COASTAL FISHERIES OCEANOGRAPHY OF THE SOUTHERN BERING SEA AND NORTH ALEUTIAN BASIN: HABITAT REQUIREMENTS OF RED KING CRAB LARVAE AND JUVENILES

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PREFACE

Fluctuations in adult king crab populations have been monitored for many years, and the data has been used extensively for management purposes. Stocks of sub-adults have declined and recruitment from juveniles to commercial-sized adults has been low. However, the causes of interannual variability in stock abundance observed are unknown at present.

Many basic biological requirements of king crabs (particularly of larvae and juveniles) are unknown; knowing some of these requirements may be necessary for understanding recruitment success. Changes in ocean temperature and currents have been proposed as mechanisms to explain unsuccessful recruitment of larvae and localization of some crab populations (Armstrong 1983; Armstrong et al. 1983; Hayes 1983; McMurray et al. 1984). The ability of king crab larvae to position themselves in the water column is not known; however, by controlling vertical position in response to environmental stimuli such as light, temperature, salinity and currents, larvae may be able to optimize water conditions and feeding, and minimize predation. Water currents are instrumental in distributing larvae of many crab species to nursery areas where proper habitat and food availability enhance survival and growth of young-of-the-year (YOY) crabs.

The roles of habitat and diet in relation to molting success of juvenile red king crabs have not been defined, but are thought to be critical for growth and for protection from each other and other predators. King crabs less than 2 years old are extremely

prone to cannibalism in the laboratory while molting, and require protection from each other (Nakanishi 1987). YOY crabs have characteristically been found in the field in association with kelp patches, attached invertebrate fauna, fibrous epifaunal cover and rock niches (Sundberg and Clausen 1977; McMurray et al. 1984; Pearson and Woodruff 1984) and on open cobble beaches (Personal observations). The importance of habitat type and density of crabs within a habitat area may change with age. Older (2-3 yr.) juveniles crabs form large, mobile aggregations presumably for protection from predators (Powell and Nickerson 1965). King crabs are omnivorous and juveniles forage in search of food (Wallace et al 1949). The kind of prey consumed varies by area, depth, season and size of the crab (Takeuchi 1962; Jewett and Feder 1982). Effects of limitations in variety of natural foods is not known, nor is the optimal diet for growth and successful molting for juvenile king crabs in the laboratory.

There were two major parts to this project - one covering larval red king crabs and the other, early juveniles. In Part I, optimum salinity-temperature combinations for larval survival and larval ability for vertical positioning in the water column were determined, and response patterns obtained in the lab compared to larvae collected at depths in the field. In Part II, habitat preference and the effect of cohort density and cover on cannibalism by juvenile crabs, and the effects of different diets on growth and molting success in juveniles were determined. Optimum salinity for growth and molting in juvenile red king crabs, another objective of this project, is scheduled for completion in 1988.

PART I. LARVAL STUDIES

OBJECTIVE 1. Determine the optimum salinity-temperature combinations for survival of larval red king crabs.

Introduction

Natural fluctuations in ocean temperature and salinity may have a large influence on larval survival and may affect year class strength either directly by mortality or by affecting length of the planktonic larval period. In some areas, king crab larvae are distributed immediately adjacent to pronounced thermoclines and haloclines (Shirley and Shirley, unpublished). Synergistic interactions between temperature and salinity tolerances, most probably occur. That is, the stress of exposure to the sub-optimal range of temperature should limit the ability of larvae to survive in the sub-optimal range of salinity and vice versa. The survival of zoeae in a matrix of temperatures and salinities coupled with behavioral responses of zoeae exposed to gradients of temperature and salinity (see Objective 2, this report) should provide insights into the temperature and salinity tolerances and preferences of king crab larvae in naturally occurring populations.

Methods

Ovigerous red king crabs, Paralithodes camtschatica, were maintained at 4 to 5 ^{o}C in the laboratory until hatching occurred.

Twenty stage 1 zoeae (2 d old) were placed in covered 100 ml glass vessels containing natural, filtered seawater (32 ppt) diluted with distilled water to salinities of 10, 15, 20, 25 and 30 ppt . Three replicates of each of the five salinity treatments were placed in temperature-controlled water baths of 0, 3, 6, 9, 12, 15, 18, 21, 24 and 27 ^{o}C, requiring a total of 3000 zoeae per experiment. Zoeae were fed concentrated, live Artemia nauplii every 24 h. Salinity, temperature and dissolved oxygen were monitored. At 24, 48, 72 and 96 h, the number of surviving zoeae and the number of molts were recorded. Dead zoeae were removed. The experiment was repeated for 20 d old stage 2 zoeae. Results presented are cumulative over 96 h.

Results

Survival of zoeae over 96 h in 50 combinations of temperature and salinity was significantly affected by temperature, salinity and zoeal stage (ANOVA, $P<0.001$). Stage 1 zoeae had high percentages of survival ($\geq$ 85%) at temperatures from 0 to 12 ^{o}C and salinities of 20 to 30 ppt (Fig. 1A). Survival at 15 ^{o}C was also high, 88%, at 25 and 30 ppt. At temperatures of 21 ^{o}C above, no larvae survived. At salinities $\leq$ 15 ppt, survival was poor with only 50% of zoeae at 15 ppt surviving at 0, 3 and 6 ^{o}C. At high salinities, zoeae tolerated a high temperature of 15 ^{o}C, while at low temperatures (0 and 3 ^{o}C) zoeae tolearated a low salinity of 15 ppt.

Stage 1 zoeae molted at temperatures of 12 to 18 ^{o}C and salinities of 20 to 30 ppt with the highest percentage of molts, 53%,

occurring at 15 °C and 30 ppt (Fig. 1B). At 18 °C and 25 ppt, 34% molted, but only 7% of the zoeae in that temperature/salinity combination survived.

Stage 2 zoeae exhibited the highest percent survival at temperatures of 0 to 6 °C and salinities of 20 to 30 ppt (Fig. 1C). The decline in survival at temperatures of 12 °C and above was more pronounced in stage 2 zoeae than in stage 1 zoeae.

The percentage of stage 2 zoeae molting during 96 h was higher than stage 1 zoeae at temperatures of 3 to 18 °C and salinities of 15 to 30 ppt (Fig. 1D). The highest percent molting, 76%, occurred at 9 °C at 30 ppt, with 84% survival for all zoeae in that temperature/salinity combination.

Discussion

Stage 1 zoeae survived 96 h within a range of temperatures and salinities normally encountered in the field. Ocean temperatures in nursery grounds for red king crabs in Alaska range from -1.8 to 14 °C annually. Salinities range from 15 ppt at the surface during the summer to full strength seawater at depth in Auke Bay, Alaska (Shirley and Coyle 1986). In a similar study, 100% survival of combined stage 1 and 2 zoeae after 48 h occurred at temperatures of -1.8 to 13 °C and salinities above 20 ppt (Nakanishi 1987). Although freshwater run-off and meltwater create lenses of dilute seawater at the surface during the summer months, salinities below 5 m usually exceed 20 ppt (Shirley and Coyle 1986). In a vertical profile of the water column, king crab

zoeae rarely inhabit depths less than 10 m and display a sinking behavior in response to dilute seawater in a salinity gradient (see Objective 2, this report).

Stage 2 zoeae had lower 96 h survival at temperatures above 3 °C and below 25 ppt compared to stage 1 zoeae, and greatly reduced survival at temperatures above 6 °C. The differences in survival may be attributable to decreased temperature/salinity tolerance with ontogeny, or to the age of the zoeae in relation to the time of their next ecdysis. The intermolt period for zoeae in the laboratory at 4 to 5 °C was 14 d. The stage 1 zoeae used in the temperature/salinity tolerance study were 2 d old, or 12 d from molting. Stage 2 zoeae were 20 d old or 8 d from molting to stage 3 zoeae. In the laboratory, molting zoeae sink to the bottom of the rearing tank where they remain for several hours, and are vulnerable to predation by other zoeae.

A higher percentage of stage 2 than stage 1 zoeae molted during the 96 h period. Reduced survival of stage 2 zoeae may have been a result of the higher natural mortality associated with molting combined with tolerance limits for survival at temperatures and salinities outside of the optimal range.

Additional studies with later zoeal stages will provide more insight into ontogenetic changes in temperature and salinity tolerance of larval red king crab.

OBJECTIVE 2. Determine the ability of larval king crabs to vertically position themselves in the water column and compare response patterns to larvae collected at depths in the field.

Introduction

Vertical positioning may be an important behavioral mechanism for maximizing growth and survival of planktonic larval king crabs. Many planktonic crustaceans are known to migrate vertically in response to currents, prey fields, light, barometric pressure, gravity and temperature (Bigford 1977; Jacoby 1982; Orsi; Forward 1987). Some species of crab larvae migrate vertically to utilize tidal currents for transport (Epifanio et al. 1984; Wooldridge and Erasmus 1980; Orsi 1986; Shanks 1986). Changes in larval photoresponses may be responsible for natural patterns of diurnal vertical migrations (Jacoby 1982; Cronin and Forward 1986; Marsden 1986; Forward 1987). The extent of or stimulus for vertical movement of king crab larvae is unknown.

The objectives of this study were to determine the responses of king crab zoeae to stimuli and current conditions encountered during their planktonic period, and to assess the ability of larvae to select an optimum habitat for survival and growth. Behavioral responses to gravity, horizontal water currents and different intensities and wavelengths of light were measured, as were zoeal swimming and sinking rates. The effects of larval stage, age and nutritional condition on

the behavioral responses and on swimming and sinking rates were examined. The vertical distribution of king crab larvae over 24 h was determined in the laboratory and in the field.

Methods

Day-old larvae hatched in the laboratory were transferred to 40 l culture tanks supplied with unfiltered, flowing seawater at a rate of 650 $ml \cdot min^{-1}$. Zoeae were fed live *Artemia* nauplii twice daily, and plankton was available as supplemental food in the incoming seawater. Water temperatures in the culture tanks ranged from 4.2 °C in early April to 5.8 °C in early June. Zoeae were reared in a natural photoperiod which varied from 13 h light:11 h dark in early April to 18 h light:6 h dark in early June.

All experiments were conducted in a refrigerated environmental room with the room temperature set to the seawater temperature in the larval culture tanks. The phototaxis, geotaxis, swimming, sinking and preference studies were conducted in 2 m long plexiglas columns (inside diameter 32 mm) which could be oriented horizontally or vertically. The columns were capped at both ends and equipped with an entry port in the middle, and a sealed glass tube was inserted into one end to permit introduction of light into the column. The length of the column was marked at 20 cm intervals. Columns were filled with filtered, natural seawater saturated with oxygen and cooled to the environmental room temperature.

Phototaxis

A fiber optic illuminator with a 150 watt type EK quartz-halogen lamp was used as the light source for all experiments. Light intensity was varied from 1.3 x 10^{11} to 5.1 x 10^{15} $q \cdot cm^{-2} \cdot s^{-1}$ using a rheostat and neutral density filters. Intensities were measured in seawater-filled columns at 1 m distance from the source with a quantum scalar irradiance meter in units of $quanta \cdot cm^{-2} \cdot s^{-1}$. The wavelength of light was altered with red (Kodak #25), green (Kodak #58) and blue (Kodak #47A) gelatin filters with dominant wavelengths of 617, 532 and 478 nm, respectively. Light levels in the field were measured twice a week at the sea surface and at 2, 4, 6, 8, 10, 15, 20, 25 and 30 m depth in Auke Bay for comparison to experimental intensities. Additionally, light intensity was continuously recorded at 10 m depth throughout the larval period by another research group working in Auke Bay (D. Ziemann, Oceanic Institute, personal communication).

Twenty zoeae were introduced into a horizontal column through the entry port and their positions in the column were recorded. The room lights were turned off and a light source at one end of the column was turned on. The positions of the zoeae were recorded at 10 min intervals. No zoeae were used more than once for each test. Phototaxis was positive if significant zoeal movement occurred in the direction of the light stimulus, and negative if zoeae moved away from the light.

Geotaxis

Three tests were conducted to determine geotaxic response. Columns were positioned vertically and zoeae were introduced into the top of the column. Zoeal position was recorded after 10 min in total darkness, after 10 min with the overhead room lights as the only light stimulus (5.0×10^{14} $q \cdot cm^{-2} \cdot s^{-1}$, and after 10 min with the fiber optic light positioned at the base of the column. Geotaxis was positive if zoeae moved toward the floor.

Swimming and Sinking Rates

Horizontal and vertical swimming speeds of zoeae were measured in response to white light (5.1×10^{15} $q \cdot cm^{-2} \cdot s^{-1}$). The time required for individual zoeae to swim 20 cm without turning or stopping was measured. Upward swimming was measured by introducing zoeae to the center of the column via a 1 m tube and placing the light stimulus at the top of the column. Zoeae were introduced into the top of the column and the light was positioned at the middle of the column to measure downward vertical swimming speed.

Sinking rates of non-narcotized zoeae and zoeae narcotized with tricaine methanesulfonate (MS-222) were measured in vertical columns with overhead room lights as the only light source. Non-narcotized zoeae were induced to sink by placing them in vertical columns filled with low salinity (20-23 ppt) water. Sinking rates were measured after an initial descent of 20 cm as the time required to sink 20 cm without swimming or stopping.

Temperature and Salinity Preference

Cold temperature gradients were established by placing one end (20 cm) of a column into a bath of ice, seawater and rock salt. Both horizontal and vertical gradients were tested. Temperature was monitored through ports located every 10 cm along the length of the column. The temperature ranged from -1.8 to 6.7 ^{o}C over 2 m. A total of 33 stage 1 zoeae were tested in two trials. Zoeae were inserted into the center of the column where the temperature approximated the larval rearing temperature. After 30 min, the position of the zoeae was recorded with the corresponding temperature for that position in the gradient. Zoeal response in a vertical cold temperature gradient was also tested by inserting 20 zoeae into the top of a column containing a gradient of -1.5 to 7.0 ^{o}C.

Zoeal response in a warm temperature gradient (6.6 to 12.6 ^{o}C was measured in horizontal columns. Forty stage 1 zoeae were placed in the center of the column, and position and temperature were recorded after 30 min.

Salinity gradients were made by slowly layering waters of different salinities into a vertical column using a peristaltic pump, with the denser, higher salinity waters near the bottom of the column and lower salinity waters near the top. Before and after each experiment, water samples were withdrawn through ports in the column wall with a syringe, and the salinities were verified with a vapor pressure osmometer. The salinity range in the gradient was 18 to 30.2 ppt.

Twenty stage 1 zoeae were introduced into the top of each of two columns containing the salinity gradient. The position of the zoeae in the column was recorded at 10 min intervals for 30 min. The salinity preference test was repeated with 41 stage 2 zoeae.

Starvation Studies

Day-old stage 1 zoeae were placed in filtered seawater in 1.0 l flasks with gentle aeration and were not fed. Water was changed every 2 d and debris and dead zoeae were removed. Phototaxis, swimming and sinking rates and salinity preference of zoeae that had been starved for 4, 6 and 8 d were measured.

Rheotaxis

Rheotaxic responses of individual zoeae were measured within a glass tube (inside diameter 1 cm) connected in series with two-way valves, Tygon tubing and a pump to form a closed system of circulating water of known velocity (Fig. 2). By opening and closing valves in sequence, water and zoeae could be introduced and removed from the system while maintaining the water volume without introducing air into the system.

A peristaltic pump equipped with a flow integrator to minimize pulsation was used to generate horizontal water currents of 0.47 to 2.59 $cm \cdot s^{-1}$. Current speeds were calculated from the volume of water moved through the system ($ml \cdot min^{-1}$) and the cross-sectional area of the glass tube using Bernoulli's equation. Overhead room lights provided uniform lighting of 5.1×10^{15} $q \cdot cm^{-2} \cdot s^{-1}$.

Rheotaxis was positive if zoeae were aligned in the direction of the current flow. The ability of zoeae to maintain position or swim against currents of different velocities for 30 s was tested. If zoeae were unable to maintain position and were swept along with the current the swimming response to the current velocity was negative. Periods of 30 s with no water current were alternated between tests of current velocities. The velocity at which a negative response occurred was tested twice before terminating the experiment.

Diel Vertical Distribution of Larvae

Vertical position of stage 1 and 2 zoeae was measured in the laboratory over 24 h in four vertical columns. Twenty zoeae were introduced into the top of each column at 1800 h. Forty stage 1 and 40 stage 2 zoeae were tested. All lights were turned off at 2400 h and turned on at 0800 h the following day. Columns were sealed in black plastic during the dark hours of the experiment. At 4 h intervals, the positions of the zoeae were recorded.

To monitor vertical position of king crab larvae in the water column, plankton samples were collected with triplicate horizontal tows of an opening/closing 1.0 m^2 NIO net (0.505 mm mesh) at the surface, 5, 10, 15, 20 and 30 m depths at 4 h intervals on 22-23 May 1987 in Auke Bay. Volume of water filtered with each tow was estimated using a digital flowmeter. Samples were preserved immediately in 5% formalin. King crab larvae were counted and identified to stage using the criteria of Sato and Tanaka (1949). Densities of larvae at each depth were calculated as number·100 m^{-3}.

Results

Phototaxis

In darkness, there was no significant movement of zoeae in any direction. Stage 1 and 2 zoeae were positively phototaxic to white light at intensities of 5.1×10^{12} $q \cdot cm^{-2} \cdot s^{-1}$ and greater (Fig. 3), with the magnitude of the phototaxic response directly related to light intensity. Negative phototaxis occurred at intensities of 1.0×10^{12} $q \cdot cm^{-2} \cdot s^{-1}$. The threshold intensity for phototaxis of king crab zoeae, the stimulus intensity that induced no directional movement of zoeae, was 1.6×10^{12} $q \cdot cm^{-2} \cdot s^{-1}$. The phototaxic response of stage 1 zoeae was stronger than that of stage 2 zoeae at the same stimulus intensity.

Zoeae were also phototaxic to red, green and blue light. The threshold intensity for red light was 3.2×10^{13} $q \cdot cm^{-2} \cdot s^{-1}$, an order of magnitude higher than the threshold for white light. Negative phototaxis also occurred to stimuli below the threshold intensity for red light.

Geotaxis

When stage 1 zoeae were introduced into the top of a vertical column in the dark, a significant downward movement of zoeae occurred ($P<0.01$), although 75% of the zoeae remained within the upper one-third of the column. When zoeae were introduced into a vertical column with the light positioned at the base of the column, all of the zoeae moved to the bottom 20 cm of the column. Geotaxis of stage 1 king crab zoeae

was negative, but phototaxis prevailed when the position of the light stimulus was coincident with the direction of the gravitational force.

Swimming Speeds

In a horizontal column with a light source at one end, king crab zoeae swam toward the light along the upper edge of the column with the telson towards the stimulus and the dorsal side down.

Stage 1 zoeae <4 d old swam significantly faster horizontally, 2.41 $\pm$ 0.07 $cm \cdot s^{-1}$, than zoeae $\geq$4 d old, 1.70 $\pm$ 0.10 $cm \cdot s^{-1}$ ($P<0.05$, Fig. 4). Stage 2 zoeae did not swim significantly faster than $\geq$4 d stage 1 zoeae, and swimming speed did not change with age of stage 2 zoeae.

Zoeae swam straight up or in an upward spiral along the inner wall of a vertical column with the telson toward the light stimulus. Vertical swimming speed averaged 1.57 $\pm$ 0.06 $cm \cdot s^{-1}$ and was not significantly different between zoeal stages 1, 2 and 3 (Fig. 5). In a downward direction, the vertical swimming speed of stage 1 zoeae, 1.25 $\pm$ 0.12 $cm \cdot s^{-1}$, was significantly lower than the upward vertical swimming speed ($P<0.05$).

Sinking Rates

As a non-narcotized zoea was introduced into low salinity water, it flicked its telson vigorously several times, then curled its abdomen over the anterior end and sank with its dorsal side down. Sinking rates did not change from stage 1 (0.75 $\pm$ 0.02 $cm \cdot s^{-1}$) to stage 2

zoeae (0.72 ± 0.02 $cm \cdot s^{-1}$). No differences in sinking rates were observed between narcotized and non-narcotized zoeae.

Temperature and Salinity Preference

No significant movement of zoeae in any direction occurred in any of the temperature gradients.

In a salinity gradient, zoeae sank through the low salinity water in the upper part of the column until reaching higher salinities, where zoeae resumed and maintained posture and orientation at the preferred salinity. Stage 1 zoeae preferred a salinity of 27.5 ppt which was significantly lower ($P<0.01$) than the preferred salinity of stage 2 zoeae, 29.4 ppt.

Starvation Effects

A decrease in phototaxic response to white light (5.1×10^{15} $q \cdot cm^{-2} \cdot s^{-1}$) resulted from starvation of stage 1 zoeae. After 4 d of starvation, zoeae were positively phototaxic but the response was significantly less than that of fed zoeae ($P<0.05$).

Horizontal swimming speed of stage 1 zoeae was significantly lower ($P<0.05$) after 4 d of starvation (Fig. 6). After 8 d of starvation, zoeae did not swim horizontally in response to a white light stimulus. Vertical swimming speed was significantly reduced ($P<0.01$) to 0.78 ± 0.15 $cm \cdot s^{-1}$ after 8 d starvation.

Zoeal sinking rates were reduced after 8 d of starvation to 0.67 ± 0.02 $cm \cdot s^{-1}$ ($P<0.05$).

The preferred salinity of stage 1 zoeae starved for 6 d was not significantly different from that of fed zoeae. After 8 d of starvation, however, the preferred salinity, 29.4 ppt, was significantly higher than that of fed zoeae ($P<0.01$).

Rheotaxis

Stage 2 zoeae were positively rheotaxic and maintained position or swam against horizontal water currents with speeds up to 0.94 ± 0.11 $cm \cdot s^{-1}$ (Fig. 7). Twenty-four percent of the zoeae maintained positions at a maximum current speed of 0.47 $cm \cdot s^{-1}$, 43% at 0.68 $cm \cdot s^{-1}$, 28% at 1.53 $cm \cdot s^{-1}$ and 5% at 2.16 $cm \cdot s^{-1}$. The mean current speed at which zoeae no longer maintained position was 1.44 ± 0.11 $cm \cdot s^{-1}$. Zoeae failed to maintain position or swim against current speeds significantly ($P<0.01$) lower than the mean horizontal swimming speed of stage 2 zoeae, 1.81 ± 0.07 $cm \cdot s^{-1}$.

Vertical Distribution of Larvae

In the laboratory study, stage 1 and 2 zoeae remained at the top of the column until the room lights were turned off at 2400 h. At 0400 h, the zoeae had descended to the lower one-third of the column (Fig. 8). At 0800 h, the lights were turned on and the zoeae began a small ascent, but remained at about the mid-point of the column for the duration of the study.

In the field study, a pattern of diel vertical migration was evident for king crab larvae. During the daylight hours, 0800 h to 2000 h, zoeae were concentrated at 5 m, except at 1200 h when the

larvae moved to 10 m (Fig. 9). The highest density of larvae (all stages combined), 106·100 m^{-3}, occurred at 10 m at 1200 h. At 2400 h, most of the king crab larvae had descended in the water column to depths greater than 30 m, our maximum sampling depth. The maximum density of larvae at 2400 h at 30 m was 7.59·100 m^{-3}. Very few larvae were present in any of the surface samples. All four zoeal zoeal stages and the glaucothoe were present in the plankton samples, and exhibited similar vertical migration patterns.

Enumeration of king crab larvae has been completed on two of the three replicates. In addition, all other major plankton groups have been counted in two replicates for analysis of potential prey items and predators of larval king crabs.

Discussion

King crab zoeae exhibited a spectral sensitivity as well as a sensitivity to the intensity of the light stimuli. The zoeae had a greater range of spectral sensitivity than has been reported for many zooplankters. Photoresponses to red light are not common in brachyuran crab larvae, but have been reported in some anomuran larvae (Pagurus spp., Forward 1987). The enhanced spectral sensitivity may not be important during the larval phase, as the longer wavelengths are not usually encountered at depths greater than 10 m in moderately turbid coastal waters (Saffo 1987). However, juvenile king crabs have been found in shallow tide pools or aerially exposed intertidally, subjecting them to full spectrum light.

Negative phototaxis of crustacean larvae in response to low light intensities has been explained as a shadow response for predator avoidance or as a mediator of diel vertical migration (Forward 1974). The latter hypothesis seems applicable to king crab larvae which undergo a reverse diel vertical migration, rising to the surface after sunrise and descending to depths below 30 m after sunset. Most planktonic crustaceans, including zoeae of anomuran crabs, are reported to rise to shallow waters at night and descend to deeper waters during the day.

Negative phototaxis has been observed in brachyuran crab larvae in response to high light intensities (Herrnkind 1968; Forward 1974). King crab larvae were photopositive to the maximum intensities tested in the laboratory, but surface levels of irradiance in the field often exceed the intensities tested in the laboratory. The maximum light intensity in the field would be expected to occur at 1200 h, the time that king crab larvae made a descent from 5 to 10 m, suggesting possible negative phototaxis to high intensities of light. Overall, the photoresponses of king crab larvae are consistent with the vertical migration patterns of larvae observed both in the lab and field over 24 h.

The swimming and sinking rates of zoeae measured in the laboratory were of sufficient velocities to account for the degree of vertical migration observed in the field over time, and were within the range reported for other decapod crustacean larvae (reviewed by Chia et al. 1984).

Although king crab zoeae were positively rheotactic, only a small percentage of stage 2 zoeae maintained position in current velocities equal to or greater than the mean horizontal swimming speed. Currents near Auke Bay have been measured from 0.8 to 31.2 $cm \cdot s^{-1}$ from April through June at depths to 20 m (NOAA Southeast Alaska Circulation Survey 1984). Zoeae would be able to control horizontal position only against the minimum velocity currents by swimming. Horizontal swimming may be more important for zoeal feeding and predator avoidance than for determining direction or degree of larval transport. Vertical swimming may be used by the larvae to move into or out of horizontal currents to affect advective processes.

Zoeae were able to detect salinity and avoid low salinities by sinking through a vertical gradient. Interestingly, zoeae opted for the slower mode of sinking rather than faster, downward swimming to avoid low salinities. Sinking may be energy conservative during the stress of exposure to a hyposaline environment or the response may have been due to the shock of exposure to low salinity. A salinity profile of Auke Bay showed that the hyposaline lens at the surface reduces the salinity of the upper 5 m, but at depths greater than 5 m, the salinity is 20 ppt or greater (Shirley and Coyle 1986). The zoeal sinking response to low salinity water is consistent with the absence of king crab larvae in the upper 5 m of the water column, in Auke Bay where reduced salinities were present during field sampling.

Zoeae failed to respond to temperature gradients either because of an inability to detect temperature gradients or because survival was

not negatively affected by the range of temperatures in the gradient. At temperatures from 0 to 12 °C (and salinities of 20 to 30 ppt), king crab zoeae had high rates of survival for 96 h (see Objective 1, this report).

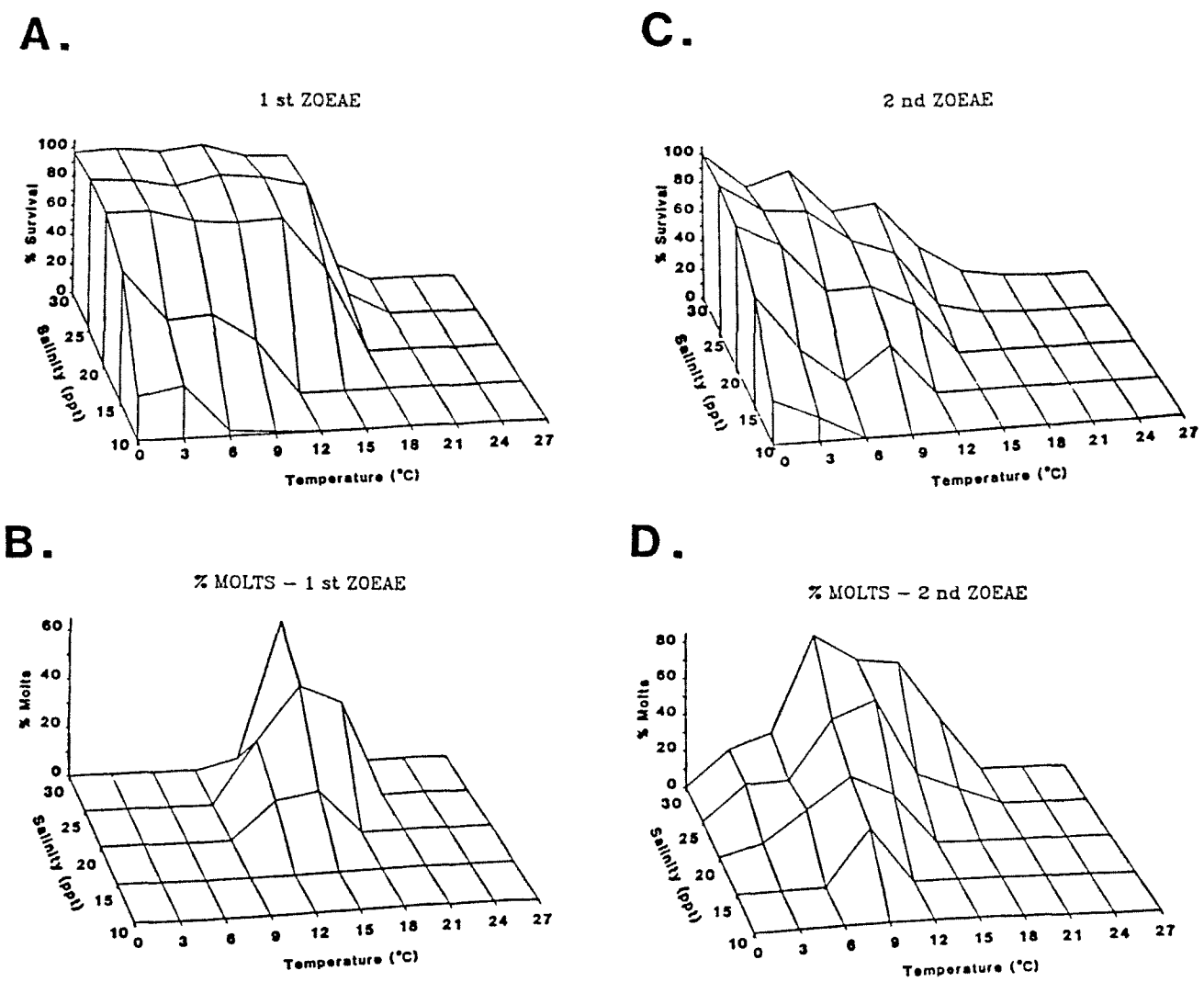

Figure 1.—Percent survival of stage 1 (A) and stage 2 (C) red king crab zoeae after 96 hr in a matrix of temperature and salinity combinations and the percentage of stage 1 (B) and stage 2 (D) zoeae that molted during the 96 hr temperature/ salinity tolerance study.

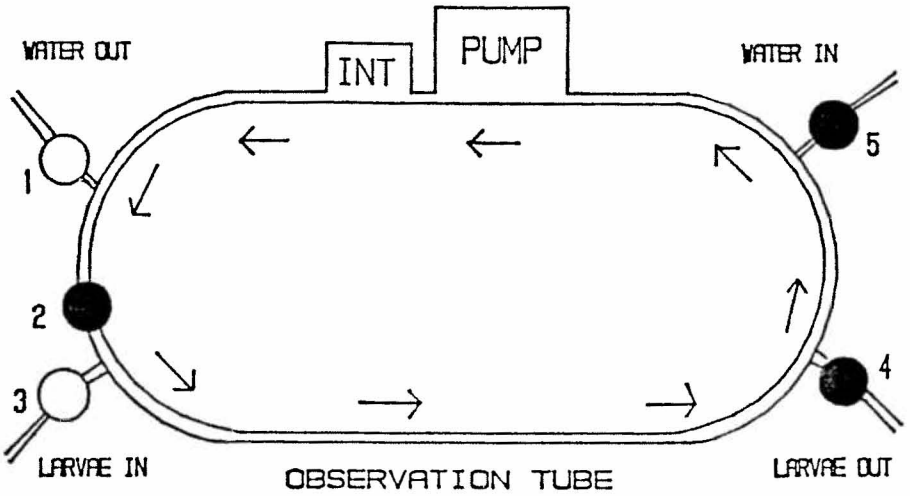

Figure 2.--Apparatus for measuring rheotaxis and ability of king crab zoeae to swim against currents. Currents were generated with a peristaltic pump equipped with a flow integrator (INT). Larvae and water were introduced to and removed from the system by a series of 2-way valves (1-5).

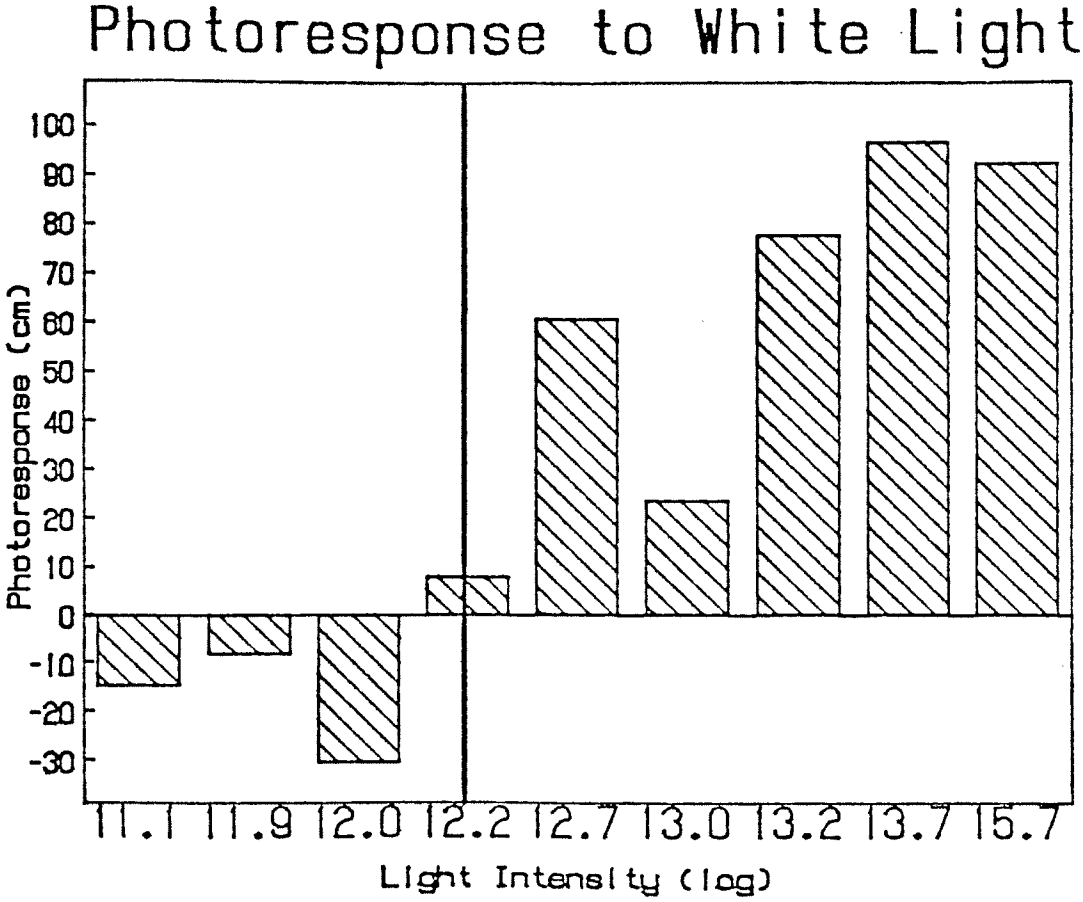

Figure 3.--Phototaxic responses of stage 1 king crab zoeae to different intensities of white light. Response was measured as the distance (cm) zoeae moved toward or away from the stimulus. Light intensities ranged from the logarithm of 1.3×10^{11} to 5.1×10^{15} quanta$\cdot cm^{-2} \cdot s^{-1}$. The vertical line represents the threshold intensity for phototaxis of king crab zoeae.

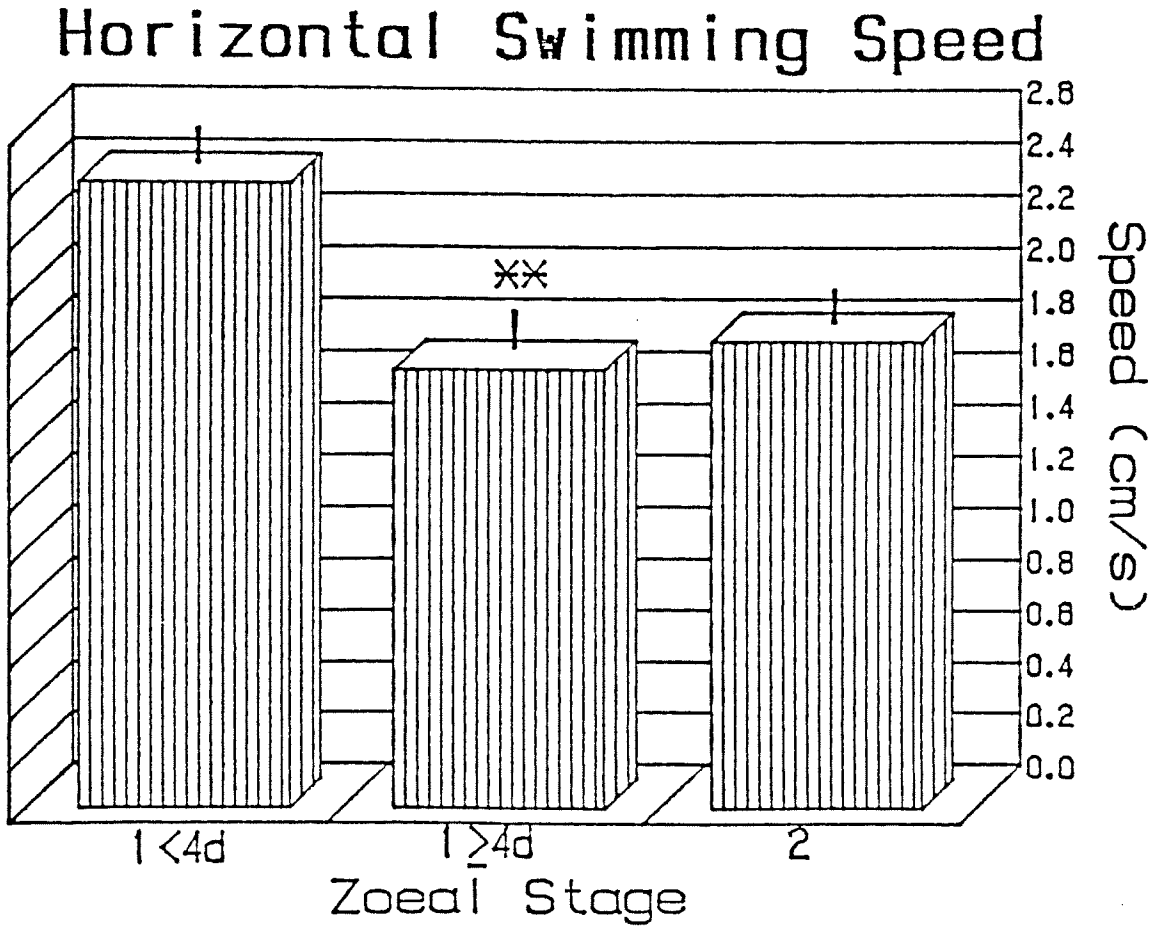

Figure 4.--Horizontal swimming speeds ($cm \cdot s^{-1}$) of stage 1 zoeae less than 4 days old, stage 1 zoeae 4 days old or older and stage 2 zoeae of red king crabs. Histobars represent means $\pm$ 1 S.E. (**=P<0.01).

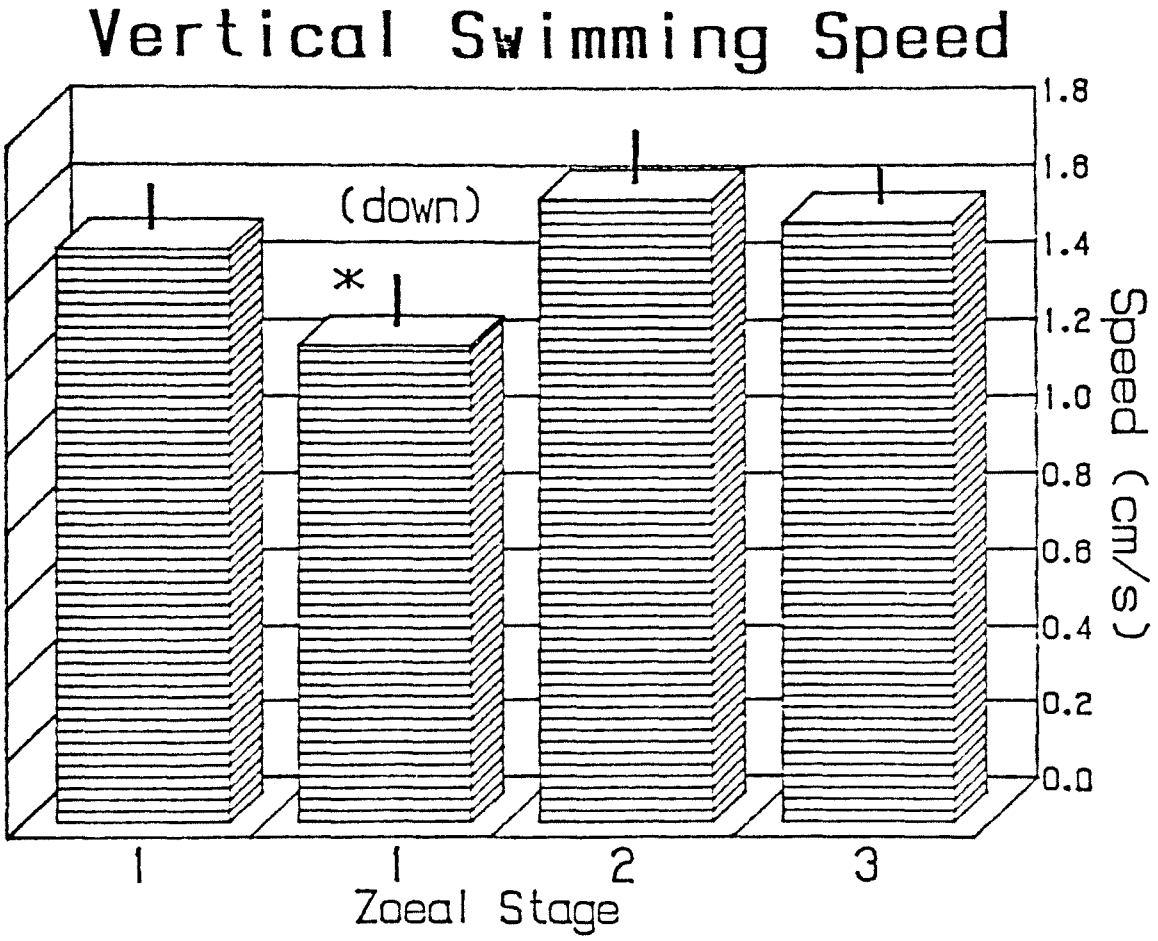

Figure 5.--Upward vertical swimming speed ($cm \cdot s^{-1}$) of stage 1, 2 and 3 king crab zoeae, and downward swimming speed of stage 1 zoeae. Histobars represent means ± 1 S.E. (*=$P<0.05$).

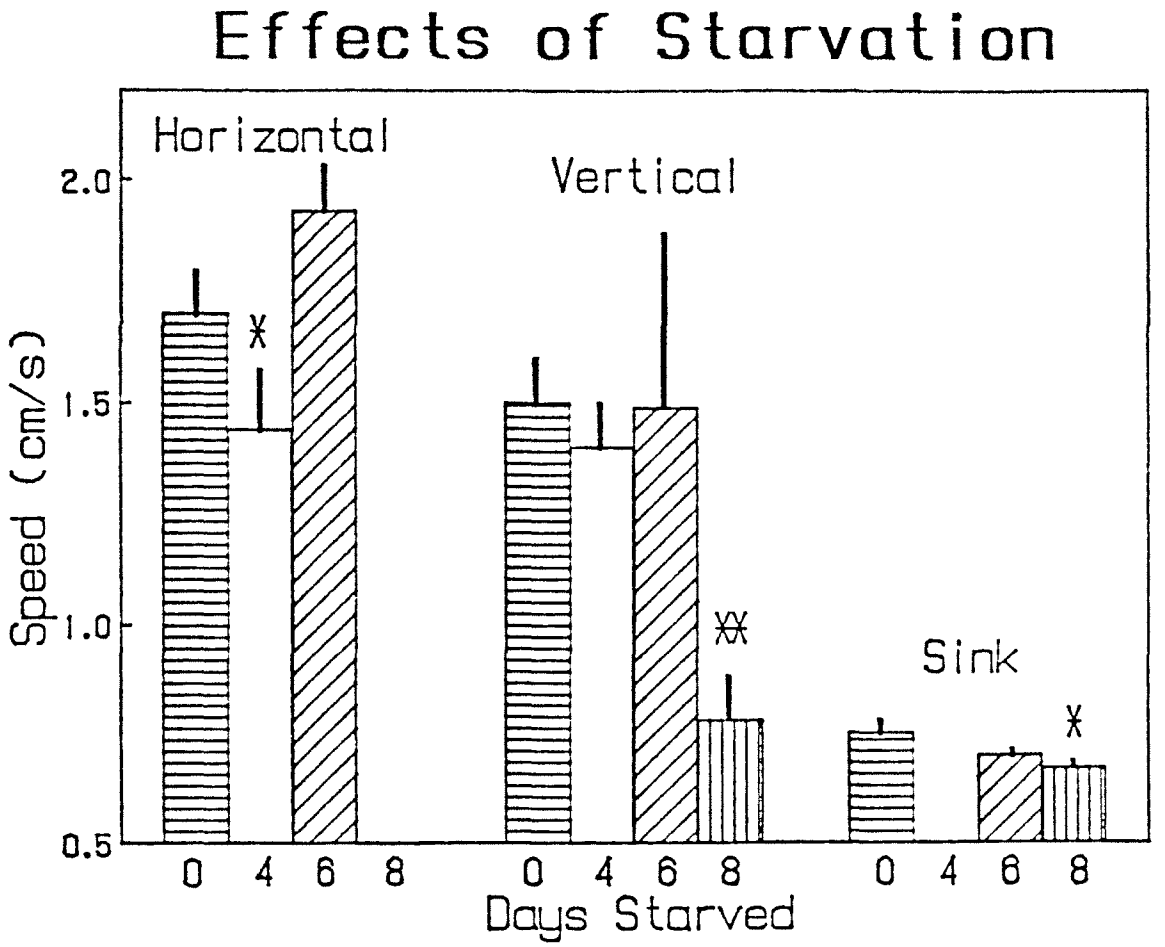

Figure 6.--Horizontal and vertical swimming speeds and sinking rates of stage 1 zoeae starved for 0, 4, 6 and 8 days. Histobars represent means ± 1 S.E. (*=P<0.05, **=P<0.01). No sinking data was collected for zoeae starved for 4 days.

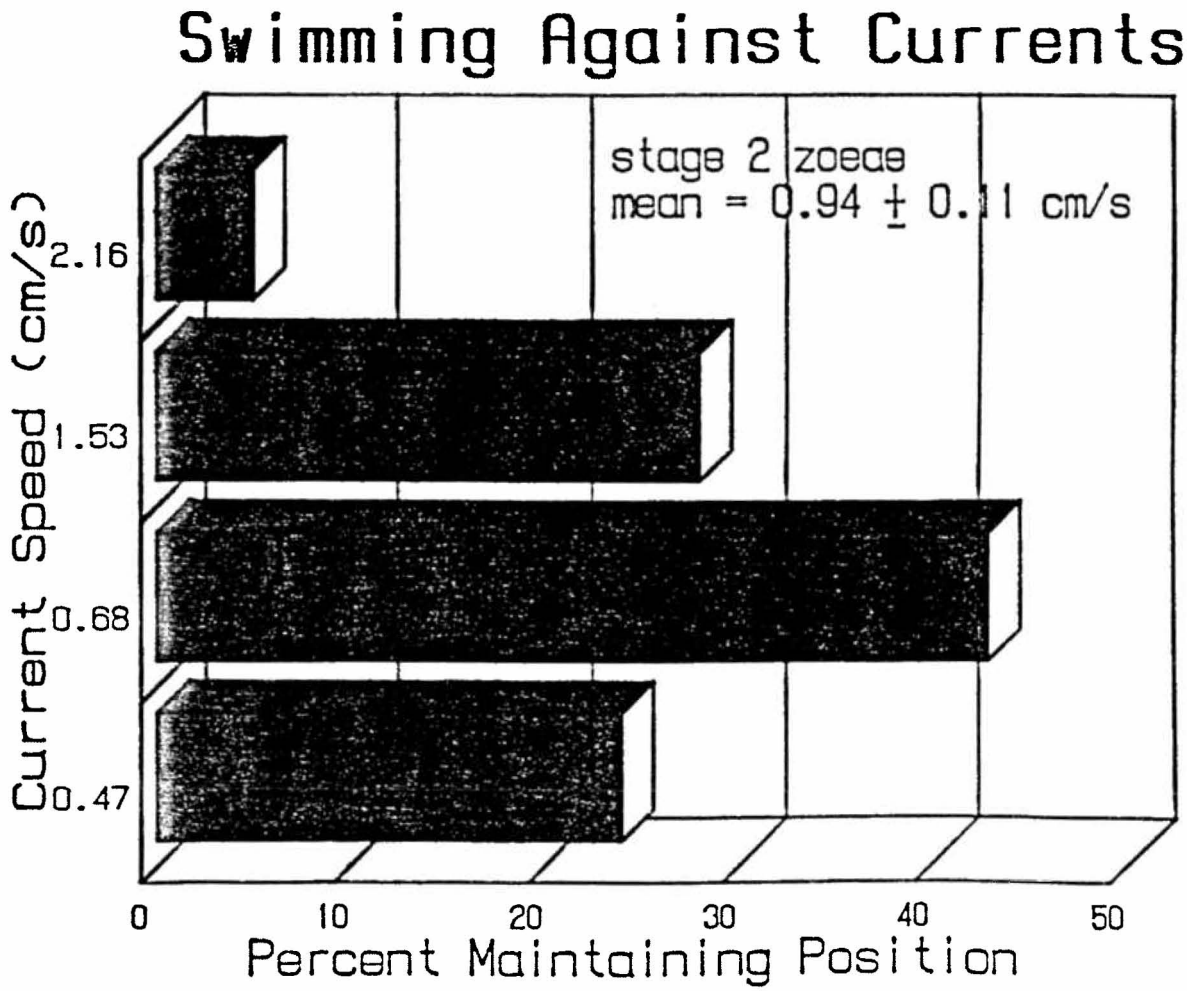

Figure 7.--Ability of stage 2 king crab zoeae to swim against current velocities of 0.47 to 2.16 $cm \cdot s^{-1}$. Histobars represent percentages of 21 zoeae that could maintain position or swim against different velocity currents.

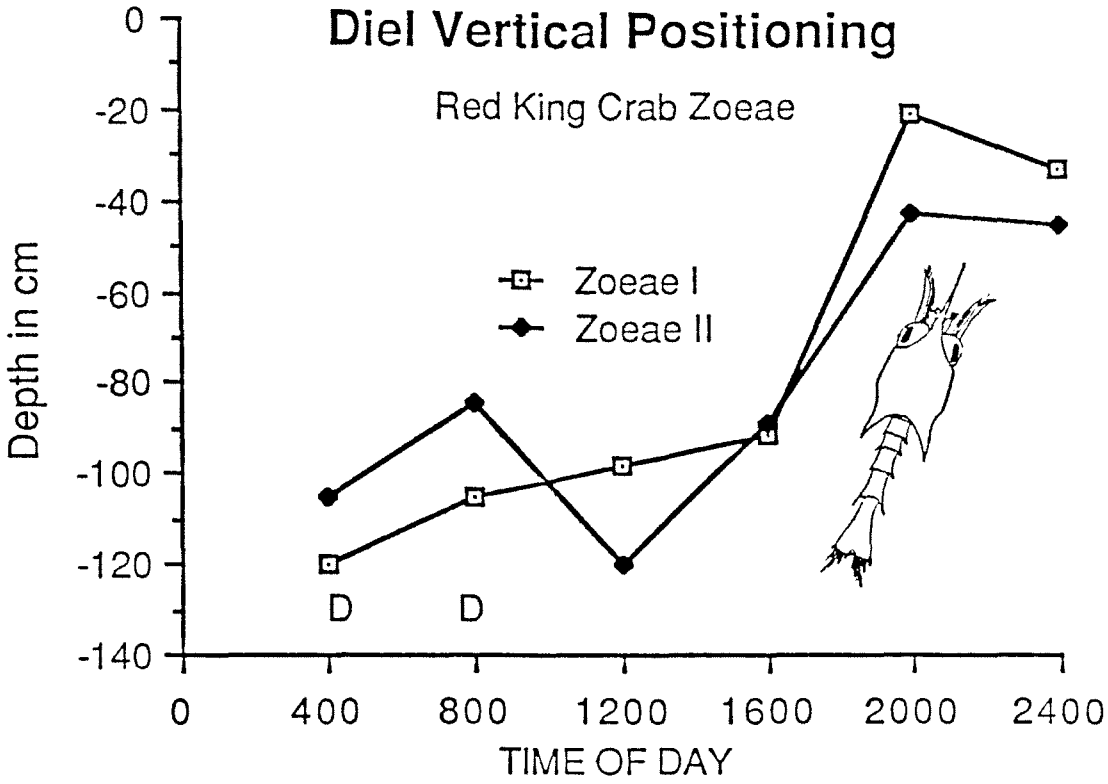

Figure 8.--Laboratory measurements of vertical positioning of stage 1 and 2 king crab zoeae in a 2 m column over 24 h. Data points represent the mean column position (cm) or depth of 40 zoeae. Times of day when zoeae were exposed to darkness are indicated by D.

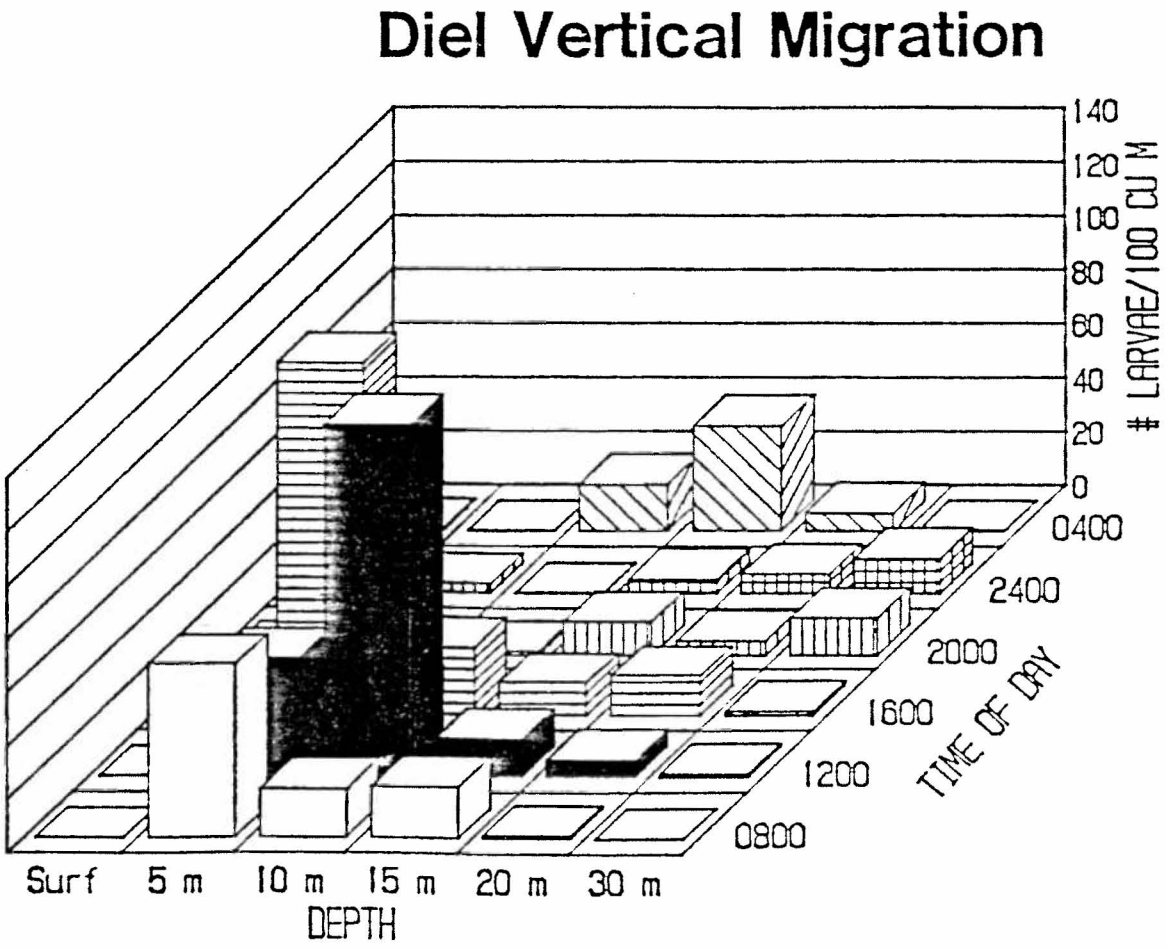

Figure 9.--Mean densities (per 100 m^{-3}) of king crab larvae (all stages combined) at six depths over 24 h in Auke Bay, Alaska, on 22 May 1987. Data are presented as the means of two replicate plankton samples taken at each depth/time combination.

PART II. JUVENILE STUDIES

OBJECTIVE 3. Determine the optimum salinity for growth and molting in juvenile (YOY and 2-3 year) red king crabs.

Introduction

YOY king crabs probably tolerate a wider range of salinities than do 2-3 year old crabs. YOY crabs are frequently found in the lower intertidal zone where they are exposed to low salinity waters while 2-3 year and older king crabs are found in subtidal areas. Adults are never found in the intertidal zone, and are known to be vulnerable to low salinities.

This study will examine the short term tolerance of three life stages to low salinity waters, and the long term growth and molting success of juvenile crabs at reduced salinities.

Methods

An acute 72h salinity bioassay was performed on juvenile (carapace length, 43.7 - 38.2 mm) red king crabs. Ten crabs were transferred to 18, 15, or 12 ppt sea water from a holding salinity of 29 ppt. Weight was taken initially and blood samples were taken at 0, 5, 10, 24, 48 and 72 hours. Osmolarity and N^+ and K^+ concentrations were determined for the blood samples.

A similar acute bioassay was performed on adult female king crabs (carapace length, 11.9 - 13.8 cm). Eight crabs were tested at each salinity of 21, 18, or 15 ppt. Blood samples were taken as above.

Salinity acclimation tests were conducted on juvenile king crabs. Twenty crabs were subjected to decreasing salinities at

increments of 3 ppt every 48 hours. Ten animals were weighed and blood samples removed before transfer to the next lower salinity. Salinities tested were 28, 24, 21, 18, 15, 12 and 9 ppt. A similar series of decreasing salinities were also performed on adult female king crabs (n = 10, with 5 animals being weighed and blood samples taken prior to each salinity decrease).

Results and Discussion

Juvenile crabs were slightly more tolerant than adults in both acute and acclimated low salinity exposures. The acute 72-h LC-50 for the juvenile crabs was 16.6 ppt and for the adult females - 17.5 ppt. The LC-50s shown for the acclimation test were 10 ppt and 12 ppt for the juveniles and adults, respectively.

The blood osmolarity and ion analyses have not been statistically analyzed yet, but they show clearly that king crab are osmo-conformers, and that survival at the lower salinities is a function of tolerance and not regulation. All crabs subjected to low salinities were swollen in the abdominal areas, were lethargic, and were obviously stressed.

Short term salinity challenges were completed for adult and older juvenile red king crabs, but the life stage likely to be most tolerant was not studied because of lack of numbers. A pilot study on long term growth of older juveniles was completed, but needs to be redone with more juveniles, and with the younger life stage. We plan to continue and expand our research under this Objective in 1988, and have already obtained sufficient numbers of 1+ yr. old crabs to begin testing.

OBJECTIVE 4. Determine the effect of cohort density and habitat cover on cannibalism and growth in juvenile king crabs and differences between YOY and 2-3 year groups.

Introduction

YOY crabs are found naturally well spaced out in intertidal areas or in habitat that provides cover, while 2-3 year crabs often congregate in large pods. YOY king crabs held together in laboratory tanks are extremely prone to cannibalism of molting individuals; 2-3 year old crabs are less prone to cannibalism. These facts lead to the hypotheses 1) that YOY king crabs, given a choice of substrates, will tend to occupy the substrate providing the most cover, 2) that YOY crabs maintained at lower densities and/or on substrates providing more cover will show higher survival through the molting process, and 3) that molting success in 2-3 year old crabs will be less affected than that of YOY crabs by density and cover.

The study we undertook to test these hypotheses consisted of 2 parts: (4-A) a test of habitat preference in YOY and in 2-3 year old crabs, and (4-B) a test of survival at different densities and in different amounts of cover for both ages of crabs. The 2 parts are presented separately here.

Objective 4-A. Habitat Preference

Methods

Young-of-the-year crabs were collected in intertidal areas of Auke Bay, Alaska, at tides below -2.5 ft. Individuals from pods of 2-3 year old crabs were collected by Auke Bay Laboratory

(ABL) divers. In addition, 6 YOY crabs were obtained with the bryozoan/hydroid assemblages, one of the test habitats, when this material was collected, also by ABL divers.

YOY (initial carapace length, 5.9 - 14.0 mm) crabs were held in Heath* incubators with divided trays (Arasmith et al, in Press). These incubators were supplied with filtered Auke Bay sea water. Crabs were checked daily for molts and mortalities and fed a rotating diet (squid, shrimp, octopus, clams, and various fish species) 2 to 3 times per week. Uneaten food from the previous feeding was removed at each feeding. The older juveniles were held together in large tanks, and similarly monitored and fed.

To facilitate tracking individual molting, growth, and test performance during the preference tests and the long-term tests covered in Objective 4-B and 5, we tagged individual crabs. YOY crabs were tagged with colored beads and the 2-3 year crabs with numbered plastic tags which were attached with cyanoacrylic glue. Initial length, postmolt lengths and weights were recorded for each crab; tags were replaced 1-3 days after molting.

YOY habitat preference tests were run in fiberglass tanks with translucent fiberglass covers. All tanks were outdoors and supplied with filtered sea water at ambient temperature (6-7^{o}C) and salinity (~29^{o}/oo) at 50-80 ml/sec to a depth of 25 cm. Each of the five 208x55x56 cm tanks was divided by screens into 3 sections. Each of these 15 sections provided crabs a choice of 4 of 5 habitat types closely resembling habitat encountered by

*Reference to trade names does not imply endorsement by the National Marine Fisheries Service, NOAA.

juvenile crabs in their natural environment:

1. Sand, 3 cm deep,
2. Shell hash covering 100% of sand base,
3. Shale fragments covering 100% of sand base,
4. Cobble covering up to 50% of sand base, and,
5. Bryozoan/hydroid assemblages (Dendrobeanina murrayana, Microporina articulata, Sertularella sp., Sertularia sp.) anchored in a shale-covered sand base.

Sand was obtained locally, washed and graded (0.06-2.36 mm). Sand not only served as one of the habitat choices but also supplied the base for the other 4 habitats. Shell hash, shale fragments, and cobble (4-6 cm diameter in YOY tests, 10-17 cm diameter in 1-3 year old tests) were collected from local intertidal areas. Bryozoan/hydroid assemblages were collected from depths of 15-20m by ABL divers.

Four of the 5 habitats were arranged in each section to minimize tank effects and to provide crabs an equal choice of adjacent habitats (Figure 10). This design (modified from Aziz and Greenwood 1982) presented the test animals with all possible combinations of the 5 habitats. Crabs were introduced into the center of tank sections, insuring uniform access to the 4 habitats.

A total of twelve 24-h trials were run in the period 6 June 1986 - 1 July 1986. Crabs were not fed during the runs, but some naturally occurring food associated with the bryozoan/hydroid assemblages may have been available in that habitat.

Additionally, we tested the effects of starvation on preferences: Food was withheld from crabs for a week prior to the beginning of 4 of the runs, to determine if hunger affected habitat and degree of cover chosen. Habitat preference was tested at crab densities of 1 and 4 crabs/section. Starvation (hunger) tests were at a density of 4 crabs/tank section. In a given run, we attempted to use individuals that had not been used in the immediate preceding run, but this was not always possible; therefore, a period of at least 24h elapsed between runs. Each test condition (habitat arrangement and crab density) was replicated 3 to 4 times.

During each run the location of each crab and its degree of cover were recorded every 3 hours after an 1 hour adjustment period. Water temperature and cloud cover were also noted.

The 2-3 year crab (initial carapace length, 23.6 - 38.3 mm) habitat preference tests were conducted in 122 cm diameter fiberglass tanks with translucent fiberglass covers. Tanks were outdoors and supplied with filtered sea water at ambient temperature and salinity at a depth of 70 cm. In each of the 5 tanks, habitat types and arrangement was similar to that described for YOY test sections (Figure 10). Because a standpipe precluded introduction of crabs in the section center, they were introduced evenly spaced in the 4 habitats adjacent to the standpipe.

These tests were conducted simultaneously with the YOY runs. Crabs were tested at 4/tank and 12/tank. Densities in the hunger runs were 12/tank. Each test condition was replicated 3 to 5 times. Observation schedules and variables monitored were the same as for the YOY tests except that in runs with 12 crabs/tank,

locations were recorded, but individuals not identified.

Results and Discussion

The 2-3 yr. crabs clearly preferred, whether there were 4 or 12 cohorts present, the bryozoan assemblages or cobble (Figure 11A). At the lesser density of 4 cohorts, bryozoans were the unequivocal favorite. For the crabs that had been starved 1 week before testing, bryozoans were still the preferred habitat but there was no statistical differences among the remaining 4 habitat choices - cobble, shale, shell or sand.

These crabs were exposed (in clear view) in their environment for 73 - 98% of the observations (Figure 11B). Although the ratio of the cover (bryozoans and cobble) size to the size of these test crabs was such that it was difficult for them to be completely covered from our view, 17 to 27% of the time during the regular tests, they achieved at least some degree of cover. In contrast, the starved crabs were partially covered or covered only 2% of the observations.

The amount of light available had only a slight effect on preference (Figure 12). Nighttime observations showed a clear preference for the bryozoan assemblages with cobble and bryozoans chosen during daylight hours. Although the majority of the crabs were exposed regardless of the time of observation (Figure 13), during daylight hours, crabs achieved some degree of cover in 33% of the observations.

All the data has been entered onto computer files, and data for the older juvenile red king crabs partially analyzed. The data for the YOY crabs is yet to be analyzed. This section

should support one formal manuscript.

Objective 4-B. Effect of Habitat and Density on Molt Survival

Methods

For the YOY habitat/density test, 4 fiberglass tanks were divided and supplied with sea water as in 4-A. One of 3 habitats was placed in each of the 12 tank sections:

1. Sand
2. Cobble
3. Simulated bryozoan/hydroid assemblages

Because bryozoan/hydroid assemblages proved hard to maintain in good condition >30 days, we substituted similar sized artificial aquarium plants, which were a reasonable facsimile.

Crabs at densities of 3 or 11 were placed in each tank section. Densities for each test habitat were duplicated. This test ran from 20 July - 6 December 1986 (139 d), 2 intermolt periods for 67% and 3 intermolt periods for 23% of the crabs. Tanks were checked daily for molts or deaths. Lengths and weights were measured 1-3 days after molting. Crabs were fed a rotating diet of clams, shrimp, squid, octopus, and various fish species twice a week.

The habitat/density test for the older juveniles was conducted in eight 208x55x56 cm fiberglass tanks with translucent covers. Tanks were divided by screens into 2 sections, each containing sand or cobbles as test habitats. One hundred twenty crabs were placed in the 16 tank sections at 3 density levels - 3, 7, or 11. Test conditions were replicated 2 to 3 times. Monitoring and feeding schedules were conducted as described in above. Test duration for this age class was also 139 days during

which all crabs completed at least 1 intermolt period.

Results and Discussion

Preliminary inspection of the data shows that overall survival was somewhat better at lower densities and in habitats providing more cover (Figure 14). This was true for both YOY and 2-3 year crabs, although the differences were greater for YOY crabs. These facts cannot yet be used to support theories about cannibalism of molting crabs, because we have not yet calculated the rate of deaths/molt or separated cases of cannibalism from other deaths.

An unexpected finding of this study is the relationship of diet to cannibalism. Cannibalism was most common when crabs had not been fed shrimp for several days, and was rare when shrimp was the current food. See further discussion on page 40.

These long-term exposures ended 6 December 1987. Most of the data has been entered onto computer files, and some has been partially analyzed. This section should support one formal manuscript.

OBJECTIVE 5. Determine the effect of different diets on growth and molting success of juvenile red king crabs.

Introduction

King crabs are extremely opportunistic feeders, reported to feed on dozens of species from at least nine different phyla, and to eat very different diets, depending on their location and on season within a given location. However, effects of available diet on crabs have not been studied. We had two major objectives. We wished 1.) to determine the possibility of effect on crab growth due to limitations on variety of prey items available in the field, even when there is not a shortage in quantity of food, and 2.) to compare the effects of different practical laboratory diets before choosing a standard one for future juvenile king crab work.

Methods

Test YOY red king crabs were collected intertidally, and maintained in the laboratory in modified fish-egg incubators, as described under objective 4-A.

We tested the growth and energetics of of YOY crabs on 8 diet regimes. Four of the diets consisted of single food items: clams (whole body, shucked), shrimp (tails only, meat and shell), herring (meat, skin and bone), and squid (mantle meat). A 5th diet regime consisted of all 4 items in rotation, and a 6th consisted of the same rotation but with Laminaria also available to the crabs at all times. The 7th diet was a commercial shrimp food (Rangen shrimp production pellets) we hoped would prove a convenient laboratory diet. All foods were available ad libidum.

The eighth regime was starvation, a worst case against which to gauge the other diets. All diet items tested are readily accepted by juvenile king crabs and known to support their growth for at least several months. Except for the commercial pellets, the items are also similar to known natural foods of juvenile kings, and probably are eaten in the field if available.

Eight groups of 20 YOY king crabs were maintained on the 8 test diets for 2 complete intermolt periods. Each diet group was divided into 3 sub-groups that were maintained in 3 separate divided incubators. There were 2 or 3 diet-groups in each incubator tray. Each crab began it's assigned diet on the day of it's first molt after the study began. Crabs were measured (carapace length) and weighed (live weight) 2 or 3 days after each molt. The diets were compared in terms of crabs' relative weight gain per molt and per day, relative length gain per molt and per day, and time between molts. When crabs had completed 2 intermolt periods on the test diets, they underwent energetics measurements. Feeding rates, assimilation efficiencies, respiration rates, ammonia production and tissue weights were measured to determine their "scope for growth", or food energy available to the crabs beyond that needed for body maintenance, using methods similar to those in Stickle et al 1984.

Results & Discussion

Diet effects juvenile king crab growth even when food is available ad libidum. Diets that included shrimp, singly or in combination, supported the greatest growth rates (Figures 15, 16). The test diets showed the same relative pattern of effect

on growth over 2 intermolt periods, whether growth was measured in terms of molting rate (time between molts), weight gain, or length gain (Figure 15). In all cases, mixed diets and shrimp occupied the first 3 positions (i.e., supported the fastest growth), herring was 4th, clam and squid were 5th and 6th, and the commercial pellets the worst (starved crabs did not molt). Since the better diets supported more growth in less time, the same pattern was even more distinct when growth was measured in terms of weight or length gained per day (Figure 16).

The assimilation efficiency of juvenile king crabs eating commercial shrimp pellets was poorer than for other foods (Figure 17). All the food items had fairly high (>75%) organic content, with shrimp and herring slightly lower than the other foods because of the presence of shell and bones. (The crabs did eat both bones and shell, but tended to leave some of the shrimp shell uneaten.) However, the organic fraction of feces was considerably higher for crabs eating the commercial pellets, indicating lower efficiency in the crab's ability to assimilate organic material from the pellets.

Scope-for-growth measurements have not been calculated yet; we expect them to mirror the growth rates. Certainly the starved crabs will show a negative scope for growth since their feeding rate was 0. The contributing measurements are presented in Figure 18. Differences in ammonia production do not appear to be significant. Oxygen consumption was variable but slightly lower for shrimp and mixed diets than for the other test items. Feeding rates of juvenile red king crabs show a wide variance,

due to erratic eating habits and the imprecision involved in measuring their food before and after eating, but some differences in consumption rates for the different foods are apparent. The data on calories available per gram of each food are not worked up yet.

Herring as a food item was associated with higher mortality. Seventy-nine percent of the crabs eating herring died before the first crabs were removed from the study for energetics measurements on day 150. Even the starved crabs had better overall survival, only 2 of the 8 dying, both after day 144. Three pieces of evidence seem to indicate that the problem with herring is not simply that it is nutritionally inadequate, but that there are other risks associated with proximity to herring pieces. First, crabs that survived on the herring diet showed good growth--better than crabs eating clams, squid, or commercial pellets. Second, the risk of dying was not related to the specific diet a crab ate so much as with the degree of association the crab had with herring (Table 1). Even if a group of crabs did not eat herring themselves, their survival was related to the amount of herring eaten by the other group(s) of crabs in the same incubator tray. And finally there is the simple observation that herring is a very oily food that causes tanks and especially screens around animals eating it to require more cleaning than other foods. Fish oil acting as a substrate for bacterial growth or physically clogging crabs' gills are possible explanations for the mortalities associated with herring.

In summary, diets that included shrimp, singly or in combination, supported the best growth, and the commercial food (ironically formulated for maximum shrimp growth) supported the least crab growth of any food. Herring appears to pose a risk of death when used as a laboratory diet, that is unrelated to its ability to support reasonable growth. The major implication for understanding natural king crab population fluctuations is the clear demonstration that even if there is no overall shortage of prey, growth of young crabs can be seriously affected by the prey species available if the variety of species is limited. Implications for laboratory rearing of juvenile king crabs include the recommendation that shrimp be included in their diet and that herring and the commercial shrimp pellets be excluded, and the caveat that absolute growth rates should not be compared between studies unless the test animals were eating the same diet.

An observation with interesting possibilities regarding shrimp as a diet factor was made on the juvenile king crabs in the habitat/cover study (Objective 4-B). Those crabs were fed twice per week, with one type of food at each feeding. The foods included fish of various species, squid and octopus, clams, and shrimp. A preliminary look at the results of that study seem to show that the food currently available had more effect on a crabs' chances of surviving molting without being cannibalized than did any of the other variables, with molting being safest when shrimp was the available food. In conjunction with the results of the diet study, this leads to speculation that there is a dietary factor important for crab growth that can be

supplied by eating shrimp or by eating other king crabs that cannot be supplied by a diet of clam, fish, or squid. Further study in this area is needed.

Data collection is complete, and much of the data analysis has been done. Analysis should be completed by March 1988, and the results are expected to support one formal manuscript.

Table 1.--Risk of death associated with the presence of herring as a food item in the same incubator tray with juvenile red king crabs. Two or 3 diet-groups were present in each tray. Crabs fed a mixed diet had herring present 25% of the time; crabs fed herring alone had it present 100% of the time. Only deaths occurring before day 150, when the first crabs were removed from the study for energetics measurements, are included here; "day of 1st death" is number of days after beginning of study.

	Contact with Herring				
	Crabs' own diet	Diets of other crabs in same tray	n	Percent Mortality	Day of 1st death
1.	No herring	No herring	43	.14	126
2.	No herring	Mix	14	.21	131
3.	Mix	Mix or No herring	29	.41	113
4.	No herring	Herring	16	.50	106
5.	Mix	Herring	4	.50	105
6.	Herring	Mix or No herring	19	.79	92

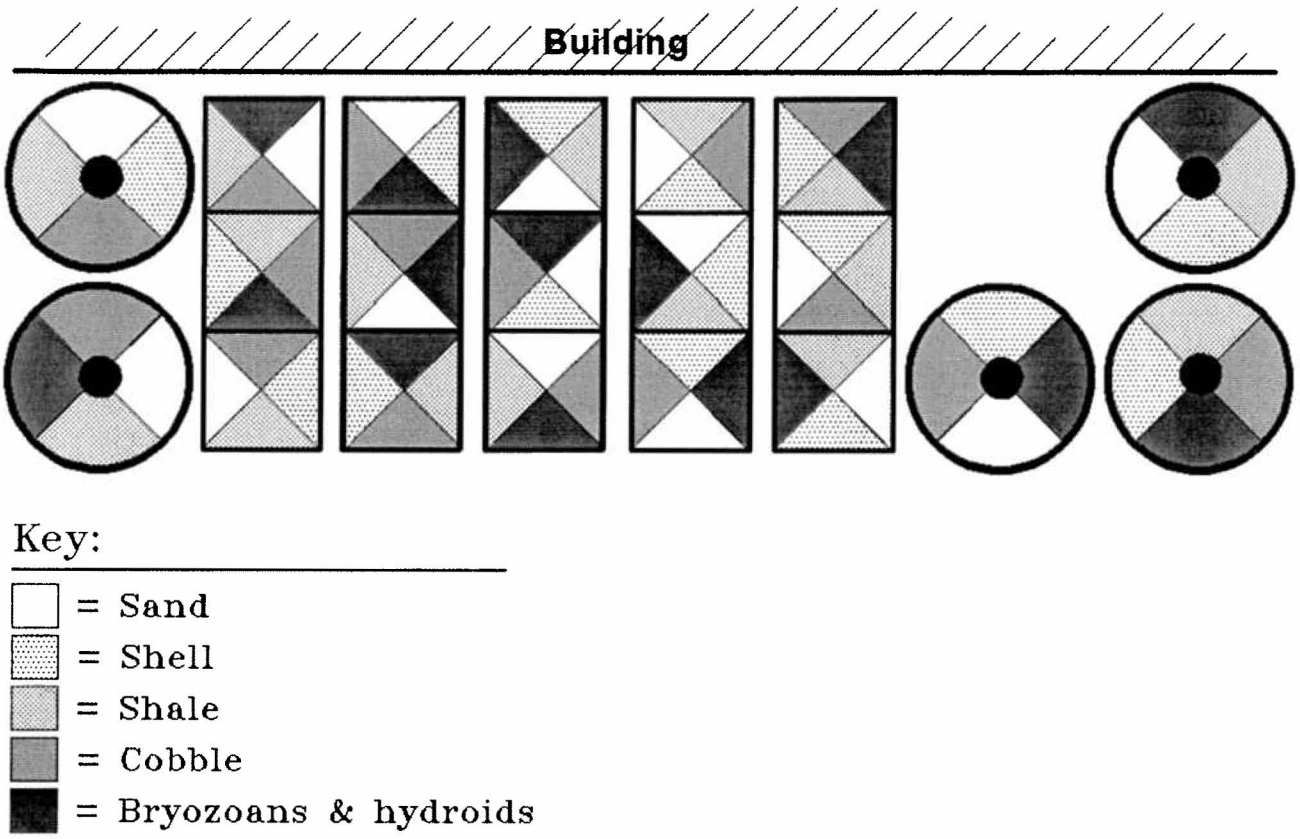

Figure 10. Diagrammatic representation of the arrangement of substrates in tanks used for determining habitat preference in juvenile king crabs. The rectangular tanks were divided into 3 square sections with screens, and used for the testing YOY crabs. The round tanks were used for testing 2-3 year crabs. Spatial relationships of tanks and building were as shown.

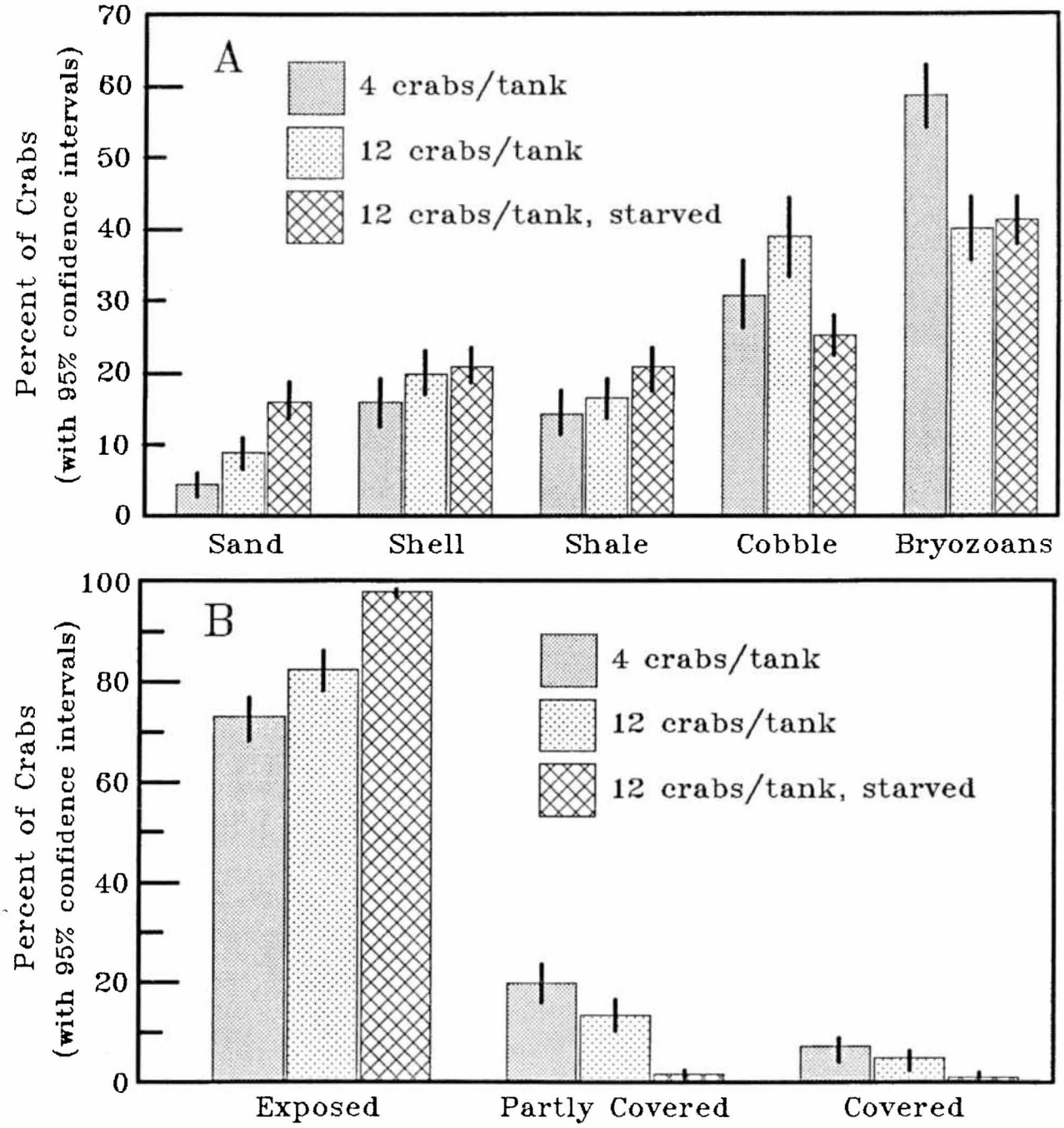

Figure 11. Habitat chosen and degree of cover noted for 2-3 yr. king crabs during 24-h preference tests. Observations were made every 3 h from noon on day 1 and ending at 9 a.m. on day 2. 4-A. Actual habitat chosen for crabs at densities of 4 or 12 per test condition and starved crabs at a density of 12 per test condition. 4-B. Degree of cover noted during observations. Vertical bars = 95% Confidence Intervals.

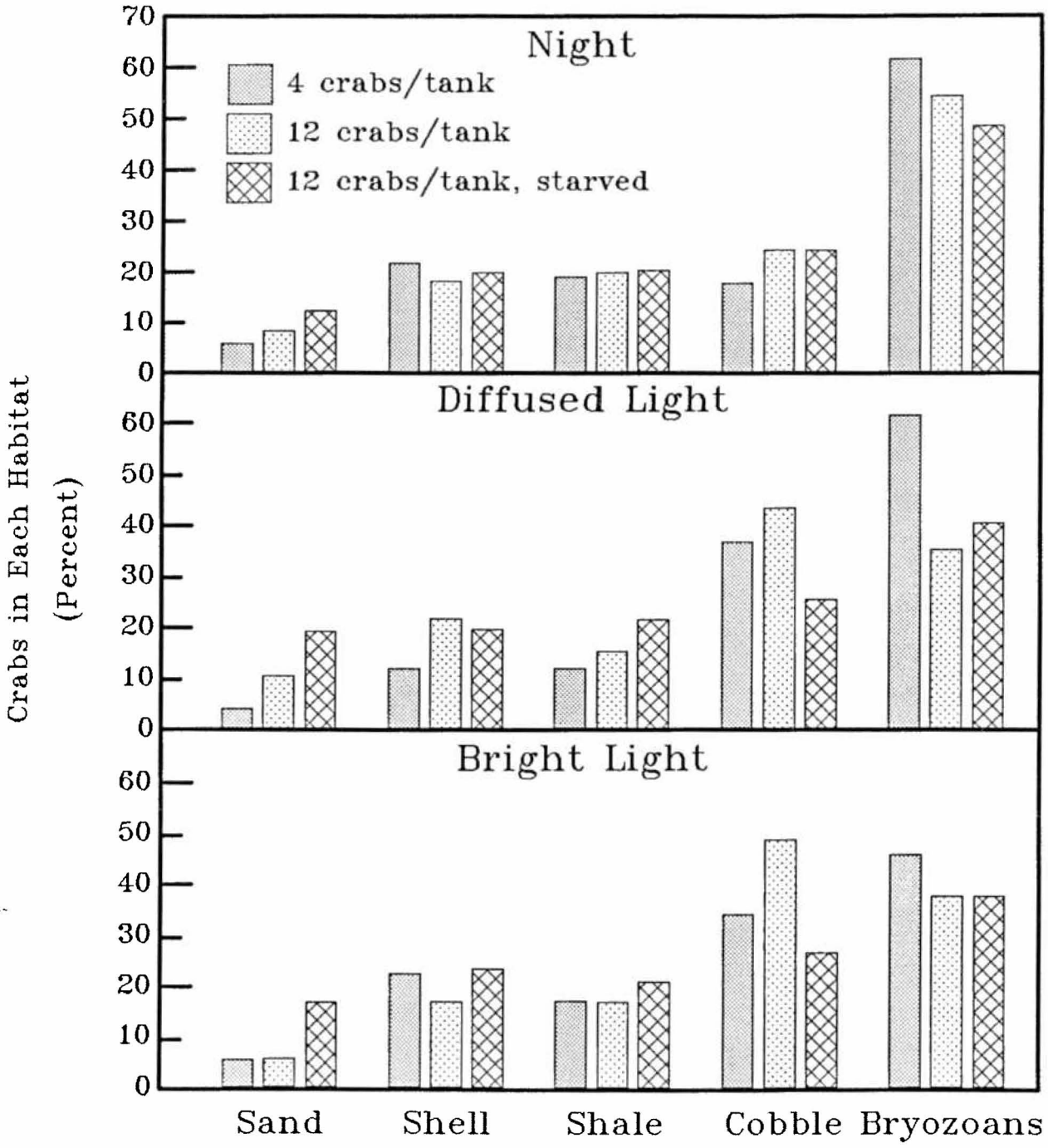

Figure 12. The effect of amount of available light on habitat chosen for 2-3 yr. king crabs during habitat preference tests.

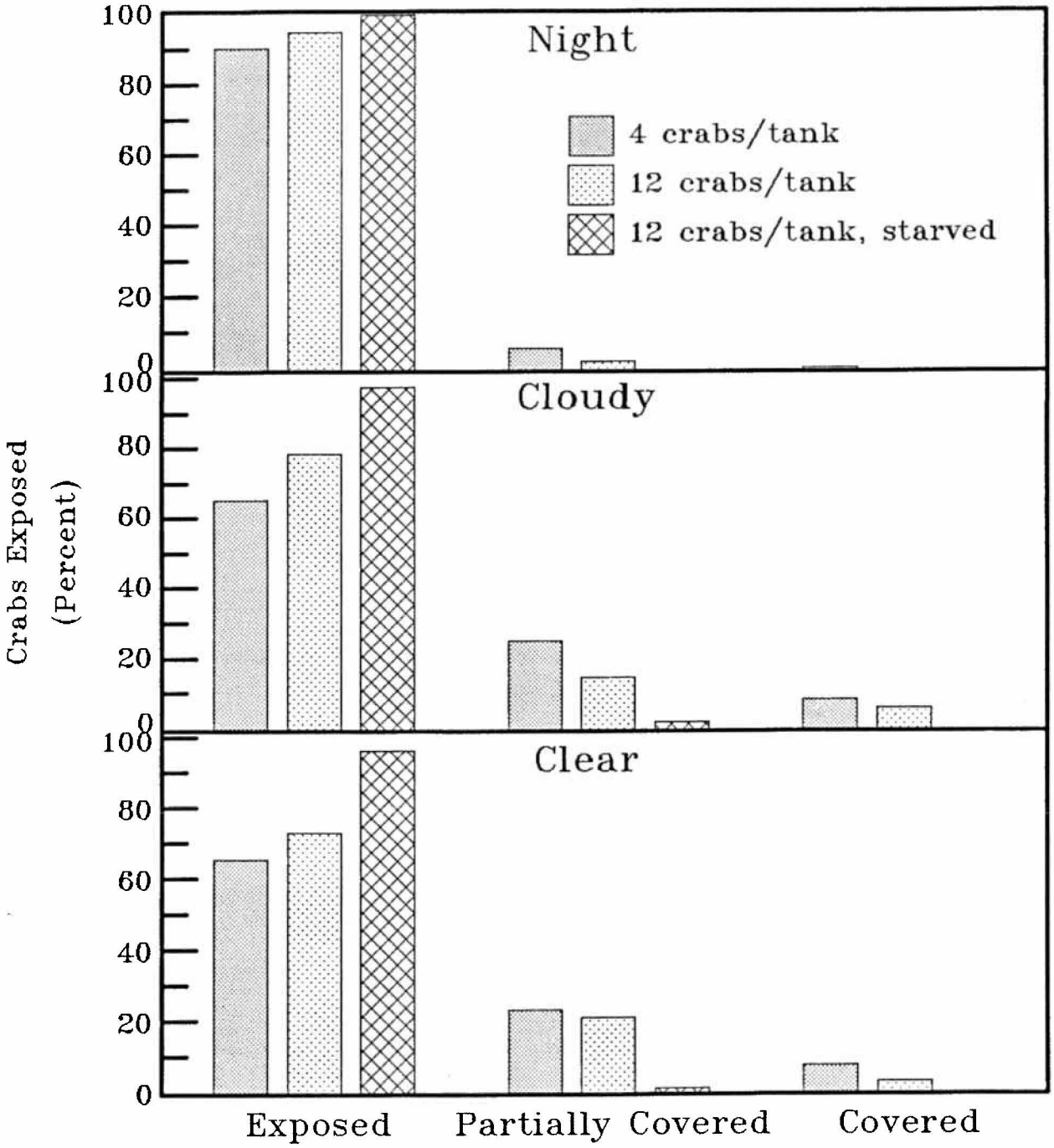

Figure 13. The effect of amount of available light on degree of cover noted in 2-3 yr. king crabs during habitat preference tests.

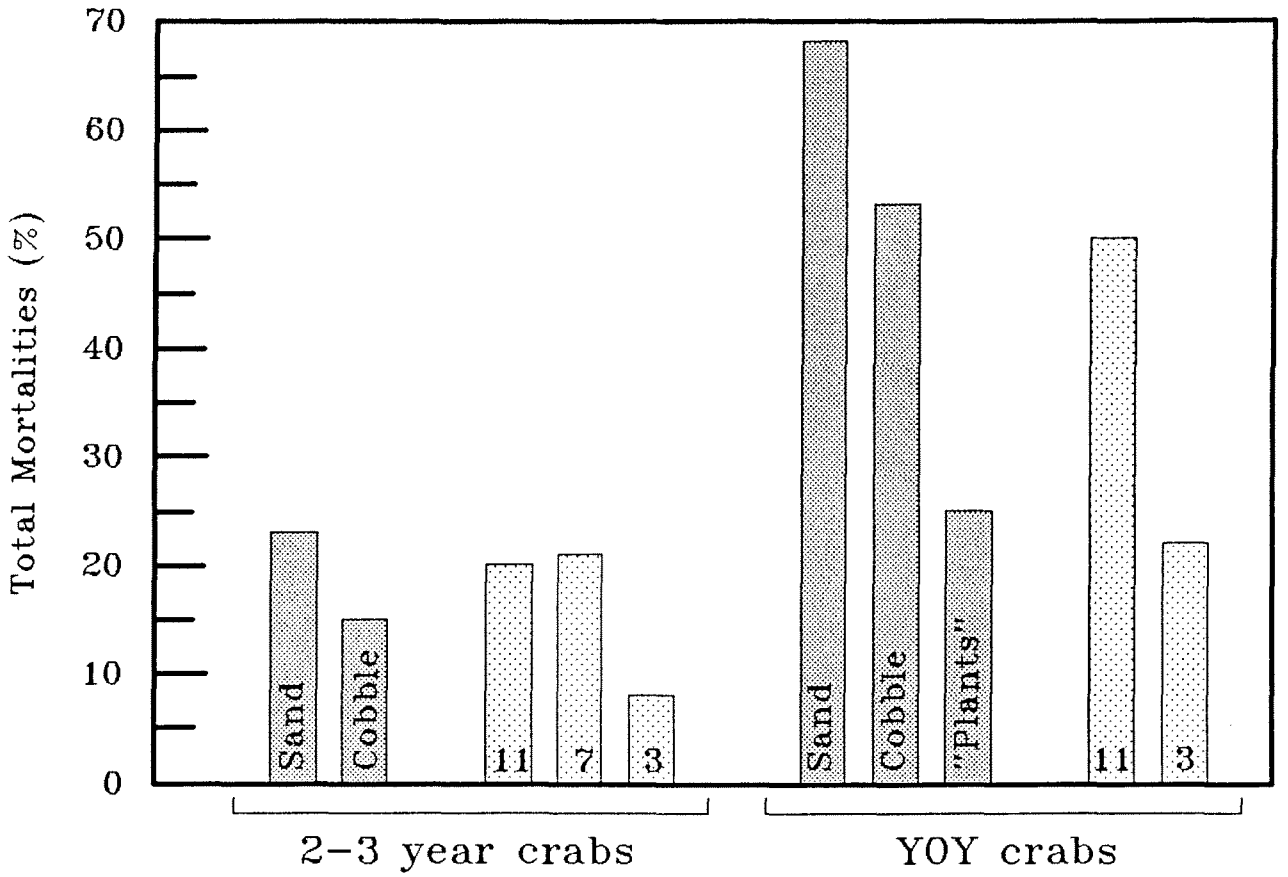

Figure 14. Total mortalities from all causes in habitat/density study. Mortalities for different habitats include all densities combined; mortalities for different initial densities (original number of crabs/tank) include all habitats combined. Data are preliminary; no adjustments have been made for number of molts or cause of death.

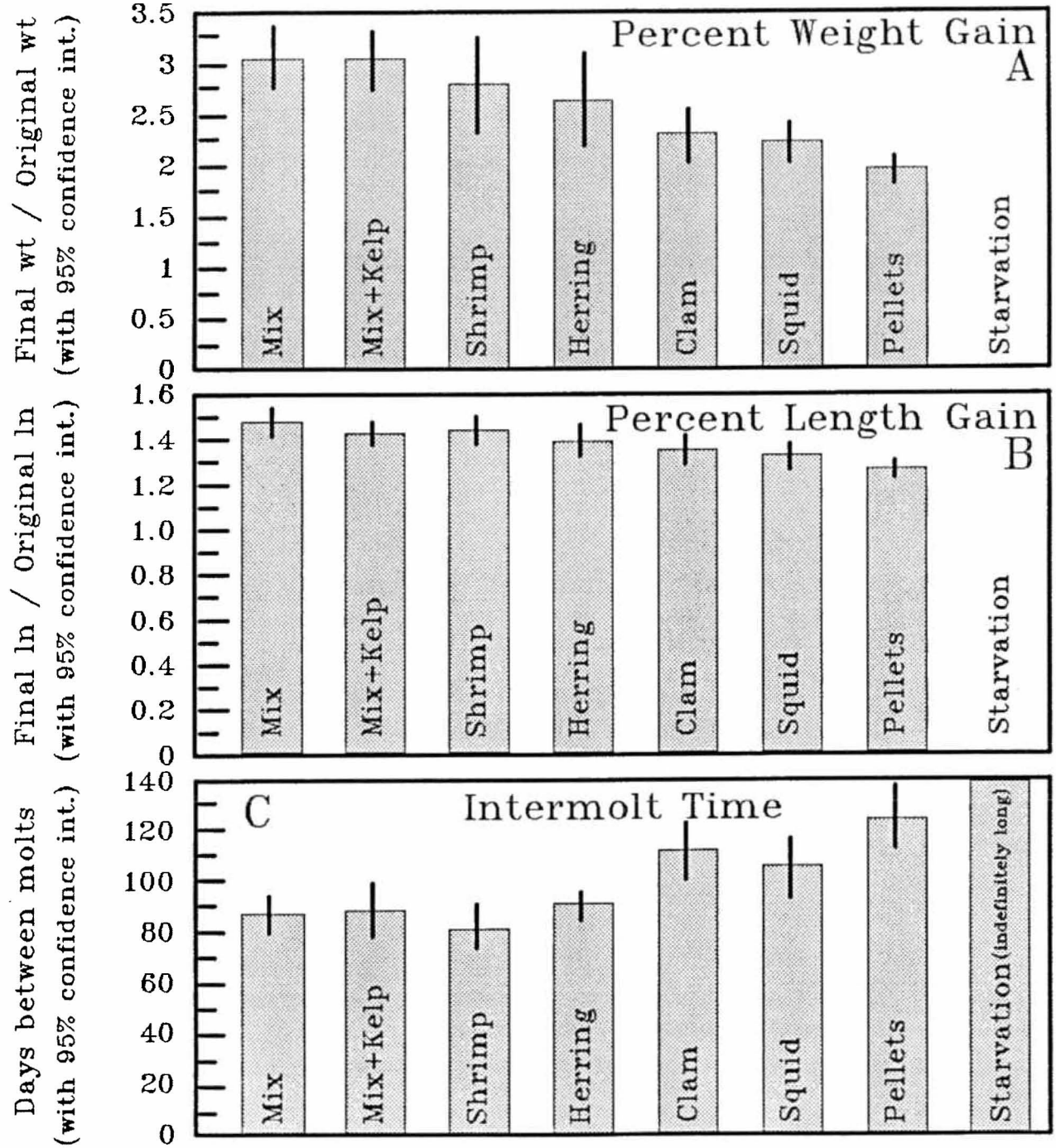

Figure 15. Growth rates of juvenile (young-of-the-year) red king crabs over two intermolt periods on the indicated diets. Mixed diets consisted of shrimp, herring, clam and squid, with a different food offered at each feeding.

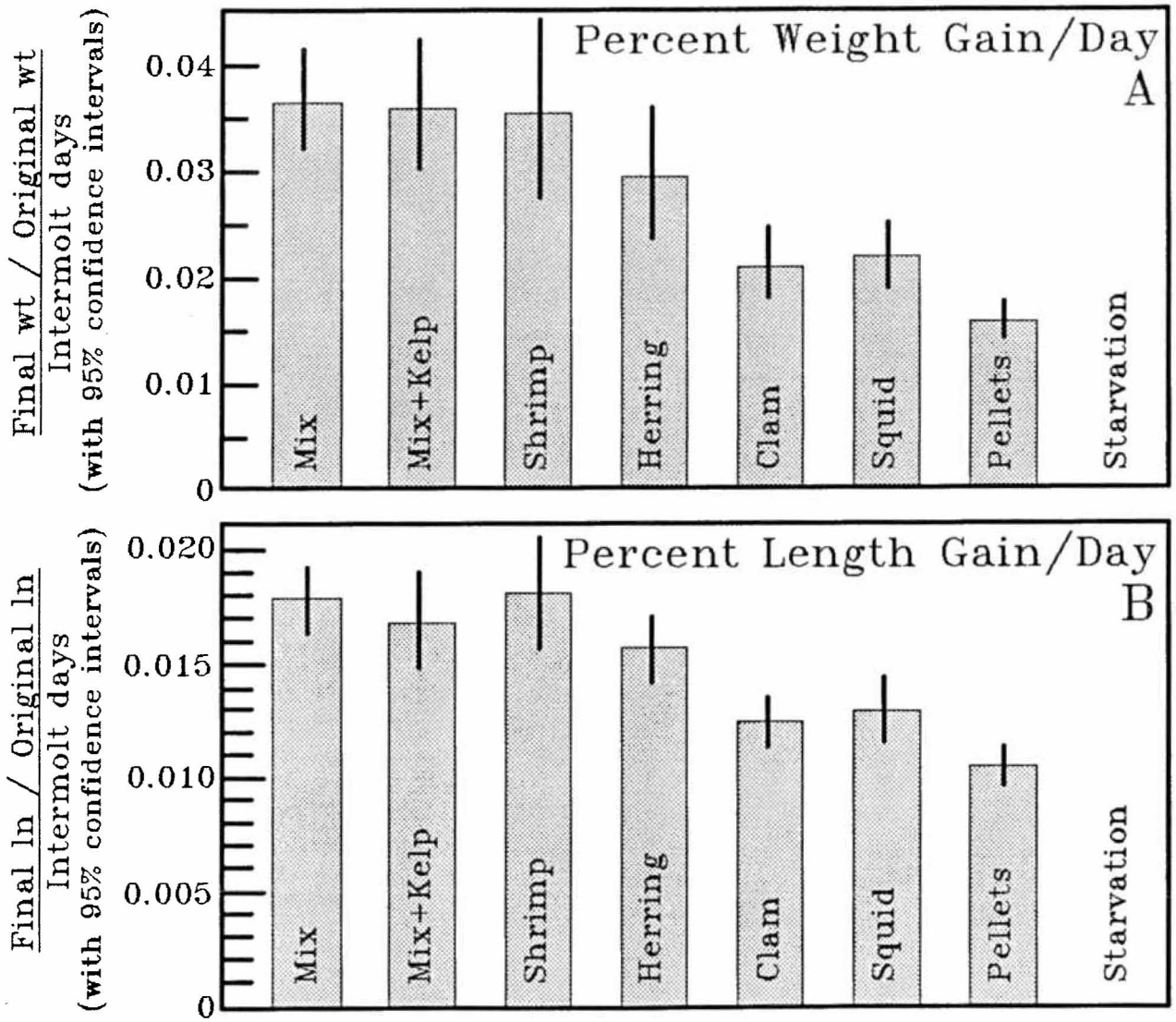

Figure 16. Daily growth rates of juvenile (young-of-the-year) red king crabs measured over two intermolt periods on the indicated diets. Mixed diets consisted of shrimp, herring, clam and squid, with a different food offered at each feeding.

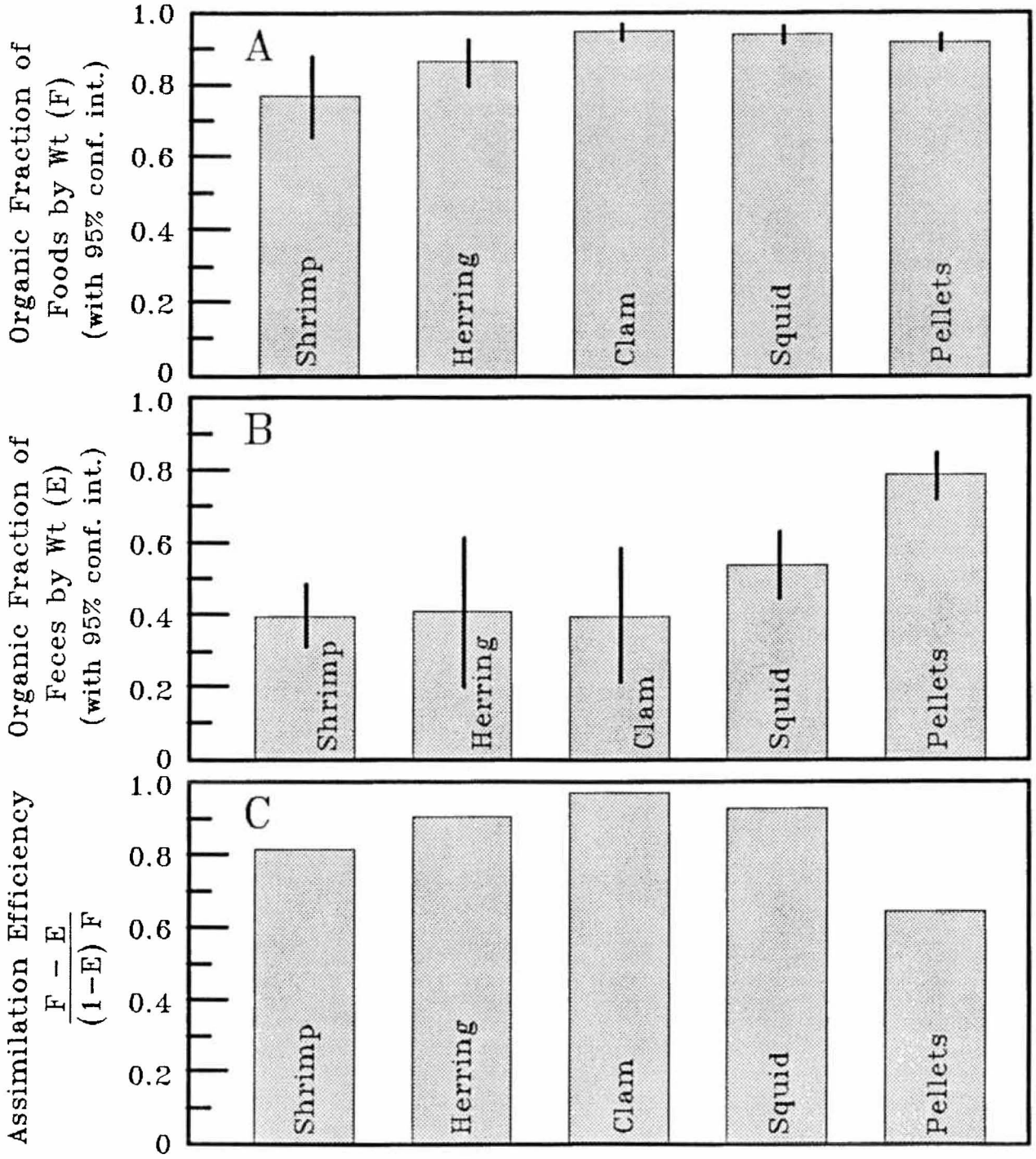

Figure 17. Assimilation efficiencies of juvenile (young-of-the-year) red king crabs for the indicated food items; A. organic fraction in food items as offered to crabs, B. organic fraction in feces collected from crabs after 3 months on the indicated diets, and C. the calculated assimilation efficiencies.

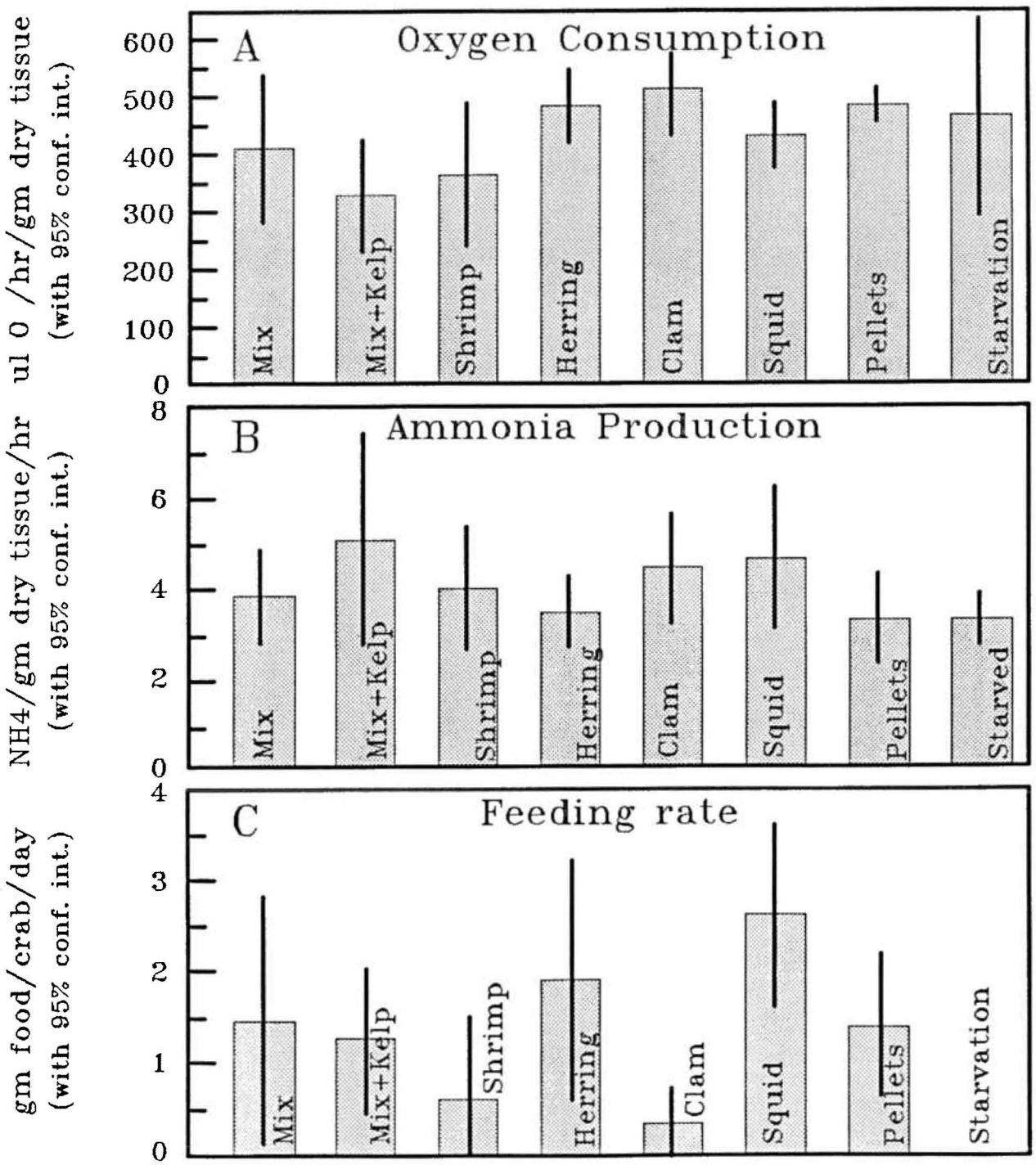

Figure 18. Energetics measurements for juvenile (young-of-the-year) red king crabs taken after crabs were fed the indicated diets for 3 months; A. oxygen consumption, B. ammonia production, and C. feeding rate.

RESEARCH PRODUCTS (THROUGH JANUARY 1988)

Two research papers were presented at the annual meeting of the American Society of Zoologists which met concurrently with The Crustacean Society in New Orleans, Louisiana, December 27-30, 1987. The abstracts for those presentations were published in the American Zoologist and were cited as follows:

SHIRLEY, T. C. and S. M. SHIRLEY. 1987. Photoresponses and swimming ability of red king crab larvae. Am. Zool 27(4):103A (Abstract #541).

SHIRLEY, T. C. and S. M. SHIRLEY. 1987. Diel vertical movements of Alaskan red king crab zoeae. Am. Zool. 27(4):103A (Abstract #542).

A manuscript entitled "Behavior of red king crab larvae: responses to light, gravity and current" will be submitted to Marine Behaviour and Physiology in February, 1988.

PROBLEMS ENCOUNTERED

Larval mortality after stage 2 precluded testing stage 3 and 4 zoeae and glaucothoe. Survival should be improved by reducing the density of larvae in the culture tanks and supplementing the larval diet with more phytoplankton and other small zooplankters.

Light intensities used in the lab did not include the maximum intensities encountered at the sea surface on sunny days. A stronger light source will be sought for future lab work.

Funding was received approximately two weeks before larval hatching began. This left little time for ordering supplies and preparing experimental apparatus for the project. If delays in funding occur in 1988, some of the larval work may have to be omitted.

The amount of labor required for the larval work was underestimated, and the time and salary budgeted were not sufficient for the labor required. For future work, inclusion of funds for part-time technicians and re-evaluation of the labor-intensive part of the project should resolve the problem.

Young-of-the-year (YOY) red king crabs were unusually scarce in Auke Bay intertidal areas in the spring of 1987. Concerted searching by experienced crab collectors netted many fewer crabs than we have found in previous years with considerably less effort. The YOY king crabs we did collect were generally at the lower edge of the intertidal area, -3 ft. or lower, while in most years they are found as high as the -2 ft. level. The low number of YOY king crabs on the beaches in 1987 reflects the fact that in the spring of 1986, the peak in red king crab hatching in Auke

Bay did not coincide with the peak phytoplankton bloom, as it usually does (Shirley and Shirley, 1988).

Because availability of YOY crabs was so limited, we were not able to complete all projects planned. Work on Objective 3, determination of optimum salinities for juvenile king crabs, omitted any tests on YOY crabs in 1987. Other life stages were tested, but are relatively meaningless with the target life stage missing. In 1988, we plan to fill the data gaps. The elimination of YOY crabs from Objective 3 was in accordance with assignment by OCSEAP of lowest priority. YOY and 1-2 year old red king crabs are already (January 1988) available in Auke Bay and we are confident that we will be able to complete the study as planned.

While limited numbers of YOY crabs did not affect experimental design of the habitat preference runs (Objective 4-A), we were forced to use each test animal in more than one run. This may bias the data by introducing a learning curve; we have not completely analyzed the data yet for this possibility. Limited numbers of YOY crabs curtailed the experimental design of Objective 4-B, determination of effect of habitat and density on survival of molting. We would have preferred the maximum density to have been more than 11 crabs/tank, and to have had more than 2 test densities, and more replicates. However, the results of our reduced study are adequate to determine the validity of our hypotheses, and any further work we do in this area will be extensions beyond the original study rather than enlargements of it.

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