomura: Paguridae), though of no direct commercial value, have received special attention because of the abundance and widespread distribution of their larvae in the study area.

Larval abundance is reported throughout most of this text as estimated number of larvae per 100 m^2 sea surface area (number/100 m^2). This provides a common unit of measure by which the abundance of various larvae can be compared and summed, regardless of differences in their vertical distribution in the water column. The larvae of some taxa are more concentrated in some depth intervals than others, and this may change for the various developmental stages. Vertical distribution patterns and mean densities of larvae (numbers per 1000 m^3) are described for most of the major taxonomic groups. These data are used in the interpretation of potential oil impacts.

In our annual report (Armstrong et al. 1981), all larval abundance data were reported in units of numbers/1000 m^3. This volumetric basis for representing mean abundance was abandoned because it did not" include larvae below 60 m depth (although the error introduced by this omission was small) and because it was not an accurate reflection of how larvae are distributed in the ocean. The units presently used (number/100 m^2 of sea surface) include all larvae sampled and provide no misconception about "uniform distribution." Estimates of abundance from the annual report can be compared with the data provided here in the following way. In virtually all cases the majority of larvae were found above 60m (Tanner crab mainly in the upper 20 m), so this was considered a lower limit for calculations of numbers/1000 m^3. The surface area of a 1000 m^3 volume extending to 60 m depth is about 16.7 m^2. To convert the volumetric estimates of abundance to units of numbers/100 m^2, a multiplication factor of 5.99 is used ($100 \div 16.7 = 5.988$). For sampling in depths less than 60 m this multiplier changes. For example, density values for larvae caught in 40 m of water will be only four times greater in units of 100 m^2 than 1000 m^3. However, few samples reported in the 1981 annual report were integrated over water columns of less than 60m depth.

2.6 Data Sensitivity and Accuracy

The volume (or mass) of plankton retained by the comparatively large mesh of the Bongo nets was frequently much smaller than that retained by the finer mesh nets used on MOCNESS. Yet the estimated volume of water sampled by nets of the two devices (according to the flow meters) was often similar (generally 200-300 m^3). It was determined above that all decapod larvae would be retained by any of the mesh sizes employed for the samples, so that the nets, in theory, should serve equally well for estimating the density of decapod larvae at various stations. However, at least three factors affect the estimates we make: (1) systematic differences in the degree of subsampling dictated by corresponding differences in the volume of plankton retained by each net per volume of water filtered; (2) inherent differences in net clogging related to net porosity and (3) differences in the location of the flow metering device.

When the volume of water filtered by a MOCNESS and a Bongo are approximately the same but there are large numbers of small organisms retained by MOCNESS and not by the larger mesh Bongo nets, the former will be sub-sampled to a greater extent than the latter. When the net plankton samples from MOCNESS and the Bongo are approximately the same size and, consequently, subject to the same sub-sampling, it is frequently because the former has sampled less water than the latter. It is only when small plankton (in the intermediate size range 150-333 µm or 150-505 µm) are rare that the volumes of water filtered and the number of sub-sampling splits can be the same for both MOCNESS and Bongo samples. Since the latter condition does not usually prevail, the representative volume of water actually examined in MOCNESS sub-samples is almost always smaller than that examined from Bongo samples. This has the effect of decreasing the lower level of detection, or numerical sensitivity, of the MOCNESS samples relative to the Bongo.

Bongo samples were usually split no further than 1/8, and were never split to less than 1/16, of the original sample. Such splits place the lower level of detection in sub-samples at about 8-16 animals of each taxon per 200-300 m^3 average tow, assuming perfectly uniform distribution of the larvae in the splitting process. Early in the season, the zooplankton community is not well developed, so splits were usually not necessary. Under these conditions the entire sample is examined and the probable lower level of detection for reporting becomes about 1 in 250 m^3 (assuming an average tow), or roughly 5 per 1000 m^3 or 30 per 100 m^2.

MOCNESS nets filtered about three times more water per meter of depth than the Bongo tows (200-300 m^3 per 20 m depth interval for MOCNESS compared with 200-300 m^3 per 60 m for Bongo nets). However, our share of PROBES MOCNESS samples was 20% of the original (the splits were done on board ship), so we always examined plankton from a smaller volume of water with MOCNESS samples than Bongo samples. Theoretically, MOCNESS samples should be less capable of detecting low larval abundance than Bongo samples. In addition, the finer mesh of the MOCNESS nets usually necessitated more sub-sampling, but not early in the season (April and early May) at early stages in the development of the zooplankton community.

Since MOCNESS nets had a finer mesh, they were more prone to net clogging than the larger mesh Bongo nets. Clogging may be caused by phytoplankton as well as zooplankton, and reduces the actual amount of seawater filtered. The analytical problem created by this condition is compounded by the location of the flow-metering device. Unlike the

Bongo frame, the MOCNESS frame cannot accommodate a flowmeter positioned in front of the net opening (because of the sliding nets and the way the frame is handled on deck). Instead, the flowmeter sits atop the frame, where it is insensitive to actual changes in flow into the net. The MOCNESS theoretically over-estimates the volume of water filtered, and our calculations should routinely underestimate the density of decapod larvae present. This problem is not even internally consistent within a station, since phytoplankton and other zooplankton are not uniformly distributed with depth and may affect only some of the nets used. The 0-20 and 20-40 m nets are usually subject to more clogging than the deeper ones, so that calculations of abundance in the upper 40 m should be underestimated relative to calculations for deeper samples.

While these potential difficulties should be remembered in interpreting plankton data, they do not appear to have presented a major problem in this study. This may have been due to differences in the calibration and/or performance of the flow meters. Incze (1983) compared estimates of abundance of *Chionoecetes* larvae made with MOCNESS and Bongo nets deployed at the same stations and found no consistent bias in the estimates. Rather, small-scale patchiness in abundance was sufficient to mask differences in the accuracy of flow estimation based on a comparison of coefficients of variation. In this study, all gear were considered to provide similar estimates of abundance.

2.7 Vertical Distribution Patterns

Discrete depth interval samples collected by MOCNESS were used to examine patterns of vertical (depth) distribution of abundant decapod larvae. A computer program was used to generate listings of all MOCNESS stations where larvae of a particular taxon were found. For each depth interval (0-20, 20-40, 40-60, 60-80, and >80 m) at each station, the estimated abundance of larvae (number/1000 m^3), the number of larvae actually counted for the estimate, and the size of the sub-sample providing this count were listed. Stations with estimates of larval abundance based on too few specimens and/or on very small sub-samples were not considered. Although no strict criteria could be developed for making this decision, it was generally not difficult to decide by inspection whether the data were sufficient for adequately describing a vertical distribution pattern. For each station with sufficient data, the vertical distribution of larvae was determined by calculating the proportion of all larvae collected at each depth interval. This was done for each year of MOCNESS samples (1980 and 1981), and, sometimes, for individual larval stages. For some taxa, diurnal patterns were also examined.

2.8 Geographic Division of the Study Area

The study area was divided into twelve sub-areas, or strata (Fig. 2.21), for estimating mean larval abundance. The divisions were based on regional hydrographic structure, faunal distribution patterns and the availability of sampling data. A breakdown of the southeastern Bering Sea into strata facilitated comparisons of timing and abundance of certain taxa between areas and years. This approach worked best with Tanner crab and pandalid shrimp larvae, but also facilitated a summary of general larval distributions for taxa that were less common or were poorly sampled, such as king crab and Korean hair crab. Estimates of abundance within strata were made by averaging data from all stations sampled within certain time intervals (usually one month; see Incze 1983 for details). For illustrating patterns of larval abundance, however, individual station data were used. Further subdivisions of strata were made for descriptive and statistical purposes in the case of Tanner crab larvae (Section 4.0).

Figs. 2.1 - 2.18. Station locations for zooplankton samples examined for decapod larvae and reported here. Sponsoring agency/ programs, year, cruise number, and dates as follows (NOAA 1976 through 1979 = OCSEAP program; NOAA 1981 = NMFS program):

2.1. NOAA 1976. Cruise MF-76A, 26 April - 31 May. Three stations west of 172*W not shown.

2.2. NOAA 1977. Cruise RP-4-MF-77B, 16-30 April.

2.3. NOAA 1977. Cruise RP-4-MF-77B, l-17 May.

2.4. NOAA 1978. Cruise MF 78-1, 11 February - 16 March. Six stations west of 172°W not shown.

2.5. NOAA 1979. Cruise 3 MF-79, 1-27 June.

2.6. PROBES 1978. Cruise TT 131 (University of Washington), Leg 1 11-28 April.

2.7. PROBES 1978. Cruise TT 131 (University of Washington), Leg 3 27 May - 11 June.

2.8. PROBES 1978. Cruise TT 131 (University of Washington), Leg 4 17-29 June.

2.9. PROBES 1980. Cruise TT 149 (University of Washington), Leg 2 6-21 April.

2.10. PROBES 1980. Cruise TT 149 (University of Washington), Leg 3 27 April - 18 May.

2.11. PROBES 1980. Cruise TT 149 (University of Washington), Leg4 22 May - 8 June. PROBES A-line shown.

2.12. PROBES 1980. Cruise AX 9 (University of Alaska) Samples collected 4 and 5 October.

2.13. PROBES 1981. Cruise TT ?59, Leg 1, 17-26 April

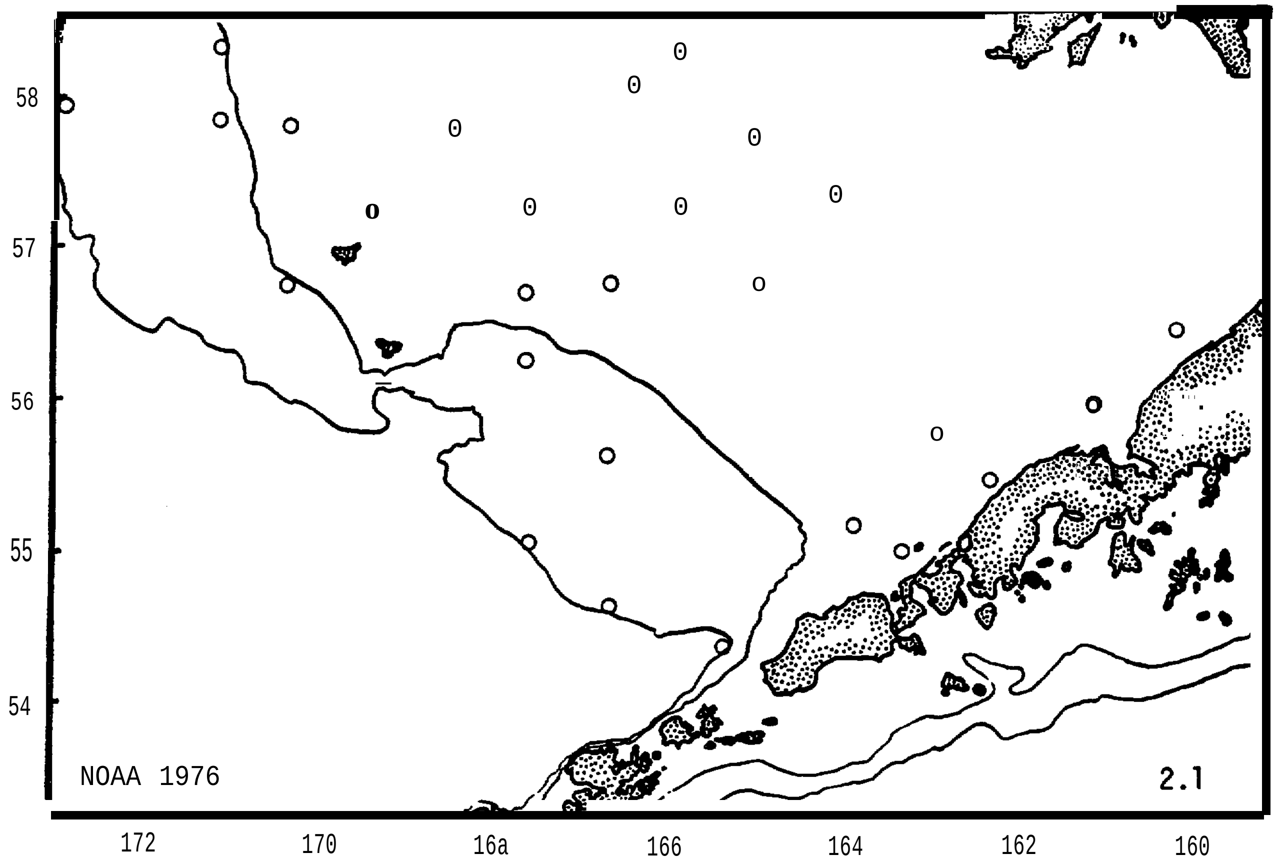
2.14. PROBES 1981. Cruise TT 159, Leg 2, 2-25 May

2.15. PROBES 1981. Cruise TT 159, Leg 3, 31 May - 20 June

2.16. PROBES 1981. Cruise TT 159, Leg 4, 27 June - 19 July

2.17. NOAA 1981A. Cruise RP4-D1-81A, 14-31 May

2.18. NOAA 1981B. Cruise AL/811, 24 May - 20 July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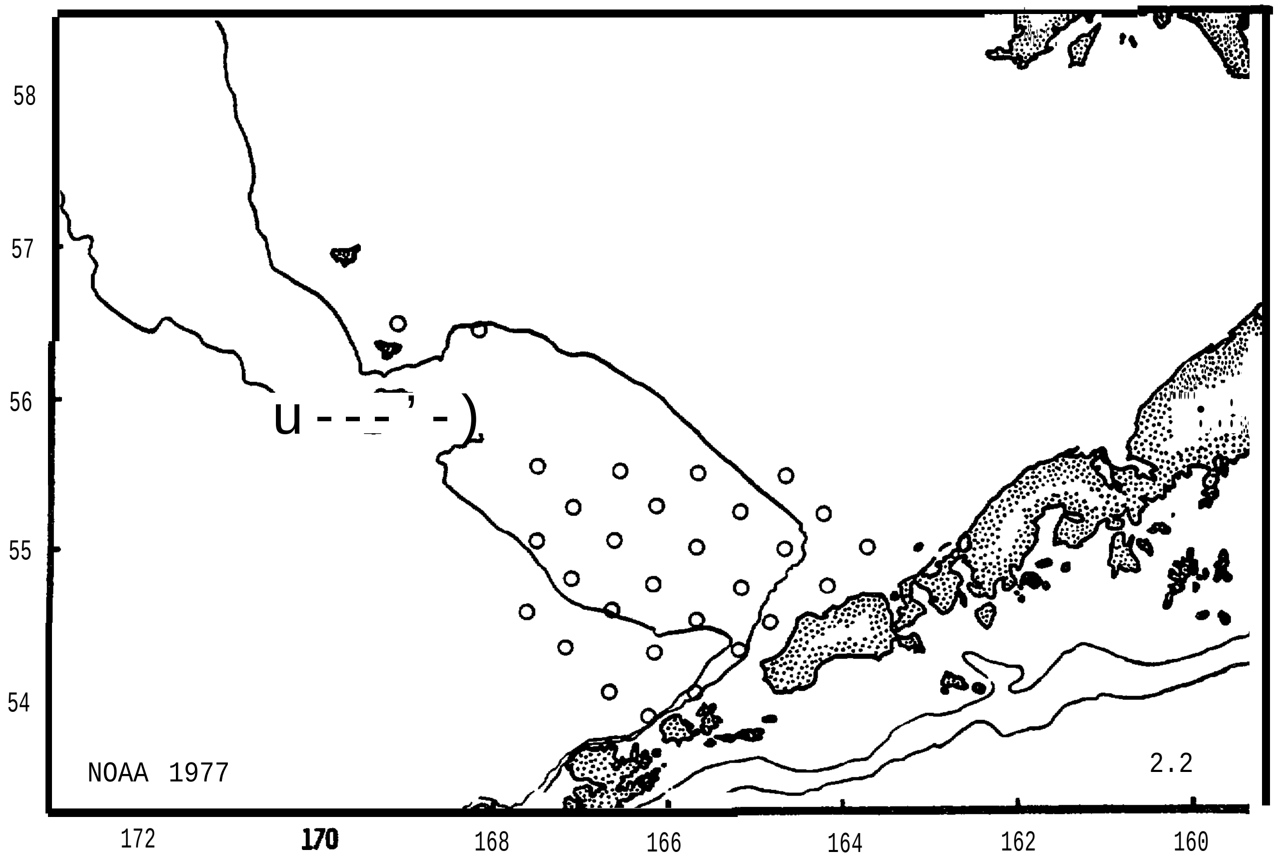
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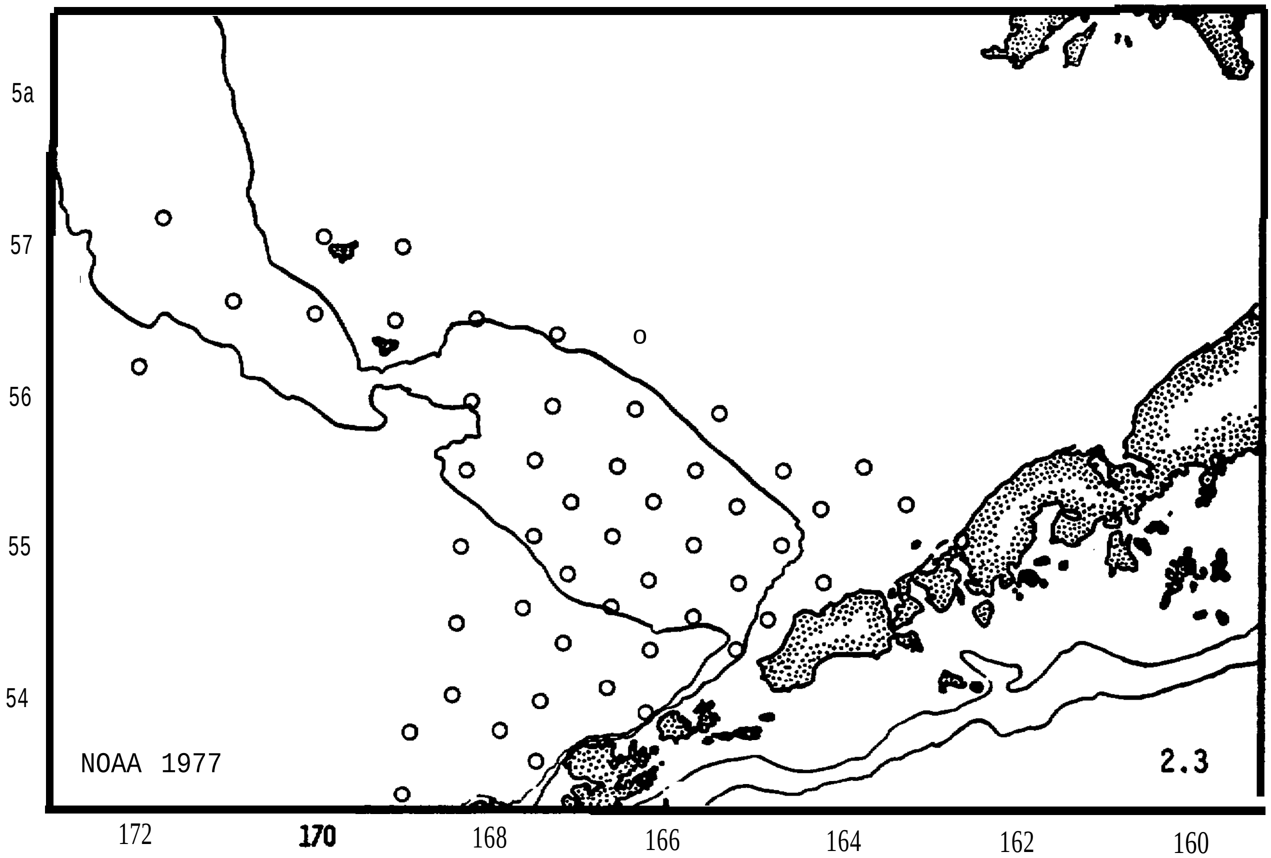
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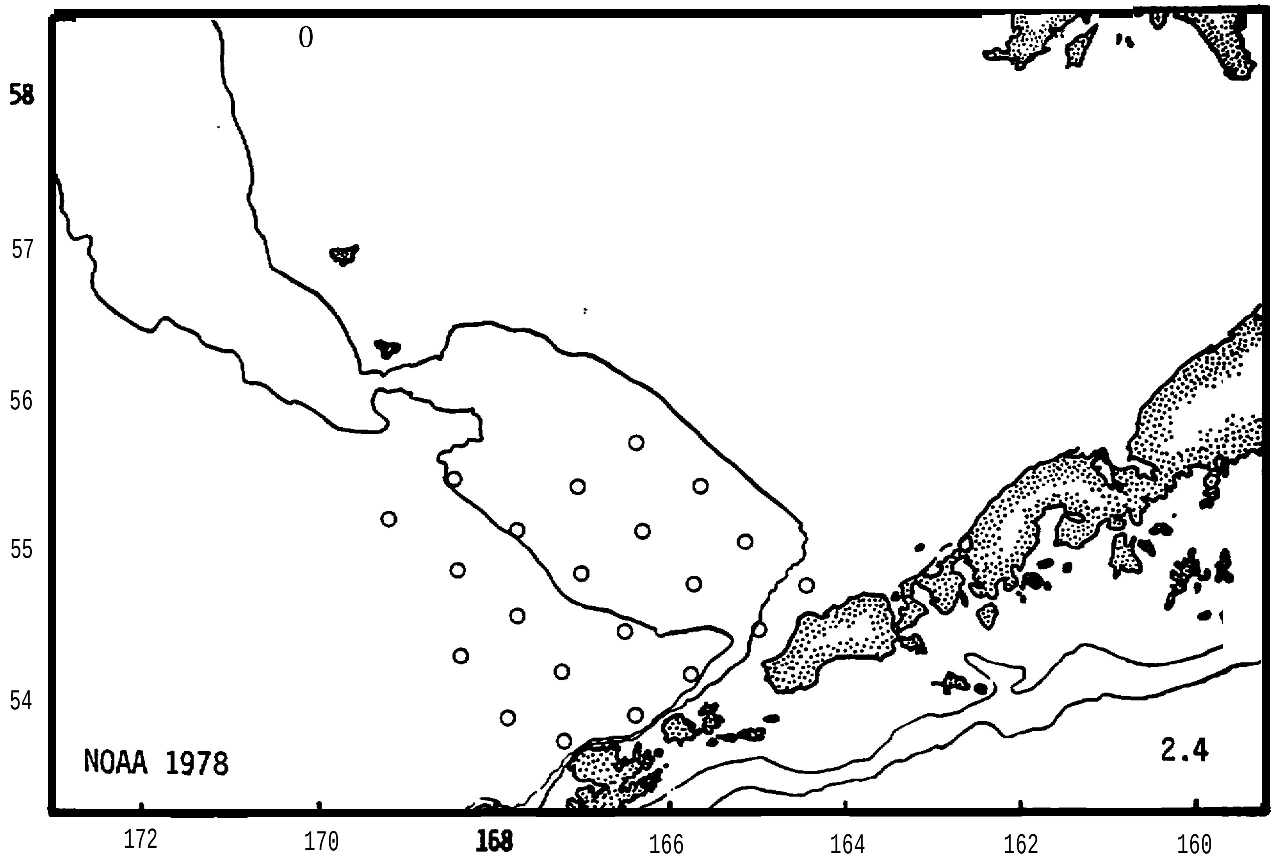
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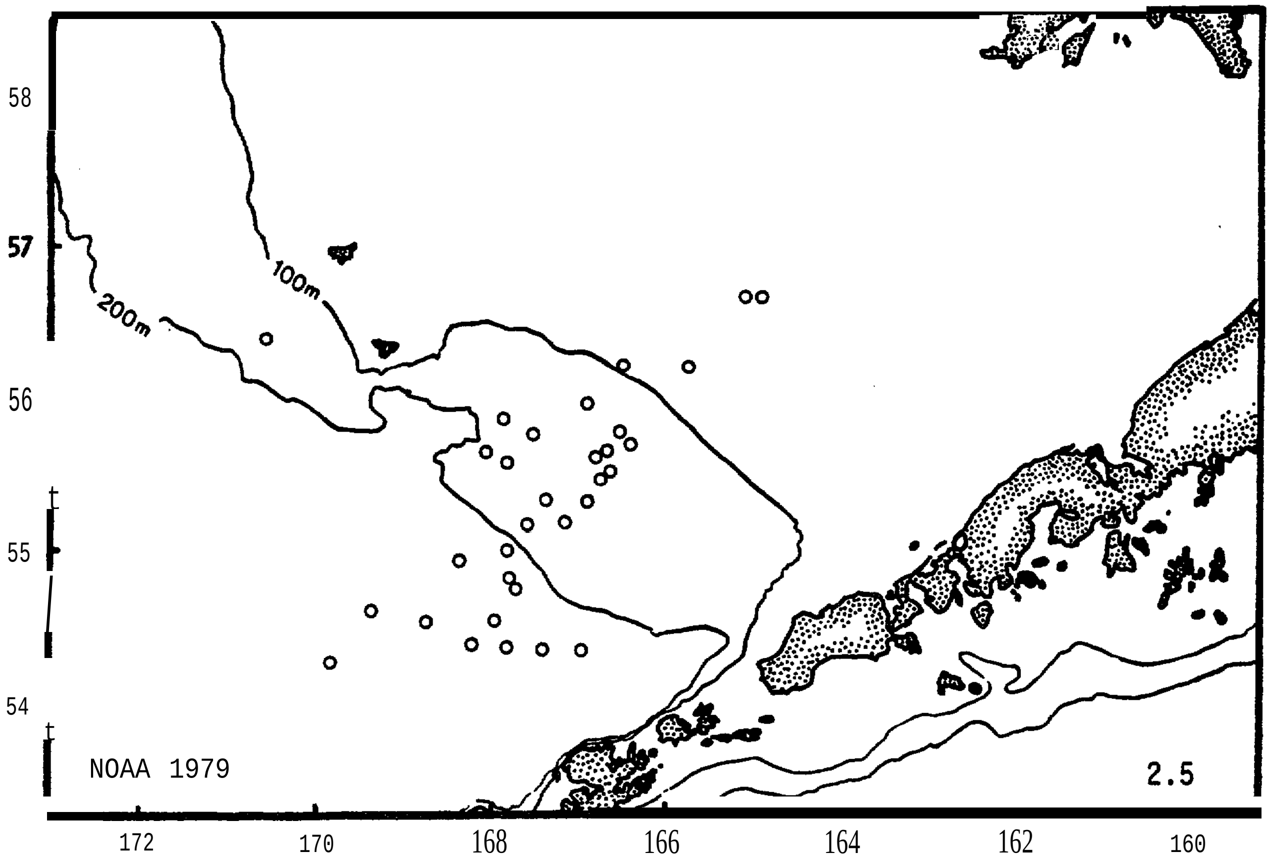
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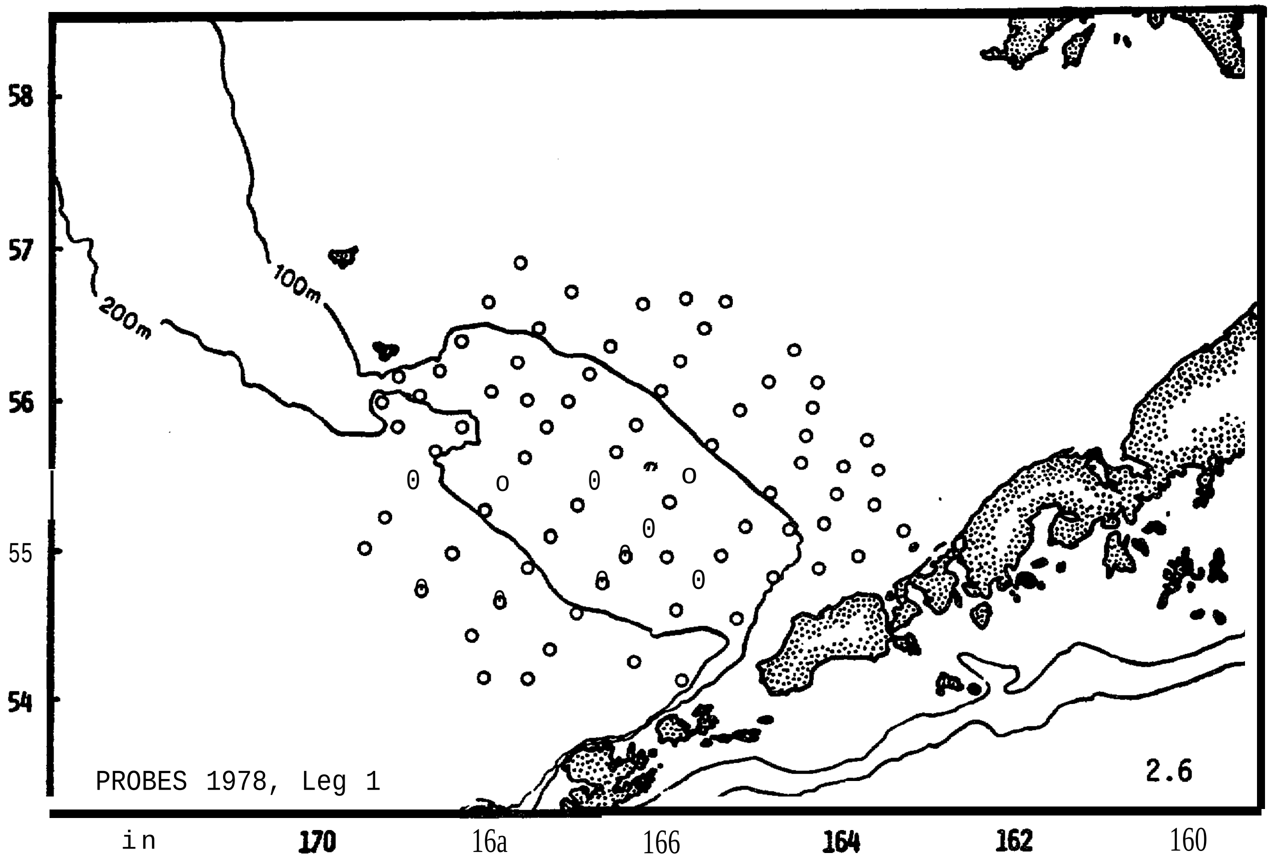
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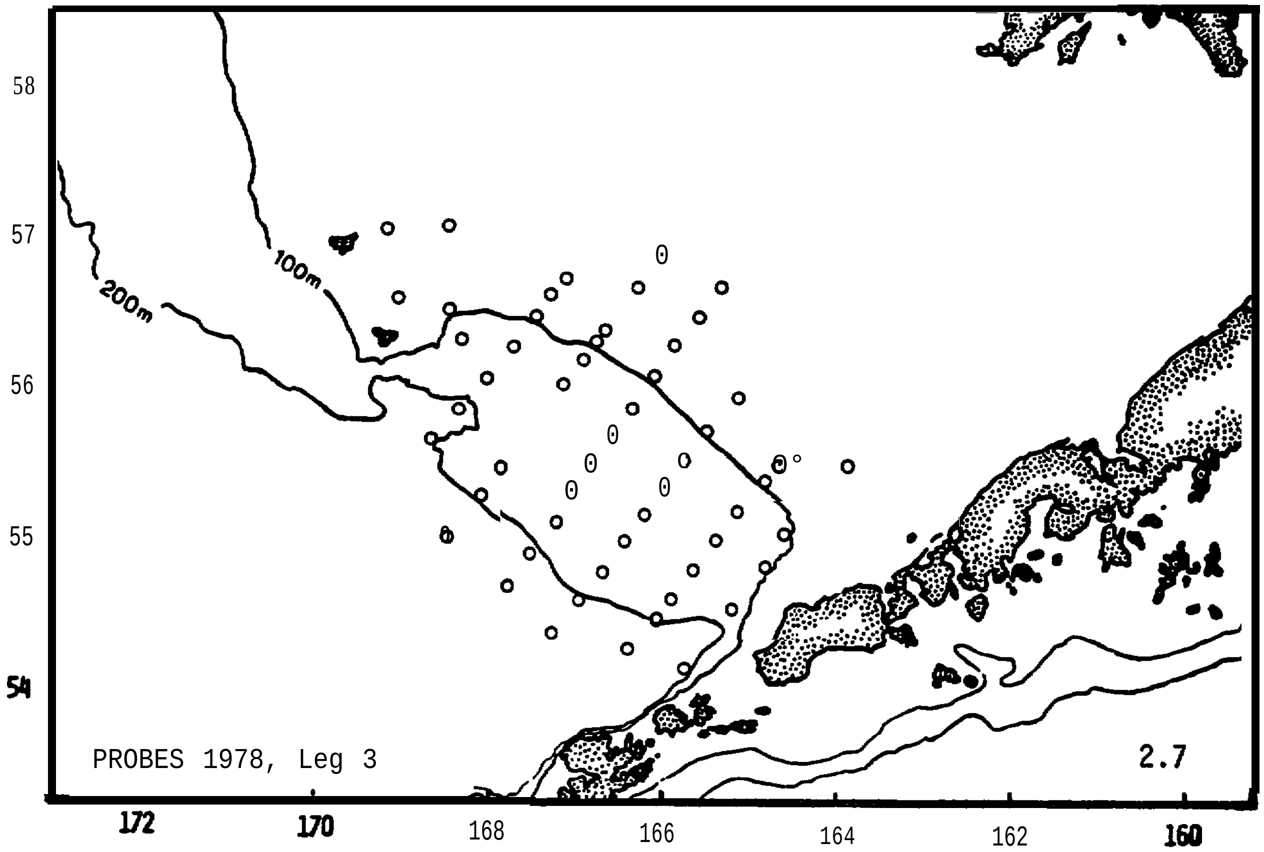
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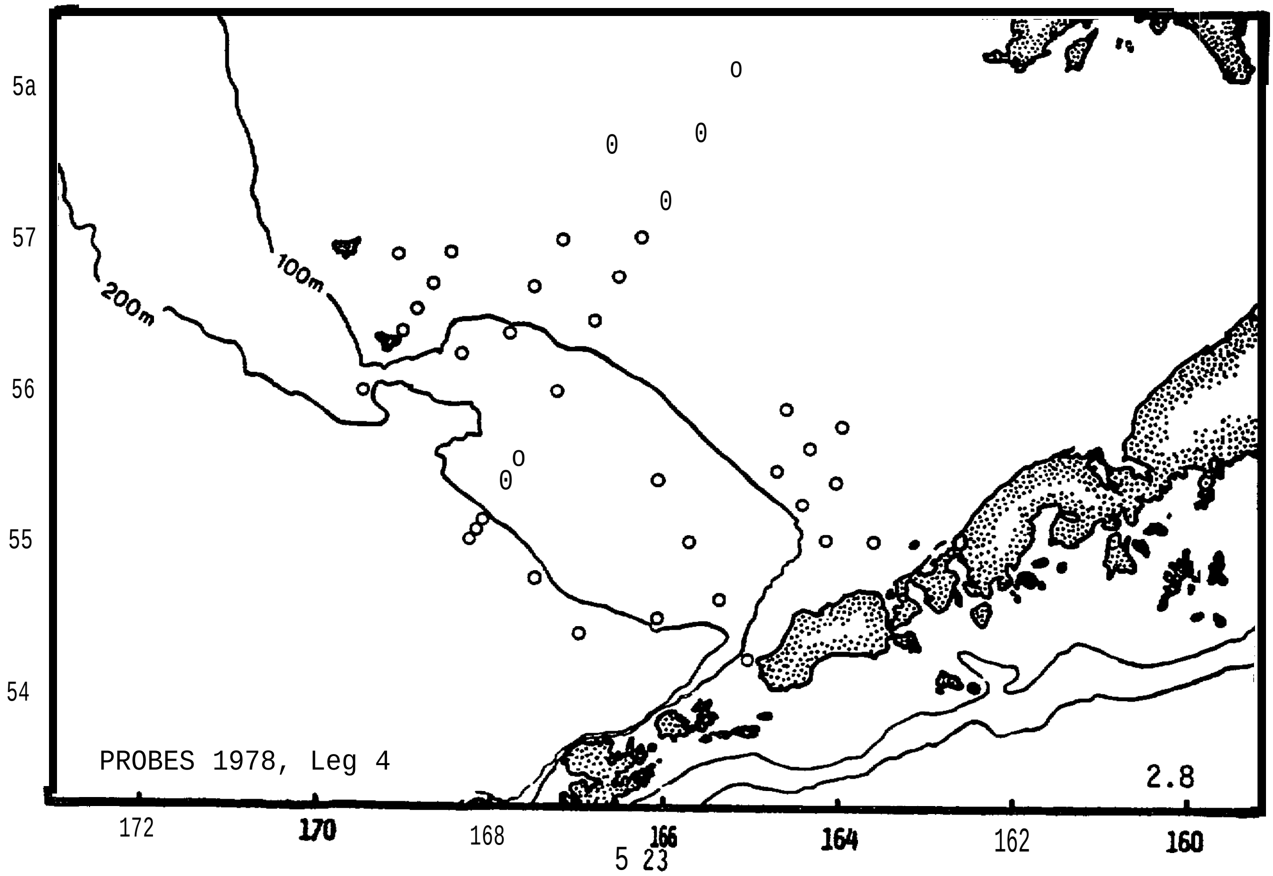
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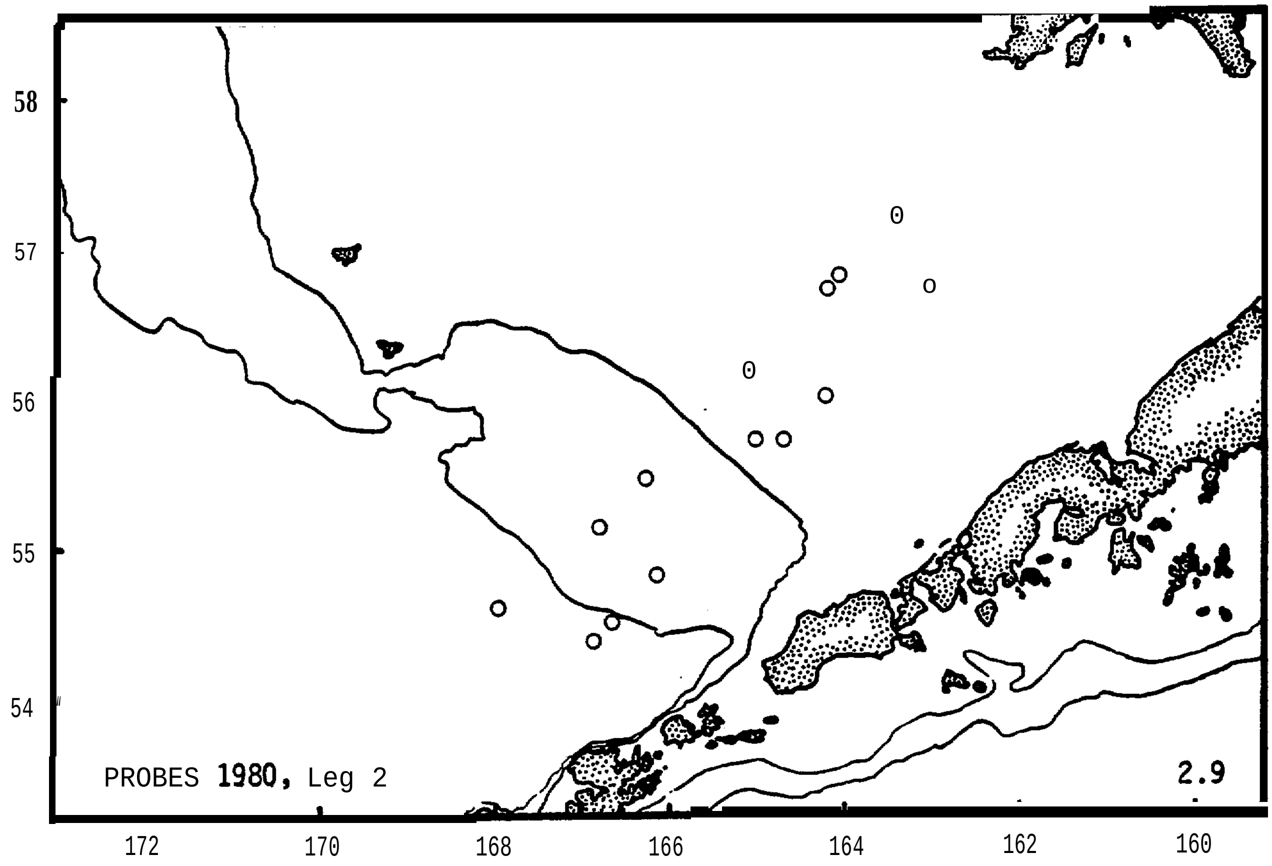
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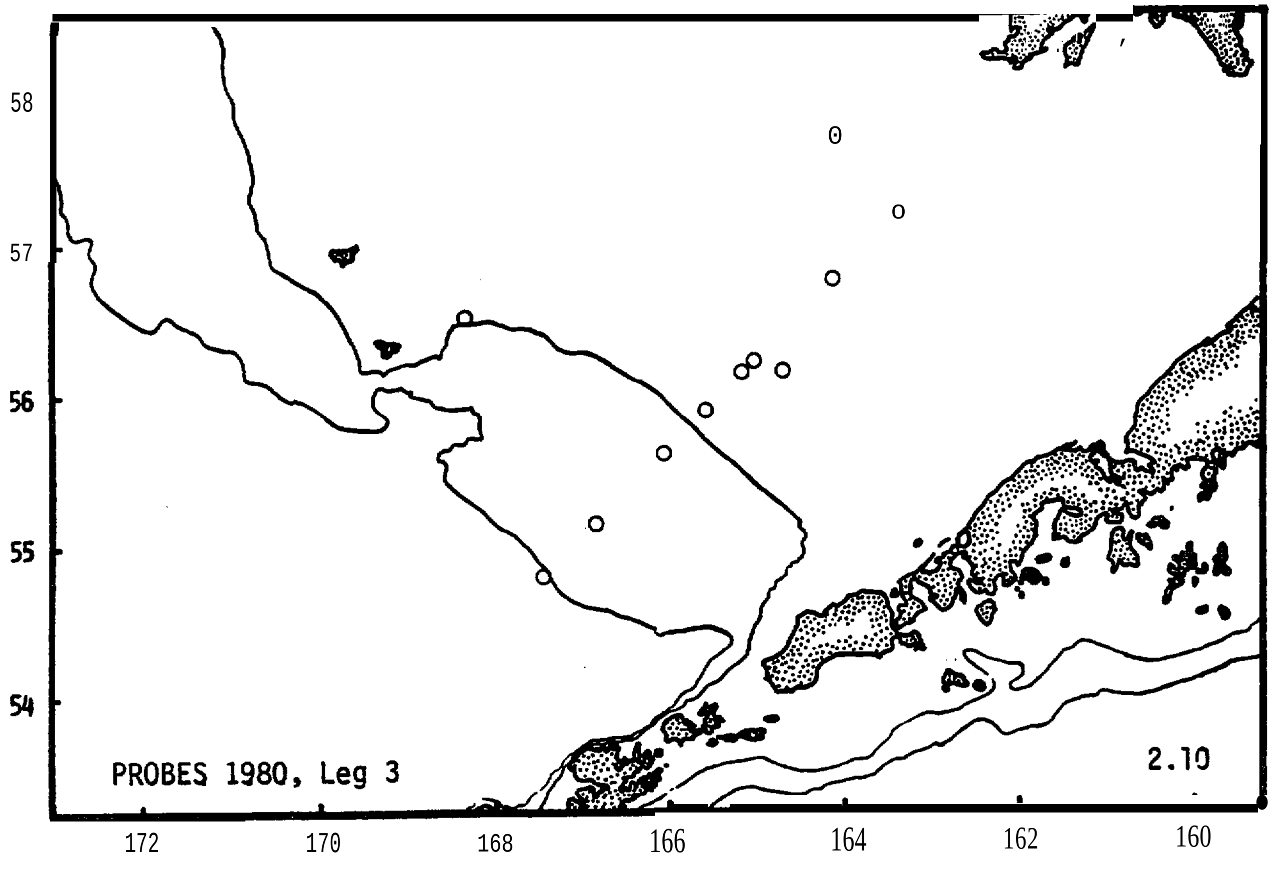
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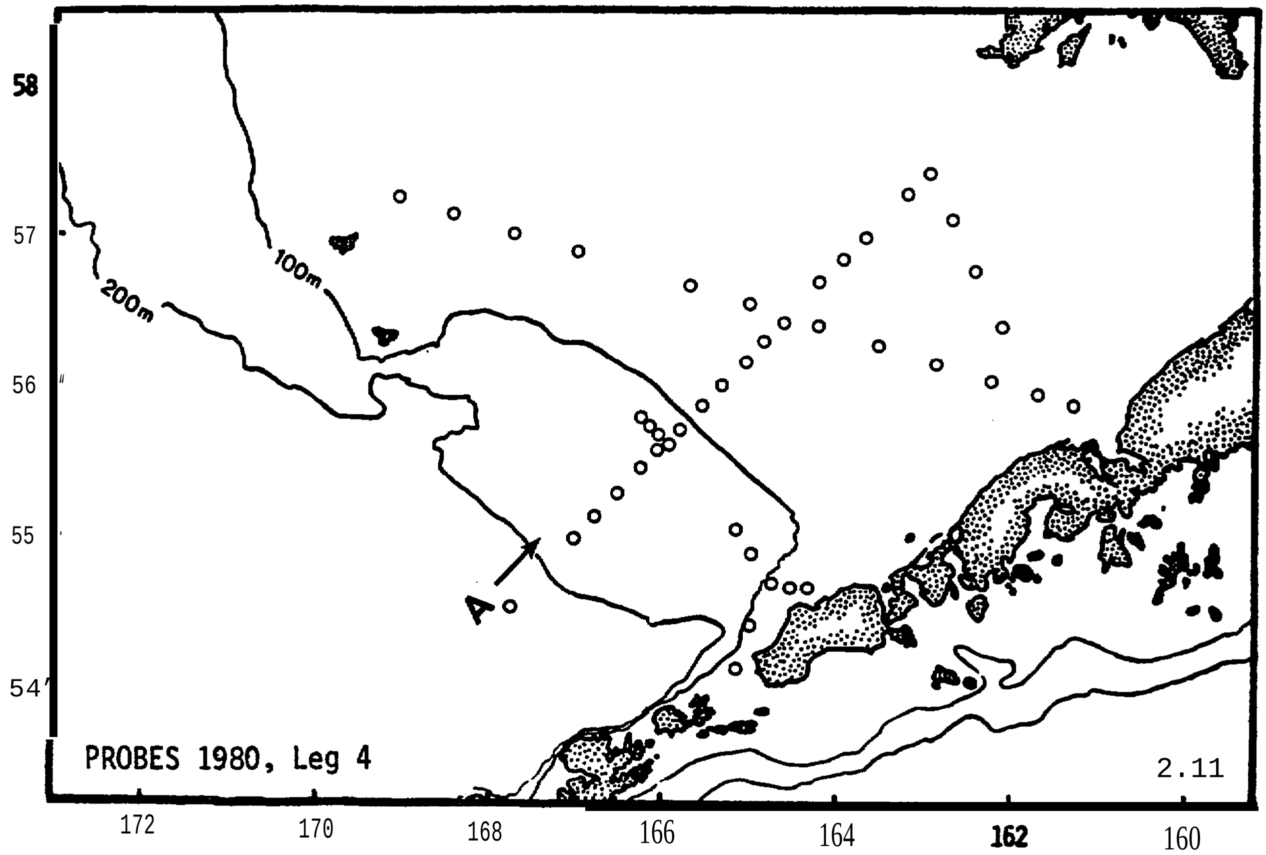
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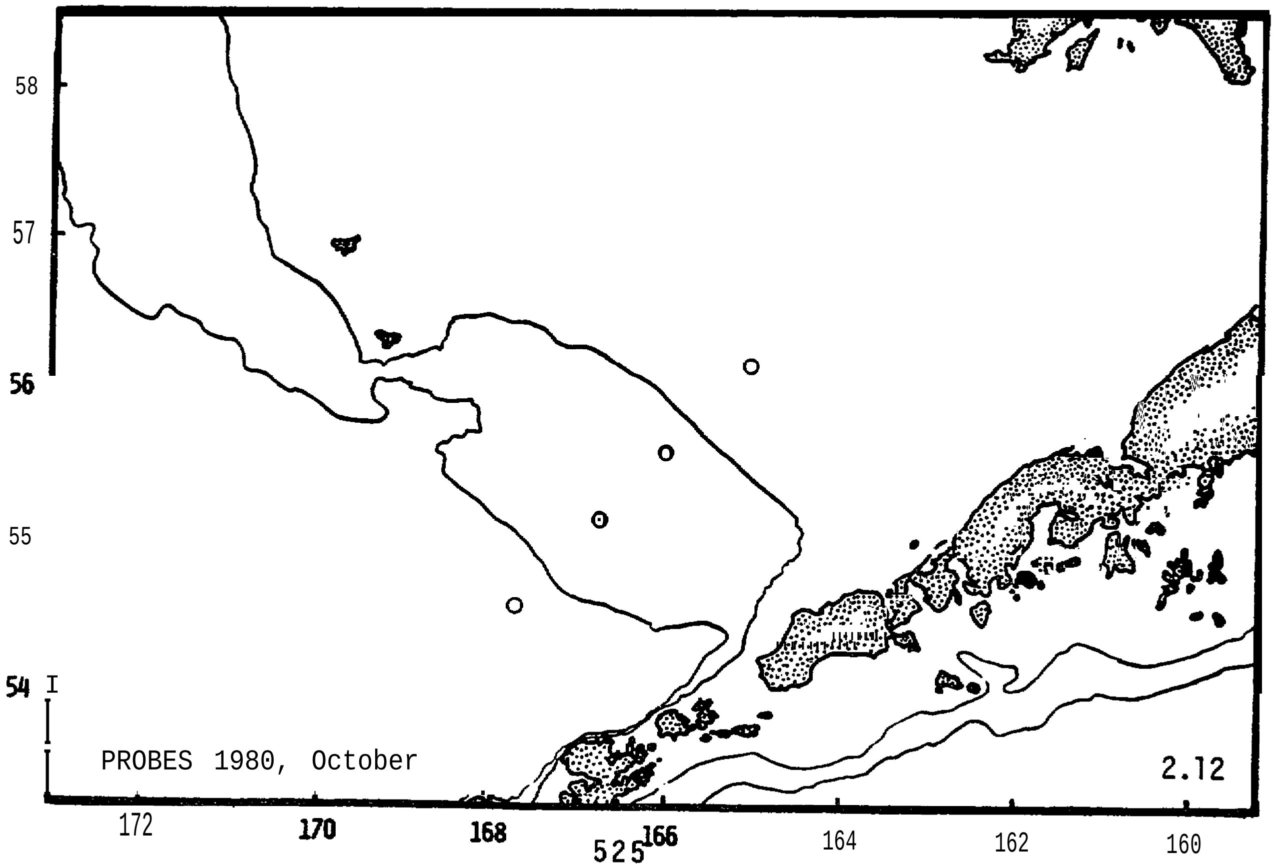
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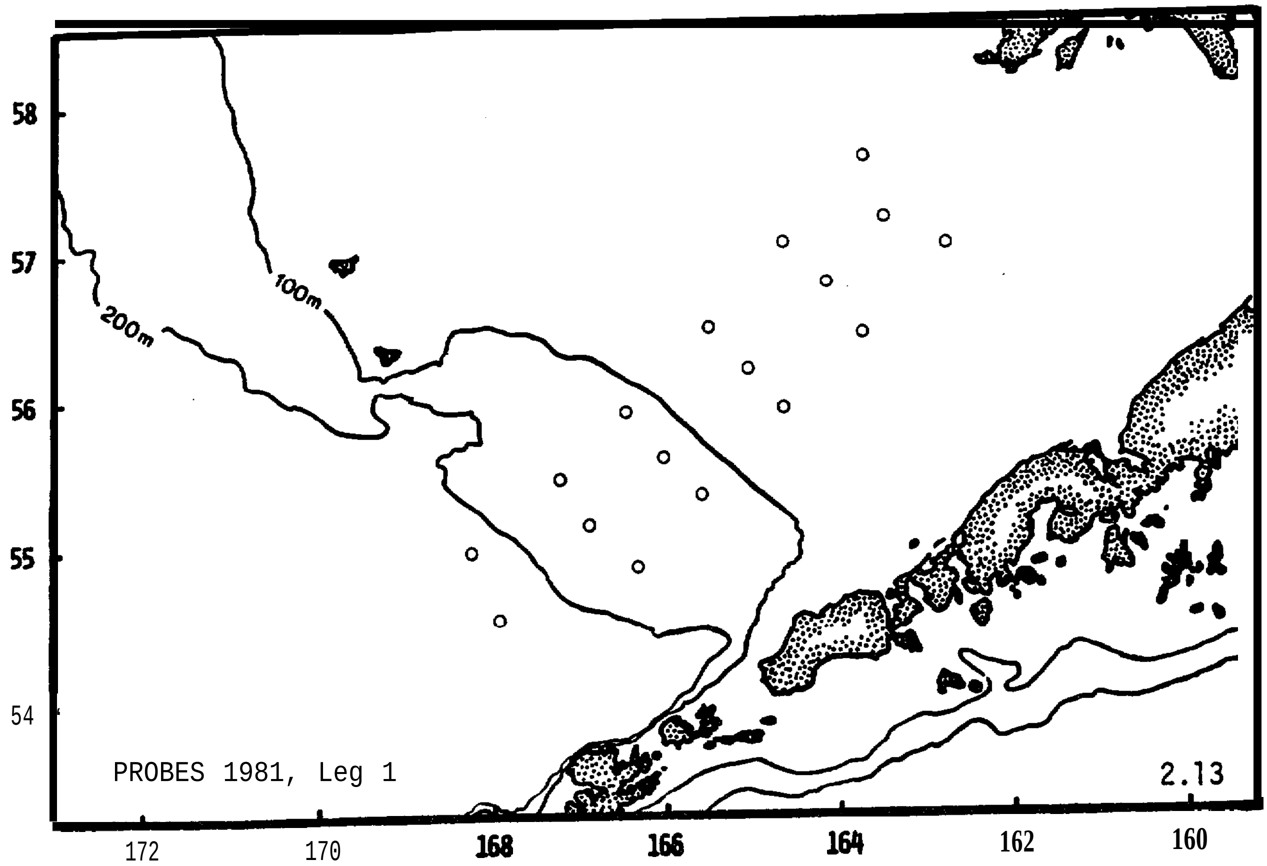
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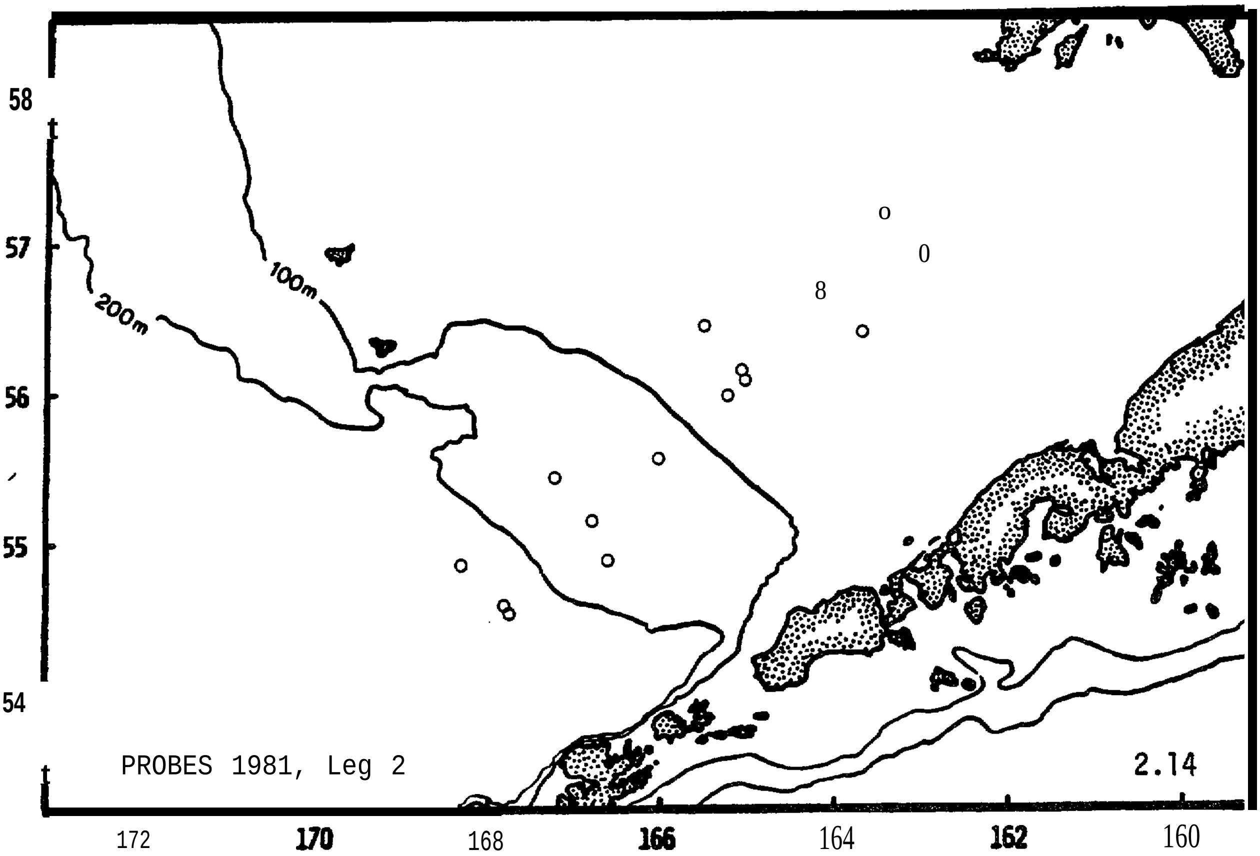
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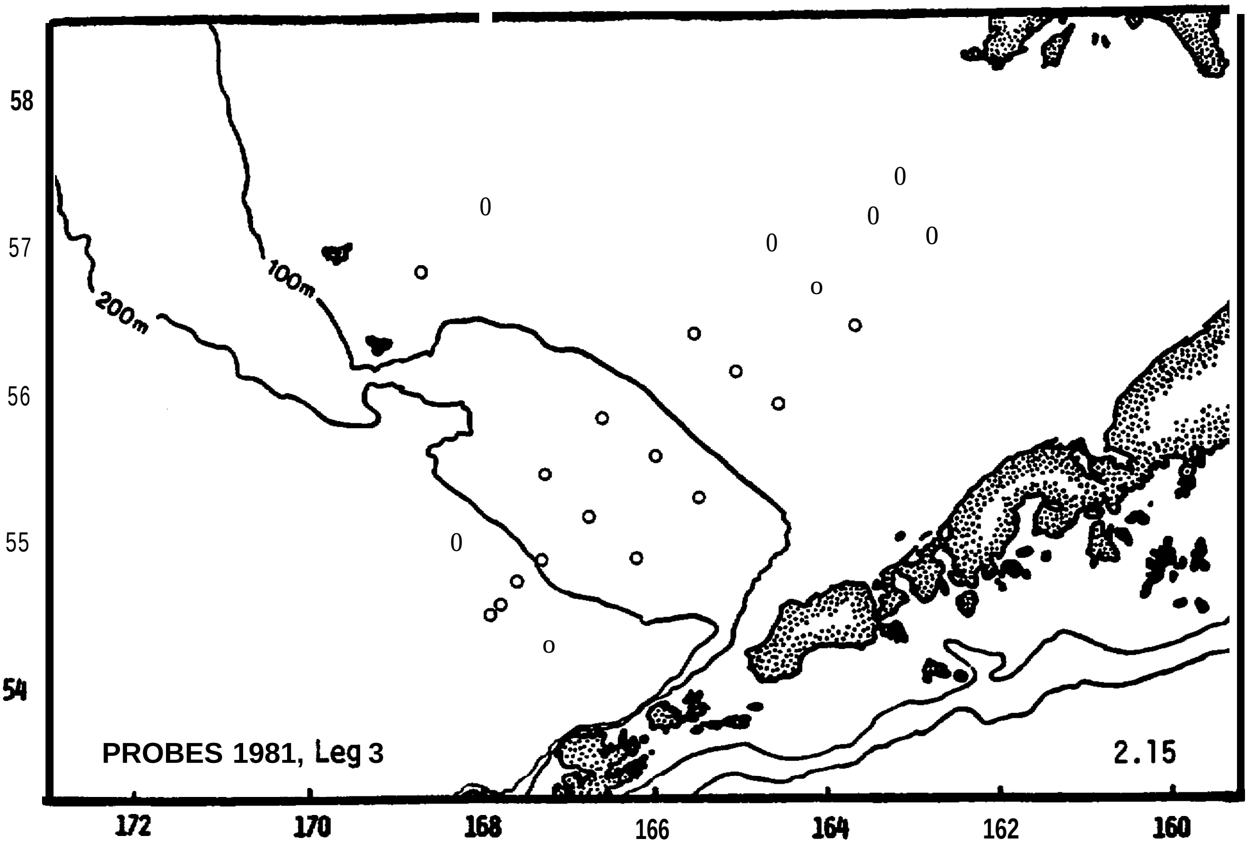
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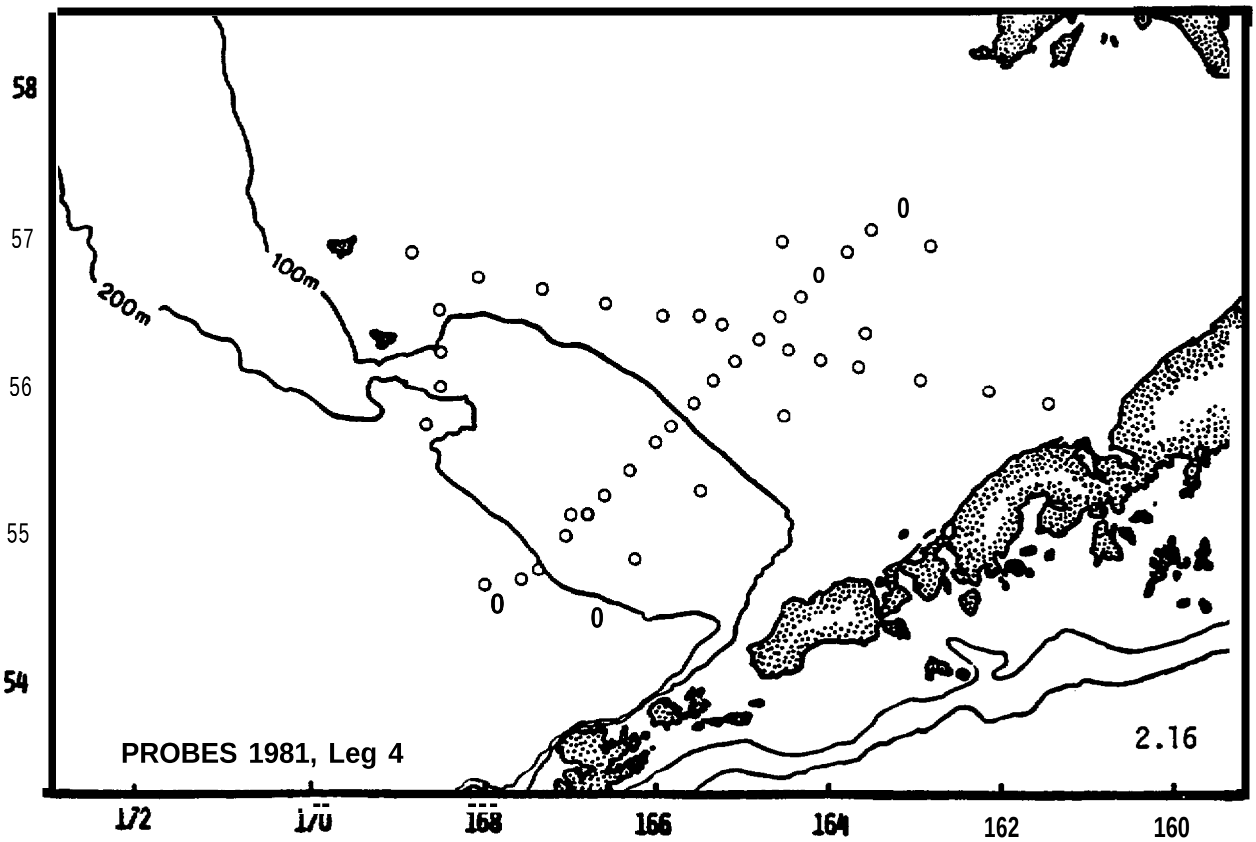
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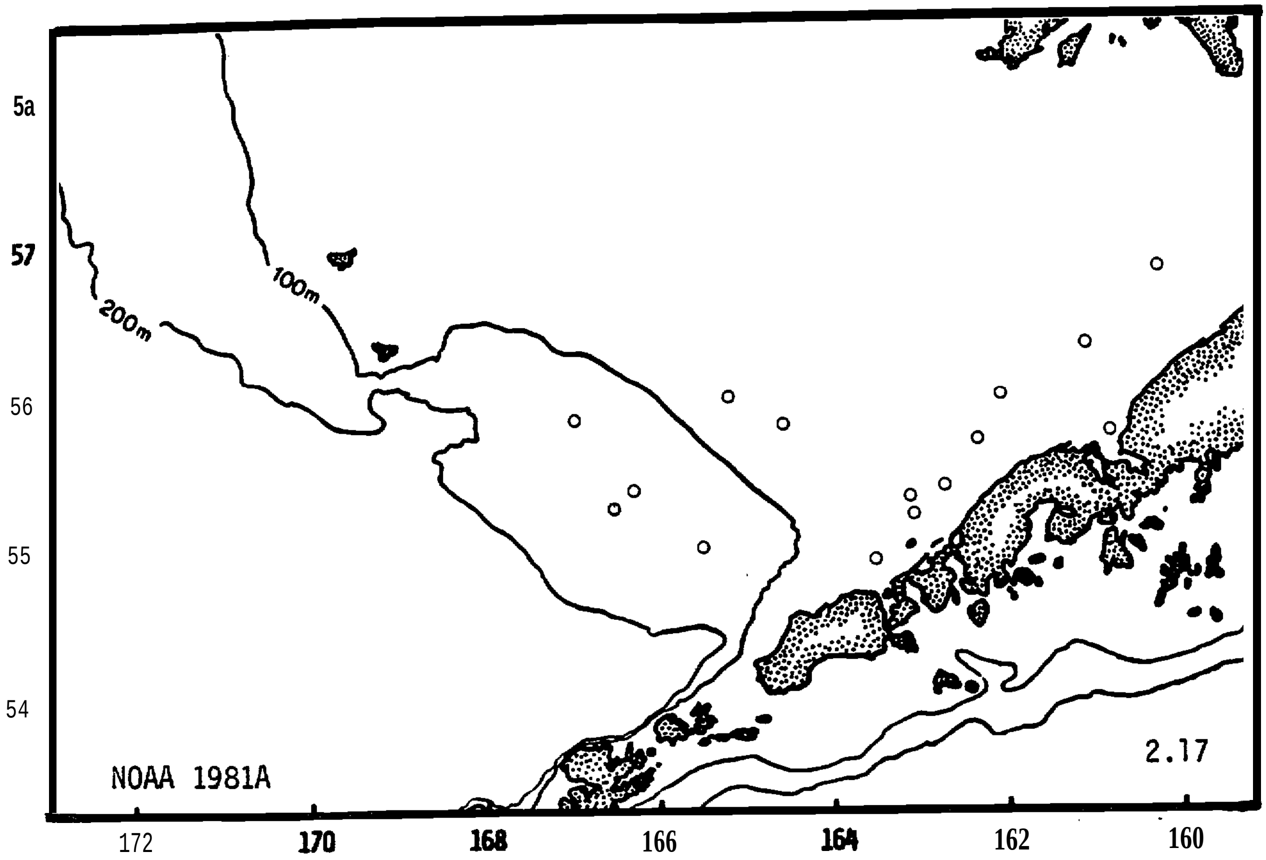
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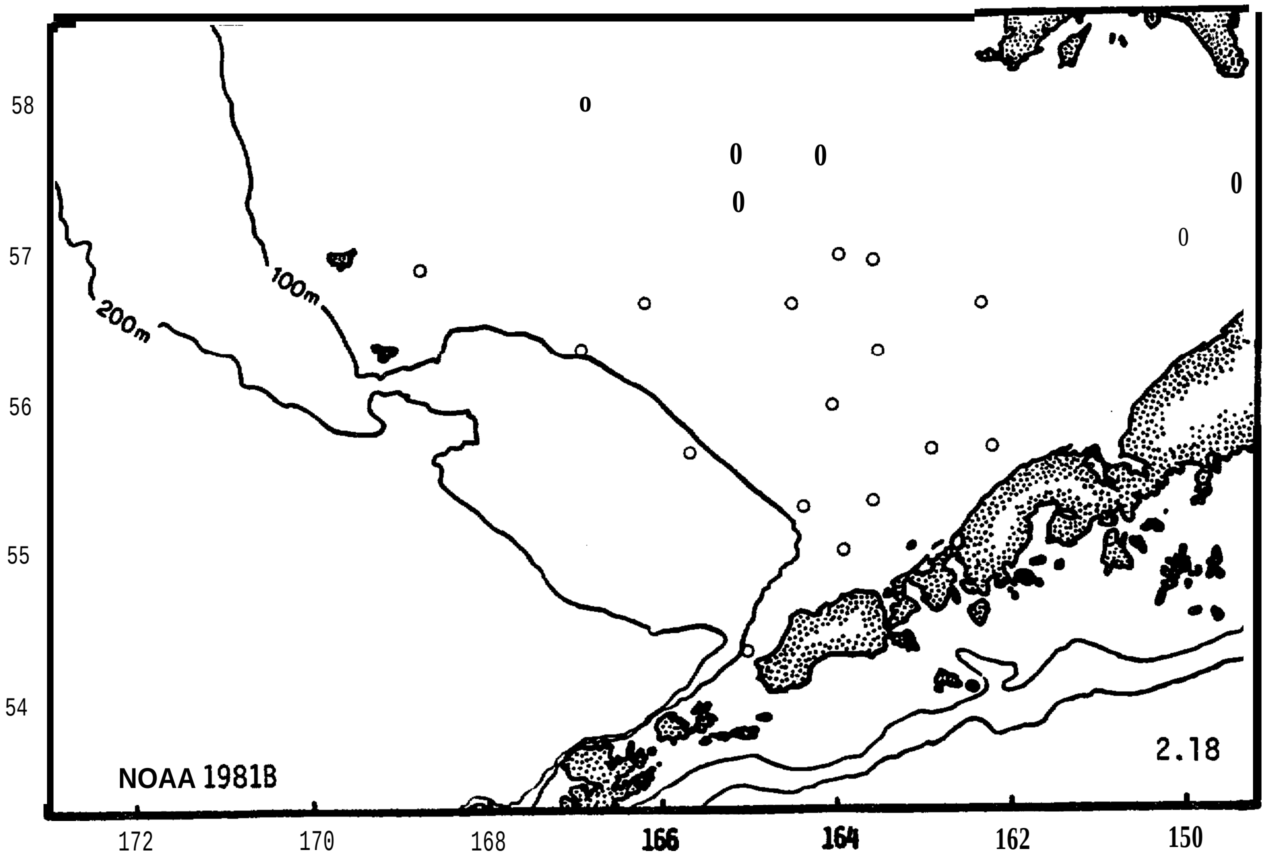
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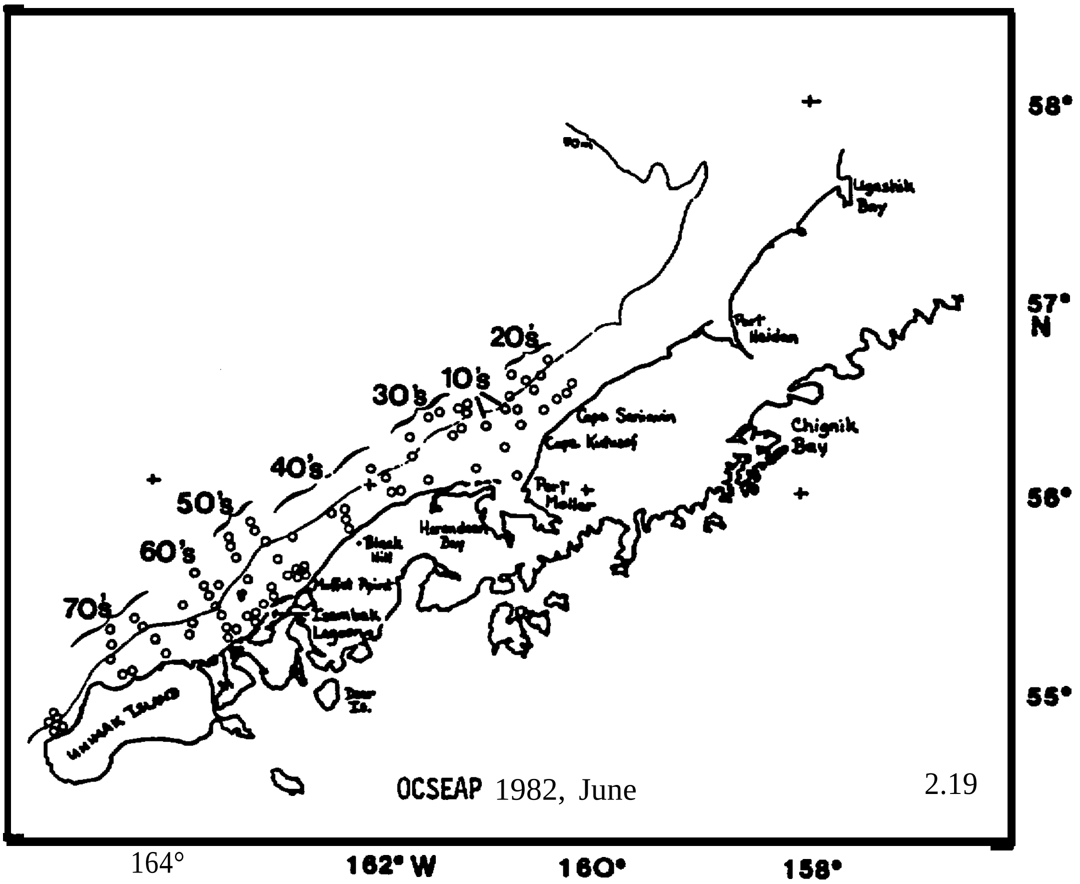


Figure 2.19 Station locations of June 1982 nearshore North Aleutian Shelf samples; OCSEAP Miller Freeman cruise. Units of ten indicate station sequence in time and space of zooplankton samples (see Section 4.0).

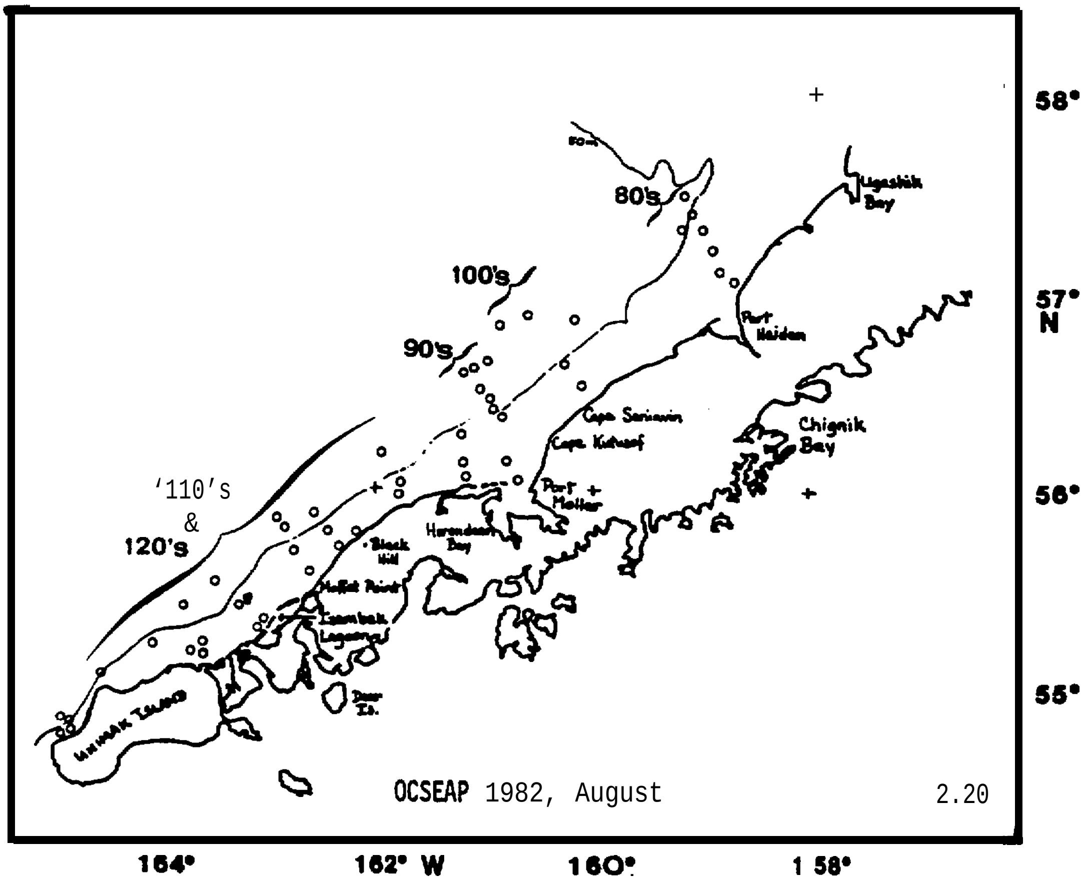


Figure 2.20 Station locations Aug. 3-10, 1982 nearshore North Aleutian Shelf samples; OCSEAP Miller Freeman. Units of ten show station sequence in time and space.

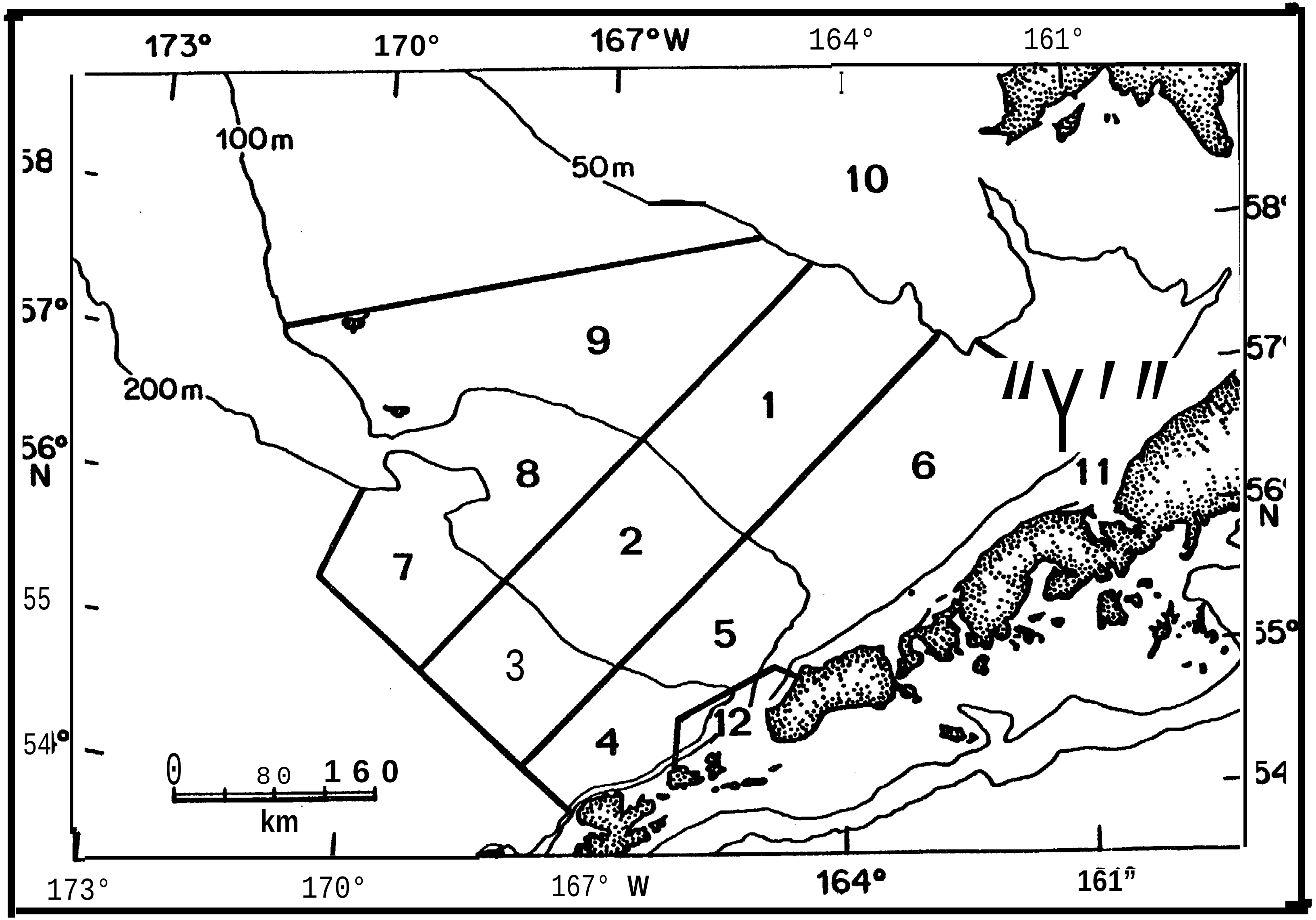


Figure 2.21 Locations and boundaries of strata used to contrast spatial distribution of decapod larvae in the S.E. Bering Sea. Strata 7, 3, and 4 encompass the shelfbreak/Oceanic domain; strata 8, 2, and 5 the Outer Shelf domain = the St. George Basin; strata 9, 1, and 6 the Middle Shelf domain; and stratum 11 the nearshore North Aleutian Shelf region,

3.0 DISTRIBUTION AND ABUNDANCE OF KING CRAB LARVAE, *PARALITHODES CAMTSCHATICA*, AND *P. PLATYPUS*, IN THE SOUTHEASTERN BERING SEA

David A. Armstrong

3.1 Life History and General Biology: *Paralithodes camtschatica*

3.1.1 Distribution and Abundance

The Bering Sea shelf including Bristol Bay has been characterized as three principal water domains, the coastal, middle shelf, and outer shelf domain that extend to about the 50 m, 100 m, and 200 m isobaths, respectively (Kinder and Schumacher 1981; Fig. 3.1). Information on distribution and abundance of red king crab in these shelf areas is more comprehensive than for any other decapod fished by U.S. fleets (*see* Section 4.0 for discussion of Tanner crab). For more than 12 years, the National Marine Fisheries Service has conducted broadscale trawl surveys in the southeastern Bering Sea (Fig. 3.2), and Otto (1981a) provides a history of information gathered by Japanese and Russian fleets during their participation in the fishery. A series of annual reports by the International North Pacific Fisheries Commission (INPFC) since the late 1950's provides a continuum of detailed data on king and Tanner crab stocks in the southeastern Bering Sea as well as in other locations fished by member nations.

Red king crab are widely distributed from the Sea of Japan in the western Pacific through the Kuril Islands to the Kamchatka Peninsula, across to the southeastern Bering Sea and as far south as British Columbia in the eastern Pacific (Marukawa 1933; Vinogradov 1946; Weber 1967). The species is rather uncommon north of latitude 57°N and is

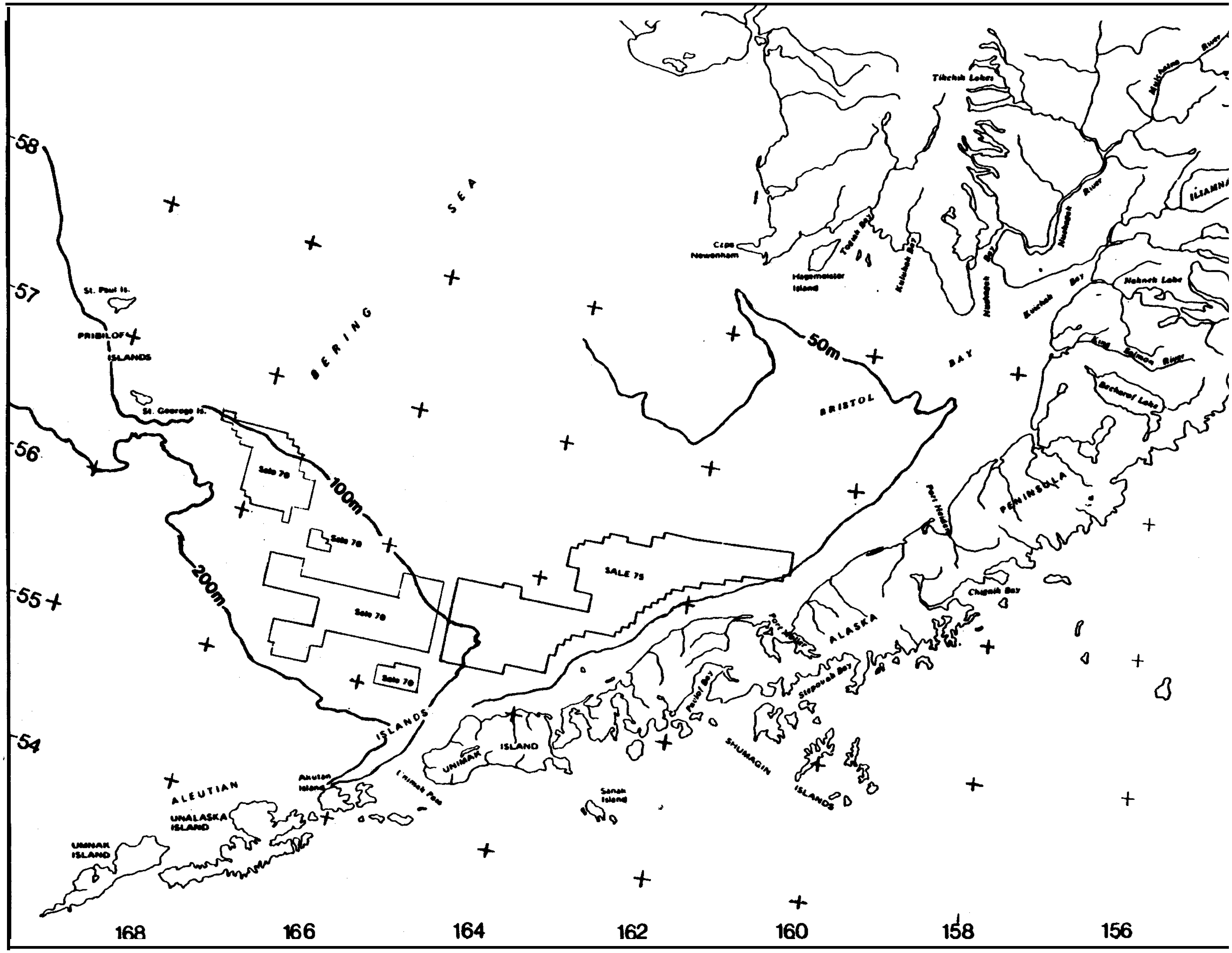


Figure 3.1. Location of proposed lease sale areas for the North Aleutian Shelf (Sale 75) and St. George Basin (Sale 70). Frontal systems marked by the 50m, 100m and 200m isobaths are also shown (after Kinder and Schumacher 1981a).

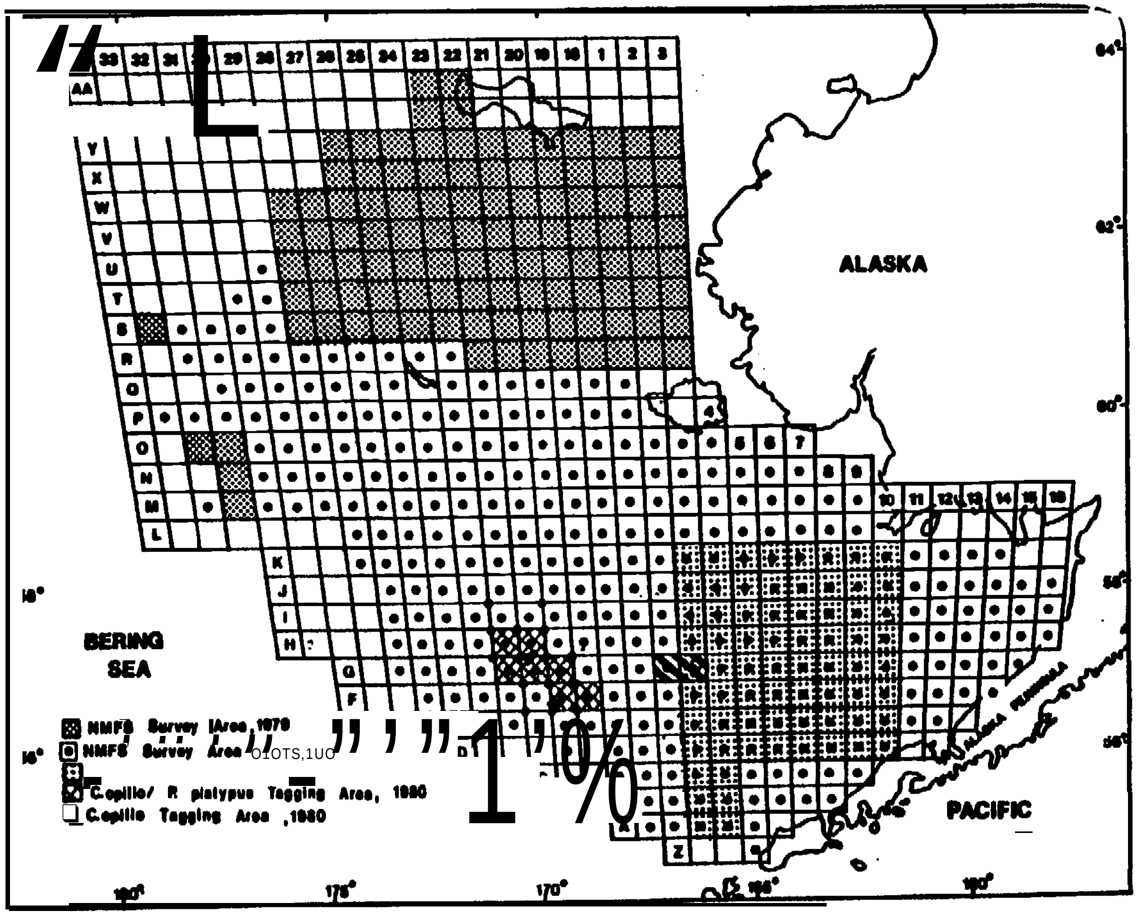


Fig. 3.2. NMFS eastern Bering Sea crab survey areas in 1979 and 1980. From Otto, Macintosh, Armetta and Wilson (1980). These survey grids are typical of years since 1970 through 1982.

characterized as part of the subarctic-boreal faunistic system (Neyman 1963, 1969). Further, Russian scientists rarely find it in large numbers north of the Anadyr faunistic barrier (a line from the Anadyr River to St. Matthew Island), in marked contrast to the blue king crab which ranges farther north and seems to inhabit colder water (Slizkin 1973).

In the southeastern Bering Sea where a major fishery is centered, red king crab are distributed somewhat in accord with sex and life-history stage. In general, female and small male king crabs are found closer to shore and somewhat east of large males (Otto, Macintosh, Armetta and Wilson 1980; Otto 1981b; Figs. 3.3 and 3.4; small crabs are classified as males <110 mm carapace length and females <89 mm). Very young juvenile red king crabs of O+ to 4+ age classes are rarely caught in nets throughout the survey area of Fig. 3.2, even though mesh used will retain animals as small as 30 mm. The implication is that juvenile crabs up to 60 mm in carapace length (about 3 years old; Weber 1967) are absent from the survey area and likely very nearshore along the North Aleutian Shelf or upper Bristol Bay.

Abundance estimates have fluctuated between years in the last decade and cycles of high to low abundance may occur in this species' populations as observed for Dungeness crab, *Cancer magister* (Botsford and Wickham 1978). Landings from the Kodiak king crab fishery increased to 94 x 10^6 lb by 1965, fell to 10 x 106 lb by 1971, and have remained around 14 x 106 lb to the present (NOAA 1981); poor recruitment is cited as the cause. In the southeastern Bering Sea, crabs were in moderate abundance in 1953, increased in abundance to 1959, fell between 1964-70,

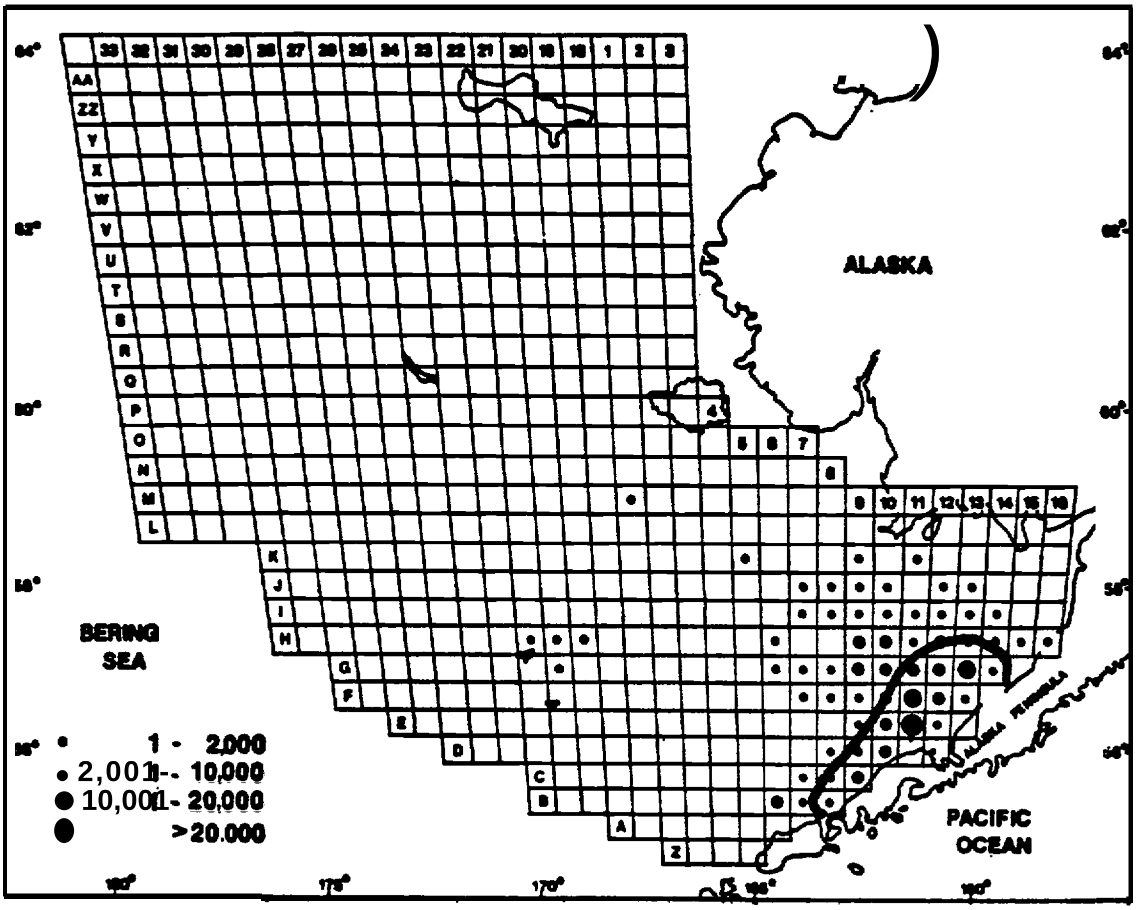


Fig. 3.3. Distribution of female red king crab (*P. camtschatica*) greater than 89 mm carapace length, in the eastern Bering Sea during May-July, 1980. From Otto, Macintosh, Armetta and Wilson (1981).

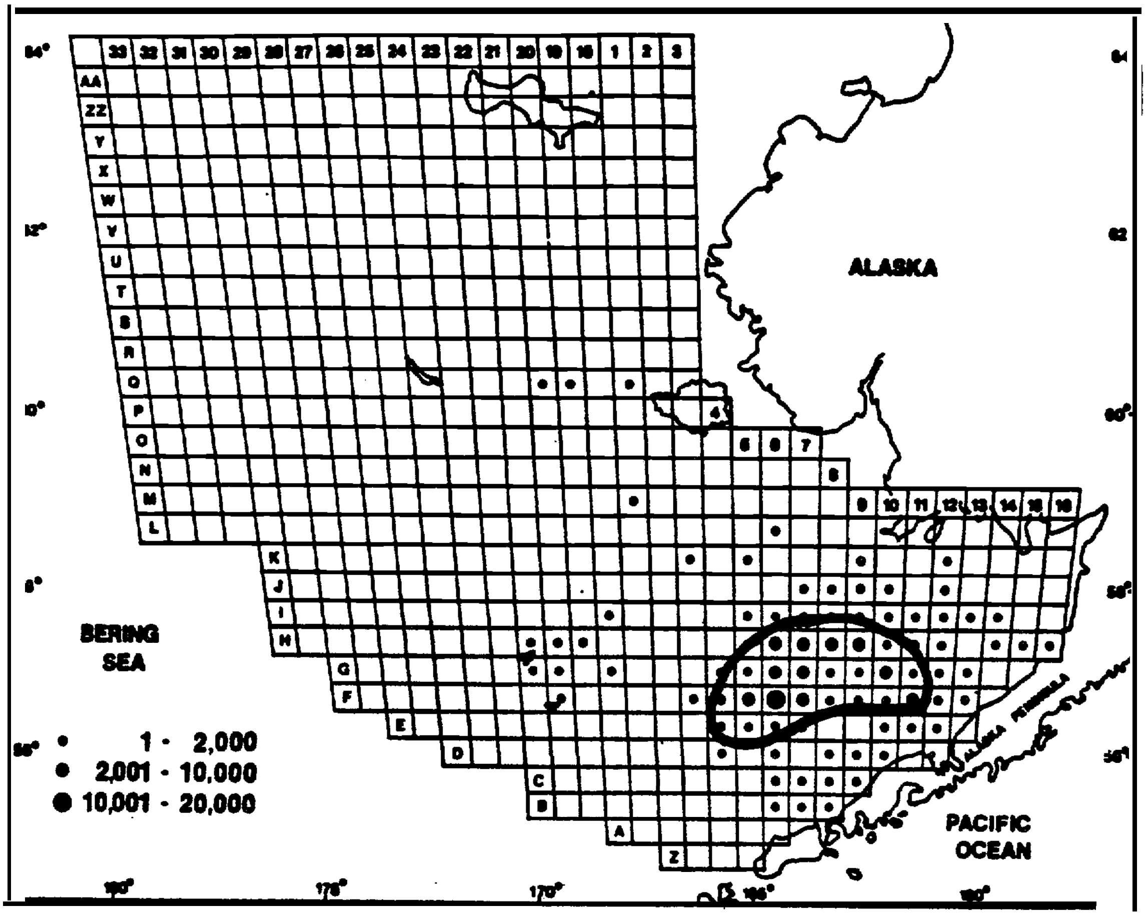


Fig. 3.4. Distribution of male red king crab (P. camtschatica) greater than 134 mm carapace length, in the eastern Bering Sea during May-July, 1980. From Otto, Macintosh, Armetta and Wilson (1981).

and then increased through 1979 (Otto 1981a). However, abundance estimates for total male king crab in this area have declined from 181 million animals in 1977 to 129 million in 1982 (Otto et al. 1982). Most importantly, estimates of sublegal males one to tw years from entering the fishery have declined nearly threefold from 64 to 17 million, leading to predictions of several consecutive years of poor fisheries. Abundance estimates of legal male crabs dropped from over 45 million animals in 1979 to about 5 million in late 1982 (Fig. 3.5; Otto et al. 1982; M. Hayes, NMFS, Seattle, pers. communication), which has resulted in severe reductions in commercial landings from 130 million lb to less than 4 million in the same period (see Section 1.0).

Change in abundance of king crab populations is an important biological factor to consider later in discussing oil impacts. Cycles of abundance suggest that year class failure or success may be based on survival of critical life-history stages such as larvae or young juveniles, probably in nearshore habitats. Annual instantaneous mortality rates of Juvenile and sublegal, sexually mature crab are estimated to be low, about .10 until entering the fishery (Balsiger 1976; Reeves and Marasco 1980). Consequently the magnitude of a future fisheries cohort is largely determined by the reproductive success and survival of larvae and young-of-the-year (0+ crab) in nursery areas. Vagaries of temperature, food supply, and predator populations are factors affecting survival, now the question of potential oil perturbations could add to natural pressures on larval and juvenile populations and further suppress stocks.

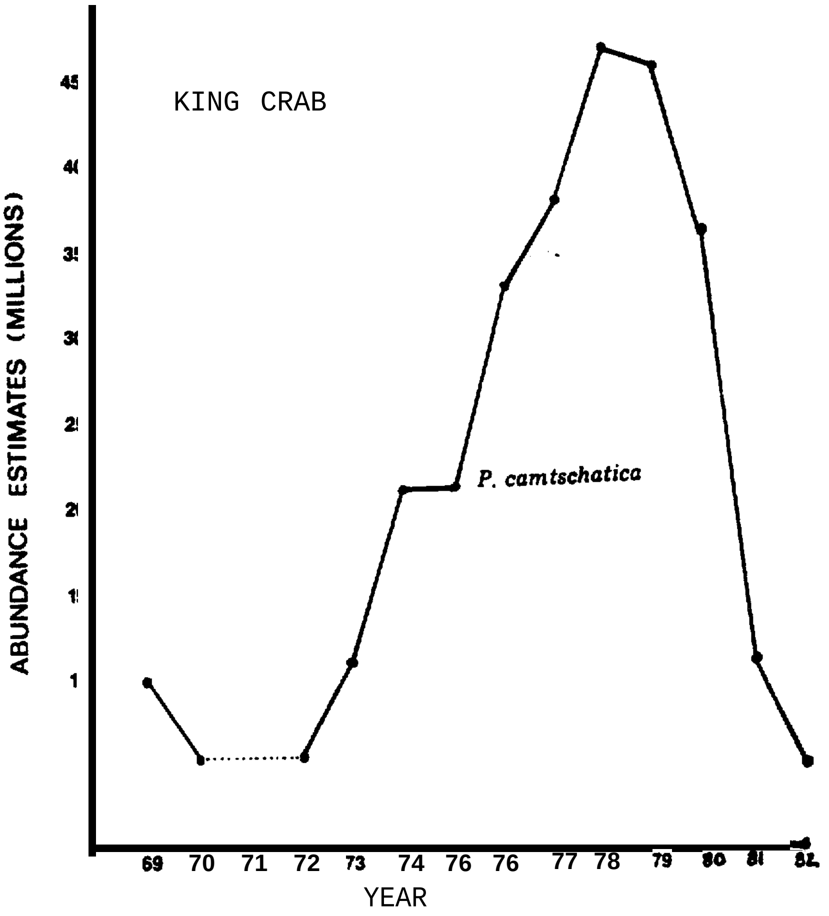


Figure 3.5. Abundance estimates of legal male red king crab based on annual NMFS groundfish surveys (from Otto 1981; Otto et al 1982).

3.1.2 Reproduction

In late winter and early spring adult males apparently migrate from deeper, offshore areas to join females in shallow water for breeding around Kodiak Island (Powell et al. 1974; Weber 1967; NOAA 1981; it is not known if such migratory behavior exists in the southeastern Bering Sea). Eggs carried from the previous year hatch about April 1-20 (Haynes 1974; Weber 1967) and females soon undergo physiological changes leading to molt. By pheromone attraction (NOAA 1981) sexually mature males locate preecdysial females, embrace them for as long as 16 days, and mate just after the female molts (Powell et al. 1974). The nearshore, shallow water habitat is apparently selected in part for warmer water temperatures (and perhaps greater food supplies). The average temperature inhabited by sexually mature males and females is 1.5° and 4"C, respectively; (NOAA 1981). Stinson (1975) correlated male and female abundance with temperature and, from NMFS survey data through 1975, located most sexually mature females inside a 4°C isotherm nearshore off Unimak Island and directly in front of Port Moller. Weber (1967) summarized data on temperature-related hatchout time and development, noting both regional and annual differences in larval appearance and rate of development attributable to temperature variations,. Larval development time can double with a decrease of temperature from 10° to 5°C (Kurata 1960, 1961), and an average of 460 degree days (= cumulative average daily temperature from hatch of egg to metamorphosis of megalops) is required for the species (Kurata 1961).

After molting a female must be located and mated within 5 days for viable eggs to be produced (possible impact of oil on chemosensory pheromone cues could impair males' search for females). For 97% of all mating pairs males are larger than females (Powell et al. 1974); insemination of larger females by smaller males results in reduced clutch size (egg number). Any combination of events through natural and fishery mortality and pollution that substantially reduce numbers of large males at some point in time could threaten the breeding potential of the species. Reeves and Marasco (1980) estimated that a male-female weight ratio of 1.7 is required for 100% copulation - this estimate based, in part, on behavioral observation by Powell et al. (974). Below this value, decreasingly smaller males will have less success breeding mature females. This relationship portends the observations of the 1982 NMFS survey cruise that found an unusually large number of barren female crabs (had not extruded eggs) in a year of very low male abundance (depressed fishery). Whether there is or is not a relationship between spawners and eventual recruits for this species is unclear (Reeves and Marasco 1980).

Females carry eggs for up to eleven months as embryos develop through naupliar stages to prezoea (Marukawa 1933). This protracted developments'l time makes eggs (during early cleavage) and later embryos susceptible to long-term benthic oil pollution, and will be considered in scenarios of oil mishaps and possible perturbations to larval populations (see Section 8.0). Again, gravid king crab females are aggregated nearshore in relatively shallow water along the North Aleutian Shelf but such distribution is poorly studied to date.

3.1.3 Larval Development

Larvae are hatched nearshore (Haynes 1974), molt through four zoeal stages about every three weeks (Marukawa 1933), spend two-four weeks as megalopae and then metamorphose to first instars about late July to August (Kurata 1960; Weber 1967). Eggs normally begin to hatch in early April (Sato 1958; INPFC 1960, 1963, 1965; Haynes 1974), although female king crab may vary in time of hatch between widely separated populations from Unimak Island to Port Moller. Korolev (1968) summarized data collected by Soviet scientists for June, 1959 along the North Aleutian Shelf. Over 95% of the female populations between 161°25′ to 164”10’W had spawned and carried new egg masses (purple to brown color) in June, while 90% of females east of 161°25'W (Port Moller and east) carried empty egg cases indicative of recent hatch and only 10% carried new purple egg masses.

Interannual timing of the onset of hatch and seasonal occurrence of pelagic larvae can vary by as much as a month. Japanese data (INPFC 1963, 1965) show that nearly 100% of gravid females sampled during 1960 carried “eyed” eggs (fully developed zoeae, hatch immiment) until May 10 and 50% carried empty egg cases by May 20-30. In 1963, eyed eggs were carried until April 20 and 50% had hatched by April 30. Such changes in the general timing of larval hatch are important for predictions of potential oil impact to pelagic larvae of the species.

Horizontal transport of king crab larvae by currents is thought to move them significant distances from the origin of hatch, and implies to some authors that recruitment of juveniles to a given area might depend on larvae hatched elsewhere, including areas south of the Alaska Peninsula (Hebard 1959; Haynes 1974). Hebard (1959) calculated that larvae hatched at Amak Island could be transported over 60 miles to the northeast and metamorphose at Port Moller (net current speed of 0.04 knot moving northeasterly along the North Aleutian Shelf; Kinder and Schumacher 1981, show a current speed of 2-5 cm/sec in that region). He further discussed possible transport of larvae from south of the Peninsula through Unimak and False Pass. Haynes (1974) adds credence to this supposition by showing a northerly dispersion of king crab larvae off the southwest tips of Unimak Island, and a northeast shift in areas of larval abundance from Black Hills into Bristol Bay (May-July, 1969 and 1970; this pattern may in part be due to inadequate spatial sampling). Transport of larvae by currents is also important to consider in predicting oil impacts. Oil reaching relatively unproductive areas of the North Aleutian Shelf (low female abundance, few larvae hatched) could still be lethal if larvae are transported through such contaminated areas. Alternatively, oil and larvae could be transported together in a water mass resulting in relatively long-term exposure of sensitive zoeal stages to hydrocarbons.

Temperature is considered one of the most crucial physical factors affecting survival and growth of larvae, and Kurata (1960, 1961) calculated that 460 degree-days were required to progress from hatch to metamorphosis. Lethal temperatures are those greater than 15°C or lower than 0.5-1.8°C (Kurata 1960). He found greatest survival of zoeae between 5-10″C and formulated an equation that relates developmental time to temperature. Time from egg-hatch to molt of stage I (S1) to stage II

(S11) varies from 24 days at 2°C to 9 days at 8°C (Kurata 1960). Severe climatological changes could account for large fluctuations in survival of a year-class and later recruitment to the fishery. Niebauer (1981) shows the limit of ice in the southeastern Bering Sea (as a relative measure of water temperature) was several hundred kilometers farther south in 1976 than 1979 and actually extended to the Alaskan Peninsula near Black Hills. Both 1975 and 1976 were severely cold years and poor survival of larvae and juveniles then could account for low abundance of sublegal males 5-6 years later in 1981-1982.

Growth rates of 0+ and older juveniles have been studied and animals reach mean carapace lengths of about 11 mm, 35 mm, 60 mm, and 80 mm at 1, 2, 3, and 4 years, respectively (Powell and Nickerson 1965; Weber 1967). Growth models for the species have been developed by Weber (1967), McCaughran and Powell (1977) and Reeves and Marasco (1980). Young-of-the-year molt from 8 (Powell 1967) to 11 (Weber 1967) times in the first year; such high frequency molting could make them particularly susceptible to nearshore oil perturbations since ecdysis is the time of greatest sensitivity to toxicant stress (Armstrong et al. 1976; Karinen 1981).

Juvenile crabs in 2+ to 3+ age classes (entering their third through fourth year) form large aggregates called “pods” in the Gulf of Alaska (Powell and Nickerson 1965). Podding behavior is probably based on chemosensory cues (subject to oil effects) and is thought to serve as protection from predators. It is not known if the same behavior occurs among nearshore juveniles of the North Aleutian Shelf. If so, such aggregations could influence susceptibility to oil since these "patches" of crab are fortuitous in space relative to oil mishaps, but if juxtaposed could affect large numbers of crabs in small areas.

Red king crab are sexually mature at about 95-100 mm carapace length for males (Weber 1967, NOAA 1981), and 85-90 mm for females in the Bering Sea (Weber 1967) or 93-122 mm in the Gulf of Alaska (Powell and Nickerson 1965). Animals are 5-6 years old at sexual maturity and males are therefore capable of breeding 2-3 years prior to entering the fishery at about eight years old.

3.2 Life History and General Biology: *Paralithodes platypus*

3.2.1 Distribution and Abundance

This is the most insular species of crab in the southeastern Bering Sea (Fig. 3.6), with major populations (and fisheries) centered at the Pribilof and St. Matthew Islands (Otto et al. 1982), and other populations at Kodiak Island in the Gulf of Alaska (Somerton and Macintosh 1982). There is 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 is to the east and north of St. Paul Island, with few animals caught west near the shelf break or about St. George Island (Fig. 3.7a and b). This pattern of distribution is generally accurate for 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). The complete absence of blue king crab over most of the southeastern Bering Sea Shelf (where red king crab, *P. camtschatica* are abundant) suggests either inextricable dependence on

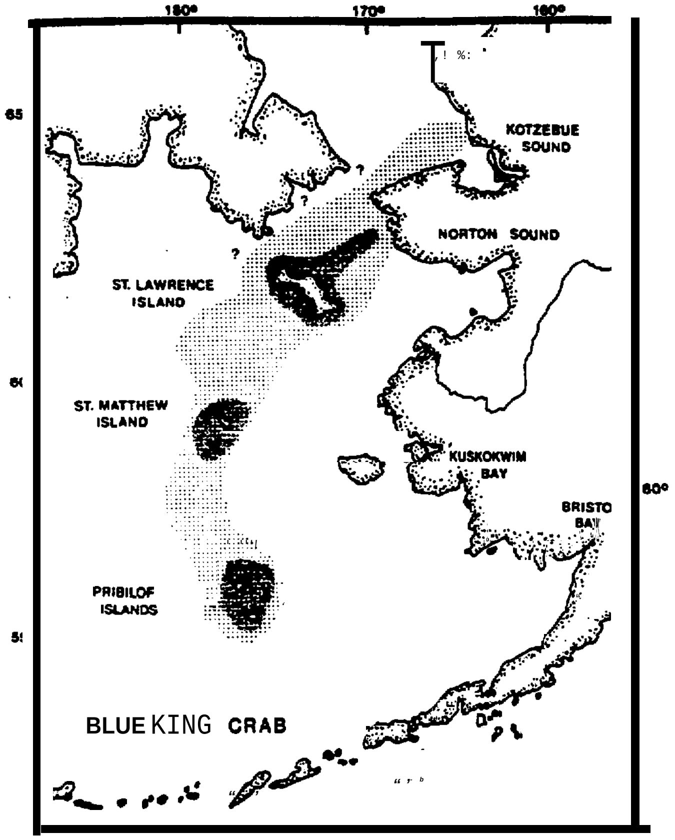


Fig. 3.6, Distribution of blue king crab (*Paralithodes platypus*) in the eastern Bering Sea. Darkly shaded portions indicate areas of consistent abundance (Otto, 1981).

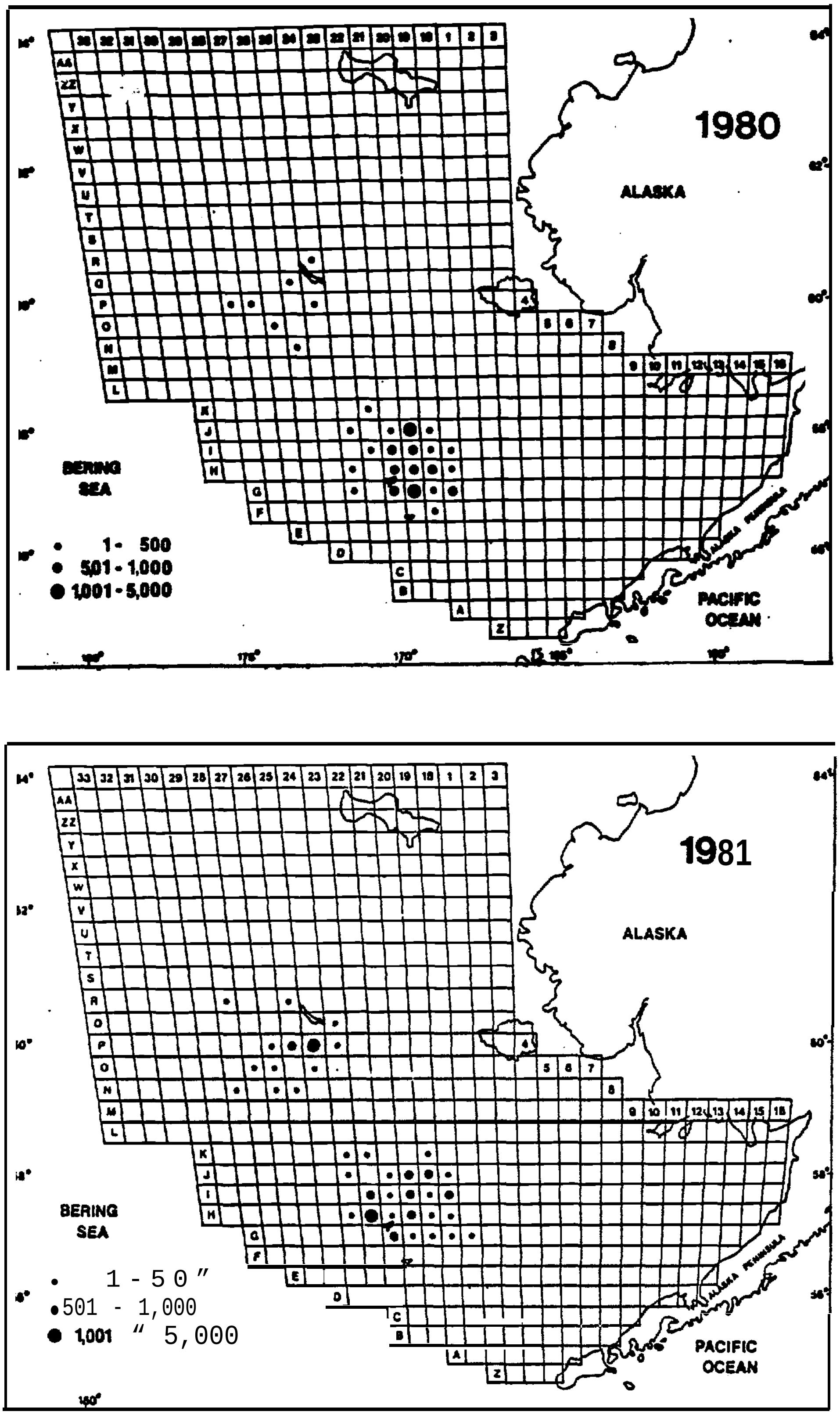


Fig. 3.7a. Distribution and relative abundance (number per square mile) of male blue king crab (P. *platypus*) greater than 134 mm carapace length in 1980 and 1981 (from Otto, Macintosh, Armetta, and Wilson 1980; Otto et al. 1981).

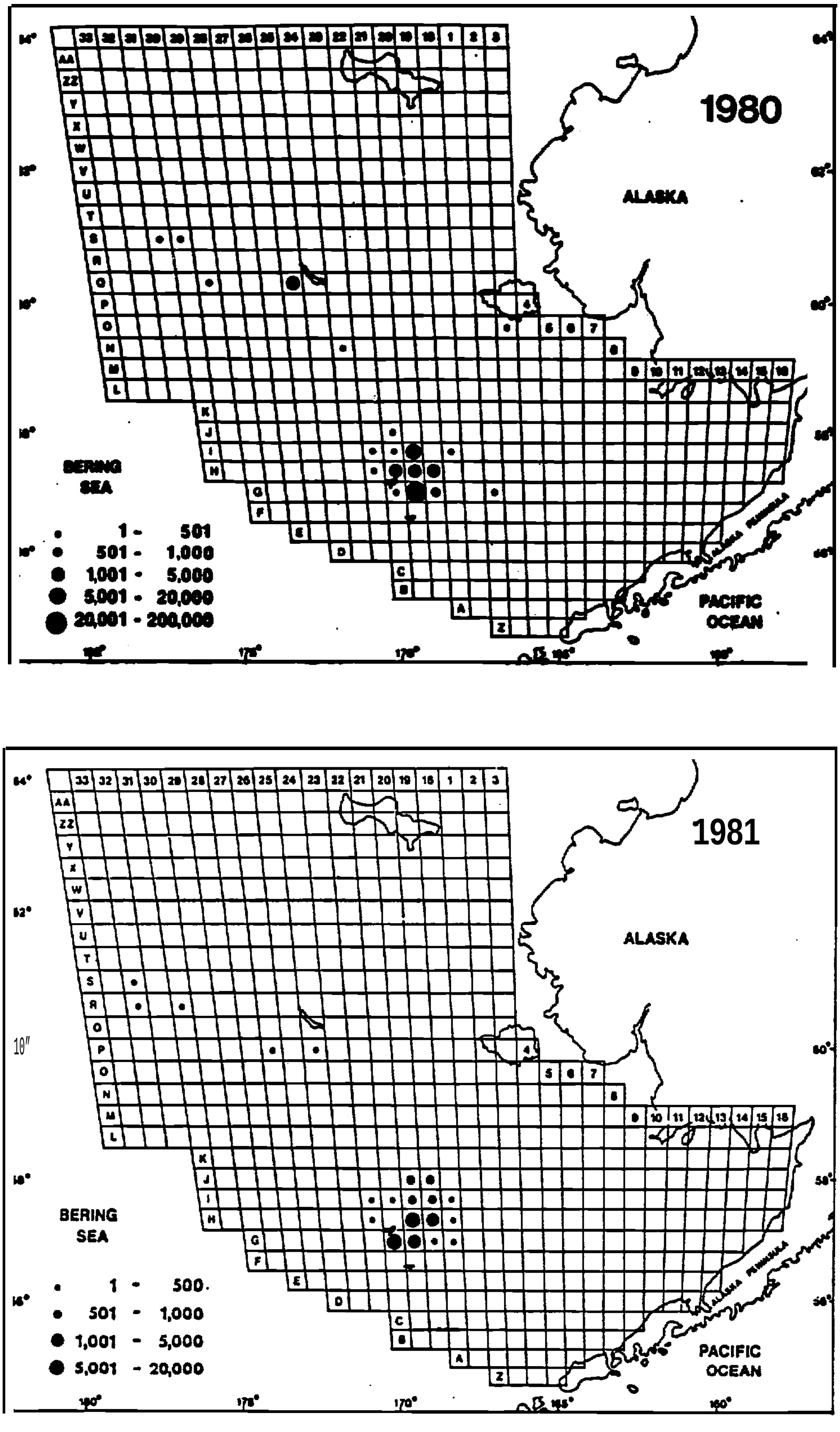


Fig. 3.7b. Distribution and relative abundance (numbers per square mile) of female blue king crab (*P. platypus*) greater than 89 mm carapace length, in the eastern Bering Sea in 1980 and 1981 (from Otto et al. 1980a, 1981).

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 a small area about St. Paul Island makes them extremely vulnerable to oil catastrophes originating in the northern St. George Basin lease sale area (Fig. 3.8).

On a broader scale, blue king crab tend to be more northerly in distribution than red king on both sides of the Pacific. Slizkin (1973) found high abundance of adults off Cape Navarin and reported juveniles even farther north to Cape Cukotsky (64°N latitude). He concluded that blue king crab are more tolerant of colder temperatures (1-2°C) than are red king crab, and that this differential partially explains species separation.

The depth range of main aggregations of blue king crab is about 45-75 m on a mud-sand bottom, although gravel to rocky substrate is found immediately adjacent to both Pribilof Islands. Otto et al . (1982) note that estimates of female and juvenile blue king crab around both the Pribilof and St. Matthews islands are low because of some distribution over rocky, untrawlable bottom. These observations strongly suggest that spawning and successful recruitment of first instar juveniles may depend on availability of nearshore, rocky-cobble substrate for protection of both females and small juveniles. Later, as older and larger animals, populations disperse farther offshore although still in a small area on the scale of the southeastern Bering Sea. Dependence of early benthic juveniles on refuge substrate is substantiated by

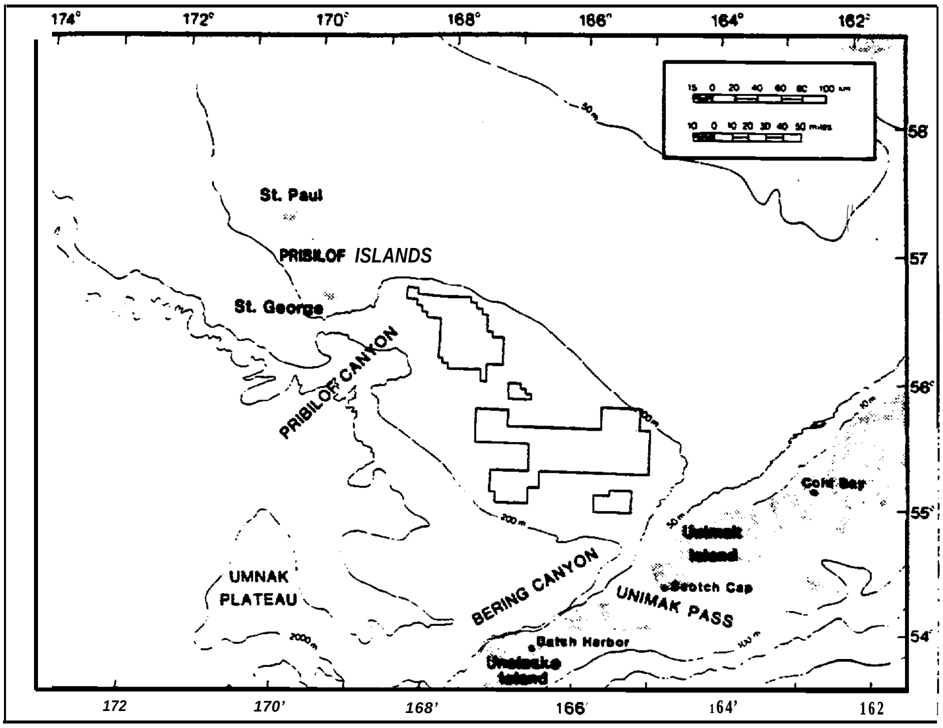


Fig. 3.8. Index map for proposed OCS Lease Sale #70, St. George Basin.

conclusions of Slizkin (1973) who reported finding no small juveniles over expansive areas of sand/silt bottom. Rather, these stages are abundant in areas of cobble and dense sponge, hydroid and barnacle assemblages.

Distribution and abundance of larval stages is poorly studied and only a few observations about the Pribilofs are available (Armstrong et al. 1981). Larval densities of blue king crab seem to be an order of magnitude less than high values recorded for red king crab, and larvae have only been found to the east of the Pribilofs.

Estimates of benthic blue king abundance made by NMFS indicate less fluctuation than found for red king crab, but still populations have decreased in recent years (Otto et al. 1981, 1982). Legal males (>134 mm) have declined from an estimated abundance of 9.4 million in 1977 to 2.2 million in 1982, and sexually mature females were calculated to be 35.5 million animals in 1978 and 8.6 million in 1982. Otto et al. (1982) conclude that stocks will remain low for several years.

3.2.2 General Biology

There is relatively little biological information published on blue king crab although Somerton and Macintosh (1982, 1983a, 1983b) have recently summarized work from the Bering Sea and Kodiak Island. Animals are thought to grow at a rate comparable to red king crab and reach sexual maturity at about 96 mm and 108 mm carapace length for females and males, respectively, when they are about 6 years old (Powell and Nickerson 1965; Somerton and Macintosh 1982; Weber 1967). Fecundity of females is a function of body size and ranges from 50,000-200,000 eggs per female. Larvae hatch around the Pribilof Islands about mid-April based on limited data of Armstrong et al. (1981), and development rates may be similar to those of red king crab larvae. By June most larvae are third and fourth stage zoeae, and in July 1981 Armstrong (unpublished data) caught only megalops larvae off St. George Island. This implies that metamorphosis to benthic juvenile could occur in early to mid-August.

An intriguing question concerning reproduction of blue king crab is whether egg development may require more than one year thus putting individual reproductive effort on a biennial schedule. Sasakawa (1973, 1975) suggested that a high incidence of sexually mature, barren female blue king crab in the western Bering Sea was evidence of a 2-year cycle; 19 months to incubate eggs and 5 months barren. Somerton and Macintosh (1982) disputed this hypothesis based on their study of female crabs in Olga Bay, Kodiak Island. They observed males grasping ovigerous females (prelude to copulation) as the mature egg masses were hatching, and from histological evidence of ovarian maturation they concluded that individual females may reproduce in sequential years. However, a high percentage of mature females within the Olga Bay population were barren throughout the year (38%-52%), dramatizing a greatly reduced reproductive potential compared to red king crab. If such impairment of population fecundity exists about the Pribilof Islands, then oil catastrophes could greatly exacerbate reproductive success in a year of low mature female abundance and a high incidence of barren animals, A further observation germane to the female reproductive cycle at the Pribilof Islands is that egg hatching in Olga Bay occurred in both January and March (Somerton and Macintosh 1982). Allowing for a latitudinal delay for reproductive events in the Pribilofs (e.g., Dungeness crab in California hatch eggs about 1.5 months earlier than populations in Washington), it may be that a portion of the females hatch eggs in February or early March, others in April and May. This notion may reflect timing differences between primiparous and multiparous females.

3.3 The Fishery

Red king crab until recently have been the most important crab fishery of the United States in both dollars and pounds landed. In 1980 king crab landings were 185 x 10^6 lbs and even exceeded blue crab (*Callinectes sapidus*) landings of the east coast (NOAA 1981). In 1979 to 1980 the value of king crabs landed was about $168.7 million or 58% of total U.S. ex-vessel value of crabs (Otto, Macintosh, Armetta and Wilson 1980; Eaton 1980; Otto 1981b; NOAA 1981) (Fig. 3.8). Of the total Alaska statewide king crab landings in 1978-79 and 1979-80, over 75% came from catches in the southeastern Bering Sea (117 x 10^6 and 130 x 10^6 lbs, respectively; NPFMC 1980; Pacific Packers Report 1981). Red king crab commercial catches (Fig. 3.9) come largely from the middle shelf between 50 and 100 m, and 50 to more than 200 km offshore of the North Aleutian Shelf (Otto 1981a, b).

King crab are the largest and oldest crab caught by U. S. fisheries. Males are 50% recruited to the pot fishery at 8 years of age and fully recruited by 9 years (McCaughran and Powell 1977; Reeves and

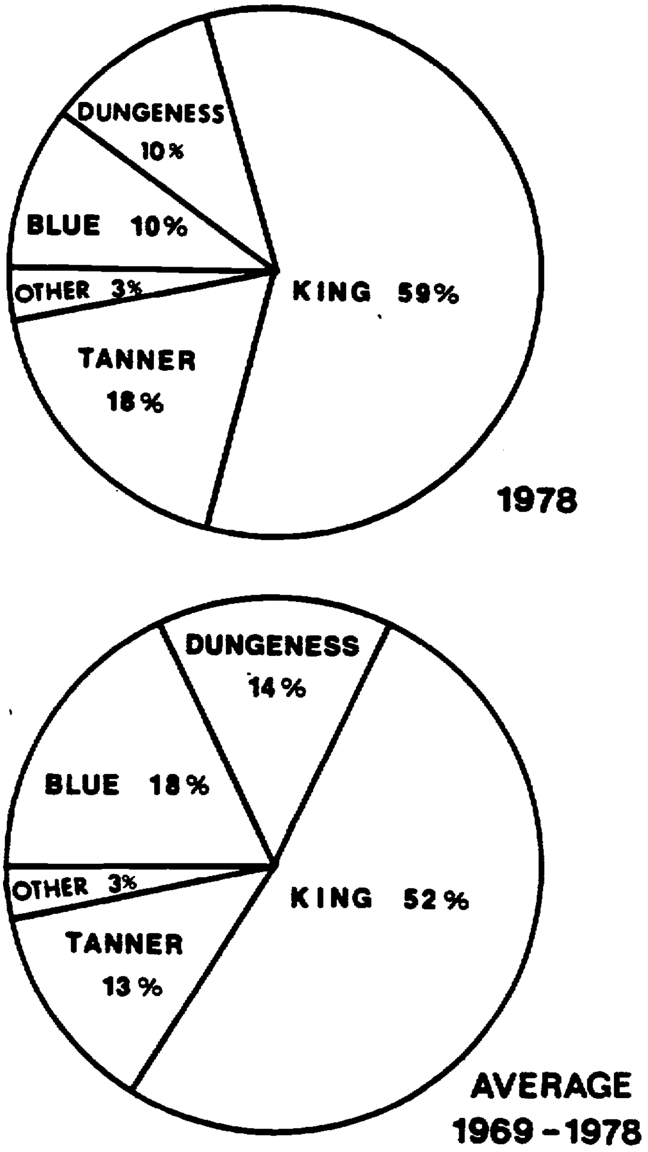


Fig. 3.9. Relative contributions of various crabs to the value of United States crab landings. From Otto (1981a).

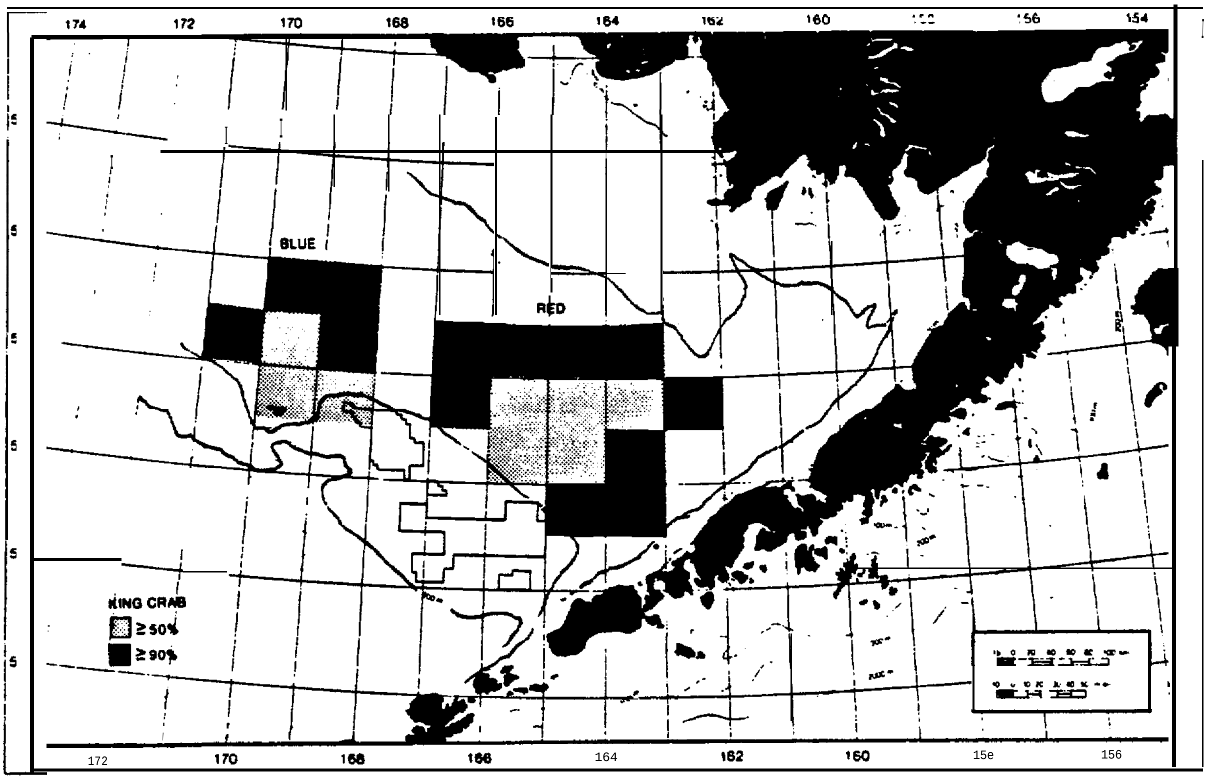


Fig. 3,10. Major king crab catch areas relative to St. George Basin lease area (Otto, 1981a).

Marasco 1980). Legal size at recruitment is about 135 mm carapace length and 165 mm (6 1/2") width and mean annual weight per animal fluctuates from 6.4 to 7.5 lbs (Eaton 1980; NOAA 1981). Annual fishing mortality is managed to approximate 40% (NOAA 1981) but the percent of the fishery constituted by new recruits has varied from 67% in 1977 to 47% in 1979, indicating that differential natural mortality rates can significantly affect the importance of any single year-class to the fishery (Eaton 1980). Oil pollution that adversely affects a significant portion of larvae in any year-class could eventually impact the fishery despite both longevity of the species and commercial stock comprised of two to three year-classes.

Most of the U.S. Bering Sea fishery for blue king crab is centered off St. Paul (Fig .3.6) and St. Matthew Islands. Landings have increased from about 2.4 million lb in 1975 to 10.8 million lb 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 NMFS trawl survey. It is significant that for the first time in the fisheries, landings of blue king crab surpassed those for red king in the southeastern Bering Sea during 1982 (R. Otto, NMFS Kodiak, pers. communication, 1-5-83).

3.4 Results

3.4.1 Distribution and Abundance

Analyses of over 1000 zooplankton samples collected between 1976 and 1981 clearly show that the overall distributions of both red king (*P. camtschatica*) and blue king crab (*P. platypus*) in the southeastern Bering Sea are restricted to discrete areas along the NAS into Bristol Bay and east of the Pribilof Islands, respectively" (Fig. 3.11). As stressed in the annual report (Armstrong et al. 1981), the most striking feature of this pattern is the associated absence of larvae over most of the St. George Basin and the middle shelf between 50 m and 100 m. Larvae are only found in the very southern portion of the St. George Basin, north of Unimak Pass, as part of a nearshore band that continues to the northeast along the 50 m isobath.

Due to such restricted distribution of king crab larvae, use of strata delineated in Figure 2.21 to contrast temporal and spatial distribution and abundance did not work well, as it did for other decapod groups (see sections 5.0, 6.0., and 7.0). Not only was the spatial coverage of interannual sampling quite variable, but only portions of certain strata ever contained larvae. Therefore, to include all stations of a stratum in calculations of mean densities would always add numerous zeros to the observations. Areas of greatest larval king crab occurrence relative to strata are shown in Figure 3.12. Blue king crab larvae occurred in the western half of stratum 9 but not in any other strata. The majority of high density red king crab stations fell in southern half of stratum 6, with a few in stratum

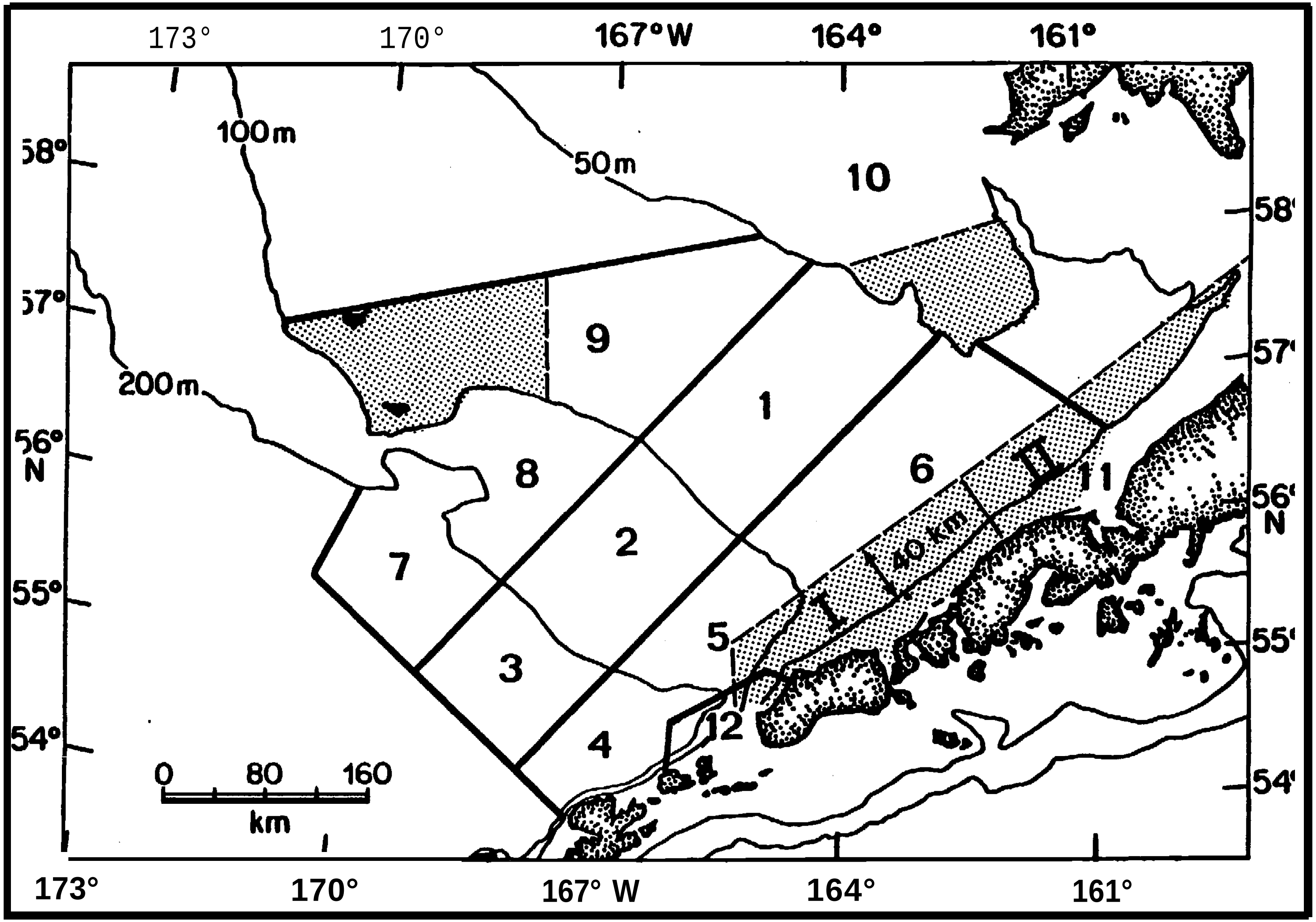


Fig. 3.12. A modification of Fig. 2.21 that shows areas of greatest larval king crab abundance relative to strata 1 to 12. Only areas nearshore along the North Aleutian Shelf were sampled with enough frequency to allow spatial and interannual comparisons. Two new strata I and II are shown that extend from shore to about 40 km seaward of the 50 m isobath.

11 and 12 (Figs. 3.11, 3.12). Too few samples were taken in strata 9 and 10 on which to base any sort of interannual comparison of larval abundance. Only the area along the NAS was sampled with enough frequency to compare certain years and, to a lesser extent, areas. Two new strata, I and II, are shown in Figure 3.12 that divide the NAS region into an east and west sector at 162° W near Black Hills. These strata more realistically encompass major areas of king crab hatch, and thereby permit limited spatial and temporal comparisons of distribution and abundance.

Red King Crab: Distribution of red king crab larvae based on data of this project (1976-1981) is in accord with results of a 1970-1971 survey conducted by Haynes (1974) who also found larvae to be relatively nearshore along the NAS into Bristol Bay. Unfortunately, the survey patterns of most years between 1976 and 1981 were largely focused offshore over the outer and middle shelves and, as a consequence, relatively few samples were taken over the apparent spawning habitat of *P. camtschatica*. Figure 3.11 shows that only about 13 samples over six years were collected near the 50 m isobath from Unimak Island to Port Moller, and only three fell shoreward of this depth. In the years of best spatial coverage, 11% to 23% of samples sorted had king crab larvae (Table 3.1). However, this percentage range is even less in the case of red king crab since a number of samples were positive for blue king crab near the Pribilof Islands. Further, about half of all positive stations had larval densities of less than 500/100 m^2 (Table 3.1) which was the lowest numerical category used to quantify density. Such low abundance reiterates the fact that many positive stations were still collected in marginal areas probably off the main spawning grounds.

The highest densities of *P. camtshatica* larvae occurred from western Unimak Island to Port Moller. Densities that ranged an order of magnitude from 5,000 - 50,000 larvae/100 m2were typical of this area. The highest densities recorded were 67,000 larvae/100 m2 north of Unimak Island in May 1977, and 114,000/100 m^2 just northwest of the 50 m isobath off Port Moller in May 1980 (Both values shown by star symbols in Fig. 3.11). The 50 m isobath is about 22-33 km (12-18 NM) offshore of the NAS coast from Unimak Island to east of Port Moller (about Cape Seviavin; Fig. 3.11), and marks the shoreward limit of zooplankton collections in most years. Virtually all high density red king larval stations occurred along this depth contour or within a 4(I km band to seaward (Fig. 3.11, 3.12). Occasional collections made from the PROBES A line (Fig. 2.11) toward Port Moller revealed larval densities of a few hundred to 3000/100 m2 out to the 50 m isobath at about 57°30'N, 162°30'1/. Collections made from NOAA ships in 1981 also showed fairly high densities of 2000-4000 larval/1011 m^2 up to Port Heiden in Bristol Bay (Fig. 3.11). However, these few stations north and east of Port Moller were the only available since 1976, so the extent and abundance of larvae east of Cape Seniavin into Bristol Bay remains unknown; a substantial informational gap in the picture of larval biology compiled to date.

Because of the poor spatial coverage of zooplankton stations between 1976-1981 in regards to king crab larvae, opportunistic collections were made in June and August, 1982, nearshore along the NAS from Unimak Island to Port Heiden (Figs. 2.19, 2.20). The primary objectives were to study nearshore distribution of larvae and gather information on growth rates. Samples were collected in water as shallow as 16 m within 3 km of shore, out to about 70 m depth some 40-50 km offshore. Collections were first made betwen June 14-28, which repeats a time frame typical of most previous years analyzed in this study, and again from August 3-10 which is the latest seasonal collection from king crab spawning grounds.

Larval red king crab in June, 1982, were most abundant from Amak Island (off Izembek Lagoon) east to the limit of sampling off Cape Seniavin (Fig. 3.13). Again as in previous years, samples were not collected throughout Bristol Bay and so the extent of larval distribution could not be fully gauged over the area occupied by benthic juveniles and adults. The most striking features of the distribution are: 1) the absence of larvae from western Unimak Island to about Amak Island [in contrast to data of Haynes (1974) and data of this study from 1976-1977; Fig. 3.16]; 2) the preponderance of larvae along the 50 m isobath and; 3) a decline of larvae close to snore in many areas sampled.

Larval distribution and abundance in 1982 were further analyzed by selecting groups of stations that constitute approximate transect lines running perpendicular to shore, although the opportunistic collection

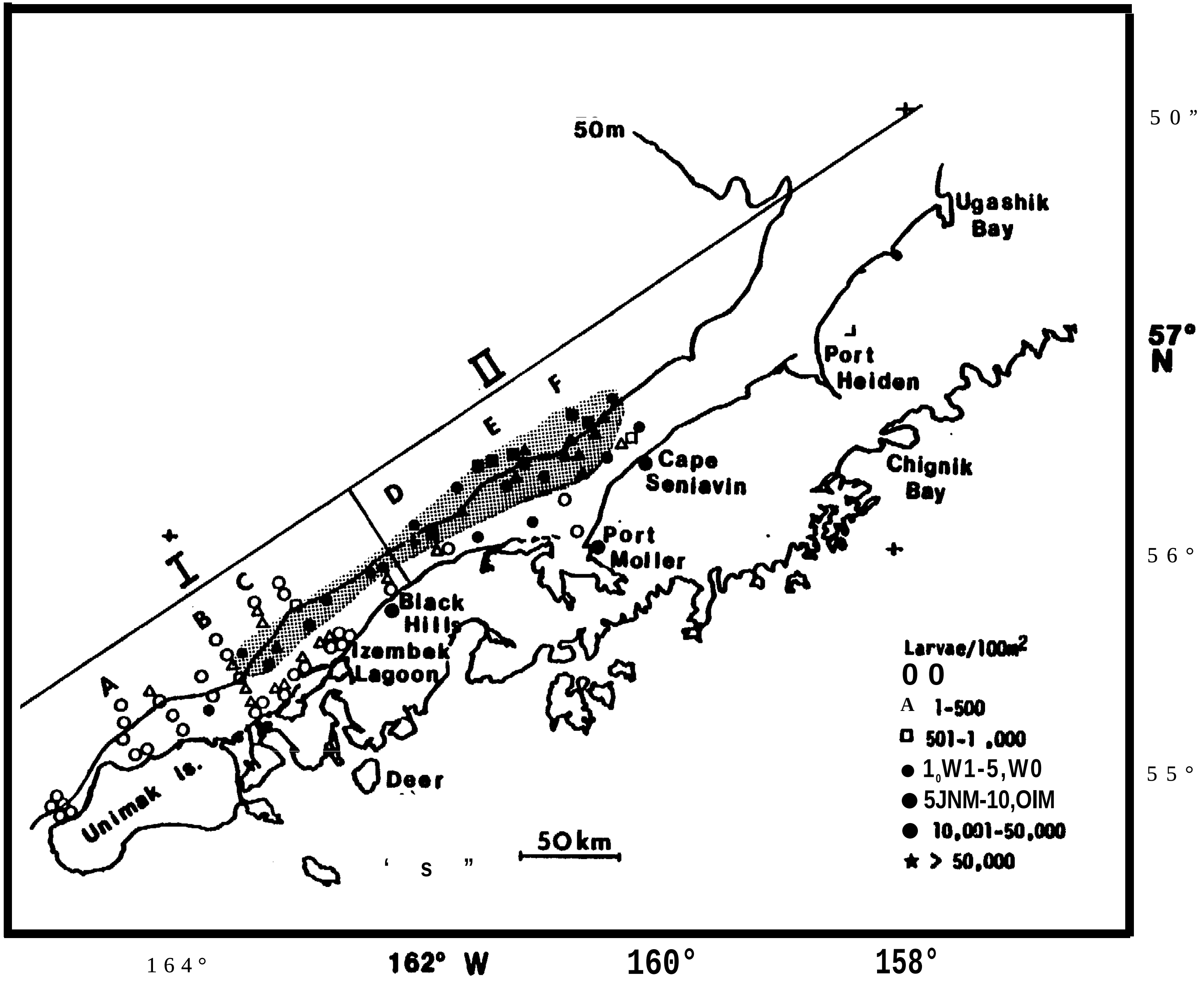


Fig. 3.13. Distribution and relative abundance of larval and king crab in modified strata I and 11 (see Fig. 3.12) during June, 1982.

made them imperfect in areas (Fig. 3.13, 3.14). Stations were grouped in broad depth intervals of 20-40 m, 41-60 m, and 61-80 m because narrower depth intervals were not common in all transect lines A to F. In fact, depths to 80 m were only collected on lines A to C, while D and E went only to 70 m and F had a deepest station at 63 m (Fig. 3.13).

The longshore pattern of distribution is one of relatively low densities inside 40 m with peak abundance of about 2,000 larvae/100 m^2 on the E line off Port Moller (Fig. 3.14). Virtually no larvae were found from mid Unimak Island through Black Hills, a distance of about 180 km. In contrast, densities between 41-60 m reached 6600 larvae/100 m^2 by the C line off Izembek Lagoon (Fig. 3.13), and averaged 6,300 to over 12,500 m^2 up to Cape Seniavin within this depth interval (Table 3.2; Fig. 3.13). Larvae were not found, or only in very low densities, farther offshore between 61-80 m from Unimak Island to Black Hills (Fig. 3.14). However, abundance off Nelson Lagoon and Port Moller was very high at depths from 61-70 m, and averaged 15,300 larvae/100 m^2 on the E line with a range from 8,800-24,700/100 m^2 (Fig. 3.14; Table 3.2).

Summary: 1) Larval densities in June were very low nearshore from 10-12 km off the coast throughout the entire study area. 2) Peak abundance occurred 25-30 km offshore from Amak Island to Cape Seniavin. 3) Abundance declined farther offshore in water of 61-80 m depth in the western portion (stratum I) of the sampling area (Fig. 3.13),

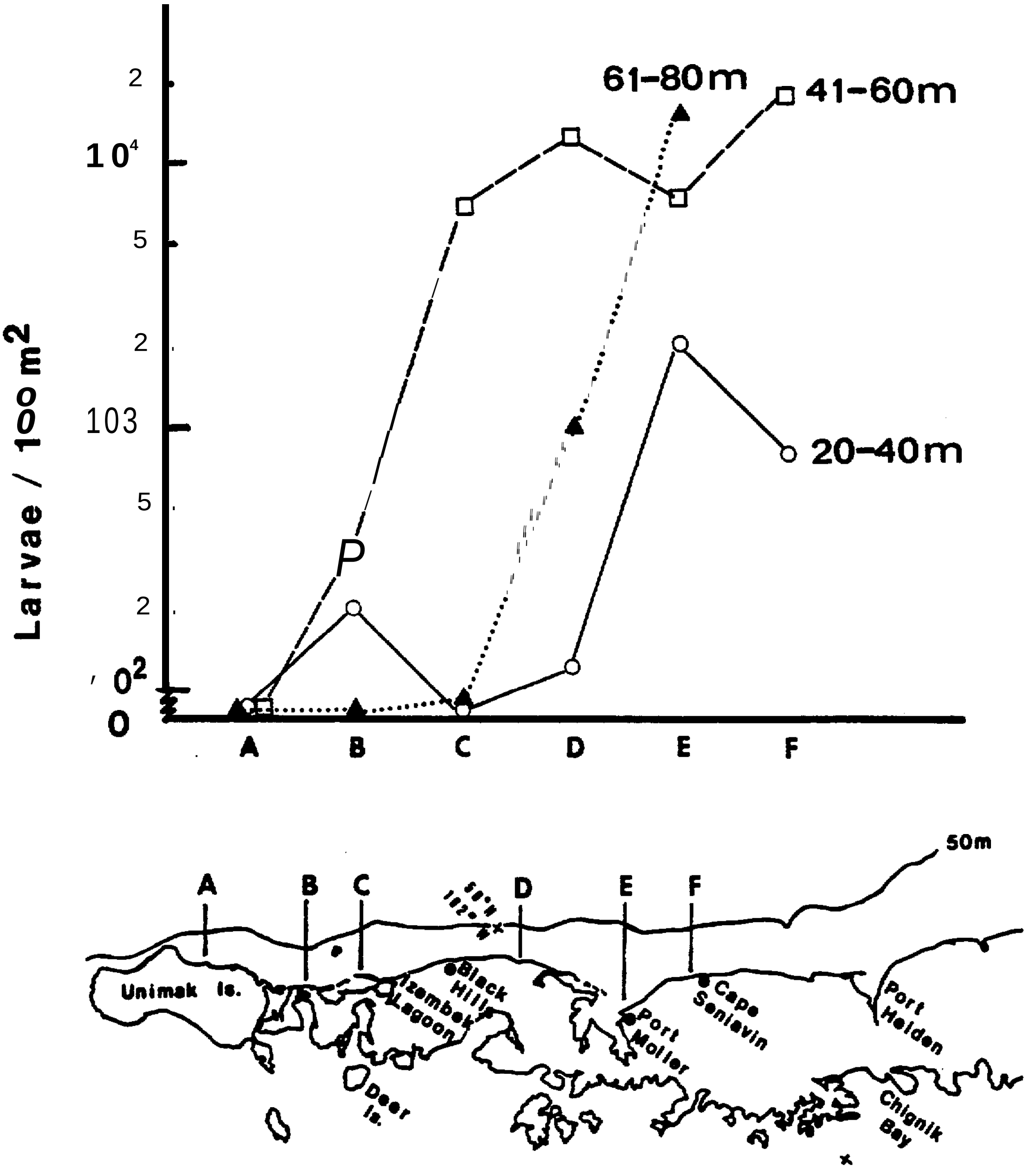


Fig. 3.14. Abundance of red king crab larvae as a function of depth (distance from shore) along the NAS. All stations used in this presentation were collected within six days of each other in June, 1982. See Fig. 2.19 for details of station locations.

Table 3.2. A summary of larval red king crab densities in June, 1982, along the North Aleutian Shelf. stations were grouped into three depth intervals along six transect lines to contrast nearshore and alongshore distribution (see Fig. 3.14).

Transect line	Depth* interval	n**	X (No. larvae/100 m2)	Range
A	1	3	0	--
	2	3	0	--
	3	2	0	--
B	1	2	202	0-405
	2	3	350	120-590
	3	2	0	--
C	1	3	26	0-78
	2	1	6,624	--
	3	3	80	0-126
D	1	2	125	0-250
	2	1	12,231	--
	3	1	1,120	--
E	1	2	2,000	0-4,000
	2	2	6,930	4,300-9,550
	3	5	15,350	8,800-24,700
F	1	3	780	50-1,300
	2	5	17,300	6,400-36,240
	3	0	--	--

* 1 = 20-40 m, 2 =41-60 m, 3 = 61-80 m

** n = number of stations on the transect lines within each depth interval; see Fig. 3.13 for locations.

but larvae were very abundant in 61-70 m depth about 40-50 km off Port Moller (stratum II).

By early August, 1982, *no* red king crab larvae were found from western Unimak Island through stratum I and beyond to Port Moller (Fig. 3.15). Very low densities of 100-300/100 m^2 were sampled about the 50 m isobath off Port Moller. Higher densities were found only on a transect line off Port Heiden. Here again, shallow stations nearshore had less than 100 larvae/100 m^2 while stations betweem 41-60 m averaged 1535/100 m^2 (Fig. 3.15). It is not known whether the disappearance of larvae up to Cape Seniavin represents northeasterly transport out of stratum I or earlier metamorphosis to the benthos in the westerly area of hatch (see Section 3.4.3 for further discussion).

Blue King Crab: Few samples were taken in the area of blue king crab abundance east of the Pribilof Islands (Figs. 3.7a and b). Most larvae were found 50-90 km east of St. Paul and St. George Islands, and none were caught at five nearshore stations about St. Paul (Fig. 3.11). Densities were low compared to areas of larval king crab abundance. The highest zoeal density was 1550 larvae/100 m^2 (n = 9, SD = ± 478; all years combined).

3.4.2 Interannual Variations

There were too little data in strata 9 and 10 (Figs. 3.11 and 3.12) to note differences in abundance of blue king crab year to year. Only the nearshore of the NAS was sampled with some regularity, although the number of annual stations were few. As previously noted, two new

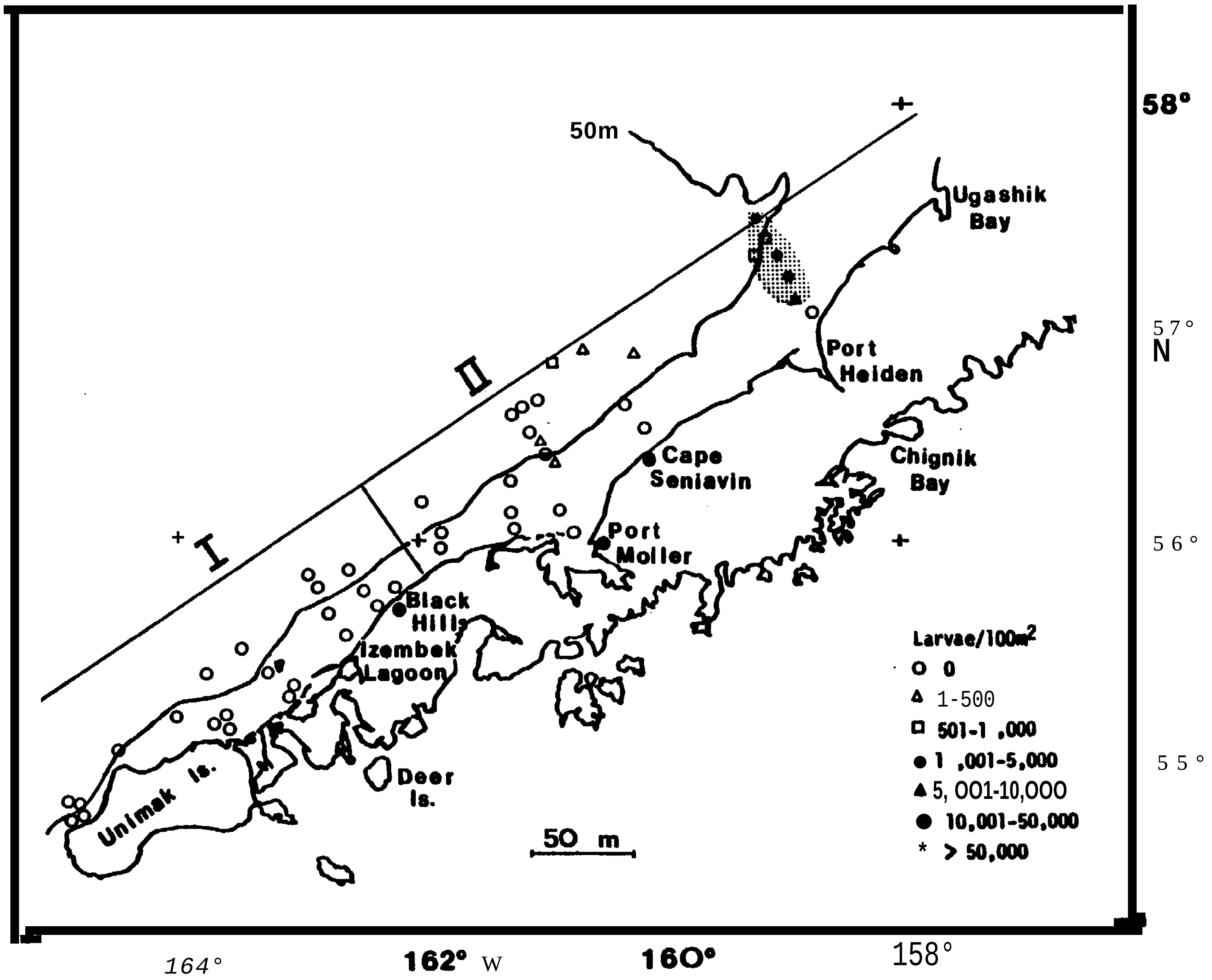


Fig. 3.15. Distribution and relative abundance of red king crab larvae in early August, 1982. Note the virtual absence of larvae from Unimak Island to Port Heiden.

strata (I and II) were created to give a qualitative sense of interannual spatial and temporal changes in abundance. No statistical contrasts were attempted since extensive sampling was done only in 1982 (Tables 3.2 and 3.3). In all other years, sample size for the two-month period of May through June never exceeded 15 per stratum for areas that exceed 12,000 km^2 (Fig. 3.12).

Large differences in density of larvae were noted both between years and between strata I and 11 (Fig. 3.16 and Table 3.3). Most samples were taken in the western NAS area in stratum I, which was sampled every year from 1976 to 1982. The years of greatest abundance were 1976-1977 when densities averaged 13,200 larvae/100 m^2 (Fig. 3.16; densities in this stratum were very similar in both 1976 and 1977 and so stations were combined to increase sample size). Average densities in the years 1978-1982 were about 20 times lower in the range of 450-710 larvae/100 m^2 (Fig. 3.16, Table 3.3).

Stratum 11 was sampled only in the years 1980, 1981 and 1982. Densities of larvae were highest in 1980 at 47,200 larvae/100 m^2 (only three stations), and substantially less in 1981 at 1,780/100 m^2. Comparison of strata averages (Figure 3.16 and Table 3.3) shows that larvae were always more abundant in stratum II than in I when both were sampled in the same years (only two samples in stratum II, 1976 and 1977 combined). In 1982, average densities were 7,900/100 m^2 and 441/100 m^2 in strata II and I, respectively, and the few samples collected in 1980 indicate a 100-fold increase in average densities from west to east.

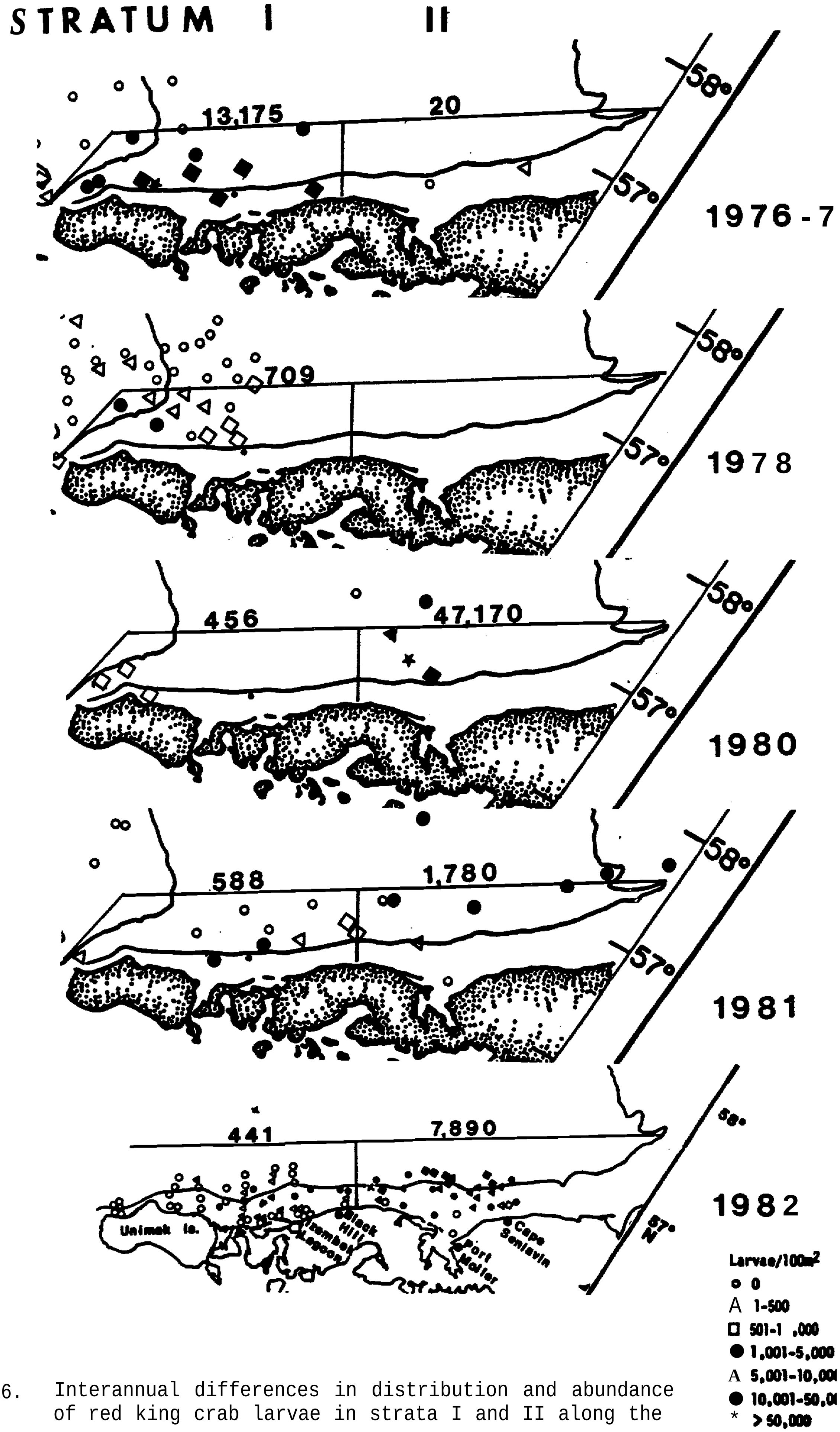


Fig. 3.16. Interannual differences in distribution and abundance of red king crab larvae in strata I and II along the NAS. Shown are station locations and symbols of abundance and the average density for each stratum (see Table 3.3 for details).

Table 3.3. Mean abundance of larval red king crab along the North Aleutian Shelf during May and June in 1976 through 1982. The region is divided into two strata that separate distributions east and west of 162°W latitude near Black Hills. Values are larvae/100 m^2. (See Fig. 3.12 for strata boundaries).

	Stratum I				Stratum II			
Year*	n**	$\bar{X}$	± SD	Range	n	$\bar{X}$	± SD	Range
1976-77	15	13,175	17,200	650-67,000	2	20		0-39
1978	12	709	537	170-1,760			none	
1980	5	456	421	0-850	3	47,170	58,300	7,500-114,000
1981	8	488	943	0-2,570	9	1,780	1,512	0-4,500
1982	48	441	1,181	0-6,620	30	7,893	1,584	0-36,240

*Larval densities in 1976-77 were very similar in Stratum I so they were combined for a larger sample size. No samples were collected in either Stratum in 1979.

**n · the total number of stations collected, including zero stations, [An interesting note on annual abundance: collections made along the NAS in April and June, 1983, indicate a drastic reduction in larval densities from 1982 levels. Samples taken along similar transect lines and throughout Bristol Bay to Cape Newenham show larvae are at least 10 to 20 times less abundant this year than in 1982 (D. Armstrong, University of Washington and VTN, Oregon, unpublished data).]

Summary: 1) Larval densities were much lower along the western NAS from Unimak Island to Black Hills (stratum I) than in the eastern area from Port Moller into Bristol Bay (stratum II). 2) 1976-77 was a year of highest average densities in stratum I and 1980 in stratum II. 3) Lowest densities in both strata occurred in 1981. 4) Both 1980 and 1982 were probably good years of larval production along the NAS.

3.4.3. Hatchout and Settlement

Red King Crab: The time series of samples collected in any year from 1976 through 1982 were never long enough to span the period of complete larval development from hatch through metamorphosis. Enough data are available, however, to: 1) assign a realistic average date of hatch and discuss interannual differences in timing of peak hatch; 2) calculate the appropriate duration of each larval stage and the frequency of molt (next subsection 3.4.4); and 3) follow development to the megalops stage and predict an approximate period of metamorphosis and settlement to the benthos.

Six time intervals were established to study larval hatch and development (Fig. 3.17a and b). They are based on average sampling dates of cruise legs in various years, and usually span three-week intervals. The earliest zooplankton samples collected that contained red king crab larvae were prior to April 18 in 1977; the latest collections were made In August, 1982. Based on data from 1977 and 1978, S1 larvae were abundant by mid-April and S11 by late April, 1978 (Fig. 3.17a). In some years, therefore, larvae hatch as early as April 1 (note that 40% of all larvae were already S11 in late April 1978). In other years hatching can begin a month or more later. In mid-May, 1976, virtually all larvae were still S1 and in early June, 1980, 40% of larvae were S1. (During the first NAS leg from April 18 to May 7, 1983, no larvae were found along the entire NAS from Unimak Island. to Port Heiden on the first pass. Larvae were present on the return, however, at stations revisited between May 1-6, indicating hatch began about May 1). The largest interannual difference in apparent time of hatch was between the years 1976 and 1979 (Fig. 3.17a) when all larvae were S1 in mid-May, 1976, but all were SIV in mid-June, 1979, indicating a very late and early hatch, respectively.

Larval hatch is apparently not a synchronous event throughout the female population along the NAS as evidenced by the presence of several larval stages at most stations (Fig. 3.17a and b). Data of 1980, 1981, and 1982 show that four larval stages were present in the water column during several time intervals, although only two stages were usually dominate (Fig. 3.17b).

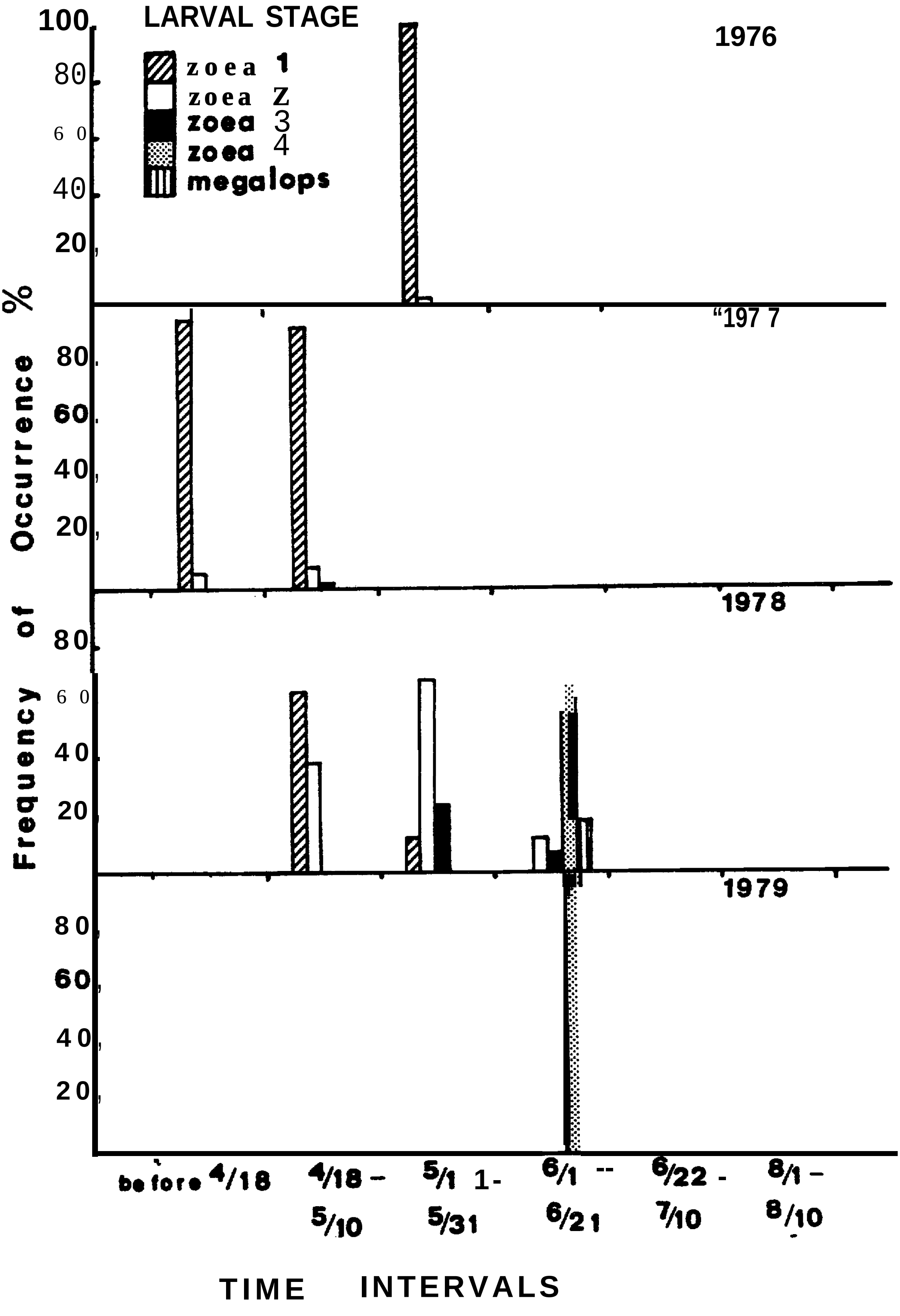


Fig. 3.17a. Frequency of occurrence of one megalops and four zoeal larval stages of red king crab in the years 1976-1979. There were no samples collected between July 10 and August 1 of any year.

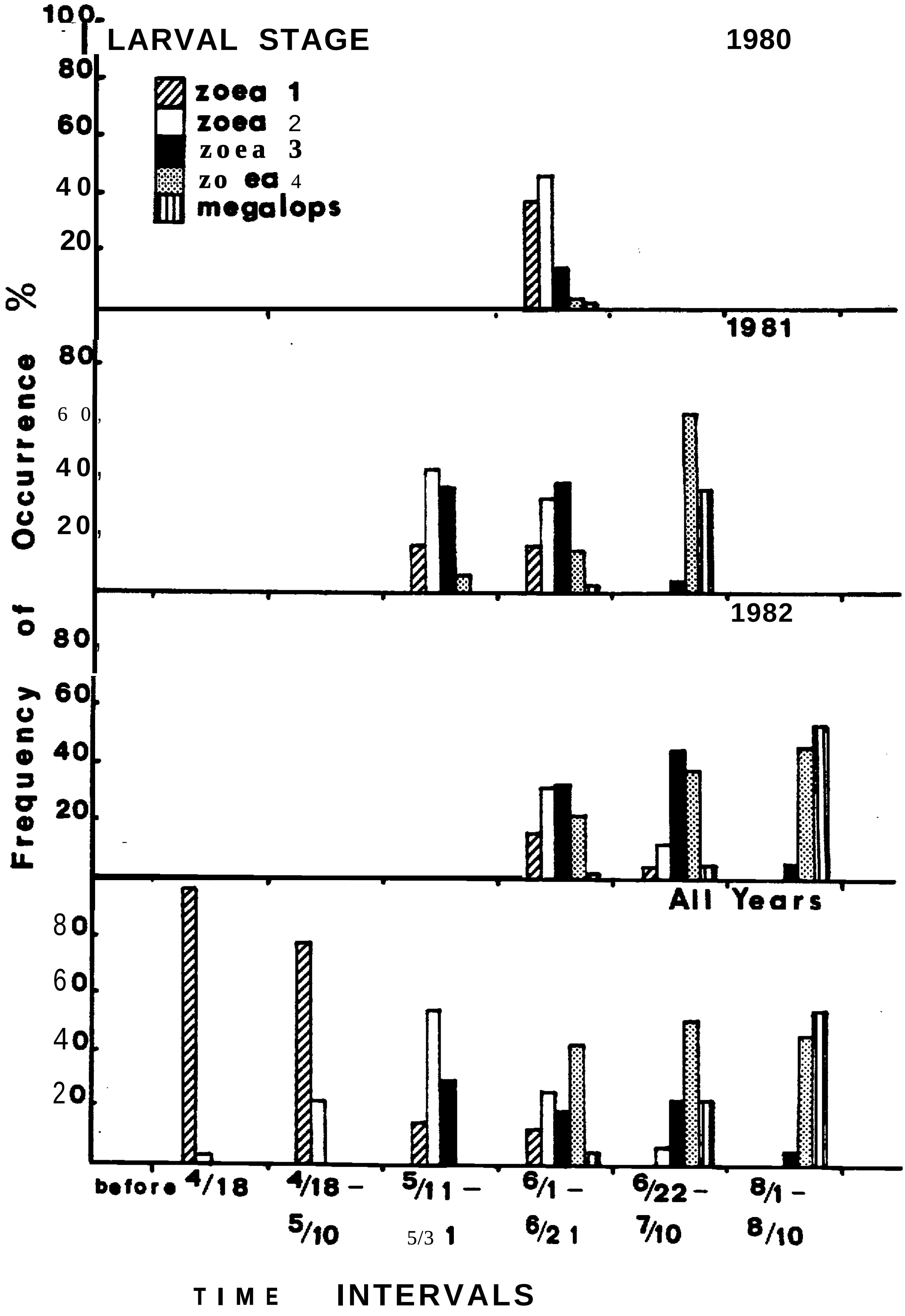


Fig. 3.17b. Larval frequency of occurrence in the years 1980 through 1982. The data from all years 1976 through 1982 have been summarized in the last frame to show a pattern of the change in proportion of each larval stage over time.

The occurrence of a multi-stage larval population may, in part, simply reflect geographic differences in hatch time. Data in Figures 3.17a and b were grouped from the entire geographic area of strata I and II for the time intervals shown because samples were so few. However, in 1982, stations from **Amak** Island to Cape **Seniavin** were collected in a six-day period along this 215 km distance. By grouping **zoeal** stages **SI+SII** and **SIII+SIV,** and calculating frequency of occurrence, the resultant data suggest an earlier hatch along the western than along the eastern NAS (Fig. 3.18). Around Amak Island, **SIII+SIV** larvae comprised 80 to 100% of total populations but by Cape **Seniavin SIII+IV** were only 32% (Fig. 3.18).

The total period of larval development is estimated to take about 4.5 months from hatch of first **zoeal** in early April, to metamorphosis of **megalopae** in mid to late August (Fig. **3.17b). Megalopae** were collected as early as June 15 in 1978, but more typically in early July and August, 1981 and 1982, respectively. Since 45% and 55% of larvae **were** **SIV** and **megalopae in** early August, 1982 (Fig. **3.17b),** metamorphosis to the benthos probably did not occur until late August to early September for much of that year class.

Blue King Crab: Very little data are available with which to gauge hatch and metamorphosis **of P. platypus** (the **OCSEAP** FY83 **Pribilof** Island program on blue king crab should improve this data base). The earliest samples containing blue king crab were collected in late May, 1976, and all larvae were S1 and II. In late June, 1978, a few **Pribilof** Island stations had **SIV** larvae, and in early July, 1982, all larvae caught were

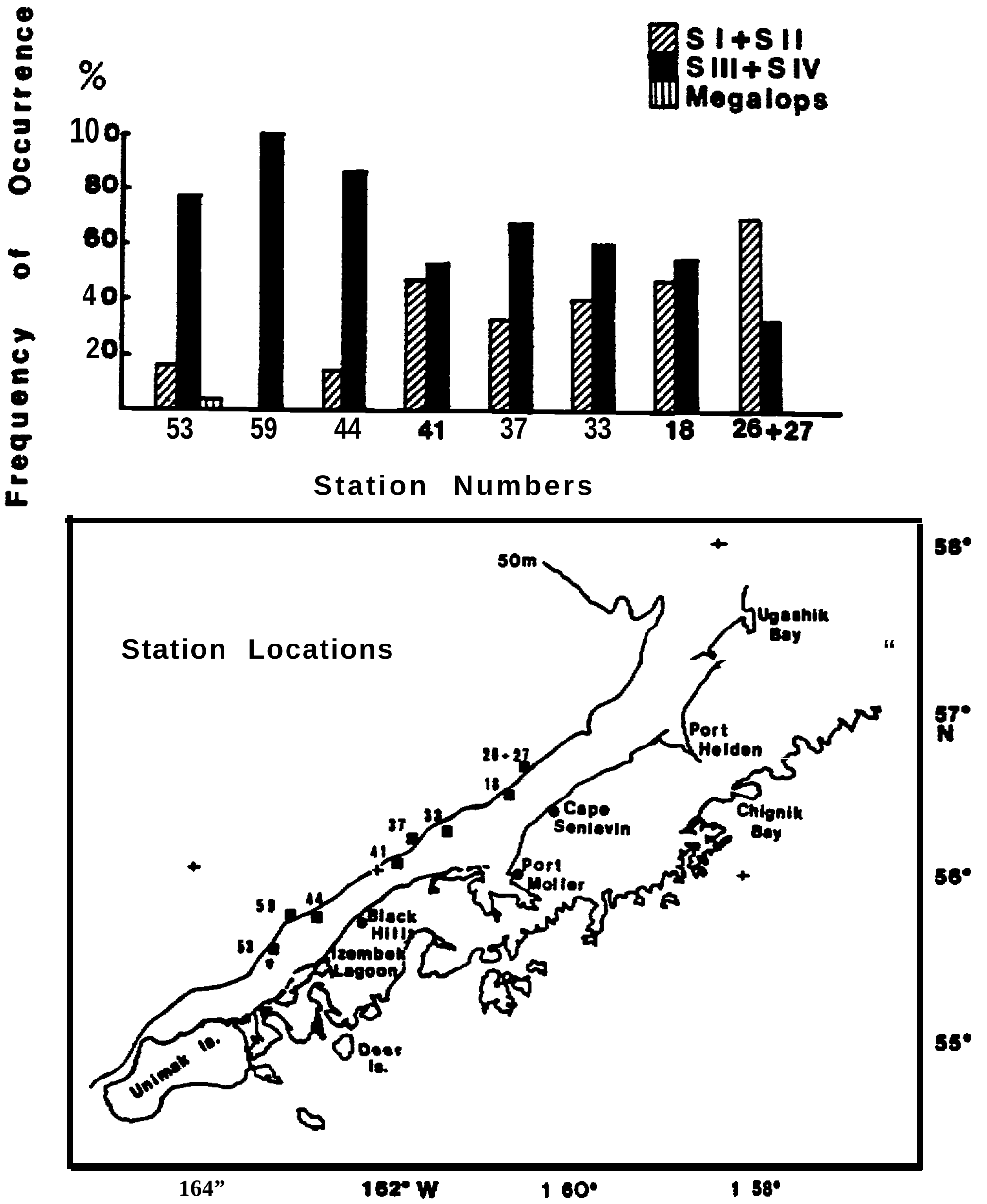


Fig. 3.18. Differences in apparent hatch time of red king crab larvae in the western and eastern NAS area. All samples were collected within a six day period. Note that at western stations around Amak Island there is a higher percentage of older S111 + IV larvae than found farther east off Cape Seniaven.

megalopae. These combinations of years and larval stages are similar to data for red king crab (Fig. **3.17a and b).** There is, however, an indication that **larval** hatch and, therefore, metamorphosis might **occur** somewhat earlier for blue king crab based on data of 1981. All larvae in **early July** were **megalopae** and many were approaching the molt to first **instar** juveniles. Almost 50% of **megalopae** held in rearing chambers onboard ship molted to first **instars** within a week of capture (by July 14; D. Armstrong, University of Washington, unpublished data). Metamorphosis to the **benthos** for blue king crab might, therefore, occur by mid to late July; a month earlier than predicted for red king crab.

3.4.4. Molt Frequency and Growth

Red King **Crab:** Data *on* molt frequency for red king crab larvae were previously summarized in Figures 3.17a and b. A preliminary analysis of frequency of occurrence of various larval stages was done on data of 1978 **(Fig.** 3.19; Armstrong et al. 1981). Based on the proportion of each larval stage (S1, II, II, IV, **megalops)** in samples from four cruises between April 10 to June 29 (see Section 2.0 for cruise maps), it was estimated that larvae molt every 2.5-3.0 weeks (Fig. **3.19).** If so, then the elapsed time of development from hatch to metamorphosis would be about 12.5-15.0 weeks, or about 3.0-3.5 months. However, a **summary** of larval stage data from all years 1976 to 1982 combined, indicates that development might take 4.0 to 4.5 months from hatch to metamorphosis (Fig. **3.17b).** Although annual hatching time will vary (section 3.4.3), mid-April seems a reasonable annual time to expect the hatch **of P. camtschatica** larvae. **Megalopae** are common from early July

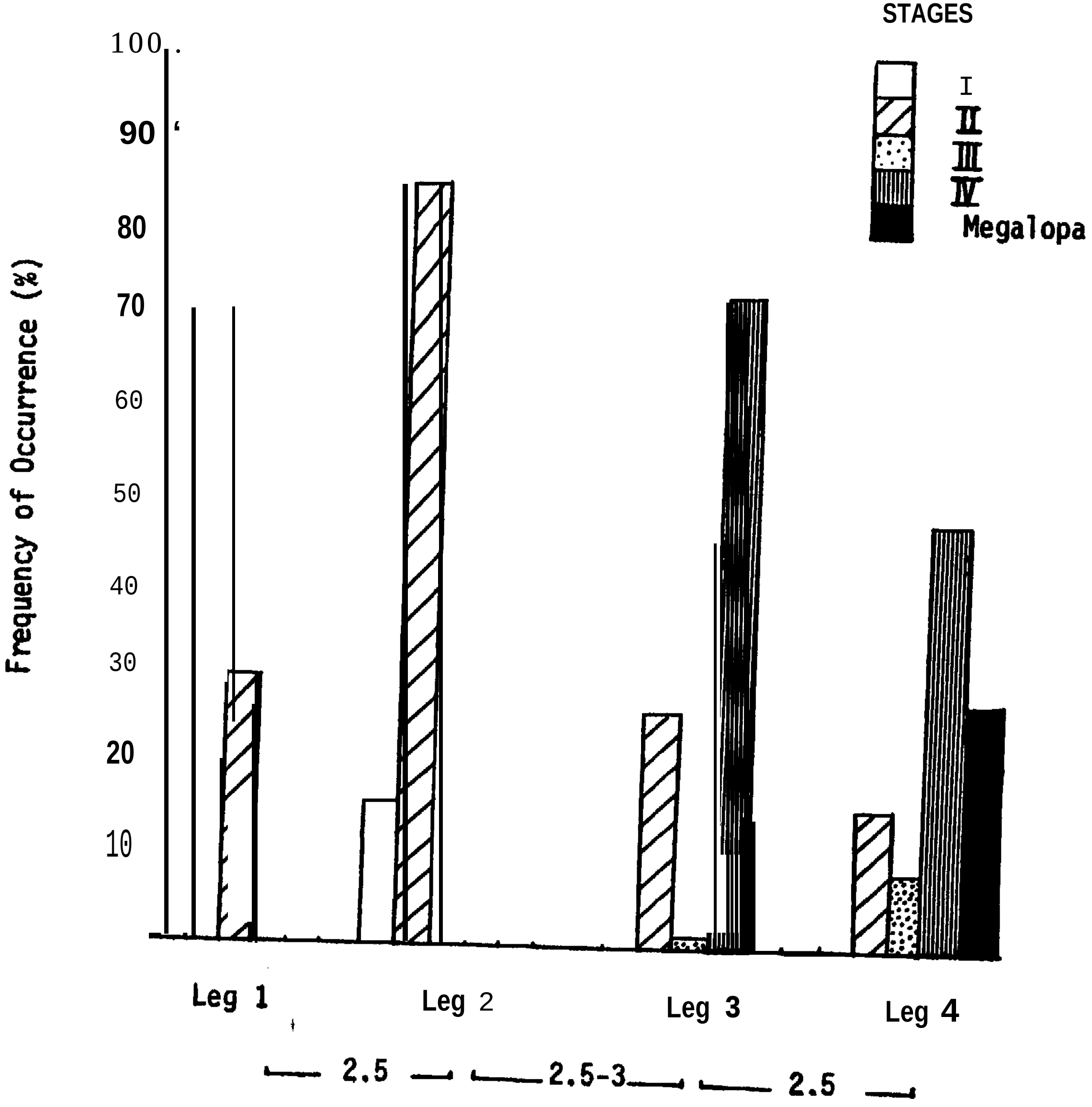


Fig. 3.19. Frequency of occurrence of *Paralithodes* spp. larval stages collected during four legs of the 1978 PROBES cruises. The number of weeks between mid-points of legs are shown along the bottom axis and serve as an approximate gauge of molt frequency.

to early August (Fig. 3.17b), and still have three to four weeks development before molt to first instar juveniles; an event predicted to occur from mid-August to September.

Molt frequency of larval red king crabs is estimated to be once every three weeks, based on a simple division of four months development time by five larval stages. Examination of frequency-of-occurrence data for al 1 years combined (Fig. 3.17b), shows a major shift in the proportion of larval stages occurs in three-week intervals depicted. It is not known from these data, however, if the intermolt duration changes with stage (e.g. shorter as S1, longer as megalopae) as a function of temperature and mass, or is rather constant as assumed above. Relative to oil pollution, it seems reasonable to assume that exposure of larvae for a week or more would encompass ecdysis of some portion of an asynchronous population (see Section 8.0 for further discussion of this point).

Growth of larvae is substantial during this four-month period. From a mean egg weight of 220 mg dry wt., larvae increase almost six-fold to 1300 mg as megalopae (Fig. 3.20). The data of Figure 3.20 were obtained by collecting fresh red king crab larvae in the southeastern Bering Sea, staging, drying and weighing each animal on an electrobalance. The data not only show the weight gain from one larval stage to the next, but also the increase in dry weight within a single stage (i.e. intermolt growth). Stage II larvae had initial mean weights of 370 mg/larva but increased to 440 mg/larva prior to the molt from S11 to S111 (Fig. 3.20). Likewise, the mean weight of SIV larvae was

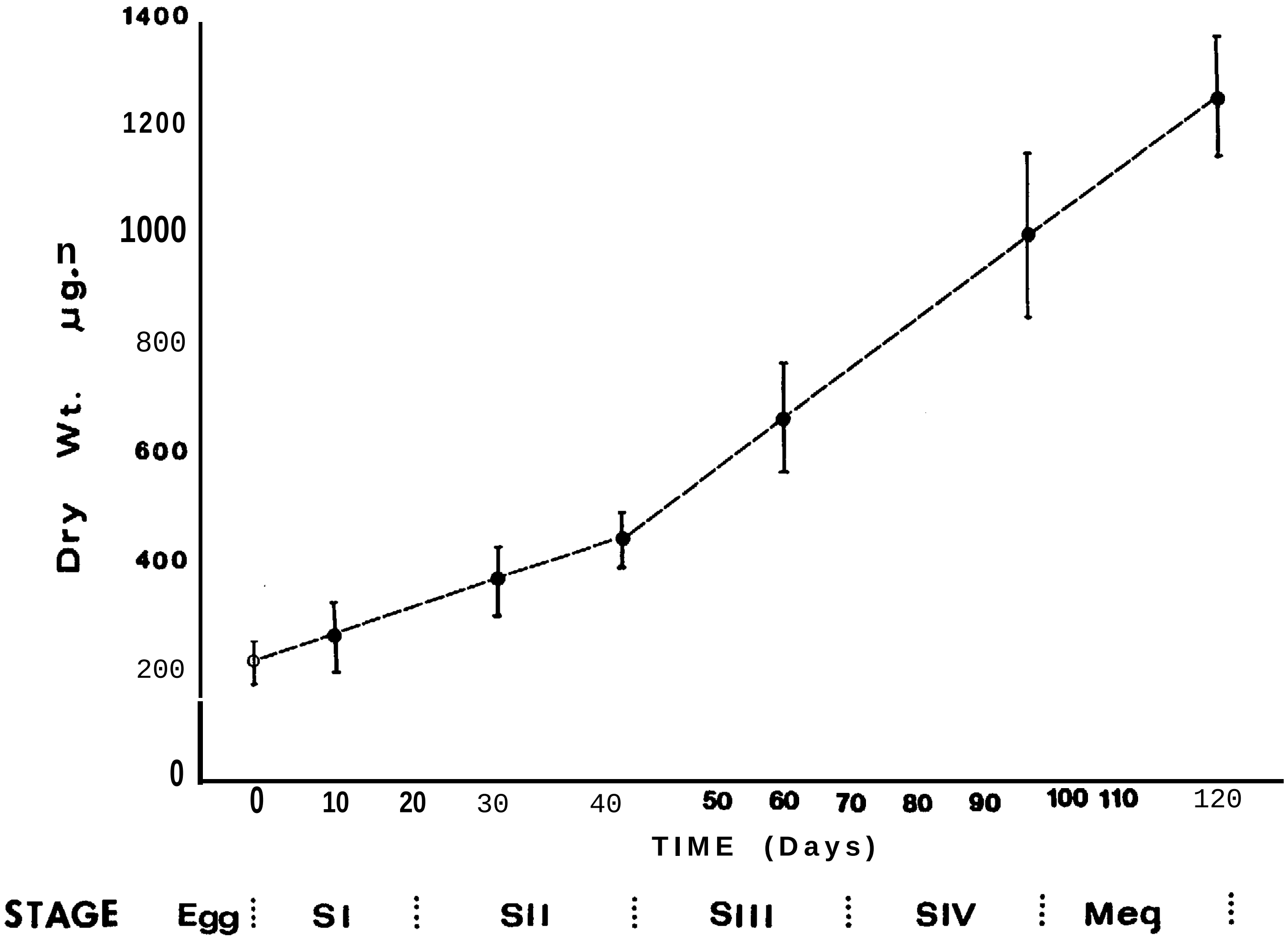


Fig. 3.20. Increase in dry weight of red king crab larvae from the mature egg through megalops stage. The approximate duration of each stage is shown for a total development period of about 4.0 months. Data are the mean ± SD; n = 15 to 30 for each mean.

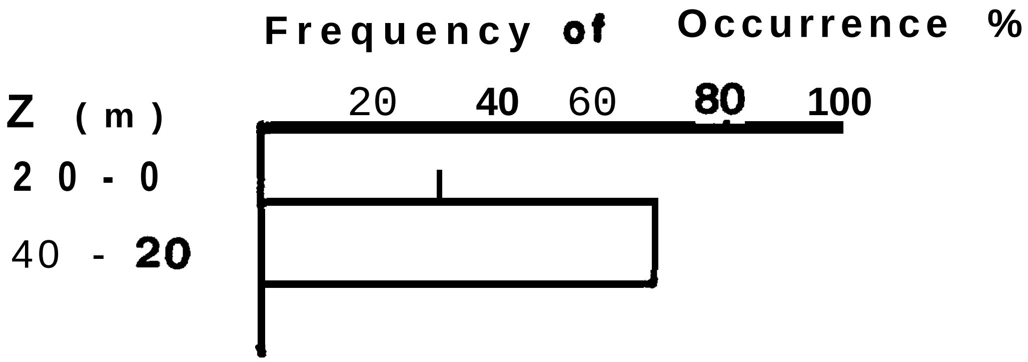


Fig. 3.21. Vertical distribution of red king crab larvae from six MOCNESS stations, PROBES 1981. Percent frequency of occurrence is based on a total of 600 larvae from the six stations.

1008 mg/larva, but those molting to megalopae weighed 1200 ug/larva. Such change indicates that growth is not a static event that occurs only at molt. Rather it is a process that continues throughout an intermolt period as larvae feed. Perturbations that disrupt feeding for portions of an intermolt cycle could inhibit weight gain necessary for ecdysis to the next stage.

Blue King Crab: No comparable data on larval growth of this species are available.

3.4.5. Vertical Distribution

Few MOCNESS samples were taken in areas where larval king crab occurred. Most larvae were caught at shallow stations where MOCNESS intervals were 0 to 20 m and 21 to 40 m depth. In such samples, 68% of larvae were in the lower depth interval of 21 to 40 m (Fig. 3.21). At a few MOCNESS stations in deeper water, larvae were also least common in the upper 20 m and equally distributed at 42% occurrence in both the 21 to 40 m and 41 to 60 m intervals. However, very few larvae comprise this last observation (n=7 larvae) and, in general, more work is needed to clarify patterns of vertical distribution and possible diel changes.

3.5 Discussion

If oil development in the southeastern Bering Sea impacts king crab, it would likely be most severe as exposure of pelagic larvae or, possibly, of egg-bearing females, since reapidly developing embryonic and larval life-history stages are usually more sensitive to chemical perturbations than are older individuals of a species. (The nature and consequences of oil exposure scenarios are discussed in Section 8.0). In this section, data have been summarized that pertain to the general biology and ecology of larval king crab, primarily *P. camtschatica.* Information gained from data of 1976-1981 is fragmentary and a story of larval biology is far from complete. Opportunistic work in 1982 and OCSEAP programs along the NAS in 1983 have and will greatly contribute to a backdrop of biological information against which oil impact scenarios can be cast and analyzed. With the data gathered in this study, a sense of the spatial and temporal susceptibility of red king crab larvae to oil has been gained.

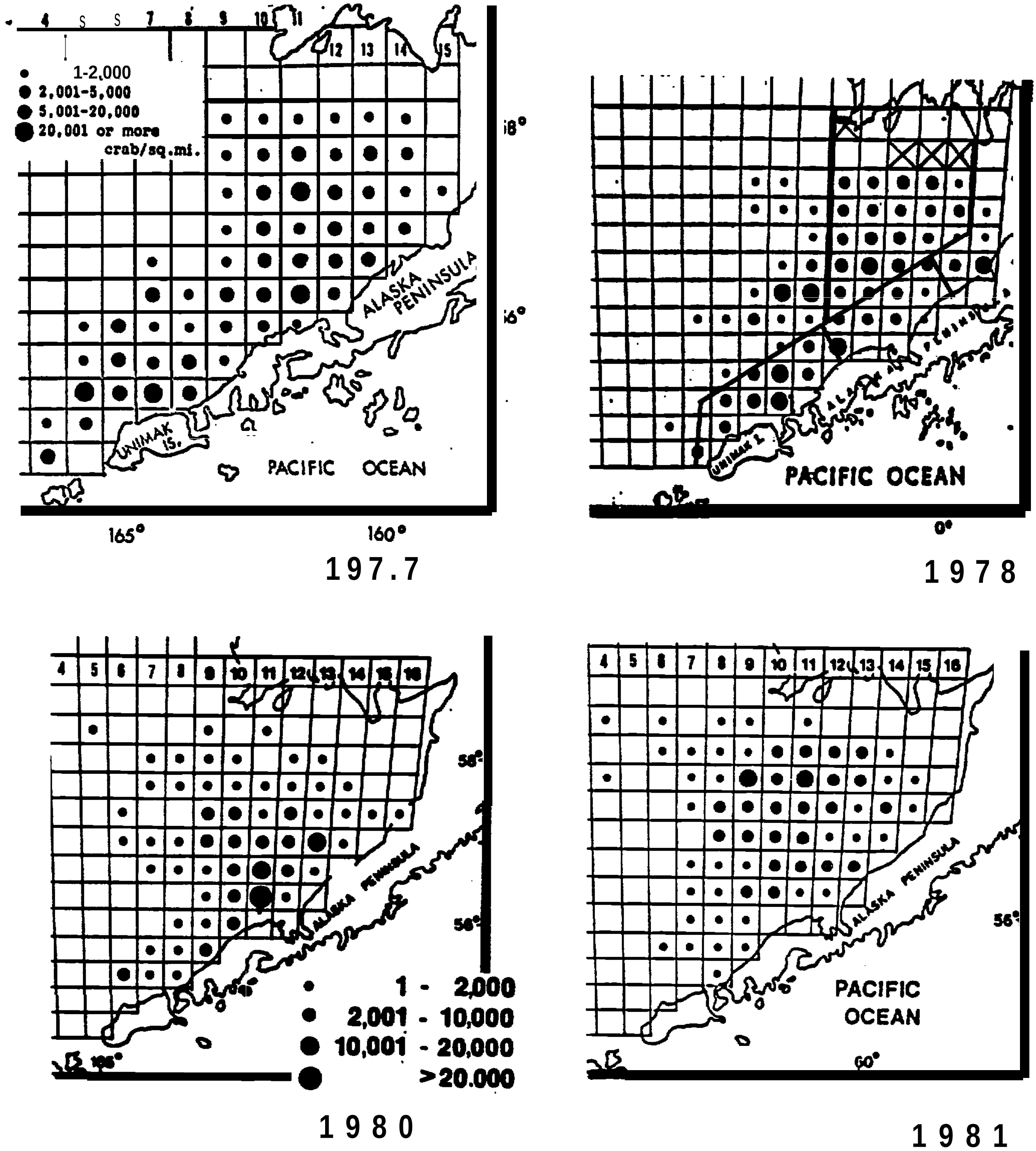
The ultimate effects of oil perturbations would be to reduce year-class (es) strength and, in turn, reduce the number of animals entering the fishery. Year-class strength is highly variable as evidenced by the tenfold decline in legal males between 1979 and 1982 (Fig. 3.5), and a decrease from 150 mill ion mature females in 1977 to 55 million in 1982 (Otto et al. 1982). Year-class strength is probably determined by some combination of: 1) reproductive success of the mature female population; 2) survivorship of larvae and; 3) survivorship of young benthic juveniles for one to two years after metamorphosis.

A suite of biotic and abiotic factors (e.g. temperature, currents, food, refuge habitat, predators) act in optimal or perturbational combinations on these three life-history links to produce changes in abundance. Even the fishery itself may exacerbate the effects of suboptimal conditions influencing reproductive effort and survivorship of environmentally sensitive life-history stages. Important points to consider in regard to king crab biology, lease sale areas, and oil perturbations are: 1) the distribution and abundance of mature females; 2) abundance, distribution and transport of larvae; 3) time and duration of annual larval hatch; 4) frequency of molting; and 5) area(s) of larval metamorphosis and settlements of juveniles.

Distribution of red king crab larvae nearshore along the NAS is in partial accord with that of the sexually mature female population in the southeastern Bering Sea. The annual NMFS groundfish survey in that area shows that female crab are abundant in the area of high larval density (Figs. 3.5, 3.11), but also for greater distances offshore (up to 120 km) and in northwestern Bristol Bay (e.g. high abundance around 57°30'N, 162°W as a focal point; Fig. 3.3). While females seem to be distributed more widely than larvae along the NAS, a similar conclusion cannot be drawn for Bristol Bay (east and north of Cape Seniavin) because of very limited larval sampling in that area. Still, since larvae of red king are apparently found over a more restricted range than adult females, a variable percentage of the females may be superfluous to the annual reproductive effort because they spawn in areas unsuitable for larval and/or early juvenile survival. Therefore, exposure of females to oil in the area of larval hatch may be a more important consideration than exposure of females elsewhere within the species range in the southeastern Bering Sea.

Larval abundance appears to vary appreciably on an annual and geographic basis along the NAS, although data are few for some years and areas (see Fig. 3.16 and Table 3.3). The extent to which larval abundance in time and space is correlated to that of mature females cannot be solidly analyzed from data on hand; specifically a long-term series of comprehensive larval red king crab collections does not exist. Still, there is an indication that changes in abundance and distribution of benthic females might influence larval production in the water column.

Population estimates for mature female red king crab (as well as males and other species of crab) are computed by NMFS for 400 NM* quadrats as part of an annual groundfish survey (see Otto, Macintosh, Armetta and Wilson 1980; Otto et al. 1981, 1982). Fig. 3.22 shows data for four years and depicts major shifts in numbers and location of mature females in southeastern Bering Sea. A gross analysis of this data was performed by averaging population estimates in quadrats that fell within three general areas: 1) stratum I along the western NAS; 2) stratum II to the east; and 3) the remainder of Bristol Bay (all three areas are shown for the year 1978 in Fig. 3.22; strata I and II correspond to areas used for larval analyses in Fig. 3.16). Actual catch values could not be obtained from NMFS in time for this report, so mean female abundance was calculated by taking midpoint values for the ranges shown in each quadrat. In the years 1975-1977 ranges were 1-2,000 crabs (midpoint = 1,000), 2,001-5,000 (3,500), 5,001-20,000 (12,500), and greater than 20,001 (25,000). From 1978 through 1982 ranges were somewhat different; 1-2,000 (midpoint = 1,000), 2$001-10,000 (6,000), 10,001-20,000 (15,000), and greater than 20,000 (25,000).



197.7

1978

1980

1981

Fig. 3.22. Annual distribution and relative abundance of female red king crab greater than 89 mm carapace length (sexually mature). Note the decrease in numbers along Unimak Island to Black Hills from 1977 to 1981. The boundaries of three areas used to constrast spatial and temporal abundance are shown for 1978 (see Table 3.4). Note the difference in ranges of abundance between 1977 and all other years (all data from NMFS, e.g. Otto et al. 1980a, 1981).

Female crabs were abundant in stratum I from 1975 through 1978 and averaged about 8,000 to 10,000/NM^2, but had declined in this area to less than 1,000/NM^2 by 1981-82 (compare 1978 and 1981 in Fig. 3.22; Table 3.4). Corresponding larval abundance was high in stratum I in 1976-77 and low in 1980-82 (Fig. 3.16), but this trend was not always consistent since in 1978 larval abundance was low and that of females high (Figs. 3.16, 3.22).

Female abundance was more constant within stratum II off Port Moller, and ranged from yearly averages of 3,000 to 9,000 NM^2. In the only years of concomitant data (1980 to 1982), larvae seemed abundant in 1980 but less so in 1981-82 when female abundance declined from 7,500 to 3,800/NM^2 (Tables 3.3, 3.4). However, because larval data are so few between 1967 through 1981, any relationship between female abundance and larval production is highly speculative at this time. There has unquestionably been a shift of females away from the area of stratum I in recent years, and larval densities there are also very low. There is only a suggestion that the decrease in female abundance in stratum II since 1980 has resulted in fewer larvae, but the subject deserves further study as the population continues to decline in 1983.

Female abundance in the remainder of Bristol Bay generally ranged from 2,000 to 8,000/NM^2, and the contribution of this population to larval production remains unknown to date because very few zooplankton samples have been collected in that area.

Table 3.4. Relative annual abundance of female crabs greater than 89 mm carapace in the three areas of the southeastern Bering Sea. Stratum I and II are along the North Aleutian Shelf (see Fig. 3.16), and Remaining Bristol Bay is delineated in Fig. 3.22 for the year 1978. Values are the mean + 1 SD of crabs per square mile (see the text for details on calculations).

Year*	Stratum I (n = 11)**	Stratum II {n = 10)	Remaining Bristol Bay (n = 19)
1975	7,700311,150	3,055 ± 3,690	550 ± 446
1976	8,400 ± 7,360	4,000 ± 4,681	2,200 ± 3,005
1977	9,400 ± 8,840	9,300 ± 7,080	6,400 ± 6,800
1978	10,100 ± 9,800	7,100 ± 7,200	8,300 ± 6,800
1980	1,600 ± 2,200	7,500 ± 7,700	2,000 ± 2,300
1981	635 ± 500	3,600 ± 2,700	5,900 ± 2,950
1982	820 ± 920	3,80034,800	3,380 ± 3,870

*Data for 1979 were not available.
‘Numbers of NMFS stations used for calculating the mean of each area.

If a positive relationship exists between mature female abundance and larval production, it is not clear how this relates, in turn, to eventual year-class strength as measured by abundance of five-year-old juveniles (youngest prerecruits routinely sampled by NMFS; Reeves and Marasco 1980) or older age-classes. Reeves and Marasco (1980) attempted to model spawner-recruit relationships with ambiguous results from both Beverton-Holt and Ricker models. The only reasonable conclusion to be drawn was that very high levels of mature females are not always correlated to high recruitment. This reasoning could be expanded by observing that: 1) the mature female population could fall below a level needed for strong recruitment (Fig. 4.A in Reeves and Marasco, 1980); and 2) populations of adequate spawning strength could be poorly situated geographically in terms of hatching larvae in areas for optimal growth and metamorphosis of juveniles to protective benthic habitat.

As noted in Section 3.4.2, surveys in 1983 have revealed a greatly reduced larval hatch compared to 1980-1982, and mature female abundance has also declined precipitously (D. Armstrong, U. Washington; VTN Inc., Portland; R. Otto, NMFS, Kodiak; unpublished data). Oil mishaps in years of low larval production could impact eventual juvenile settlement more severely than during years of high production (obviously the extent of any oil impact is inextricably linked to the timing, duration, and coverage of the spill).

As to the influence of geographic distribution of females on survival of larvae and eventual settlement of juveniles to appropriate refuge habitats, only speculative comments can be made. The greatest data gap in this regard is definition of areas where O+ juvenile crab settle and survive. Rarely does the NMFS survey catch very small crab (gear and survey area 1 imitations). Based on data of Smith and Bakkala (1982) and of 1983 surveys throughout the NAS and Bristol Bay (D. Armstrong, U. Washington; VTN Inc., Portland; unpublished data), much of the southeastern Bering Sea would not be suitable for survival of newly settled king crab. Very large populations of flatfish (e.g. yellowfin and rock sole) and other predators, coupled with a uniform bottom of mud/sand that affords little refuge, would probably result in tremendous predator pressure and low (to no) survival of 0+ crabs metamorphosing in such areas. Preferred habitat of young king crab around Dutch Harbor and Kodiak Island (Weber 1967; Jewett and Powell 1981), indicate the species relies on cobble, shell, and aggregates of invertebrates (polychaetes, barnacles, ascidians, etc.) and algae for refuge. To date, an OSCEAP survey of nearshore juvenile crab distribution confirms this juvenile-refuge association in the southeastern Bering Sea.

Consequently, while the sheer magnitude of initial larval hatch and numbers surviving to metamorphosis may be important determinants of year-class strength, the geographic location of survivors at metamorphosis could be more important if refuge habitat is scarce and/or patchy. As suggested by Hebard (1959) and Haynes (1974), larval populations are probably transported varying distances from the origin of hatch. From data on development time of this study and current speeds (Kinder and Schumacher 1981c), larvae could be transported over 200 km from hatch to metamorphosis. Larvae hatched off western Unimak Island could reach Cape Seniavin; those hatched off Port Moller could reach Kvichak Bay. Whether the bottom of one area is better suited for survival of 0+ crabs than the other is presently unknown. If optimal bottom type does not occur uniformly along the NAS into Bristol Bay, then location of spawning female populations and the interplay of oceanographic factors and influences (e.g., currents and direction, wind speed and direction, storm events) during development time could be the major determinants of placement of larvae over optimal benthos at metamorphoses.

Much research on king crab biology and ecology should yet be done. some topics of importance include:

1) Examination of NMFS survey data to detect interannual differences in female abundance relative to areas of larval hatch and development in the southeastern Bering Sea.

2) Reexamine spawner-recruit relationships developed by Reeves and Marasco (1980) in light of Item 1 and results of juvenile surveys. This effort would enable a better gauge of minimum numbers of spawners required for high recruitment based on abundance in "optimal spawning habitat," and estimates of progeny younger than the five-year lag currently required of NMFS data.

3) Study interannual variation in peak egg hatch based on NMFS "clutch" data. Annual shifts of 1 - 1.5 months might reflect winter-spring temperatures and influence larval development time, settlement, and first-year summer growth of 0+ juvenile crab.

4) Investigate timing of the oogenic cycle to partially determine if adverse temperature would sometimes delay reproductive events (e.g., molting and copulation, egg extrusion note late hatch of 1976 larvae, Fig. 3.17a) with detrimental effects on larval growth and survival.

5) Examine NMFS data to determine major annual shifts in the percentage of the mature female population that are primiparous (newly recruited mature year-class) or multiparous in regions suggested under item 1. Incorporate data on clutch size and relate both factors to

fecundity to derive potential larval hatch. Correlate annual reproductive effort lagged to population abundance of juveniles.

6) Conduct several consecutive years of larval surveys to compare initial abundance at hatch and survivorship at metamorphosis to later abundance of specific juvenile year-classes.

7) Incorporate physical oceanographic events (notably current patterns and rates, and storm events) to examine the annual direction and extent of larval transport. Use information to gauge the extent of settlement onto optimal "refuge" habitat as a prediction of 0+ survivorship.

8) Determine lower lethal thermal limits of zoeae and their energetic-growth responses to very low temperatures as an indication of potential survival in years of below-average cold (e.g., 1976).

9) Study food preferences of larvae and also feeding rates as a function of temperature and prey density to address requirements for adequate growth and the possibility of starvation.

10) Determine areas along the NAS and in Bristol Bay where major populations of young juveniles occur (0+ through 4+ age-classes).

11) Characterize the substrate and plant-animal assemblages" associated with juveniles to define "refuge" habitat. Estimate the extent of such habitat in different regions of the southeastern Bering Sea.

12) Determine interannual differences in location of year-class settlement and relate to annual distribution of female stocks, areas of larval hatch, and predictions of larval transport as previously noted.

13) Synthesize such data into a qualitative prediction of annual 0+ survivorship based on the extent of settlement into appropriate refuge habitat. Incorporate information on the magnitude of potential prey populations (e.g., yellowfin and rock sole, Pacific cod) as an indication of the importance of such habitat.

4.0 DISTRIBUTION AND ABUNDANCE OF THE LARVAE OF TANNER CRABS IN THE SOUTHEASTERN BERING SEA

Lewis S. Incze

4.1 Introduction

Tanner crabs are brachyuran crabs of the genus *Chionoecetes* (Family Majidae). In the southeastern Bering Sea (SEBS) *Chionoecetes bairdi*, *C. opilio* (both numerous) and unknown numbers of *C. angulatus* and *C. tanneri* occur (Garth 1958; Somerton 1981). The latter two species are deepwater organisms inhabiting slope water generally more than 300-400 m deep. These crabs are small, are of no commercial interest, and probably have an exceedingly small role in the benthic and pelagic shelf sea environments. On the other hand, adult *C. bairdi* and *C. opilio* are comparatively large organisms which occur over a large portion of the southeastern Bering Sea shelf from depths of 50 to 200m; they are the target of a large commercial fishery of growing economic importance (Otto 1981) and they are dominant organisms in the benthic ecosystem (Feder and Jewett 1981). This section examines the larval life history of these two species of Tanner crab. Of particular concern is the definition of spatial and temporal patterns of larval abundance.

4.2 Description of the Fishery and Stocks

Prior to 1964 the catch of Tanner crab was only incidental to the king crab catch of Japanese and Russian fishermen. After 1964, however, U.S. restrictions on foreign harvest of declining king crab stocks encouraged exploitation of Tanner crabs as a substitute. The initial fishery was based exclusively on *C. bairdi* because of its larger size, its better quality of meat for processing, and its occurrence in and around the traditional king crab fishing areas. By 1969 the directed harvest of this species had increased to the level where fishing quotas became necessary, As a result of restrictions imposed by the United States, foreign vessels began harvest of C. opilio, a smaller animal which occurs in greater numbers and over a wider geographic area than its congener.

'As total landings of Tanner crab from the eastern Bering Sea (EBS) increased (from 12 to 24 million crabs from 1967 to 1970), so did American interest in the fishery. Through a series of unilateral (U.S.) harvest quotas and bilateral agreements, foreign participation in the EBS Tanner crab fishery was gradually reduced and forced north and west. Today, all Tanner crab fishing in the southeastern Bering Sea (except for by-catch) is conducted aboard American vessels (154 vessels in 1979-80) and is directed at both C. bairdi and C. opilio. Landings from this region steadily increased from 1975 to 1980 and totaled more than 74 million pounds (40.4 million crabs) during the 1979-80 fishing season (November-September, Fig. 4.1). The contribution of C. opilio to the Tanner crab fishery has increased dramatically in -recent years (Table 4.1). In 1981 and 1982, total Tanner crab landings, mostly from the SEBS, exceeded those of king crab by 65% and 140%, respectively. However, total landings of Tanner crabs also have declined over the past two fishing seasons (unpublished data, National Marine Fisheries Services, R. Otto, pers. communication).

Eastern Bering Sea stocks of Tanner crabs have been assessed by annual trawl surveys conducted by the National Marine Fisheries Service

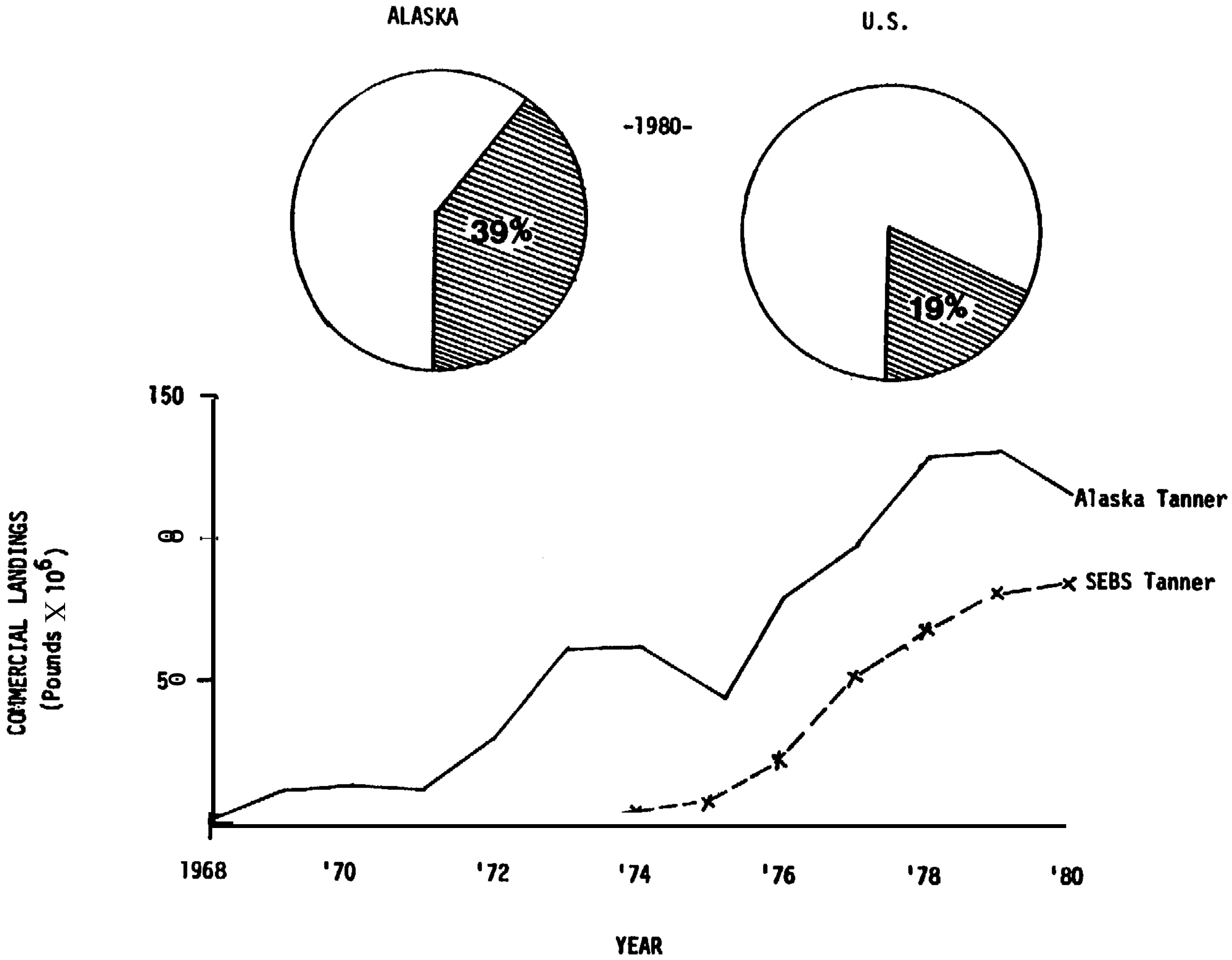


Fig. 4.1. Commercial landings of Tanner crabs from the southeastern Bering Sea (SEBS) compared to total commercial catch for Alaska, 1968-1980 (lower). Pie diagrams show Alaska tanner crab landings as a percentage of total Alaska and total U.S. commercial crab landings for all species combined for 1980. [Compiled from data of Eaton (1980), Fisheries of the United States, 1980 (1981) and Pacific Packers Report, Spring 1981 (1981)].

Table 4.1. Historic U.S. Tanner crab catch in the eastern Bering Sea, 1968-1982 (From Eaton, 1980, 1981)

Year	Number of Vessels*	Number of Landings	Number of Crab	Number of Pounds	Number of Pot Lifts	Average Weight	Average Crab Per Pot	Price Per Pound
1%8		7	6,408	17,858	1,426	2.8	5	
1969		131	353,273	1,008,898	29,851	2.9	12	
1970		66	482,307	1,410,721	16,372	2.9	29	
1971		22	61,347	166,058	7,343	2.7	‘8	
1972		30	42,561	119,170	6,728	2.8	6	
1973		45	132,941	301,868	16,530	2.3	8	
1974	18	69	2,531,825	5,044,197	22,014	2.0	115	
1975	27	80	2,773,770	7,028,378	38,462	2.5	72	.13
1976	66	305	8,949,886	22,341,475	141,179	2.5	63	.19
1977	83	580	‘20,412,566	51,876,235	305,052	2.5	67	.30
1978								
C.bairdi	119	823	26,188,543	66,228,040	508,776	2*5	51	.38
C.opilio	15*	38	1,267,196	1,716,249	13,177	1.3	96	.30
TOTAL		861	27,455,739	67,944,289	521,953	2.5	53	
1979								
C.bairdi	138	801	16,711,455	42,518,233	393,788	2.5	42	,52
C.opilio	101 *	490	22,118,498	32,187,039	190,746	1.5	116	.30
TOTAL		1,291	38,829,953	74,705,272	584,534	1.9	66	N/A
1980								
C . bairdi	154	804	14,739,611	36,614,315	488,434	2.5	30	.52
C.opilio	141 *	603	25,706,262	39,538,896	272,065	105	94	.21
TOTAL		1,407	40,445,873	76,153,211	760,499	1.9	53	N/A

(CONTINUED)

Table 4.1 (Cont.)

Year	Number of Vessels*	Number of Landings	Number of Crab	Number of Pounds	Number of Pot Lifts	Average Weight	Average Crab Per Pot	Price Per Pound
1981								
C. bairdi	169	759	11,873,513	29,702,071	588,621	2.5	21	.58
C. opilio	155*	867	34,416,334	52,753,034	435,762	1.5	79	.26
1982								
C. bairdi	136	785	4,937,736	10,977,390	487,463	2.2	10	1.35
C. opilio	126*	797	24,032,434	29,229,193	467,895	1.2	51	.60

*Vessels landing C. opilio also have C. bairdi, so the total number of vessels participating in the EBS Tanner crab fishery is equal to the number landing C. bairdi for 1978-1982.

(NMFS) since the early 1970's. In addition, an extensive, joint NMFS-OCSEAP survey was conducted in the EBS in summer 1975 and reported by Pereyra et al. (1976). Two of the sub-areas defined in the NMFS-OCSEAP survey (Fig. 4.2a) are of particular interest in this report. Sub-area 2 contains nearly all of the St. George Basin and Sub-area 1 contains the proposed oil lease areas of the North Aleutian Shelf. Both areas contain "large stocks of Tanner crab (Fig. 4.2b and Pereyra et al. 1976:326, 331) and are the principal focus of recent commercial fishing efforts (Fig. 4.3). The *prognosis* is for a continued high yield from the fishery when both species are considered together, although the stocks have continued to show a decline since 1975 (Otto 1981).

The fishery for Tanner crabs is managed for the harvest of males only. For *C. bairdi,* the lower legal size limit is 139 mm (5.5 inches) across the widest portion of the carapace (carapace spines not included). No size limit was in effect for male *C. opilio* through the 1982 fishing season. The average landed Tanner crab of the two species was 2.2 and 1.2 pounds, respectively, in 1982, with mean carapace widths (CW) of 148.7 and 109 mm (Eaton 1982). The catch per unit effort (CPUE) for *C. bairdi* and *C. opilio* have shown a steady decline since 1979 (Table 4.1). The number of vessels involved in the American Tanner crab fishery increased from 1974 to 1981, but decreased in 1982 to 136 (Table 4.1). Primary landing ports for Tanner crab caught in the SEBS are Dutch Harbor and Akutan. Otto (1981) provides a detailed history of the Tanner crab fishery of this region.

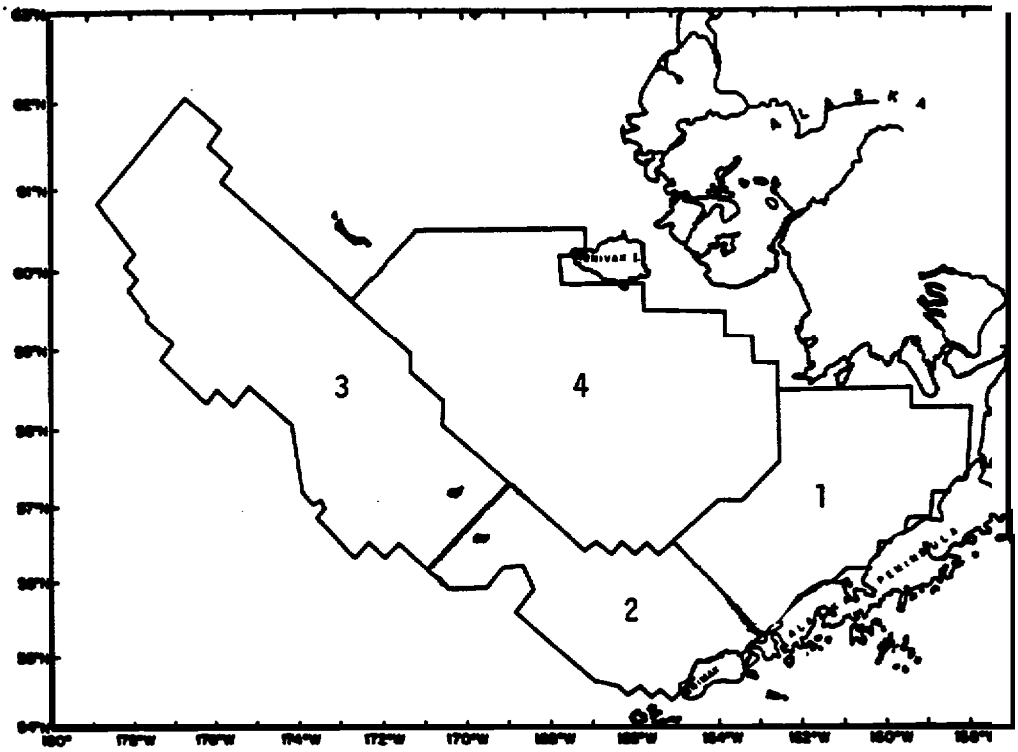


Fig. 4.2a. Sub-areas definedforthe **NMFS/OCS-BLM benthic faunal** resource survey of 1975 (from Pereyra _et al._, 1976). Areas 1 and 2 contain large stocks of commercial Tanner crabs.

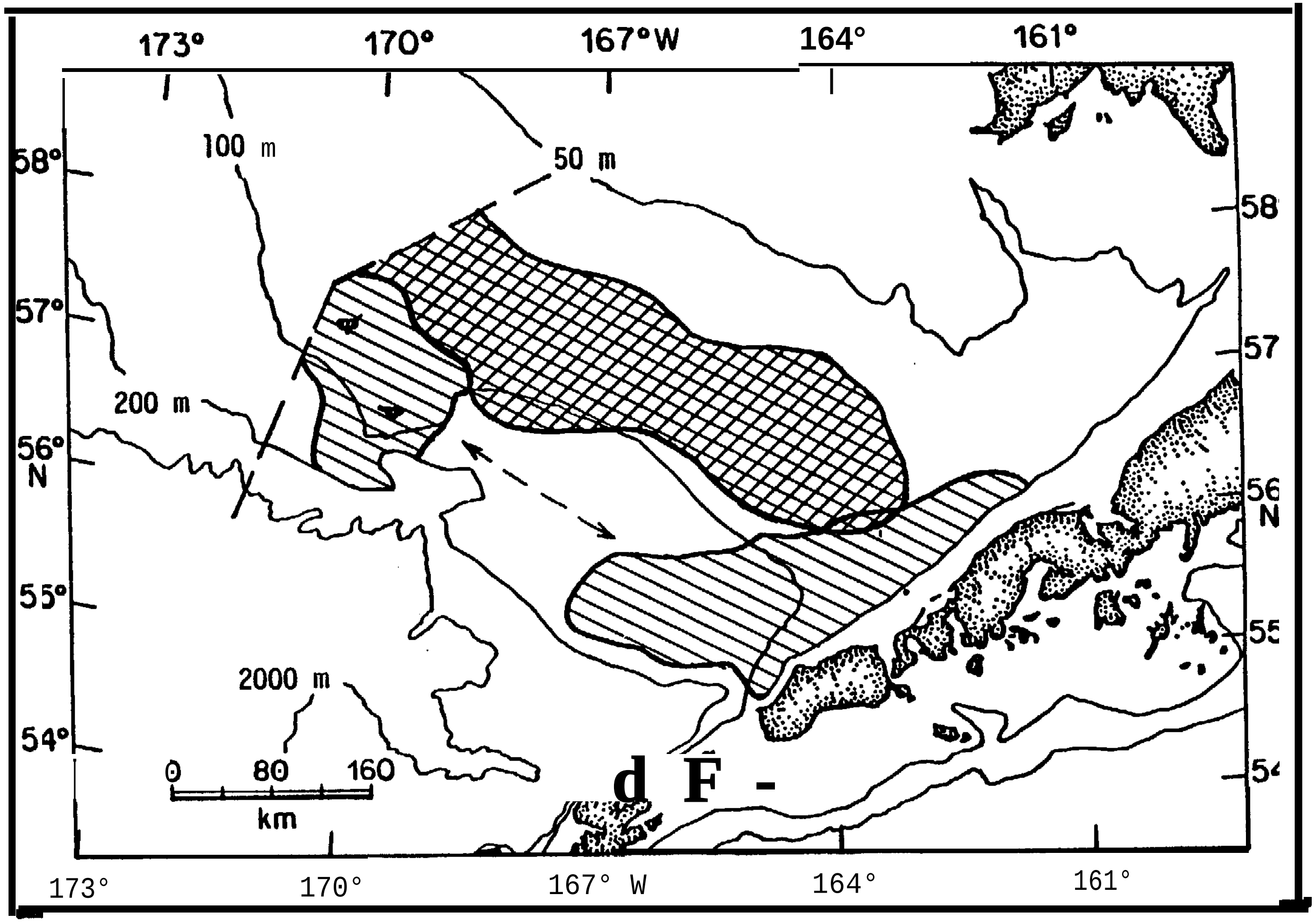


Fig. 4.2b Centers of abundance of **benthic** C. bairdi (diagonal) and C. opilio (crossed diagonal) in the southeastern Bering Sea. Areas are smoothed from illustrations of Pereyra et al. (1976: Figs. IX-93, IX-101) and show areas ≥ 10 kg live weight/km of bottom-trawl. Greatest biomass densities for both species exceed 50 kg/km. Arrows in outer shelf denote the continuity of the C. bairdi population, but at slightly lower biomass levels.

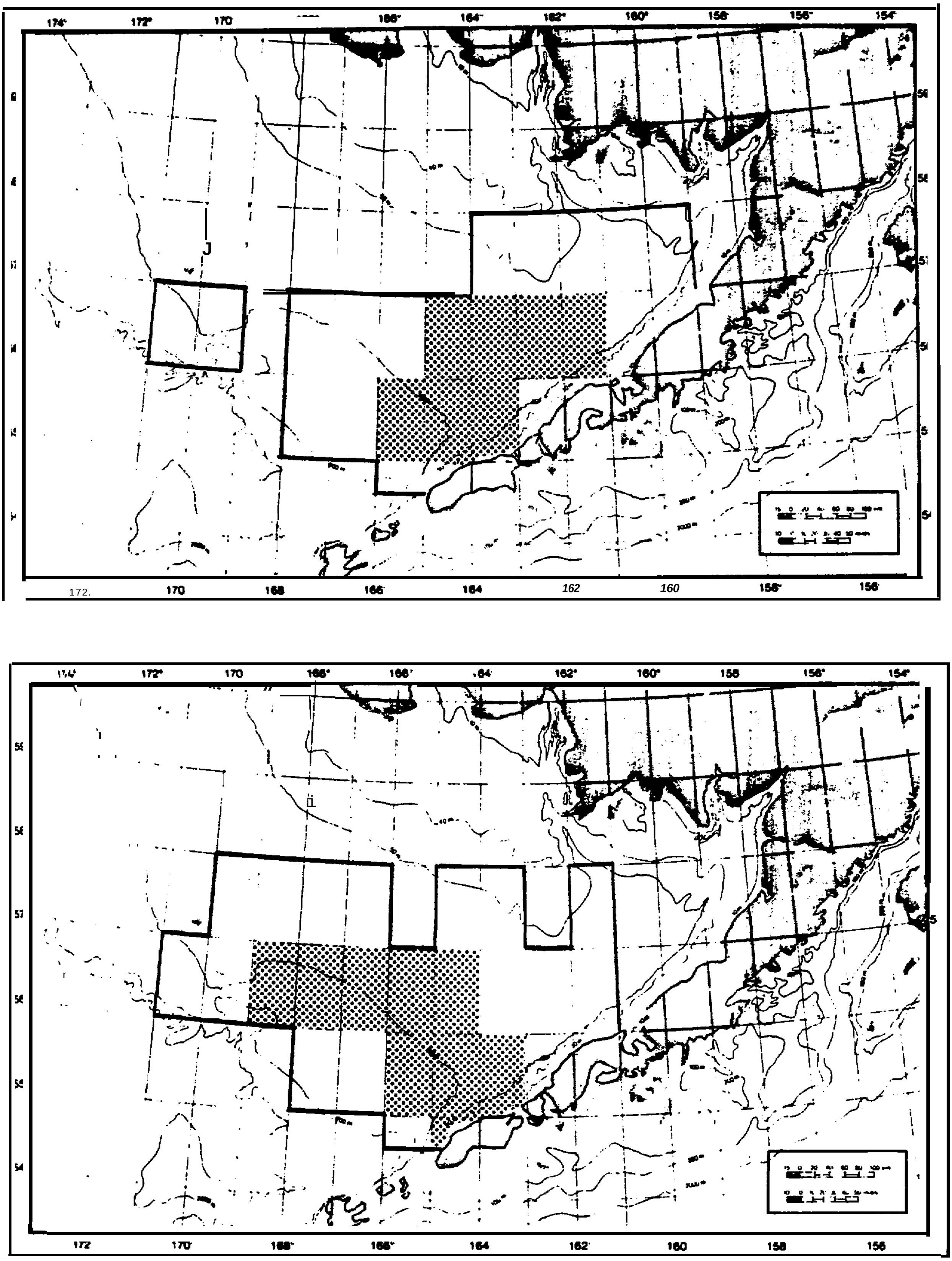


Fig. 4.3. Principal areas of 1980 Tanner crab catch in the southeastern Bering Sea, **Chionoecetes bairdi** (upper) and **C. opilio** (lower). Shaded areas yielded **1×10^6 pounds** or more. (After Eaton, 1980).

4.3 Reproduction and Description of Spawning Stocks

Populations of juvenile and adult *Chionoecetes bairdi* and *C. opilio* in the southeastern Bering Sea are surveyed each year by the National Marine Fisheries Service for purposes of fishery forecasting. Distribution and abundance of the spawning stocks are consequently well known. While both species are found over a wide region of the shelf from depths of 50-200 m, the majority of the populations of each (see Fig. 4.2b) are associated with areas which are distinguishable on the basis of average summer hydrographic conditions. The bulk of the population of *C. opilio* is found in the middle shelf environment betwween 70 and 100 m depths, where relatively cold bottom water temperatures prevail throughout summer. [The cold bottom water mass is formed *in situ* during winter and is isolated by stratification of the water column in spring.] Most of the population baof *C.* is found in the outer shelf environment at depths of 100-200 m and in the middle shelf environment near the Alaska Peninsula. Sexually mature female crabs appear to be patchily distributed within these regions, but generally are found over wide areas similar to the rest of the population of each species.

The age at sexual maturity is about five years for females of both *C. bairdi* (Donaldson et al. 1980) and *C. opilio* (from Adams 1979: Tables 10 and 11; and Watson 1970). Females undergo a terminal puberty molt at sexual maturity, but the size (carapace width) at which this occurs can vary substantially (Ito 1970; Haynes et al. 1976; MacIntosh et al. 1979; Jewett 1982). The size at which 50% of *C. bairdi* females reach sexual maturity is about 84 mm (post-molt) carapace width (Hilsinger et al. 1975; Donaldson et al. 1980); 50% maturity in *C. opilio* females occurs at about 50 mm carapace width in the Gulf of St. Lawrence (Watson 1970) and the southeastern Chukchi Sea (Jewett 1982), and slightly more than this in the Sea of Japan (Ito 1970). These data and size frequency plots of female crab of the two species found in the southeastern Bering Sea (e.g., Pereyra et al. 1976) provide an approximation of the size of sexually mature crabs in the study area.

Fecundity varies with size and reproductive year of these crabs. Haynes et al. (1976) estimated the number of eggs from 42 female *C. bairdi* of mixed spawning history (primiparous and multiparous spawners) from the southeastern Bering Sea in the autumn (September-October). Using a regression equation relating number of eggs to carapace width gives an estimate of about 175,000 eggs per 95 mm female, which roughly corresponds to the average mature female *C. bairdi* from the 1975 survey of the southeastern Bering Sea (Pereyra et al. 1976:325). The regression estimate of number of eggs produced by an average size, 60-65 mm carapace width, female *C. opilio* is about 40,000 eggs for primaparous spawners from the southeastern Bering Sea (23 specimens) and multiparous spawners from the Gulf of St. Lawrence (99 specimens). [The numbers are not strictly comparable because the St. Lawrence crabs were caught in spring and presumably had lost part of the egg mass during winter (Hilsinger 1976)]. Most of the difference in female egg production between the two species appears to be due to differences in average size of the crab. Haynes et al. (1976) found similar egg numbers for both species for 80 mm specimens, but this size represents opposite extremes of mature female size for the two species.

Eggs hatch in the spring, generally April for C. opilio and late April-early May for C. bairdi in the southeastern Bering Sea (Incze et al. 1982; Incze 1983). Within a few weeks after the old eggs have hatched, a new egg mass is extruded and attached to pleopods on the female's abdomen. These eggs remain attached until they are fully developed and hatch, about one year after spawning. The larvae emerge as prezoeae, about 2.5 mm long, which are covered with an embryonic cuticle and molt to first stage zoeae generally within an hour (Ken 1967, 1970; Kuwatani et al. 1971; Haynes 1973). The two zoeal stages (Haynes 1973, 1981) and the megalops stage (Jewett and Haight 1977) last about one month each (Incze et al. 1982; Incze 1983; see also Adams 1979, Table 9), and remain primarily in the upper 20m of the water column during this period (Incze 1983). The megalops is the final planktonic stage in the life history of these crabs; all subsequent stages are benthic.

4.4 Taxonomy

Chionecetes bairdi and C. opilio zoeae were identified by D. Wencker using criteria outlined by Wencker et al. (1982; manuscript is appended to this report). These criteria make use of descriptions of the species by other authors (Kurata 1963, 1969; Motoh 1973, 1976; Haynes 1973, 1981), but also include some new diagnostic characteristics which were necessary for distinguishing between the two species in the southeastern Bering Sea. The morphological descriptions by Wencker et al. (1982) were corroborated by field studies on larval dynamics which are reported in detail by Incze (1983). The description by Jewett and Haight (1977) was used to distinguish megalops larvae of the two species.

4.5 Results and Discussion

4.5.1 Timing of Hatchout

The timing of initial hatchout of larvae of the two species was examined by plotting against time the mean larval densities (number/ $1000m^3$) estimated from samples collected during April and May of 1977, 1978, 1980, and 1981. Because crab larvae were relatively rare during these months, plankton samples were searched completely, not sub-sampled. The following criteria were used to select stations with data adequate for this analysis: 1) if a sample from a station contained larvae, the estimated abundance at that station was recorded for the corresponding date; 2) if a sample did not contain larvae but subsequent occupation of the sampling area (within a radius of approximately 27.8 km, 15 NM) showed that there were eventually larvae there, the "zero" abundance was recorded for the earlier date; 3) if a sampling location did not contain larvae and was not occupied again later, or was occupied and continued to show no larvae, the "zero" datum was not entered into the analysis. In this way, the period before any detectable hatchout occurred could be identified without risk of biasing the analysis with data from sample locations not yielding zoeae of that species in that year. Sample coverage in the study area was not sufficient during any one year to enable a statistical comparison of initial hatchout times for different sub-areas (eg. middle shelf vs. outer shelf). Consequently, the data from all stations were pooled for various dates. The data presented here describe initial hatchout periods of larvae primarily for areas where water depth exceeds 90 m.

The results of the analysis of hatchout for *C. bairdi* are listed in Table 4.2, which shows the number of stations involved in the analysis and the mean value and range of larval densities encountered. The analysis is not shown beyond the time of maximum mean larval densities. Sampling continued well beyond these dates in 197$ and 1981, and no further significant increases in abundance were observed. Thus, the "peak" of hatchout as determined by larval density estimates had occurred. Figure 4.4 presents the data from Table 4.2 as plots of relative density of larvae over a 40-day period in each of three years. A value of 1.0 represents the maximum mean density observed in a particular year. Data for 1980 were infrequent during the period of predicted peak hatchout (early May) but also show extremely low larval densities ($\leq 6/100m^2$, n=7) for the period 18-20 April.

For the three years shown in Figure 4.4, the greatest increase in mean larval abundance occurred between late April and early May and was quite abrupt, implying a relatively synchronous hatch of larvae throughout the adult populations underlying these stations. In 1978 and 1979, these stations covered a large part of the outer shelf, so hatchout from a considerable portion of the outer shelf adult population of these species was sampled. The fact that a discernible time-averaged contribution to the larval population did not occur after the peak densities of early May had been attained suggests an appreciable decline in hatching activity. This is corroborated by the fact that nearly all egg-bearing

Table 4.2. Timing of appearance of Stage I zoeae of Chionoecetes bairdi in the southeastern Bering Sea by year and date. N1: number of stations sampled during specified period; N2: number of stations used in the analysis. Density of larvae is reported as number per 100 m^2 (range in parentheses).

Year	Dates	N1	N2	Density of Larvae
1977	18-19 Apr	13	8	150 (0-1140)
	24-25 Apr	19	7	138 (0-600)
	16 May	9	8	8,058 (.0-28,446}
	18 Apr	*	1	348
	24 Apr	*	1	7,476
	9 May	*	1	11,634
1978	16-21 Apr	31	16	6 (0-114)
	26-28 Apr	26	23	966 (.0-4,224)
	11-14 May	6	6	65,052 (1,644-148,000)
1981	17 Apr	4	4	36 (.0-150)
	1 May	1	1	888
	U-14 May	6	3	3,288 (768-7,572)

*observations from a single station outside the area of other stations; data are provided here for comparison.

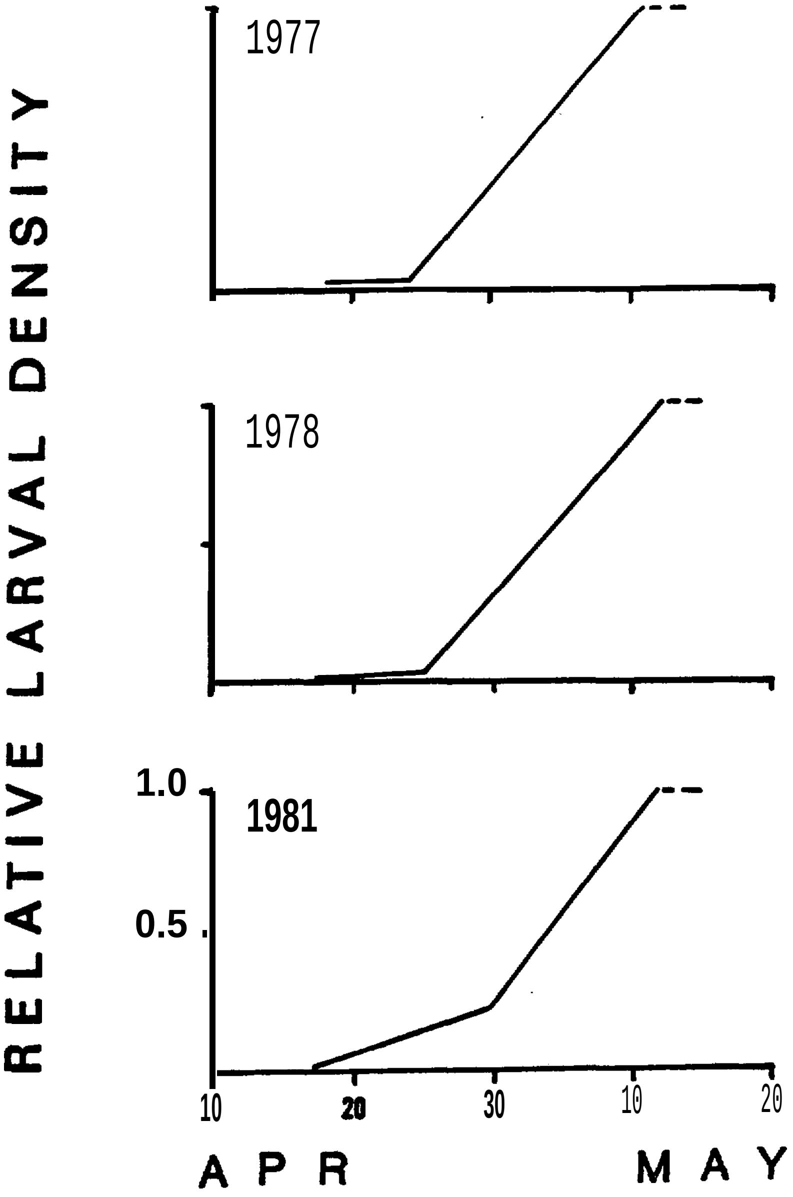


Fig. 4.4. Timing of appearance of larval _C. bairdi_ in plankton of the southeastern Bering Sea. Data on mean larval density (Table 4.2) are represented as cumulative proportion of the maximum mean density observed at peak hatchout.

female crabs sampled in late May and early June by National Marine Fisheries Service surveys have immature (recent" y extruded) egg masses (Somerton 1981).

The initial hatchout period of C. opilio larvae was not documented as well as that for C. bairdi. There aDDeared to be a considerably earlier hatchout for this species, as shown in Table 4.3 with data from 1977 and 1978. Although there is a considerable range in larval densities shown over time (possibly due to a wider range of sample locations than was used for C. bairdi), high densities were clearly found by 20 April in both years (sampling started 6 April 1977 and 11 April 1978}. Throughout most of the area of the southeastern Bering Sea sampled in this study, 1980 and 1981 were both markedly "poor" years for C. opilio larvae (see later discussion) and collections were not adequate in either year to define a hatchout curve. However, larval densities typical of those two years were also found by middle April. Data on development rates of Stage I (S1) zoeae of C. opilio and on the time of appearance of Stage II (S11) zoeae of this species in 1981 (see Incze 1983 and following section) further support the suggestion that significant hatchout of C. opilio larvae occurred two to three weeks prior to the major hatch of C. bairdi larvae.

4.5.2 Rates of Larval Development

The rates of development of C. bairdi and C. opilio S1 zoeae in the southeastern Bering Sea were analyzed by examining the ratio of S1 to total zoeae (SI:SI+SII) for each species at stations where at least six individuals of a species were examined in the sample or subsample. Using

Table 4.3. Timing of appearance of Stage I zoeae of _Chionoecetes opilio_ in the southeastern Bering Sea by year and date. N1 : number of stations where _C. opilio_ larvae were found; N2: mean number of zoeae per 100 m^2. (range in parentheses).

Year	Dates	N1	N2
1977	17-19 Apr	9	8,592 (1,710-33,234)
	24-25 Apr	8	10,026 (1,452-19,596)
	10 May	9	21,462 (828-134,970)
1978	16-21 Apr	23	103,870 (0-626,700)
	26-28 Apr	23	154,300 (96-1,523,712)
	11-14 May	14	17,628 (,638-82,050)

this low number of larvae increased the number of observations (stations) which could be included in the analysis and produced no obvious detrimental impact on the data variance, since a large variance existed even among stations with abundant larvae. The data were grouped into time periods not exceeding 10 days and the mean ratio calculated (unweighed ratio method). The number of larvae examined in each 10-day period ranged from43 to over 2,000. From one to thirty stations were included in each period.

Rates of development of second stage (S11) zoeae were analyzed by examining the ratio of SII:SII + megalops larvae (no S1 zoeae were present during this period). The data were grouped into time periods of not more than 13 days. The number of larvae examined in each period ranged from 780 to 2032, while the number of stations ranged from 10 to 41.

For both molting analyses above, weighted ratios were also calculated by pooling data on all larvae of a species from each 10-day period and determining the ratio of the larval stages in question. This method gave results similar to the unweighed method, but the results of the unweighed ratio method were used for illustration because these data allowed variance of data to be expressed.

Observations of the stomach contents of yellow fin sole (*Limanda aspera*) collected in early September 1980 (K. Haflinger, Univ. of Alaska, unpubl. data) and plankton samples collected in October 1980 provided some information on the late summer-early autumn presence of

megalops larvae of both species and first post-larval (first instar) crabs of C. opilio.

Data on rates of **larval** development show considerable variability from one station to the next *once* molting in the population was under *way.* This is reflected in a large variance about the mean over 10-day periods (Tables **4.4 and** 4.5). The weighted ratios are provided for comparison in Table 4.6, which also shows the number of larvae examined in each period. Despite the large variance, **larval** stage data are useful for pointing out several features of the larval development process in the populations: 1) the point in time where molting to S1 begins for each species can be fairly well defined; 2) the length of time required for the population of S1 zoeae to molt to S11 can be seen; and 3) differences in timing of the onset of molting in larval populations of the two species can be seen.

Observations (1) and (3) are generally consistent with earlier observations on the timing of first appearance of larvae in the plankton. In particular, data for 1978 and 1979 both show that the molt to S11 was well underway in the C. opilio population before C. bairdi larvae noticeably began this process (Figure 4.5). However, this pattern did not appear to hold true in 1980 or 1981. These interannual differences will be discussed later in this report. Observation (2″) indicates that most of the **hatchout** occurred within a period of 30-40 days, although other factors (temperature regime, **planktonic** feeding conditions or survival of only part of a year-class) also may affect apparent duration of the inter-molt period.

Table 4.4. Zoeal development of *Chionoecetes bairdi* and *C. opilio* showing proportion of Stage I to total zoeae: Mean of sample observations ± one standard deviation (number of stations sampled in parentheses).

Year	Species	Date				
1978		7-17 May	27-31 May	1-10 June	11-20 June	21-29 June
	C. opilio	1.0 (11)	0.92±0.17(20)	0.81±0.22(30)	0.34*0.25(10)	0.25±0.29(21)
	C. bairdi	1.0 (7)	1.0 (7)	0.99*0.01(17)	0.99±0.01(6)	0.8510.23(8)
1979				1-6 June	19 June	21-22 June
	C. opilio			0.53±0.33(8)	0 (3)	0.01±0.02(6)
	C. bairdi			0.99 (7)	0.31±0.17(4)	o * (2)
1980		13 May	26-29 May	2-8 June		
	C. opilio	1.0 (1)	1.0 (5)	1.0 (2)		
	C. bairdi	1.0 (1)	1.0 (7)	1.0 (20)		
1981		15-16 May	23-30 May	1-10 June	11-19 June	
	C. opilio	1.0 (4)	0.98 (2)	0.94±0.08(5)	0.14±0.25(3)	
	C. bairdi	1.0 (19)	1.0 (15)	0.9810.04(19)	0.54±0.36(13)	

*Four other stations sampled during the period 21-27 June contained Stage I zoeae of *C. bairdi* but contained too few larvae (< 6) to be considered in this analysis; the zero datum is thus artificially low.

Table 4.5. Proportion of Stage II to megalops larvae (total larvae) of *Chionoecetes bairdi* and *C. opilio* in plankton samples from the southeastern Bering Sea in 1981: Mean of sample observations ± one standard deviation (number of samples in parentheses). Number of larvae examined is shown beneath date. No Stage I zoeae were present for either species during the time period shown.

	27 June - 10 July N=2032	11-20 July N=780
C. opilio	0.78 ± 0.34 (23)	0.11 ± 0.20 (10)
C. bairdi	1.0 (41)	0.78 ± 0.22 (17)

Table 4.6. Weighted average proportion of Stage I to total zoeae of *Chionoecetes bairdi* and *C. opilio*: Proportion of all zoeae examined during specified time periods (number of larvae examined is in parentheses).

Year	Species	Date				
1978		7-17 May	27-31 May	1-10 June	11-20 June	21-29 June
	C. opilio	1.0 (396)	0.97 (2,357)	0.82 (1,846)	0.31 (329)	0.25 (1,398)
	C. bairdi	1.0 (255)	1.0 (90)	0.99 (456)	0.99 (267)	0.83 (518)
1979				1-6 June	19 June	21-22 June
	C. opilio			0.46 (305)	0 (43)	0.02 (125)
	C. bairdi			0.99 (176)	0.39 (69)	0 (15)
1980		13 May	26-29 May	2-8 June		
	C. opilio	1.0 (318)	1.0 (423)	1.0 (33)		
	C. bairdi	1.0 (22)	1.0 (130)	1.0 (528)		
1981		15-16 May	23-30 May	1-10 June	11-19 June	
	C. opilio	1.0 (45)	0.98 (133)	0.93 (142)	0.17 (52)	
	C. bairdi	1.0 (1,513)	1.0 (1,411)	0.98 (1,555)	0.29 (463)	

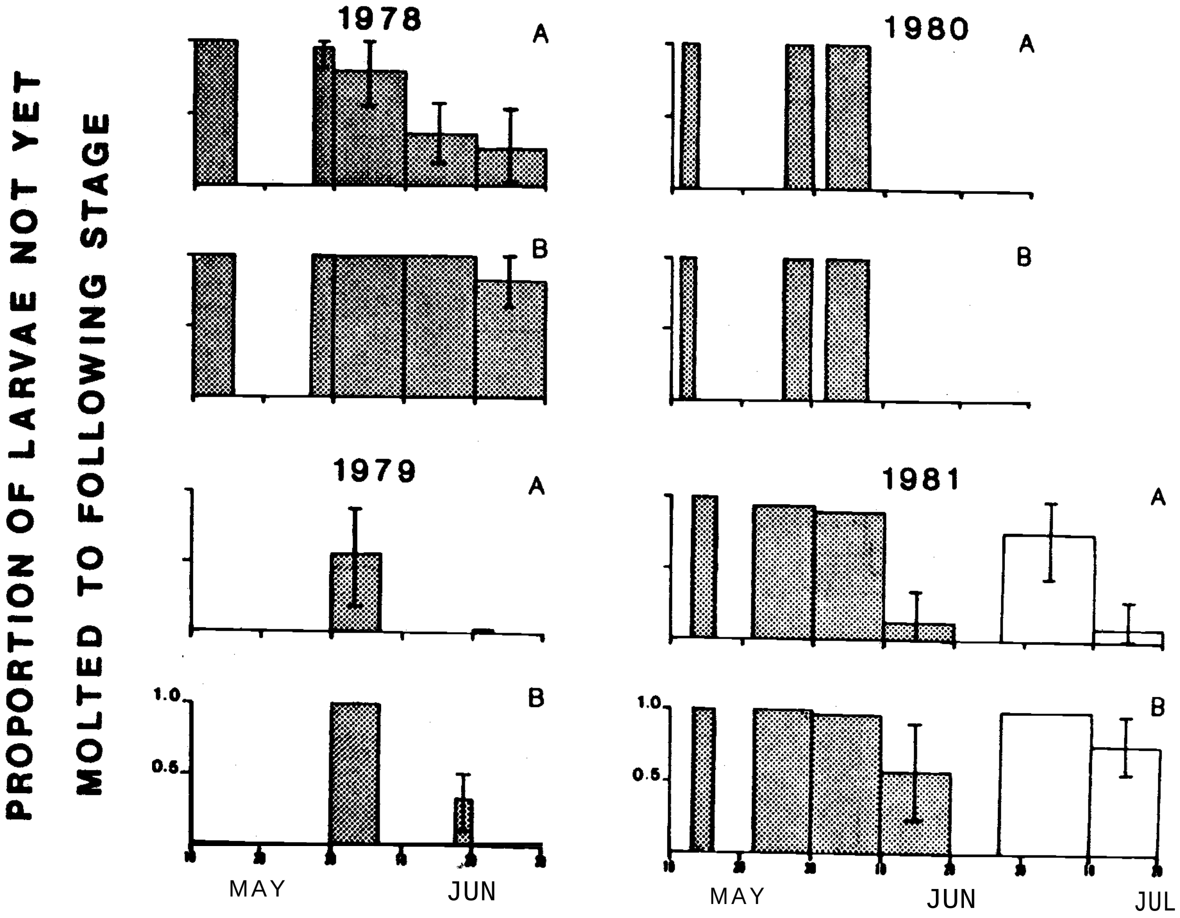


Fig. 4.5. Temporal aspects of development in larval Populations of *C. opilio* (A) and *C. bairdi* (B) during four years of study. Shaded bars show proportion of Stage I to total zoeae (no megalops present); open bars show proportion of Stage II to total larvae (no Stage I present). Values shown are mean proportions from sampled stations ± one standard deviation standard deviations are truncated at 1.0. Data are summarized in Tables 4.4 and 4.5.

Data on the timing of molt from S11 to megalops larvae in 1981 show the beginning of this process in C. bairdi and the end for C. opilio (Table 4.5, Fig. 4.5). Although the data do not cover the entire period for this molt, the rate of change in the population as a whole during the time period sampled indicates that the S11: megalops molting is about as long as the earlier SI:SII transition. The data for C. bairdi in 1981 further show that the molt to megalops stage larvae began approximately one month after the first S11 zoeae appeared. The same situation is indicated for C. opilio, since no megalops stage larvae were found before 20 June.

The data presented above show an approximate 30-day period for each of the two zoeal stages for both species in the southeastern Bering Sea. Furthermore, the approximate 30- to 40-day period of molting in larval populations of each species is an indication that the hatchout period is of similar duration. The estimates of the duration of the two zoeal stages in the southeastern Bering Sea are in close agreement with most of the observations of C. opilio larvae in Japanese waters (Yamahora 1965; Fukataki 1969; Fukui Pref. Mar. Exp. Sta. 1969), although some estimates for the latter environment are for periods as brief as 19-2(I days for each stage (Ken 1970).

Samples collected in early October 1980 indicate that substantial numbers of C. bairdi megalops were still in the water column at that time (the estimated densities from October samples ranged from 560-1370/ 100 m^2, number of stations = 4, compared to May samples of S1 zoeae ranging from 1,800-18,000/100 m^2 at the same stations). This comparison assumes a relatively homogeneous distribution of C. bairdi larvae in the outer shelf since advection over this time period is not considered. No C. opilio larvae were collected in October of 1980, but this may have been due to low larval abundance for this species in 1980 in most of the area of our plankton studies.

Examination of the stomach contents of yellow fin sole (Limanda aspera) collected at 57°09'N Lat., 166°39'W Long. on 9 September 1980 indicated that settlement of C. opilio larvae and metamorphosis to first instar crab had begun by that date, but that substantial numbers of megalops larvae remained, presumably somewhere in the water column. [The stomachs of small sole (20 cm length) which contained the megalops contained no organisms of benthic origin at the time of sampling. Stomachs of larger sole (24-69 cm length) contained first instar C. opilio. Unpublished data are from K. Haflinger, University of Alaska.] These data indicate the beginning of settlement of C. opilio larvae to the benthos, but provide no insight into the duration of this transition. According to observations in Japanese waters, there may be considerable variation in the duration of this stage, since megalops larvae were observed in the plankton up to six months after their initial appearance (Fukataki 1969). Prolongation of the megalops stage in Japanese waters was also indicated by examination of the stomach contents of salmonid (Fukataki 1965, 1969) and zoarcid (Ito 1970) fish. A review of estimates of the duration of the larval stages of Chionoecetes spp. from other environments is provided by Adams (1979:78).

Kon (1970) reported on the basis of laboratory studies that the duration of the larval stages of *C. opilio* was inversely proportional to temperature over some physiologically acceptable range of temperatures. This response has been experimentally demonstrated with the larvae of other crabs as well (Anger and Nair 1979; Johns 1981), and the results presumably also apply to *Chionoecetes* spp. larvae in the plankton. During the course of this study, however, temperature effects on duration of the larval stages could not be isolated for certain from the effects of other environmental factors (Incze 1983). A period of about 30days for each zoeal stage and a period of at least 30 days for the megalops stage appears to be a reasonable estimate of the duration of larval stages of these species over the shelf of the St. George Basin and outer portion of the middle shelf.

4.6 Vertical Distribution of Larvae in the Water Column

Knowledge of the vertical distribution of larvae is essential to understanding the role various factors and processes may have in determining larval distribution and abundance. For example, the influence of environmental temperature on rates of growth, development and metabolism; the effects of subtidal- and wind-driven transport on larval distribution patterns; the impact of predators on larvae; the availability of appropriate food for larval feeding and the impact of catastrophes, such as major oil spills, cannot be properly interpreted without fairly accurate knowledge of vertical distributions. Estimates of larval abundance made from oblique plankton tows, such as with Bongo nets, can also be improved when patterns of depth distribution of larvae are known.

Methods for analysis of depth distribution patterns are discussed in Section 2.8. Results of that analysis and examination for potential vertical migrations are discussed here.

4.6.1 General Patterns

The vertical distribution of zoeae from 1980 and 1981 MOCNESS samples is shown in Fig. 4.6. *C. bairdi* and *C. opilio* zoeae show similar depth distributions, with more than 95% of the larvae occurring in the upper 40 m and 80% or more occurring in the upper 20 m.

For all data collected after 11 May in 1981, the depth distribution pattern for S1 and S11 zoeae combined was virtually the same as in 1980 for S1. Only prior to 12 May 1981 and only for *C. bairdi* zoeae was there a significant departure from this pattern (Figure 4.7). The pattern seen for this species before 12 May is primarily the result of four separate tows taken approximately six hours apart at a single station during a 24-hour period on 11 May.

A comparison of the vertical distribution of S1 and S11 zoeae made in two ways showed no significant difference in distribution between the two stages. First, data were considered only from stations where both S1 and SII zoeae occurred (8 stations sampled during 1981). The results are shown in Figure 4.8. Second, all data for S1 zoeae (15 stations) and all data for S11 zoeae (24 stations) during 1981 were tabulated separately. Again, similar patterns of distribution for the two stages were indicated; overall, 92% and 93% of S1 and S11 animals, respectively,

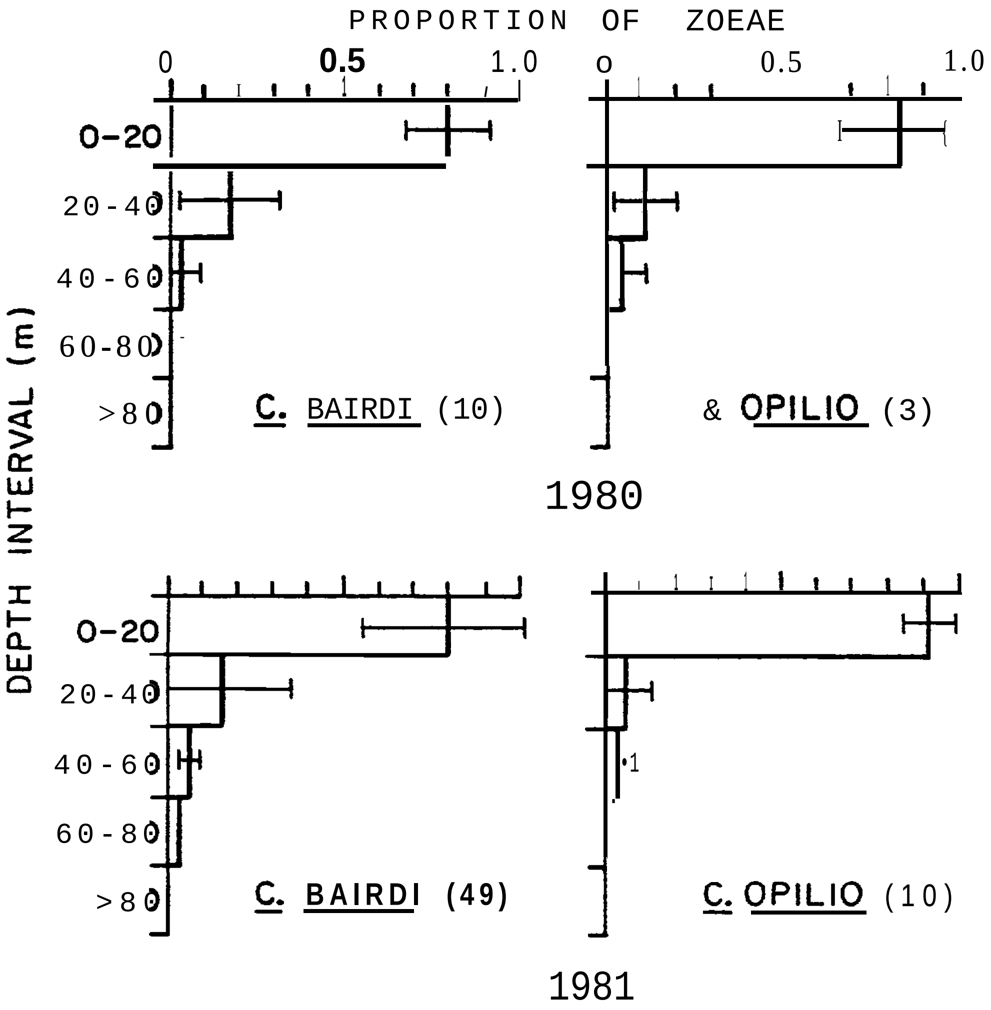


Fig. 4.6. **Vertical distribution of zoea larvae of C. bairdi and C. opilio sampled by MOCNESS nets, 1980-1981. Horizontal bars show mean proportion of larvae in depth interval ± one standard deviation. Both Stage I and Stage 11 zoeae are included (cf. Fig. 15). Number of stations from which data were taken is shown in parentheses.**

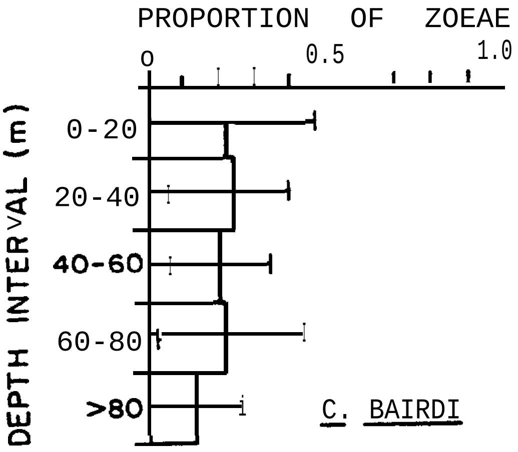


Fig. 4.7. Vertical distribution of *C. bairdi* Stage I zoeae sampled during the hatchout period for that species, early May 1981. Horizontal bars are mean proportion of larvae in each depth interval ± one standard deviation.

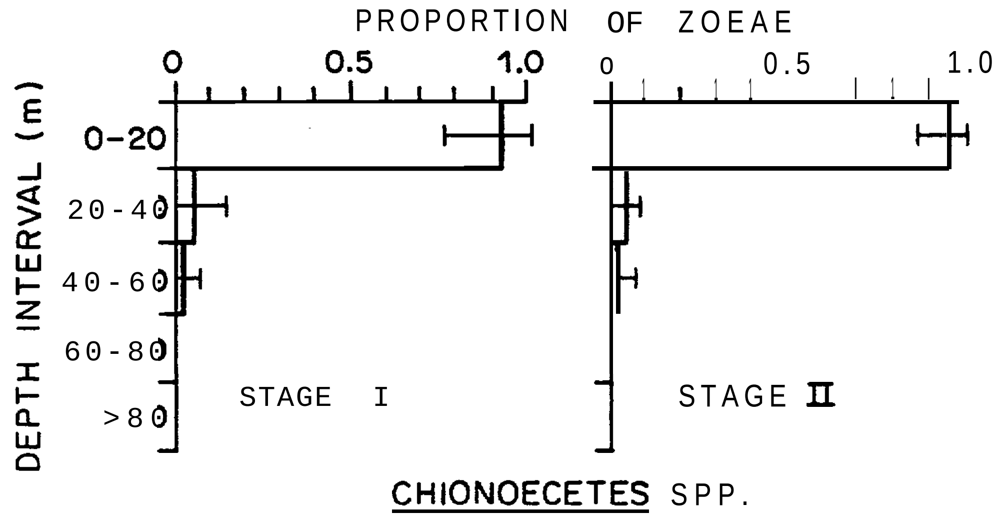


Fig. 4.8. **Vertical distribution of Stage I and Stage II zoeae** from eight stations (1981) where both occurred in sufficient numbers for analysis. Horizontal bars show mean proportion of larvae in each depth interval ± one standard deviation. Both species were combined for the analysis.

were found in the upper 40 m. Eighty-six percent of S1 and 82% of S11 zoeae were found in the upper 20 m.

The depth distribution of megalops larvae, analyzed with both species combined, also showed a tendency for distribution higher in the water column. However, greater variability was found at all depths for this stage than for the zoeal stages and a greater proportion of megalops occurred at 40-60 m depth compared to zoeae (Fig. 4.9). At 16 stations (18 tows) during June and July 1981, only one megalops larva was found below 60 m depth.

4.6.2 Vertical Migrations

Although the data indicated that only a small proportion of all Tanner crab larvae were found below 40 m, the data were further analyzed for possible diurnal patterns masked by the overall analysis. This was done by examining the proportion of larvae found below 40 m at various times of the day. Forty meters was selected because on the average few larvae were found below this depth, so any' diurnal pattern should be readily seen. The day was divided into six periods (0000-0300, 0300-0600, 0600-0900, 0900-1800, 1800-2100 and 2100-0000), roughly corresponding to various light intensities and periods of increasing or decreasing light. The data (proportion of larvae below 40 m) for each station were entered according to the time of day the sample was taken. Data from twelve diel (24-hr) stations were analyzed and then the data from all 79 stations were analyzed. The-data were re-examined using the proportion below 20 m as the migration criterion.

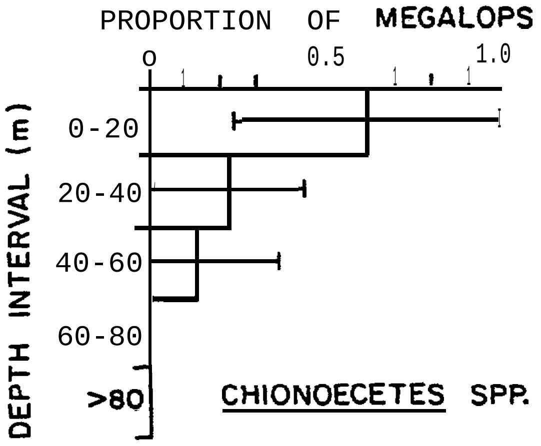


Fig. 4.9. Vertical distribution of *C. bairdi* and *C. opilio* megalops larvae at seven sampling locations in 1981. Horizontal bars are mean proportion of larvae in each depth internal ± one standard deviation.

From the diel stations, 10% or more of the zoeae occurred below 40 m six times during night-time sampling (2100-0300) and four times during day-time sampling (0600-1800). When all samples were considered together, 10% or more of the zoeae occurred below 40m nine times during daytime and five times during night. More than 10% of the megalops larvae occurred below 40m only once during night-time and twice during daytime sampling. When the proportion of larvae below 20m was listed, the results were variable and showed no diurnal pattern. The ratio of daylight (0600-1800) to night-time (2100-0300) samples in these anlyses was 1.5:1. The ratio of daylight (0600-1800) to twilight and dark (1800-0600) samples was 1.1:1.

Neither the diel stations nor all stations considered together provided any evidence of significant diurnal vertical migrations of zoeae or megalops larvae when 40 m or 20 m was used as the depth criterion for migration. About equal numbers of night-time and daytime samples were used, so the resulting data should accurately describe the average vertical distribution of larvae, especially the zoeae, which were well-sampled. The majority of zoea larvae of both species and stages occur in the upper 20 m of the water column (Figure 4.6 and 4.8), and this is where most planktonic interactions involving these larvae can be expected to take place.

The exception to this pattern was the vertical distribution of _C. bairdi_ zoeae on 11 May (Figure 4.7). The sampling location for these data was one of abundant _C. bairdi_ zoeae, and the samples were collected at the time of larval emergence from adult egg masses (see earlier discussion). There was no diurnal periodicity to the depth distribution pattern within the area of sampling, suggesting that the peculiar distribution may have been the result of sampling at the time of hatchout. Although the results (Figure 4.7) suggest a homogeneous distribution, the large standard deviations show that, in fact, the vertical distribution was highly variable from one sample to the next. The vertical pattern could have resulted from 1) a hatchout which was locally (at least within the advective area of sampling) quite synchronous, and/or 2) a relatively slow upward movement of newly molted zoeae, so that dense patches were found at various depths within the area. There is insufficient information in the existing data to further evaluate these findings, except to point out that the distribution 1) was not common, and 2) was not the result of unusual vertical water column structure, as evidenced by other variables. Hydrographic structure and the distribution of nutrients, chlorophyll and the remainder of the zooplankton community all showed normal vertical patterns at this location (PROBES 1981 consecutive station numbers 2058, 2060, 2061, 2062, 2063).

The megalops larvae do not appear to have been quite as concentrated in the upper 20 m as the zoeae, but they were still found primarily in the upper 40 m during the period of sampling. Neuston samples collected during night-time hours in July 1981 (Armstrong and Incze, unpubl. data) sometimes contained impressive numbers of megalops larvae which rivaled the estimates of abundance (per area of sea surface) obtained from oblique tows taken within the area. Although there are many difficulties in quantitatively sampling the neuston, the occasionally high abundance of megalops larvae found there suggests that 1) some vertical migrations take place, or 2) many megalops remain at or very near the surface most of the time. However, it is not currently known whether or not surface layer aggregations are common for this species, either temporally or spatially, as they may be for the megalops of other species (cf. Smyth 1980; Rice and Kristensen 1982). When aggregated at the surface, megalops larvae are particularly vulnerable to predation by seabirds (Schneider and Hunt 1982) and to impacts from oil spills.

4.7 Spatial and Interannual Patterns of Larval Abundance

Patterns of distribution and abundance are based on estimates of larval abundance which are highly variable, even on small spatial and temporal scales. Coefficients of variation for data collected in this study were usually around 100%, whether for samples taken in rapid succession or samples collected within a sampling stratum over a period of three to four weeks. This variability is typical of plankton distributions and is a problem which must be dealt with in all zooplankton studies (e.g., Wiebe et al. 1973; Fasham 1978). Despite this variability, however, it was possible in this study to distinguish certain “high abundance” and “low abundance” areas and years using standard statistical methods (Incze 1983).

In this section, spatial patterns of larval abundance are illustrated for selected years and months for each species. These periods were selected to illustrate the general patterns of distribution and abundance with the minimum number of figures requiring interpretation. In general, spatial patterns of larval abundance do not change much, so a limited number of charts suffice. However, there were major *interannual* changes in abundance, primarily of *C. opilio* larvae. The analysis of these changes was based on statistical comparison of estimates of monthly mean abundance for the sampling strata outlined in section 2.8. The data and methods are detailed elsewhere (Incze 1983), but the conclusions are germane to this report and are discussed here. This section focuses on two objectives: (1) the definition of areas where potential impacts on larvae are greatest; and (2) an evaluation of the potential importance of individual larval year-classes to the over-all recruitment process in populations of *C. bairdi* and *C. opilio*. Intra-annual patterns of abundance (hatchout and development) were addressed earlier and are not illustrated here.

Figures 4.10 and 4.11 summarize the distribution and abundance data from May and June of 1978 for *C. bairdi* and *C. opilio*, respectively. Larvae of both species were abundant in 1978, and a large portion of the southeastern Bering Sea was sampled (cf. Figs. 4.10 and 4.11 and cruise maps in Section 2.0). Figures 4.12 and 4.13 show the data for both species collected in 1980 and 1981. These years were both years of very low larval abundance of *C. opilio* over most of the study area (the region east and northeast of the Pribilofs excepted). Data for 1980 and 1981 are illustrated to show the low larval abundance of this species and the distribution of *C. bairdi* larvae in 1981 along the Alaska Peninsula, a region not sampled very much in earlier cruises.

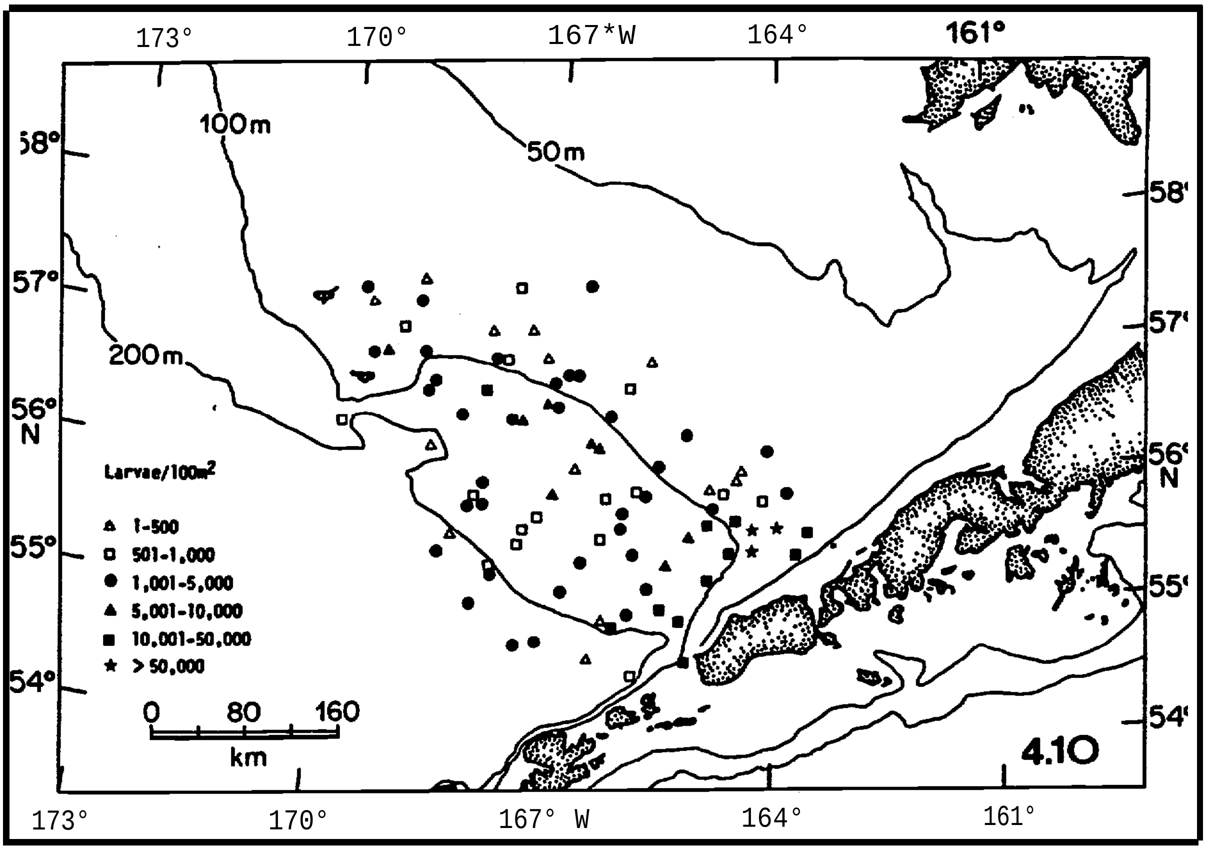


Figure 4.10 Distribution and abundance of *C. bairdi* larvae in May and June, 1978, PROBES. Zero stations not shown; see Section 2.0 for all sampling locations.

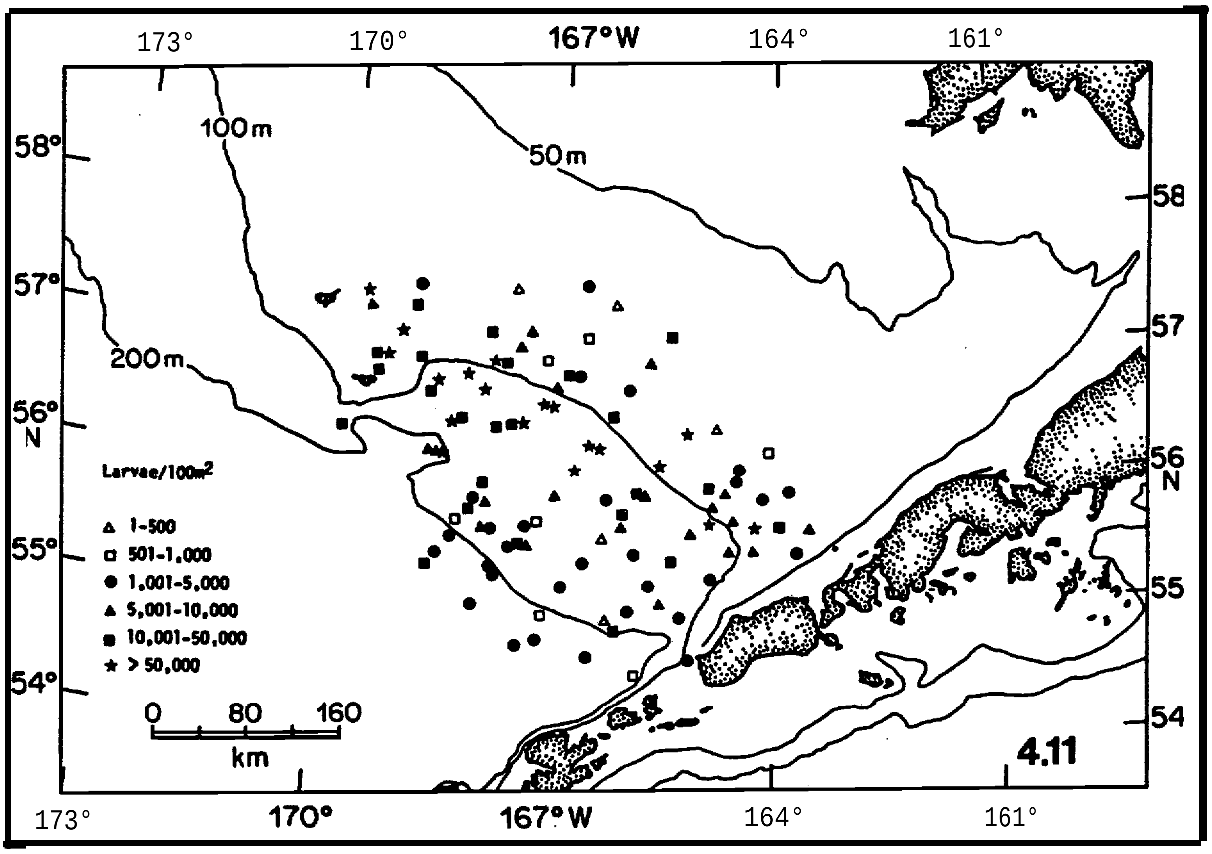


Figure 4.11 Distribution and abundance of *C. opilio* larvae in May and June, 1978, PROBES. Zero stations not shown.

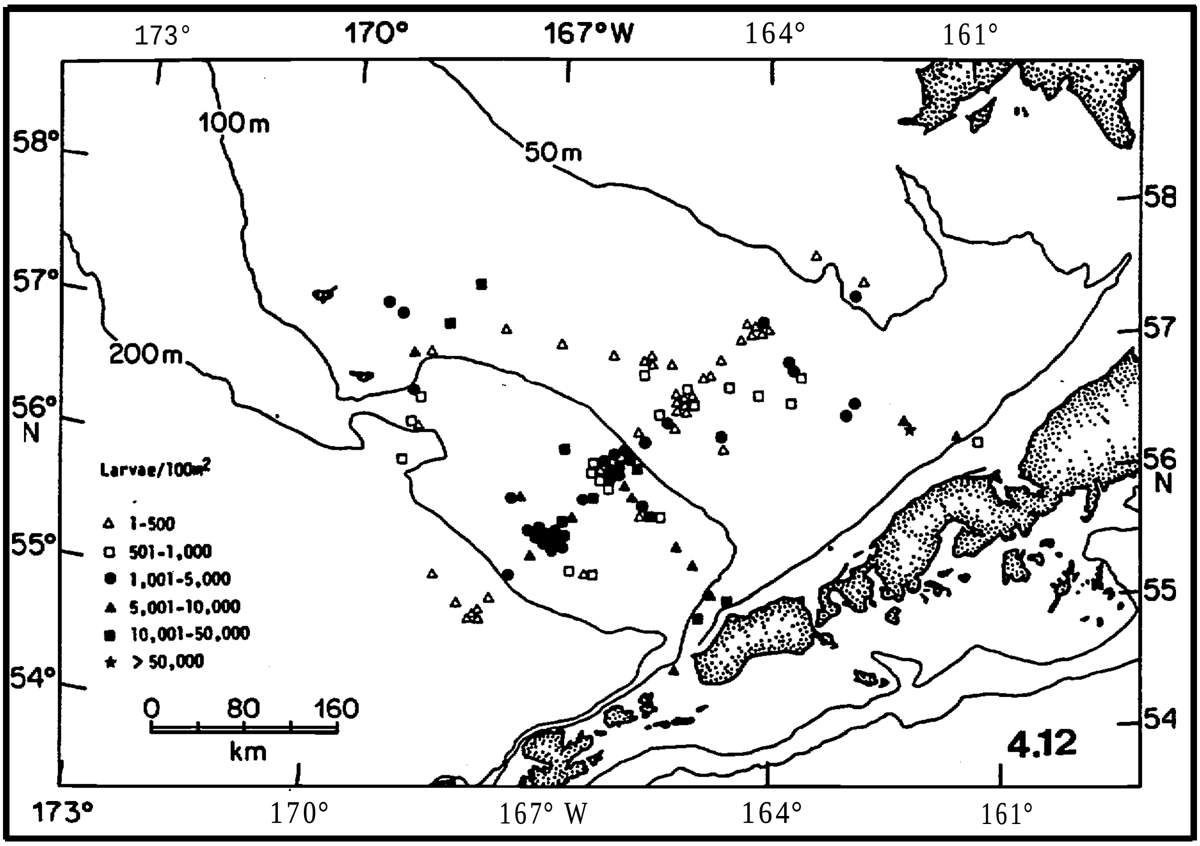


Figure 4.12 Distribution and abundance of C. bairdi larvae in the combined years 1980 and 1981. Zero stations not shown; see Section 2.0 for all sampling locations,

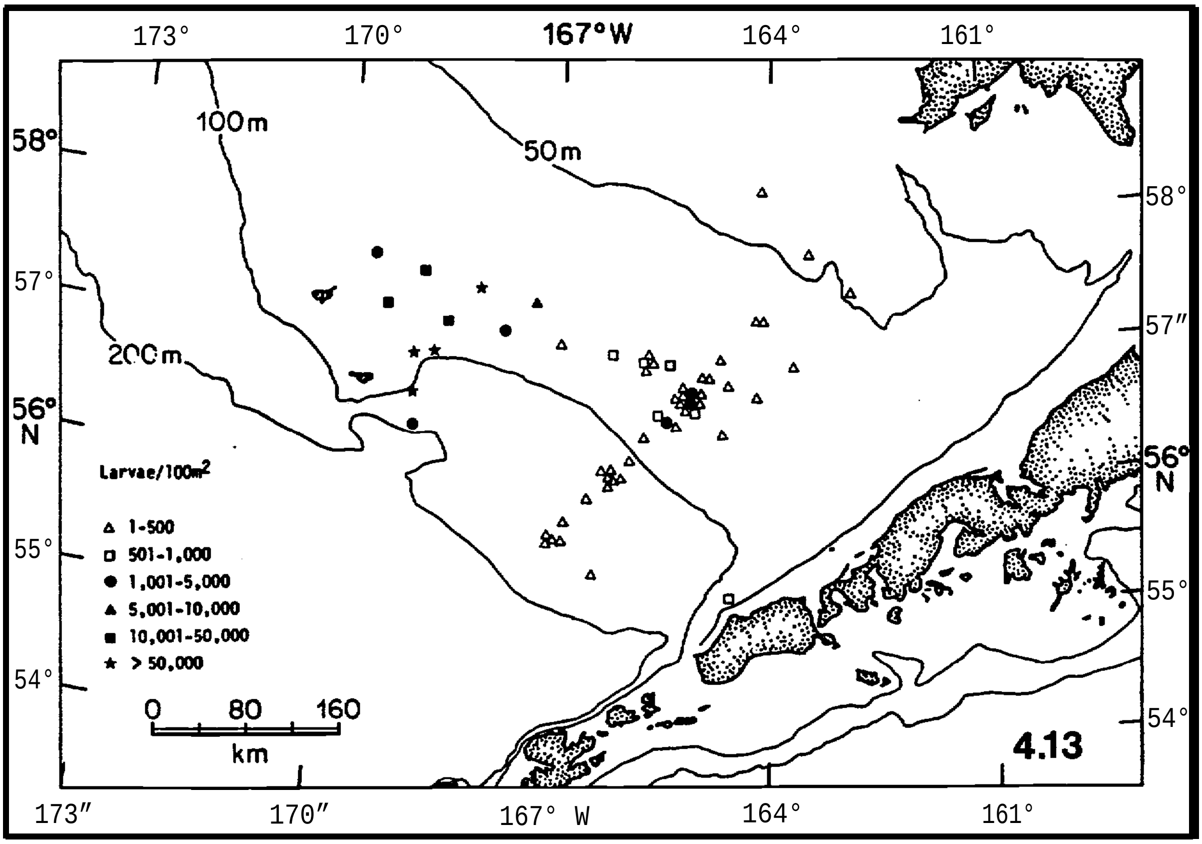


Figure 4.13 Distribution and abundance of C. opilio larvae in the combined years 1980 and 1981. Zero stations not shown.

The distribution patterns for C. bairdi larvae reflect the general pattern anticipated on the basis of the adult spawning populations. Larvae were abundant over the St. George Basin, particularly over shelf depths shallower than 150 m. Larvae were also abundant near the Alaska Peninsula, though the sampling effort in this region was comparatively low in most years. Analysis of data on estimated abundance of larvae in various sampling strata indicated that, over most of the area in this study, large interannual fluctuations in larval abundance of this species did not occur. Furthermore, in areas where adults of C. bairdi dominate, no statistically significant variations in larval year-class strength were observed.

The charted distribution patterns of C. opilio larvae do not correspond closely to the adult populations. The abundance of benthic C. opilio between 70 and 100Iu depths over the middle shelf, an area with weak net flows (Kinder and Schumacher 1981), suggests that this is where most larvae of this species should be found. Yet in 1977, 1978 and 1979, an abundance of larvae was found over portions of the St. George Basin (Fig. 4.11 shows the data for 1978 only). This pattern appears to result from three factors. First, sampling effort in years of abundant C. opilio larvae *was* more concentrated over the outer shelf (especially 1977 and 1979). Second, the most extensive sampling of the middle shelf was conducted in two years (1980, 1981) of very low larval abundance of C. opilio. Finally, the most extensive sampling of an abundant year-class of C. opilio was conducted in a year (1978) in which substantial wind-driven offshore transport occurred in April and early May (Incze

1983). The relative contribution of larvae of *C. opilio* over the St. George Basin to fishable stocks of Tanner crabs is not currently known, but is an important point to consider since *C. opilio* contribute substantially to the crab fishery.

Data from the period 1977-1981 clearly show that larval abundance of *C. opilio* can fluctuate greatly, as much as two orders of magnitude (Incze 1983). Somerton (1981) concluded on the basis of size frequency analysis of benthic populations of *C. opilio* that recruitment occurs irregularly. While other factors, such as benthic predation, also affect recruitment to juvenile and adult crab populations, success of the larval phase of recruitment is clearly important. The larval abundance data from this study indicate that some years may be much more important than others, and that relative success of larval year-classes may be a significant determinant of adult fisheries recruitment "in some years. Impacts on these "key" years might have a much greater effect on adult population dynamics than if year-class strength were more equal each year. Factors potentially contributing to the irregular success of larvae of *C. opilio* are complex and are presently not well understood (see Incze 1983 for discussion).

4.8 Summary of Principal Findings Relevant to the Assessment of Oil-Related Impacts

1. Most of the larvae of *C. opilio* hatch during April; a large proportion of the larvae appear to hatch in the first half of this month.

2. Most of the larvae of *C. bairdi* hatch in late April and the first half of May.

3. Most of the larval hatchout occurs over a period of about two weeks while the total hatchout period may cover 30 or more days.

4. The two zoeal stages last about one month each. The megalops stage lasts at least one month and perhaps considerably longer. Megalops larvae have been collected in considerable numbers over the St. George Basin as late as early October.

5. Eighty-six percent of zoea larvae were found in the upper 20 m of the water column. Megalops larvae showed a more variable depth distribution and were sometimes abundant in the neuston layer.

6. The larvae of _C. bairdi_ were always found in abundance over the St. George Basin, particularly over shelf depths of 100-150 m. Larvae of _C. opilio_ were sometimes, but not always, very abundant in this area.

7. Larval year-class strength of _C. opilio_ fluctuated by almost two orders of magnitude (difference in abundance) during this study. "Strong" larval year-classes may be critical to maintenance of _C. opilio_ stocks at high levels.

8. Larval abundances in excess of 1,000 larvae/100 m^2 sea surface area are common for both species. The maximum mean monthly abundance observed for a single species was 172,124 larvae/100 m^2 (Stage I zoeae of _C. opilio_, stratum 1, April 1978). Since 86% of zoeae are in the upper 20 m, these values correspond to estimated densities of

over 1 larva/m^3 (common abundance) and 86/m^3 (maximum estimated abundance).

9. Hydrocarbons or other toxicants distributed in the upper, wind-mixed layer would cause direct exposure to most of the larval populations of Tanner crabs. Surface films may impact a substantial portion of the megalops larvae.

5.0 DISTRIBUTION AND ABUNDANCE OF OTHER BRACHYURAN LARVAE IN THE SOUTHEASTERN BERING SEA WITH EMPHASIS ON ERIMACRUS ISENBECKII

Deborah Wencker

5.1 Introduction

There is little detailed literature on the life histories, distribution, and abundance of Brachyura in the southeastern Bering Sea belonging to the families Atelecyclidae (hair crab), Cancridae (Cancer crab), Majidae (spider crabs, other than Chionoecetes bairdi and C. opilio), and Pinnotheridae (pea crab) (see Tables 5.1, 5.2 for summary). Species without commercial value are either little studied and/or are not reported even though they are often caught incidentally during groundfish surveys. From our own experience onboard such cruises we know that noncommercial crabs and shrimp are often caught in high numbers, sorted to species, and logged in data banks. Processed agency reports mention only general listings of total shrimp or noncommercial crab (e.g., Pereyra et al. 1976), or present summary statements on these Crustacea as incidental taxa and therefore, part of communities in which commercial species reside. Some investigators, however, have provided more information on other Brachyura caught, such as catch incidence and biomass (Feder et al. 1981). Inclusion of noncommercial crab among taxa used for analyses of species associations have helped to indicate characteristic biological assemblages in which they are found (Smith and Bakkala 1982; Smith and Walters, 1982).

Sparse coverage in such reports may be due to several factors, including: 1) no commercial value; 2) low abundance; or 3) low

Table 5.1. Size, depth distribution, geographic range and habitat of Brachyura (excluding Chionoecetes bairdi and C. opilio) known to inhabit the S.E. Bering Sea.

Family, species[1]	maximum size	Depth distribution	Geographic distribution	Habitat
Atelecyclidae				
Erimacrus isenbeckii (Korean horsehair crab)	Male: 130 mm. Female: 80 mm.	10 - 360 m.	Bering Sea to Japan Sea	Mud, sand and gravel
Telmessus cheiragonus (Helmet crab)	60 mm.	Shore - 57 m.	Chukchi Sea to California, Siberia to Japan	Mud, sand and gravel
Cancridae				
Cancer magister (Dungeness crab)	Male: 250 mm.[2] Female: 165 mm.[2]	Shore - 90 m.	Aleutians to Baja California	Sand, mud
Cancer oregonensis	40 mm.	Shore - 272 m.	Bering Sea to California	Sand, mud, and empty shell of Balanus nubulus
Majiidae				
Chionoecetes angulatus	Male: 139 mm.	49 - 3000 m.	Pribilof Is. to Kamchatka and Oregon	Mud, sand
Oregonia bifurca	35 mm.	486 m. - 1375 m.	Western Bering Sea	Sand, mud with broken shell
Oregonia gracilis (Decorator crab)	50 mm.	Shore - 382 m.	Bering Sea to Japan and California	Among algae and eel grass
Hyas lyratus (Lyre crab)	50 mm.	Shore - 650 m.	Bering Sea to Washington	Sand, mud with broken shell
Hyas coarctatus alutaceus	70 mm.	Shore - 400 m.	Chukchi Sea to Japan and and northern coast Siberia, Beaufort Sea to West Greenland to Newfoundland	Sand, mud and gravel
Pugettia gracilis (Graceful kelp crab)	30 mm.	Shore - 80 m.	Unalaska to California	Eel grass and kelp
Mimulosa foliatus	30 mm.	Shore - 40 m.	Unalaska to Mexico	No information
Pinnotheridae				
Pinnixa occidentals	20 mm.[2]	18 - 430 m.	Unalaska to So. California	Commensal in burrows
Pinnixa schmitti	20 mm.[2]	10- 150 m.	Unalaska to San Francisco	Commensal in burrows and tubes
Fabia subquadrata	20 mm.[2]	Shore to 80 m.	Akutan Pass to California	Commensal on bivalve mollusks

[1] Table compiled from Rathbun 1918, 1925, 1930; Garth 1958; Kozloff 1973 and Otto et al. 1980.

[2] Measurement of width.

Table 5.2. Early life history information on several species of Brachyuran crabs found in the S.E. Bering Sea.

Species	Seasons female ovigerous	Period of hatch	Number of larval stages		Period of larval development[2]	Total length (mm) Zoea Megalops	Reference[5]
			Zoea	Megalops			
Erimacrus isenbeckii	NI[1]	Spring	5	1	~5 months	2.7 mm.- 7.2 mm.	1,2,3
Telmessus cheiragonus	June-Oct.	Spring	5	1	~5 months	2.3 mm.- 5.411111.	1,2,3,4
Cancer magister	Fall-winter	Early spring	5	1	4-5 months[3]	2.5 mm.- 11 mm.	5,6,7
Cancer oregonensis	NI	Jan., early spring	5	1	4-5 months	2.24 mm. - 7 mm.	6,8
Oregonia gracilis	Mar. - Sept.	Mar., Apr., June and July	2	1	4 weeks	2.5 mm. - 4.3 mm.[4]	2,9
Hyas lyratus	Year round	Apr. - July	2	1	5 weeks	2.5 mm. - 4 mm.[4]	9
Hyas coarctatus alutaceus	Late spring, early summer	May - July	2	1	NI	2.7 mm. - 4.2 mm.[4]	2,4,10
Pugettia gracilis	Year round	May and June	NI	NI	NI	NI	11
Fabia subquadrata	Summer	May - July	4	1	54 days[3]	.75 mm. - 2.1 mm.	12

[1] NI = No information.
[2] Time of development from 1st zoea to megalops.
[3] Time of development from 1st zoea to first benthic instar.
[4] Body length = does not include rostral length.
[5] References: 1) Kurata 1963b, 2) Makarov 1966, 3) Takeuchi 1969, 4) Feder and Jewett 1980, 5) Hoopes 1973, 6) Kendall et al. 1980, 7) Poole 1966, 8) Lough 1975, 9) Hart 1960, 10) Kurata 1963a, 11) Knudsen 1964, 12) Irwin and Coffin 1960.

matchability in survey gear used. Whatever the causes, too little available data on benthic distribution make spatial correlations between larval and adults tenuous. In this section, larval density and distribution will be summarized and related to benthic stocks if possible. The natural history of each species will be presented in taxonomic order. The results and discussion of the larvae of each taxon from our study will be presented with the most commercially important species (Erimacrus isenbeckii), first, followed, in descending order, by those taxa with the highest frequency of occurrence in samples.

5.1.1. Atelecylidae

Erimacrus isenbeckii (Korean horse hair crab), a recent target of an American fishery, occurs from depths of 10-360 m from the Bering Sea to the Japan Sea (Table 5.1). Males reach lengths of at least 128 mm, , and the largest recorded by NMFS in the southeastern Bering Sea weighed 1.95 kg (Otto et al. 1980). In 1981, 2.4 million pounds of Erimacrus were taken in the fishery (Otto et al. 1982). In 1982, however, less than a half a million pounds were caught, primarily due to lower market demands for the product (Otto et al. 1982). The fishery is centered around the Pribilof Islands where the majority of the 1980 estimate of 12.9 million sexually mature males with carapace length greater than 80 mm occurred. In years prior to 1980, fairly high concentrations were frequently reported just north of the Alaska Peninsula (Otto et al. 1980). Females, which are rarely larger than 80 mm in carapace length, (Sakurai et al. 1972, cited in Otto et al. 1980) are not part of the fishery, and accurate estimates of abundance and patterns of distributions are not available for them. During a survey of the epibenthos of the Bering Sea in 1975 and 1976, Feder and Jewett (1980) encountered Erimacrus in 25.6% of trawls made in water between 40 and 100m deep and 31.7% of trawls made in water between 100 and 200 m. Greatest biomass of Erimacrus occurred between 40-100 m depth and was 1.5% (9.073 g wet weight/m^2) of total epifaunal biomass in the Middle Shelf domain (Jewett and Feder 1981).

Literature on Erimacrus isenbeckii is scarce, but Yoshida (1941) gives the following account of its reproduction. Copulation takes place immediately after the female's first molt to maturity while the carapace is still soft. Eggs are extruded and carried on pleopods under the abdominal flap until zoeae hatch in early spring. Reproduction is inextricably linked to molting in most crabs on an annual basis and likely accounts for large differences in body size between larger sexually mature males and smaller females. Erimacrus females may molt only every other year which slows growth as does the need to put large quantities of energy into egg production (Yoshida 1941).

Telmessus cheiragonus, closely related to Erimacrus but smaller in size (approximately 60 mm in length), occurs in shallow more northerly shelf areas and near river estuaries (Makarov 1966; Table 5.1). It is distributed as far north as the Chukchi Sea. No literature on the reproduction of this species in the southeastern Bering Sea is currently available, but ovigerous females have been found in the Bering Sea from June through September (Feder and Jewett 1980; Lowry et al. 1981). Telmessus cheiragonus is exceedingly abundant in shallow coastal lagoons of the North Aleutian Shelf, particularly Izenbek Lagoon where it is an important consumer of eelgrass (Zostra marina) production (McRoy 1966; Barsdate et al. 1974).

Erimacrus and Telmessus are food items of secondary importance to other animals of the Bering Sea. Lowry et al. (1981) report that Telmessus is often eaten by the bearded seal and they cite Cunningham's (1969) statement that Erimacrus is occasionally eaten by the red king crab.

Kurata (1963b) described the 5 zoeal stages and megalops stage of both species from the Sea of Japan (Table 5.2). Unfortunatley, most of the text is in Japanese and it is not known if it contains other valuable life history information.

5.1.2 Cancridae

Cancer magister, currently of commercial importance in the Gulf of Alaska, has been reported to inhabit the Bering Sea (Garth 1958), but species lists prepared from more recent surveys of this area (Pereyra et al. 1976; Feder and Jewett 1980) do not include this species. Trawl work aboard the Miller Freeman in June 1982 netted several ovigerous female C. magister north of False Pass (D. Armstrong, personal observation). Dungeness crabs inhabit bays, estuaries, and the open ocean to depths greater than 50 m, from Amchitka Island on the Aleutian chain to Baja California. In British Columbia both males and females reach sexual maturity after twelve molts, two years after metamorphosis from the larval stage. Female growth then becomes slower relative to male, and females rarely attain widths greater than 165 mm, while males may grow to as wide as 250mm wide by a maximum age of ten years (Butler 1960, 1961). Mating occurs when adults migrate to shallow water in the spring and the female has molted. Females do not extrude eggs until the following fall. Egg development requires seven to ten months (Hoopes 1973).

Cancer oregonensis is a small crab up to 40mm carapace that lives on rocky shores and in empty shells of *Balanus nubulus* at greater depths in the Bering Sea. No information is available in the literature on its growth and reproduction.

Cancer spp. are eaten by the Irish lord (*Hemilepidotus jordani*) and the rock sole (*Lepidopsetta bilineata*) (Feder and Jewett 1981).

Poole (1966) describes the five zoeal stages and megalops stage of *Cancer magister* reared in a laboratory on the coast of California. Lough (1975) discussed larval stages and development of *C. oregonensis* from the plankton off the coast of Newport, Oregon.

5.1.3 Majidae

The family Majidae includes, in addition to *Chionoecetes* spp., several small "decorator" crabs of no commercial importance that are distributed widely throughout the southeastern Bering Sea. *Hyas coarctatus alutaceus* is found from the southern Bering shelf to the Arctic, and *Oregonia gracilis* and *Hyas lyratus* occur in more southerly areas (McLaughlin 1963; Feder and Jewett 1980). During epibenthic assessment of the southeastern Bering Sea in 1975 and 1976, *H. lyratus* occurred in 22.1% of trawls taken between 100 and 200 m, while *H. coarctatus* alutaceus was encountered in 47.8% of the trawls made between 40 and 100 m (Feder and Jewett 1980). Wet weight biomass of this last species was 0.028 g/m^2 and comprised only 0.6% of total epifaunal biomass in the Middle Shelf Domain (Jewett and Feder 1981). The kelp crabs Pugettia gracilis and Mimulosa foliatus inhabit the area near Unalaska Island (Rathbun 1925).

Accounts of reproduction of these species are scant or nonexistent, but most mating appears to be associated with females molting (Knudsen 1964). Ovigerous females of the species Oregonia gracilis, Hyas coarctatus altaceus and H. lyratus have been reported from the southeastern Bering Sea in the late spring and early summer (Feder and Jewett 1980). Fecundity in Puget Sound was reported by Knudsen (1964) who found that female Oregonia gracilis 17 to 25 mm in carapace length carried 2,800 to 17,400 eggs, and female Pugettia gracilis 20 to 25 mm in length carried 6,200 to 13,300 eggs.

Several of these species have been reported as food items for Pacific cod (Gadus macrocephalus, sculpins, rock sole (Lepidopsetta bilineata), and the sea-stars Asterius amurensis and Pycnopodia helianthodes (Feder and Jewett 1981). Hyas coarctatus alutaceus is an important food item in the Bering Sea bearded seal diet (Lowry and Frost 1981) and of secondary importance for red king crab (Cunningham 1969).

All majid crabs molt through two zoeal stages and a megalops stage (Hart 1971). Hart (1960) described laboratory-reared larvae of Oregonia gracilis and Hyas lyratus from British Columbia. Hyas coarctatus *alutaceus* larvae were collected from the Sea of Japan and described by Kurata (1963a). Other species of majid crab larvae have not been described (Table 5.2), but Hart's key (1971) allows easy separation of the sub-families.

Chionoecetes angulatus may attain a carapace length of 139 mm as adults and are distributed on the continental slope and deeper in the southeastern Bering Sea. Several were encountered at depths greater than 140 m during a NWAFC continental shelf groundfish assessment, but abundance estimates were not made (Otto et al. 1979).

5.1.4. Pinnotheridae

Unlike other families discussed thus far, pinnotherids are generally commensal crabs that reside in polychaete tubes and burrows or in mantle cavities of bivalves and gastropod. Data on the distributions of pea crabs in the southeastern Bering Sea are not available. Irwin and Coffin (1960) suggest that the growth of *Fabia subquadrata* is related to the growth of its host (a bivalve mollusk) and describe the early life history of laboratory-reared larvae from the coast of Washington. The larval stages of *Pinnixa occidentals* and *P. schmitti* have not been described. There is also a conflict in the literature as to the number of zoeal stages for the Pinnotheridae. Irwin and Coffin (1960) report four zoeal stages for *Fabia subquadrata*, while Lough (1975) reports five for the same species and unidentified species of *Pinnixa* from the plankton of the Oregon coast.

5.2 Purpose and Scope

The purpose of this section is (1) to both extend and summarize data sets discussed in the annual report of Armstrong et al. (1981) by the inclusion of 1981 data now available, and (2) to examine the spatial patterns of larval distribution and density of the non-*Chionoecetes* Brachyura in the southeastern Bering Sea. This information should allow a better understanding of where and when larvae of a taxon may be most susceptible to the detrimental effects of oil and it should extend the knowledge of a taxon's early life history and ecology.

5.2.1 Taxonomy

Identification of decapod larvae in this section was made to the taxonomic level listed in the right-hand column of Table 5.3. Because of limited literature on larval descriptions of crab species known to inhabit this region (left-hand column, Table 5.3), only larvae of *Erimacrus isenbeckii* and *Telmessus cheiragonus* were identified to species. The literature listed in Table 5.4 was used to identify species to the lowest possible taxonomic level.

5.2.2 Patterns of Larval Distribution Examined

After all data from the years 1976-1981 were summarized for brachyuran larvae, they were analyzed to determine the following patterns of distribution and density: 1) vertical, 2) temporal, and 3) horizontal. However, certain limitations of the data in this study are evident that preclude a thorough analysis of these factors for all taxa, because the plankton samples available are from collections intended for other uses. Periods and regions from which samples were collected varied

Table 5.3. Species list of non-*Chionoecetes* Brachyura known to inhabit the S.E. Bering Sea, and taxonomic level to which they were identified.

Taxa	Level of Identification
Atelecyclidae	
Erimacrus isenbeckii	*E. isenbeckii*
Telmessus cheiragonus	*T. cheiragonus*
Cancridae	
Cancer magister	*Cancer* spp.
C. oregonensis	
Majidae - Subfamily Oregoniinae	
Hyas coarctatus alutaceus	non-*Chionoecetes* Oregoniinae
H. lyratus	
Oregonia gracilis	
Majidae - Subfamilies Acanthonychinae/Pisinae	
Mimulosa foliatus	Acanthonychinae, Pisinae
Pugettia gracilis	
Pinnotheridae	
Fabia subquadiata	Pinnotheridae
Pinnixa occidentals	
P. schmitti	

Table 5.4. Brachyura taxa identified among larval decapods, larval stages and references used for identifications.

Species/Taxon	Larval Stages	References
Erimacrus isenbeckii	Stages I-V & Meg	Hart 1971, Kurata 1963b, Jewett & Haight 1977
Telmessus cheiragonus	Stages I-V & Meg.	Hart, 1971, Kurata 1963b, Jewett & Haight 1977
Cancer spp.	Stages I-V & Meg	Hart 1971, Poole 1966, Lough 1975
non-Chionoecetes Oregoniinae	Stages I, II & Meg	Hart 1971, Jewett & Haight 1977
Subfamily Acanthonychinae and/or Pisinae	Stages I, II & Meg	Hart 1971, Lough 1975
Pinnotheridae	Zoea &Meg	Hart 1971, Lough 1975

annually, which resulted in little consistency of spatial and temporal data from which to delineate patterns of distribution and density. These limitations required that the data be analyzed in the following ways: 1) in most cases, data from all years were combined when examining spatial distribution of taxon; 2) intra- and interannual comparisons could only be made for three years for the non-*Chionoecetes* (Malidae referred to here as Oregoniinae; See Section 4.0 *Chionoecetes* and for Pinnotheridae; and 3) these two taxa were the only ones analyzed for vertical patterns of larval distribution based on adequate representation in the MOCNESS samples of the years 1980 and 1981.

5.3 Results, Discussion, and Summaries

5.3.1 Vertical Distribution

Vertical distributions of Oregoniinae and Pinnotheridae were examined (1) to assure that bongo net samples collected routinely from 60 m to the surface, or to within 10 m of the bottom in depths less than 60 m, included representative numbers of larvae on which to base abundance estimates, and (2) to determine the vertical location of the majority of these larvae in the water column.

Criteria for the analysis of the vertical distribution of individual taxa were established and applied to 198(I and 1981 MOCNESS stations in order to determine the mean percentages of larvae located at different depth intervals. These criteria are: 1) a total of six larvae of each taxon had to be counted in the subsample examined before an individual MOCNESS station was used as an observation; and 2) at least five stations had to satisfy criterion No. 1 before the taxon was analyzed for patterns of vertical distribution. After these criteria were met, a taxon was analyzed by calculating the percentage of total larvae that were caught at successive 20 m depth intervals. These percentages were summed by depth intervals for all stations and the mean and standard deviation calculated.

The only two taxa that satisfied the criteria outlined above were **Oregoniinae** and **Pinnotheridae,** which were collected respectively at 30 and 7 of the combined 1980 and 1981 MOCNESS stations (all 7 **Pinnotherid** stations came from 1981 collections). Furthermore, of the 30 stations with adequate **Oregoniinae** larvae, 63% were sampled from the surface to below 80 m (in 20 m intervals) and 93% were sampled to 80 m depth. All 7 **Pinnotheridae** stations were sampled below 80 m.

The means and one standard deviation of the percentage of larvae collected at each -20 m depth interval of the 30 **Oregoniinae** stations are shown in Figure 5.1. The majority of larval **Oregoniinae** (87%) were caught in the upper 40 m: 58% in the upper 20 m and 29% between 20 and 40 m. Most of the **Pinnotheridae** larvae (75%) were also located in the upper 40 m of the water column at the 7 stations examined for their vertical distribution (Figure 5.2). The upper 20 m contained 42% of these larvae and 33% occurred between 20 and 40 m.

Although the data for the other taxa that include **Erimacrus isenbeckii, Telemessus cheiragonus,** Cancer spp. and the subfamilies **Acanthonychinae** and **Pisinae** did not satisfy the criteria established for

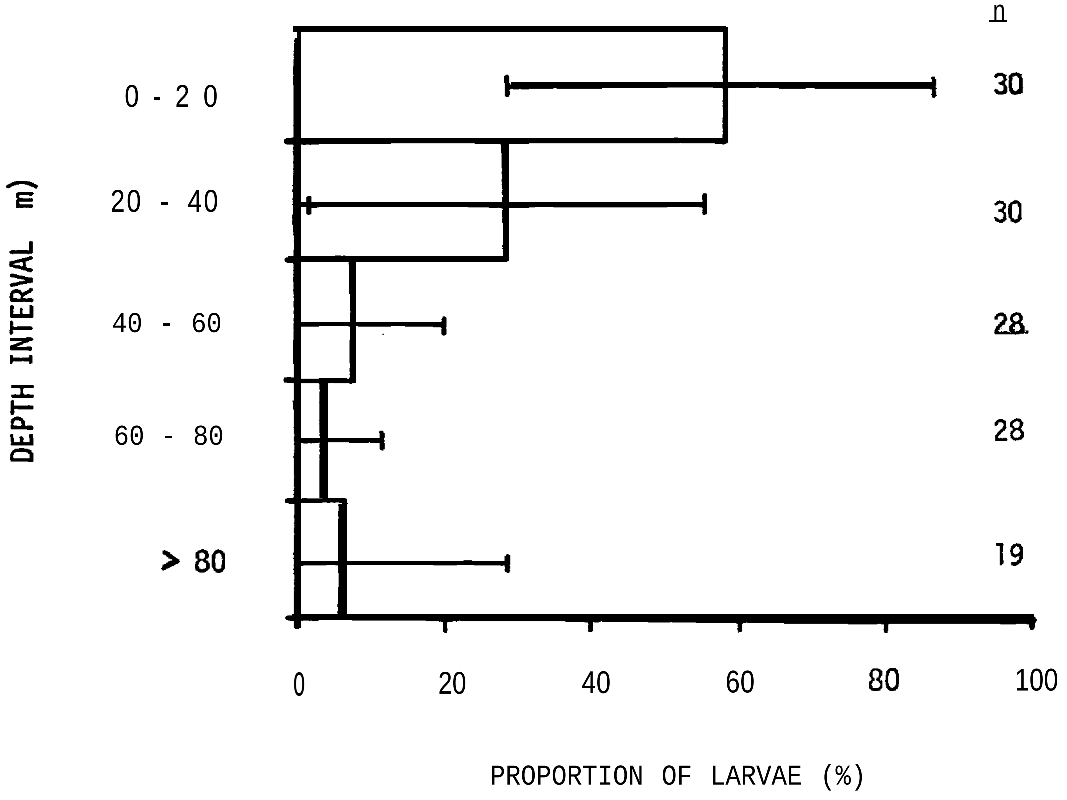


Figure 5.1 Vertical distribution of Oregoniinae brachyuran larvae in 1980, 1981 MOCNESS samples from the southeastern Bering Sea. The bars represent the mean percentage of larvae (±1 standard deviation) collected in 20 m intervals from 0-80 m and deeper than 80 m. N equals the number of stations sampled from which at least six larvae of the taxon were observed and from which the mean of each 20 m interval was calculated.

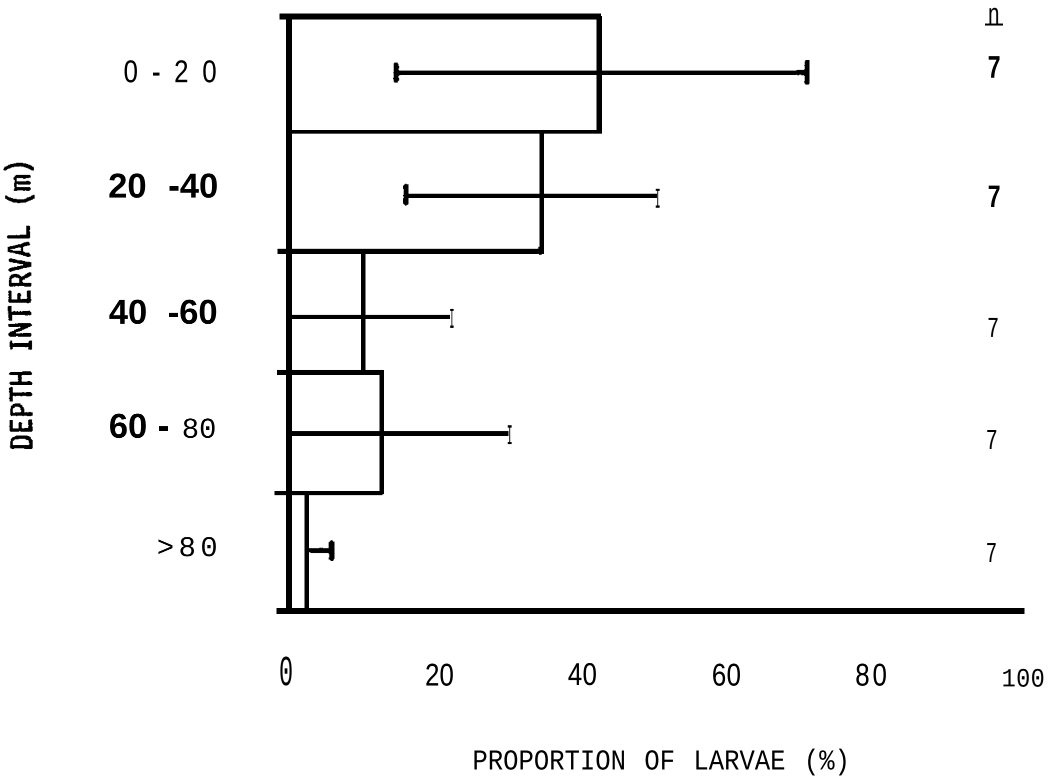


Figure 5.2 Vertical distribution of Pinnotheridae larvae in 1981 MOCNESS samples from the southeastern Bering Sea. The bars represent the mean proportions of larvae (±1 standard deviation) collected in 20 m intervals from 0-80 m and deeper than 80 m. N equals the number of stations from which at least six larvae of the taxon were observed and from which the mean proportion of each 20 m interval was calculated.

examining their vertical larval distribution, a brief examination of vertical distribution of these larvae in the 1980 and 1981 MOCNESS stations suggest that they too were concentrated in the upper 40 m of the water column. Thus, 40 m can be considered a reasonable lower depth limit in calculating density of these taxa in the water column.

Summary

1) The majority of Oregoniinae and Pinnotheridae occurred in the upper 40 m of the water column sampled by the MOCNESS year in 1980, 1981.

2) Although analyses of the larval vertical distribution of the other Brachyura taxa was not possible, that data too (1980 and 1981 MOCNESS) suggest that the majority of these larvae appeared in the upper 40 m..

5.3.2 Temporal and Horizontal Patterns of Larval Distribution and Density

Temporal patterns of larval distribution of the non-*Chionoecetes* Brachyura during the years 1976-1981 were examined to determine when these larvae were present in the plankton of the southeastern Bering Sea (Fig. 5.3). Criteria were established to assure a conservative approach to examination of the duration of larval stages (molt-frequency). These criteria were: 1) $n \geq 6$, where n is the number of larvae of an individual taxon observed in a sample, and 2) at least three samples were used to calculate the mean percent of each larval stage during each one-week interval. Consequently, only one taxon, Oregoniinae, was examined for molt-freqency patterns and only in the year 1981 because all other taxa were collected too sporadically in time and space to satisfy the criteria above.

Horizontal patterns of distribution and density were determined for zoeae and megalopae from the spring and summer months of the years 1976-1981 combined in the cases of Erimacrus isenbeckii, Cancer spp., Telemessus cheiragonus and the subfamilies Acanthonychinae and/or Pisinae. Most larvae were present in May and June; therefore this was the time period used to calculate their frequency of occurrence by stratum. These taxa were relatively uncommon and too little data were available from separate years for interannual comparisons. However, Oregoniinae and Pinnotheridae were well represented (over 20% of all annual stations produced zoeae and/or megalopae) in the years 1978, 1980 and 1981, which allowed both intraannual comparisons between sub-areas or strata (see Section 2.8), and interannual comparisons between the three years. Samples from February and March 1978 and October 1980 were excluded from such analyses because they were collected only in a single year.

Mean densities, standard deviations, and ranges of values for Erimacrus isenbeckii, Cancer spp., Telemessus cheiragonus and Acanthonychinae and/or Pisinae larvae were calculated for each stratum by using densities only from stations at which these larvae occurred. While interannual difference in timing of hatch and density of larvae would make such averaging quantitatively inaccurate, these relatively rare taxa were each grouped over 1976-1981 for a qualitative sense of where larvae predominated. Mean densities of Oregoniinae and Pinnotheridae were calculated for April, May, and June of 1978, 1980, and 1981, and also July of 1981. Within strata, both positive values (stations where larvae were caught) and zero stations were averaged for comparisons and contrasts of **intra-** and interannual density and distribution along or across the shelf.

5.3.2.1 Erimacrus isenbeckii

Seasonal Occurrence: Larvae of this species were generally uncommon but were collected in the plankton from mid-April to late-June when data from all the sampling periods of the years 1976-1981 were combined (Fig. 5.3). Individual larval stages were present as follows: Stage I (S1), from late-April to mid-June; S11, from mid-April to mid-June; S111, from mid-May to mid-June; SIV in mid-April and June; SV, in June; and **megalops** larvae in June.

Because the seasonal occurrence of S1 and IV larvae did not overlap from year to year, gaps appear in the bars representing occurrence of these stages over the sampling periods of all years combined in Figure **5.3**

Distribution: Larvae **of E. isenbeckii** were collected at only 9% of the stations analyzed from the years 1976-81. Of the samples with larvae, 85% were collected in May and June, which was therefore the time frame selected in which to examine frequency of occurrence. Frequency of occurrence (percent) of **Erimacrus** larvae is listed by stratum in Table 5.5 and the locations of **stations** at which **Erimacrus** larvae were collected are plotted on a map of the study area in Figure 5.4. These results show that larvae **were** collected throughout the study area, but were most

Table 5.5. Frequency of occurrence of *Erimacrus isenbeckii* within each stratum in May and June of the combined years 1976-1981. Percentages were derived from the proportion of all stations within each stratum at which *E. isenbeckii* were found (see Fig. 2.21). As noted in the text, only 9% of the total stations analyzed in all years contained larvae of this species.

Stratum number	Frequency of occurrence (percent) of larvae within strata
1	7
2	10
3	11
4	18
5	19
6	31
7	6
8	3
9	6
10	14
11	38

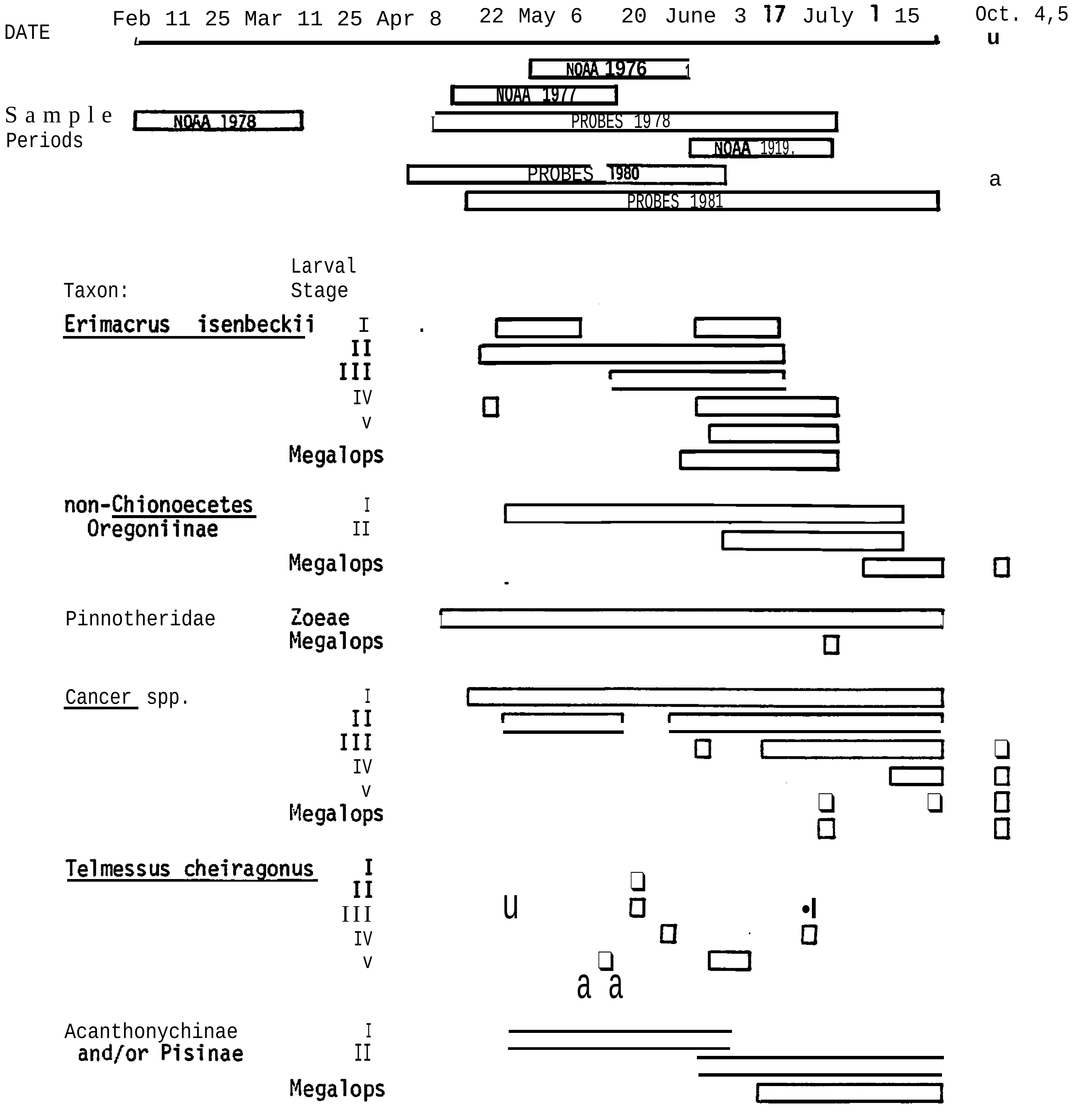


Figure 5.3 Seasonal occurrence of larval stages of selected beachyuran taxa in the southeastern Bering Sea in the years 1976-1981. Also depicted are the seasons and durations of cruises that collected zooplankton samples from which these data are derived (see Section 2.0 for more details). Gaps in bars showing duration of larval stages are due to relative scarcity over much of the total sampling period.

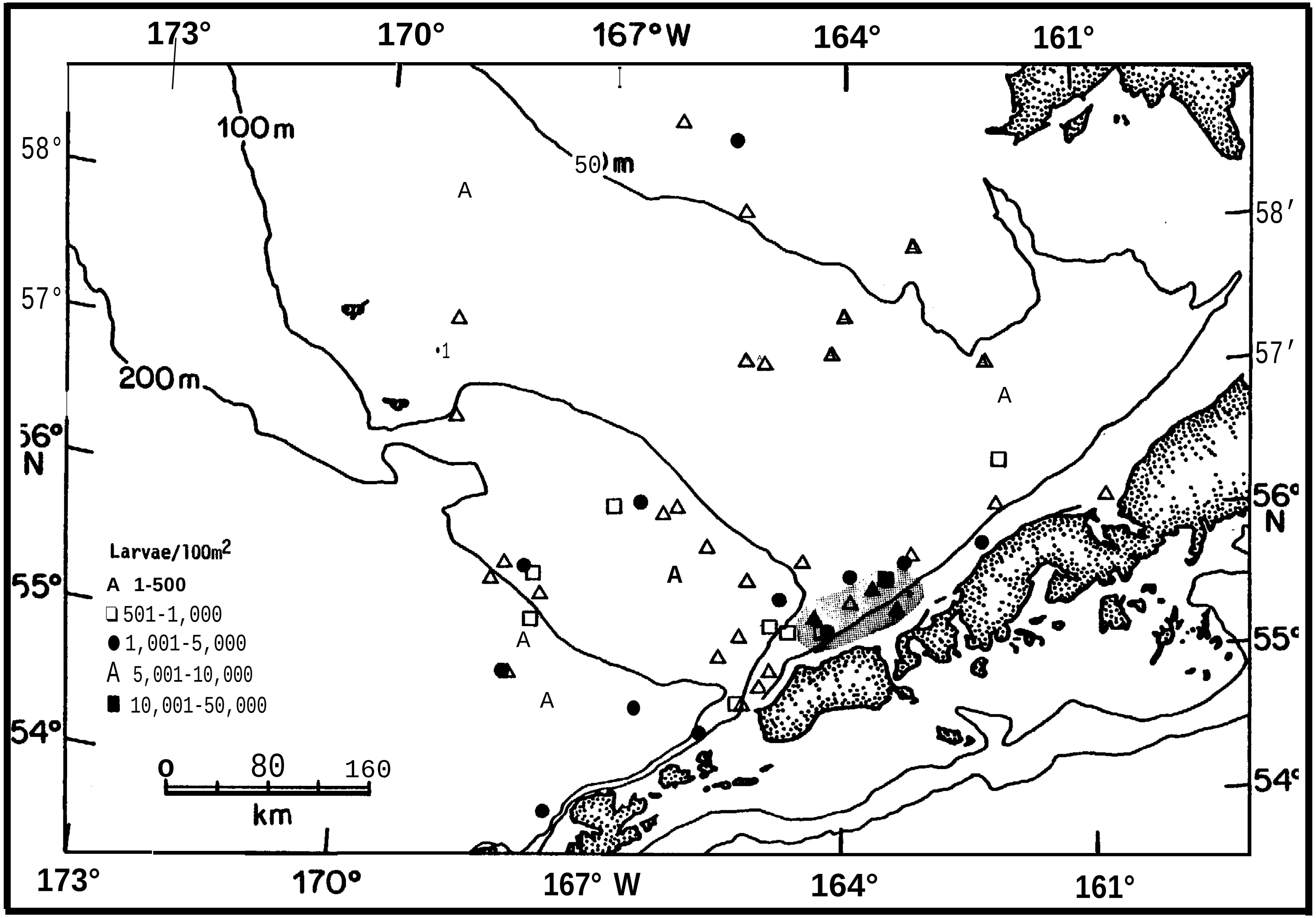


Figure 5.4 Locations and densities of *Erimacrus isenbeckii* larvae collected in the southeastern Bering Sea in the years 1976-1981. Locations where no larvae were found are omitted, but all station locations for these years are illustrated in Figures 2.1 - 2.18.

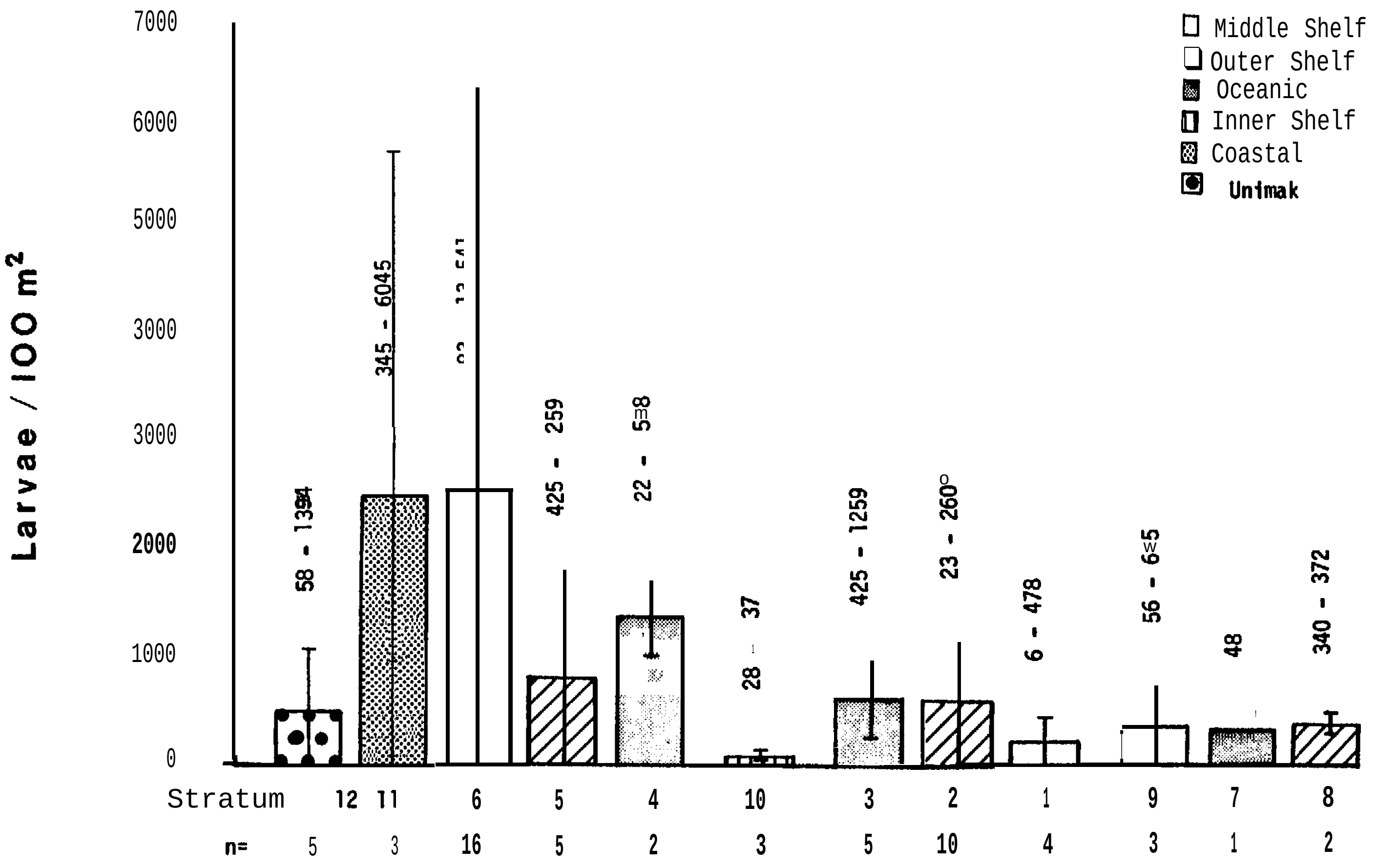


Figure 5.5 Mean density and one standard deviation of **Erimacrus isenbeckii** larvae in the southeastern Bering Sea for all years, 1976-1981, combined. The range of densities from which these means were calculated are listed above each corresponding bar; while the number of samples used to calculate each mean, n, are listed on the lower axis. Stations at-which no larvae were found were not used in calculating the mean density of **Erimacrus isenbeckii** larvae within each stratum (see Fig. 2.8).

abundant in strata 6, 11, and 12 in an area near their junction at eastern Unimak Island and Bechevin Bay (Figure 5.4). This pattern is somewhat in accord with NMFS groundfish survey data that shows relatively low density of female E. isenbeckii throughout the southeastern Bering Sea, with somewhat greater numbers near Unimak Island and at the Pribilof Islands (Otto et al. 1982). Perhaps because few samples were collected in this latter location the density of larvae at the Pribilofs was very low (Fig. 5.4). However, to date there is no definitive information to indicate important regions of female abundance or larval hatch but nearshore areas are suspected.

Density: Mean density ± 1 standard deviation, the range of densities and the number of stations at which larvae were present for each stratum are shown in Figure 5.5. Strata are labeled as to the regime (inner, middle, and outer shelf; oceanic zone; Alaska coastal and Unimak Island) in which they are located. Individual stations sometimes contained fairly high densities of larvae (in excess of $5,000/100m^2$), but commonly numbers were very low, often less than $500/100m^2$ (Figure 5.4). Average densities were highest in strata 6 and 11 with over $2,000/100\ m^2$. But the enormous range (83-13,541 larvae/100 m^2 in stratum 6) and standard deviations associated with the data reflect the vagaries of interannual differences in seasonal occurrence and densities of larvae. Stations from other strata usually lacked E. isenbeckii larvae or contained them in low densities of a few hundred/100 m^2 (Figs. 5.4, 5.5; in comparison with values in excess of 100,000/100 m^2 for Tanner larvae in Sec. 4.0).

Long-shelf density of Erimacrus larvae seemed to be greatest along the 100 m and 200 m isobaths of the middle shelf and oceanic regimes. Again the confluence of 50 m and 100 m isobaths just north of Unimak Island was the area of greatest occurrence and density (Fig. 5.4).

Summary

1) Erimacrus isenbeckii larvae were collected at 9% of all stations sampled during 1976-1981.

2) These larvae were generally distributed throughout the study area but their frequency of occurrence was higher near the Alaska Peninsula in the coastal, middle shelf and Unimak Is. regimes.

3) Mean densities of larvae were appreciably higher in the eastern region of the southeastern Bering Sea than in the central and western regions, while larval densities were very low at the Pribilofs which may reflect the fact that few samples were collected there.

4) Zoeal stages were found in April through June and megalops larvae in June only.

5.3.2.2 Oregoniinae (Hyas spp., Oregonia spp.)

Seasonal Occurrence: Larvae of this taxon were present in the plankton from mid-April to early-October when all data were combined for years 1976-1981 (Fig. 5.3). Each larval stage appeared as follows: S1, from mid-April to mid-July; S11, from early-June to mid-July and megalops larvae from early to mid-July and October. This time sequence was refined somewhat based on data from 1981 that was used for molt-frequency analysis (Fig. 5.6). The samples used for this analysis, late May through about June 10, showed all larvae were S1 zoeae (90-99%). From June 13 to July 4 S11 were dominant, and after July 11 megalopae were the most abundant stage. Assuming that megalopae require about one month for development (similar to Tanner larvae, Section 4.0), the majority of the population would have metamorphosed in mid- to late-August in 1981. Add to this time about one month for S1 zoeal development, and total planktonic time for this taxon would be about 3.5 months.

Distribution: Larvae of this taxon were found at 42% of all stations sampled in 1976-1981. Of these stations, 77% were collected in May and June, which was therefore used as the time frame for analyses of interannual densities between strata. During May and June, larval Oregoniinae were most frequently (> 60% of stations) collected in strata 1, 4, 5, 9, 10 and 12, and least frequently (< 30% of stations) in strata 7, 8, and 11 (Table 5.6; See Fig. 2.8 for strata). This May/June distribution and density are shown in Figures 5.7, 5.8, and 5.9 for the years 1978, 1980 and 1981, respectively. There tend to be fewer larvae over the middle and inner shelf to the extent they were collected, and more along the 100m isobath and outer shelf. High densities are shown near western Unimak Island in all years (Figs. 5.7-5.9) which is likely due to the presence of Oregonia gracilis spp. that were found in high abundance nearshore in 1982 (Armstrong, unpublished data).

Density: Because sampling within all strata in each year was not consistent, it is somewhat difficult to compare larval densities between

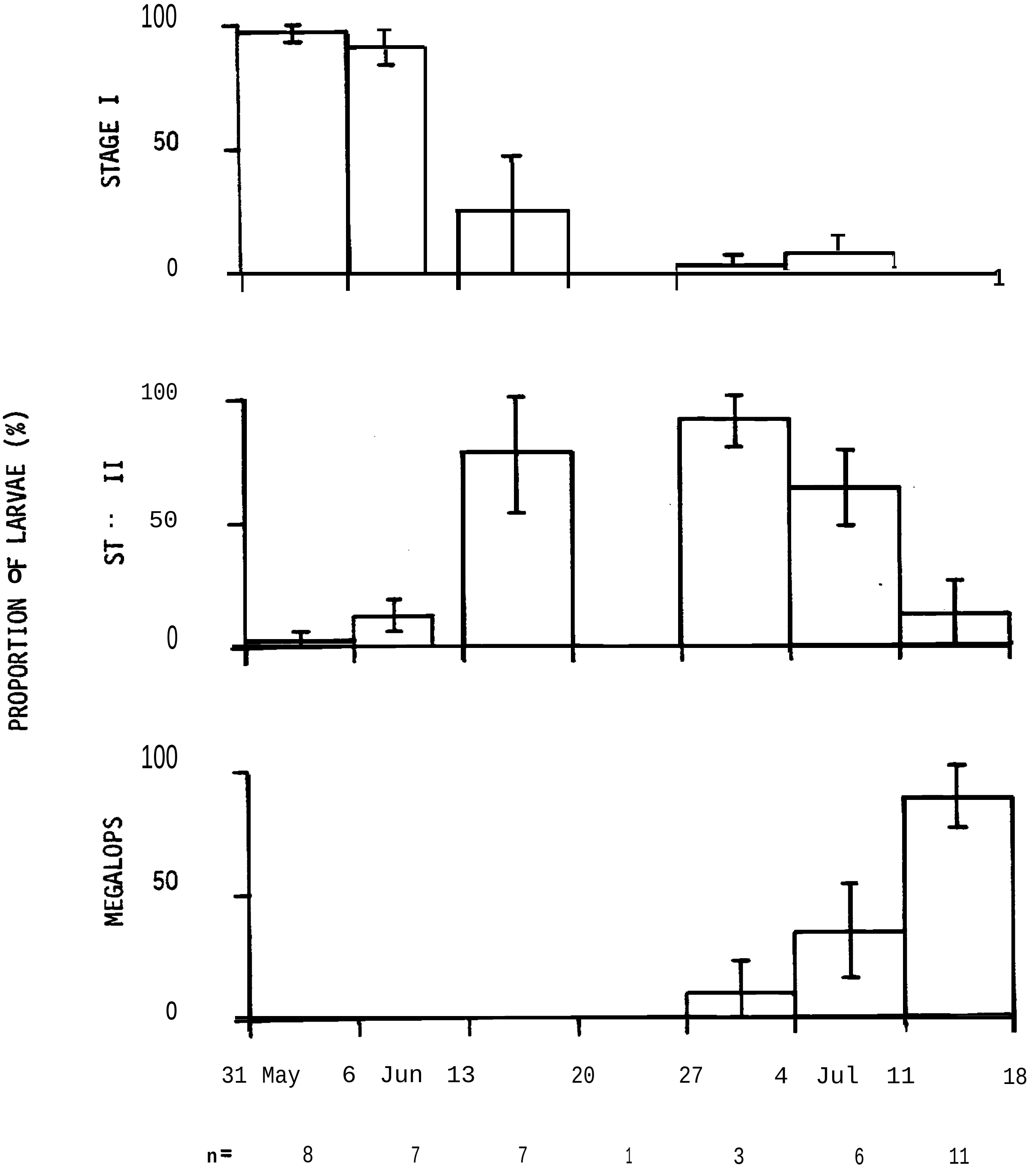


Figure 5.6 Frequency-of-occurrence of larval stages of Oregoniinae during weekly intervals from 31 May to 18 July 1981. The number of samples used to calculate the mean percent and one standard deviation of each stage for each week is equal to no Molt frequency from stage I to stage II to megalopae is about 30-35 days.

Table 5.6. Frequency of occurrence (as percent) within each stratum of **Oregoniinae** in May and June of the combined years 1976-1981. Percentages were derived from the proportion of all stations each stratum at which **Oregoniinae** were found.

Stratum number	Frequency of larval occurrence within each stratum percent)
1	60
2	53
3	44
4	82
5	62
6	33
7	-25
8	28
9	
10	71
11	25

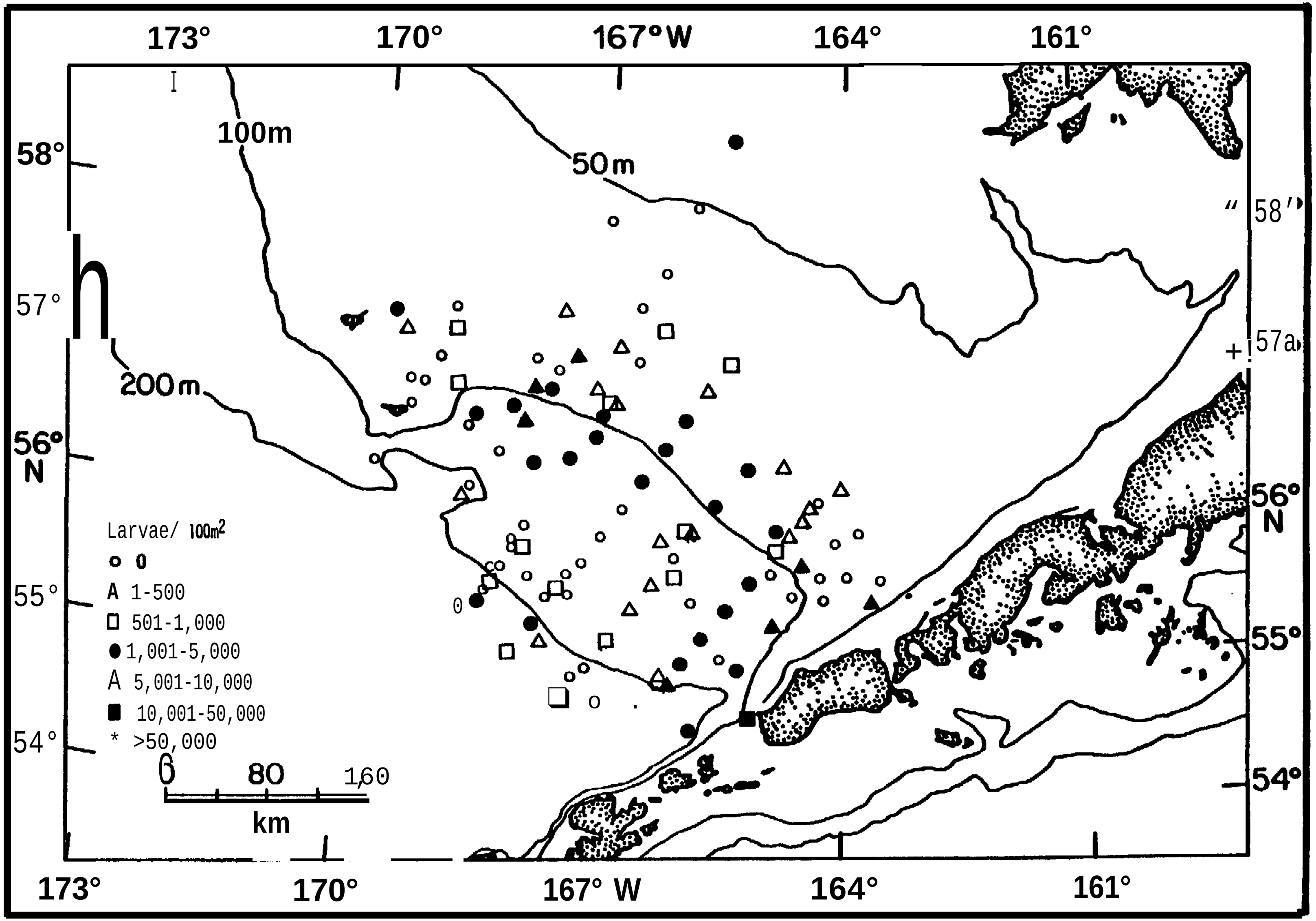


Figure 5.7 Distribution and abundance of **Oregoniinae** larvae **in May/June** 1978.

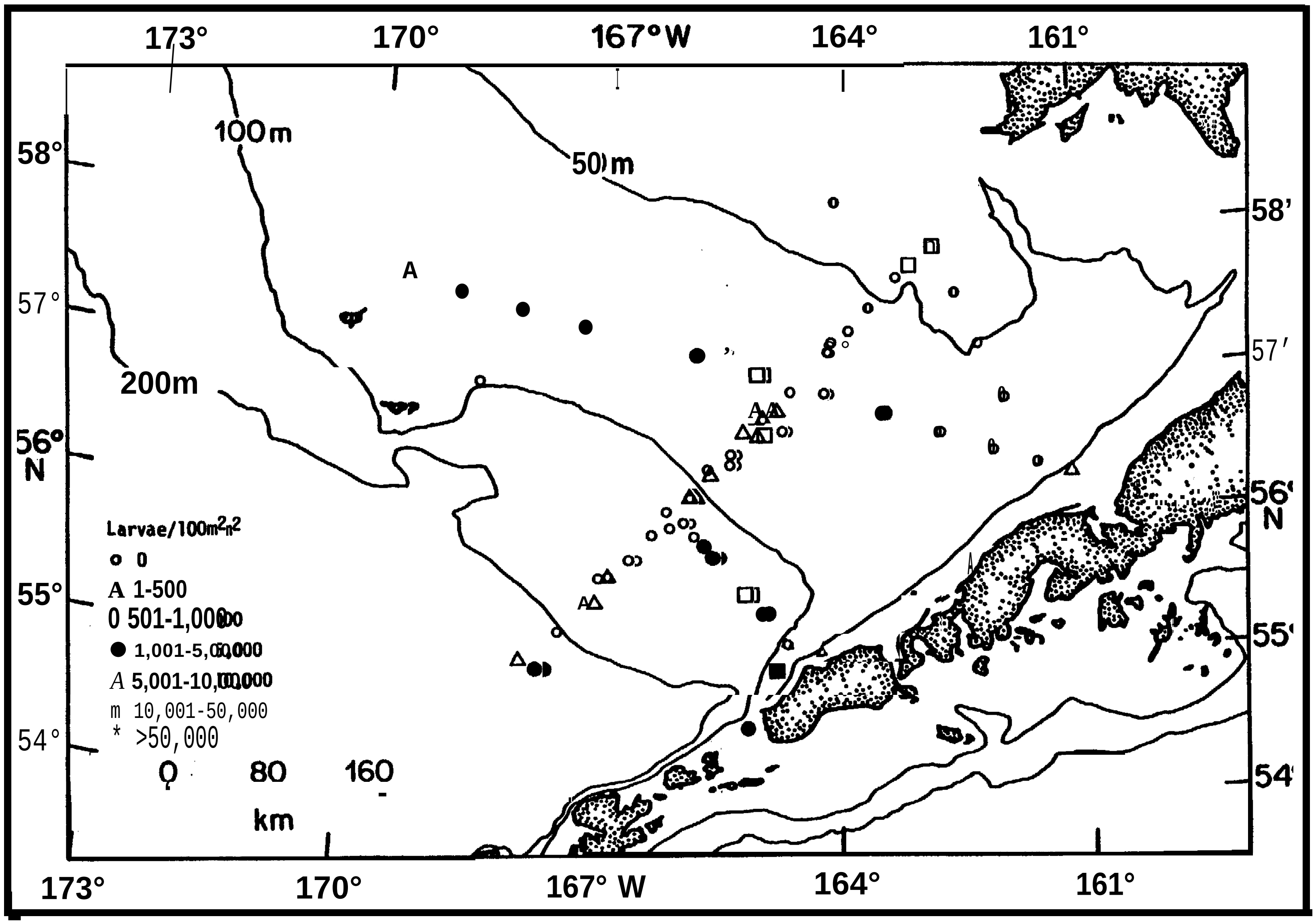


Figure 5.8 Distribution and abundance of Oregoniinae larvae in May/June 1980.

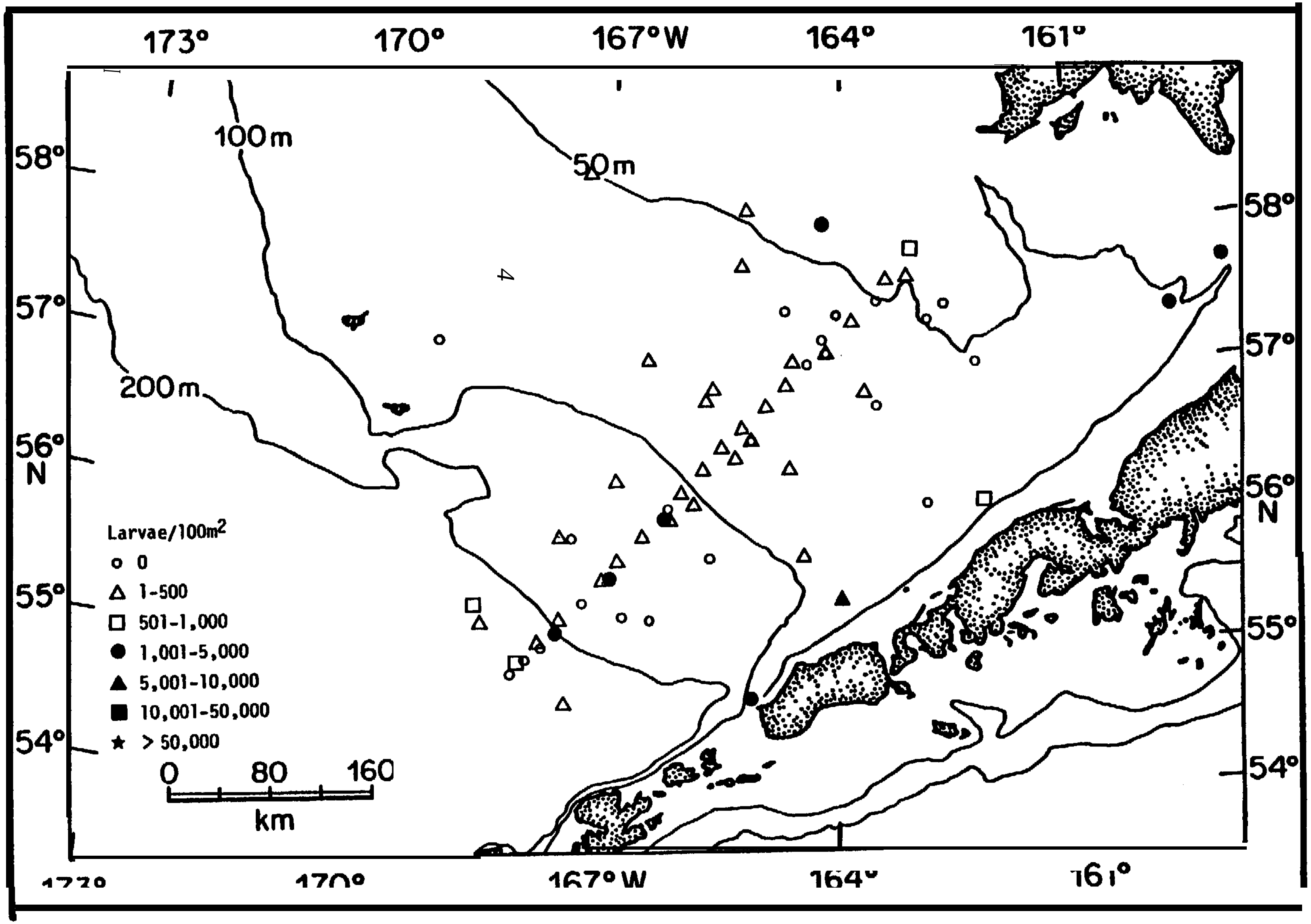


Figure 5.9 Distribution and abundance of Oregoniinae larvae in May/June 1981.

them. Contrasts can be made to highlight seasonal, regional and annual differences in densities (Figs. 5.10-5.12). These mean larval densities were only calculated when the number of stations sampled in each stratum during the time period indicated was $\geq$ 5; consequently, densities for some strata are not given.

Some seasonal changes in regional densities were found when April was compared to May/June (Fig. 5.10 a & b) in 1978. There was apparently an earlier hatch over the middle shelf than over the outer shelf. Strata 1 and 9 had mean densities of about 1500-2500 larvae/100 m^2 while strata 2 and 8 had virtually none (Fig. 5.10a). In May/June larvae were widely distributed over the shelf but more abundant over the outer (1142-2222 larvae/100 m^2) than the middle shelf (922 -1845 /100 m^2). It is not known to what extent this shift in regional density represents differences in timing of species hatch across the shelf (Hyas spp. vs. Oregonia spp.) and/or intraspecific variability between regions (i.e. strata).

For interannual comparison of larval densities, May/June samples were available from strata 1, 2, and 6 in 1978, 1980 and 1981 (Figs. 5.10b, 5.11, 5.12a). Although standard deviations about mean densities of each stratum are large, larval density was higher in 1978 than in either 1980 or 1981. The latter two years showed very low abundance of larvae in the plankton; densities were 2-18 times less than those found in 1978. The nature of spawner-recruit relationships for this taxon are unknown, and so the extent to which more or less pelagic larvae indicate good or poor year-classes cannot be assessed. Still low larval abundance

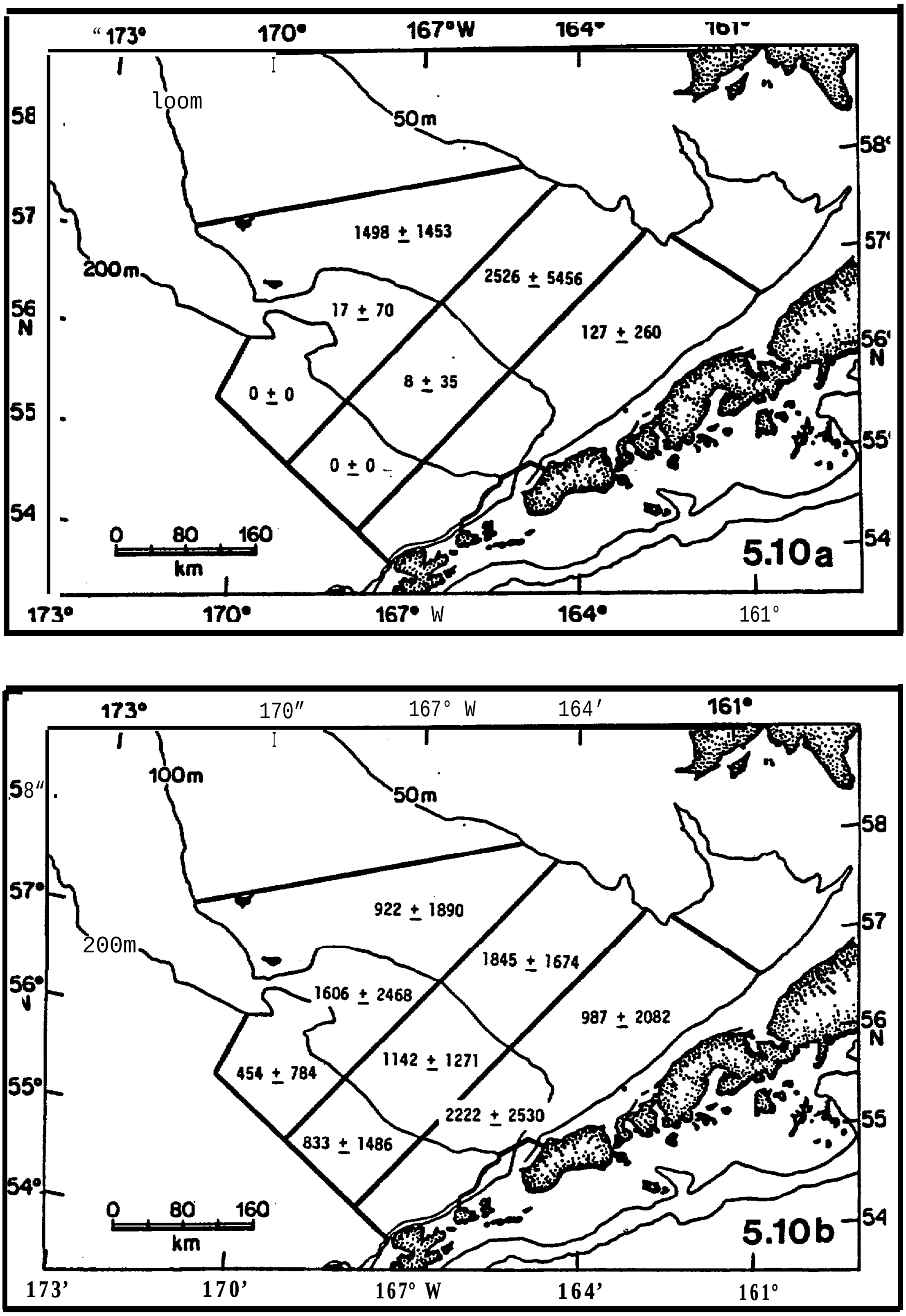
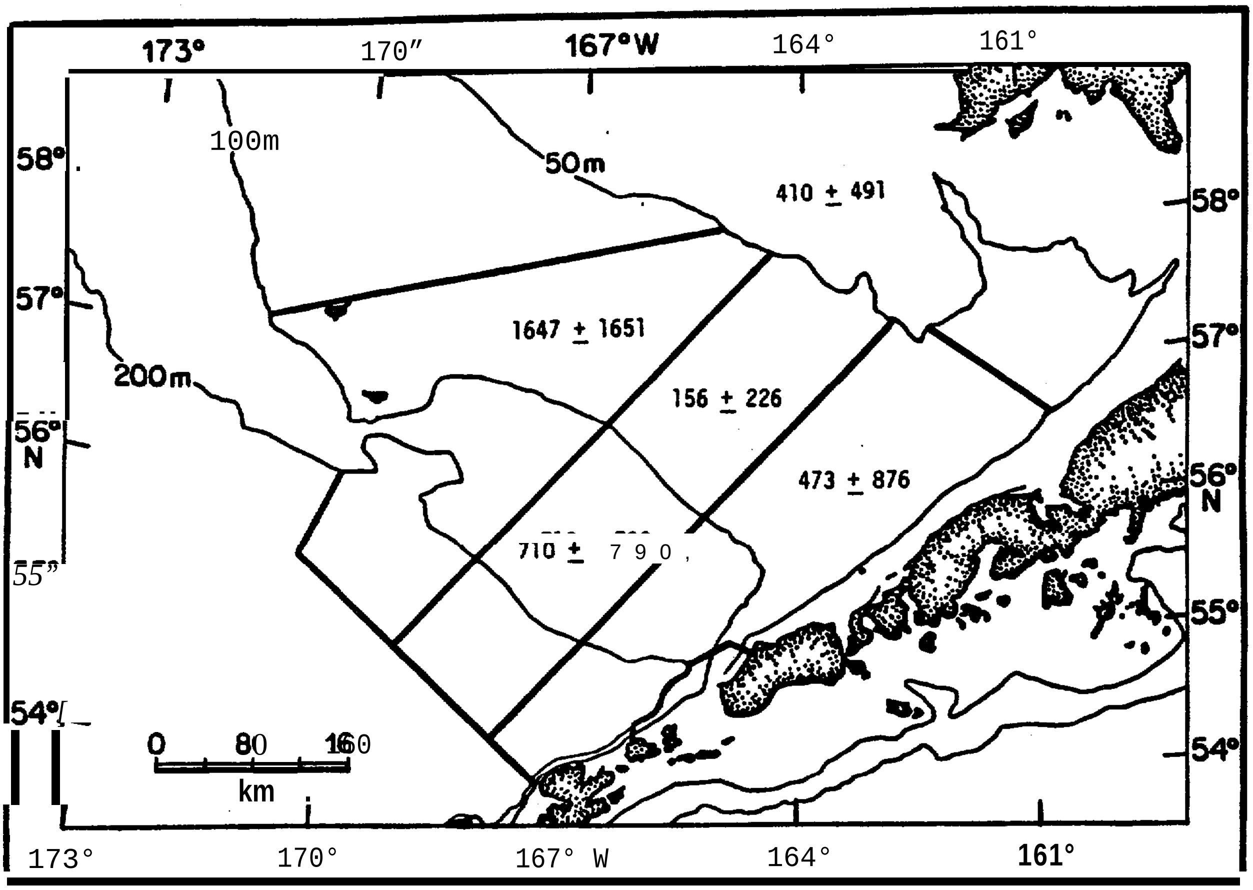


Figure 5.10 Distribution of mean density with one standard deviation of non-Chionoecetes Oregoniinae larvae/100m^2 in the S.E. Bering Sea in April (a) and May and June (b) of 1978. Means were calculated with zeros for stations at which no larvae were found and for only those strata in which the number of samples collected during these time periods was ≥ 5.



5.11 Distribution of mean density with one standard deviation of non-Chionoecetes Oregoniinae larvae/100m^2 in the southeastern Bering Sea in May and June of 1980. Means were calculated with zeros for stations at which no larvae were found and for only those strata in which the number of samples collected during this time period was ≥ 5.

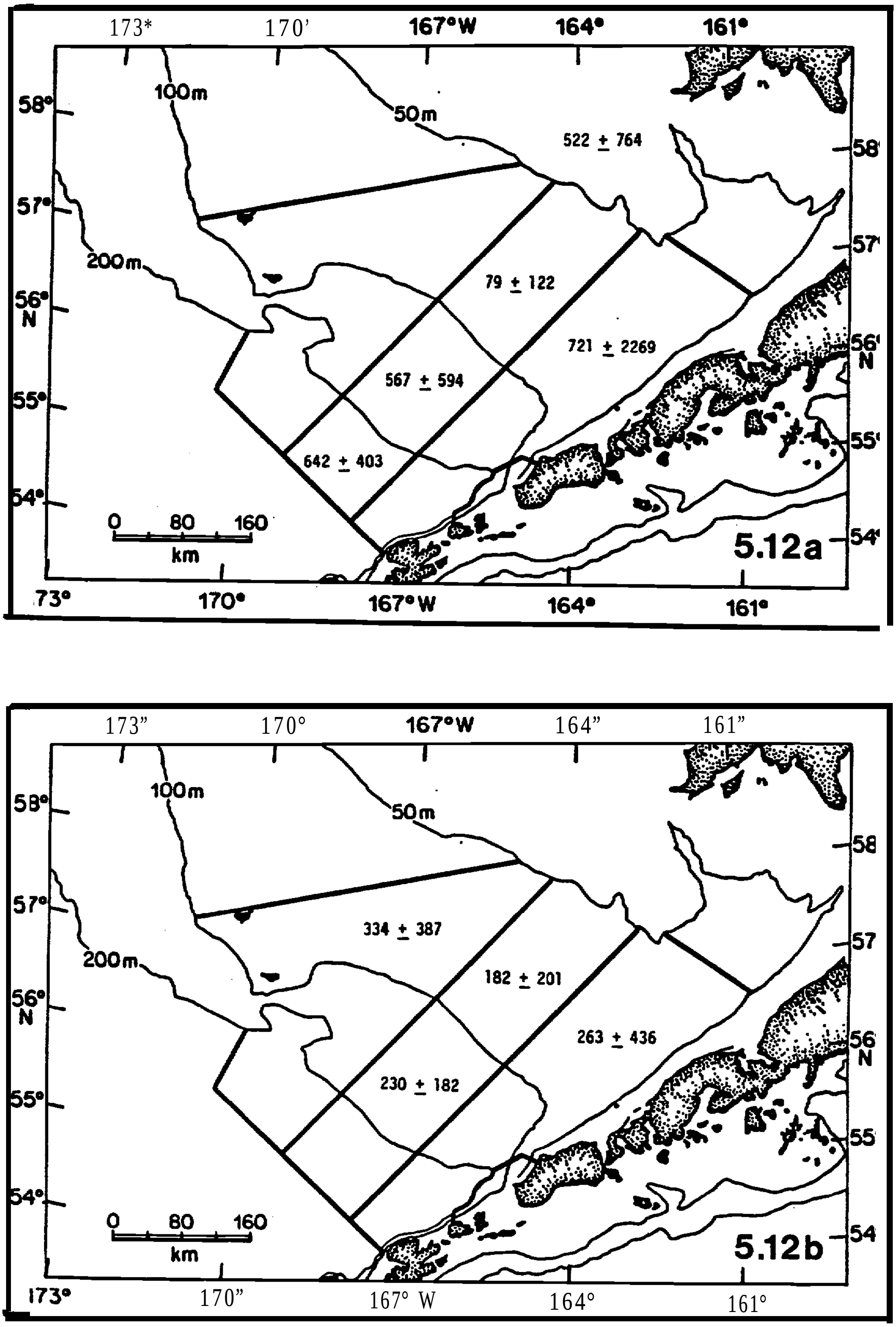


Figure 5.12 Distribution of mean density with one standard deviation of non-Chionoecetes Oregoniinae larvae/100m^2 in the S.E. Bering Sea in May and June (a) and July (b) of 1981. Means were calculated with zeros for stations at which no larvae were found and for only those strata in which the number of samples collected during these time periods was ≥ 5.

hints at the species' response to adverse conditions that might be exacerbated by oil pollution.

Summary

1) Oregoniinae larvae were encountered at 42% of the stations sampled during this study.

2) The taxon is widely distributed over the southeastern Bering Sea, although densities appear to be greater seaward of the 100 m isobath over the outer shelf regime and shoreward near Unimak Island.

3) Densities varied between areas within a year. Hatching may occur earlier in April over strata of the middle shelf and in May over the outer shelf.

4) Interannual comparisons showed that larval density was similar in 1980 and 1981, which were both low years compared to 1978.

5.3.2.3 Pinnotheridae

Seasonal Occurrence: Zoeae of this family were present for the total length of the spring-summer sampling periods of the years 1976 to 1981, which was a period of 14 weeks (Fig. 5.3). Because individual zoeal stages of the Pinnotheridae could not be identified, the seasonal occurrence of all zoeal stages combined is represented. Megalops larvae of this taxon appeared one year in late-June.

Distribution and Density: Considering the wide geographic range over which zooplankton samples were collected between 1976-1981, Pinnotheridae are more narrowly distributed than some other taxa. They were found at 21% of all stations sampled and greatest densities were found on both sides of the 100 m isobath from St. George to Unimak islands (Fig. 5.13). Densities were also high near Amak Island between Bechevin Bay and Izenbek Lagoon. Considering the relationship between this family of crab and bivalve molluscs, larval crab distribution is somewhat in accord with infaunal distribution and abundance of bivalves in the southeastern Bering Sea (McDonald et al. 1981). The frequency-of-occurrence of pinnotherid larvae within strata is shown in Table 5.7 and reflects high abundance in strata 2, 5, and 6.

The pattern of larval distribution shown in Figure 5.13 was further analyzed by averaging larval densities within depth intervals of 50-74 m, 75-125 m, 126-200 m and > 200 m for the years 1978, 1980 and 1981 (Figs. 5.14a, b, c). Most larvae occurred between 75-125 m where mean densities in 1978 ranged from 2178 to 10,603 larvae/100 m^2 (Fig. 5.14a). There was an obvious drop in larval density both shallower and deeper than this depth interval in all years analyzed (Figs. 5.14 a, b, c), where densities were zero to a few hundred larvae/100 m^2. Interannual differences in density during May/June were difficult to assess but there is an indication of reduced density in the 75-125 m interval of strata 1 and 2 in 1980 and 1981 (about 200 larvae/100 m^2; Figs. 5.14 b and c) compared to 1978 (2178/100 m^2).

Summary

1) Pinnotheridae larvae were collected at 21% of all the stations sampled during 1976-1981.

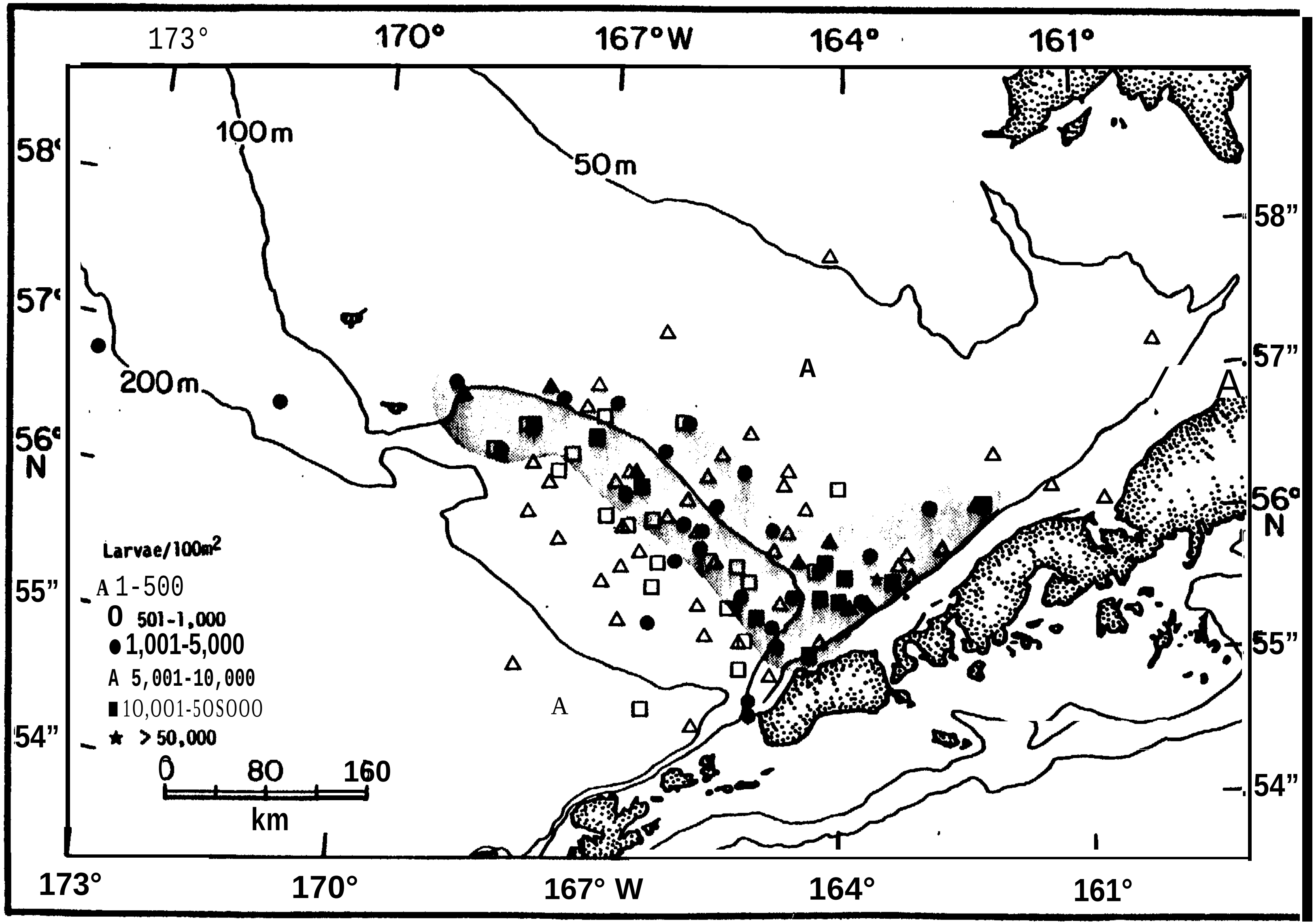
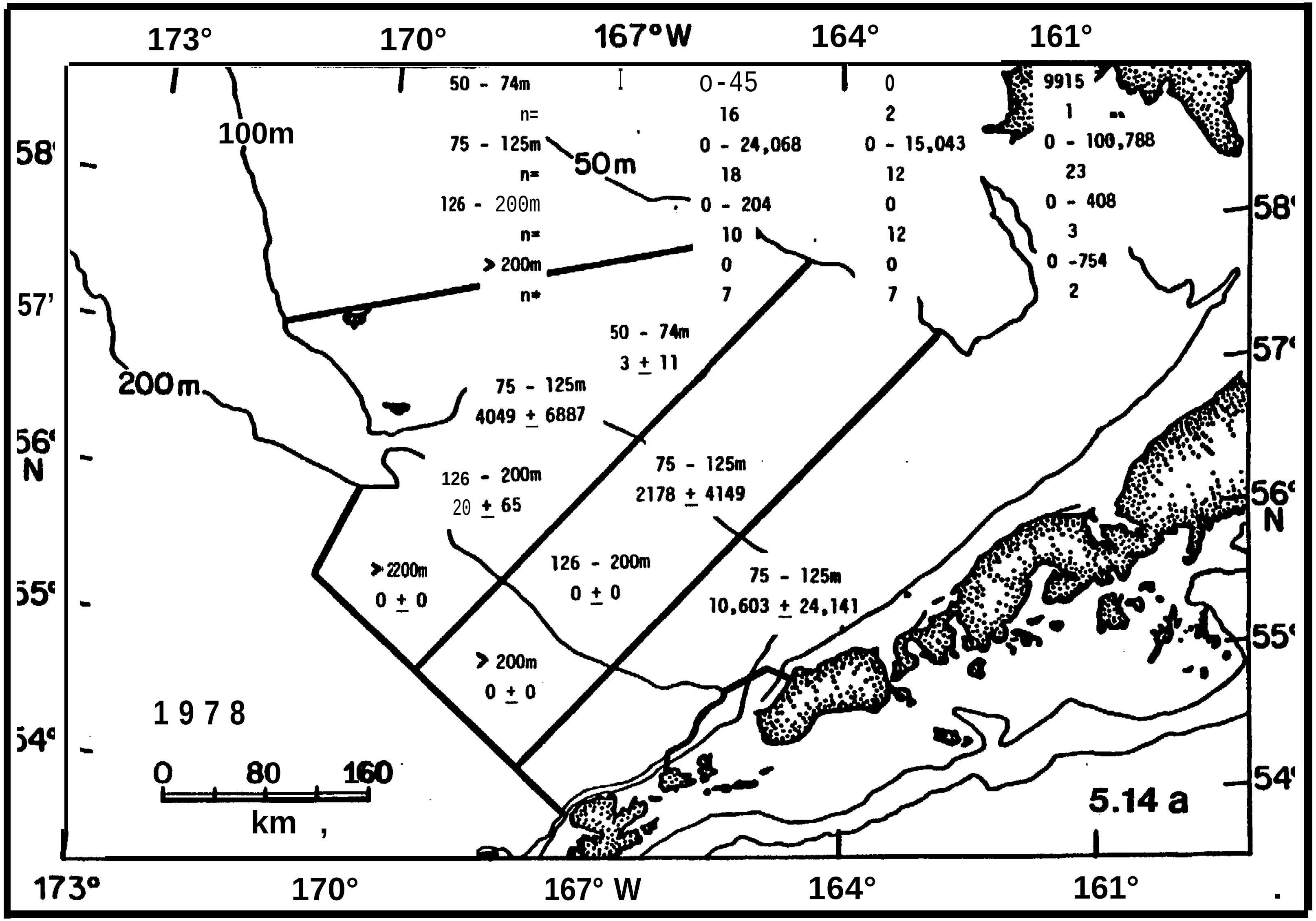


Figure 5.13 Locations and densities of **Pinnotheridae larvae** collected in the southeastern Bering Sea in the years 1976-1981. Locations where no larvae were found were omitted, but all station locations for these years are illustrated in Figures of Section 2.0.

Table 5.7. Frequency of occurrence (percent) within a stratum of Pinnotheridae larvae in May and June of the years 1977-1981 combined.

Stratum number	Frequency of occurrence within each stratum percent)
1	25
2	38
3	8
4	18
5	57
6	67
7	8
8	20
9	18
10	5
11	25
12	33

Figure 5.14 Cross and long-shelf pattern of mean density with ± one standard deviation of Pinnotheridae larvae/100 m^2 in the southeastern Bering Sea in May and June of 1978(a), 1980(b) and 1981(c). The depth interval for which means were calculated are listed above each mean in the general vicinity of their occurrence; while the range of density and the number of samples, n, collected at each interval are listed above each region. Means include both zero and positive stations. Only those depth intervals in which the number of positive samples collected is ≥ 4 (n) are included.



173°
170°
167°W
164°
161°
58°
57°
56° N
55°
54°
100m
50m
200m
50 - 74m
n=
75 - 125m
n=
126 - 200m
n=
> 200m
n=
0-45
16
0 - 24,068
18
0 - 204
10
0
7
0
2
0 - 15,043
12
0
12
0
7
9915
1
0 - 100,788
23
0 - 408
3
0 -754
2
50 - 74m
3 ± 11
75 - 125m
4049 ± 6887
75 - 125m
2178 ± 4149
126 - 200m
20 ± 65
126 - 200m
0 ± 0
75 - 125m
10,603 ± 24,141
> 200m
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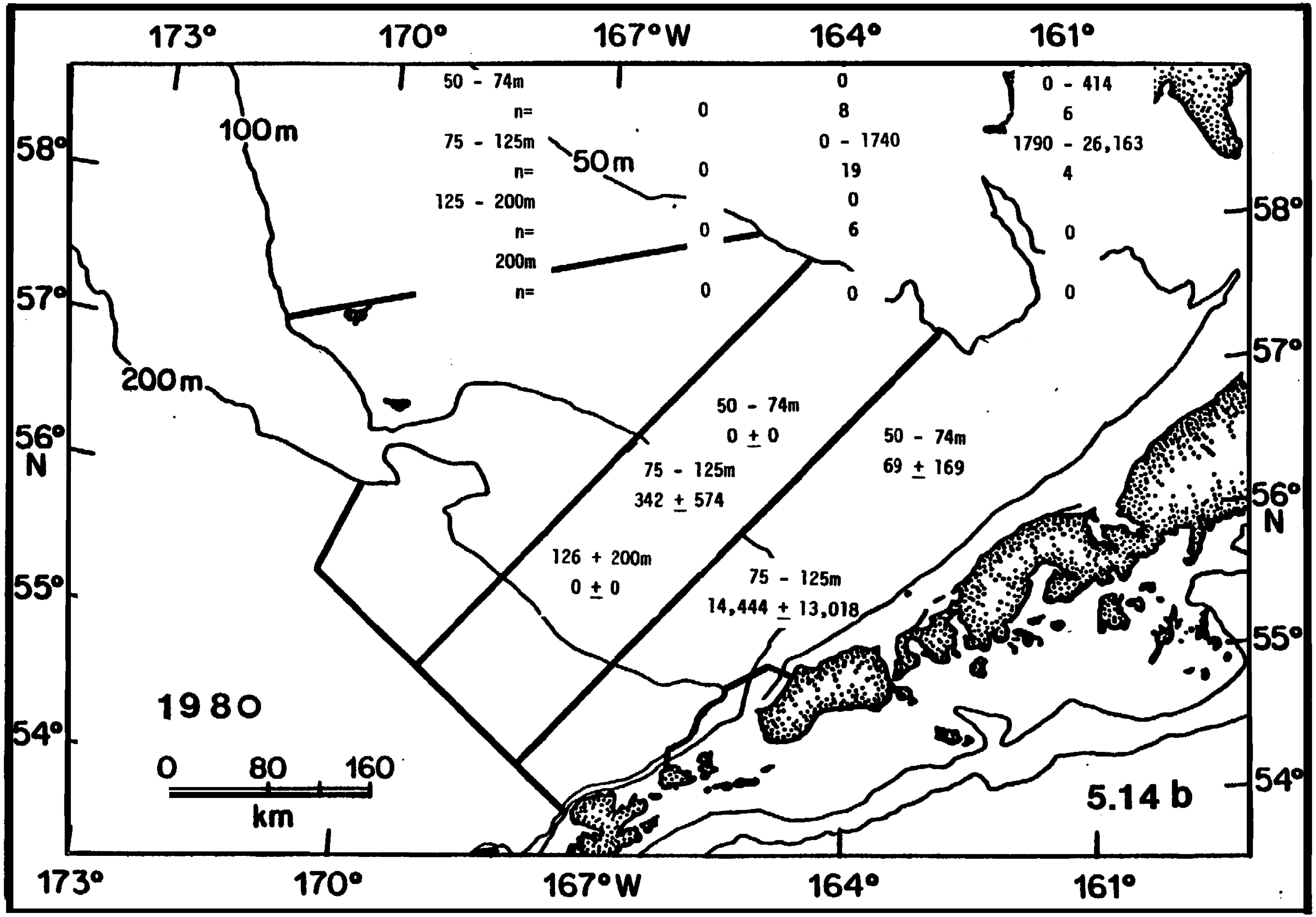
1978
0 80 160
km
173°
170°
167° W
164°
161°

5.14 a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75 - 125m
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125 - 200m
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200m
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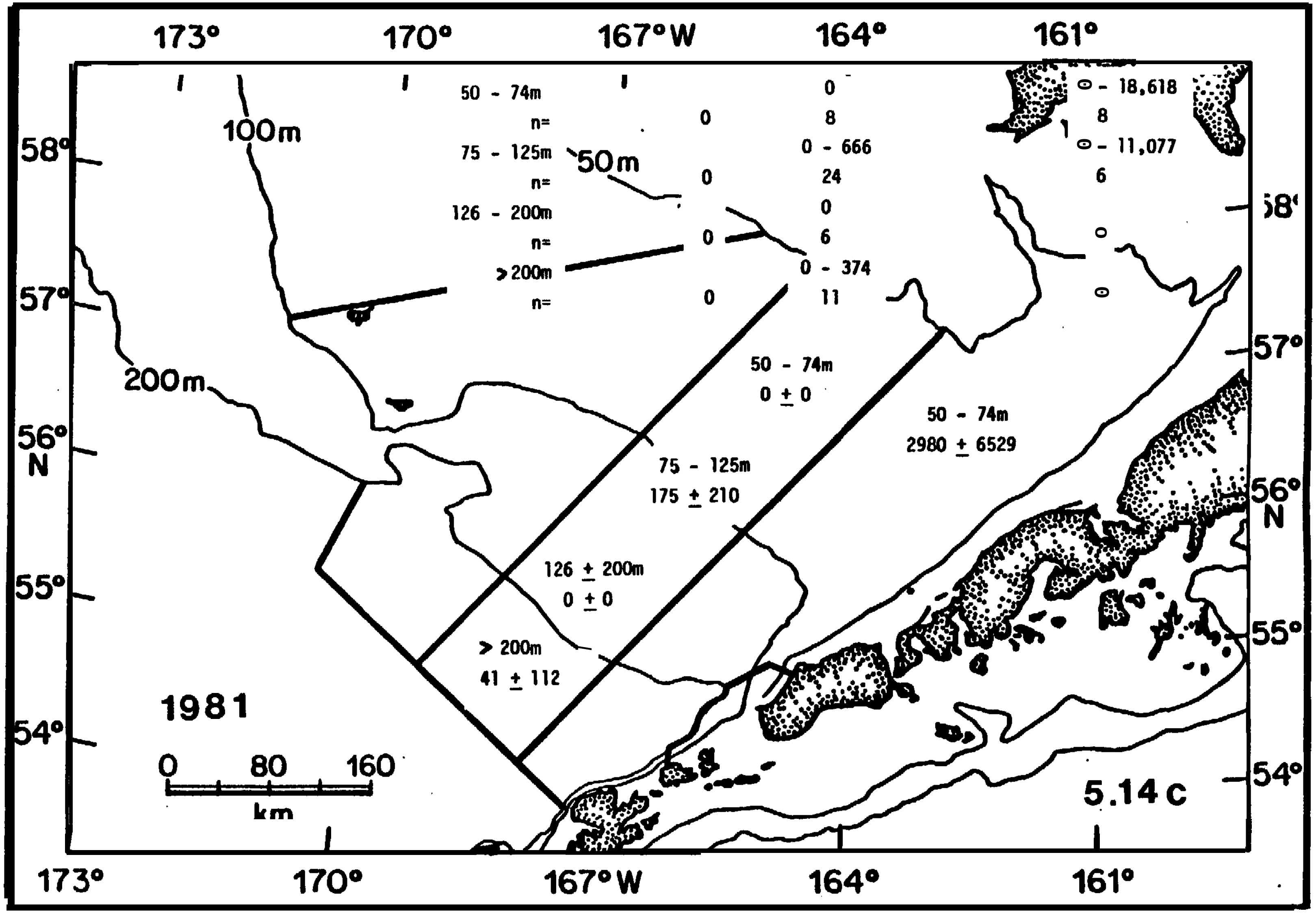
0
0
8
0 - 1740
19
0
6
0
0 - 414
6
1790 - 26,163
4
0
0
50 - 74m
0 ± 0
75 - 125m
342 ± 574
126 + 200m
0 ± 0
50 - 74m
69 ± 169
75 - 125m
14,444 ± 13,018
1980
0
80
160
km
5.14 b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100m
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200m
50 - 74m
n=
75 - 125m
n=
126 - 200m
n=
> 200m
n=
0
0
0
0
0
8
0 - 666
24
0
6
0 - 374
11
0 - 18,618
8
0 - 11,077
6
0
0
50 - 74m
0 ± 0
50 - 74m
2980 ± 6529
75 - 125m
175 ± 210
126 ± 200m
0 ± 0
> 200m
41 ± 112
1981
0
80
160
km
5.14 c

2) In May and June of all years combined, the majority of these larvae were distributed between the 75 and 125 m depth interval.

3) A significantly higher mean density of larvae was found in water 75-100 m deep in the eastern region of the southeastern Bering Sea during May and June of the year 1978 than in 1980 or 1981.

4) High densities ranging from 13,675 to 100,788 were found in May and June throughout the major area of distribution in the years 1978, 1980, and 1981.

5.3.2.4 Cancer spp.

Seasonal Occurrence: The six larval stages of Cancer spp. appeared in the plankton samples collected in the years 1976 to 1981 combined from mid-April to early-October, which is a period of 24 weeks (Fig. 5.3). Individual larval stages were collected during this time period as follows: SI, from mid-April to mid-July; SII, from late-April to mid-July; S111 from early June to mid-July and October; SIV in mid-July; SV in late-June, mid-July and October, and megalops larvae in late-June *and* October.

Distribution and Density: Larvae were found in 13% of all samples sorted from 1976-1981. The frequency-of-occurrence was highest in strata 4, 5, and 12 (73%, 57%, and 67%, respectively) and was low in all others (Table 5.8). Cancer larvae were most abundant near Unimak Island and over the shelf break west of Unimak Pass (Fig. 5.15). High densities along western Unimak Island was likely due to larvae of Cancer oregonensis where adults are common in rocky cobble substrate, and larvae in

Table 5.8. Frequency of occurrence (percent) within each stratum of Cancer spp. larvae in May and June of the years 1976-1981. Depicted is the percent of all stations within each stratum at which Cancer spp. were found.

Stratum number	Frequency of occurrence within each stratum percent)
1	2
2	25
3	19
4	73
5	57
6	18
7	0
8	3
9	0
10	5
11	13
12	67

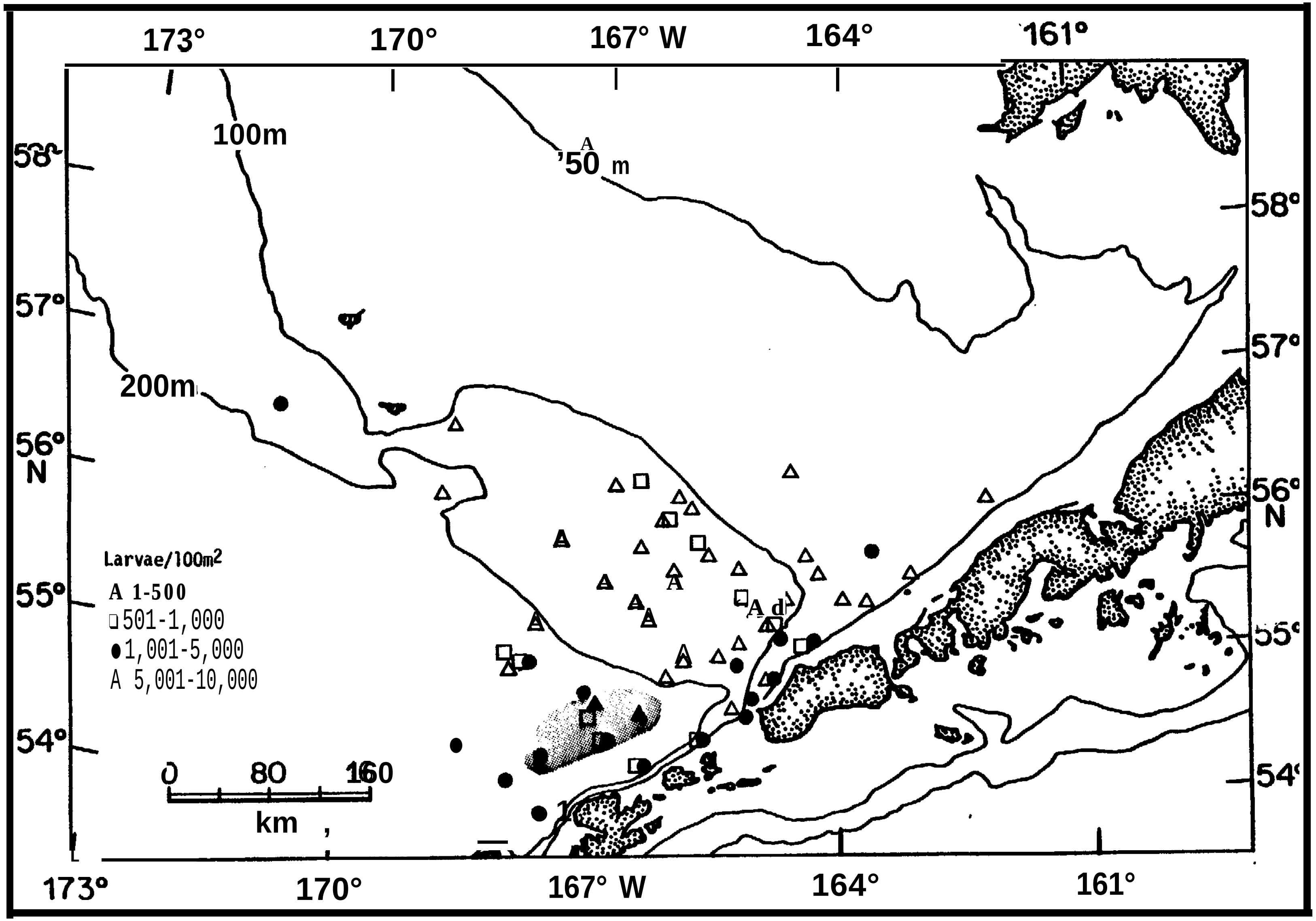


Figure 5.15 Locations and densities of Cancer spp. larvae collected in the southeastern Bering Sea in the years 1977-1981. Locations where no larvae were found were omitted, but all station locations for these years are illustrated in Figures of Section 2.0.

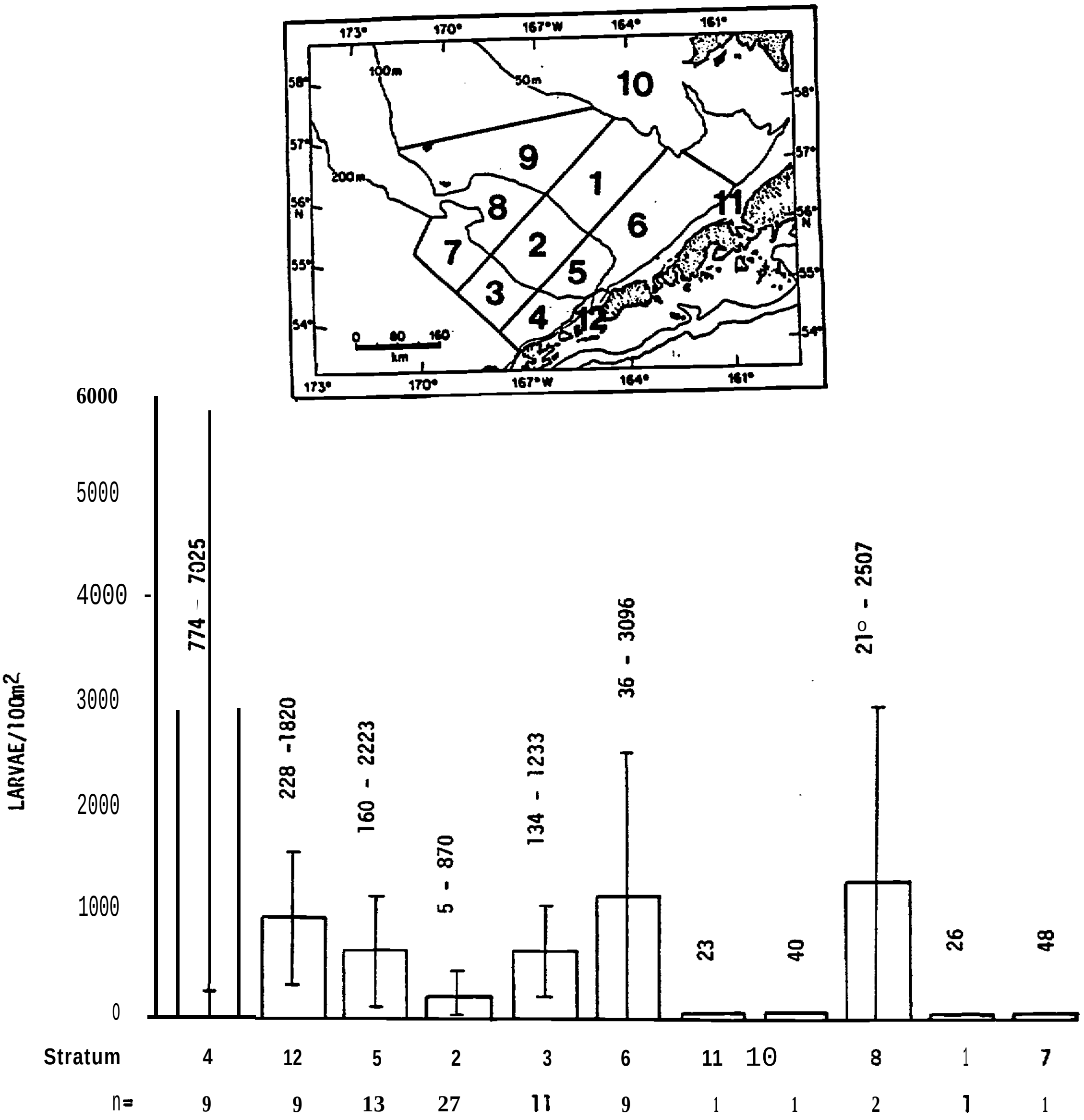


Figure **5.16** Mean density and one standard deviation of <u>**Cancer**</u> spp. larvae in the southeastern Bering Sea for all years, 1977-1981, combined. The range of densities from which these means were calculated are listed above each corresponding bar; **while** the **number** of samples used to calculate each mean, n, are listed on the lower axis.

excess of 100,000/100 m^2 were found in 1982 (Armstrong, unpublished data).

Mean densities calculated by stratum were highest in stratum 4 (about 3000/100 m^2) and less, but comparable, in strata 3, 5, 6, 8, and 12 (about 500-1100 m^2) (Fig. 5.16). The highest single density of 7025 larvae/100 m^2 occurred in stratum 4.

Summary

1) *Cancer* spp. larvae were collected at 13% of *all stations* sampled during this study.

2) Larvae were generally most abundant nearshore of Unimak Island and west over the shelf break.

3) The highest density found was over 7000/100 m^2 but means between 1000-3000/100 m^2 were more typical of high abundance areas.

5.3.2.5 *Telemessus cheiragonus*

Seasonal Occurrence: These larvae were collected in the plankton from late-April to late June, a total period of 10 weeks, when data were combined from the years 1977-1981 (Fig. 5.3). Individual larval stages were present during these sampling periods as follows: S1 in mid-May; S11 in mid-April, mid-May, and late-June; S111 in late-May and late June; SIV in mid-May and early-June; and SV in early and mid-May. Megalops larvae were never observed in the plankton samples of this study.

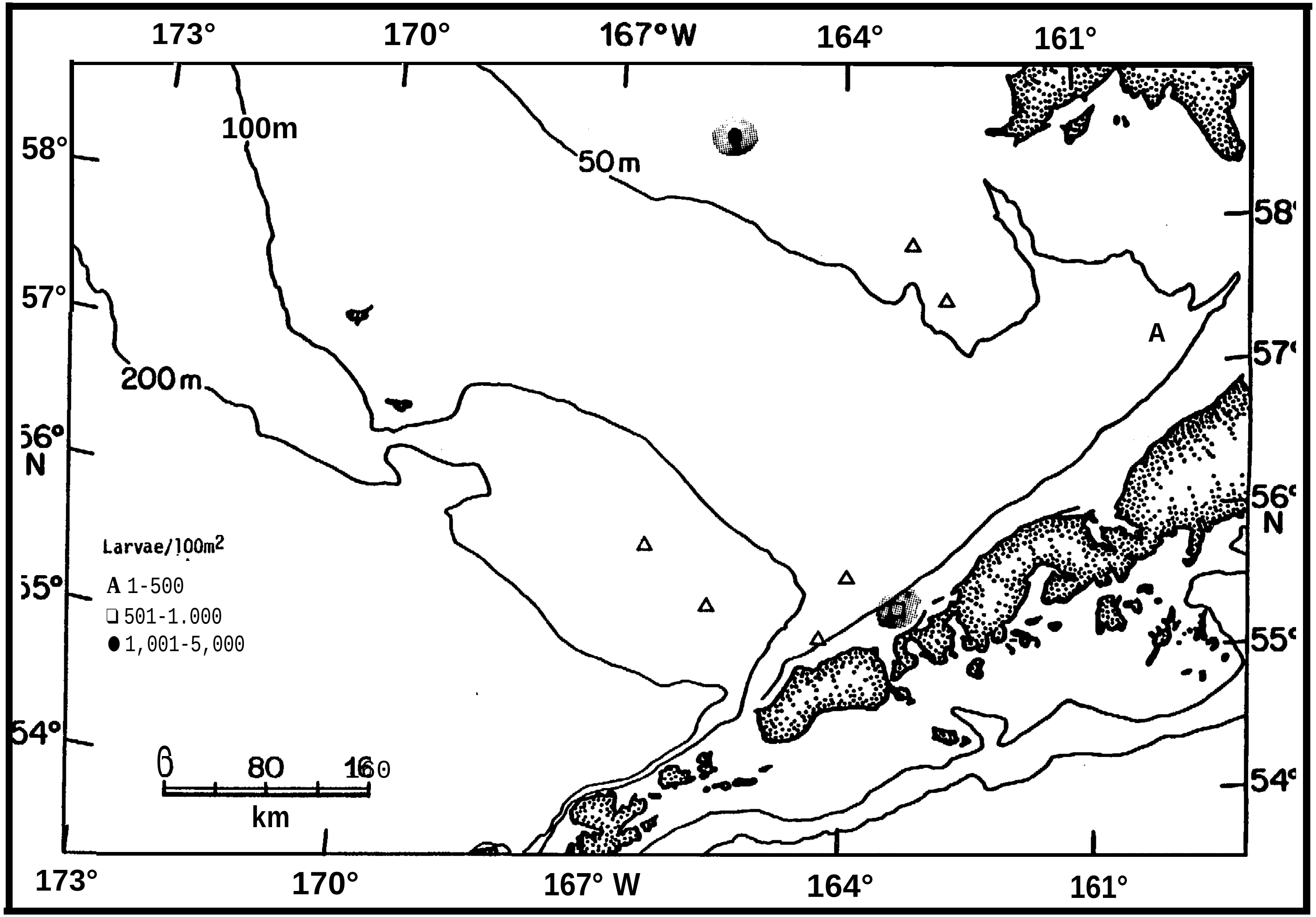


Figure 5.17 Locations and densities of Telmessus cheiragonus larvae collected in the southeastern Bering Sea in the years 1976-1978 and 1981. Locations where no larvae were found were omitted, but all station locations for these years are illustrated in Figures of Section 2.0.

Table 5.9. Frequency of occurrence (percent) of *Telmessus cheiragonus* larvae within each stratum in May and June of the years 1976-1981 combined.

Stratum number	Frequency of occurrence within each stratum percent)
1	0
2	1
3	0
4	0
5	5
6	7
7	0
8	0
9	0
10	14
11	13
12	0

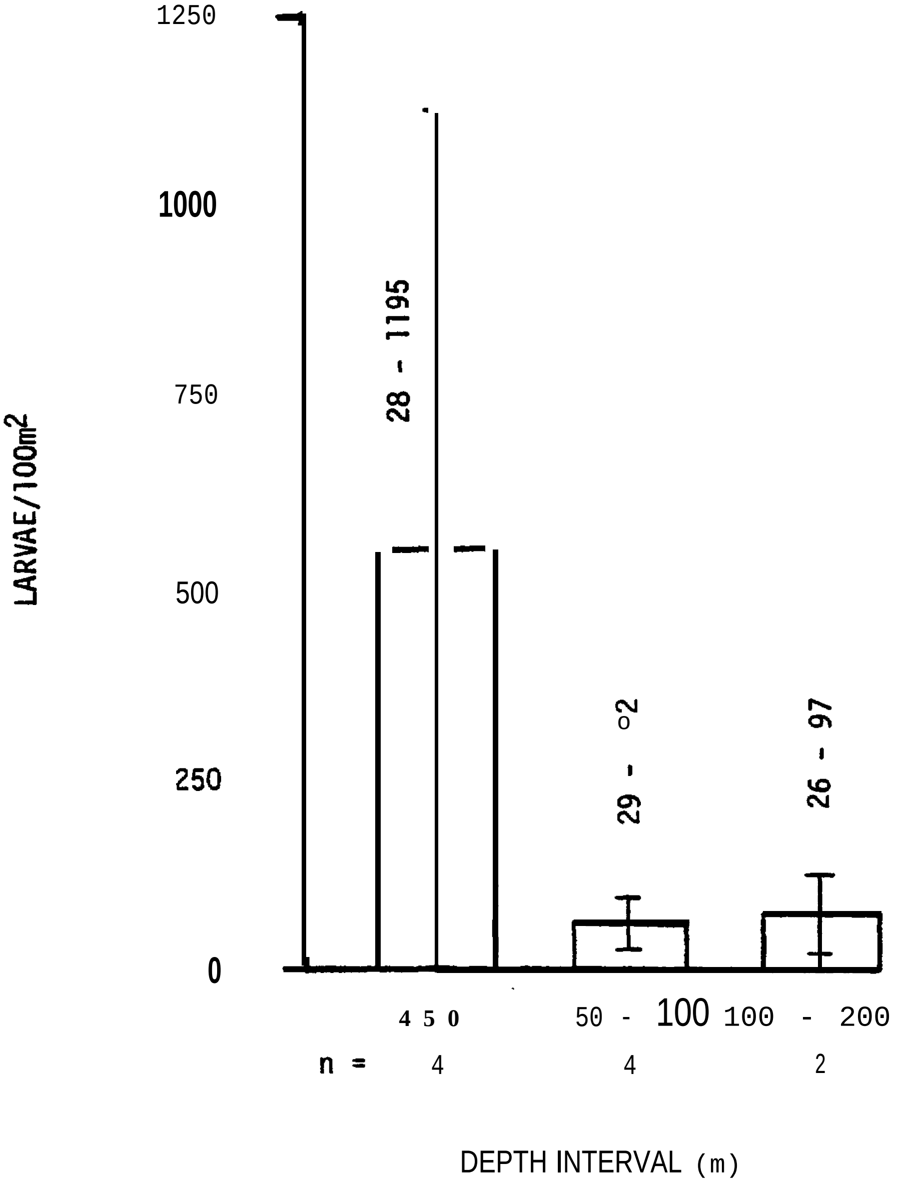


Figure 5.18 Mean density and one standard deviation of **Telmessus cheiragonus** larvae collected at stations with water depths ranging from 40-200 m in the southeastern Bering Sea for all years, 1976-1981, combined. The range of densities from which these means were calculated are listed above each corresponding bar; while the number of samples used to calculate each mean, n, are listed on the lower axis. Stations at which no larvae were found were not used in calculating the mean density of **Telmessus cheiragonus**.

Distribution and Abundance: Larvae of the species were found in only 2% of all stations, the lowest percentage of all non-*Chionoecetes* Brachyura taxa studied. This is reflected by the low frequency-of-occurrence within each stratum that never exceeded 14% (Table 5.9). Little can be said of their distribution other than the surprising scarcity (Fig. 5.17). Since Izembek Lagoon is known to support large populations of adults (McRoy 1966), higher larval densities in that area were expected. However, the majority of all larvae found were at stations less than 50 m deep nearshore (Fig. 5.18), where the mean density was 552/100 m^2. The highest single density found was 1195 larvae/100 m^2.

Summary

1) Larvae were only collected at 2% of *all* stations sampled during 1976-1981.

2) No larvae were collected in water deeper than 200 m, near the Pribilof Islands or in the central region of the middle shelf.

3) Distribution and density appear related to depth since the highest relative frequency-of-occurrence and the highest relative mean density of these larvae were found in water shallower than 50 m.

5.3.2.6 Acanthonychinae and Pisinae

Seasonal Occurrence: Larval stages of these subfamilies were found in the plankton from late-April to mid-July, a total period of 12 weeks, when their appearance in all the sampling periods of the years 1976 to 1981 were combined {Fig. 5.3). Individual larval stages were present during these sampling periods as follows: S1, from late-April to early-June; S11 from early-June to mid-July and the megalops larvae from mid-June to mid-July.

Distribution and Density: Larvae were collected in 5% of all samples, most in stratum 12 at the western tip of Unimak Island (Table 5.10 and Fig. 5.19). Larvae of the taxa were rarely found in the water deeper than 200 m and never near the Pribilof Islands. Mean densities were low, less than 500 larvae/100 m^2 in all of the eight strata where they were found (Fig. 5.20). The highest density found was 1536/100 m^2 in stratum 12 and the lowest was 13/100 m^2 in stratum 2.

Summary

1) Larvae *were* only collected at 5% of all stations sampled during this study.

2) No larvae were collected near the Pribilof Islands.

3) The stratum with the highest relative frequency of occurrence of larvae and at their greatest density was stratum 12, Unimak Pass.

Table 5.10. Frequency of occurrence (percent) of larvae of the subfamilies **Acanthonychinae** and/or **Pisinae** within a stratum in May and June of the years 1976-1981.

Stratum number	Frequency of occurrence within each stratum percent of total stations)
1	0
2	11
3	3
4	18
5	19
6	4
7	8
8	0
9	0
10	5
11	0
12	83

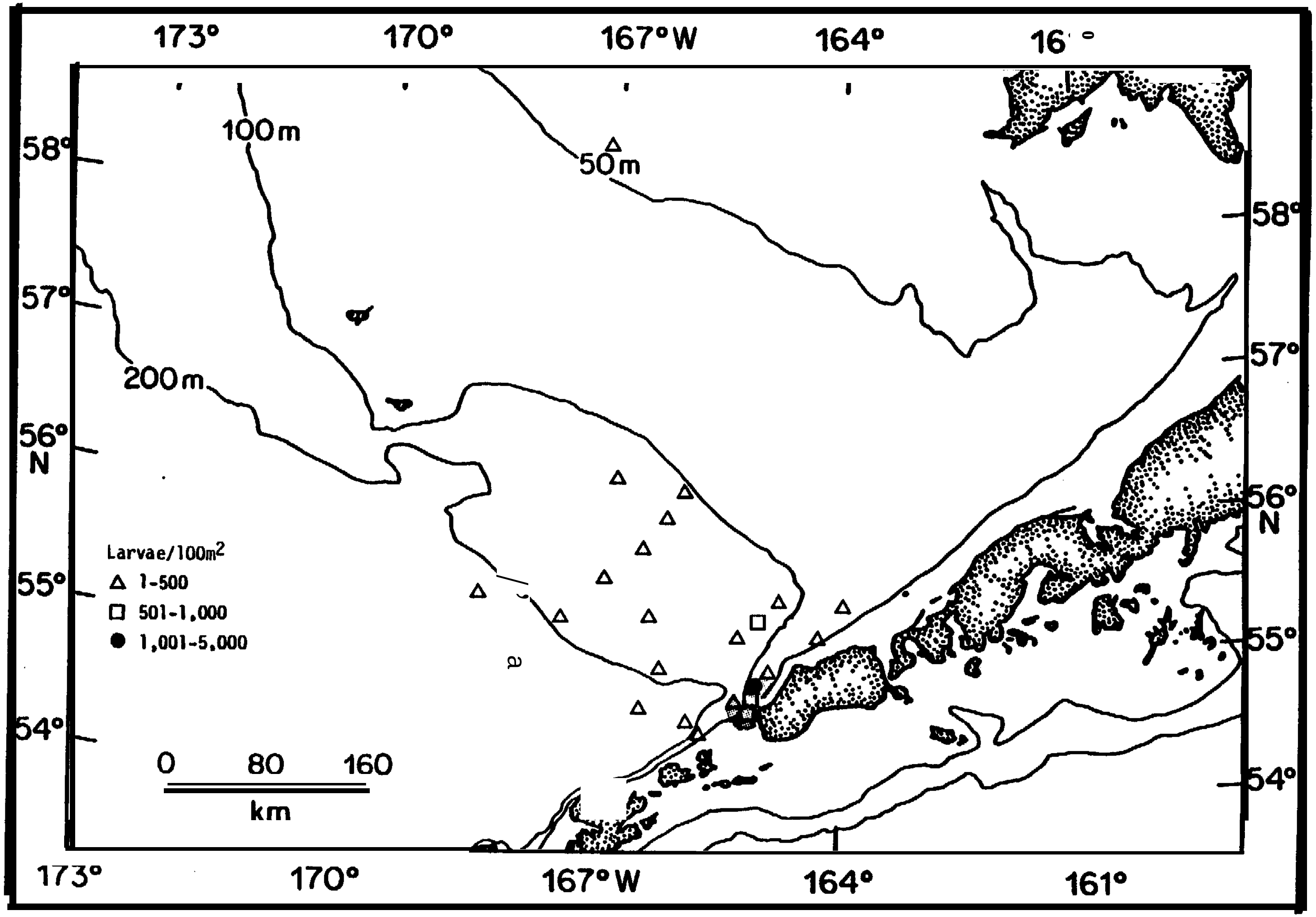


Figure 5.19 Locations and densities of Acanthonychinae and/or Pisinae larvae collected in the southeastern Bering Sea in the years 1976-1981. Locations where no larvae were found were omitted, but all station locations for these years are illustrated in Figures of Section 2.0.

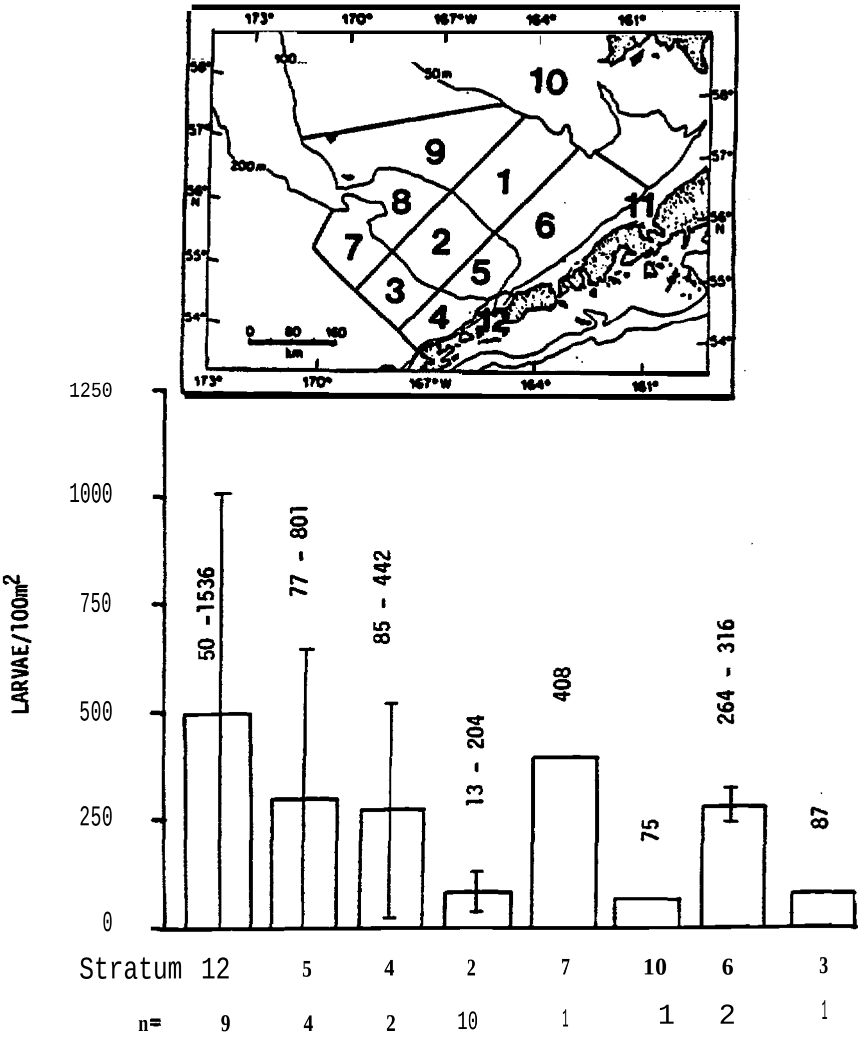


Figure 5.20. Mean density and one standard deviation of Acanthonychinae **and/or Pisinae** larvae **in** the southeastern Bering Sea for all years, 1976-1981, combined. The. range of densities from which these means were calculated are listed above each corresponding bar; while the number of samples used to calculate each mean, n, are listed on the lower axis. Stations at which no larvae were found were not used in calculating the mean density of **Acanthonychinae** and/or **Pisinae larvae.**

6.0 DISTRIBUTION AND ABUNDANCE OF SHRIMP LARVAE IN THE SOUTHEASTERN BERING SEA WITH EMPHASIS ON PANDALID SPECIES

Janet Armstrong

6.1 Introduction

Bering Sea shrimps, suborder Natantia, belong to at least six families of decapod crustaceans. In addition to the commercially important family Pandalidae, represented by 5 species in the southeastern Bering Sea, other families are Hippolytidae and Crangonidae (Butler 1980), and possibly a species of the family Penaeidae (K. Coyle, U. of Alaska, IMS personal communication). Feder and Jewett (1980) give an extensive list of the adult species found in this area that includes members of the families Oplophoridae and Pasiphaeidae. (From all samples sorted to date only a single oplophorid larva was found and these families are thus of no consequence in this report.) Butler's monograph (1980) on Pacific Coast shrimp gives ranges for many adults which were added to Feder's list (see Appendix A).

Pandalidae are the only shrimp of direct commercial importance and have thus received most attention in the literature. Thorough larval descriptions for pandalid populations of different geographic locations are given by Berkeley (1930) for British Columbia, Pike and Williamson (1962) for the North Sea, Kurata (1964c) for Hokkaido, Japan, and Rothlisberg (1980) for the Pacific northwest coast (see Appendix B for complete list of references on larval shrimp). For identification of Bering Sea pandalid larvae the following comprehensive species descriptions were used:

Pandalus borealis - Haynes 1979
Pandalus goniurus - Haynes 1978a
Pandalus montagui tridens - Haynes 1980
Pandalus stenolepis - Needler 1938
Pandalopsis dispar - Berkeley 1930

6.2 Pandalidae

6.2.1 Pandalus borealis: Life History and General Biology

Distribution: *P. borealis*, an amphiboreal species, ranges from Point Barrow, Chukchi Sea southwest through the Okhotsk Sea to the Sea of Japan and Korea, and southeast throughout the Bering Sea and Gulf of Alaska to the mouth of the Columbia River. In addition it is found in the Barents Sea, the North Sea, and from the Gulf of Maine to western Greenland in 16-1380 m depths (Butler 1980). *P. borealis* is thought to be the bridge species between the Atlantic and Pacific Ocean pandalid groups (Rasmussen 1967). Fishable populations occur between 54-400 m depths (Ronholt 1963), but the species is often dominant between 70-150 m at the outer edge of the continental shelf where bottom temperatures range between 1.8°-3.8°C (Ivanov 1969). Post-larval stages can tolerate a wide temperature range from -1.68° to 11.13°C (Allen 1959) while larvae can survive an upper limit of 14°C (Poulsen 1946 in Butler 1971). Haynes and Wigley (1969) describe *P. borealis* preference for soft mud, sand and silty substrates with relatively high organic content (0.5-1.5% organic carbon) in the Gulf of Maine. Survival is optimal at salinities from 25.9 to 35.7°/00 (Allen 1959; Butler 1964).

Reproduction: Like all Alaskan pandalid shrimp, *P. borealis* are protandric hermaphrodites (Berkeley 1930). Animals first achieve sexual maturity as males at age 3.5 years in the Bering Sea and remain breeding males for two seasons. After a transitional period they subsequently develop female characteristics by 5.5 years (Ivanov 1969; Butler 1971). Females can mature early and circumvent the male phase entirely in populations found in southern parts of the range (Allen 1959; Butler 1964), but this event has not been recorded in the Bering Sea (Ivanov 1969). Rasmussen (1967) gives comparative reproductive data for Norwegian populations and Haynes and Wigley (1969) summarize this information, adding data on ovigery for Maine shrimp. Sexual development is hormonally controlled and has been studied by Carlisle (1959). Table 6.1 compares life history data of *P. borealis* and other pandalid species.

Colder water temperatures of the Bering Sea slow growth and development, extend the ovigerous period, and greatly determine the seasons of spawning and hatching (Butler 1971). The normal life span for *P. borealis* in the S.E. Bering Sea can be up to 6 1/2 years (Ivanov 1969) compared to 3 1/2-4 years for populations in the warmer water (North Sea, Allen 1959; British Columbia, Butler 1964).

Ovarian development occurs in mature females (age 5 years) in the summer, followed by spawning from August to mid-September in the southeastern Bering Sea. Eggs are extruded, fertilized and carried on the pleopods through the winter and hatch from April through mid-May (NPFMC 1978). The average ovigerous period lasts from 7.5 to 9.5 months. Females from Kachemak Bay, Alaska carry approximately 914 eggs per clutch (Haynes and Wigley 1969), but a range of 300-3400 eggs, has been noted for different P. *borealis* populations world-wide (Allen 1959; Haynes and

Table 6.1. Comparison of life history and reproductive information for pandalid species.

	Depth preference (m)	Sexual maturity[1] Male (mm) Size	Age	Female (mm) Size	Age	Maximum age year	Reproduction Fecundity Eggs/clutch	Ovigerous period	Larval hatch
P. borealis[2,3]	90-120	120 TL 19.5 CL	3 1/2	150 TL 25 CL	5 1/2	6 1/2	914 1631 2150	Nov.-Mar.	Apr., May
P. goniurus[4,5]	38-124	62 TL 13 CL	1	78 TL 16.5 CL	2	2 1/2	2000	Nov.-Apr.	
P. tridens[4]	200-470	83 TL 15 CL	, 1/2	123 TL 22 CL	2 1/2- 3	4		Nov. -Apr.	Apr.
P. stenolepis[4]		76 TL 14 CL		82 TL 18 CL				Nov. -Apr.	
Pandalopsis dispar[2,3,6]	>200	182 TL 31 CL	1 1/2	208 TL 36 CL	2-4	4	1129, 4150	Al 1 year	Nar. Apr.

References:

[1] Data represent average length and age.
[2] NPFMC: Fishery Management Plan and E. 1.S. for the shrimp fishery in the Bering Sea, November 1978.
[3] McBride 1974- Kachemak Bay Ak. stocks (unpublished).
[4] Butler, T. 1980- Strait of Georgia, B.C. stocks.
[5] McLaughlin, P. 1963- S.E. Bering Sea stocks.
[6] Hynes, F. 1930 - S.E. Alaska stocks.

Wigley 1969; Rasmussen 1953 from Butler 1971). No fecundity data are available for the southeastern Bering Sea. Stickney and Perkins (1980) are currently studying the fluctuating fecundity of Maine stocks of P. borealis which, after declining in the early 1970's, seem to be rebuilding. Horsted and Smidt (1956 from Butler 1980) report that a parasite Hemiarthrus abdominalis can cause as much as 50% reduction in the number of eggs carried by P. borealis females in the North Atlantic Ocean.

Larval Development: P. borealis has 5 planktonic zoeal stages and one megalops stage (often referred to as a "mysid" stage) before molting to a juvenile (Haynes 1979). Larvae grow from 6.7 mm mean total length at Stage I to 18.5 mm at the megalops stage. The average mean growth increment per molt is 2.36 ± 1.04 mm total length. Duration of planktonic life is approximately 3 months according to Berkeley (1930). In the North Sea, Allen (1959) found P. borealis molts as many as 14 times from larval metamorphosis to the male phase (from 21 to 93 mm total body length). At age 1.5 years, the Pribilof stocks are all immature males with a carpace length (CL) of 12-13 mm (Ivanov 1969). At age 2.5 years (CL = 18-19 mm) some shrimps become sexually mature males and participate in autumn breeding for the first time. Allen (1959) found that 5 molts are necessary before males exhibit mature sex characteristics. Most shrimp in the 3+ and 4+ age classes (CL = 22mm and 25 mm, respectively) are breeding males with a small proportion as females. By 5.5 years of age (max CL = 27-32 mm) all shrimp are females. Few shrimp survive to 6.5 years and according to Ivanov (from NPFMC 1978), all at this age are non-reproducing or sterile females. Usually females undergo 3 molts between ovigerous periods (if they produce more than one brood) but do not molt from the time the eggs are extruded until 2 weeks after the zoeae hatch. The majority of Bering Sea P. borealis have only one brood (Ivanov 1969) and it is this last age class (5.5-6.5 yr) that supports the fishery.

Food Habits: Food habits of zoeae were studied by Stickney and Perkins (1980). Preliminary findings indicate that diatoms may be a major food source for newly hatched zoeae in Maine and the timing of phytoplankton blooms may be crucial for early stage survival. Older larvae rely more on a zooplankton diet. Paul et al. (1978) performed prey density and feeding response experiments with Stage I (S1) P. borealis. Juvenile food habits received little attention. Adult diets consist of both benthic mollusks, detritus, small crustaceans, polychaetes, echinoderms, and protozoans, and pelagic copepods, euphausiids, mysids and other shrimp and crab larvae (Barr 1970; Butler 1971). Pelagic organisms are caught during diel vertical migrations when shrimp leave the bottom at dusk, disperse throughout the water column, and return to the bottom by dawn (Barr 1970).

Ontogenetic Migrations: Life stage and seasonal migrations of southeastern Bering Sea stocks are also assumed to occur. Stage I-III zoeae remain generally within the area of hatch but thereafter migrate to shallower water (46-64 m) where metamorphosis occurs and they spend their first summer as juveniles (Berkeley 1930, for Canadian stocks); thereafter they move to deeper water to join the adults. Ovigerous females in the

Gulf of Maine were found to move into shallower water as eggs developed (Haynes and Wigley 1969). Pribilof populations affected by winter cooling migrate" 30-40 miles toward the outer shelf from 85-100 m depths to 95-120 m depths where temperature is warmer and more stable (Ivanov 1969).

Predators: Principal predators include many commercial fish species: Pacific cod, white pollock (Feder 1978), sand sole (Miller 1967), silver and white hake, halibut and dogfish (Butler 1980). Grey and humpback whales, marine birds (NPFMC 1978) and harbor seals (Lowry et al. 1978) also prey on pandalid shrimp.

Competitors for the same habitat Include Pandalus tridens and Eualus macilentus. It was theorized in "A Review of the First Northern Hemisphere Pandalid Shrimp Workshop" held in Kodiak, Alaska (Frady 1981), that after depletion by commercial fisheries (i.e., Japanese overfishing the Pribilof area stocks 1961-63) or by predators, P. borealis shrimp stocks may have been replaced by other competitor species of fish and shrimp.

6.2.2 Commercial Fishery

Historically the southeastern Bering Sea fishery has been dominated by Japan and the USSR. After catches of Japanese flounder trawlers indicated large populations of P. borealis in 1960, the Japanese targeted on shrimp stocks northwest of the Pribilof Islands and in 1961 took 14,000 metric tons (MT). Catches peaked in 1963 at 30,000 MT and declined thereafter until the area was abandoned in 1969 (NPFMC 1978). Overfishing of

Bering Sea stocks during the early 1960's caused severe depression and slow recovery of stocks and there has been no significant fishery since 1966 (Paul Anderson - NOAA Cruise Results, Cruise No. 79-02, R/V Sunset Bay). In 1975 and 1976 3,500 and 1,700 MT of shrimp were taken by the Japanese from along the 100m isobath on the continental shelf edge. Biomass estimates in 1978 stood at 30,600 MT (69 million lb) for an area of 24,000 square nautical miles (nm^2) northwest of the Pribilofs (NPFMC 1978). The maximum sustainable yield (MSY) from this population was estimated to be 11,000 MT but the current Allowable Biological Catch (ABC) has been set at 1,000 MT. This low quota reflects the current management goals of giving these stocks time to rebuild, and encouraging the maintenance of a healthy resource at historic levels which then could promote the development of a strong domestic shrimp fishery. The current ABC level will allow the management agency to assess annual catch-per-unit-effort and collect biological specimens to construct age-class structure of the population.

Stock estimates for P. borealis surveyed in 1979 over an extended area of 30,400 nm^2 (Pribilofs to St. Matthew Island and out to the U.S.-U.S.S.R. convention line) indicate a mean biomass estimated at 63.56 x 10^6 kilograms (140 million lb with an 81)% confidence interval of 120.5 - 159 million lb; P. Anderson, NMFS, Kodiak AK correspondence, Oct. 1981).

The above biomass estimates are based on an area northwest of the St. George Basin. Other estimates close to the St. George Basin come from 1979 NOAA/NMFS Cruise Results (Cruise No. OR-79-03 R/V Oregon) of a shrimp survey conducted in Unalaska, Makushin and Pavlof Bays. Biomass estimates for Unalaska Bay for 1979 were 0.95 million lbs for P. borealis compared to 8.1 million lbs in 1978. Population estimates for 1979 were only 10-35% of 1978 estimates indicating a substantial decline.

No biomass estimates have appeared in the literature recently for the St. George Basin shrimp populations, and no commercial shrimp fishery is presently centered in that area.

6.2.3. Other Pandalus spp.

Other pandalids in the southeastern Bering Sea include P. goniurus, P. tridens, P. stenolepis and Pandalopsis dispar. The range of P. goniurus, the flexed pandalid, is from the Chukchi Sea and Bering Sea to Puget Sound in 5-450 m (Butler 1980). In southeastern Bering Sea this shrimp prefers depths of 38-124 m and a mud to coarse sand bottom habitat at -.3° to 6.4°C (McLaughlin 1963). Very few P. goniurus zoeae have been found in our samples (see Section 6.6.1, Results and Discussion).

P. tridens, the yellow leg pandalid, ranges from the Bering Sea to San Nicholas Island, California, in 5-1984 m (from Butler 198(I). Adults prefer depths of 200-470 m and rocky habitats. The reproductive biology for P. tridens, also a protandric hemaphrodite, has been studied for Canadian populations (Butler 1964) but remains fragmentary for the Bering Sea. Haynes' (1980) study of P. tridens larvae show growth from 3.2 mm Total Length (TL) for S1 to 13.0 mm TL for SVII and megalops. No data are available for age and size at maturation for males and females in the Bering Sea but Butler (1980) gives this information for a Canadian population (see Table 6.1). P. tridens was caught Incidentally at only one station during the 1979 pandalid survey cruise in the southeastern Bering Sea from the Pribilof to St. Mathew Island group and out to the U.S. - u.S.S.R. convention line (NOAA 1979, Cruise Results No. 79-02, R/V Sunset Bay).

The rough patch shrimp, P. stenolepis, is known to occur from Unalaska Island to Hecata Bank, Oregon in 49-229 m depths over muddy bottoms (Butler 1980). Reproductive biology is poorly known fOr Canadian populations (Butler 1964) and unstudied for the southeastern Bering Sea but it is assumed to follow a typical pandalid pattern. Needler (1938) gives descriptions of 6 larval stages plus a first postlarva. Larvae grow from 5 mm TL at S1 to 14 mm TL at SVI in British Columbia. The ovigerous period lasts from November until April in Canadian waters (Butler 1980). No commercial concentrations of this species are known to occur in the North Pacific.

The side-stripe pandalid, Pandalopsis dispar, prefers greater depths (>200 m according to Butler 1980) than P. borealis, and ranges from the Pribilof Is. to Manhattan Beach, Oregon (Butler 1980). Growth and reproduction were studied for Canadian populations (Berkeley 1930; Butler 1964) but no information is available for Bering Sea stocks. Berkeley (1930) describes 5 or 6 larval stages of P. dispar growing from 10 mm TL at S1 to 30 mm TL at SV. In Canadian populations males matured at 18 months and were reproductively active for two seasons. Transition to females occurred by age 3 yr and death followed the hatching of a single brood (Berkeley 1930). It is assumed that the colder waters of the southeastern Bering Sea retard growth and maturation and prolong the life span. Harris et al. (1972) studied the relationship between carapace length and egg number. Puget Sound P. dispar were found to have a mean egg count of 904 eggs/clutch versus 4,150 eggs/clutch found by Hynes (1930) in a southeastern Alaskan population (Table 6.1). Also, P. dispar females were found to be smaller at the same age in Puget Sound than in Southeastern Alaska. Commercial quantities of P. dispar have been taken by trawlers off the British Columbia coast but usually P. dispar occurs in mixed catches with P. borealis in Alaska.

Comments on Bering Sea Pandalids: The ecological and potential commercial importance of pandalids in the southeastern Bering Sea is difficult to ascertain and the following points should be stressed.

1. NMFS groundfish trawl surveys routinely underestimate sizes of shrimp stocks due to the large mesh size of their nets.

2. Little attention has been given these families in studies of benthic ecology since they are not found in commercially exploitable quantities or sizes.

3. An underestimation of the importance of these groups has resulted and scant attention has been given to the crucial trophic role they may play in the diet of commercial fish and marine mammals.

6.3 Hippolytidae

The Hippolytidae are the largest family of shrimp with respect to number of species in the North Pacific Ocean (Butler 1980) and are represented by 17 or more species in the southeastern Bering Sea (see Appendix A). As a group they are generally small to medium sized shrimp dominating the 40-80 m depths of the continental shelf (Ivanov 1969; Table 6.2). Larval descriptions appear in the literature for five species (Williamson 1957; Haynes 1978b; Pike and Williamson 1960; Appendix B) while mention of the others is either incomplete or totally lacking. There is a wide range in number of hippolytid zoeal stages from 2 in lebbeids to 5-9 in eualids (Table 6.3). No complete larval series is available for Heptacarpus.

Adult descriptions are given by Butler (1980) for Eualus avinus, E. barbatus, E. fabricii, E. pusiolus, E. townsendi, Heptacarpus camtschatica, H. moseri, Lebbeus grandimanus, L. groenlandicus, Spirontocaris arcuata, S. lamellicornis, S. ochotensis, S. prionata, and S. snyderi. Additional species of hippolytids may have been overlooked in compiling the list in the appendix. The most abundant of these species are probably E. gaimardii belcheri, E. macilentus, and one of the spirontocarids in our study area.

The crucial role these species play in the food web of the Bering Sea is reflected in such studies as Lowry et al. (OCS 1981 report). They showed that Eualus gaimardii belcheri feeds upon ostracods, euphausids, copepods and benthic phytoplankton. In turn, E. belcheri comprised 20-38% by volume of the total diet of ringed seal pups and was the major

Table 6.2. Life history information for hippolytid species.

	Depth (m)	Range	Total length Male (mm)	Female (mm)	Number of larval stages
Eualus avinus	46-642	Pribilofs - Oregon	29	44	
E. barbatus	82-507	" "	76	95	I-V or 1-IX then megalopa
E. fabricii	4-255	Circumboreal	27	42	
E. g. belcheri[1]	5-55	" northern form			
E. macilentus[2]	50-100	No data			
E. pusiolus	0-1381	Circumboreal			
E. stoneyi[1]	No data				
E. suckleyi[1]	No data				
E. townsendi	38-630	Pribilof < Sea of Japan Puget Sound	35	44	
Heptacarpus moseri	0-1100	Pribilof - Wash.		43	No data
H. camtschatica	0-108	Chukchi < Sea of Japan Str. of St. George	32	45	
Lebbeus grandimanus	6-180	Bering Sea - Sea of Japan SanJuan Is.	36	45	"
L. gröenlandicus	11-518	Bering Sea - Sea of Japan + N. Atl., Wash.	58	107	1, II and megalopa
Spirontocaris arcuata	5-641	Chukchi - Sea of Japan Wash.	22	46	
S. lamellicornis	3-192	Commander Is. - Pt. Arena, CA.	42	63"	
S. murdocki	No data			-	I - V and megalopa
S. ochotensis	0-247	Bering Sea < Sea of Japan Vancouver Is. WA.	22	31	
S. prionata	4-163	Bering Sea < Sea of Japan Monterrey. CA	19	28	
S. snyderi	4-141	Bering Sea - Cedros Is., CA	18	24	

References: Butler. T. 1980.
[1] Anderson, P. (personal communication) - common in St. George Basin.
[2] Ivanov, 8. 1969 - common in S.E. Bering Sea.

summer food for spotted seals. Feder and Jewett (1981) depict small, miscellaneous shrimp as food items for several species of fish (cod, starry flounder) in the southeastern Bering Sea, but quantification of use is not given.

6.4 Crangonidae

Crangonid shrimp are represented by eight or more species in the southeastern Bering Sea (*see* Appendix A), of which four are common (*Crangon dalli*, *C. communis*, *Sclerocrangon boreas* and *Argis dentata*). As a group they are generally medium-sized shrimp dominating the 0-50 m depths of the continental shelf (Ivanov 1969; Table 6.3). They are an important food source for demersal fish and invertebrates although they do not support a direct commercial fishery in Alaska. Crangonids eat benthic diatoms, detritus, polychaetes, small crustaceans, crustacean eggs and larvae, gastropod, foraminiferans and ophiuroids (Squires 1967), and mysids captured during diel vertical migrations (Sitts and Knight 1979). They are preyed 'upon by sand sole (Miller 1967), starry flounder (Feder and Jewett 1978), Pacific cod (Feder 1978), yellowfin sole (Feder and Jewett 1981), Beluga whales and phocid seals (Lowry et al. 1981), and Dungeness crabs, tomcod, and sculpin (Stevens et al. 1982).

Very little literature exists on the relative abundance of crangonid stocks. Their shallow, in-shore habitat has not been extensively sampled by suitable methods. These species bury in the sand during the day and thus dredging rather than trawling might yield more complete data. *Crangon dalli* and *A. dentata* appeared in 34 and 31% of the OCSEAP 1975 tows and *C. communis*, *A. dentata* and *A. ovifer* appeared in 24, 29, and

Table 6.3. Life history information for crangonid species.

	Depth (m)	Range	Max. T.L. (mm) Male	Max. T.L. (mm) Female	Number of larval stages	Fecundity eggs/clutch
Crangon dalli[2,3]	38-110	Chukchi - WA. and Sea of Japan	50	80	I - V and megalopa	4290
C. communis	16-1537	Chukchi - CA. and Sea of Japan.	61	80		2200
C. alaskensis	5-50	Bering Sea - WA. and Kurile Is. Japan	52	65	I - V and megalopa	
Sclerocrangon boreas[2]	0-366	Circumboreal	110	108	Direct development,	448
Argis alaskensis	18-221	Pribilof - Ore.	44	67		
A. crassa	4-125	Northern Bering Sea - WA. and Sea of Japan	40	56		448
A. dentata[2]	0-2090	Circumboreal	46	83	I - II and megalopa	
A. lar[2]	10-280	Chukchi - Str. of St. George and Sea of Japan	56	79	Larval life <1 month	980
A. ovifer	102-673	Pribilof	38	67		

[1] Data compiled from Butler, T. 1980.
[2] Anderson, P. - personal communication - most common crangonid species in the St. George Basin NMFS surveys.
[3] Ivanov, B. 1969. Host common crangonid specie.

21% of the 1976 tows (Feder 1978). *Crangon communis* is abundant where *Pandalus borealis* and *Pandalopsis dispar* are found (Butler 1980), and is commonly found on mixed mud and sand bottoms at depths of 62-95 m and temperatures of 0.5-3.6°C (McLaughlin 1963). Population estimates of crangonids in the southeastern Bering Sea have not been made. Estimates made from trawl surveys in Grays Harbor, Washington, were as high as 38 million shrimp for the bay during summer months, and even this figure was thought to be low because of gear inefficiency (Hoeman and Armstrong 1981). Crangonid populations in the Bering Sea may be substantial. Their ecological and community role both as detrital processors (Rice 1981) and predators, and as prey for commercial fish and crustaceans make them an important group to consider in scenarios of oil impact.

Larval descriptions are complete for 3 species; *C. dalli* (Makarov 1966), *C. alaskensis* (Loveland 1968) and *A. dentata* (Squires 1965). Five larval stages and one megalops are known for *C. dalli* and *C. alaskensis*, while *A. dentata* had only 2 zoeae before the post-larval stage and *Sclerocrangon boreas* undergoes direct development in which larvae hatch as juveniles (Table 6.3). No information appears in the literature describing the reproductive biology of these species in the southeastern Bering Sea. Allen (1960) reported that hatching occurs from May through August in *Crangon dalli* from North Sea stocks. On the Kamchatkan shelf, Makarov (1967) noted that argids hatched from May to the end of June.

6.5 *Penaeidae*

Among the plankton collected in the southeastern Bering Sea and sorted in our project is a series of four larval stages from a very distinctive group. Most notable characteristics of this group are long dorsal and lateral spines on the dorsal margins of each abdominal segment and five spines above each eye. Makarov (1967) assigned this spiny larva to the family Crangonidae, Paracrangon echinata, while Kurata (1964) relegated them to the family Glyphocrangonidae, Glyphocrangon spp. Ken Coyle from the University of Alaska (personal communication) disagrees with both designations and has assigned these larvae to the family Penaeidae since Glyphocrangon sp. do not range to the Bering Sea. These larvae will appear in our summaries as a deep-water penaeid until further clarification reveals otherwise.

6.6 Results and Discussion

6.6.1 Pandalidae

Frequencies of Occurrence of Pandalus borealis. Larvae of this species were consistently the most prevalent pandalid in samples from 1976-1981. The percent frequency of larval occurrence by month from PROBES 1981 for the 5 pandalid species is given in Figure 6.1. P. borealis larvae were present at 37% of the stations in April, 30% in May, 42% in June, and 65% in July. A very dramatic rise in P. tridens larval occurrence was seen from a low of 5% in April to 37% in June. P. stenolepis larvae did not appear in samples before June but were abundant thereafter, taken at 36% and 28% of the stations from June and July. P. goniurus larvae and Pandalopsis dispar larvae were rarely taken - never at > 5% of the stations per month. As an average between April and July, P. borealis larvae were found at 45% of stations analyzed (Fig. 6.1). This frequency of occurrence is comparable to values from PROBES 1978 and 1980 when

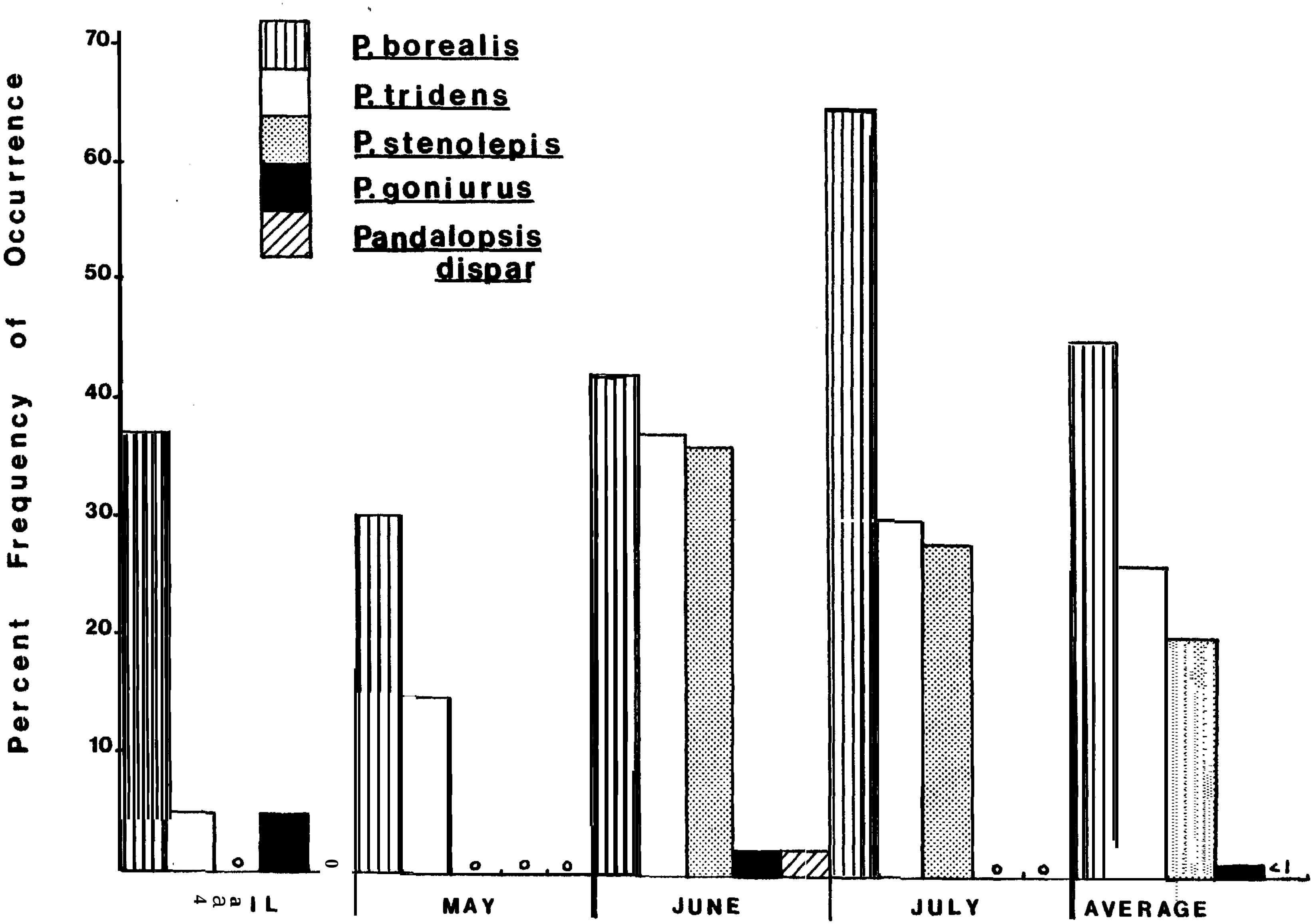


Figure 6.1 Frequency of occurrence of pandalid shrimp larvae at PROBES stations collected in 1981 by months April - July.

sampling patterns within the St. George Basin covered similar areas (Table 6.4). Frequency of occurrence of pandalids in 1981 (PROBES) was relatively high compared to values from 1980 samples. *P. borealis* was taken at 38-45% of the stations from 1978, 1980, and 1981. *P. stenolepis* consistently showed the most variability in frequency of occurrence from a low of 2% in 1980 to a high of 20% in 1981. *P. goniurus* and *Pandalopsis dispar* larvae were taken rarely during 1980 and 1981 and not at all in 1978.

Larval Duration. Zooplankton samples collected in February and March 1978 contained no pandalid zoeae and thus first hatch was assumed to occur about April 1st. Stage I zoeae of *P. borealis* were present throughout the St. George Basin in early April during the first sampling days of the NOAA 1977, PROBES 1978, 1980 and 1981 cruises and continued to be taken as late as mid-May in 1978 and 1981. Figure 6.2 shows the duration of each stage during the PROBES 1981 cruise for *P. borealis*, *P. tridens* and *P. stenolepis* larvae. The intermolt period for *P. borealis* was calculated by taking the midpoints of each larval stage duration and figuring the difference between adjacent midpoints. Thus 12-20 days (2-3 weeks) seems to be the average intermolt period for *P. borealis* larvae. These zoeae would require approximately 3 months of planktonic life to accomplish the 5 molts to the megalops stage (VI) and to settle to the benthos. Although the sampling periods of cruises from 1978-1981 did not extend past mid-July, *P. borealis* larvae would apparently settle out by mid-August. Future examination of samples from the NOAA 1982 summer cruise will help substantiate the exact length of the larval period.

Table 6.4. Frequency of occurrence (percent) of **Pandalid** shrimp larvae from PROBES stations collected in 1978, 1980 and 1981.

	1978	1980	1981	Years
P. borealis	42	38	45	
P. tridens	22	11	26	
P. stenolepis	5	2	20	
P. goniurus	0	1	1	
P. dispar	0	1	<1	

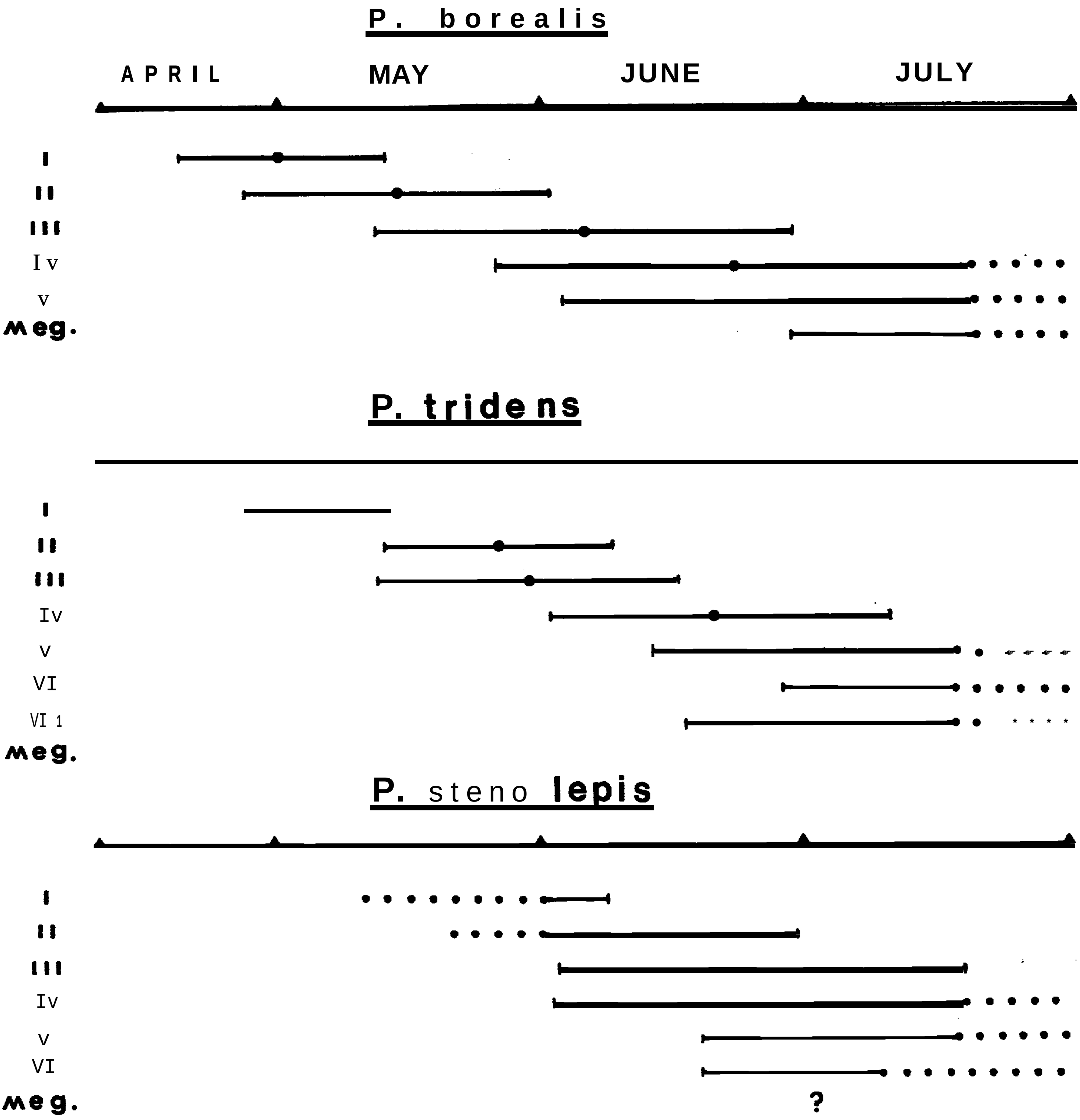


Figure 6.2 Duration of larval stages of three pandalid shrimp species collected at PROBES stations in 1981. Megalops stages of P. tridens and P. stenolepis were not taken. Dots represent hypothetical time periods for which there are no data.

A stage frequency histogram for P. borealis (Fig. 6.3) shows a slightly later or a more protracted hatchout period for larvae in 1978 as compared with 1981. In May, fifty percent of the larvae were still S1 in 1978 as compared to 1% of the larvae in 1981. By June 1978, only 10% of the larvae had reached SIV or megalops compared with 31% in 1981.

P. tridens seemed to follow the same pattern of emergence, appearing first in mid-April in 1977 (NOAA) and by late April in 1978 (PROBES). No P. tridens larvae were collected until the end of April in 1980 and 1981 since sampling did not occur until late April at stations > 200m preferred by the P. tridens adults.

Duration of the larval stages of P. tridens and P. stenolepis, as given in Figure 6.2, are less clear cut than seen for P. borealis larvae. P. tridens and P. stenolepis larvae were less abundant and sampled less frequently thereby giving only an incomplete representation of larval stage durations. Two to three weeks is still probably the average intermolt period for P. tridens and P. stenolepis larvae. Since these two species have 7 and 6 larval stages before metamorphosis, respectively, and since no megalops of either species were ever found, larvae may be in the water column until late August or early September, a planktonic life of approximately four months is thus indicated.

A stage frequency histogram for P. tridens larvae, Figure 6.4, compares data of 1978 and 1981. Only one Stage I larva was found in 1981 April samples due to sparse sampling beyond the shelf break. The P. tridens larval population seemed to lag about one stage behind during

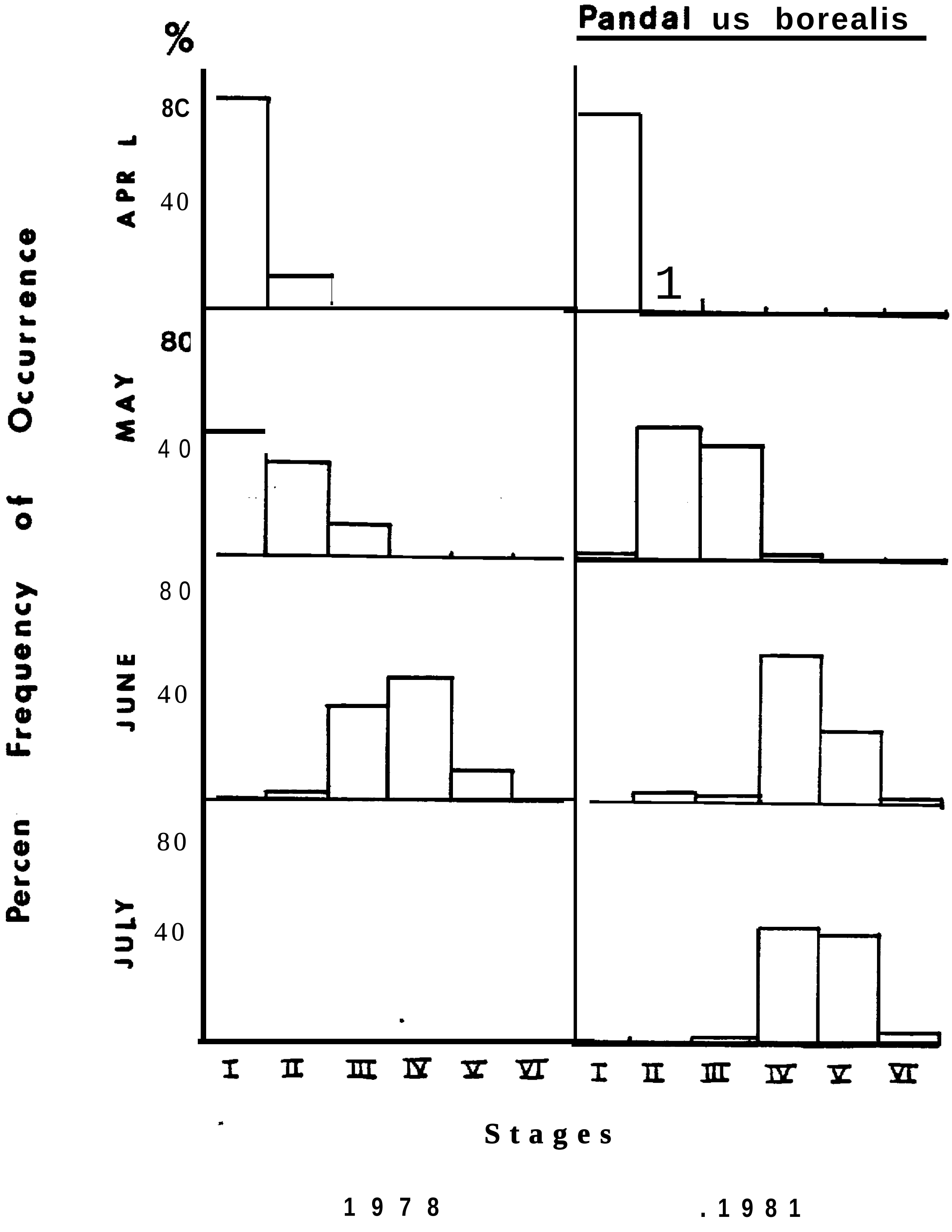


Figure 6.3 Pandalus borealis stage frequency histograms by month from PROBES 1978 and 1981. No samples were taken in July 1978.

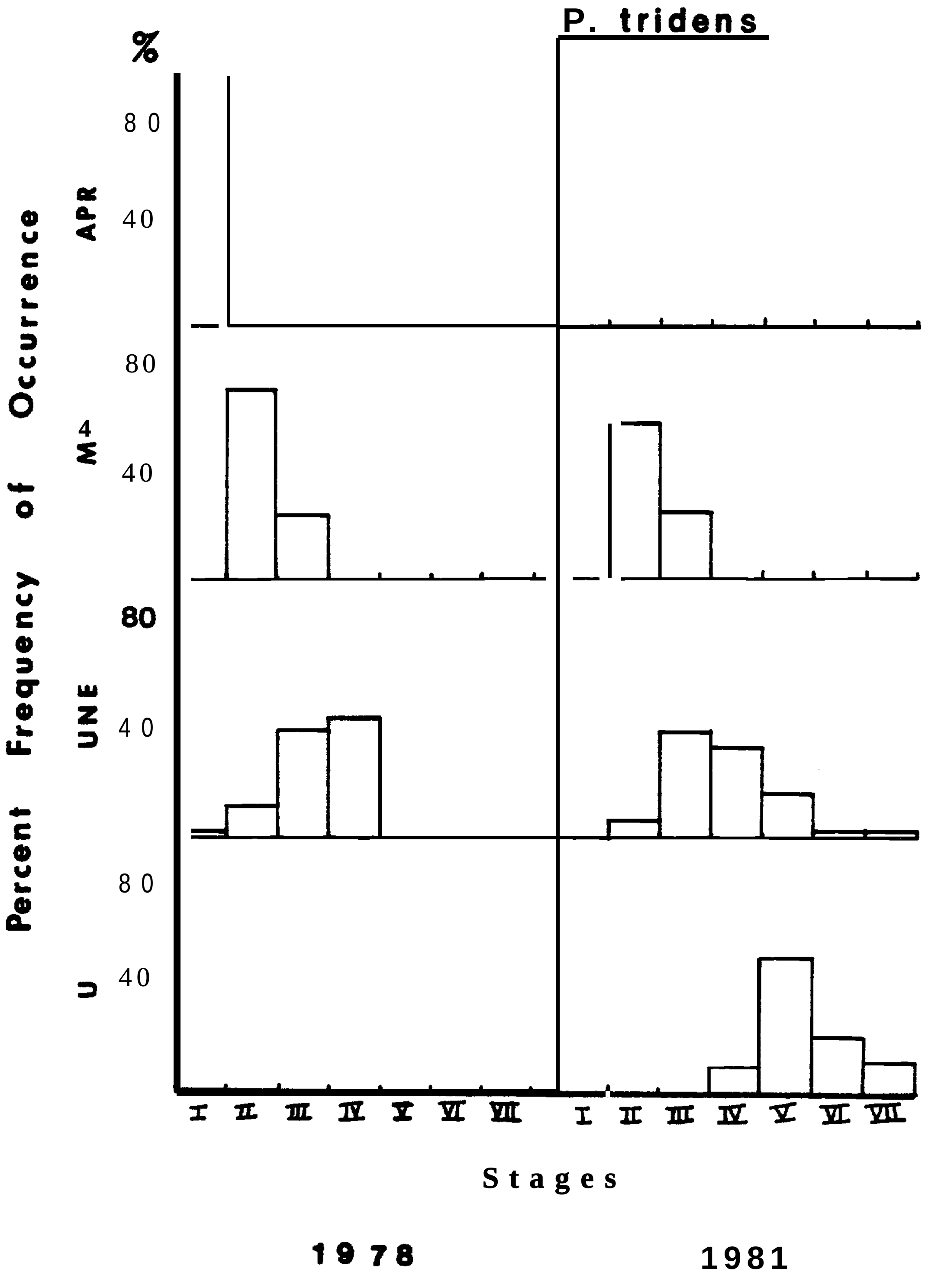


Figure 6.4 *Pandalus tridens* stage frequency histograms by month from PROBES 1978 and 1981. No samples were taken in July of 1978.

June 1978 compared to June 1981. Contrasting P. tridens with P. borealis larval development (Figs. 6.3 and 6.4), P. tridens larvae were generally one stage or one molt behind P. borealis larvae by June of both years. For example, in June 1978, 60% of P borealis larvae were SIV or greater compared to 46% of P. tridens larvae, while in June 1981, 93% of P. borealis larvae were SIV or greater versus 54% of P. tridens larvae.

The northernmost extent of the range of P. stenolepis is given by Butler (1980) as Unalaska Island. The NOAA 1977 cruise first took P. stenolepis S1 in mid-April just west of Unimak Pass. No other cruises sampled this area during April. All other cruises took S1 zoeae from mid-May until early June. The frequency of P. stenolepis occurrence was so low it is not possible to make definitive statements regarding this long S1 duration (except possibly asynchronous hatch-out within the population). Figure 6.2 shows duration of stages from April until July for PROBES 1981. Since early sampling was not done near Unimak Pass, first hatch-out and the duration of S1 and S11 is not well-documented. Sampling in May and June over central St. George Basin took later S of P. stenolepis (II-VI), but no megalopae were found. With respect to staging, P. stenolepis larvae were mostly stages I and II during late April-early May (NOAA 1977), stages III and IV during early-mid June (PROBES 1981), and stages IV and V from late June to early July. These larvae would probably not complete metamorphosis before late August.

Pandalus goniurus adults are commonly taken from the St. George Basin (Feder 1978) in the 38-124 m depths on a mud to coarse sand bottom. A pandalid larval type that was smaller and had fewer setae on the antennal scale than the P. borealis larvae (as described by Haynes 1978) was found sporadically at scattered locations over the mid-shelf domain in samples from 1976-1981. While this larval type agreed with a description of P. borealis S1 larvae from Hokkaido, Japan (Kurata 1964), it seemed significantly smaller and with different setal counts than the majority of P. borealis larvae. At the same time, it had a larger body size than the S1 P. goniurus described by Haynes (1978) from Kachemak Bay, Alaska. The colder water temperatures of the Bering Sea may cause significant size differences in larvae compared to -populations from the Gulf of Alaska, and thus size alone cannot be used as a definitive characteristic for the species. Size of Bering Sea larvae were consistently larger and had consistently different numbers of antennal setae, maxillule spines, and maxilla setae counts than Haynes' Kachemak Bay. Larval specimens were sent to Dr. Evan Haynes of the NMFS Auke Bay Laboratory to confirm identifications of P. goniurus. All P. borealis S1 larvae from 40-120 m stations were re-examined and re-assigned to P. goniurus if they proved to be < 5.0 mm from rostrum to telson, with less than 19 setae on the antenna, less than 9 spines on the basipodite of the maxillule, and less than 11 setae on the scaphognathite of the maxilla. Relatively few P. goniurus larvae were found following this extensive review of 1976-1980 samples. Only 2.4% of the PROBES stations sampled in 1981, and 0% and 4.5% of the NOAA 1981 stations (two cruises) contained P. goniurus larvae. Figure 6.5 illustrates station locations of P. goniurus larvae from all years combined.

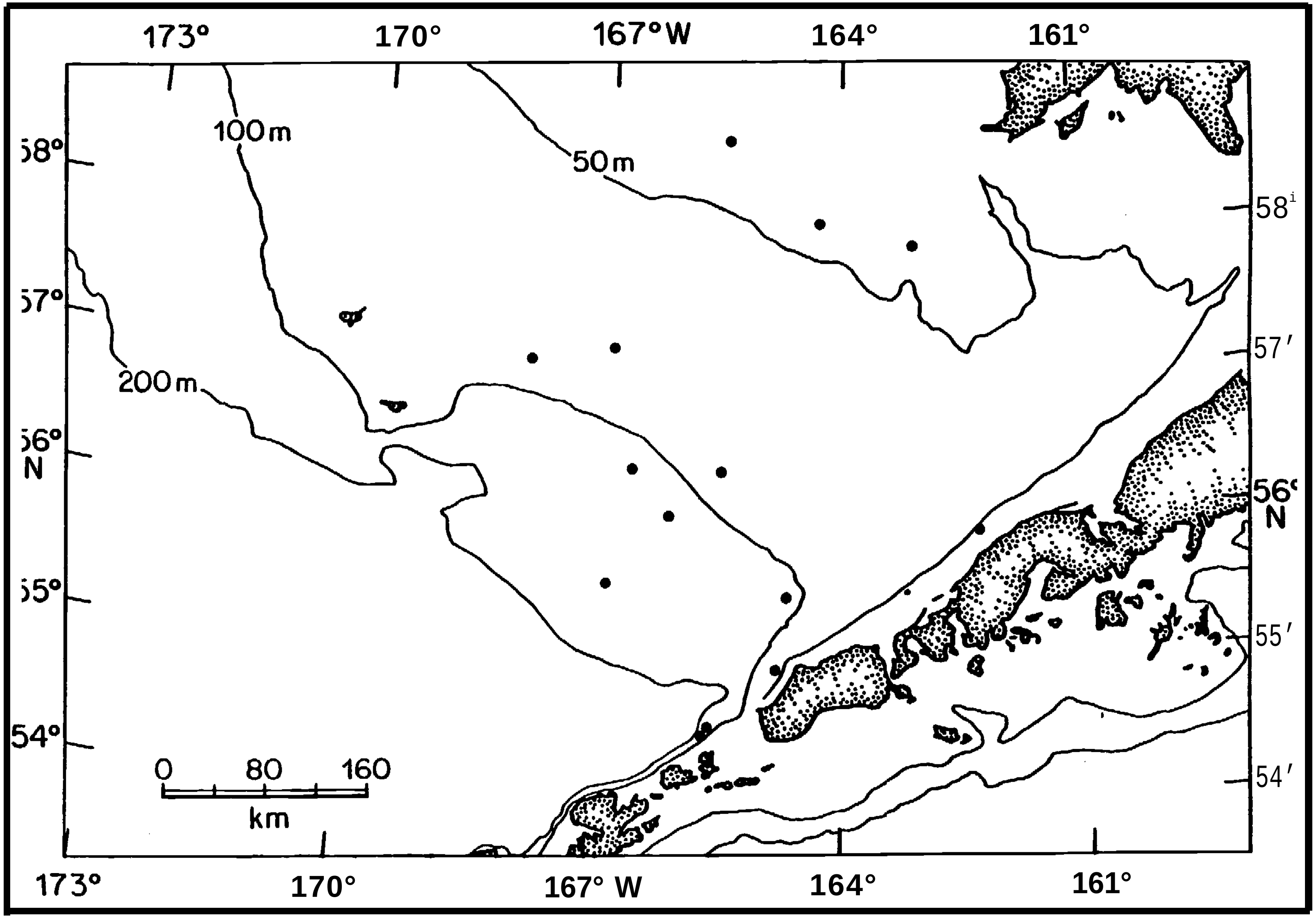


Figure 6.5 Distribution of *Pandalus goniurus* larvae (black dot), all years 1976-1981, and all months April - July combined. Refer to station maps of Section 2.0 for extent of coverage.

Pandalopsis dispar was taken only once during the following cruises; PROBES 1981, NOAA 1981 (R/V Alaska), PROBES 1980 and 1978, thus making it the least frequently caught pandalid species. Stages I, II, IV, and V were taken during the months of June and July. The northernmost range for this shrimp is given as the Pribilof Islands where the NOAA 1981 (R/V Alaska) cruise caught a single animal.

Distribution and Abundance of Pandalus borealis: Larvae of this species were found in the greatest abundance between the 100 and 200 m isobaths over the St. George Basin (Figs. 6.6 to 6.9). Highest P. borealis larval densities were found during the NOAA 1977 cruise in April and May (Figure 6.6) with concentrations ranging from 1200-6200 larvae/100 m^2. Comparably high larval densities, ranging from 1100-7200 larvae/100 m^2, were also found in June 1979 (NOAA cruise, not pictured). PROBES 1980 larval densities for P. borealis followed this same general distribution pattern but with higher abundances near the 100m isobath.

In marked contrast, very low P. borealis densities were found during the 1981 PROBES and NOAA cruises compared to 1977 (Fig. 6.7 vs. 6.6). Although larvae seemed to be more widely dispersed up into the middle shelf domain during 1981, their abundance over the outer shelf domain was rarely greater than 500 larvae/100 m^2.

Monthly variation in P. borealis distribution and abundance between April and May/June 1978 is shown in Figures 6.8 and 6.9. The relatively clustered pattern of high density (1000-5000 larvae/100 m^2) in April 1978 (Fig. 6.8) over the central outer shelf, spread throughout the St.

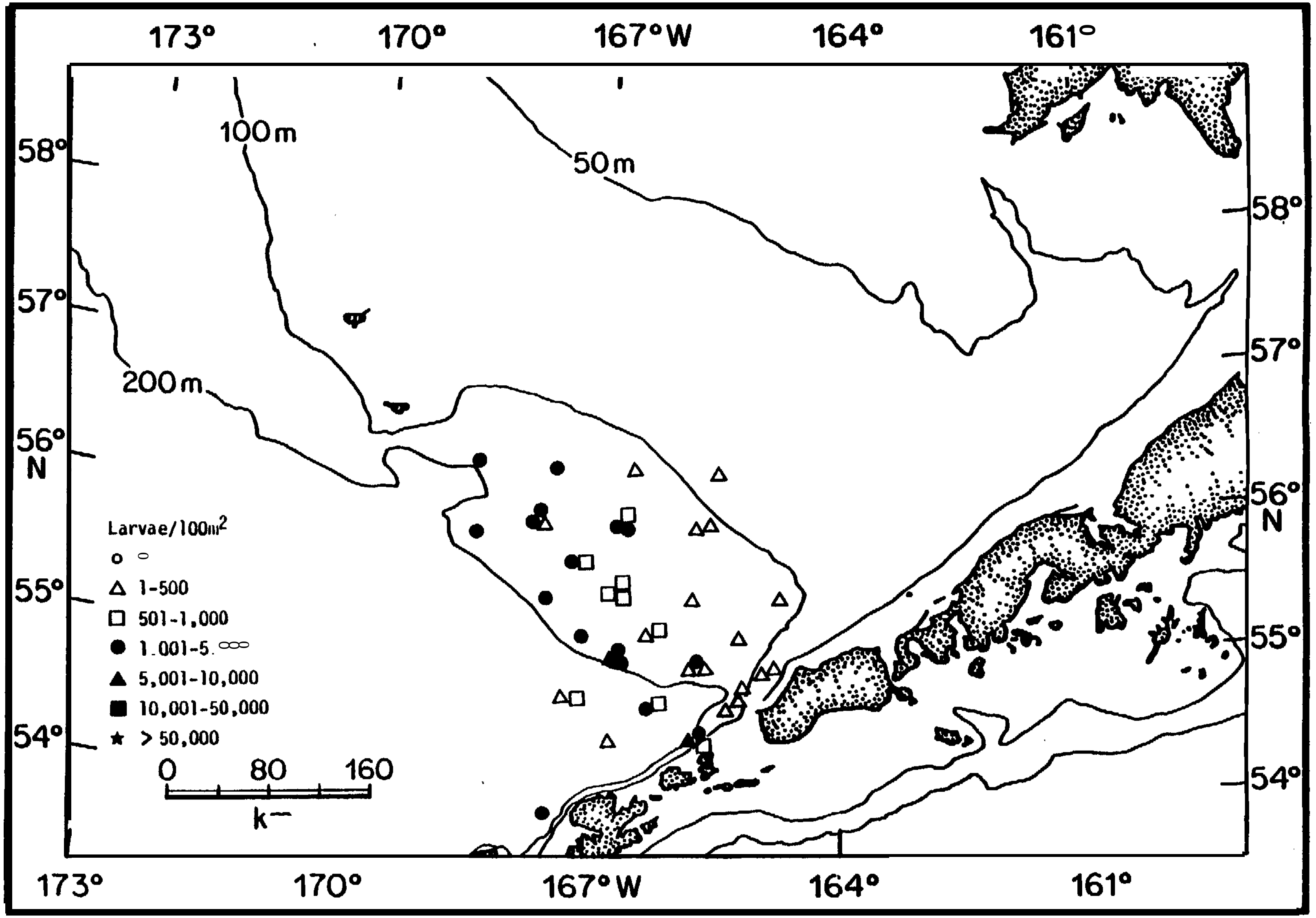


Figure 6. Distribution and abundance of *Pandalus borealis* larvae from NOAA 1977, April and May combined. Only positive stations are shown; see Section 2.0 for cruise tracks and all station locations.

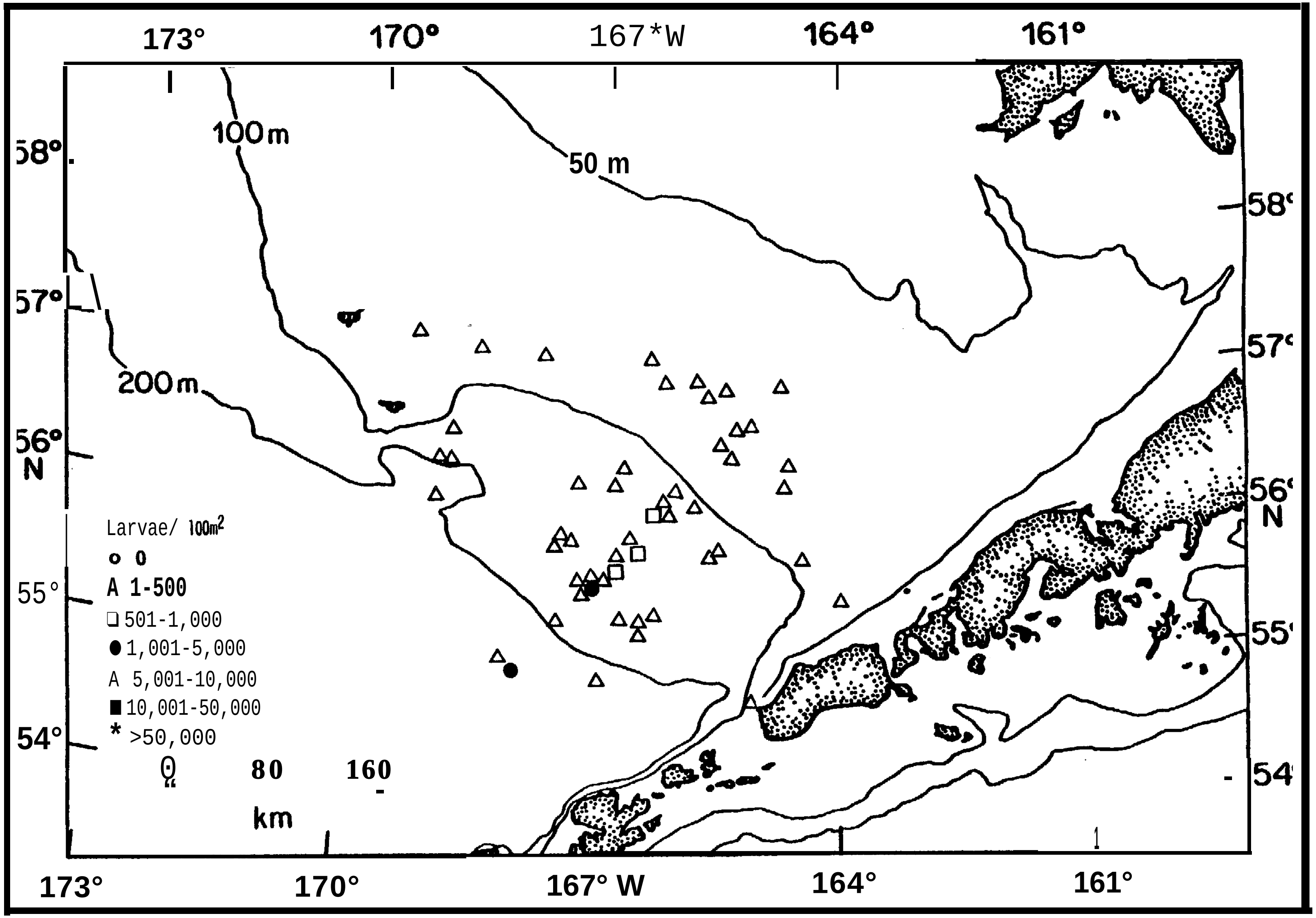


Figure 6.7 Distribution and abundance of P. borealis larvae from PROBES 1981 and NOAA 1981, April-July combined. Only positive stations are shown; see Section 2.0 for cruise tracks and all stations.

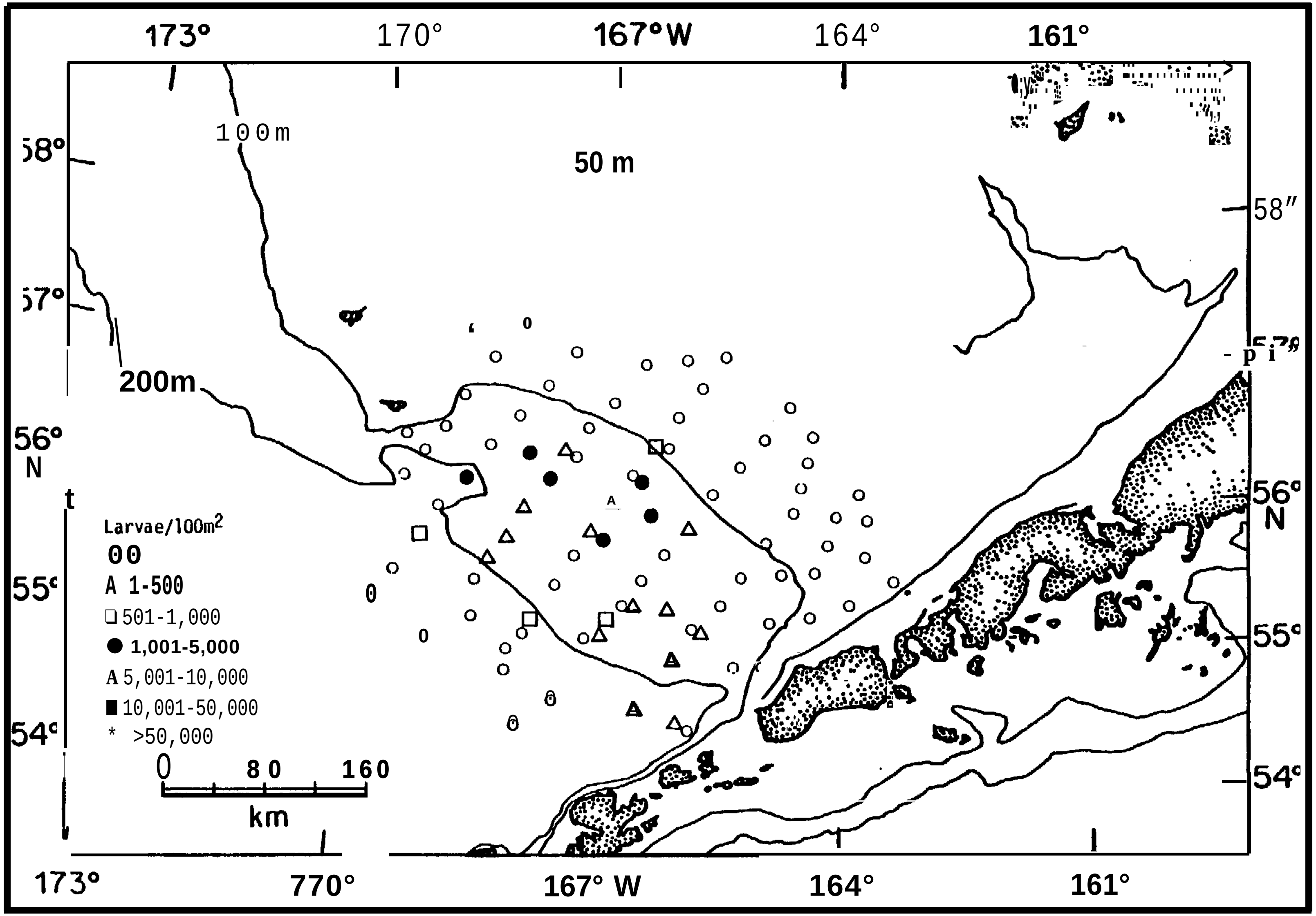


Figure 6.8 Distribution and abundance of *P. borealis* larvae from PROBES 1978, April only. Zero stations where no larvae were caught are included.

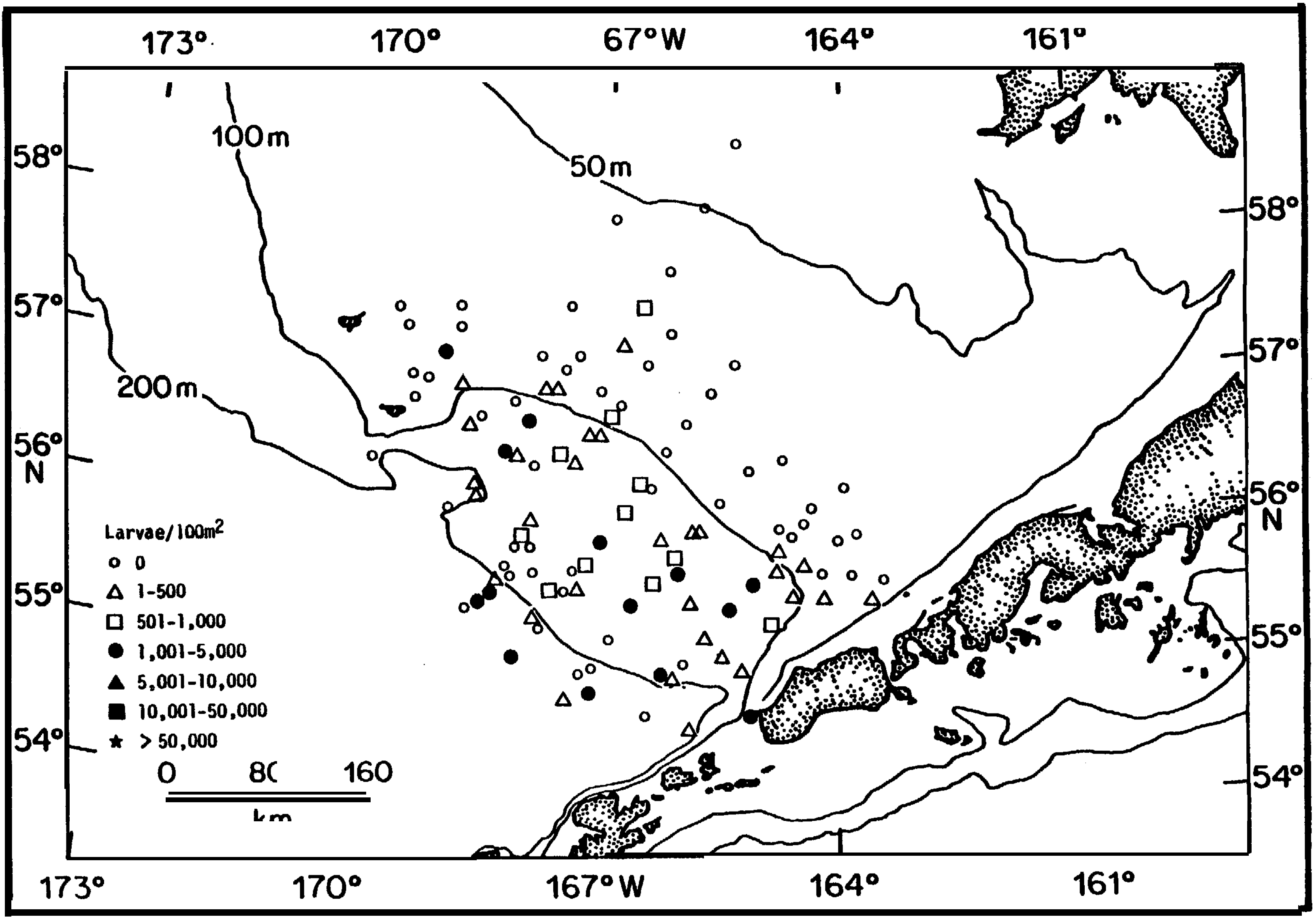


Figure 6.9 Distribution and abundance of *P. borealis* arvae from PROBES 1978, May and June combined. Zero stations are included where no larvae were caught.

George Basin and extended over the shelf break beyond the 200m isobath by May and June 1978 (Fig. 6.9).

The outer shelf domain, where P. borealis larvae were primarily found, was assigned to strata 2, 5, and8 (see Fig. 2.21) for computer assisted data analysis (see Section 2.0). Figure 6.10 gives a monthly comparison of the mean densities of P. borealis larvae in stratum 2 for four years. Generally, densities increase over time from April to June from less than 500/100 m^2 to over 1000/100 m^2. The very high values of 1172 larvae/100 m^2 given for April 1977 may indicate that P. borealis hatched out somewhat earlier that year. Generally, stratum 2 mean densities ranged from 250 larvae/100 m^2 in April to 720 larvae/100 m^2 in May to 1340 larvae/100 m^2 in June. The PROBES 1981 cruise, as shown earlier in Figure 6.7, had consistently lower mean densities; 102 larvae/100 m^2 in April, 373 in May, 197 in June, and 227 in July. These lower densities may reflect a real decrease in abundance or a geographical sampling bias imposed by adhering mainly to the PROBES A line (see Fig. 2.13, middle transect).

A cross-shelf comparison of P. borealis mean densities appears in Table 6.5 for PROBES 1978 data; no other cruise sampled these 9 strata . as extensively during May and June. Comparing strata 8, 2, and 5, the outer shelf domain, gives a picture of relatively homogeneous distribution of P. borealis larvae over the St. George Basin between the 100-200 m isobaths. A comparison of the middle domain, strata 9, 1, and 6with the outer shelf domain shows a decrease in both mean densities (Table 6.5) and percentage of positive stations. A similar comparison of the

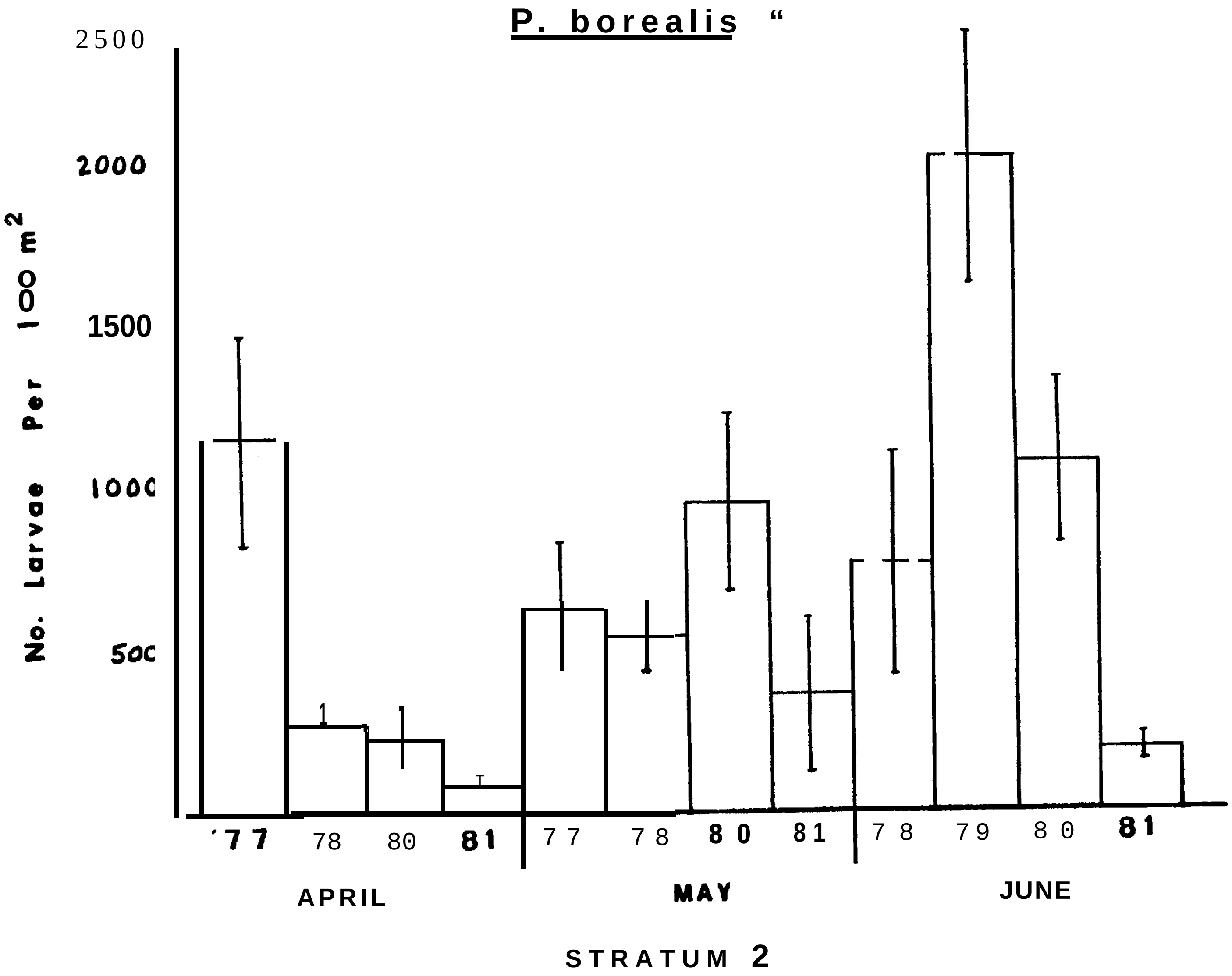
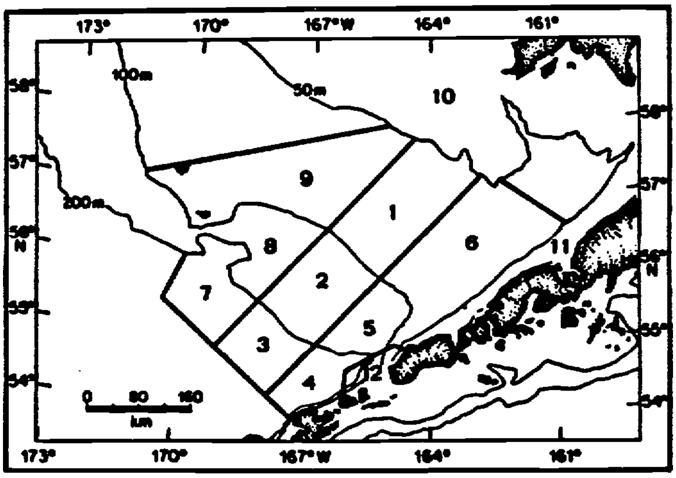


Figure 6.10 P. borealis larval abundance in stratum 2 during April, May and June from 1977-1981. Values are the mean density ±1 standard error. Zero stations are included in calculations.

Table 6.5. Cross-shelf comparison of mean densities of *P. borealis* larvae during May and June from PROBES 1978. Zero stations omitted from calculations. Total number of stations (N) sampled within each stratum shown. See Figure below for strata locations.

Stratum	Mean Density ± S.D. (# larvae/106 m^2)	% positive stations	N
	Oceanic/Shelf Break Domain		
7	714 ± 729	71%	7
3	1003 ± 680	57%	7
4	*	*	
	Outer Shelf Domain		
8	675 ± 615	59%	17
2	878 ± 702	68%	19
5	626 ± 494	92%	12
	Middle Shelf Domain		
9	377 ± 318	35%	26
1	0	0%	7
6	175 ± 81	27%	15

*Insufficient data.



outer shelf with the oceanic area beyond the shelf break shows high values for mean larval density and percentage of positive stations (note that fewer stations were sampled beyond the shelf break). Unfortunately, stratum 4 was not sampled sufficiently to complete the matrix.

Vertical Distribution of P. borealis: PROBES 1980 and 1981 MOCNESS data were used for analyses of vertical depth distribution. Both unweighed and weighted average abundance values were calculated for each depth interval. Even though there were few stations with extremely high larval densities at any one depth interval , unweighed (zero stations included) values were determined to give a clearer picture of larval depth distribution. Figure 6.11 illustrates the proportion of the total population of P. borealis larvae at each depth interval for 1980 and 1981 PROBES cruises. The total cumulative percentages of larvae in each of the depth intervals for 1980 and 1981 were 17-32% in the upper 20m, 49-61% in the upper 40 m, 65-75% in the upper 60 m, and 90-95% in the upper 80 m. From the values it is evident that P. borealis larvae are relatively homogeneously distributed throughout the water column down to 80m, with about 50+% of the larvae in the upper 40 m and 40+% in the lower 40 m.

Distribution and Abundance of Pandalus tridens: The earliest record of P. tridens larvae was from samples collected near Unimak Pass in mid-April 1977 (no larvae were found in the February-March collections). By late April in 1978 they were found southwest of St. George Island, whereas in 1980 and 1981, they were first found along the PROBES A line at stations at depths from about 150 m to more than 200 m.

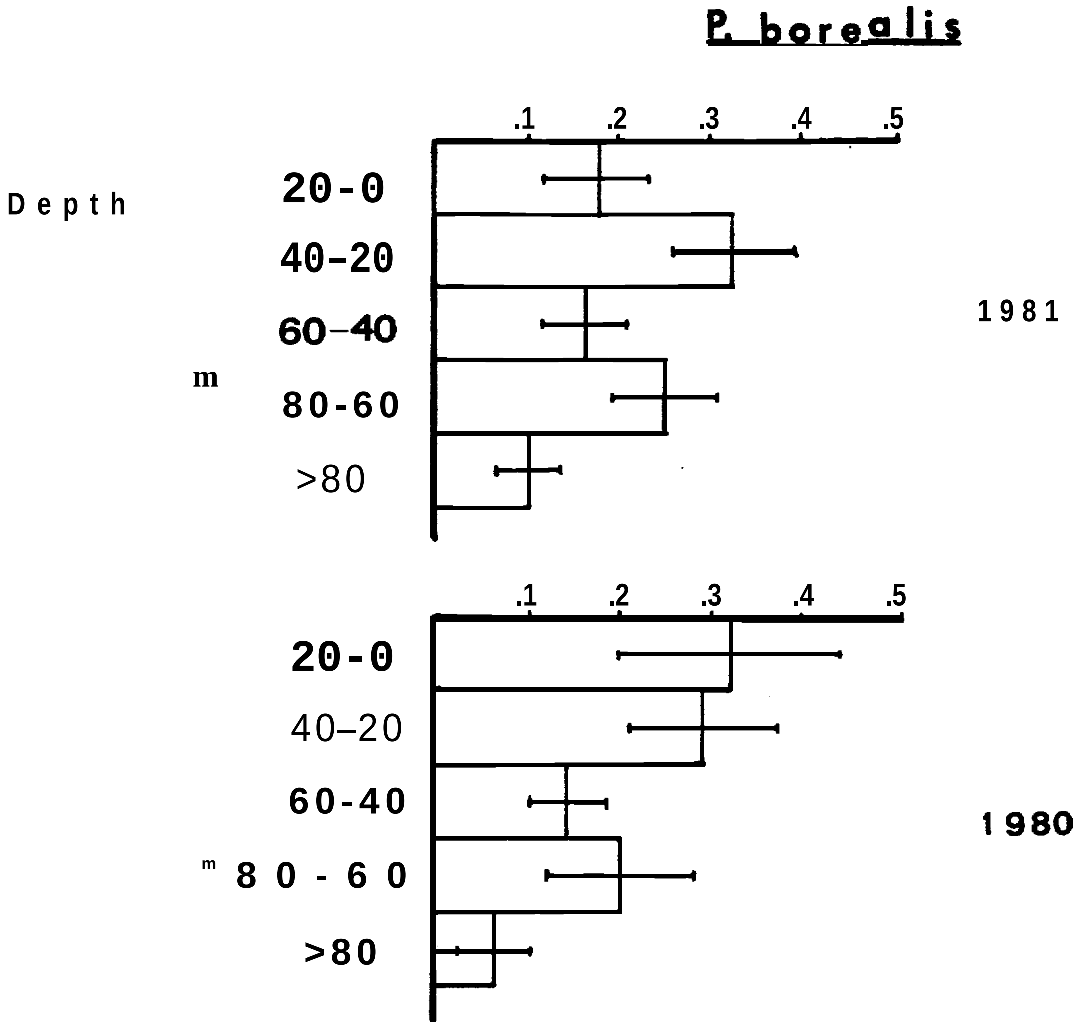


Figure 6.11 Vertical Depth Distribution of P. borealis larvae (all zoeal stages) from PROBES 1980 and 1981. Values expressed as an average proportion ±1 standard error.

Since P. tridens occurred less frequently than P. borealis, Figure 6.12 shows abundance and distribution for April-July for all year combined except PROBES 1978. Highest larval densities were clustered southwest of the 200m isobath over the shelf break (1000-4000 larvae/100 m^2) and from Unimak Pass to Unalaska Island (5000-6000 larvae/100 m^2). The highest mean larval density by stratum was 1461 larvae/100 m^2 for stratum 12 in the Unimak Pass area during the NOAA 1977 cruise. In general, P. tridens larvae were found only rarely shoreward of the 100m isobath over the middle shelf domain.

Figures 6.13 and 6.14 compare P. tridens larval distribution in April with May and June distribution from PROBES 1978. April hatch out occurred south of St. George at the Pribilof Islands late in April (Fig. 6.13). By May and June larvae were most abundant southwest of the shelf break (1000-4000 larvae/100 m^2 in strata 3 and 4) and over the southern part of the St. George Basin (1000-2000 larvae/100 m^2 in stratum 5). By May and June, P. tridens overlapped P. borealis larval distribution over the St. George Basin and west of the shelf break (compare Figs. 6.9 and 6.13).

Figure 6.15 contrasts May and June mean larval densities in stratum 2with stratum 3 for the years 1978, 1980, and 1981. (Since this species was less common than P. borealis, and since the extent and degree of sampling varied within strata interannually, zero stations - no larvae found - were omitted from calculations of mean density.) There was a three- to five-fold increase in larval density of P. tridens in stratum 3 beyond the shelf break as compared to stratum 2 of the

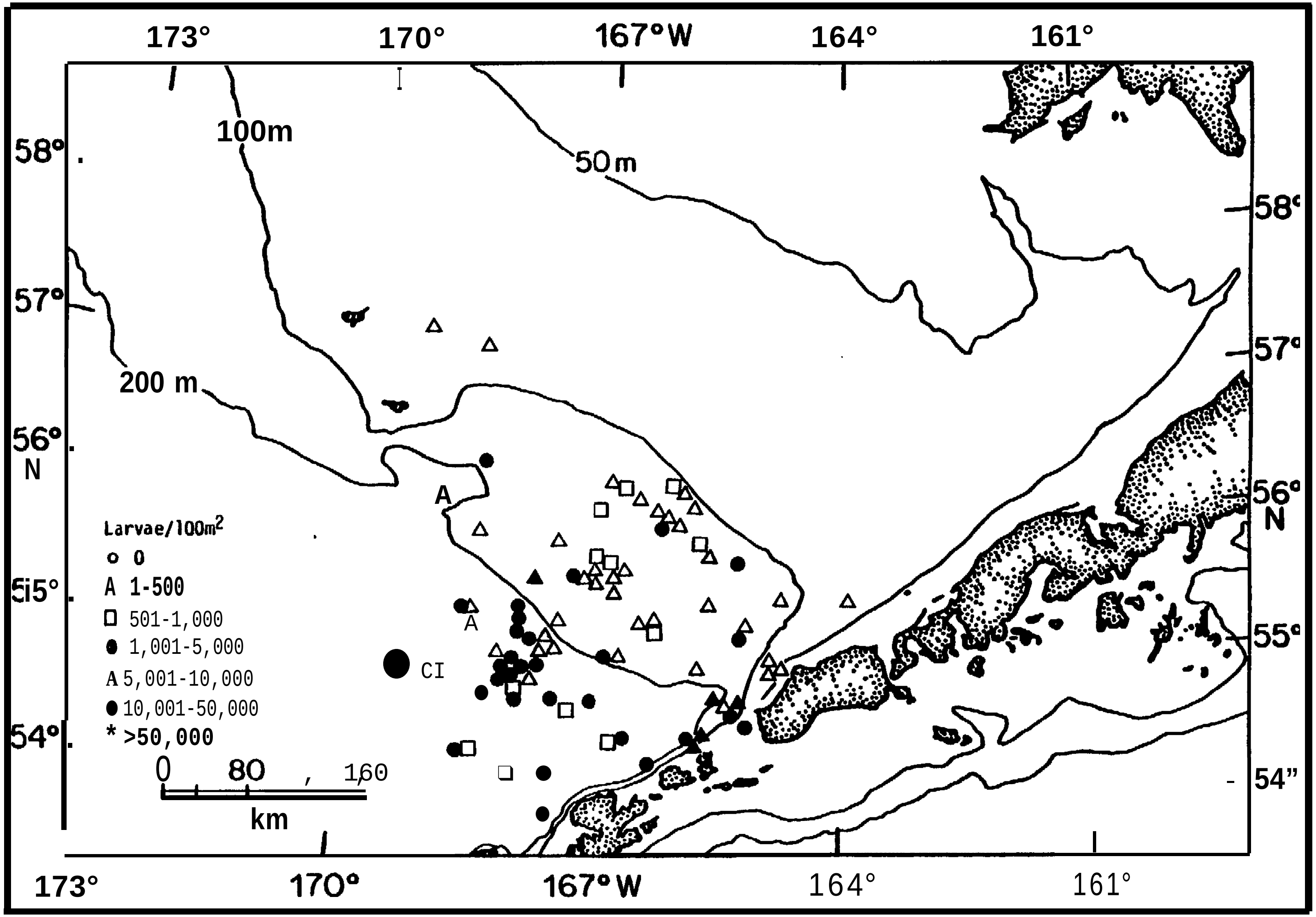


Figure 6.12 Distribution and abundance of *Pandalus tridens* larvae from all months April-July, all years except PROBES 1978 combined. Zero stations omitted; see Section 2.0 for cruise maps and stations.

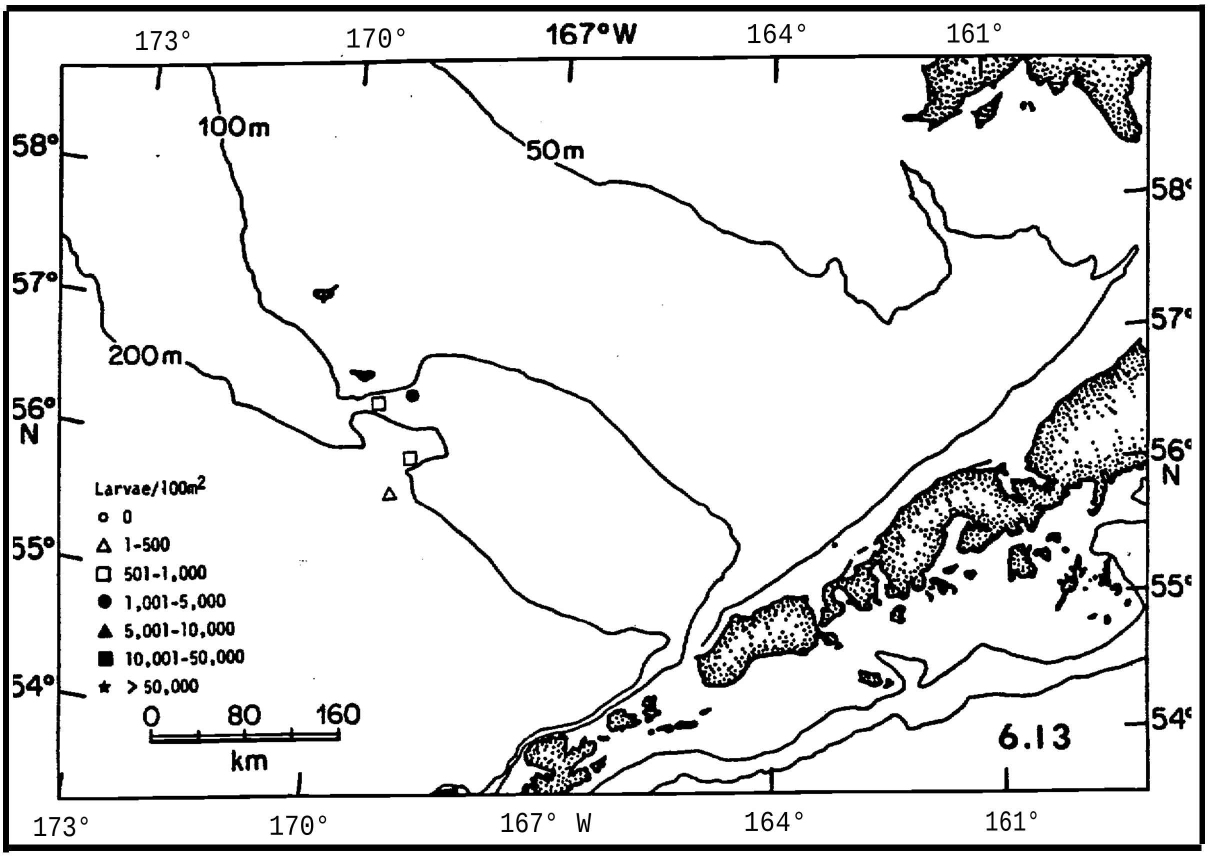


Figure 6.13 Distribution and abundance of P. tridens larvae from PROBES 1978, April only. Zero stations omitted; see Section 2.0 for cruise maps and stations.

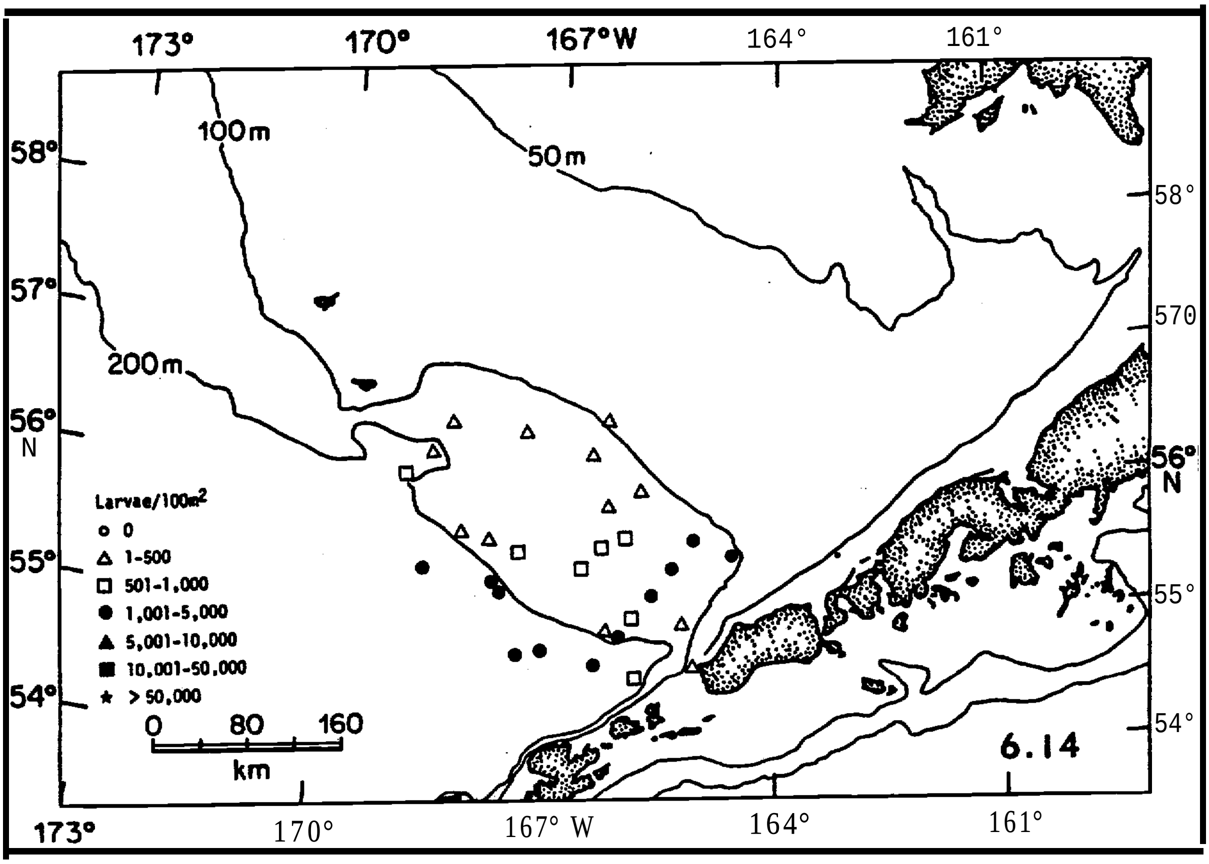


Figure 6,14 Distribution and abundance of P. tridens larvae from PR08ES 1978, May and June. Zero stations omitted. See Section 2.0 for location of all stations sampled during this cruise.

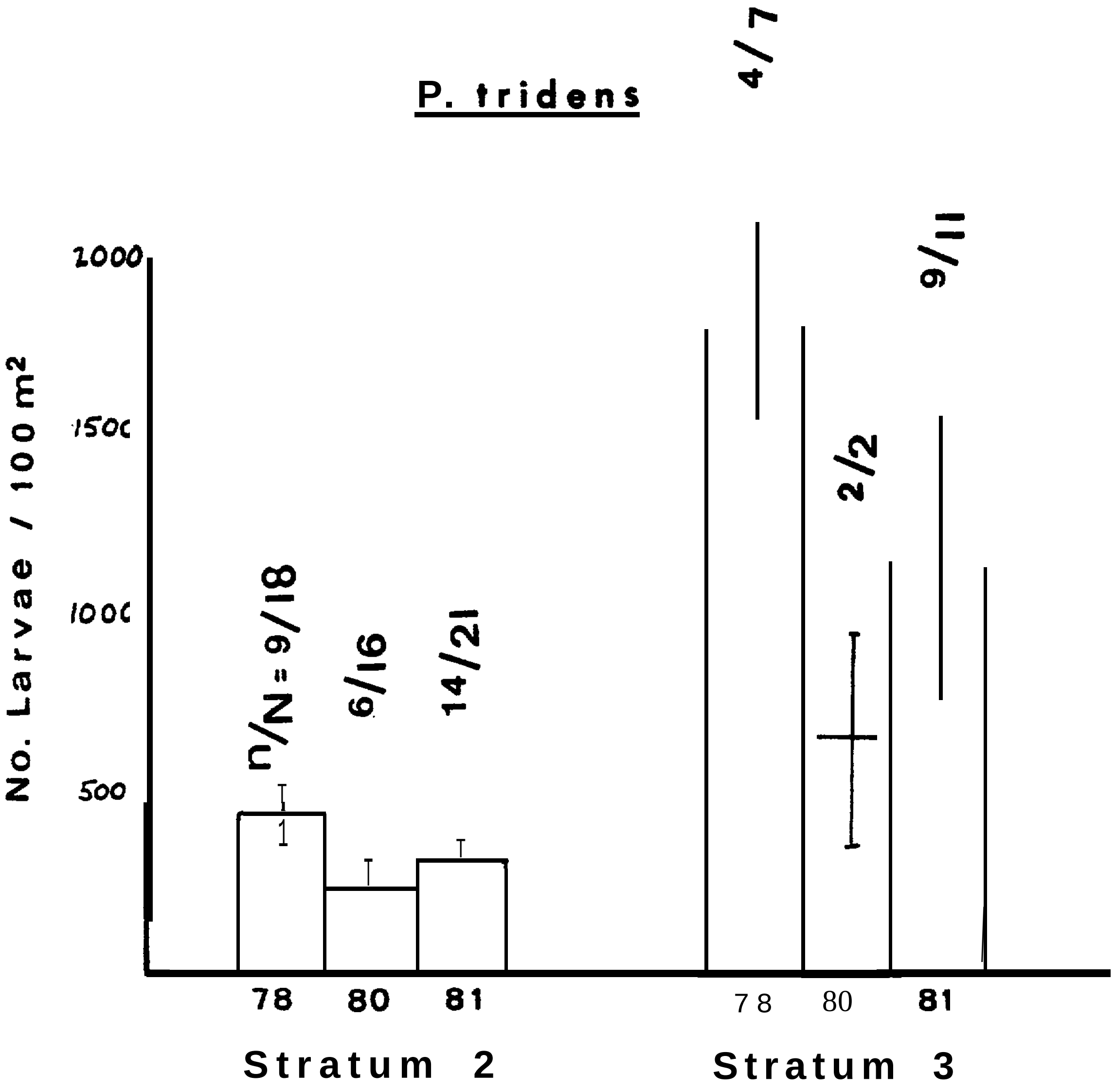


Figure 6.15 P. tridens larval abundance in strata 2 and 3 during May and June from PROBES 1978, 1980 and 1981. Values expressed as mean density ±1 standard error. Zero stations are not included in these calculations. The number of positive stations (n) and the total number of stations sampled (N) for each stratum-year combination is shown above the bars.

outer shelf during those years. Samples in June 1979 (NOAA) confirmed this trend when the highest monthly mean density of 1798±926 P. tridens larvae/100 m^2 occurred in June 1979 in stratum 3.

A cross-shelf comparison of P. tridens larvae incorporating 1978 PROBES data appears in Table 6.6. Unlike the homogeneous distribution of P. borealis larvae throughout the St. George Basin between the 100-200 m isobaths (Table 6.5; strata 8, 2, and 5), P. tridens larval distribution was much more concentrated near the Aleutian Peninsula (stratum 5) in the outer shelf domain just north of Unimak Pass. Generally higher larval densities seaward of the shelf break showed that to be the area of greatest abundance with the maximum density appearing closest to the coastal area in stratum 4 (although this last density was calculated from only 2 stations). P. tridens larvae were less abundant in the outer shelf domain and virtually absent (except for 1 of 36 stations) from the middle shelf domain.

P. tridens larvae were not caught in sufficient abundance to analyze the vertical depth distribution in 1980, but MOCNESS data from PROBES 1981 (Fig. 6.16) revealed a homogeneous depth distribution of P. tridens larvae in the top 60m, similar to P. borealis larval vertical distribution (Fig. 6.11). The total cumulative percentages of larvae in each of the depth intervals were 31% in the uper 20 m, 54% in the upper 40m, 83% in the upper 60 m and 97% in the upper 80 m. A breakdown of the data gave similar results for both 100.200 m stations and 200-1800 m stations.

Table 6.6. Cross-shelf comparison of mean densities of *P. tridens* larvae during May and June from PROBES 1978. Zero stations omitted from calculations. Total number of stations (N) sampled within strata shown. See Figure 2.21 for strata locations.

Stratum	Mean Density ± S.D. (# larvae/100 m2)	% positive stations	N
	Oceanic/Shelf Break Domain		
7	873 + 719	43%	7
3	1816-+ 733	57$	7
4	**2740 ± 3033**	100%	2
	Outer Shelf Domain		
8	190 ± 132	18%	17
2	436 + 301	50%	18
5	1127′ 610	75%	12
	Middle Shelf Domain		
9	0	**0%**	15
1	187*	**14%**	7
6	0	o%	14

*Based on 1 positive station.

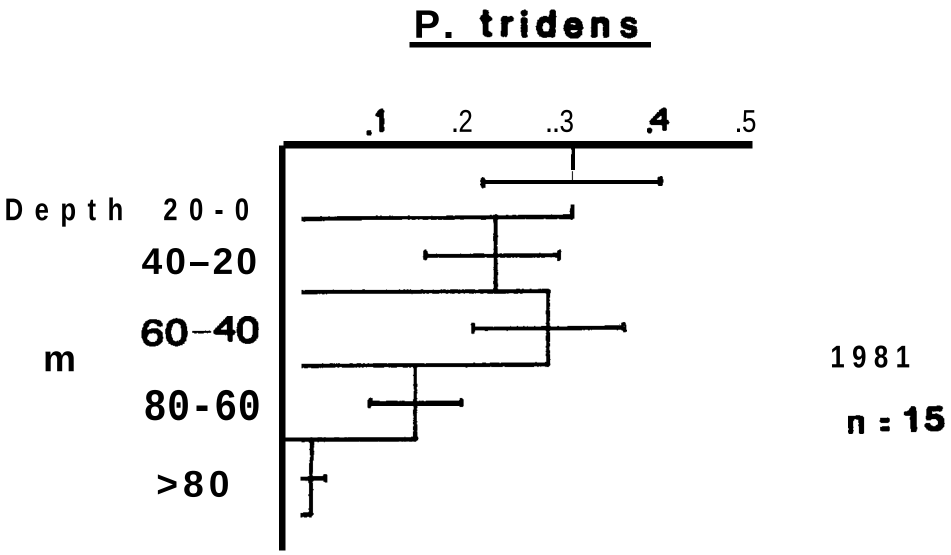


Figure 6.16 Vertical depth distribution of *P. tridens* larvae from PROBES 1981. Values expressed as the mean proportion ±1 standard error. A total of 15 MOCNESS stations at which *P. tridens* occurred were used for analyses.

Distribution and Abundance of Pandalus stenolepis: Larvae of P. stenolepis were infrequently caught on all cruises from 1976 to 1981. Figure 6.17 shows abundance and distribution of P. stenolepis larvae from all cruises, all months combined. Their distribution overlaps both P. borealis and P. tridens larvae with highest densities located near Unimak Pass. Mean densities in 1981 ranged from 290-480 larvae/100 m^2 in strata 2 and 3 during summer months. Larvae were completely absent from the northwestern section of the St. George Basin in accord with northern limits of adult ranges at Unalaska Island (Butler 1980). Occurrence of larvae in the lower St. George Basin may indicate the extent of larval drift in currents coming north through Unimak Pass, although it would not account for the isolated locations near the Pribilof Islands or on the middle shelf domain where P. stenolepis larvae were taken. The presence of these larvae may indicate that the range of P. stenolepis extends further north than previously thought.

The greatest density of P. stenolepis larvae for all years and all strata, 1284+1129 larvae/1(10 m^2, was found during NOAA 1977 in stratum 12 at Unimak Pass. P. stenolepis larvae were not caught with enough regularity to do either a comparison of density by stratum, a cross-shelf comparison, or a vertical depth distribution analysis. No P. stenolepis larvae were taken during the NOAA '76 cruise. Their percent frequency of occurrence among all stations sampled ranged from a low of 2% in 1980 to a high of 17% in 1977.

Summary of Pandalus SDD. Distribution and Abundance:

1) Larvae of the pandalids apparently hatch in early April.

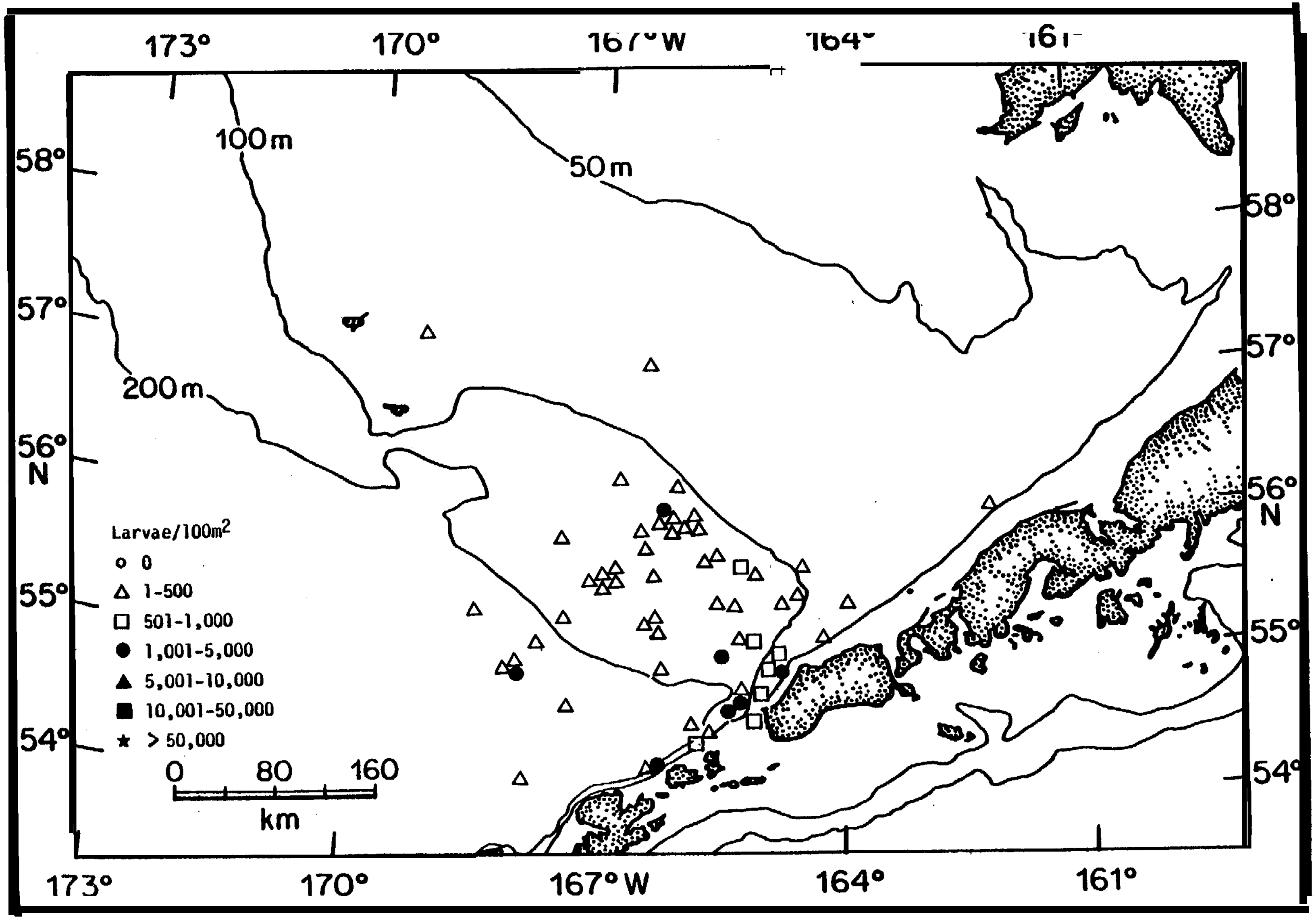


Figure 6.17 Distribution and abundance of *P. stenolepis* larvae from all years 1976-1981, all months April-July combined. Zero stations omitted. See section 2.0 for all station locations.

2) While hatchout of P. borealis larvae does not occur over a protracted period of time (no greater than a 3-week period), the hatchout time for P. tridens and P. stenolepis may be somewhat longer.

3) P. borealis larvae are generally most abundant in the outer shelf domain over the St. George Basin. P. tridens larvae are most abundant beyond the shelf break over deep water, but also range throughout the outer shelf domain. P. stenolepis occur over much of the St. George Basin between the 100 and 200m isobaths but with much lower frequency than P. borealis or P. tridens larvae.

4) Mean densities of P. borealis larvae over the St. George Basin were about 600-900 larvae/100 m^2 in May and June. Mean densities of P. tridens larvae beyond the shelf break were about 600-1000 larvae/100 m^2 in May and June. Mean densities for other species (P_. stenolepis, P. goniurus and Pandalopsis dispar) were significantly less.

5) Larvae were distributed homogeneously throughout the water co" umn from 0-80 m; more than 80% of larvae were found in the upper 60m.

6) Larvae molt about every 2-3 weeks so P. borealis would progress through six larval stages, metamorphose to a megalops, and settle to the benthos about mid-August. P. tridens and P. stenolepis may take until late August or early September because they have more larval stages.

6.6.2 Hippolytidae

Larval Duration: Hippolytid larvae were the only shrimp zoeae collected in the early spring (mid-February to mid-March, NOAA cruise 1978), when

S1 zoeae were first taken in March 1978 near Akutan Island. While the adults most commonly taken in this area include *Eualus gamardi belcheri*, *E. suckleyi*, and *E. stoneyi* (Paul Anderson, NMFS, Kodiak, Alaska, personal communication, October 1981), approximately five types of larval hippolytids and their larval stages were delineated from 1976-1981 samples. The sheer number of possible species (about 20, see Table 6.2) and lack of definitive larval descriptions for all species made further identification impossible at this point. Assigning definite zoeal stages is difficult because genera in this family have from 2 to 9 stages. The five different types of larval hippolytids were staged, but analysis of stage frequency and molt frequenty was not conducted. As with the pandalids, sampling did not continue late enough in the summer to document the timing of metamorphosis to the benthos.

Distribution and Abundance: Ivanov (1969) states that adult hippolytids generally dominate over shelf depths of 40 to 80m. This may very well be true, but the larvae apppeared to be a ubiquitous group, as prevalent as the pandalids over the outer shelf domain at stations between the 100-200 m isobaths of the St. George Basin (Figs. 6.18, 6.19). In addition to their wide distribution, abundance was commonly greater than 1000 larvae/100 m^2 over much of the St. George Basin and 1000-8000 larvae/100 m^2 beyond the shelf break and on either side of Unimak Pass. Data of 1981 support this pattern of low density but wide distribution over the middle shelf, higher densities over the central St. George Basin of the outer shelf domain, and greatest aggregations beyond the shelf break (Fig. 6.18). The highest density (5600 larvae/100 m^2) for 1981 was taken at the southwest tip of Unimak Island. Variation between

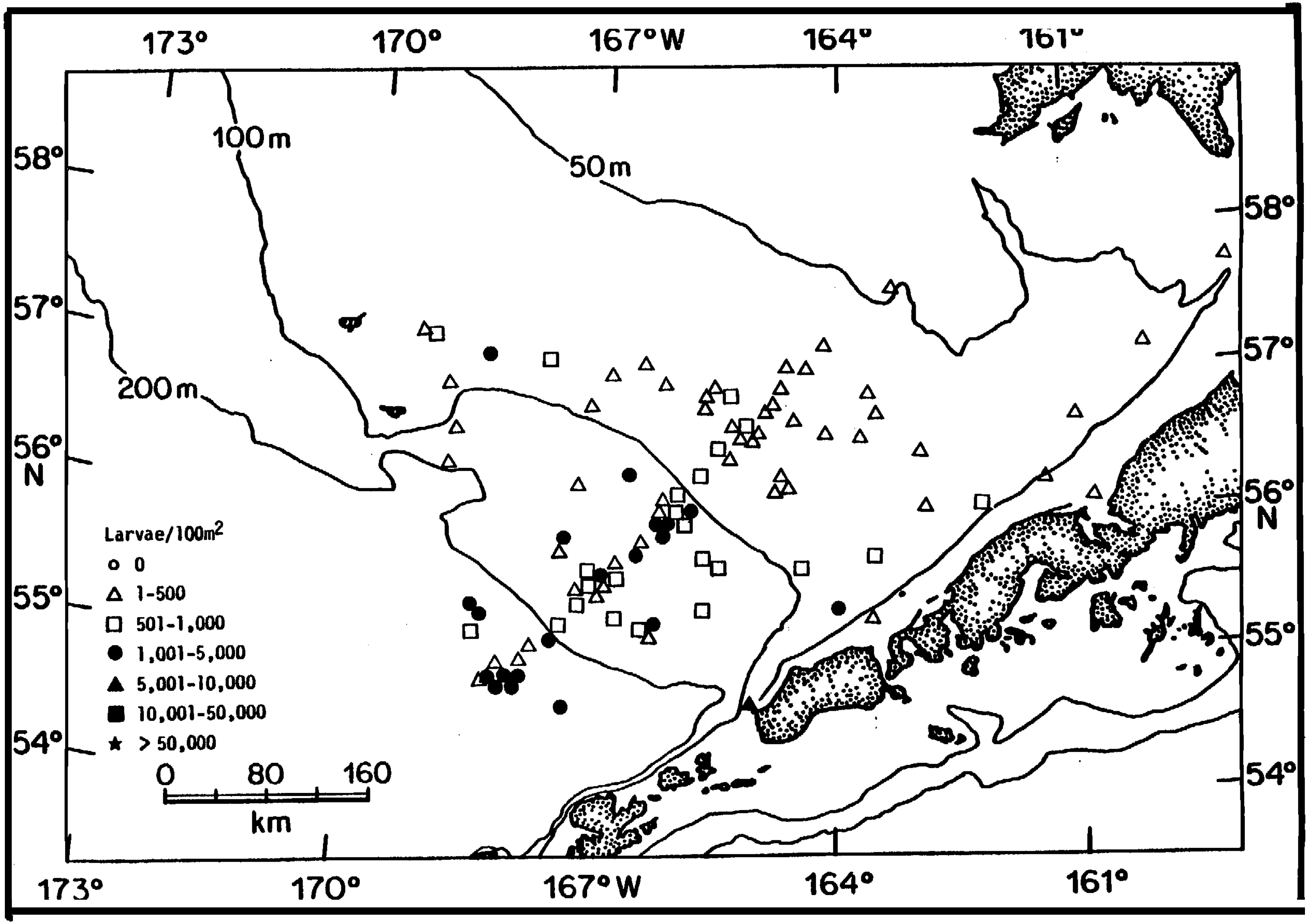


Figure 6.8 Distribution and abundance of Hippolytidae shrimp larvae from PROBES 1981 and NOAA 1981, April-July combined. Zero stations omitted.

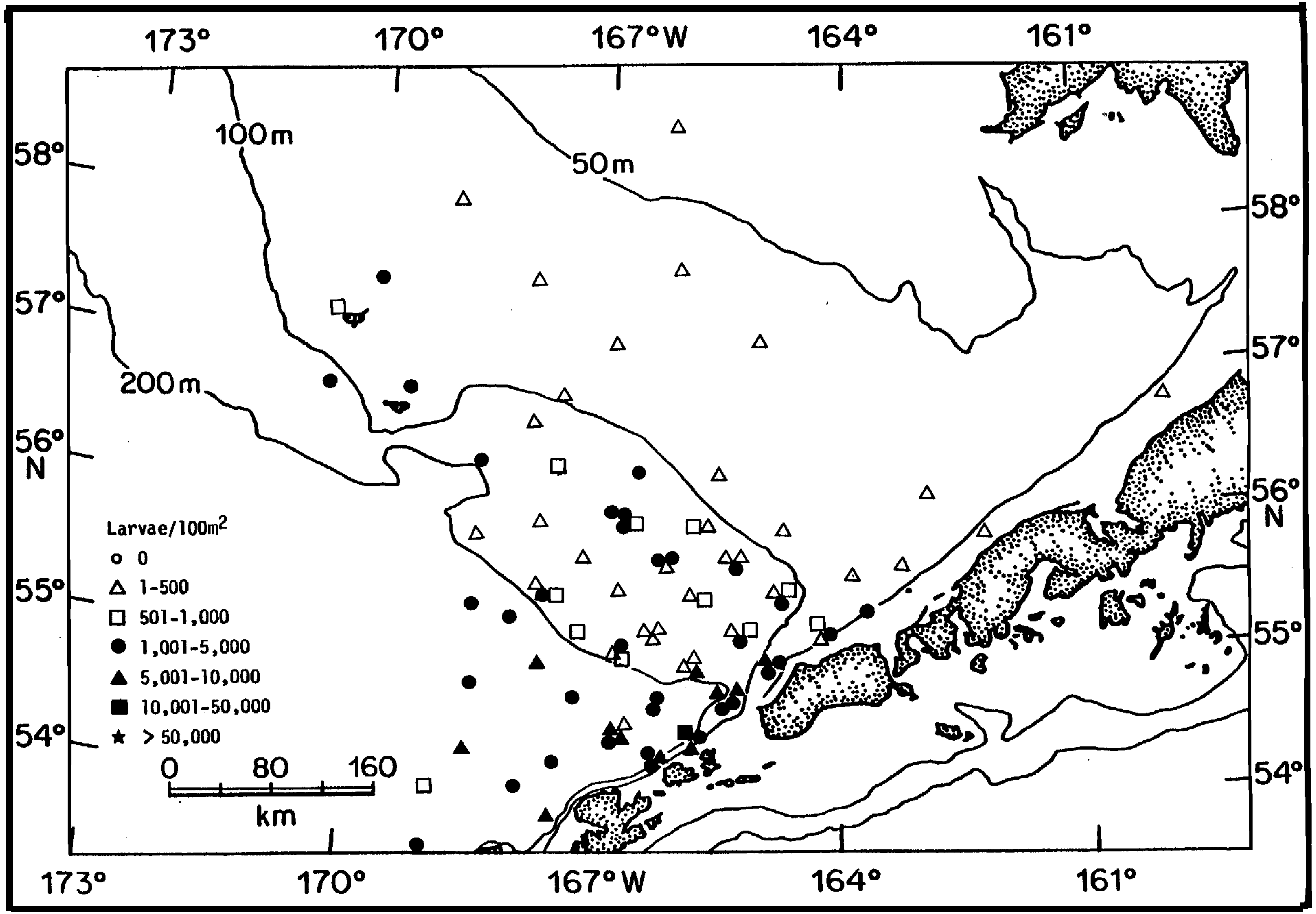


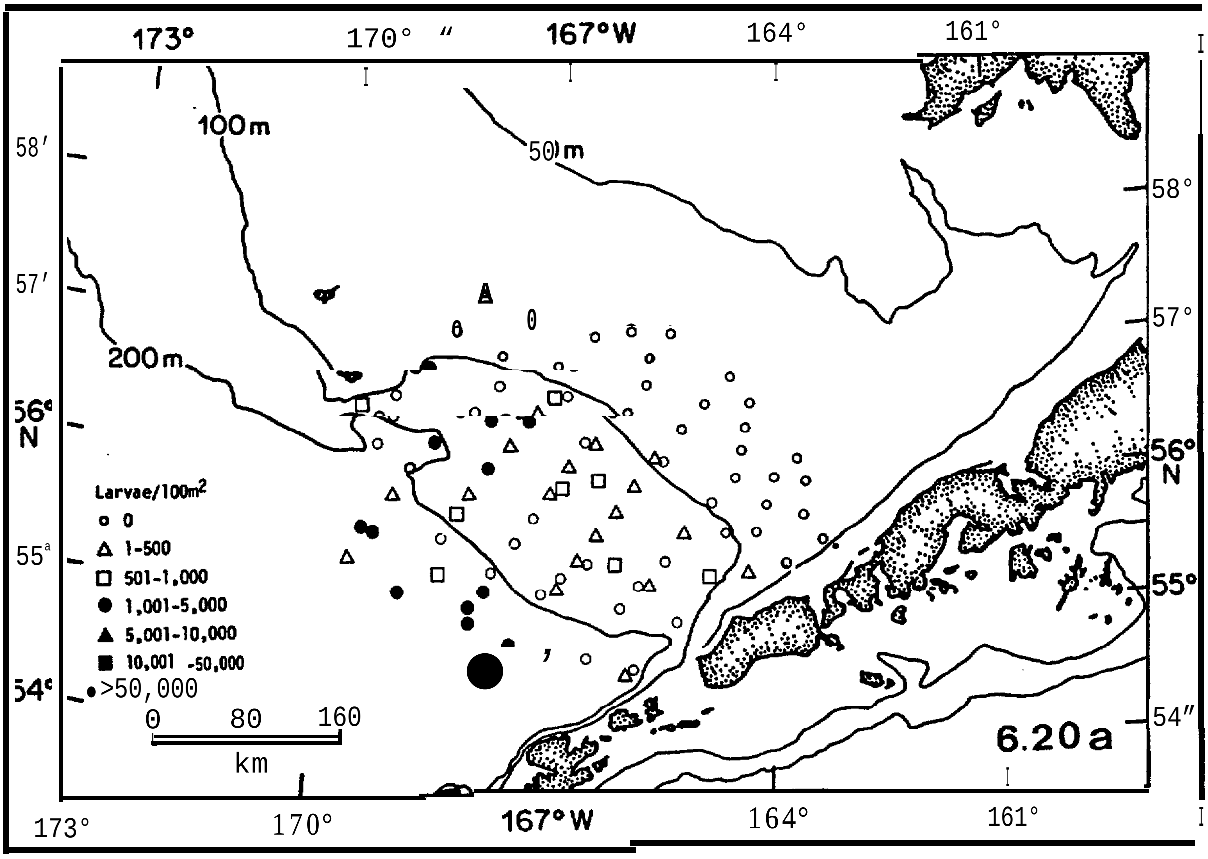
Figure 6.19 Distribution and abundance of Hippolytidae shrimp larvae from NOAA 1976 and 1977, April and May combined. All zero stations omitted.

months within a single year can be seen by comparing larval abundance for April, May and June during PROBES 1978 (Fig. 6.20 a and b). Distribution in April was widely spread over the outer shelf domain and greatest concentrations were found beyond the shelf break (Fig. 6.20a). Distribution in May and June 1978 seemed to be concentrated mainly into 2 bands; one just west of the 100 m isobath and one just beyond the shelf break at the 200 m isobath. By this time of year some larvae were found up in the middle shelf domain. The highest concentration of larvae (12,000 larvae/100 m^2) was found at the western tip of Unimak Island. Further work to identify the species within the hippolytid group would help to delineate distribution patterns of individual species.

Figure 6.21 illustrates mean larval hippolytid densities by month and by years in stratum 3 just west of the 200 m isobath. consistently high mean larval densities (1000-2400 larvae/100 m^2) were found in the months of April, May, and June in stratum 3 during the years 1977-1981. By comparison, slightly lower mean larval densities (600-1650 larvae/100 m^2) were found during May and June in stratum 2 during those years.

A more complete picture of mean larval densities for hippolytids is given in Table 6.7 for PROBES May and June 1978 data. Strata beyond the shelf break again had the highest mean densities which were three-fold greater toward the Aleutian Islands (stratum 4) than toward St. George Island (stratum 7).

Hippolytid larvae were found from 0-80 meters in the water column. Figure 6.22 illustrates the larval depth distribution of hippolytids



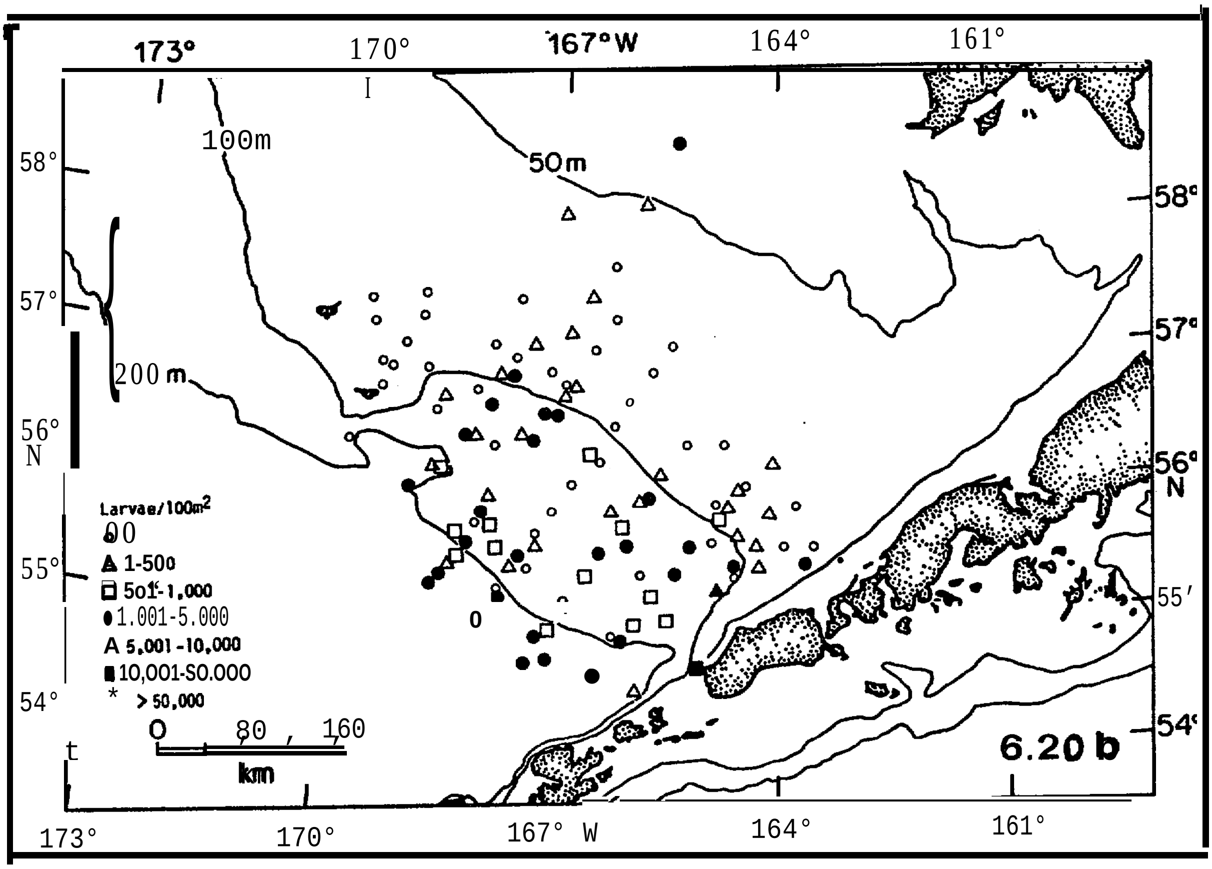


Figure 6.20 Distribution and abundance of **Hippolytidae** shrimp larvae from PROBES 1978; (a) April only, (b) May and June. Zero stations included.

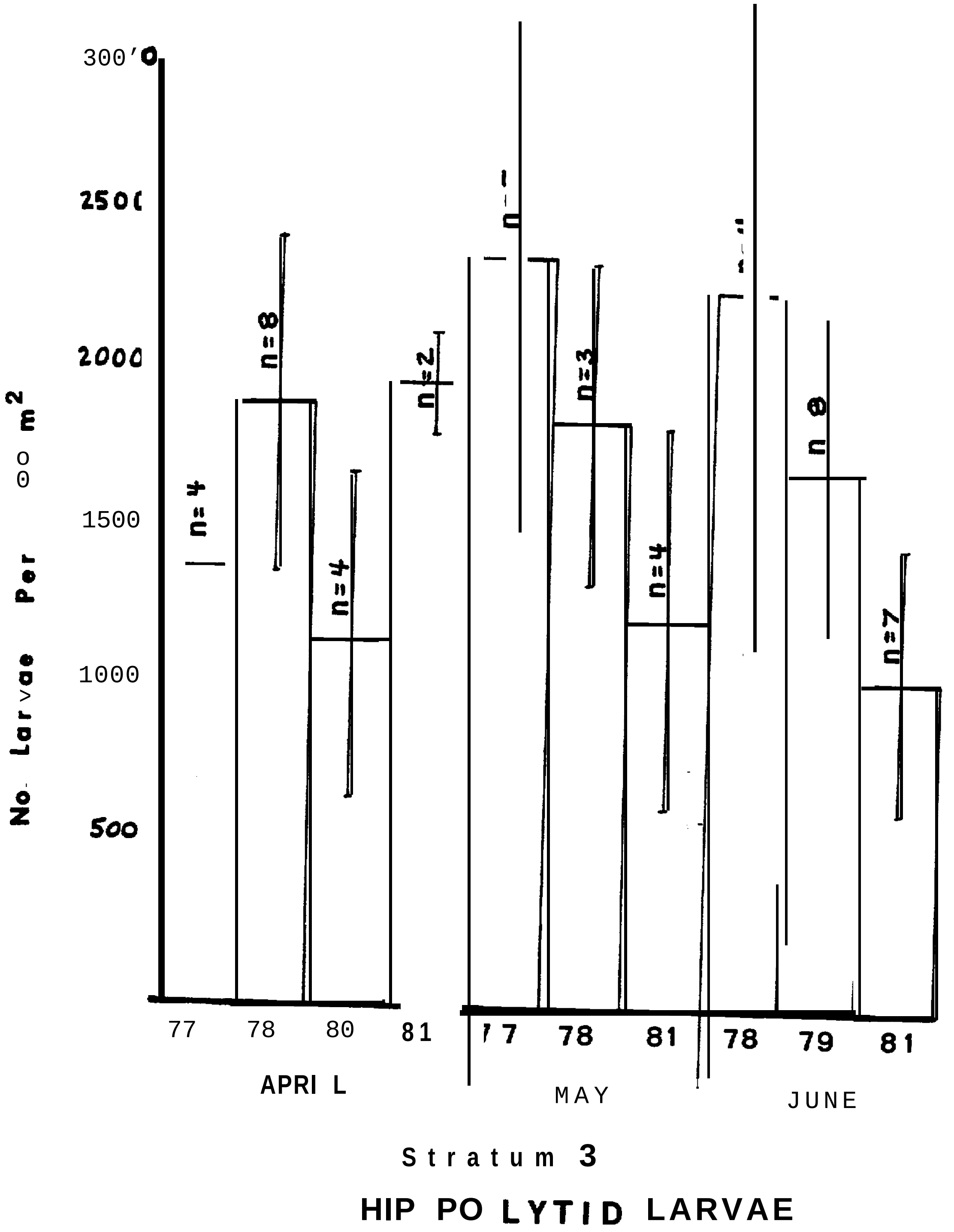


Figure 6.21 Hippolytidae shrimp larval abundance in stratum 3 from 1977-1981 by months April, May and June. Values expressed as mean density ±1 standard error. Zero stations are included in these values.

Table 6.7. Cross-shelf comparison of mean densities of **Hippolytidae** shrimp larvae during May and June from PROBES 1978. Zero stations omitted from calculations. See Figure 2.21 for strata locations. Total stations sampled = N.

Stratum	Mean Density ± 1 S.D. larvae/100 m^2	% positive stations	N
	Oceanic/Shelf Break Domain		
7	836 + 597	100%	
3	2445 ± 1575	86%	
4	2655 ± 3153	100%	
	Outer Shelf Domain		
8	956 ± 674	76%	17
2	1032 ± 1150	67%	18
5	2033 ± 1736	75%	12
	Middle Shelf Domain		
9	253 + 317	53%	17
1	143*	14%	7
6	567 ± 800	64%	14

*Based on 1 positive station.

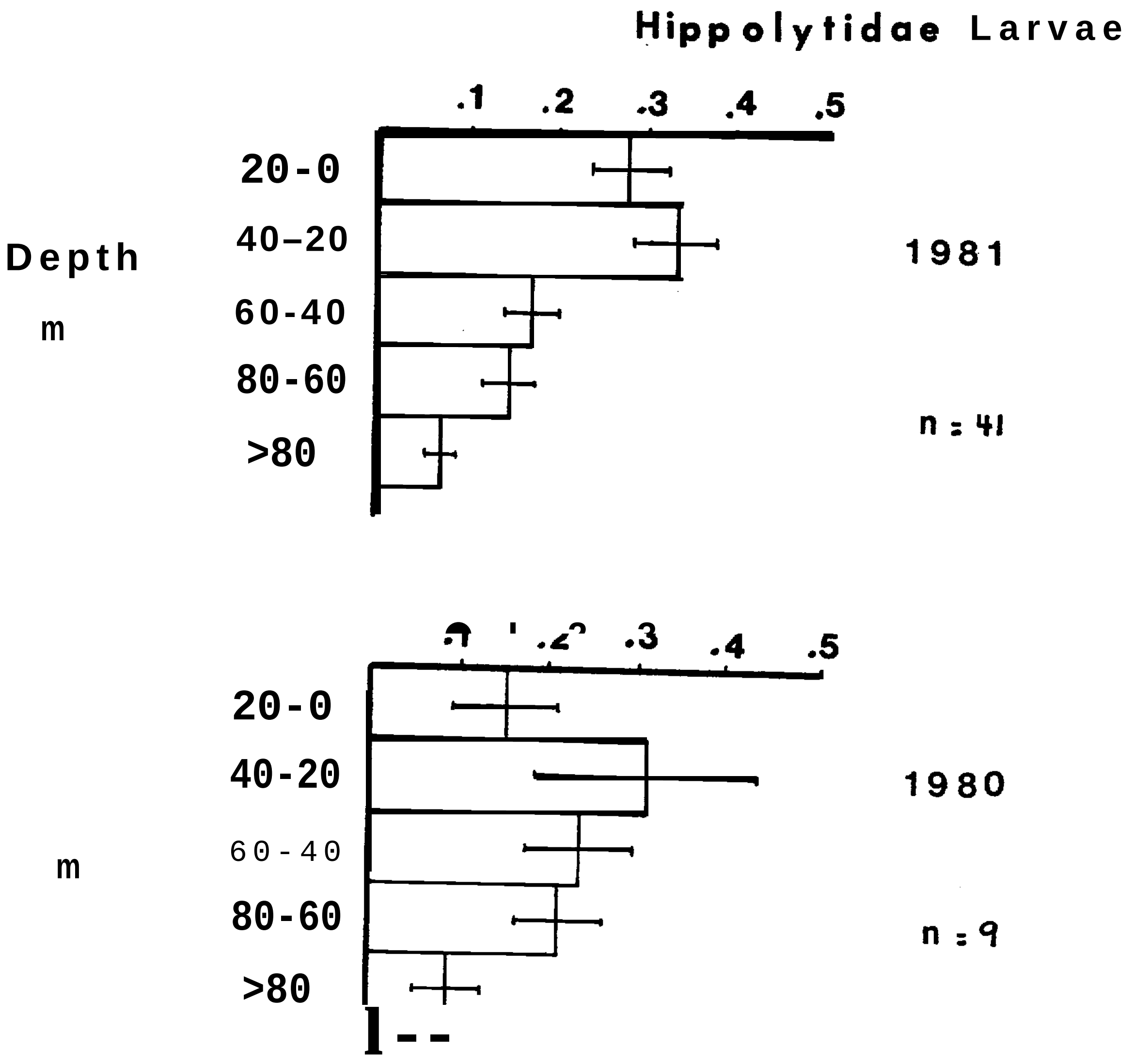


Figure 6.22 Vertical depth distribution of Hippolytidae shrimp larvae from PROBES 1980 and 1981. Values expressed as an average proportion ±1 standard error.

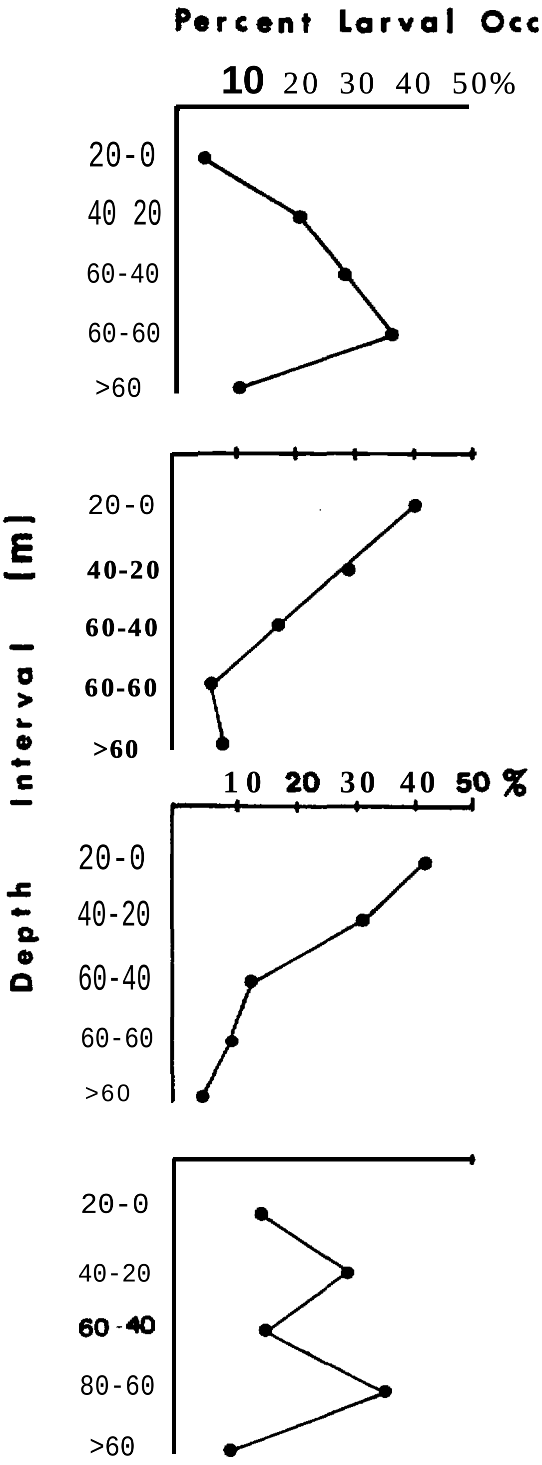
during PROBES 1980 and 1981 sampling from April to July. The total cumulative percentages of larvae in each depth interval were: 15-28% in the upper 20 m; 46-62% in the upper 40 m; 70-79% in the upper 60 m; and 94% in the upper 80 m. This homogeneous distribution from 0-80 m is similar to the pattern for P. borealis. MOCNESS data for PROBES 1981 were analyzed by month (Fig. 6.23). Larvae were concentrated in the 40-80 m depths during April, in the 0-40 m interval during May and June, and homogeneously throughout 0-80 m by late June and July. Examining the pattern of larval depth distribution within each depth interval (Fig. 6.23) clearly shows the highest percentage of larvae (about 40%) in the 20-0 and 40-20 m intervals during May and June, and a high percentage of larvae (about 30%) in the 80-60 m interval both in April and then again in late June and July. This changing pattern of hippolytid larval depth distribution might be correlated to food availability or temperature, light and other factors. Correlations are difficult to perform since the hippolytids are a multi-species group.

Summary:

1) Larvae of some hippolytids hatch out as early as March, while other species not until April or May.

2) Hippolytids are distributed widely over the St. George Basin, into the mid-shelf domain and beyond the shelf break.

3) Greatest densities occurred beyond the shelf break and along the Aleutian Islands, especially near Unimak Pass. Mean densities beyond the shelf break ranged from 1000-2000 larvae/100 m^2 in May and June during years from 1977-1981.



Hippolytidae

Leg 1 April

Larvae concentrated in the 40-80 m interval.

Leg2 May

Concentrated in the 0-40 m interval. Larvae were generally more shallow than during Leg I.

Leg 3 June

Larvae *were* still shallow within the 0-40 m interval.

Leg 4 June - July

Larvae were homogeneously distributed throughout the water column.

Figure 6.23 Vertical depth distribution of Hippolytidae shrimp larvae by month from PROBES 1981. Values expressed as percent occurrence of larvae versus depth.

4) Larvae were distributed homogeneously throughout tne water column from O-80m although the depth of preponderance sometimes shifted month to month.

5) Larvae probably metamorphose and settle out of tne water column by late August to early September.

6.6.3 Crangonidae

Larval Duration: Stage I *Crangon spp.* larvae were first collected over tne St. George Basin in early April to mid-April (1977, 1978, 1980 and 1981 cruises). They were still present in tne water column by the end of June in 1978, indicating an extended period of hatchout in that year, whereas in 1981 S1 were not taken after mid-May. The duration of larval stages in 1981 is shown in Figure 6.24. *Since S1* and II were taken from the start of sampling, hatcnout must have begun in late March 1981. An intermolt period of 12-16 days between S11-111 and III-IV is similar to the 2-3 week intermolt period found for *Pandalus borealis.* Since the larvae of *Crangon spp.* have up to 7 zoeal stages (Kurata 1964), they may be in the water column until mid- to late August. The long durations for each stage, 45-60 days, shown in Figure 6.24, are probably exaggerated since there are more than one species of crangonid larvae included in this group.

Crangonids have one of the fastest rates of development (i.e., about a 2 week intermolt period) of all natantian shrimp of the St. George Basin, as shown by the molt frequency histogram (Fig. 6.25) for data from PROBES 1981. The protracted hatchout time (April - June) is

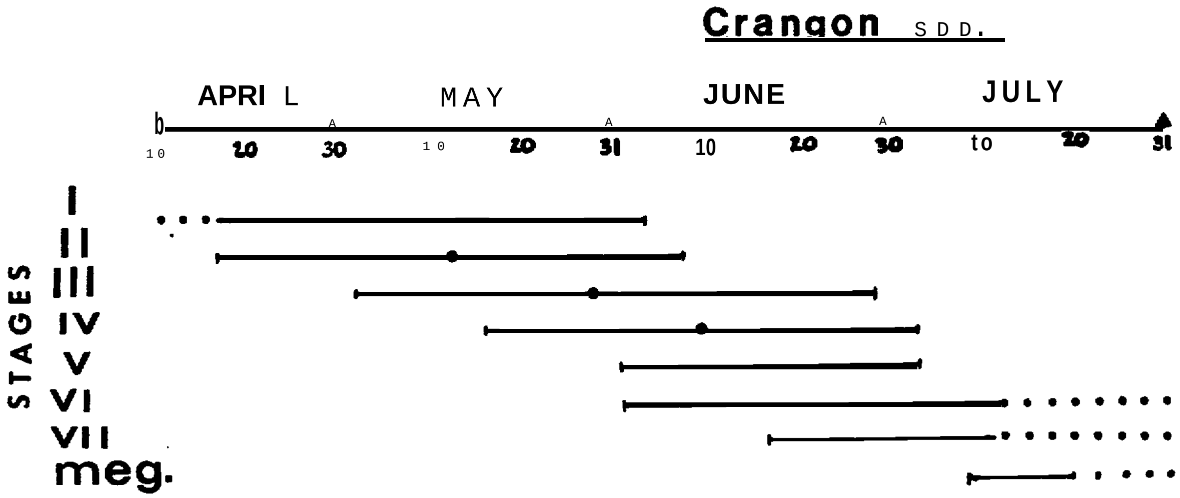


Figure 6.24 Crangon spp. larval stage durations from PROBES 1981. Dots represent hypothetical time duration for certain stages not sampled early or late enough to note complete development.

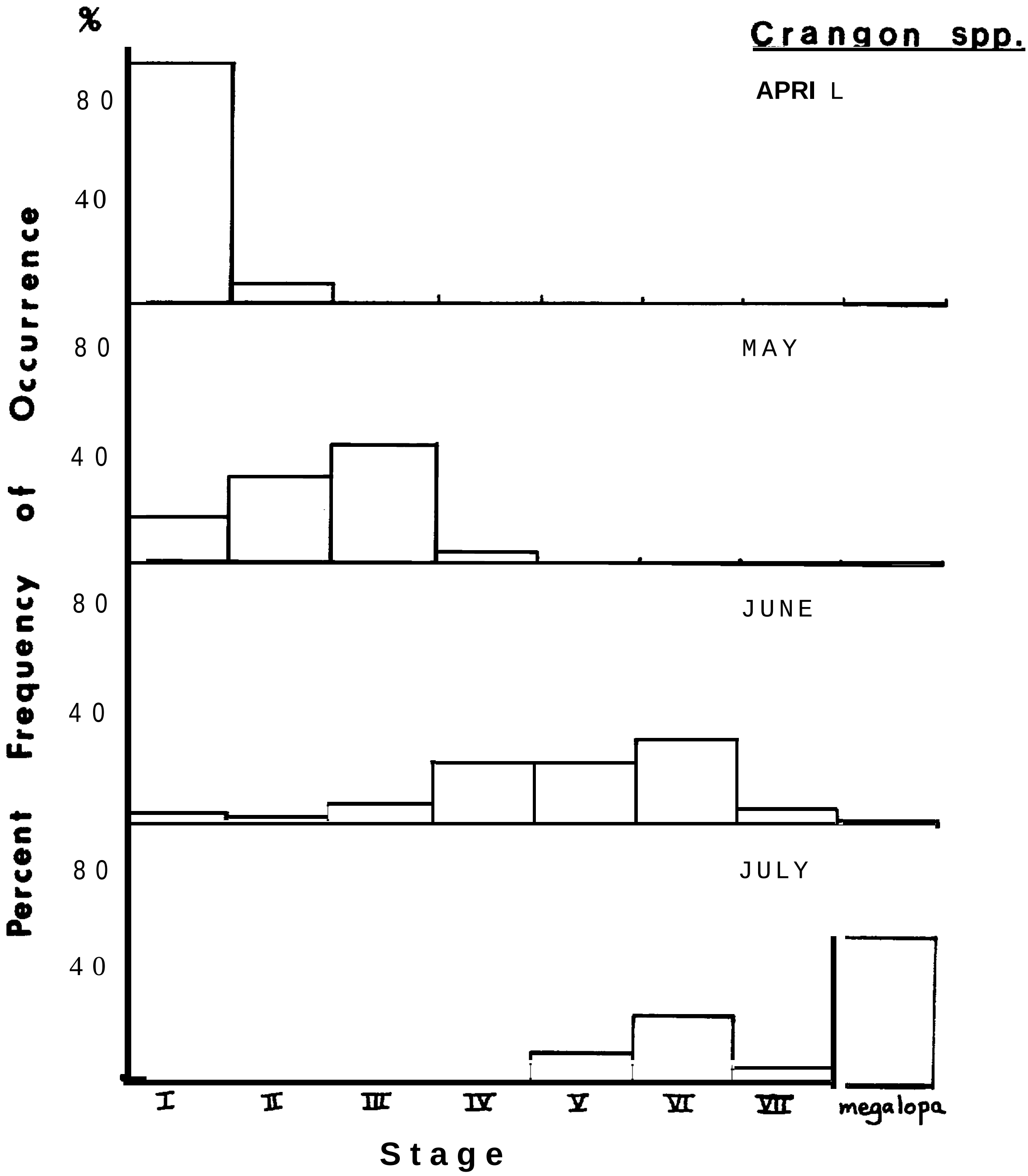


Figure 6.25 Crangon spp. stage frequency of occurrence by month from PROBES 1981.

most probably due to the mix of species in our samples. Even though they have 5-7 larval stages before the megalops is reached, the majority of larvae (given a 2 week intermolt period) would have metamorphosed and settled out of the water column by early August in 1981. In April of that year, 93% of the larvae were S1 in April , while 58% were megalopae by July.

Argis spp. (*A. lar*, *A.* _ and *A. ovifer*) were present at 2% or 13 of the 626 station locations sampled from 1976-1981 (Fig. 6.26). Except for one station (A_5 on the PROBES A line), they favored the mid-shelf domain and stations < 100 m sonic depths. All stages, I, II and megalopae, were taken during April to July. Megalopae in particular were taken as early as May 23rd (NOAA, R/V Alaska) and as late as July 4th (PROBES) in 1981.

Distribution and Abundance: Four species of adult crangonids, *Crangon communis*, *C. dalli*, *Argis dentata*, and *A. lar*, are routinely taken during trawl surveys of the St. George Basin (Paul Anderson, NMFS, Kodiak, Alaska, personal communication). According to Ivanov (1969), crangonid adults dominate the 0-50 m depth zone of the inner shelf domain. This region was only sporadically sampled during the 1976-1981 cruises and thus substantiation of this fact was difficult. However, nearshore distribution of crangonids was confirmed during the 1982 OCSEAP cruises along the North Aleutian Shelf. From Unimak Island to Port Moller, the dominant shallow water shrimp taxa were Crangonidae (D. Armstrong, pers. observation, June 1982, R/V *Miller Freeman*), primarily *C. communis*, *C. alaskensis* and *A. dentata*.

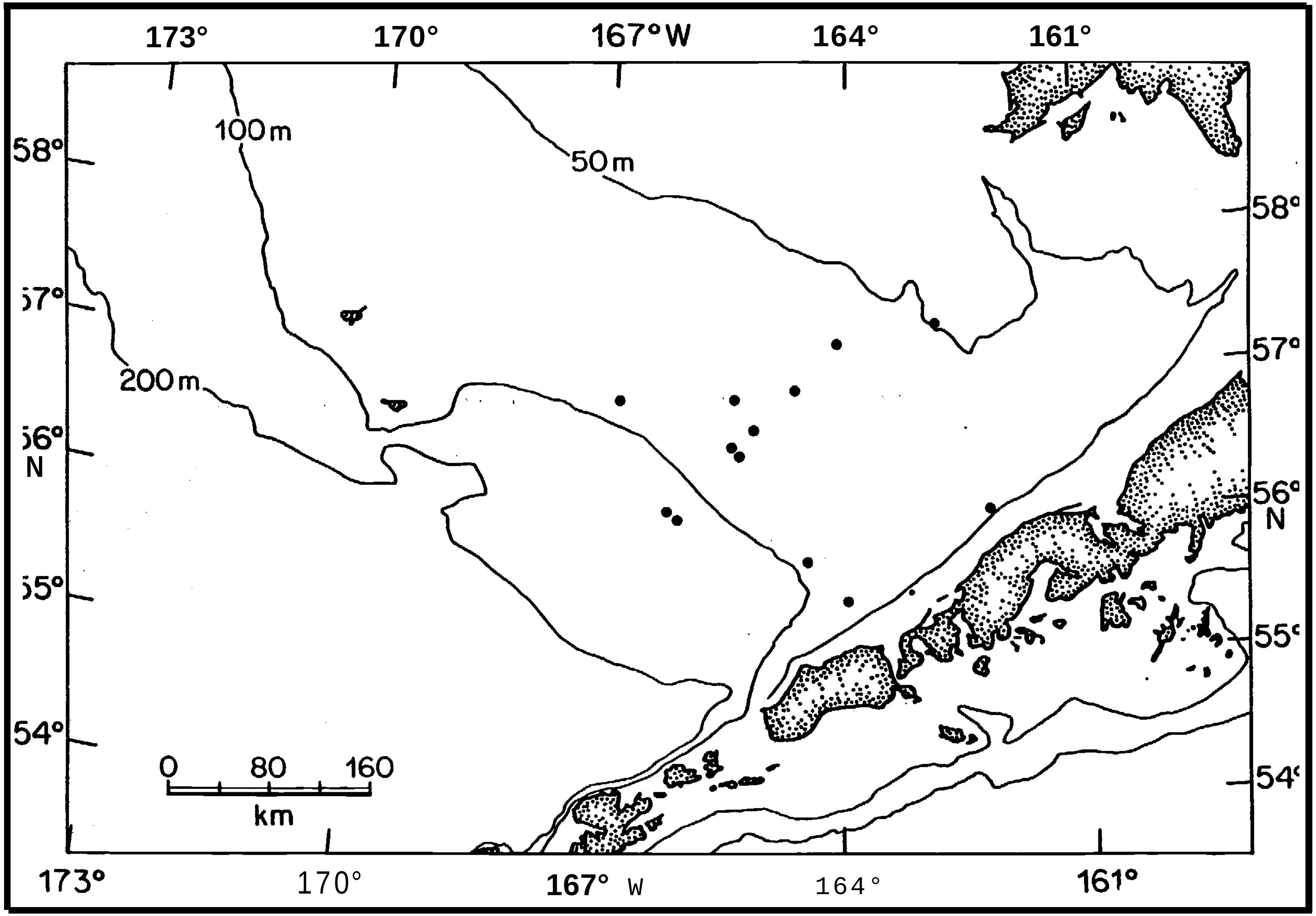


Figure 6.26 Argis spp. distribution from all years 1976-1981, all months April-July combined. Positive station locations indicated by a small black dot. See Section 2.0 for station locations and cruises.

Larval crangonids, *Crangon spp.*, were consistently found in greater abundance over the St. George Basin of the outer shelf domain in a band west of the 100 m isobath. Figures 6.27-6.30 depict the larval distribution and abundance of *Crangon spp.* from PROBES' and NOAA cruises from 1976 to 1981. While the crangonids were almost as wide ranging as the hippolytids, they were generally absent beyond the shelf break and most prevalent over the inner shelf domain (less than 50 m). The two high density (> 1000 larvae/100 m^2) stations in the inner shelf domain (Fig. 6.27) were due to a different species than found at the high density stations over the St. George Basin. Figure 6.28 gives the distribution of *Crangon spp.* larvae during April and May of 1976 and 1977 (NOAA). Greatest larval densities were found in the outer shelf domain of the St. George Basin midway between the 100 and 200 m isobaths and also off Akutan and Unalaska Islands.

Monthly variation in density is illustrated by comparing Figs. 6.29 for April and 6.30 for May and June PROBES 1978. By April in 1978, *Crangon spp.* were distributed at fairly low densities throughout the St. George Basin and infrequently over the southern half of the mid-shelf domain. By May and June, larvae were concentrated in a band along the 100 m isobath at slightly higher densities than found in April (Fig. 6.30). This is somewhat different from the pattern seen in 1981 when sampling effort concentrated on the PROBES A line and distribution by May and June was extensive over the middle shelf domain (Fig. 6.27). Monthly variation is also illustrated by Figure 6.31 that depicts *Crangon spp*. larval mean densities in stratum 2 by month and by year. Mean

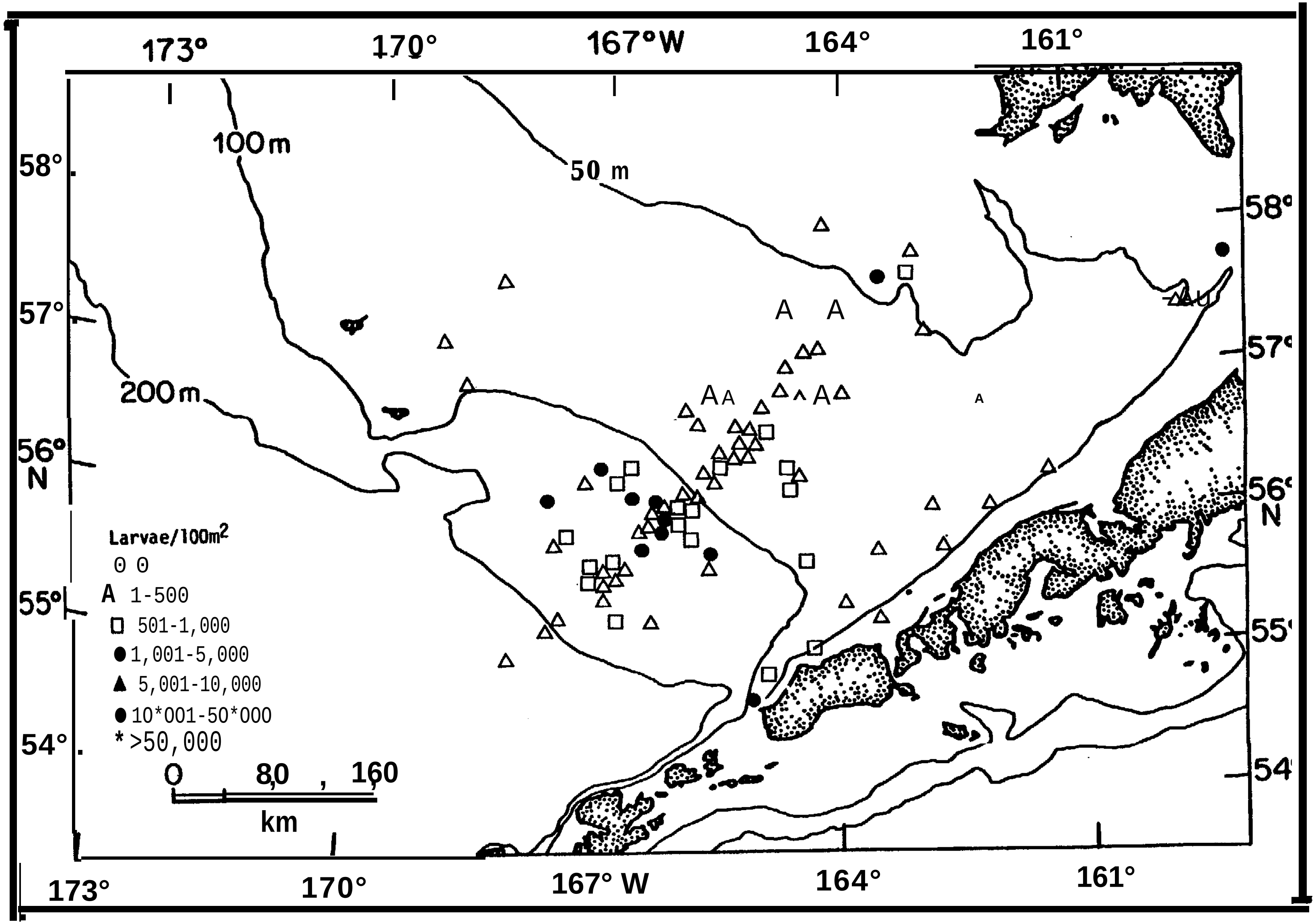


Figure 6.27 Distribution and abundance of *Crangon* spp. larvae. NOAA 1979 and 1981, PROBES 1980 and 1981, all months April-July combined.

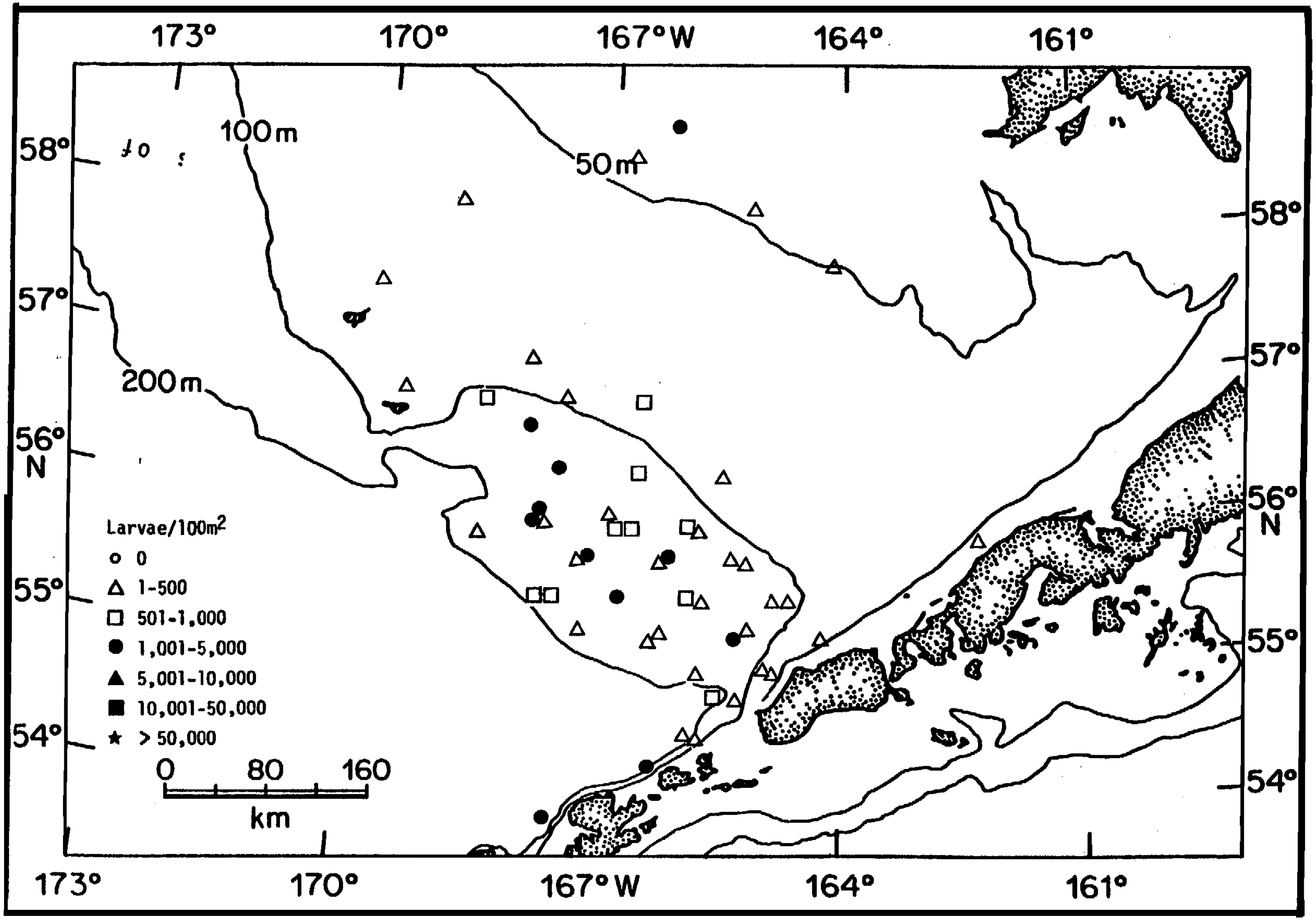


Figure ≤.28 Distribution and abundance of Crangon spp. larvae from NOAA 1976 and 1977, April and May combined. Zero stations omitted. See Section 2.0 for all station locations for these cruises.

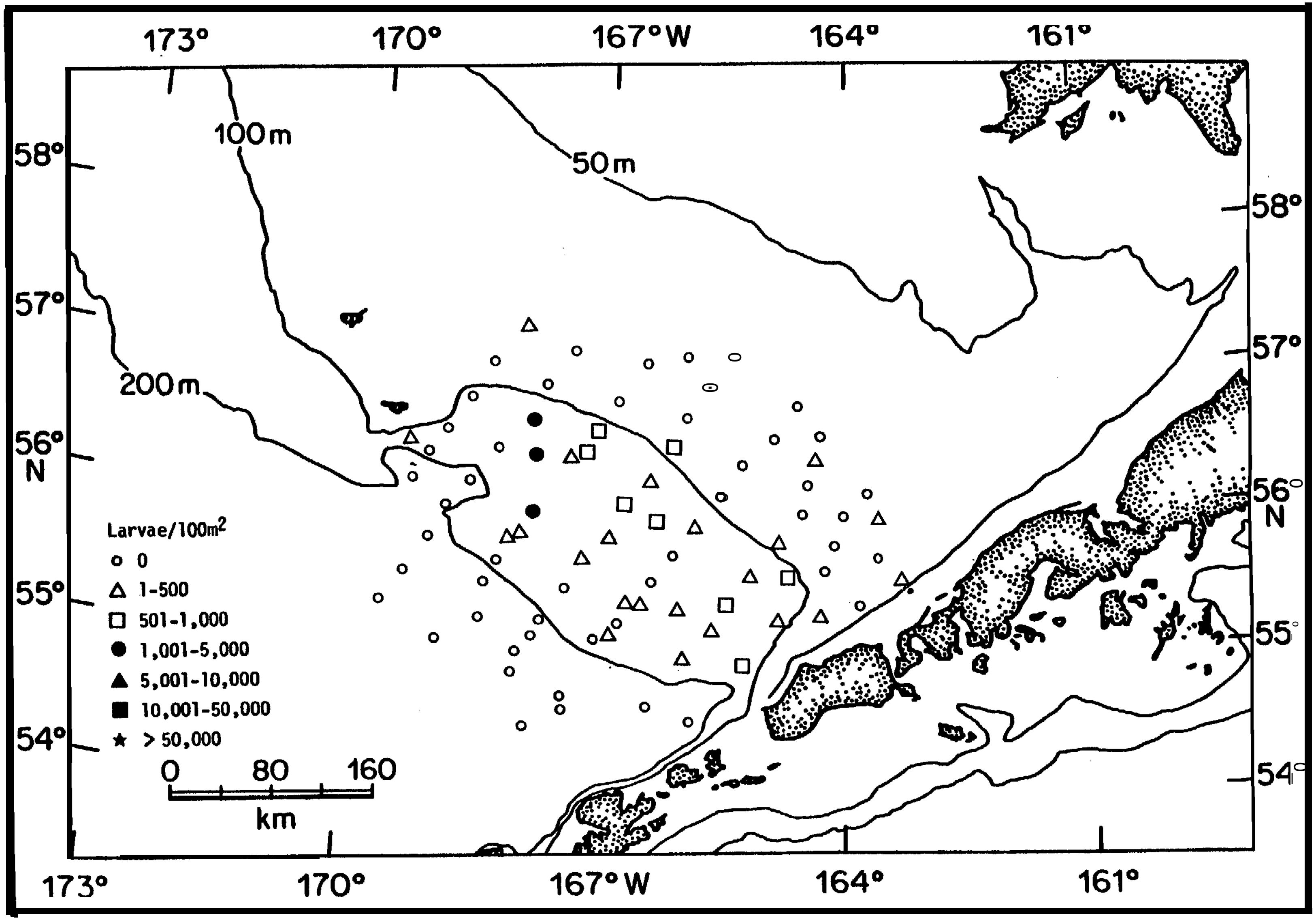


Figure 6.29 Distribution and abundance of *Crangon* spp. larvae from PROBES 1978, April. Zero stations included.

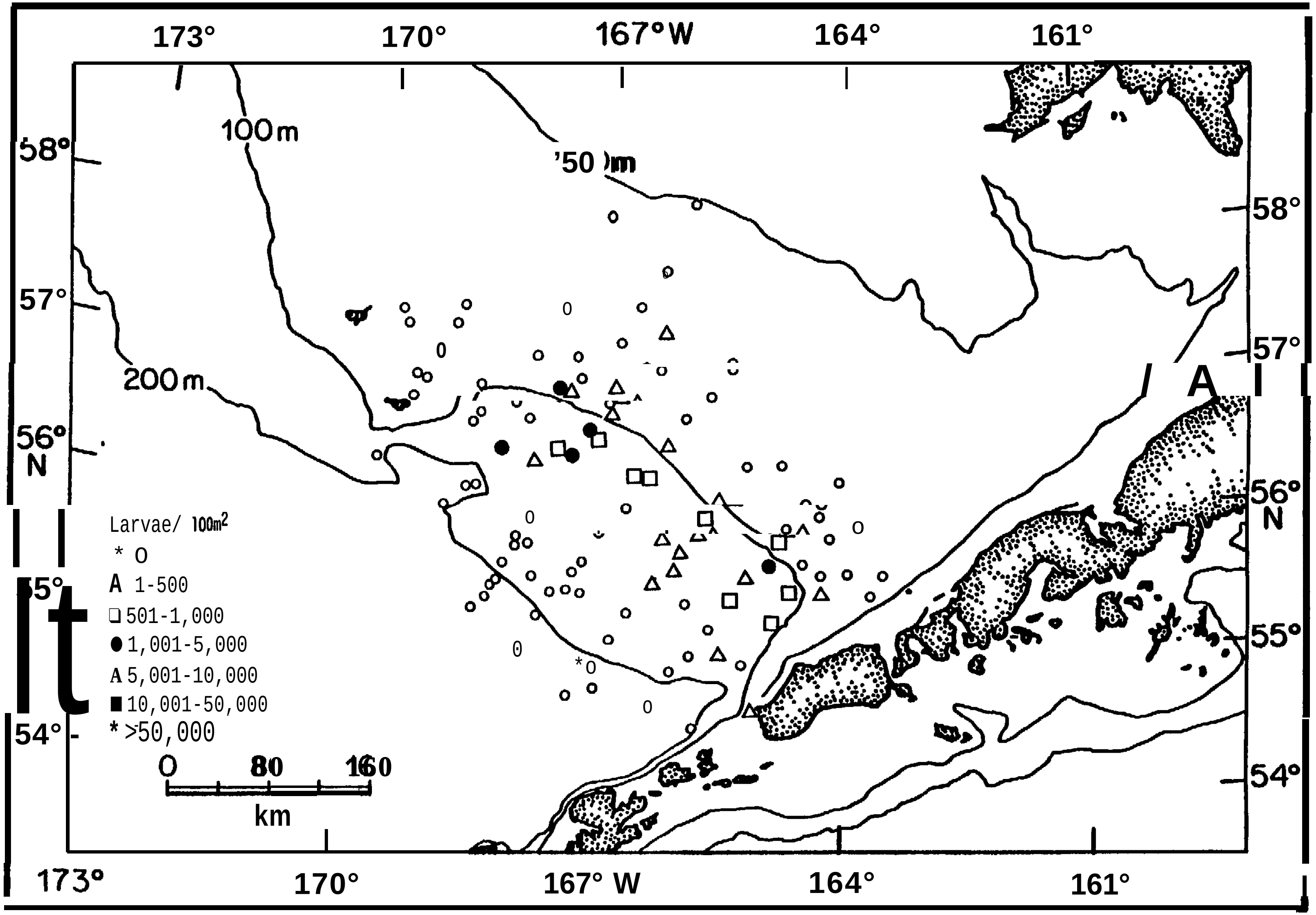


Figure 6.30 Distribution and abundance of *Crangon* spp. larvae from PROBES 1978, May and June. Zero stations included.

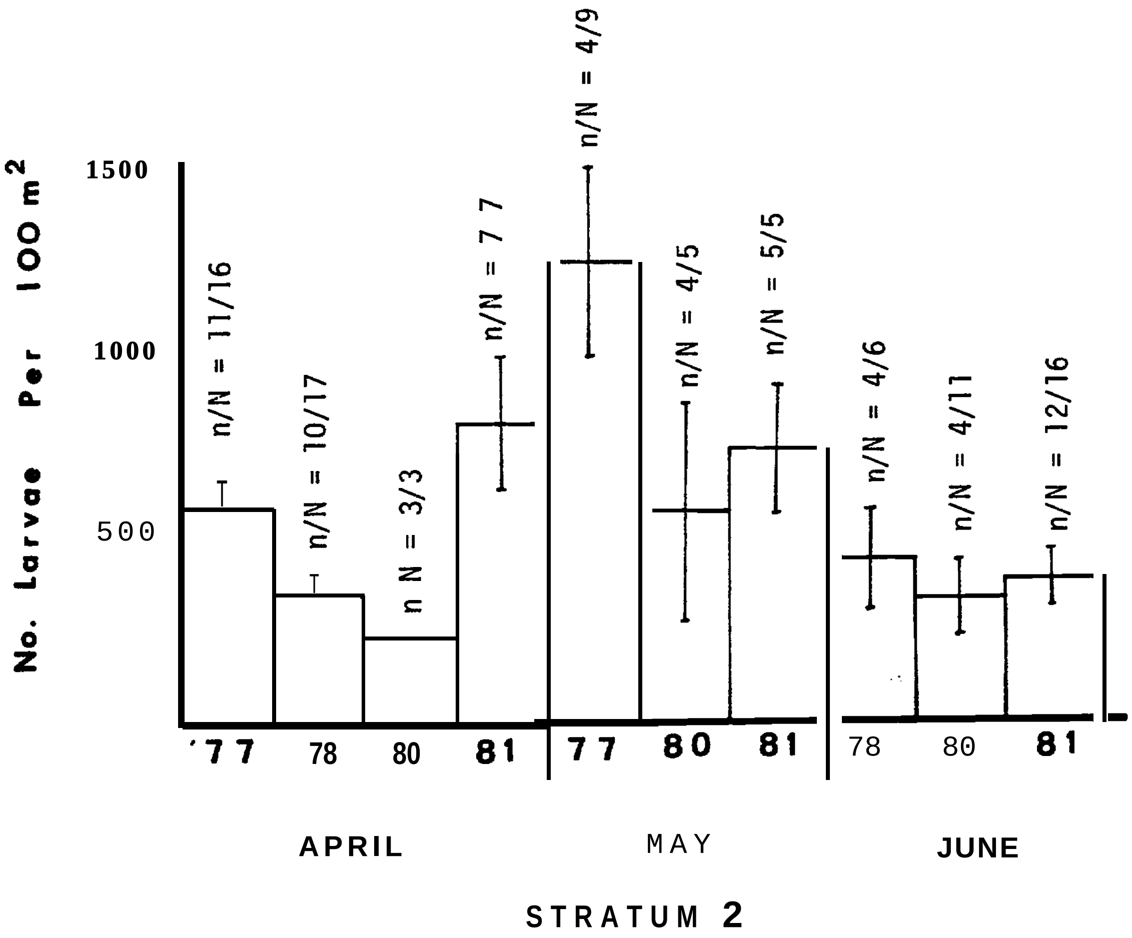


Figure 6.31 *Crangon* spp. larval abundance in stratum 2 from 1977-1981 during April, May and June. Values expressed as mean density ±1 standard error. Zero stations were excluded from these calculations. The number of positive stations (n) and the total number of stations sampled (N) for each year is shown above the bars.

larval densities were generally low (< 500/100 m^2), but greatest abundance always occurred in May (1000 larvae/100 m^2) over stratum 2. The frequency of occurrence of larval crangonids in the 1981 samples was high (present in 75-100% of the samples), whereas in other years crangonids were taken less frequently (in 33-80% of the samples). The lowest mean densities were consistently taken in 1980. Table 6.8, the cross-shelf comparison of mean densities of Crangon spp. larvae during May and June PROBES 1978, demonstrates three trends. First, the absence of any Crangon spp. larvae beyond the shelf break; second, in the outer shelf domain, highest densities were found in the north and south of the St. *George* Basin; third, crangonids were less abundant over the middle shelf with mean density between 260-375 larvae/100 m^2. Crangonids were consistently less abundant than either the pandalids or hippolytids.

MOCNESS data from PROBES 1980 and 1981 cruises were analyzed but there were insufficient stations during 1980 for a complete workup of vertical depth distribution. Only 5 stations out of a possible 26 had more than 6 larvae per station and a sample size of 5 stations was regarded as unacceptable. For the 1981 data, a homogeneous distribution of Crangon spp. larvae throughout the water column is shown in Fig. 6.32. Crangon spp. larvae were distributed between 0-80 m with 16% in the upper 20 m, 47% in the upper 40 m, 76% in the upper 60 m, and 93% in the upper 80 m.

Summary:

1) Hatchout of Crangon spp. begins in late March and the larvae remain in the water column until early August.

Table 6.8. Cross-shelf comparison of mean densities of *Crangon* spp. larvae during May and June from PROBES 1978. Zero stations in each stratum omitted in these calculations. See Figure 2.21 for strata locations. Total number of stations sampled = N.

Stratum	Mean Density ± S.D. (larvae/100-m2)	% positive stations	N
	Oceanic/Shelf Break Domain		
7	0	0%	7
3	0	0%	7
4	0	0%	2
	Outer Shelf Domain		
8	1119 ±694	35%	17
2	310 ± 260	44%	18
5	818 ± 547	50%	12
	Middle Shelf Domain		
9	375 ± 481	35%	17
1	330 ± 202	29%	7
6	264 ± 278	21%	14

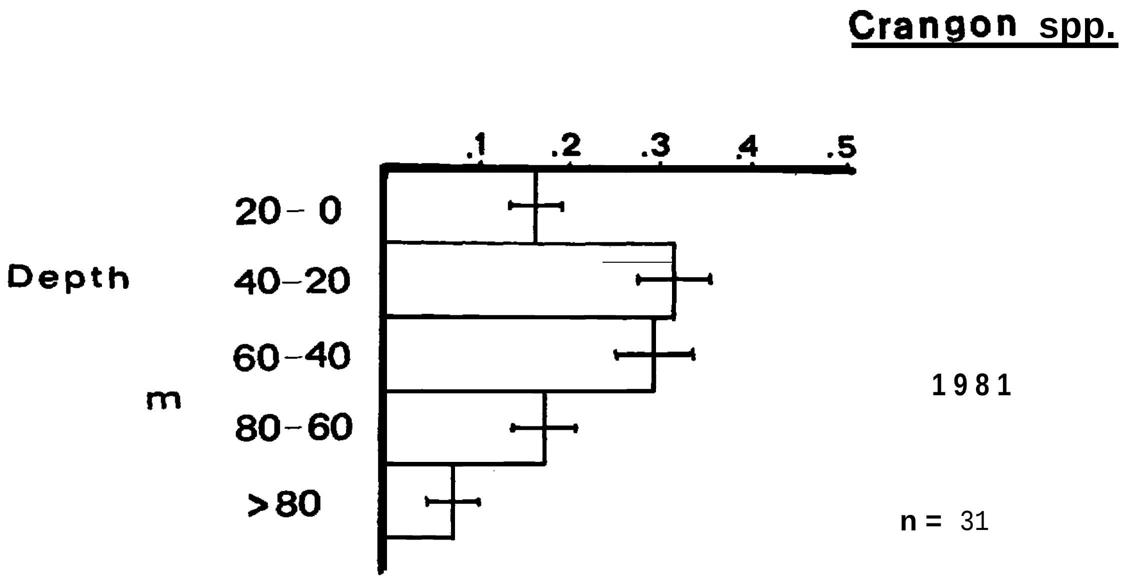


Figure 6.32 Vertical depth distribution of Crangon spp. larvae from PROBES 1981. Values expressed as an average proportion ±1 standard error. Total number of MOCNESS stations used in these calculations is given by n.

2) The intermolt period of about 2 weeks seems to be the shortest of all the shrimp taxa.

3) Crangonids are widely distributed over the St. George Basin and extend into the middle and inner shelf domains.

4) Crangonids were caught less frequently than either the pandalids or hippolytids.

5) Greatest densities occurred over the outer shelf domain where average mean densities were 300-1000 larvae/100 m^2. Middle shelf domain densities were generally about 300 larvae/100 m^2. Outer shelf domain densities tended to be greater near the Pribilofs and the Aleutian Island chain rather than over the central St. George Basin.

6) Larvae were distributed homogeneously throughout the water column from 0-80 m.

6.6.4 Penaeidae

The spiny larval form of disputed origin(s), currently assigned to the family Penaeidae, is assumed to come from deep dwelling parental stocks since larvae were most abundant at stations of depths $\geq$ 200 m.

Larval Duration: Stage I spiny larvae were first taken in mid-April in 1977, 1978, 1980 and 1981. Larval stage duration is shown in Figure 6.33 for PROBES 1981 data. Note the very long durations for S11 and III; 75 days for S11, and 56 days for S111. Although not shown by

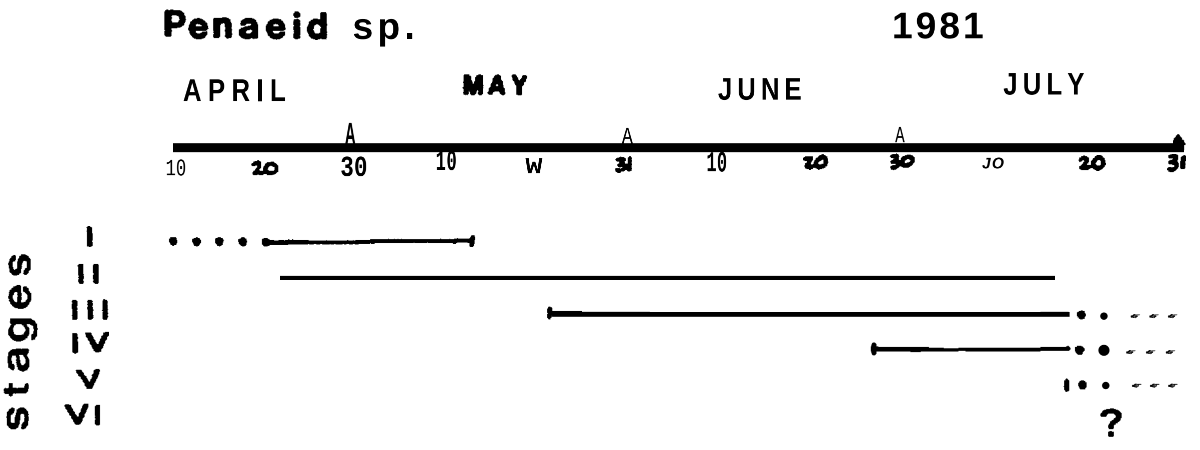


Figure 6.33 **Penaeid sp.** larval stage durations from PROBES 1981. Dots represent hypothetical portions of stage duration for which no samples were available.

Figure 6.33, these deepwater shrimp must have a protracted hatchout period. [Late summer sampling ,as taken in August 1982, will be examined for later stages (IV-VI) of this species.] Kurata (1964) described SVI and VII of a similar spiny larva, which he assigned to Glyphocrangon spp. One sample collected in October 1980 by the R/V Alpha Helix from east of the 200 m isobath contained one of these later SVI larvae. Additional late summer examples of this spiny larva may have been collected among the 1982 samples. Neither the total number of larval stages nor the total duration of planktonic larval life is known for this species.

A molt frequency histogram, based on the PROBES 1981 cruises, is given in Figure 6.34 for these spiny larvae. The intermolt period seems to be about 20 days and thus (given at least 7 larval stages) these zoeae would be in -the water column until the end of September or early October (as supported by the Alpha Helix collection in October 1980).

Distribution and Abundance: Positive station values for all years, 1976-1981, were combined for Figure 6.35. The deep water origin (> 200 m) of these spiny penaeid larvae is evident, and maximum densities of 1000-9000 larvae/100 m^2 occurred in strata 7, 3, and 4 beyond the shelf break. Abundance of these larvae over the outer shelf domain of the St. George Basin was generally very low, with densities ranging from 20-200 larvae/100 m^2 in strata 8, 2 and 5 except during May 1977 (NOAA) when higher densities of 200-3000 larvae/100 m^2 were taken in strata 8 and 5. Spiny larvae were rarely caught during the 1976, 1979, and 1980 cruises and were caught in very low numbers (< 500 larvae/100 m^2) in stratum 3

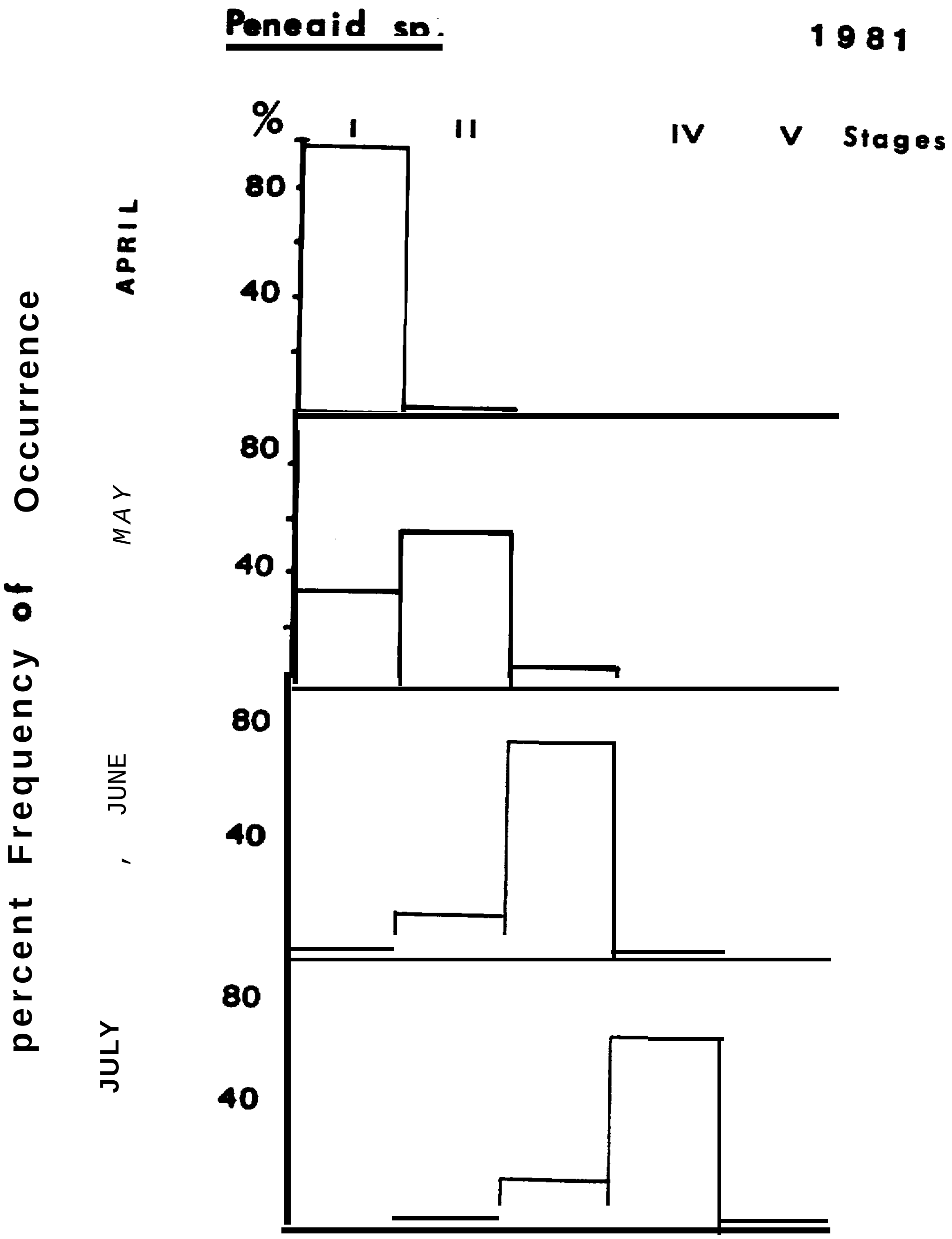


Figure 6.34 Penaeid sp. stage frequency by month from PROBES 1981.

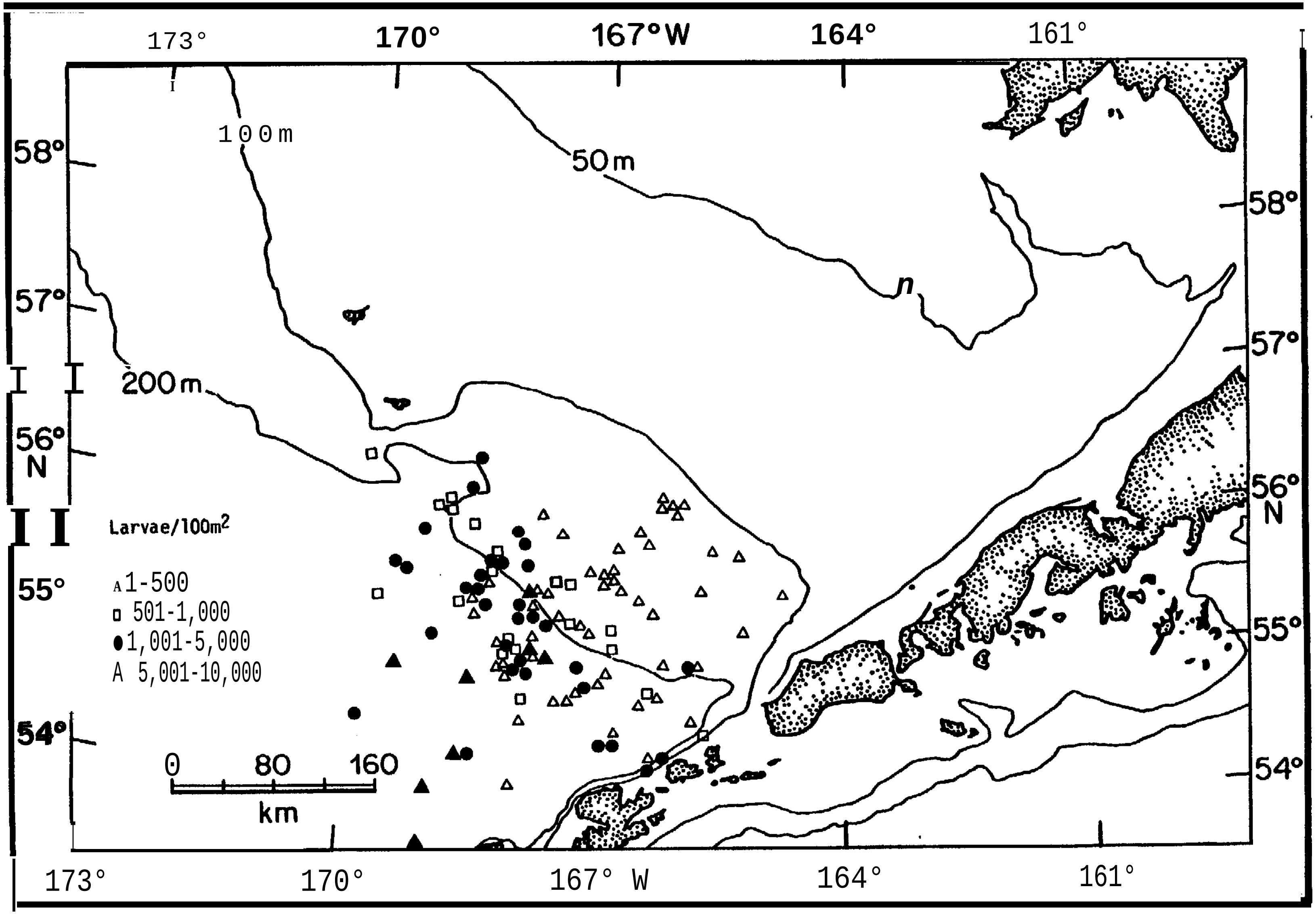


Figure 6.35 Distribution and abundance of penaeid species larvae all years 1976-1981 and all months April-July combined. Zero stations omitted.

in 1981 due to the sampling patterns employed during those years. No spiny larvae were ever found in the middle shelf domain (strata 9, 1, and 6) during any of the cruises.

Table 6.9 compares mean larval densities during April and May from NOAA 1977 with densities during May and June from PROBES 1978. Generally higher mean penaeid densities occurred during 1977 for all strata except stratum 8. In addition, the pattern of increasing abundance with increasing station depth is clearly apparent; none was found over the middle shelf, but an average of 4390/100 m^2 was found in stratum 3 over the shelf break.

Vertical Distrubtion: Of all the shrimp, these spiny larvae were the most homogeneously distributed in the water column from 0-80 m (see Fig. 6.36). Based on PROBES 19801 MOCNESS data, a cumulative total of 20% of penaeid spp. larvae appeared in the upper 20 m, 45% in the upper 40 m, 75% in the upper 60 m, and 98 % in the upper 80 m. Low abundance of these spiny larvae in PROBES 1980 samples precluded any depth distribution analysis for that year.

Summary:

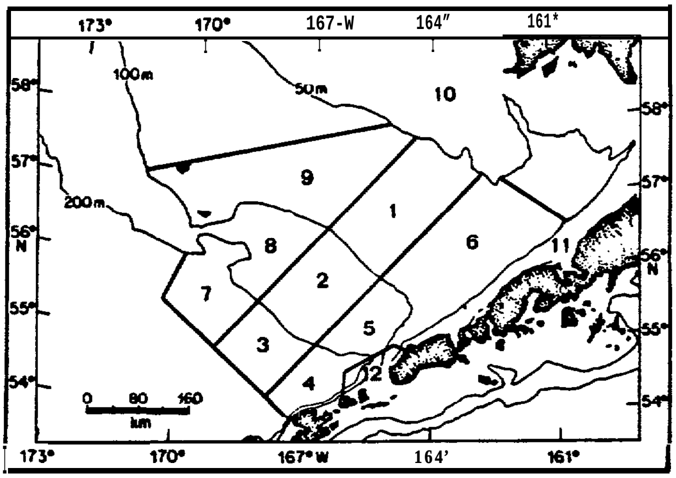
1) A type of spiny larva, tentatively assigned to the family Penaeidae, was taken less frequently 'than the other families of shrimp.

2) It was found predominant'ly beyond the shelf break in deep water (> 200 m).

Table 6.9. Cross-shelf comparison of mean densities of Penaeid sp. larvae during April and May from NOAA 1977 with May and June from PROBES 1978. See Figure below for strata locations. Total number of stations sampled = N.

	NOAA 1977 (April/May)			PROBES 1978 (May/June)		
Stratum	$\bar{X}$ ± 1 S.D.	N	% positive stations	$\bar{X}$ ± 1 S.D.	N	% positive stations
Oceanic/Shelf Break Domain						
7	1590	1	*	777 ± 508	7	86%
3	4390 ± 3748	11	82%	1196 ± 1116	7	71%
4	778 ± 912	13	69%	315 ± 84	2	100%
Outer Shelf Domain						
8	400 ± 919	8	38%	583 ± 1106	17	24%
2	336 ± 1271	25	36%	142 ± 334	24	17%
5	116 ± 287	18	33%	17 ± 59	12	8%
Middle Shelf Domain						
9	0	2	0%	0	17	0%
1	0	1	0%	0	0	0%
6	0	10	0%	0	15	0%

*Only 1 positive station sampled.



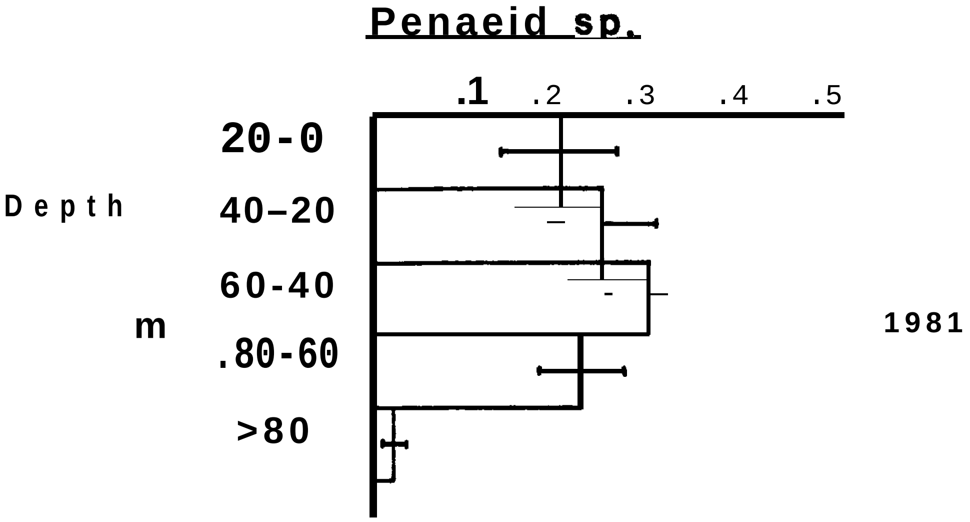


Figure 6.36 Vertical depth distribution of penaeid sp. larvae from PROBES 1981. Values expressed as an average proportion ±1 standard error.

3) Larvae were in the water column from hatchout in mid-April until metamorphosis - at least until late September or early October.

4) These larvae apparently have a protracted hatchout period and an intermolt duration of approximately three weeks.

5) These larvae are homogeneously distributed throughout the water column from 0-80 m.

6.7 General Shrimp Summary

1. Peak hatch of shrimp larvae in the southeastern Bering Sea occurs in early April for species in the families Pandalidae, Crangonidae, Penaeidae, and Hippolytidae; some larvae of the latter family hatch in early March.

2. Zoeal stages molt about every 2-3.5 weeks and are predicted to metamorphose to benthic juveniles about mid-August to September.

3. Larvae of *Pandalus borealis* and most pandalids are most densely distributed over the St. George Basin between the 100 m and 200 m isobath (Outer Shelf Domain); *P. tridens* larval densities are greatest beyond the shelf-break in deep water.

4. Hippolytid larvae are distributed throughout the St. George Basin south to Unimak Pass and in deep water southwest of the 200 m isobath to Unalaska Island.

5. Crangonid larvae are the least abundant of the three principal families and also are centered over the outer and middle shelf domains of the St. George Basin.

6. Relatively few shrimp larvae are found in the Middle Shelf Domain northeast of the 100 m isobath. Unimak Pass is a region of high larval shrimp densities.

7. Data on the magnitude of benthic shrimp populations is scarce because routine sampling gear is thought to inefficiently catch these relatively small crustaceans.

8. Although shrimp have no present commercial importance in the southeastern Bering Sea, their role in the benthic food webs of this area should not be overlooked. Shrimp are a major part of the diets of marine mammals and commercially important species of fish and crab. Environmental perturbations caused by pollution that affect major fluctuations in shrimp stocks could have ramifications throughout the benthic community.

7.0 DISTRIBUTION AND ABUNDANCE OF HERMIT CRABS (PAGURIDAE) IN THE S. E. BERING SEA

Jan Armstrong and Brett Dumbauld

7.1 Introduction

At least 21 species of hermit crab from the family Paguridae are reported to occur in the Bering Sea (Appendix 3). Some of these species are found strictly in intertidal areas (e.g. *Pagurus middendorffii*) while others are found in sublittoral areas, primarily on rocky substrata (e.g. *Pagurus beringanus*, *P. kennerlyi*, *P. hirsutiusculus*, *Elassochirus gilli*). Only seven of these species are regularly found in benthic trawls from the study area in the southeastern Bering Sea (Table 7.1).

7.1.1 Life History

The life history of hermit crabs in the genera *Pagurus*, *Elassochirus*, and *Labidochirus* includes four planktonic zoeal stages and one megalops stage (termed glaucothoe in the older literature); the latter undergoes metamorphosis and settles as a benthic juvenile (Thompson 1903; Hart 1937; Miller and Coffin 1961; Nyblade 1974; Nyblade and McLaughlin 1975). Four of the species which are commonly found in southeastern Bering Sea trawl samples have been raised from egg to adult in the laboratory (Table 7.2; Nyblade 1974; Nyblade and McLaughlin 1975). Laboratory culture has also been completed for six of the remaining species reported to occur in the Bering Sea (Nyblade 1974) and some studies have been conducted on larvae of *Pagurus middendorffii*, *P. trigonocheirus*, *Dermaturas mandtii*, and other species from plankton samples (Kurata 1964a, b; Makarov 1966).

Table 7.1. Frequency of adult and juvenile pagurid crabs in 1975 and 1976, southeastern Bering Sea, benthic trawl samples and preferred habitats (Adapted from Nyblade, 1974; McLaughlin, 1974; Feder and Jewett, 1980).

Species	Depth	% of tows in which species occurred	
		1975(<80m)	1976 (80-200m)
Pagurus aleuticus	15 -435 m soft bottom		34.6
P. capillatus	4 - 431 m mud	46.4	26.9
P. confragosus	68- 435m		44.2
P. ochotensis	Subtidal - 249m sand	38.7	
P. trigonocheirus	Subtidal - 183 m	45.9	36.5
Elassochirus cavimanus	37 - 252m		31.7
Labidochirus splendescens	Subtidal - 411 m soft bottom	32.9	

Table 7.2. Reproductive data for four species of Paguridae collected in the San Juan Islands, Washington. Species are also common in the Southeastern Bering Sea (Adapted from Nyblade 1974).

Species	Number of broods per year	Time of egg extrusion	Time of larval hatch	Egg dry wt. (µg)	Annual egg production per 100 mg female	Larval duration (days)	
						Zoea	Megalops
Pagurus aleuticus	1	No data	Spring only March-May	2.32	No data	61.2	20.2
P. capillatus	1	Jan.	Spring only March-May	3.09	1.88X 10^3	53.9	17.1
P. ochotensis	2-3	Autumn (For spring hatch)	Spring through summer March-Sept.	3.09	1.13X 10^3	59.0	21.0
Labidochirus splendescens	1	July-August	Spring only March-April	3.83	7.08x 10^2	76.1	21.0

7.1.2 Reproduction

Reproductive season among hermit crabs differs by species and locality (Nyblade 1974). Copulation and egg extrusion usually occur from autumn through spring. Some species have a single brood and release larvae only in the spring, while multiple brooders may release larvae throughout the summer months (Table 7.2). Egg development time from extrusion to hatching has been recorded only for the second brood in multiple brooding species, and varies from 1.5 to 2.0 months in the laboratory (Nyblade 1974). Egg size and number per female also vary with species. Like the larvae of other invertebrates, those of hermit crabs appear in the water column later in more northern waters (Stephenson 1935; Pike and Willliamon 1959). Therefore, with some allowance for latitude, the laboratory and field data of Nyblade (1974) for hermit crabs collected in the San Juan Archipelago (Table 7.2), may be applied tentatively to the same species found in the southeastern Bering Sea. Zoeal duration for most species falls in the range of 50-60 days. Laboratory studies have demonstrated that they are primary carnivores during this period and may feed on copepod nauplii, copepodites, barnacle nauplii, polychaete trochophores, and other small planktonic larvae (Roberts 1974). Duration of the megalops stage is approximately 21 days with little variation among species.

7.1.3 Benthic Distribution

Individual species of adult and juvenile hermit crabs were found in as many as 46% of benthic trawls taken in the southeastern Bering Sea in 1975 (primarily north of the Pribilof Islands and shallower than 80 m) and 1976 (between the Pribilof Islands and Unimak Island between the 80 and 200m isobaths; Table 7.1). The greatest number of decapod crustacean species were recorded for the genus *Pagurus* (Feder and Jewett 1980), but due to their small size they did not constitute a significant portion of the wet weight sample biomass of epifauna (e.g., 12,302 individuals of *Pagurus trigonocheirus* contributed to only 1.3% of the total wet weight of the 1975 trawl samples). Biomass estimates for pagurids averaged only .043 g/m^2 compared to .665 g/# for *Chionoecetes opilio* and .361 for *Chionoecetes bairdi*, the dominant crab species collected.

7.1.4 Food and Predators

Adult hermit crabs have been shown to be predominately omnivorous detritus feeders and use their chelipids and third maxillipeds to scrape and sort food from bottom deposits. Scavenging and predation have been shown to be accessory and opportunistic behavior patterns (Orton 1927; Roberts 1968; Greenwood 1972). In turn, hermit crabs are preyed upon by king crab (*Paralithodes camtschatica*), Tanner crab (*Chionoecetes* spp.), Alaska plaice (*Pleuronectes quadrituberculatus*), Pacific cod (*Gadus macrocephalus*), and seastars (*Asterias amurensis*) (Feder and Jewett 1980, 1981).

7.2 Results and Discussion

Pagurid crab larvae were found in 65% of all the samples examined from 1976-1980 (April-June), 61% of all PROBES 1981, and 100% of all NOAA 1981 (April-July) samples.

7.2.1 Larval Duration

Although several stage I pagurid larvae were found in early March (NOAA 1978) indicating a hatchout period of 1 ate February to early March for at least 1 pagurid species, high densities of pagurid larvae were not found until April (Fig. 7.2) indicating a mid to late March hatchout period for the majority of pagurid species. During 1981, some stage I pagurid larvae were still present as late as July (Table 7.2 and Fig. 7.1) illustrating the asynchronous hatchout periods and possibly multiple brood strategies of species in the pagurid group.

Pagurid larvae were not identified to species but were separated into individual zoeal (I-IV) and megalops stages. Densities were calculated for each individual larval stage. Average densities for each month (1981) were used to examine the relative frequency of occurrence of various larval stages. However, molt frequency is somewhat difficult to gauge from present data since numerous pagurid species are grouped together.

A larval stage frequency histogram for PROBES 1981 (Fig. 7.1) shows the basic developmental trend among the pagurids from April to July. In April and May a majority of the pagurids are S1, by June S111, and by July SIV with a small percentage of pagurids reaching the megalops stage. The intermolt period for pagurids must be 3-4 weeks between stages and thus total duration of planktonic life would approach 3.5-4.0 months from April-August for most species.

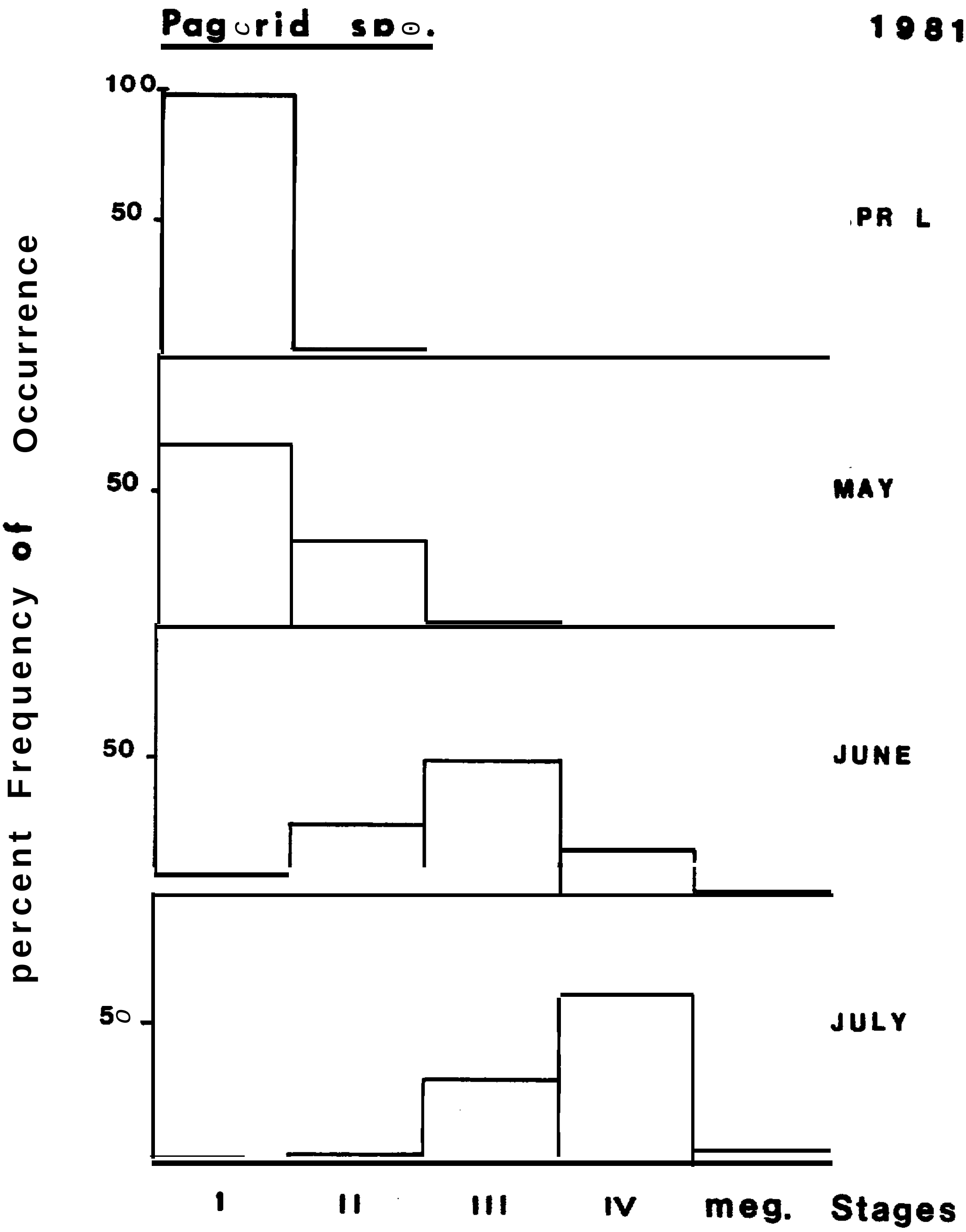


Figure 5.1 Paguridae stage frequency histogram by month from PROBES 1981 (Apr 1-July).

7.2.2 Distribution and Abundance

Since the family Paguridae encompasses several species in the southeastern Bering Sea, this group's ubiquitous distribution is not surprising. Figure 7.2 illustrates larval densities in April from PROBES 1978 and NOAA 1978 and NOAA 1977. Greatest larval densities appear in a continuous band just west of the 100 m isobath from north to south of the middle shelf domain, and along the Aleutian Islands from Amak Island to Akutan Island. Densities were typically an order of magnitude greater east of the 100 m isobath than over the outer shelf domain of the St. George Basin. Comparing April to May/June distribution (Fig. 7.3), high densities and greatest abundance were found overlapping the middle and outer shelf domains along the 100 m isobath. The same general patterns were again found from data of PROBES 1980 (Fig. 7.4) and PROBES 1981 (Fig. 7.5). While pagurid densities were generally lower in 1980, all the densities >1000 larvae/100 m^2 were taken *in* May and June. Lower densities in 1980 compared to 1981 appear along the 70 m isobath from Port Moller to the Pribilof Islands. During 1981, pagurid abundance was highest and most extensive over the middle shelf (strata 2, 5, 8) east of the 100 m isobath and along the 50 m isobath parallel to the North Aleutian Shelf from Unimak Island to Port Moller (Fig. 7.5); a continuation of the coastal band of high densities seen in Figure 7.3 from May/June 1976-79. The highest density was collected in April (57,000 larvae/100 m^2) just northeast of the 100 m isobath indicated by the star in Figure 7.2. Across-shelf comparison of mean densities of Paguridae larvae during May and June PROBES 1978 (Table 7.3) highlights the preponderance of animals over the middle shelf domain and the high density overlap

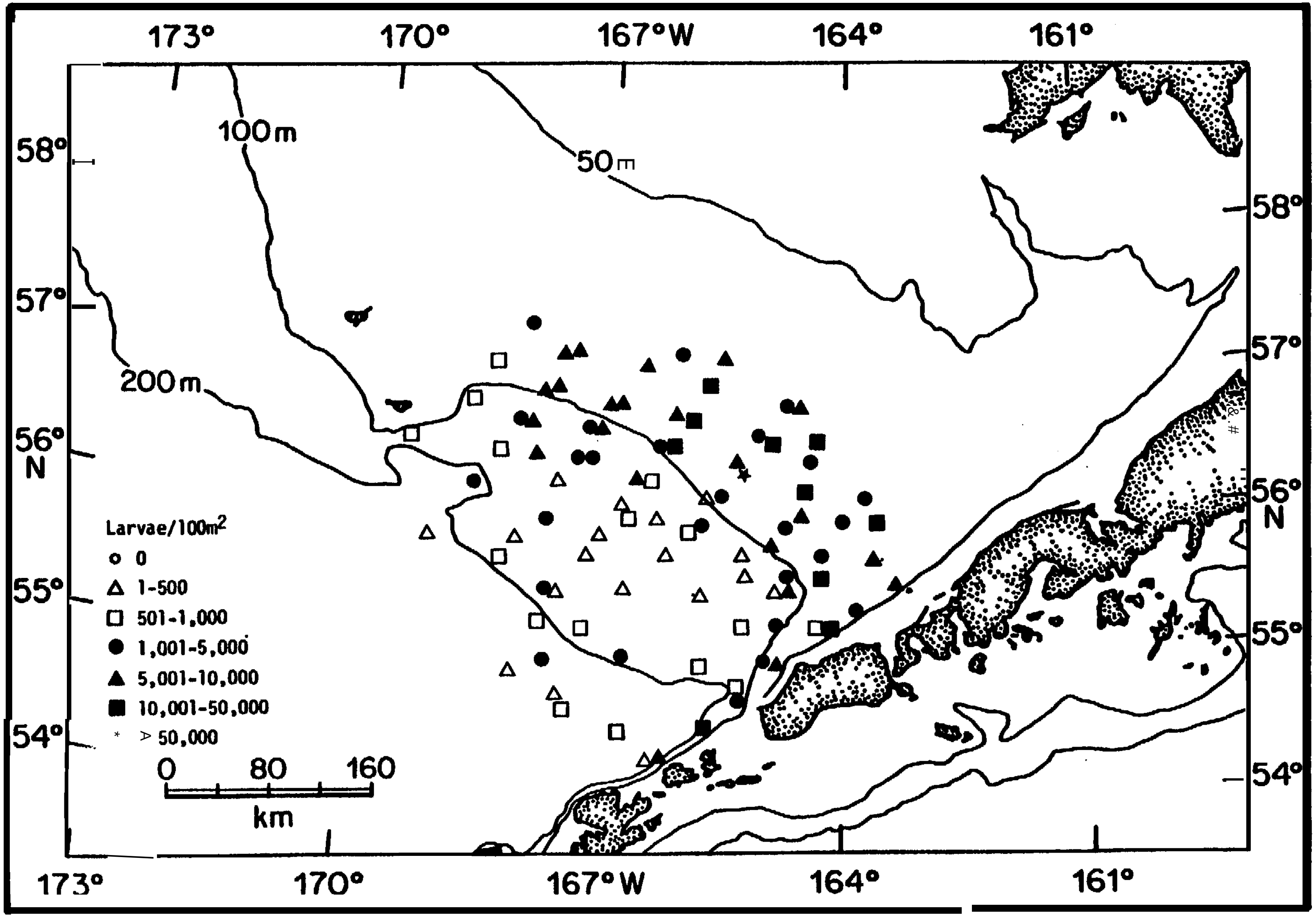


Figure 7.2 Distribution and abundance of Paguridae larvae during April from NOAA 1977 and PROBES 1978. Only positive stations were included. See Section 2.0 for all station locations.

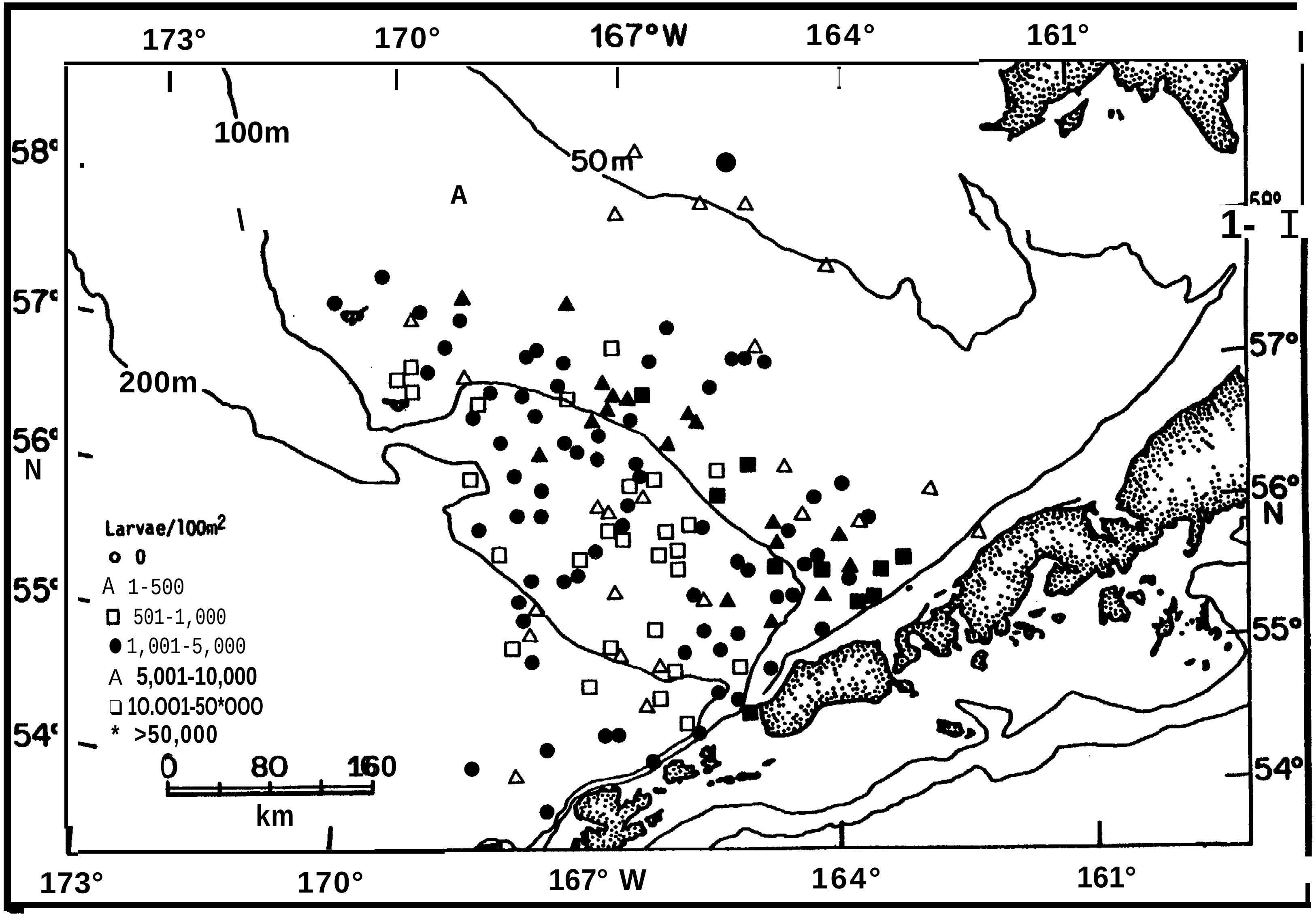


Figure 7.3 **Distribution and abundance of Paguridae larvae during May and June** from **NOAA** 1976, 1977, 1979 and PROBES 1978. **Only positive stations were included.**

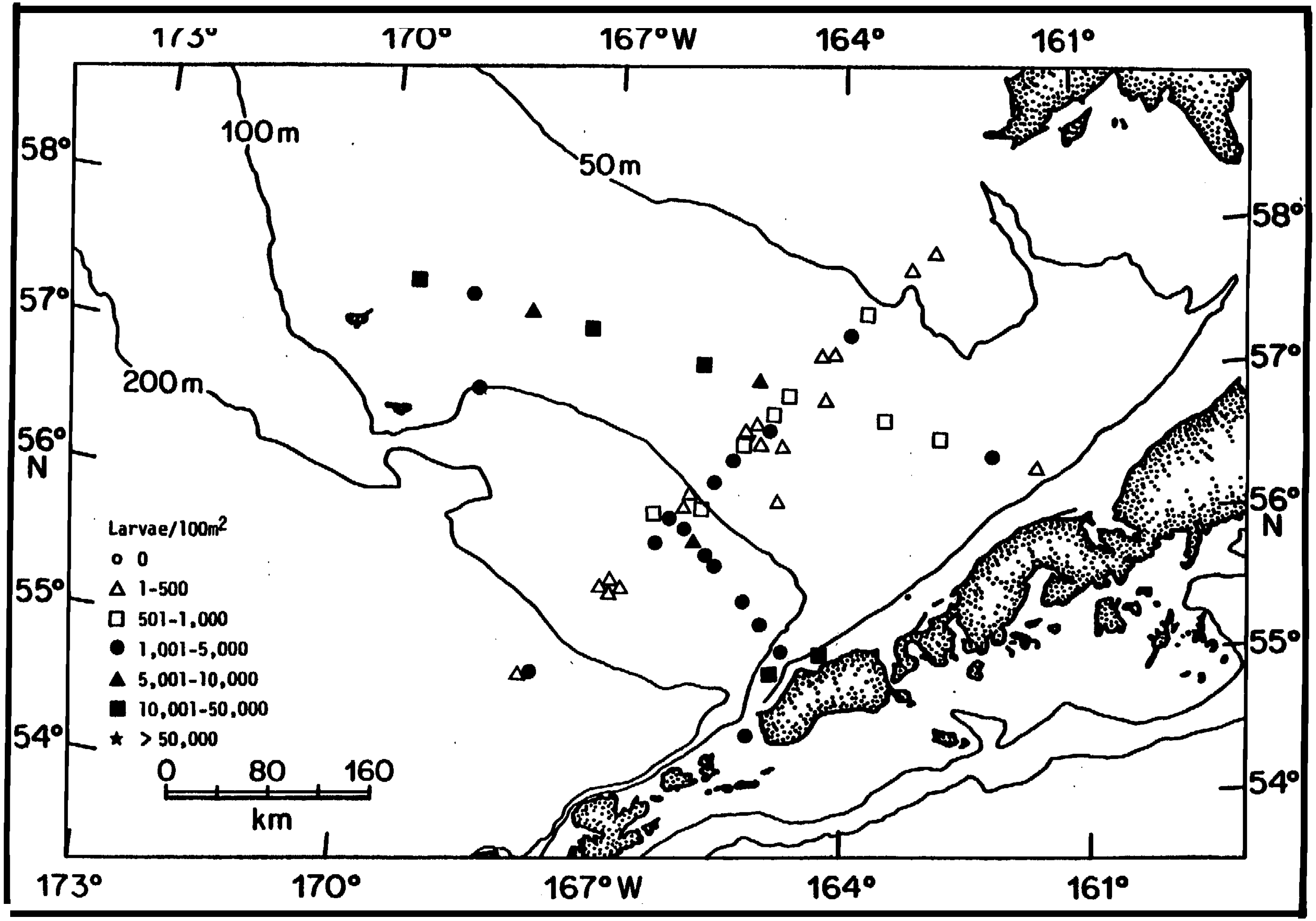


Figure 7.4 Distribution and abundance of Paguridae larvae during April-June from PROBES 1980. Only positive stations were included.

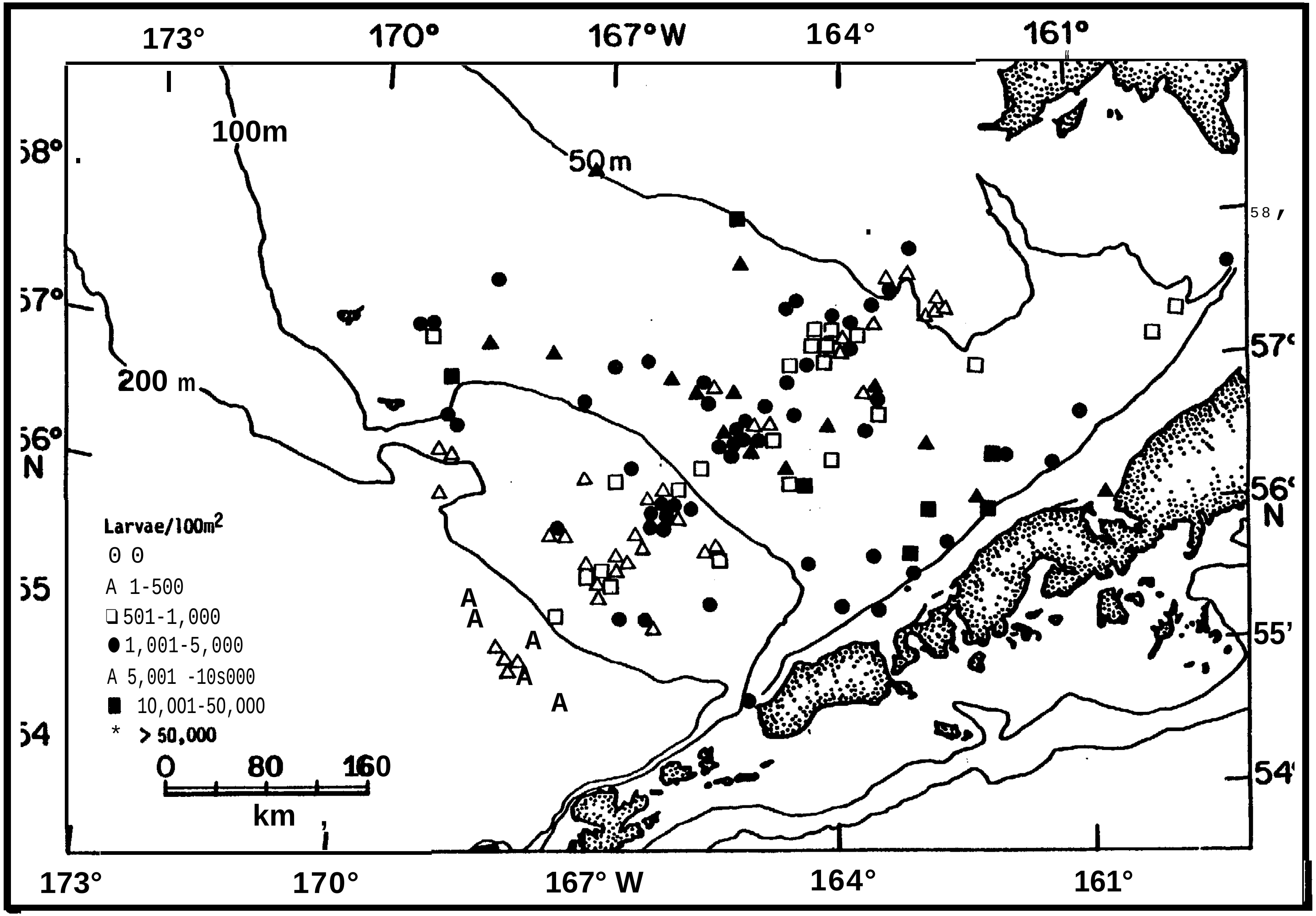
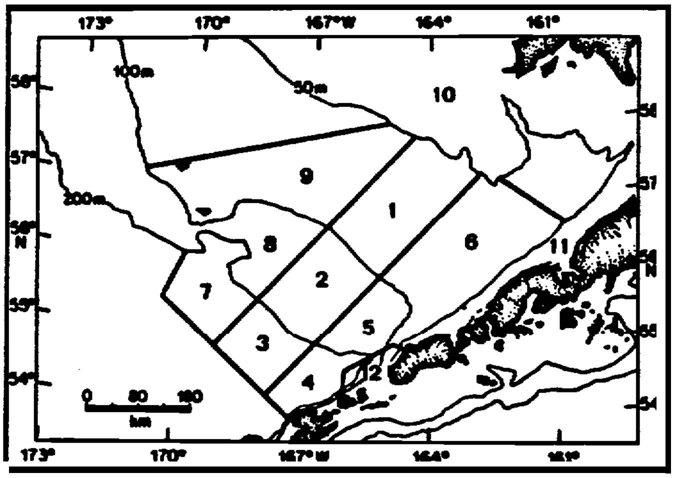


Figure 7.5 **Distribution** and abundance of **Paguridae larvae** during April-July from **PROBES** and **NOAA 1981.** Only positive stations were included.

Table 7.3. Cross-shelf comparison of mean densities of **Paguridae** larvae during May and June from PROBES 1978. Zero stations omitted in calculating these means. Total number of stations surveyed within each stratum = **N.** See Figure below for strata locations.

Stratum	$\bar{X} \pm 1$ SD (larvae/100 m2)	% positive stations	N
	Oceanic/Shelf Break Domain		
7	663*	14%	7
3	580 ± 259 .	43%	7
4	485 ± 156	100%	2
	Outer Shelf Domain		
8	3804 ± 3260	65%	17
2	1406 ± 1133	56%	18
5	4910 ± 6348	100%	12
	Middle Shelf Domain		
9	5272 ± 4350	82%	17
1	7566 ± 6911	100%	7
6	8241 ± 8741	100%	14

*Value based on **only** one positive station.



into strata of the outer shelf domain (strata 5 and 8) during May and June. The cross-shelf increase of ten-fold in density is shown in Figure 7.6 for the years 1976-1981; only data of 1980 deviated from the trend of high middle shelf density (stratum 1) to low outer shelf and shelf break densities (strata 2 and 3). Stratum 1 mean densities ranged from 1148 to 7566 larvae/100 m^2 (1980 low and 1978 high), compared to stratum 2 densities of 649 to 1364 (1979 low and 1980 high). General scarcity in stratum 3 is illustrated by mean densities of 147 to 858 larvae/100 m^2 (1981 low and 1980 high).

7.2.3 Vertical Distribution

Vertical depth distribution of Paguridae larvae was studied by analysis of MOCNESS samples from PROBES 1980 and 1981 (Fig. 7.7). Pagurid larvae were occasionally found down to 120-300 m but were primarily concentrated within 0-80 m. Unlike the homogeneous distribution found among the shrimp taxa, pagurids preferred the upper depth intervals with 44-47% in the upper *20* m, 71-76% in the upper 40 m, 84-89% in the upper 60 m, 95-96% in the upper 80 m, and 4-5% below 80m. A diel comparison of vertical depth distributions is given in Figure 7.8 for light (local mean time (LMT) = 07:00 - 19:59) versus dark (LMT = 20:00 - 06:59) at stations <100 m sonic depth (middle shelf domain) and stations between 100-200 m sonic depth (outer shelf domain) from PROBES 1981. Percent occurrence of pagurid larvae during daylight hours was consistent between middle shelf and outer shelf stations; 30-33% for the 20-0 m interval, 40-45% for the 40-20 m interval, 12-23% for the 60-40 m interval, 2-7% for the 80-60 m interval, and 0-6% below 80m. Samples taken during

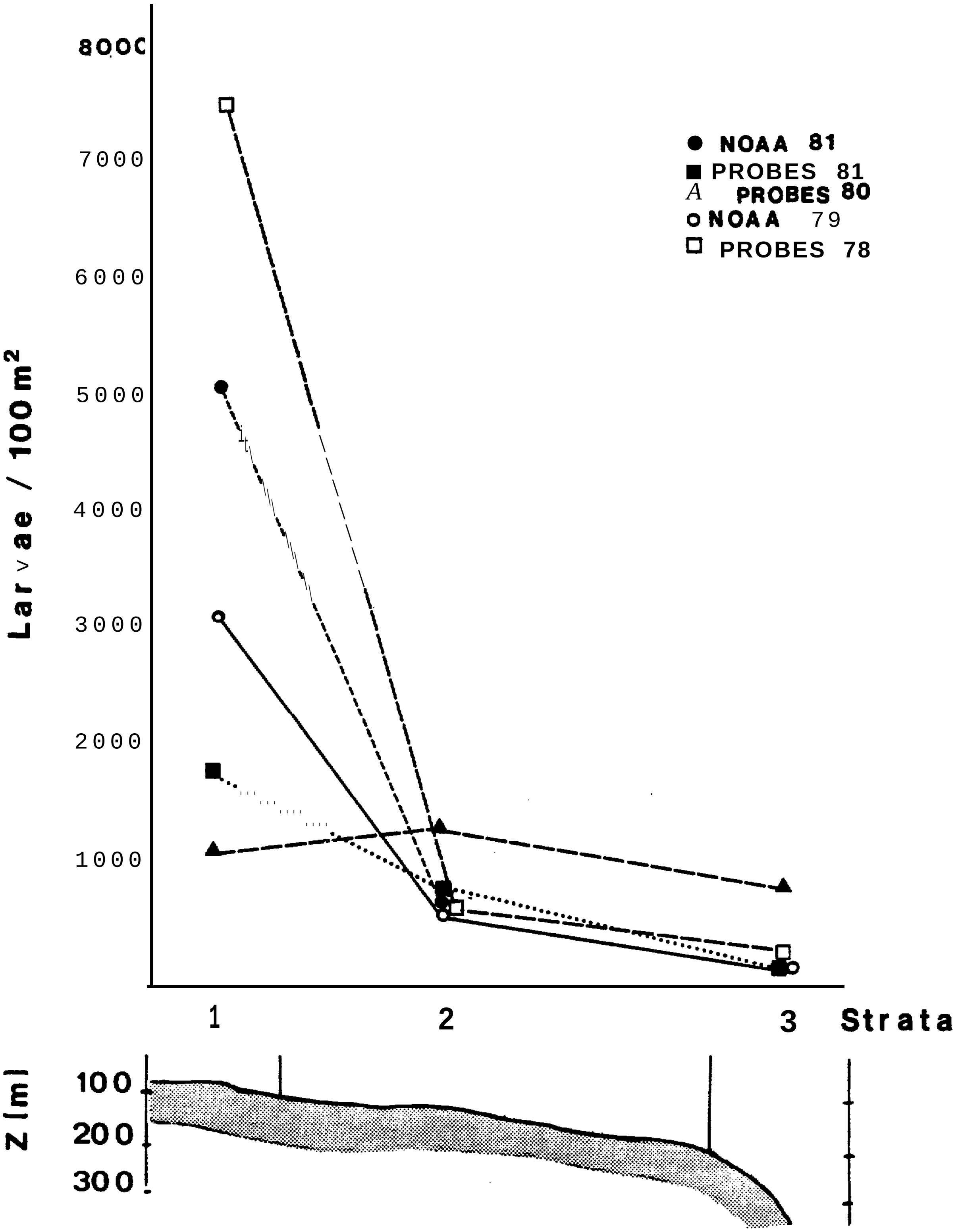


Figure 7.6 Mean larval densities of Paguridae by stratum for cruises 1978-1981.

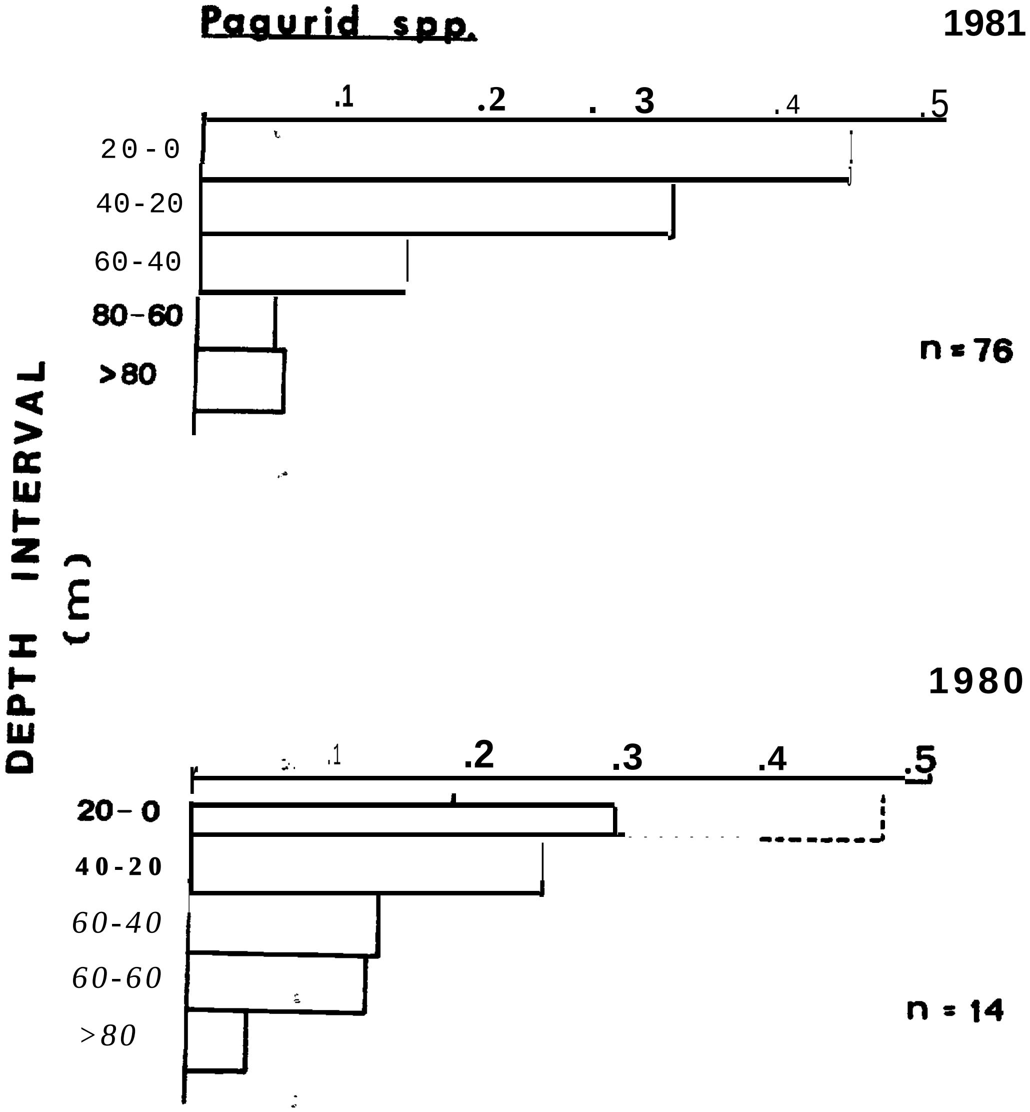


Figure 7.7 Vertical depth distribution of Paguridae larvae from MOCNESS samples PROBES 1980 and 1981. Number of stations sampled for this analysis is given by n.

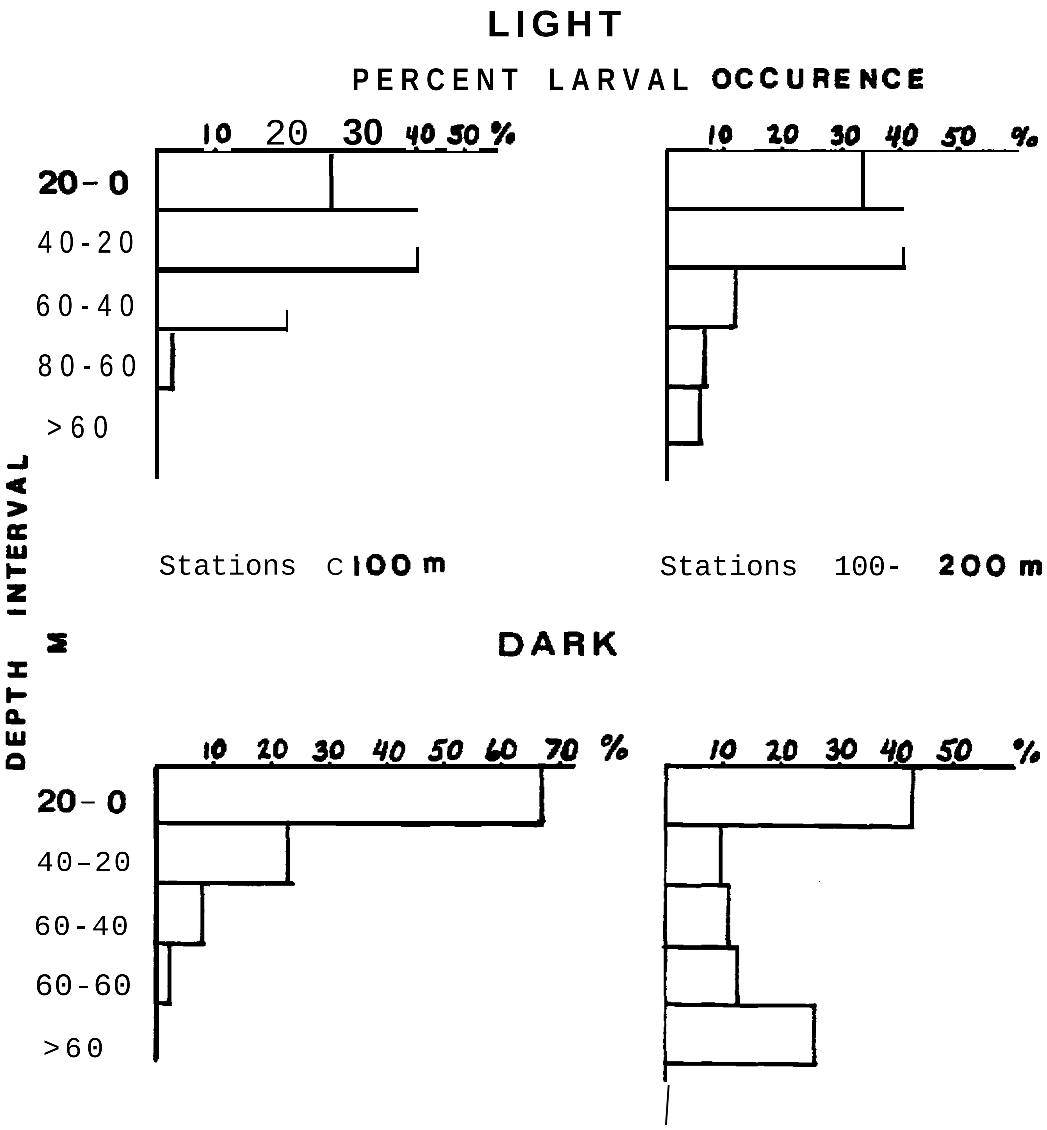


Figure 7.8 Vertical depth distribution of Paguridae larvae, diel comparison: light vs. dark, samples at stations < 100 m sonic depth and stations 100-200 m sonic depth from PROBES 1981.

dark hours showed very different distribution patterns depending on the station depth. Stations <100 m sonic depth had a majority of larvae in the upper 20 m while stations 100-200 m had many larvae in the upper 20 m but also a significant percentage in the >80 m interval. These data suggest vertical migratory behavior that could be a significant factor in exposure to surface oil.

Distribution of pelagic pagurid larvae cannot be compared with that of adults since good information is lacking on benthic distribution of adult hermit crabs in the southeastern Bering Sea. This group is routinely undersampled by conventional survey gear and yet their biomass may be substantial and their trophic position important to the benthic community that includes several commercially valuable predators of hermit crabs. Large populations of adult pagurids are expected to concentrate northeast of the 100 m isobath (as do the larvae) and along the 50-100 m isobaths along the Aleutian Island chain. A point of interest would be whether different species dominate either side of the 100 m isobath as seems to occur for *Chionoecetes bairdi* and *C. opilio* over the outer and middle shelf domains, respectively (see Section 4.0).

7.3 Summary

1) Pagurid distribution was ubiquitous throughout the southeastern Bering Sea.

2) Pagurid crab larvae were found from early March until mid July with greatest densities during April over the middle shelf.

3) Larval duration in the plankton is expected to last 3.5-4.0 months for most species which have 4 zoeal plus a megalops stage and an intermolt period of approximately 3 weeks.

4) Greatest larval densities appeared in a continuous band along and east of the 100 m isobath and and along the Aleutian Islands from Amak Island to Akutan Island between the 50-100 m isobaths; there was a substantial decline in density over the St. George Basin. Larval densities across the middle shelf domain were 10-fold higher than densities beyond the shelf break and 3-5 times higher than outer shelf densities during May and June (7566/100 m^2 vs. 249/100 m^2 vs 658/100 m^2 in 1978).

5) Pagurid larvae were generally concentrated in the upper 40 meters at both middle and outer shelf stations, and there was an indication of diel vertical migration toward the surface during dark hours.

8.0 POSSIBLE OIL IMPACTS ON DECAPOD LARVAE IN THE SOUTHEASTERN BERING SEA WITH EMPHASIS ON THE ST. GEORGE BASIN

This two-year study of population dynamics of decapod larvae has drawn on six years' worth of zooplankton samples to determine spatial and temporal variation in distribution and abundance, in order to predict the possible impacts of oil development on this most sensitive life-history stage. Other factors of general biology have been elucidated; " for example, the time and synchrony of hatch and its interannual variability, rate of larval development and time in the water column, molt frequency, and, in the case of commercial species targeted in surveys, the relationship between distribution of benthic female stocks and centers of larval abundance.

In many respects however, the data are incomplete, a shortcoming that has prompted over the past 1.5 years recommendations and proposals for additional research. Some of the proposed research is now ongoing (spring/summer 1983) as studies at the Pribilof Islands on blue king and <u>Erimacrus</u> crab biology and on red king crab along the North Aleutian Shelf. These investigations should add substantial information on critical habitat requirements of the species and allow an assessment of the relative sensitivity of such habitat to oil impact.

This last chapter is used to discuss scenarios of oil mishaps in the southeastern Bering Sea and consequences to pelagic larvae of several taxa. This will be done by first reviewing several models of water and oil transport developed for the region, discussing oil toxicity to crustacean larvae, highlighting biological misconceptions of past models and suggesting modifications based on the present study, and finally predicting oil impact on larvae over the St. George Basin and nearshore along the North Aleutian Shelf.

8.1 A Review of Water and Oil Transport Models

Attempts to predict oil impacts in the southeastern Bering Sea should be based on best possible information available regarding physical and biological processes of the system, and specific life-history and ecological information for the principal species of interest. It is often necessary to establish rather tenuous links between species biology and assumptions regarding processes that influence populations because data are sketchy or non-existent for the system in question, and must therefore come from oil studies on different species or *in* different oceans.

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

Water movement and resultant larval transport are important considerations in predictions of oil impact because larvae or oil may be moved toward or away from each other depending on area and timing of a spill, or both may be entrained together for days to weeks in a water mass circulating over the shelf. Current and transport processes in the area of major larval king and Tanner crab populations are the most important to consider, and in this regard the North Aleutian Shelf along the 50 m isobath and the St. George Basin in the vicinity of the 100 m isobath are most important. Hebard (1959) described currents moving to the northwest through Unimak Pass, with a component then moving northeast along the North Aleutian Shelf. Although the direction of the current is highly variable and changes with tide, there is a net movement of 2.0- 5.5 cm/sec eastward and northward into Bristol Bay. Hebard was the first to suggest that larvae of red king crab could be transported long distances before metamorphosis, and thus recruitment of juveniles in one area like Port Moller might be dependent on up-current populations near Amak Island. Kinder and Schumacher (1981b) summarized data for current patterns in the southeastern Bering Sea and showed weak currents of 2-5 cm/sec along the NAS and 1-5 cm/sec moving northwest over the St. Geoge Basin (Fig. 8.1). They stress that instantaneous flow can be substantially greater than these averages (up to 20X greater than the long-term vector) and direction quite variable. Cline et al. (1981) 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 in close agreement with current meter readings.

The importance of such information is to gauge the movement of crab larvae in currents relative to origins and surface speeds of oil movement. Such exercises have been done by Leendertse and Liu (1981) and

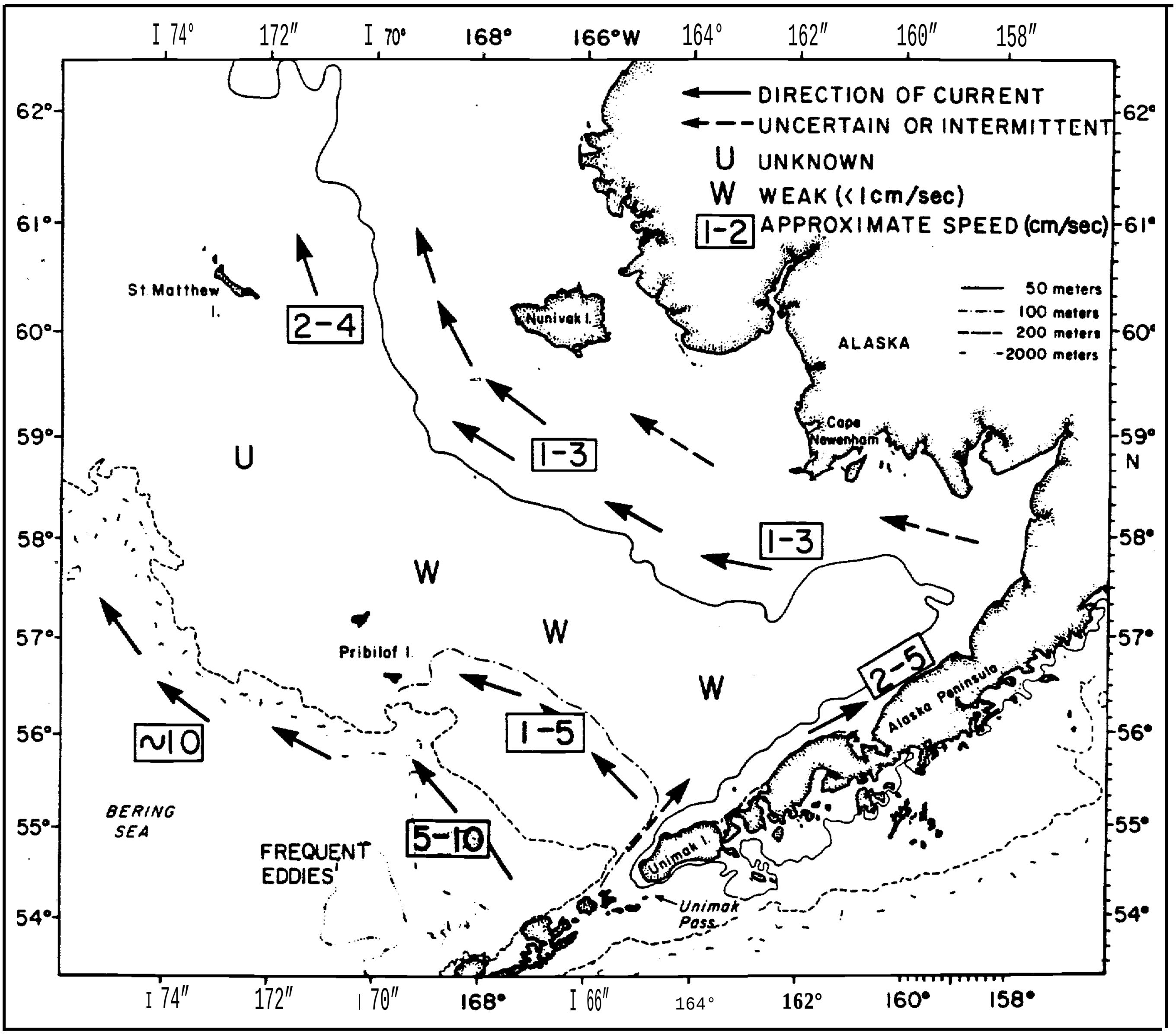


Figure 8.1 Current directions and net speed over the southeastern Bering Sea Shelf (from Kinder and Schumacher 1981a).

Sonntag et al. (1980). Following hypothetical oil spills or well blowouts in their models, oil can be moved by winds and currents, mixed by storms, transported to the benthos by several processes, and made to kill target/commercial species by direct exposure, loss of food and over-competition, or accumulation in tissues and gametes. Oil concentrations in the water column and benthic sediments are modeled as a function of the magnitude of an initial oil spill and its duration (e.g., 100,000 barrels from a tanker or 5,000 barrels/day from a well for several weeks), time of year, location of the mishap, and loss of oil fractions by processes such a volitalization. Model outputs show the trajectory and extent of oil coverage and concentration at various times after each hypothetical mishap. From data and assumptions on lethal levels, distribution and abundance of animals, sensitive life- history stages and physiological events (e.g., molting of crustaceans), predictions are made of the proportion of a year-class or population killed and the eventual ramifications such losses pose to commercial fisheries.

Concerning decapod larvae and in particular crab species, the results of several scenarios modeled at workshops in California (1980) and Alaska (1981) have predicted very slight impacts of oil spills on crab larvae over the St. George Basin (Sonntag et al. 1980) because such small areas, relative to the spatial distribution of larvae, are impacted (Sonntag et al. 1980; Curl and Manen 1982). However, several areas crucial to crab reproduction have been identified at these workshops (Pribilof Islands, North Aleutian Shelf), and oil scenarios have been suggested that could lead to substantial mortality of larvae in these areas (see Fig. 8.2) (Sonntag et al . 1980; Curl 1981; Curl and Manen 1982;

discussed by participants at the St. George Basin Lease Area Synthesis Meeting, April 1981, Anchorage; North Aleutian Shelf Synthesis meeting, March 1982). Predictions from these models may seriously underestimate possible larval mortality caused by an oil mishap (even in the St. George Basin) because of incorrect assumptions concerning larval sensitivity to oil and aspects of larval life history and ecology (these are discussed later in this section).

8.2 Oil Toxicity to Crustacean Larvae

Oil is a highly complex pollutant of water soluble and insoluble fractions and aromatic compounds that may stress organisms over a spectrum of effects from mechanical impacts to subtle biochemical impairments. Its effects on aquatic resources may be manifested in several ways (Curl and Manen 1982): 1) rapid mortality resulting from acute exposures to high doses via external contact, inhalation and asphyxiation, or assimilation of hydrocarbon compounds that become toxic on a cellular and biochemical level; 2) bioaccumulation of sublethal amounts that cause a decline in general vigor evidenced in reduced growth, susceptibility to disease, inhibition of feeding (anorexia) (effects of this nature will likely become lethal to organisms); 3) impaired reproduction, reduced broods and viability of progeny; 4) carcinogenic and mutagenic causes of tumors and morphological abnormalities; and 5) uptakeof hydrocarbons causing tainting of commercial crab sold as food.

8.2.1 Effects on Larvae

A wealth of information has been generated on oil toxicity to marine invertebrates (Malins 1977; Wolfe 1977) and many investigators have been specifically concerned with sensitivity of larval crustaceans (Wells and Sprague 1976; Bigford 1977; Caldwell et al. 1977; Tatem 1977; Cucci and Epifanio 1979). Karinen (1981) has reviewed toxicity of oil to Pacific Northwest and Alaskan species of shrimp and crab including Dungeness crab (*Cancer magister*), king and Tanner crab, and pandalid shrimp. Rice et al. (1975) and Vanderhorst et al. (1976) reported that ‘6 ‘r “50 values for juvenile and adult pandalid shrimp range from 0.8-11.0 mg/l as water soluble fractions (WSF). Pandalid larvae, however, are a more sensitive life history stage as evidenced by 96 hr LC_{50} value from 1.0 mg/l WSF down to .3 mg/1 as single aromatic compounds such as naphthalene (Mecklenburg et al. 1977; Rice et al. 1975; Rice et al . 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 S I to S II zoeae (Mecklenburg et al. 1977). Dungeness crab zoeae were susceptible to WSF as low as 0.22 mg/l (Caldwell et al. 1977). Larval king and Tanner crab are equally sensitive to hydrocarbons. Death of *Paralithodes camtschatica* larvae or failure to swim is caused by WSF of 0.8 to 2.0 mg/l (Brodersen et al. 1977; Mecklenburg et al. 1977), and *Chionoecetes bairdi* larvae are immobilized by a 96 hr exposure to 1.7 mg/1 WSF (Brodersen et al. 1977).

Larval Feeding: Studies with other larval decapods indicate that toxic oil concentrations may be even lower than those just discussed when based on assays of single hydrocarbons, exposures longer than 96 hr, or sensitive sublethal criteria. Larval lobster (*Homarus americanus*) ceased feeding at 0.19 mg/l WSF and had a 30-day LC_{50} value of 0.14 mg/1 (Wells and Sprague 1976). Specific compounds such as naphthalene are very toxic and caused narcotization followed by death of pandalid shrimp and of crab larvae at concentrations of 8-12 g/1 during brief exposures of less than 24 hr (Sanborn and Malins 1977). Chemoreceptive organs of juvenile and adult Dungeness crab can detect WSF as low as 10‘^{4} mg/1 (0.1 g/l), a concentration well within the range of oil spill concentrations (Pearson et al. 1980). This may result in behavioral changes affecting feeding and/or mating and therefore reproduction. The extent of chemoreceptive feeding by crab larvae is unknown but could be seriously impaired by very low oil concentrations, thereby disrupting food consumption by this rapidly growing stage.

Based on these studies the following generalizations can be made: 1) Larvae are more sensitive to hydrocarbons than are juveniles and adults (Johnson 1977; Moore and Dwyer 1974). 2) Toxic oil concentrations range as low as 0.15 mg/1 WSF and may be somewhat lower for specific compounds. Moore and Dwyer (1974) give a sublethal range of oil WSF to larvae of 0.001-0.1 mg/l. Wells and Sprague (1976) suggest a multiplier of .03 should be applied to LC_{50} concentrations to establish “safe” levels, which would predict that acceptable concentrations less than 1 µg/l WSF. 3) Molting is an extremely sensitive physiological event for crustaceans that results in greater toxicity of oil compounds when larvae are exposed for periods of the intermolt cycle. Since larvae molt frequently, relatively short exposures of several days may disrupt normal ecdysis.

8.2.2 Effects of Oil on Reproduction

Oil in the water column or in sediments could affect reproduction in several ways: 1) Sediment and infaunal concentrations of hydrocarbons become so high that feeding of crabs and shrimp is curtailed by either loss of prey (clams, polychaetes, other crustaceans) and/or anorexia. Energetic requirements are not met and gamete production is reduced or curtailed. 2) Hydrocarbons are absorbed and/or ingested with food and deposited in eggs and sperm. At critically high (but as yet unknown) concentrations viability of the gametes is impaired and normal development of embryos arrested, resulting in greatly reduced hatching success. 3) Normal gametes are produced and eggs fertilized and extruded, but sediment hydrocarbons are absorbed directly by the lipid-rich developing embryo and remaining yolk mass. Again, at critically high tissue levels (unknown) development is arrested and a year-class weakened by virtue of poor hatch.

The first hypothesis is predicated on the possibility that extensive mortality of epibenthic and infaunal prey would severely restrict feeding by crabs. Scenarios of oil transport to the benthos (summarized by Manen and Curl 1981) predict accumulation of amounts up to 60 g/m^2

and high resultant mortality. Sonntag et al. (1980) predicted that annual benthic productivity ("benthic food growth rate") would reach zero at sediment oil concentrations of 8 to 16 g oil/m^2, well within the range of possible sediment concentrations predicted by participants of the 1981 Anchorage Workshop. In a realistic spill scenario (about 500,000 barrels of oil; AMOCO CADIZ lost 223,000 mt = 2.47 x 10^6 barrels of oil; IXTOC 1 blowout spilled 30,000 barrels day for several months) several thousand square kilometers could be so impacted and food resources of crabs reduced on a large scale. In addition to outright loss of prey, food consumption could be reduced by a sublethal, anorexic response to increasing tissue levels of oil as shown for lobster larvae (Wells and Sprague 1976).

Reduction of food intake by either cause could trigger an energetic imbalance in which metabolic needs account for the largest expenditure of ingested energy and little remains for tissue and gamete production (Edwards 1978). Sub-optimal temperatures can exacerbate the effect of oil on growth and energy budgets of a species as theorized by Warren (1971). Sublethal oil concentrations can act synergistically with sub-optimal temperatures to reduce energy consumption (Edwards 1978) but at the same time increase respiration even at cold temperatures (Laughlin and Neff 1977), thereby further narrowing the scope for growth (Warren 1971). Similar impairment of bioenergetic demands may affect pelagic larvae exposed to sublethal oil concentrations.

The second hypothesized effect of oil on reproduction is caused by translocation of hydrocarbons ingested and absorbed by adults to gametes. Rapid uptake of petroleum hydrocarbons has been demonstrated in several species of Crustacea (Anderson 1975; Cox et al. 1975; Lee 1975; Tatem 1977). While both adult and larval stages are capable of rapid elimination of hydrocarbons accumulated via the diet, metabolic products appear to be strongly resistant to deputation (Corner et al. 1976; Lee et al. 1976; Sanborn and Malins 1977). Residues amounting to 10% of the initial level were found in adult copepods which had been exposed 34 days earlier as nauplius I to a seawater solution of naphthalene for 24 h (Harris et al. 1977). Neff et al. (cited by Varanasi and Malins 1977) found rapid accumulation of naphthalene derivatives by penaeid shrimp that reached tissue levels of 100 times greater than those in exposure water. Highest and most persistent residues were found in the hepatopancreas that directly supplies nutrient materials to the gonads for gametogenesis. Transfer of naphthalene to eggs was found to occur in the marine polychaete *Neanthes arenaceodentata* (Rossi and Anderson 1977). Blue crab (*Callinectes sapidus*) ingesting radiolabeled hydrocarbons assimilated 2 to 10% and stored up to 50% of this amount in the hepatopancreas, which was the only organ assayed that still contained radioactivity after 25 days of deputation (Lee et al. 1976). Again, a direct translocation to and biomagnification of hydrocarbons in lipid-rich gametes is possible, although not well studied to our knowledge. Sufficiently high hydrocarbon levels in egg yolk and developing embryos could cause anomalous development.

The third reproductive effect involving eggs and embryos is uptake of hydrocarbons directly from bottom or interstitial water (female Chionoecetes may bury in the sediment while carrying an egg clutch) where sediment levels are high by virtue of processes such as deposition of oil-laden fecal pellets or storm mixing in shallow waters (Manen and Curl 1981). No studies of direct hydrocarbon uptake by crab or shrimp eggs and embryos could be found, but transferal of naphthalenes to brooding eggs (high in lipids) was reported to occur in the marine polychaete Neanthes arenaceodentata (Rossi and Anderson 1977) while adsorption from seawater occurred independent of adults in eggs of the Pacific herring (Eldridge et al. 1978). The lethal effect such exposure can have on developing embryos was shown by Tatem (1977) who exposed gravid female shrimps (Palaemonetes pugio) to 1.44 mg/l WSF for 72 hr. One week later control females released an average of 45 larvae each while those exposed to oil released only 9 each. Further studies of oil toxicity to developing eggs is warranted in light of possible oil impacts to red and blue king crabs that reproduce in relatively shallow, nearshore areas. Since oil degrades slowly in the sediments of very cold arctic waters (little change in quantity and composition after one year in tests cited by Curl and Manen 1982; Butler and Levy 1978; Mayo et al. 1978), and since female king and Tanner crabs brood eggs for eleven months (Sections 3.0 and 4.0), protracted exposure of eggs to hydrocarbons can result from oil spills that reach extensive areas of reproductive grounds.

An additional mechanism of oil-related stress on crustacean reproduction might involve impairment of copulation that results in a high proportion of infertile egg masses extruded by females. As described in Sections 3.0 and 4.0, a sexually mature male locates and embraces a female just prior to her molt and they copulate immediately thereafter. Failure to copulate within five days post-ecdysis results in infertile egg masses (whether or not multiparous, older female Tanner crab copulate in later years after the terminal molt is currently under investigation at the University of Alaska). Location of a female partner is based on strong pheromone cues that are detected by chemosensory organs. Pearson et al. (1980) demonstrated that Dungeness crab can detect hydrocarbons at a few g/1. Following an oil spill, water concentrations may exceed 100-200 g/1 (Hood and Calder 1981), and might impair chemosensory location of females or otherwise alter behavior to reduce breeding within the population. Following the AMOCO CADIZ spill in the spring of 1978, the numbers of gravid crab and lobster were drastically reduced in that year and 1979 along the affected portion of the Brittany coast (Hood and Calder 1981), suggesting that breeding within the population was impaired.

8.3 Larval Decapod Biology, Sensitivity to Oil, and Oil Scenarios: Misconceptions of Past Models and More Realistic Assumptions

Summaries of biological information and predictions of oil impacts in the southeastern Bering Sea arising from OCSEAP workshops at Asilomar, California (Sonntag et al. 1980) and Anchorage, Alaska (Curl and Manen 1982) were based on available data and best possible assumptions. In reviewing these efforts, several misconceptions and inaccuracies are apparent that, if corrected, may change the predictions of oil toxicity to and impact on, pelagic and benthic crab populations. These changes include the following points:

1. An entire larval year-class was assumed to hatch during the 3 months of April, May, and June as proportions of 20%, 60%, and 20%, respectively (Sonntag et al. 1980). Based on molt frequency data of our report for larval king crab (Section 3.0), Tanner crab (Section 4.0), and shrimp such as Pandalus borealis (Section 6.0), it appears that the majority of larvae for these species are hatched in a 3-4 week period of April and early May and not over a protracted period of 3 months. Therefore the entire year-class enters the water column during a relatively brief period of time and is not followed weeks later by other cohorts for that year. First stage king crab zoeae that are killed by oil north of Unimak Island in late April, as an example, will not be replaced by other first stage zoeae hatched in June (although they may be replaced by larvae also hatched in April and transported to the affected area). Since hatching seems to be a well-synchronized event among commercial crustaceans, a major oil spill that kills a significant proportion of a larval year-class will not be mitigated by a later hatch of larvae after oil disperses below toxic levels.

2. An oil concentration of 0.2 mg/l and greater that was selected as toxic to crab and shrimp larvae is too high. Virtually all bioassay literature pertaining to Bering Sea species is based on short 96-hr exposures (Wolfe 1977; Karinen 1981). Models assumed that toxic oil concentrations would persist only one to two months, and, for such short periods, must therefore be present at relatively

high concentrations to be toxic. Based on molt frequency data of this report, decapod larvae molt every 3.5 to 4 weeks (as short as 2.5 weeks for crangonid shrimp) and thus over the duration of the hypothetical spills could be exposed 2 to 3 times during the physiologically sensitive events of ecdysis. From the perspective of relatively brief larval development time, a chronic and probably stressful exposure to oil would be one of 2 to 4 weeks duration. Given Moore and Dwyers' (1974) suggested sublethal hydrocarbon range of 1 to 100 µg/l, and Wells and Sprague’s (1976) application factor ‘f 0“03 ‘rem “50 values to “safe” concentrations, we feel that exposure of crab and shrimp larvae to WSF of oil at >50-100 µg/l (.05-.1 mg/l) for 2 to 4 weeks during a molt cycle would be toxic. The sublethal effects of such exposure could be manifested as reduced feeding, delay of molt (this results in longer development time and pelagic existence, and therefore greater susceptibility to natural mortality factors such as predation), behavioral anomalies (changes in patterns of geotaxis and phototaxis), that together synergistically reduce viability of the larvae. Obviously, models that were predicated on toxic oil levels of 200 g/1 (.2 mg/l) did not affect areas as large as those which might be polluted by concentrations 2 to 4 times lower. In this regard the models of Leendertse and Liu (1981) are probably a more accurate representation of oil transport than that of Sonntag et al. (1980). Figures 8.3 and 8.4 show results of the former simulation, and should be studied with respect to dispersion and area affected by lower toxic oil concentrations.

3. Oil was mixed to a 50-m depth in previous models (Sonntag et al. 1980) which is quite feasible but not necessary to affect crustacean larvae. Curl and Manen (1982) also discussed mixture of oil to depths of 60 m by storms as a mechanism for transport to the benthos. In the biological sections of this report (3.0-7.0) larvae of various decapod groups are shown to be distributed in the upper 60 m of water and often are most abundant in the upper 40-20 m (e.g., Tanner crab larvae). Later zoeal stages are capable of strong swimming bursts exceeding a centimeter per second. Over several days, larvae can easily move tens of meters vertically and in so doing approach or reach the surface. Megalopae of <u>Chionoecetes</u> spp., for example, were frequently caught after dark in neuston nets sampling the upper 20 cm, indicating that much of the population spends considerable time at the surface (Armstrong and Incze, unpublished data from 1981 PROBES cruise, Leg 4). Larvae of several other decapod groups studied for this report are situated high in the water column and apparently undergo diel vertical migrations (see Sections 6.0, 7.0). Thus, if spilled oil is initially mixed only to 20 m but is spread over a greater area it will still likely stress most decapod larvae of the water column as they invariably move near the surface during 10-14 days of oil residence time, but in this case the spatial effect is much greater and the population more severely impacted. To reiterate, it may not be necessary that oil is mixed much below the surface to contaminate and stress crab and shrimp larvae. Megalopae might routinely visit the surface where highest concentrations of oil would usually be found. Models should consider scenarios that spread a given volume

of oil rapidly over the surface (Leendertse and Liu 1981) and only to a depth of 20 m to derive area affected.

4. The model of Sonntag et al. (1980) did not consider any direct toxic effects of oil to benthic crab and shrimp but only indirect effects through losses of food. Curl and Manen (1982) discuss the possibility of some adult mortality in heavily impacted areas, but neither model considers toxicity of oil-contaminated sediments to developing eggs and embryos of benthic crustaceans. Armstrong et al. (1983) reviewed literature on oil impact and recovery of marine benthic communities and highlighted evidence of great perturbations to crustacean populations exposed to oil spills (Le Meal and Quillien-Monot 1981; Krebs and Burns 1978). Maurin (1981) reported that a year following the AMOCO CADIZ spill there were reduced crab catches, implying mortality of benthic stages, and fewer oviyerous female lobster suggesting effects on reproduction. We could find no literature reporting systematic studies of oil toxicity to early developmental stages of crustacean eggs, yet if hydrocarbons pass egg membranes and are sequestered in the lipid-rich yolk then the risk to rapidly cleaving embryos is probably high. Armstrong and Millemann (1974) found that embryos of the mussel *Mytilus edulis* are most sensitive to an insecticide during early cleavage stages, and they reviewed literature on protein and spindle apparatus poisons that affect both nucleic acid synthesis and normal blastomere division [it is possible that certain oil hydrocarbons act in a similar manner and Malins (1977) reviews literature on toxic derivatives of hydrocarbon metabolism that affect DNA structures and

synthesis as mutagenic/ teratogenic agents]. Eggs of fish and polychaetes absorb hydrocarbons such as naphthalene (Rossi and Anderson 1977; Eldridge et al. 1978), and Tatem (1977) showed the lethal effects of a brief 72-hr exposure of gravid female shrimp to WSF when larval hatch was subsequently reduced 80%.

The longevity of oil bound to sediments in the Bering Sea could resuit in a chronic exposure of eggs during the n-month development time for king and Tanner crab as hydrocarbons continuously desorb to interstitial and bottom water in accord with volubility, and mass balance properties. Sonntag et al. (1980) predicted that 8-16 g oil/m^2 would significantly inhibit annual benthic production. Curl and Manen (1982) discussed oil transport to the benthos via storms and fecal pellet rain, and, based on OCSEAP spill scenarios in the St. *George* Basin, predicted that 10 g/m^2 mixed 1 cm deep would result in a crude oil concentration of 3-4 ppt. Since larval stages are invariably more sensitive to pollution than are adults, we consider the same to be true of embryos, especially during chronic exposures. Therefore sediment levels of 5-10 g/m^2 (perhaps lower) could be toxic to crab and shrimp eggs over months of exposure and kill significant proportions of a following year-class as eggs, while a current year-class is killed as zoeae in the water column.

5. Both modeling efforts concluded that oil spills so severe as to eliminate an entire larval year-class would not constitute a significant effect on benthic stocks (and in turn the fishery) because longevity and fecundity of the species would mask this loss. We

strongly disagree with this hypothesis and believe that any significant reduction or a complete loss of a year-class could adversely affect the fishery 7-8 years later. As noted in Section 3.0, greater than 60% of any year's fishery may be comprised of new recruits from a single year-class. Otto et al. (1982) summarized population estimates for red king crab over the last 10 years and noted a significant decline in pre-recruit males in 1980 through 1982. Both the 1981 groundfish survey and commercial fishery have verified the existence of very weak year-classes, and the fishery in this and next year will be very poor (Section 3.0). Such reduction in commercial stocks probably results from poor survival during early life-history stages of larvae and new instars that is caused by poorly understood sources of natural mortality (exceptionally cold years of 1975-76 and excessive predatory pressures on small benthic instars are hypotheszied to be contributory causes; Section 3.0). Large-scale mortality of larvae caused by oil pollution could eventually be just as critical to the fishery as are unusually high losses due to natural causes. This would be particularly true of _C. opilio_ Tanner crab because of the apparently sporadic recruitment success of this species under natural conditions (see Section 4.0; Incze 1983; Somerton 1981). Obviously, consecutive years of oil pollution or scenarios described in Item 4 of this subsection where pelagic larvae of one year are killed and benthic eggs for the following year's hatch simultaneously poisoned, would cause even greater harm to the fishery.

One or two very weak year-classes resulting from oil pollution may have important, though unknown, ecological ramifications via impacts on epibenthic and infaunal communities. Jewett and Feder (1981) reported that commercial crabs comprise 55% and 82% of epifaunal biomass on the middle (40-100 m) and outer (>100 m) shelves, respectively. Reduction of this enormous predator/prey group by catastrophic loss of larvae could radically alter the community composition, perhaps by an increase of echinoderms (sea stars) that are also abundant. The effect of this may be to slow recovery of crab stocks faced with large populations of competitors that increase to replace one or two years of crabs lost to oil. Populations of the crab *Uca pugnax* were still adversely affected 7 years after a small oil spill at West Falmouth, Massachusetts, that reduced the overall population, lowered female to male ratios, reduced juvenile settlement, and caused heavy winter mortalities and behavioral anomalies (Krebs and Burns 1978).

8.4 Extent of Area Affected by Oil

Scenarios considered by participants of the 1981 Anchorage OCSEAP Workshop included only spills or blowouts that released 50,000 barrels which, in retrospect, is a quantity far less than might be expected from mishaps involving modern tankers. Oil spill scenarios used during the North Aleutian Shelf Synthesis meeting in Anchorage (March 1982) were even smaller for the southeastern Bering Sea. Exceedingly small spills of 10,000 barrels were modelled by Pelto (1983) and covered relatively small areas of the Bering Sea (20 km by less than 1 km). The *AMOCO CADIZ* released 223,000 mt = 2.47 x 10^6 barrels of oil (1 barrel = 35 gal; specific gravity of oil about 0.85), of which 660,000 barrels reached the coastline. The Ixtoc blowout spilled 30,000 barrels/day into the Gulf of Mexico, and the eventual 500,000 mt released (Hood and Calder 1981) was equivalent to 2.5×10^6 barrels.

Spill scenarios modeled by the 1980 Asilomar Workshop included both a 100,000 mt (= 1.11×10^6 barrels) spill over two days and a release of 5,000 ret/day (55,500 barrels) for 20 days (Sonntag et al. 1980). After mixing oil to 50 m and accounting for loss of a 25% volatile fraction, an area of 7,500 km^2 was polluted at or above 0.2 mg/l (considered a lethal threshold in that model). If as suggested in this report the same volume of oil is mixed to 20-30 m and 0.05-0.1 mg/l is considered toxic, then an area of 15,000 km^2 might be affected. Curl and Manen (1982) predicted that a 50,000 barrel spill in the St. George Basin would be lethal over a 100-300 km^2 area (0.2 mg/1 threshold; mixed to 50 m), and a more realistic spill of 500,000 barrels (half the value considered by Sonntag et al. above) would pollute an area 10 x greater. If these various scenarios are modified by mixing oil less deeply and considering oil concentrations of 0.05-.1 mg/1 WSF to be toxic, then water over an area of 10,000- 15,000 km^2 might be polluted by concentrations lethal to decapod larvae following a large spill.

Oil contamination of the benthos can also impact crab and shrimp populations by deleteriously affecting egg and embryonic development and stressing all benthic age-classes, especially very young juveniles. In the small scenario of 50,000 barrels, over 100 km^2 received oil levels of several ppt by storm mixing and fecal deposition, and hundreds of km^2

were covered by lower concentrations (Curl and Manen 1982). After larger spills of 500,000 to one million barrels, several thousand km^2 of benthos could be covered by 5-10 g oil/m^2; a level we previously suggested might be toxic to crustacean embryos during chronic exposures. Extensive coverage would be most likely and most critical nearshore in shallow water. The same magnitude of scaling up could be applied to the NAS as well, which was considered only in terms of very small, 10,000 barrel' (bbl), spills (Armstrong et al . 1983), which might cover an 8 x 20 km area with toxic oil concentrations. A large spill of 100,000-500,000 bbl north of Unimak Island, for instance, could be transported several hundred kilometers in nearshore currents to Cape Seniavin and also mixed to the benthos in these shallow waters.

8.5 Predictions of Oil Impact on Decapod Larvae

Rather than work from a specific oil scenario in this section and ask if larvae would be impacted, each major decapod group will be discussed from the vantage of how severe an oil spill must be to significantly impact a year-class. Figure 8.2 shows proposed lease sale areas of the St. George Basin and North Aleutian Shelf, and serves as reference to the following discussions.

8.5.1 Direction of Oil Transport

Physical oceanogrpahy and its relation to transport and distribution of oil in the water column was reviewed by Schumacher (1982) as part of the St. George Basin Synthesis meeting. Results of computer simulations by Leendertse and Liu (1981) were used to formulate scenarios of oil spills and direction of surface trajectories (Figs. 8.3 and

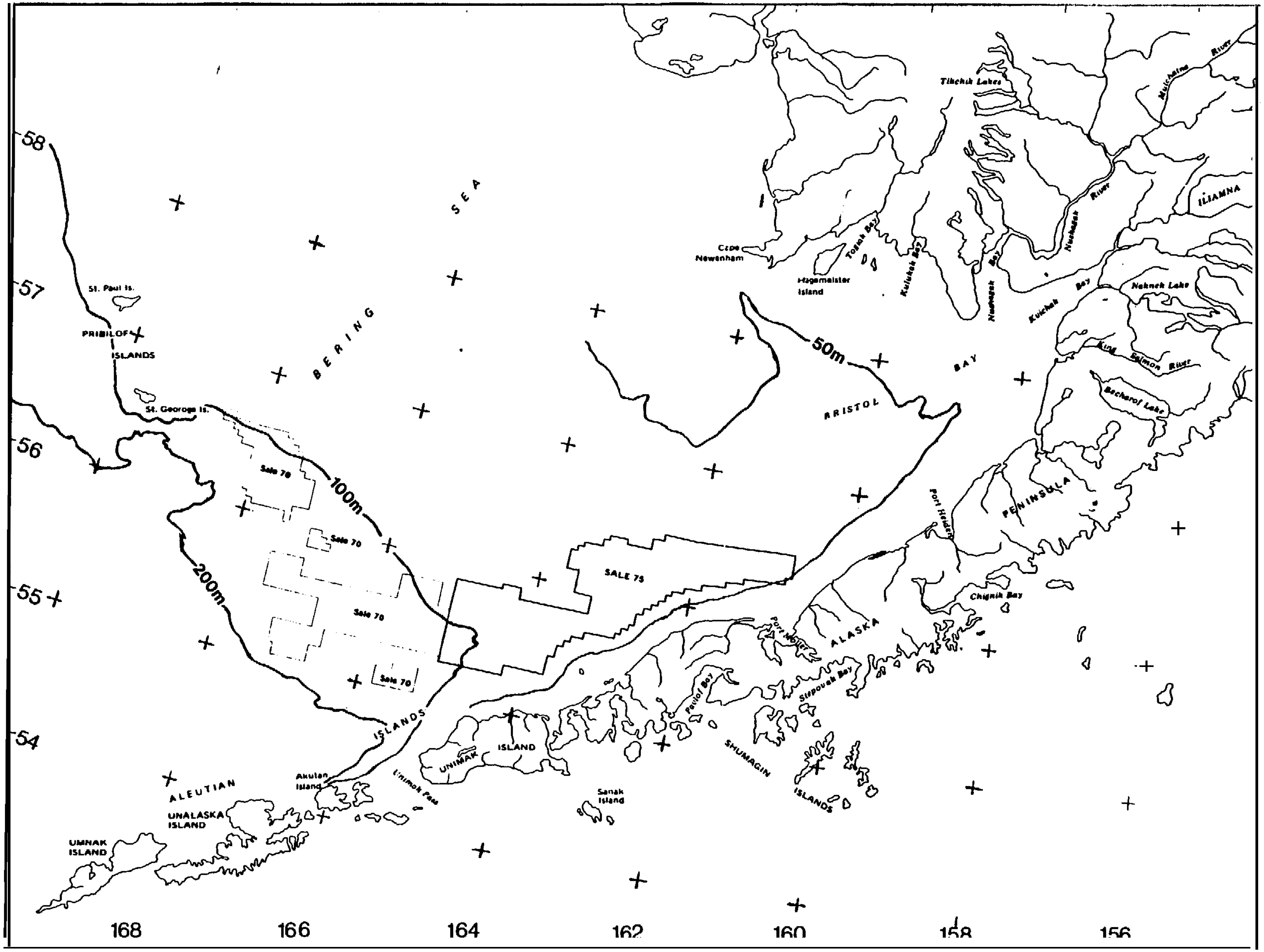


Figure 8.2 Lease sale areas in the St. George Basin between the 100 m and 200 m isobath, and along the North Aleutian Shelf.

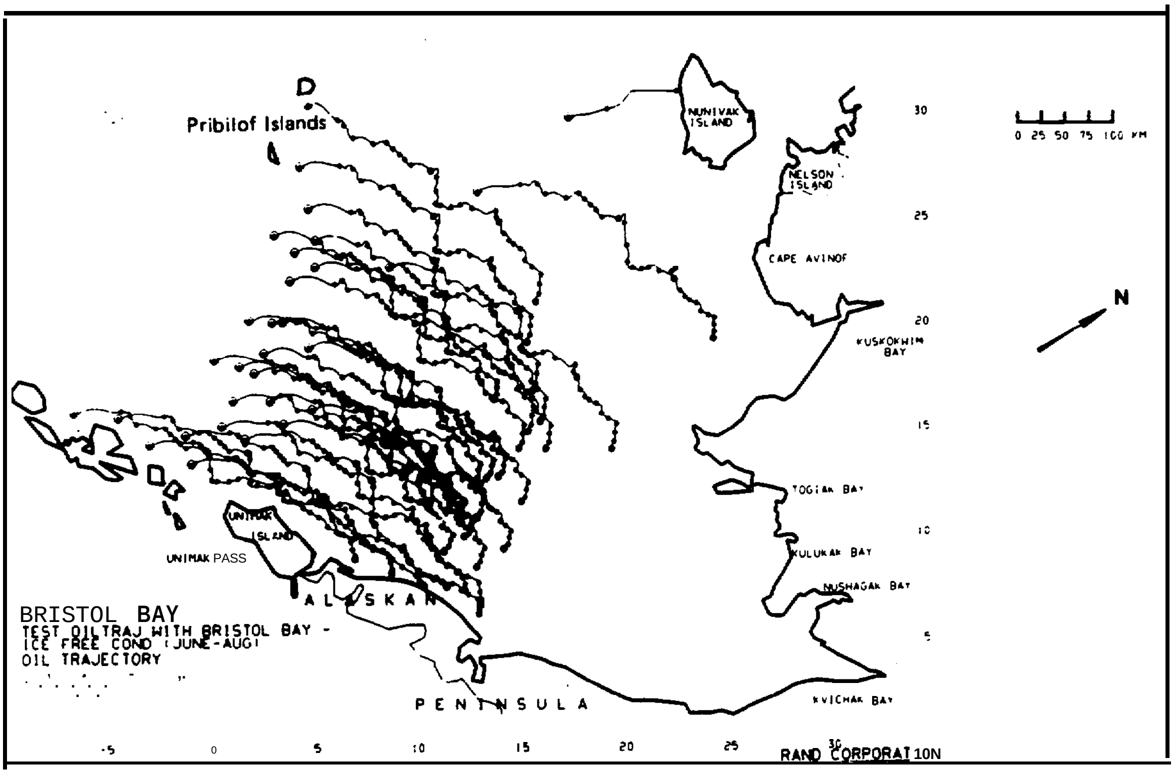


Figure 8.3 Surface oil trajectories during summer from spill points within the St. George Basin. Note easterly movement (from Leendertse and Liu 1981).

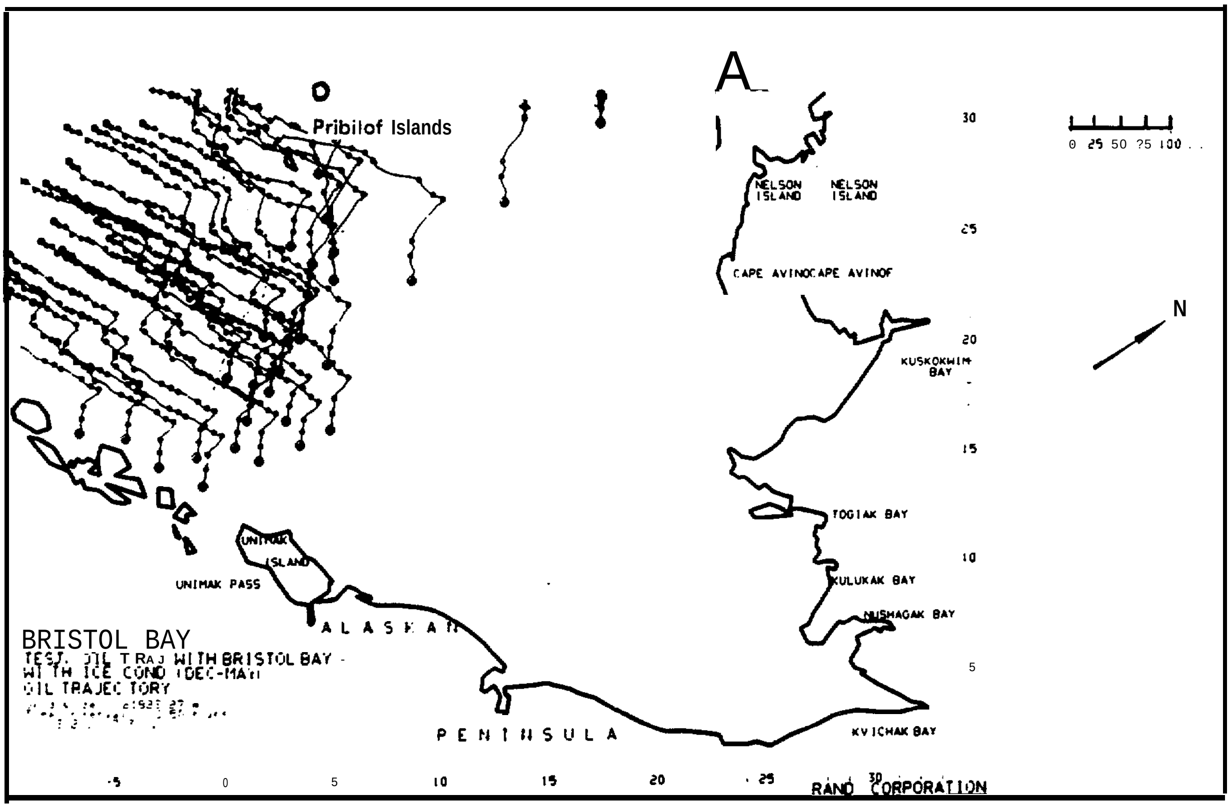


Figure 8.4 Surface oil trajectories during winter from spill points within the St. George Basin. Note westerly movements (from Leendertse and Liu 1981).

8.4). During summer and fall, oil from spills in the St. George Basin would be moved by prevailing winds east over the middle shelf and south to the North Aleutian Shelf coast at Unimak Island eastward for 200 km. In the winter, oil would be transported northwest and in both cases a spill would cover about 250 km^2 after 10 days. Most significantly, the rate of movement in summer is predicted to be about 8.5 km/day, much faster than the net current transport of crab larvae along the NAS which would be about 1.7-3.4 km/day. An oil spill in space and time that follows peak larval hatch could, theoretically, overtake a portion of the population even if initially some distance removed. However, extensive distribution of the larval population (e.g., Tanner crab) and dilution/volatilization of the oil might shield the year-class from extensive losses.

8.5.2 King Crab Larvae

As shown in Section 3.0, there are very few larvae of Paralithodes spp. over the St. *George* Basin, and consequently even an extensive oil disaster that is confined to the area between 100 m and 200 m would have no foreseeable effect on king crab populations. However, it is most probable that an enormous spill or blowout at numerous points within the lease sale area or along future tanker routes from St. George Basin, and certainly a spill along the NAS would be spread to areas critical for larval king crab development.

Blue king crab (P. platypus) and its fishery are centered about the Pribilof Islands. The Rand model of transport and fate of oil following a spill in the St. George Basin shows that winter-spring trajectories are to the west-southwest (Fig. 8.4). If a major mishap in the northern lease tract (Fig. 8.1) occurs in April or May, then oil will likely reach and surround both St. George and St. Paul Islands and affect waters in between where larvae of this species are abundant. The northern "lease area is about 125 km from St. George Island. A 50 x 150 km area of oil pollution emanating from a point around 56°45'N, 168°30'W would cover an area of 7500 km^2 (feasible in the model of Sonntag et al. 1980) including nearshore waters around the islands. In addition to killing a large percentage of the larval year-class, oil mixed to the bottom and transported to sublittoral areas around both islands could stress and kill juvenile crabs and poison eggs as previously discussed. The potential for severe decimation of blue king crab stocks by oil perturbations is high. Nearshore distribution and ecology of blue king crab is poorly understood but their dependence on the habitat must be high given the insular distribution (see results of NMFS surveys, Fig. 3.5).

Red king crab larvae (*P. camtschatica*) are distributed along the North Aleutian Shelf (see Section 3.0). Major oil spills by tankers at Unimak Pass or blowouts in southern lease-sale tracts around 55°30'N, 165°W or within the NAS lease sale area (Fig. 8.2) during summer months would result in oil being transported to king crab nursery areas according to trajectories of the Rand model for this season (Curl and Manen 1982; Armstrong et al. 1983; Fig. 8.3). The area from the west tip of Unimak Island to the eastern edge of Port Moller out to the 50-m isobath covers about 10,500 km^2. A large spill at Unimak Island could cover most of this region and, as suggested by Curl and Manen (1982) and Armstrong et al. (1983), kill virtually all of the larval year-class in this area.

More detailed station coverage of the NAS in 1982 indicates a major portion of the larval population occurs along the 50 m isobath (Section 3.0), and probably is transported by long-shore currents to the northeast as hypothesized by Hebard (1959) and Haynes (1974). Although the frontal system depicted by Kinder and Schumacher (1981a) is not as well studied along the NAS as in upper Bristol Bay, its integrity may be such to entrain subsurface oil at the front with resultant transport in the direction of larval crab movement. Cline et al. (1981) concluded from methane profiles originating from Port Moller that material rarely penetrated more than 20 km offshore and was essentially entrained shoreward of the 50 m front while moving to the northeast, thus substantiating the notion of a strong front in this region. While movement of oil as a surface film by winds results in extensive coverage within brief time periods in models of Leendertse and Liu (1981) and Pelto (1981), mixing of oil into the water column along the 50-m isobath might pose a more serious threat to red king crab larvae along the NAS for 10-20 days after a spill. It is known from work by Haynes (1974) that king crab larvae are abundant east of Port Moller up to Port Heiden and into Bristol Bay in July and August. If these larvae escape pollution then the damage done by a Unimak-Port Moller disaster might be somewhat attenuated. However, distribution and abundance of larvae east of Port Moller is poorly known and requires further study (now funded by OCSEAP in FY 83).

Large *volumes* of oil reaching shallow water of the North Aleutian Shelf would be mixed to the benthos and would directly affect *juvenile* and adult crabs, deplete food, and stress and kill developing *eggs* of gravid females. Because major populations of sexually mature females are invariably found off Unimak Island, in the area of Amak Island, and off Port Moller (based on NMFS surveys; see Section 3.0), and because extensive lagoons and estuaries support abundant bird and mammal populations as well as supply nutrients for productive nearshore pelagic and benthic communities (see discussions in Hood and Calder, Vol. 2, 1981), threats of oil pollution to the North Aleutian Shelf should be considered paramount in future research and management plans. A significant loss of any year-class should be viewed as damaging to the fishery 7-8 years later.

An important but poorly studied life history stage in the southeastern Bering Sea is newly settled juveniles up to two *years* old. Their susceptibility to oil pollution may be very high, in part, because of highly restricted distribution in critical but scarce habitat. Very young juvenile king crabs less than two years old in the Kodiak region prefer rocky, cobble habitat that affords shelter from predators (Feder et al., 1980; Jewett and Powell 1981). Very little habitat of this type exists along the NAS (Michel et al. 1982) and young-of-the-year (0+) juveniles that settle on open bottom are probably vulnerable to heavy predation (Murray Hayes, NMFS, Seattle, pers. communication). Thus any habitat that offers protection to young crabs is critical to benthic survival. During an intensive search for 0+ and 1+ juvenile king crabs along the NAS in June, August, and October 1982, the only specimens found from Unimak Island to Cape Seniavin were gathered by divers at Amak Island (trawl, video camera, and divers used to locate; Walt Pearson, Battelle Laboratory, Sequim Wa., pers. communication). Heavy oiling of the shallow sublittoral area around Amak could destroy a substantial portion of one or two juvenile king crab year-classes that metamorphosed in that area. (Distribution of small juveniles into upper Bristol Bay is currently under investigation through OCSEAP in FY 83).

8.5.3 Tanner Crab Larvae

Larvae of both C. bairdi and C. opilio are ubiquitously distributed over the St. George Basin, and C. opilio populations are also large to the north and northeast over the middle shelf (Figs. 4.10-4.15). A very large oil spill might cover 10-15% of the Basin (Sonntag et al. 1980; Manen and Curl 1981) and could have a significant impact depending on the following points:

1. Location. If a large spill was generally dispersed along 200 km of the 100-m isobath in a 50 km wide band, then the high densities of larvae associated with this depth in the years of our study (Fig. 4.7) could result in a high percentage of the year-class being affected.

2. Month. A spill that coincides with the megalops larval stage would probably be more destructive than an earlier spill when zoeae are present. Larvae of both Chionoecetes spp. are molting into the megalops stage by early July, and large numbers of megalopae may be found through September. Megalopae may spend a considerable amount

of time in the neuston layer. If their occurrence at the surface is part of a diurnal migration, then most megalopae could be expected to be exposed to surface films of oil. Further, since megalopae are the last larval stage before metamorphosis, they represent the survivors of larval development during which natural mortality has substantially reduced populations from initial densities of S1 zoeae hatched. Extensive mortality of the megalops stage could exacerbate natural mortality rates and threaten recruitment to the benthos.

3. Year. Somerton (1981) shows that C. opilio in the area of the St. George Basin have successfully recruited juveniles to benthic populations only three times in 10-11 years. If a major oil disaster occurs in what is otherwise an auspicious year for C. opilio larvae, then extensive mortality could imperil an infrequent, yet crucial year-class for this species' reproductive effort in the area of the St. George Basin.

Because of the widespread distribution of Tanner crab over the southeastern shelf, a major oil spill would be required to significantly affect a larval year-class. However, because megalopae may aggregate near the surface, a widespread spill of shallow depth could affect larvae over a very large area. Since adults of these species are primarily in water deeper than 70 m, direct impacts on adult crabs are unlikely. The results of work reported by Incze (1983) indicate that events affecting the larval stage may be responsible for much of the sporadic nature of recruitment in this species.

8.5.4 Other Brachyuran Larvae

Larvae of *Erimacrus isenbeckii* are not abundant over large areas of the St. George Basin, and highest densities were found just north of Unimak Island (Fig. 5.1). An oil mishap over the Basin proper would not threaten the species, but oil transported along the North Aleutian Shelf from Unimak Pass could impact areas of high *E. isenbeckii* abundance. Although the commercial fishery (very small at present) is centered around the Pribilof Islands, few larvae were found in that area making it difficult to equate potential loss of larvae with impact on a fishery. Ongoing OCSEAP research should help clarify *Erimacrus* susceptibility to oil around the Pribilof Islands.

Larvae of *Hyas* spp., *Oregonia* spp. and of the family Pinnotheridae are widely distributed over the St. George Basin. Any reduction in benthic populations through mortality of larvae might have some ecological repercussion (no fisheries for these groups) .--However, as noted for Tanner crab, the area affected by even a large spill might be only 10-15% of the Basin and therefore of little threat to populations of these crabs as a whole. Again, if oil from a-spill is dispersed along the 100 m isobath (roughly the middle front) for about 200 km then a greater proportion of the larval population might be killed since densities are high in this region (Section 5.0).

8.5.5 Shrimp Larvae

Larvae of *Pandalus borealis* and species of hippolytid and crangonid shrimp are ubiquitously distributed over the St. George Basin (Section 6.0). There is presently no commercial fishery for any shrimp species in this area and so deleterious effects from oil-related mortality of larvae would be ecological in nature. The combined reduction of larvae and, in turn, benthic recruitment of several major shrimp groups could impact the benthic community through predator-prey relationships discussed in Section 6.0. Again, the relatively small area of the Basin polluted by even large spills would preclude impoverishment of benthic communities to the extent various finfish and crustacean fisheries are threatened through loss of food. Nearshore surveys in 1982 along the NAS revealed very high densities of both larval and adult crangonid shrimp. Although these data have not been fully analyzed, the magnitude of populations may be such as to suggest high predator utilization of crangonids in this region by crabs and fish (Armstrong unpublished data; VTN Inc., Portland, OR, pers. communication).

8.5.6 Hermit Crab Larvae

Larvae of the family Paguridae were widely distributed over the St. George Basin and middle shelf, and higher densities were usually found east of the 100-m isobath (Section 7.0). It does not seem likely that oil would significantly impact hermit crabs as a group because of broad spatial distribution and protracted period of hatch, factors that would tend to restore larvae in oil-impacted areas after toxic concentrations had diminished.

8.6 Summary of Major Conclusions

At the conclusion of this two-year study a number of features have been elucidated regarding general biology and population dynamics of decapod larvae in the southeastern Bering Sea. Although much more research is called for on this group (OCSEAP FY 83 programs on crab biology will be very useful), several important predictions and observations pertaining to oil impact on decapod larvae in the S.E. Bering Sea can be made. These include:

1. Larvae of both red and blue king crab seem most likely to be deleteriously impacted by oil pollution because distribution is nearshore and relatively restricted over the expansive shelf. There is a high probability that significant portions of an entire year-classes could be killed by oil dispersed from a major spill, with a subsequent impact on the commercial fishery.

2. Larval Tanner crab populations could suffer extensive mortality depending on location, magnitude, season, and year of a spill as well as larval stage affected. Further modeling should be done with these species based on modified assumptions outlined in this section, particularly in regards to the last larval (megalops) stage. Many oil spills, however, might be relatively benign in their impact since these larvae are abundant over large areas of the St. George Basin and over the middle shelf near the NAS lease sales.

3. Larvae of many species of shrimp, hermit crab, and other true crabs are abundant and widely dispersed over the Basin. Most oil spills would not significantly imperil benthic populations, although the combined loss of all decapod larvae over 10-15% of the Basin could have regional consequences through impacts on predator/prey relationships in the benthic community.

4. Exposure of developing eggs and embryos of commercial crab stocks to contaminated sediments should be considered an important potential source of mortality in nearshore, nursery locations. There is no available literature on sensitivity of decapod eggs to ambient oil and research on this topic is warranted.

5. Further modeling of oil impacts to crab larvae should be done using the Leendertse and Liu and/or Sonntag models after modification of certain assumptions have been made including: a) shorter periods of hatch; b) 2-4 week molt cycles; c) greater toxicity of oil with threshold concentrations at 0.05-.1 mg/l; d) shallower mixing {20-30 m) but greater horizontal dispersion; e) stress and death of egg masses when sediment loads exceed 5-10 g/m^2; f) large spill scenarios of 5×10^5 - 1×10^6 barrels emanating from areas of the proposed lease sale near the Pribilof Islands, along the 100-m isobath, near Unimak Island, and along the NAS during April through July.

6. Significant reductions in larval populations caused by oil should be expected to adversely affect a year-class and, later, the commercial fishery when that year-class is recruited to legal size.

8.7 Research Recommendations

Areas of greatest susceptibility to oil in the southeastern Bering Sea are the Pribilof Islands and NAS which support much of the blue and red king crab populations, respectively. The following points should be given high research priorities:

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1. Impact of oil via water and sediment on egg development and embryo maturation of commercial crabs, based on both short and long-term exposures.

2* Distribution and critical habitat of blue king crab larvae, young juveniles and mature females nearshore about the Pribilof Islands.

3. Extent and timing of larval red king crab hatch in upper Bristol ‘ Bay compared to nearshore along the NAS from Unimak Island to Port Moller.

4. Area of settlement and successful juvenile development of red king crab along the NAS into Bristol Bay.

As of this writing, the latter three points are research programs sponsored by OCSEAP and scheduled for completion in summer, 1984.

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APPENDICES:

A: S.E. Bering Sea Shrimp - Species List

B: References Used for Identification of Shrimp Larvae in the S.E. Bering Sea

C: Paguridae and Lithodidae Found in the Bering Sea

D: Distinguishing Between Chionoecetes bairdi and C. Opilio Zoeae Collected in the Southeast Bering Sea

APPENDIX A: S.E. Bering Sea shrimp - Species list.

Order Decapoda
Family Pasiphaeidae
Pasiphaea pacifica

Family Pandalidae
Pandalus borealis Kroyer
Pandalus goniurus Stimpson
Pandalus montagui tridens Rathbun
Pandalus stenolepis
Pandalopsis dispar

Family Hippolytidae
Spirontocaris lamellicornis (Dana)
Spirontocaris ochotensis (Brandt)
**Spirontocaris prionota*
**Spirontocaris arcuata*
Eualus macilenta (Kroyer)
Eualus gaimardii belcheri
**Eualus fabricii*
**Eualus barbatus*
**Eualus pusiolus*
**Eualus avinus*
**Eualus townsendi*
**Lebbeus groenlandicus*
**Lebbeus grandimanus* (formerly *L. polaris*)
**Heptacarpus camtschaticus*
**Heptacarpus moseri*

Family Crangonidae
Crangon dalli Rathbun
Crangon communis Rathbun
**Crangon alaskensis*
***Sclerocrangon boreas*
Argis dentata (Rathbun)
**Argis lar*
**Argis alaskensis*
**Argis crassa*

Family Oplophoridae
**Hymenodora frontalis*
**Hymenodora facialis*

This list is based on Feder &Jewett 1980 from NMFS/NOAA 1975 and 1976 survey cruise.
*Additions to list from species ranges given by Butler 1980.
**Larvae attached to adult; not expected to appear in plankton.

APPENDIX B. References used for identification of shrimp larvae in the S.E. Bering Sea, and location of source material used by each author.

Larval Descriptions

Pandalidae

Author	Species or group, location
Berkeley, A., 1930	*Pandalopsis dispar* British Columbia
Haynes, E., 1976	*Pandalus hypsinotus* Kachemak Bay, Alaska
Haynes, E., 1978	*P. goniurus* Kachemak Bay, Alaska
Haynes, E., 1979	*P. borealis* Kachemak Bay, Alaska
Haynes, E., 1980	*P. tridens* Kachemak Bay, Alaska
Ivanov, B., 1971	*P. tridens* Kamtchatka
Kurata, H., 1964c	*P. borealis* and other pandalids Hokkaido, Japan
Needler, A. B., 1938	*P. stenolepis* British Columbia
Pike and Williamson, 1962	Pandalid sp. British Columbia
Rothlisberg, P., 1980	Pandalid sp. West Coast of U.S.A.
Williamson, D., 1967	Pandlid sp. British Columbia

Hippolytidae

Author	Species or group, location
Haynes, E., 1978b	*Lebbeus groenlandicus* Kachemak Bay, Alaska
Ivanov, B., 1971	*Eualus macilenta*, *E. barbatus*, *Spirontocaris* sp., and *L. groenlandicus* (Stage 1's) Kamtchatka Penn.
Needler, A. B., 1933	Hippolytid larvae British Columbia
Pike, R. B. and Williamson, D. I., 1960	*Spirontocaris* and related genera (includes *L. polaris* = *L. grandimanus*, L. *groenlandicus*, *E. gaimardii*, and *E. gaimardii belcheri*. *E. pusiolus*, *E. fabricii*, British Columbia

APPENDIX B. References used for identification of shrimp larvae in the S.E. Bering Sea, and location of source material used by each author. - Continued.

Larval Descriptions
Continued

Crangonidae Author	Species or group, location
Haynes, E., 1980b	*Crangon franciscorus augustimana* (Stage I) Kachemak Bay, Alaska
Kurata, H., 1964d	*Crangonidae* and *Glyphocrangonidae*, Hokkaido, Japan
Loveland, H. A., 1968	*Crangon alaskensis* San Juan Is., Washington
Makarov, R., 1966	*Crangon dalli*, *Sclerocrangon boreas*, *Argis lar*, *A. crassa*, *Paracrangon echinata* (spiny larvae)
Makarov, R., 1968	*Sclerocrangon sp*. Ochotsk Sea
Squires, H. J., 1965	*Argis dentata* N. Quebec, Ungava Bay
Williamson, D. I., 1960	Crangonid larvae North Sea, Barents Sea
Pasiphaeidae	
Elofsson, R., 1961	*Pasiphaea multidenta* and *P. tarda*, western Norway
Williamson, D. I., 1960	*P. multidentata* and *P. tarda* British Isles
Williamson, D. I., 1962	Oplophoridae and Pasiphaeidae larvae North Sea, British Isles and Barents Sea

APPENDIX C. Paguridae and Lithodidae found in the Bering Sea. (compiled from McLaughlin 1963, 1974; Pereyra et al. 1976; Federand Jewett 1980).

Family Paguridae
- *Pagurus aleuticus*
  - *beringanus*
  - *brandtii*
- P *capillatus*
  - *confragosus*
  - *cornutus*
  - *dalli*
  - *hirsutiusculus*
  - *kennerlyi*
  - *mertensii*
  - *middendorffii*
  - *ochotensis*
- *P. rathbuni*
- *P. tanneri*
- *P. townsendi*
- *P. trigonocheirus*
- *P. undosus*
- *Elassochirus cavimanus*
- *E. gilli*
- *E. tenuimanus*
- *Labidochirus splendescens*

Family Lithodidae
- *Dermaturus mandtii*
- *Haplogaster grebnitzkii*
- *Lithodes aequispina*
- *Phyllolithodes papillosus*
- *Placetron woznessenskii*
- *Pristopus verilli*
- *Sculptolithodes derjugini*
- *Paralithodes camtschatica*
- *P. platypus*

Distinguishing Between *Chionoecetes Bairdi* and C. *Opilio* Zoeae Collected in the Southeast Bering Sea

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DISTINGUISHING BETWEEN *CHIONOECETES BAIRDI* AND *C. OPILIO* ZOEAE COLLECTED IN THE S.E. BERING SEA

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ABSTRACT

Three morphological characteristics which enable separation of zoea larvae of *Chionoecetes bairdi* and *C. opilio* are discussed; two are described here for the first time. Use of all three characteristics enables species identification of most *Chionoecetes* zoeae found in plankton samples from the southeastern Bering Sea.

INTRODUCTION

Zoeae of *Chionoecetes bairdi* and *C. opilio* are morphologically very similar, being larvae of two very closely related species which apparently still interbreed in nature (Johnson 1976, Pereyra et al. 1976). Several descriptions of zoea larvae of the two species have been published: *C. bairdi* and *C. opilio* Stage I zoeae from the S.E. Bering Sea (Haynes 1973), *C. bairdi* Stage II zoeae from Cook Inlet, Alaska waters (Haynes 1981) and *C. opilio* Stage I and II zoeae from the waters of Japan (Motoh 1973, Kurata 1963[1], Kuwatani et al. 1971). Haynes (1973, 1981) compared zoeae of both species from U.S. and Japanese waters in order to define morphological characteristics which could be used to distinguish between zoeae of the two species in areas where both exist.

Based on examination in our study of several thousand zoeae of both *Chionoecetes* species from the southeastern Bering Sea (*C. opilio* and *C. bairdi*) and also specimens from the western Beaufort Sea (*C. opilio*) and the Gulf of Alaska (*C. bairdi*), we have found that: (1) the principal criterion employed by Haynes in papers describing the morphological differences between zoeae of *C. opilio* from Japan and *C. bairdi* from U.S. waters (Haynes 1981) is more useful than the criteria he employed earlier to describe differences between Stage I zoeae of- these two species from the southeastern **Bering Sea,** but (2) additional characteristics are necessary for distinguishing between the species because of variability in the diagnostic length relationships recommended. In this paper we compare our findings from plankton samples (mostly from the southeastern Bering Sea) with Haynes' findings (Haynes 1973, 1981) and describe two additional characteristics of the zoeae which extend Haynes' (1981) diagnosis of species differences.

Plankton samples from the southeastern Bering Sea are those of Incze et al. (this volume). Samples from Kodiak Is., Alaska were provided to us by A.J. Paul, Institute of Marine Science, University of Alaska, Seward; Lower Cook Inlet, Alaska samples were provided by Dr. T.S. English, School of Oceanography, University of Washington, Seattle; and western Beaufort Sea samples were provided by Dr. R. Homer, Seattle. Specimens were initially preserved in 3-4% buffered formalin and later transferred to 70% ethanol: water with glycerin.

DISTINGUISHING BETWEEN C. *BAIRDI* AND C. *OPILIO*

Observations on Length of Posterior Lateral Spine

Haynes (1973) described morphological features of Stage I zoeae of *C. bairdi* and *C. opilio* hatched from ovigerous females collected in the southeastern Bering Sea. Although the larvae described in his study were very similar, Haynes felt that they could be distinguished on the basis of subtle morphological differences:

> "Stage I zoeae [of the two species] are identical except for a few subtle differences in abdominal morphology. The most obvious difference is in the length of the posterior lateral spines on the third and fourth abdominal segments. In C. *bairdi*, the spines overlap the adjacent segments by about one-third the length of the spines. In C. *opilio*, the spines on the third segment barely extend past the posterior margin of the fourth segment, and those on the fourth segment do not quite reach the posterior margin of the fifth segment."

However, relative length of the posterior lateral spine (PLS) of specimens collected in this study usually did not provide clear evidence of the species according to the criteria outlined above. From **examination of several thousand specimens it** has become clear that a wide range of PLS lengths exist.

Measurements were made of PLS length relative to the posterior margin of abdominal segments for C. *bairdi* and C. *opilio* from Haynes' (1973) published figures to assist us in comparing Haynes' criteria with the measurements made of zoeae collected in our study. From Haynes' figures the following were calculated: (1) the percent of the third abdominal PLS that extends past the posterior margin of the fourth abdominal segment and (2) the percent of the fourth abdominal segment PLS that extends past, or doesn't quite reach, the posterior margin of the fifth abdominal segment. Our measurements made of Haynes' figures are shown in Fig. 1. Similar measurements were made on a number of Stage I zoeae of C. *bairdi* obtained from two sources: ovigerous females collected off Kodiak Is., Alaska and plankton samples collected in Lower Cook Inlet, Alaska (C. *opilio* has never been reported from these areas) . The posterior lateral spines on either side of an abdomen of these zoeae frequently differed in length, as they did in Haynes' (1973) figures. In all cases illustrated in Fig. 1, the measurement of the longer spine was used when the PLS passed the posterior margin of the following segment and the shorter was used when the PLS did not reach this margin. Still, it can be seen (Fig. 1) that the relationships of PLS length to the margin of the following segment in known C. *bairdi* zoeae can vary substantially and can be quite similar to relationships illustrated for C. *opilio* by Haynes (1973). For *Chionoecetes* spp. collected from the plankton of the southeast Bering Sea, where both species exist, the relative lengths of the PLS show a continuum of values which make it virtually impossible to separate zoeae in all but extreme cases.

Further Observations on Abdominal Morphology

Haynes (1973) also observed that Stage I zoeae of C. *opilio* from Japanese waters described by Kurata (1963) primarily differed from his Stage I zoeae in the length of the curved lateral processes on the third abdominal segment. In a subsequent paper, Haynes (1981) compared both stages of C. *opilio*, which he had obtained from Japan, with corresponding stages of C. *bairdi* from Alaska waters, and on the basis of these later observations he concluded:

> "For both stages, zoeae of C. *bairdi* are morphologically identical with zoeae of C. *opilio* from Hokkaido and the Sea of Japan, except for the length of the curved lateral Processes on the third abdominal somite. In Stage I and II zoeae of C. *opilio* from Hokkaido and the Sea of Japan,

> the--curved lateral processes reach the posterior margin of the third abdominal somite, but in Stage I and II zoeae of *C. bairdi*, they are markedly shorter."

Haynes' later paper thus emphasized the use of the curved lateral process on the third abdominal segment [the length of which was previously described for *C. opilio* by Kurata (1963)1 as a principal diagnostic feature for distinguishing between both zoeal stages of the two species: one from the eastern Pacific (C. *bairdi*) and one from the western Pacific (C. *opilio*). However, Haynes (1981) acknowledged:

> "Stage II zoea of C. *opilio* from the eastern Pacific Ocean have not been identified, and it is not known if they can be distinguished from Stage II zoeae of *C. bairdi* by the length of their lateral Processes."

Therefore, it remained unknown at that time how well these observations would apply to specimens collected in the southeastern Bering Sea.

Using the relationship of the length of lateral process on the third abdominal segment to the posterior margin of that segment (Haynes 1981), we were able to separate numerous *Chionoecetes* zoeae from the southeast Bering Sea into two groups, presumably corresponding to the two species of interest. In many instances, then, the relationship recommended by Haynes (1981) appears applicable when specimens of C. *opilio* are from the eastern Pacific, as well. However, we have found considerable variability in the relative length of the lateral process and it frequently is not possible to distinguish between the two species using this character alone. Specifically, the more slender, longer processes do not always reach the posterior margin of the segment, yet they clearly differ in shape and length from the shorter processes on other zoeae. We searched for additional characteristics in specimens from the clearly separated zoeal groups (using the above lateral process criterion of Haynes) to see if other morphological features could be used to distinguish between the two species when the lateral process length relationship did not clearly indicate one species or the other. Two additional characteristics have proven helpful in this respect: (1) length from the distal end of the rostral spine to the distal end of the dorsal spine and (2) the shape and relative length of the carapace lateral spines. These characteristics are described in the following section.

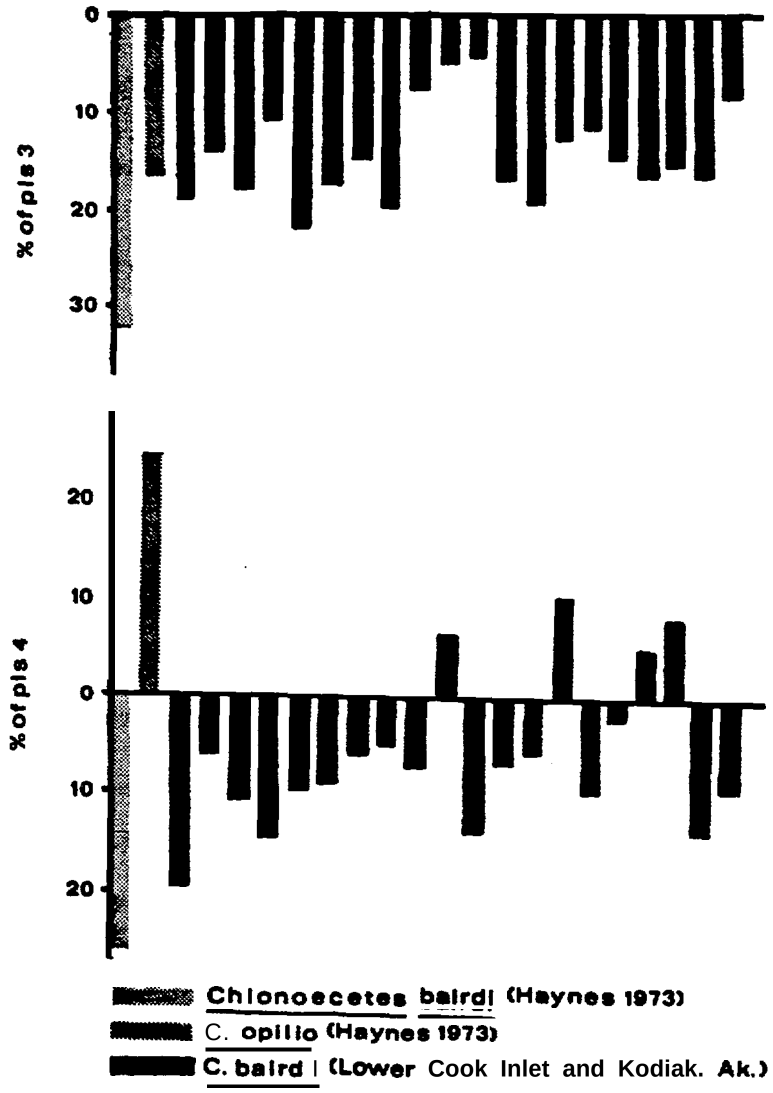

Figure 1. Comparison of PLS length in specimens illustrated by Haynes (1973) and in specimens examined in this study. Figure illustrates: (1) percent of the length of the third abdominal segment PLS that extends past the posterior margin of the fourth abdominal segment (upper chart); (2) percent of the length of the fourth abdominal segment PLS that extends past (downward in this figure) or does not quite reach (upward in this figure) the posterior margin of the fifth abdominal segment (lower graph).

Additional Morphological Features Useful in Species Identification

Measurements of length from the tip of the rostral spine to the tip of the dorsal spine (rostral-dorsal length = RDL) of Stage I and II zoeae from the southeastern Bering Sea with longer lateral processes [hereafter referred to as knobs, after Kurata (1963)] were always in the range of RDL values given by Motoh (1973, 1976) and Kurata (1963, 1969) for C. *opilio* from Japan (Table 1). That is, specimens diagnosed as C. *opilio* according to Haynes' (1981) lateral process (knob) criterion always had RDL measurements greater than or equal to 4.5 mm. Haynes (1973, 1981) did not specify a difference in RDL measurements between the two species. Those *Chionoecetes* zoeae collected from the southeast Bering Sea which had shorter knobs had RDLs in the range given by Haynes (1973, 1981) for C. *bairdi*, i.e. less than 4.6 mm for Stage I and less than 6.4 mm for Stage II. In addition, we also found that Stage II zoeae with shorter knobs had shorter RDLs than those reported by Haynes (Table 1). Measurements of these RDLs ranged from 5.5- 5.9S mm. We thus found a consistent relationship of RDL to knob length in specimens for both groups of zoeae: those with obviously short and those with obviously long knobs (lateral processes).

The zoeae from the southeast Bering Sea that constitute these two categories also differed from each other in the shape and length of their carapace lateral spines (CLS). The CLS of zoeae with long knobs appeared straight, while the CLS of zoeae with short knobs appeared to droop downward (centrally). As a general rule, the straighter CLS were shorter relative to the zoea's RDL, whereas the drooping CLS were longer relative to the RDL. These characteristics in addition to the one proposed by Haynes (1981) were used in our study to distinguish between zoeae of *Chionoecetes* spp. and are summarized in Table 2.

When these characteristics were used, most zoeae of *Chionoecetes* spp. from shelf waters of the southeastern Bering Sea could be tentatively identified as C. *bairdi* and C. *opilio*. This included the numerous specimens in which the knob length relationship did not provide conclusive evidence for species identification. Our identifications were then ‘tested” against data from plankton studies and information on the distribution and relative abundance of adults of the two species.

Table 1. Rostral-dorsal lengths of *Chionoecetes bairdi* and C. *opilio* Stage I and II zoeae tabulated from the current literature.

	C. opilio Kurata (1963,1969)	*C. opilio* Motoh (1973,1976)	*C. bairdi* Haynes (1973,1981)
Stage I	4.5 - 4.9 mm	4.8 - 5.4 mm	3.96 - 4.55 mm
Stage II	6.0 - 6.9 mm	6.2 - 7.1 mm	5.95 - 6.37 mm

Table 2. Summary of diagnostic features used to identify Stage I and II zoeae of C. *bairdi* and C. *opilio* collected in plankton samples from the southeast Bering Sea: Knob (curved lateral process), RDL (rostral - dorsal length) and CLS (carapace lateral spines) (see text for details).

		C. bairdi	*C. opilio*
Knob		**Shorter**	**Longer**
RDL	Stage I	3.96 - 4.55 mm	4.5 - 5.4 mm
	Stage II	5.50 - 6.37 mm	6.0 - 7.1 mm
CLS		**Generally long and drooping ventrally**	**Generally short and straight**

APPLICATION OF FINDINGS TO FIELD STUDIES

Certain aspects of the timing of appearance of the larvae in the plankton and spatial patterns of distribution and abundance provided evidence needed to corroborate the species identifications we had made using the above characteristics to extend Haynes' (1981) description. The larvae with the longer RDL and shorter, straighter CLS were found in the plankton earlier in the season than the larvae of opposite characteristics (see Incze et al., this volume). This was consistent with information provided to us by D. Somerton (see D. Somerton's larval paper, this volume), namely, that the state of maturation of egg masses of female Tanner crabs observed during National Marine Fisheries Service surveys in the area indicated that C. *opilio* hatched earlier than C. *bairdi*. The larval species description was further substantiated by specimens collected in areas where the bottom crab fauna was clearly dominated by one species or the other. Finally, areas of the Bering Sea which contained zoeae of only one description during a sampling season eventually gave rise to megalops larvae which were identified to species according to Jewett and Haight (1977); the megalops identifications confirmed our zoea identifications. All the above lines of evidence were in agreement with our zoea species identifications from four years of plankton samples.

Some *Chionoecetes* zoeae from the southeastern Bering Sea could not be categorized by the criteria described above. The RDL of these zoeae, found in water shallower than 200 m, often was in the area of range overlap of RDL for *C. opilio* and *C.bairdi* (Table 1); the knob character was often intermediate; and the CLS character occasionally did not match the knobs even when the latter were distinct. For these specimens, which were not abundant, no species designation could be made. It is possible that these were F_1 progeny of inter-specific matings between C. *opilio* and C. *bairdi*, but it would not be possible to determine this with morphological evidence alone. Since the relationship of genetic phenotype dominance among the various characters is unknown, it is also possible that F_1 progeny were included in one or the other (or both) of the species groups we have established above. Because the degree of inter-specific breeding is unknown, the extent of this error cannot be estimated.

Some plankton samples collected from regions overlying the continental slope contained zoeae which did not conform in appearance to any of the zoeae described above (*C.bairdi*, C. *opilio* or the unidentified *Chionoecetes* zoeae found over the shelf). These may have been the larvae of deeper dwelling species of *Chionoecetes*. As in the case of the shallower unknown zoeae, however, such specimens were not numerous.

We also compared our diagnostic features to zoeae from other areas. C. *bairdi* zoeae from Lower Cook Inlet, Alaska and Kodiak Is., Alaska exhibited all three characteristics listed in Table 2 for C. *bairdi* Stage I zoeae. Stage II *C.bairdi* which we obtained from plankton samples collected from Lower Cook Inlet, Alaska also exhibited all three of the characteristics listed in Table 2 for that stage. C. *opilio* zoeae (only 10 obtained) from the western Beaufort Sea (where *C.bairdi* does not occur) exhibited all the characteristics listed in Table 2 for C. *opilio* Stage I and II zoeae. We thus feel that the additional species characters described in this paper have general applicability to the species descriptions. In our study we found it necessary to use these characters in addition to the diagnostic feature suggested by Haynes (1981) to distinguish between zoeal larvae of C. *bairdi* and C. *opilio*.

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FOOTNOTES

1. **Kurata** (1963) described Stage I and II **zoeae** of what he called C. *opilioelongatus* based upon **Rathbun's** (1924) designation of the subspecies. According to references cited by Haynes (1981) the sub-specific designation is not warranted, therefore, we have used the species designation C. *opilio* for zoeae described by Kurata.