FEEDING ECOLOGY OF JUVENILE KING AND TANNER CRAB IN THE SOUTHEASTERN BERING SEA

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Final Report
Outer Continental Shelf Environmental Assessment Program
Research Unit 624

April 1984

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ABSTRACT

To determine the food requirements of juvenile king and tanner crab and to assess potential impacts on the crab from Outer Continental Shelf oil and gas development, three cruises north of the Alaska Peninsula were conducted by NOAA vessels in June, August and October, 1982. Juvenile red king crab, Paralithodes camtschatica (CL >40 mm), were concentrated off Port Moller whereas juvenile tanner crab, Chionoecetes bairdi (CW <20 mm) were concentrated in the Amak Island-Black Hill Region. Juvenile tanner crab, C. opilio, were not found in the study area. Both the juvenile king and tanner crab, C. bairdi, were in deeper water in August 1982 (65 to 75 m) than in June 1982 (55 to 65 m). The smallest juvenile king crab (CL <30 mm) were found in shallow nearshore areas amongst cobble and rock with abundant epifauna.

Shipboard experiments showed that multi-compartmental exponential decay models described the evacuation of stomach contents in juvenile king crab. Stomach residence times calculated from these models varied with prey type from hours to days. Power laws described the relationships between carapace size and maximum stomach volume in both king and tanner crab.

In the diel feeding chronologies for juvenile king crab (CL = 53-80 mm) in June and August peaks in dry weight of stomach contents indicated two feeding periods, 0000 to 0800 h and 1300 to 1800 h. Using the diel feeding chronologies and a multi-compartmental exponential model for stomach evacuation, the daily rations of juvenile king crab were calculated to be 6.30 and 11.92 mg dry weight per gram crab wet weight per day in June and August, respectively.

Visual examination of stomach contents gave dietary composition by frequency of occurrence. Measuring dry weights of the hard parts of prey items and estimating soft tissue intake with appropriate ratios gave a measure of dietary composition by bulk that was converted to calories. Examination of stomach contents alone did not indicate relative importance in the diet because such examinations were biased in favor of prey items with long stomach residence times. After correction for gut residence times, molluscs and echinoderms, whose hard parts dominate stomach contents, became of lesser importance whereas soft bodied polychaete worms became the first-ranking dietary item. Four taxa (two polychaetes, a sand dollar, and a clam) accounted for 92% of the soft tissue dry weight in the overall diet.

The caloric intakes by juvenile king crab (CL = 53-80 mm) were 17.5 and 42.2 calories per gram crab wet weight per day in June and August, respectively. Two polychaetes, Pectinaria sp. and a sabellid, constituted over 50% of the caloric intake in June and August. The sand dollar, Echinarachnius parma, constituted 36% of the caloric intake in June but only 2% in August. Bivalves constituted 3% of the caloric intake in June but 25% in August. The major bivalve in the August diet was a small, thin-shelled clam, Tellina sp. Juvenile king crab appear to be predators of small, poorly motile benthic organisms living at or just beneath the sedimentary surface.

The immunoassay provided evidence that juvenile king crab, especially, the smallest juveniles (CL <30 mm), consume soft-bodied prey types overlooked by conventional analyses of stomach contents. In the smallest juvenile king crab the immunoassay detected polychaetes, oligochaetes and nematodes not detected visually and not observed either visually or immunologically in the stomachs of the larger juvenile crabs. The immunoassay required more refinement than expected to apply it to the analysis of crab stomachs.

Potential impacts from oil and gas development could derive from habitat disturbance and exposure to contaminants from platform discharges and oil spills. Because of the shallow nearshore distribution of the smallest juveniles, impacts from disturbance and platform discharges appear unlikely whereas impacts from oil spills need consideration. Because of the concentration of the larger juveniles off Port Moller in depths of 40 to 70 m, potential effects from disturbance and platform discharges need consideration whereas direct effects from oil spills seem unlikely. Chronic indirect effects could derive from loss or reduction in the food supply of juvenile king crab. An oil spill in the shallow nearshore zone can reasonably be expected to reduce the density of food important to juvenile crabs, but prediction of the extent of such restriction in the crab's food supply requires prediction of the salient features of such a spill. Based on findings with other crustaceans a restriction in food supply can be reasonably expected to retard growth in juvenile king crab if alternative food is not available or taken.

FEEDING ECOLOGY OF JUVENILE KING AND TANNER CRAB IN THE SOUTHEASTERN BERING SEA

INTRODUCTION

This project was initiated by NOAA's Outer Continental Shelf Environmental Assessment Program (OCSEAP) to determine how petroleum contaminants may reach and impact the commercially valuable crab resources of the southeastern Bering Sea. The main objectives of this project were, first, to determine the food requirements of juvenile red king crab, Paralithodes camtschatica, and tanner crab, Chionoecetes bairdi, in the waters north of the Alaska Peninsula and, secondly, to assess potential impacts from Outer Continental Shelf (OCS) development. The project entailed several tasks: the location and collection of crabs; shipboard experiments on stomach clearance rates; 24-h trawling to determine a diel feeding chronology and daily ration; determination of the carapace size - stomach volume relationships; visual examination of stomach contents; calculations of dietary composition; and construction of a caloric intake schedule. Due to grinding of food by the gastric mill, difficulties in identifying prey have confounded other food habits studies of king and tanner crab (Tarverdieva, 1976,1978), but here prey types ordinarily not detectable by traditional gut analysis were identified by an immunoassay of gut contents. This state-of-the-art technique and other techniques were used to assess and correct various biases not normally considered in conventional food habits studies determining the composition of crustacean diets.

This final report gives the diel feeding chronologies and daily rations of juvenile king crab in June and August of 1982. Also reported here is the species composition of the diet of juvenile king crab. Correction of dietary composition for gut residence times indicated that soft bodied prey, especially polychaete worms, were a considerably greater proportion of the diet of juvenile king crab than conventional uncorrected analyses would indicate. The immunoassay of Feller et al. (1979) modified for the analysis of juvenile king crab stomachs gave evidence for the presence of soft bodied prey undetected by conventional gut analysis. Finally, this report synthesizes the information on the food requirements of juvenile king crab and assesses the potential impacts from OCS oil and gas development.

MATERIALS AND METHODS

CRUISE OPERATIONS

King and tanner crab were collected by trawl and SCUBA diving during three cruises in 1982 along the north Aleutian Shelf (Figures 1 to 3). The NOAA ship MILLER FREEMAN conducted the June and August cruises; the NOAA ship DISCOVERER conducted the October cruise. In June the study area extended from Cape Sarichef on Unimak Island to Cape Seniavin. In August this area was extended to Port Heiden. In June samples were collected from depths up to 70 m along 17 transect lines. In August and October collection efforts were concentrated in areas of high abundance suggested by the June catches. Station locations appear in Figures 1, 2, and 3.

To locate areas of high crab density for later intensive sampling, the search techniques included trawling, TV tows, diver sled tows, and boat-tended drift diving. To locate crabs in depths greater than 20 m, tows of 20 min with an underwater video camera and trawls of 10 min with an 18-foot try net were performed seaward of the 20-m isobath. Shoreward of the 20-m isobath diver sled tows and try net trawling were performed. To collect the smallest king crab and potential prey items, boat-tended drift diving with standard SCUBA was conducted from 1 to 20 m around Amak Island. Additional potential prey items for the immunoassay were taken from bottom grabs. Diving and bottom grabs also provided the large numbers of prey items needed for the clearance rate experiment. CTD casts provided depth profiles of temperature and salinity. Table 1 summarizes the ship operations.

Trawl catches were processed to estimate crab abundances and to obtain samples for several different shipboard and laboratory analyses. For each trawl total weight was measured, and the catch sorted for the crab species and potential prey items needed for the immunoassay. The dominant fish species and the presence of invertebrate species other than crab were noted. King and tanner crab were separated from the catch, counted and measured. Individual king crab were weighed to the nearest g, their carapace length (CL) and width (CW) measured to the nearest mm, and their shell condition qualitatively assessed. After measurement, ovigerous females were either given to Dr. David Armstrong of the University of Washington for further shipboard studies or returned to the sea. In cases where more than 10 king crabs occurred in a trawl, the crabs were flash frozen for later processing. For smaller trawls the crabs were measured

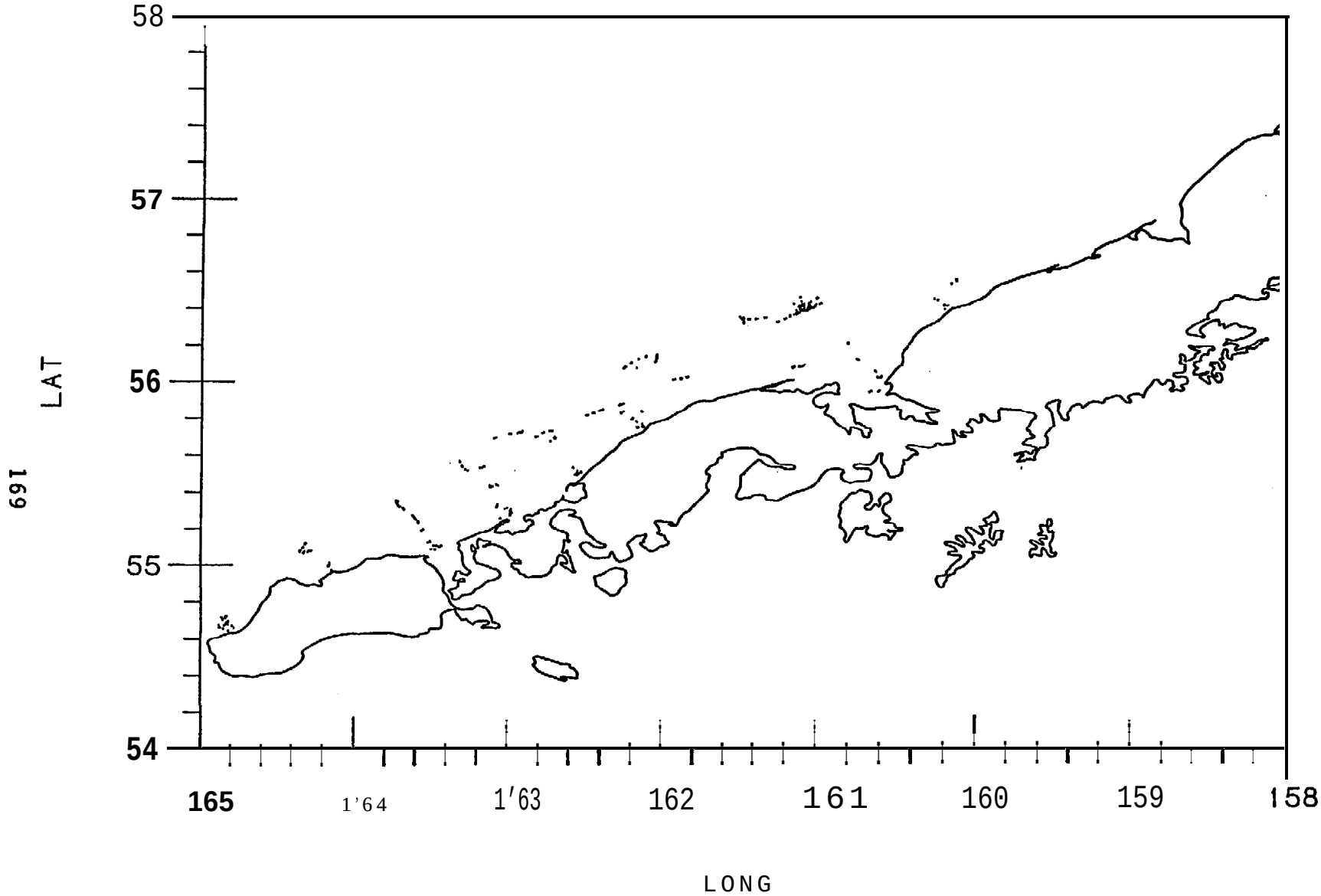


Figure 1. '-Station locations during the June 1982 cruise. NOAA ship **Miller** Freeman.

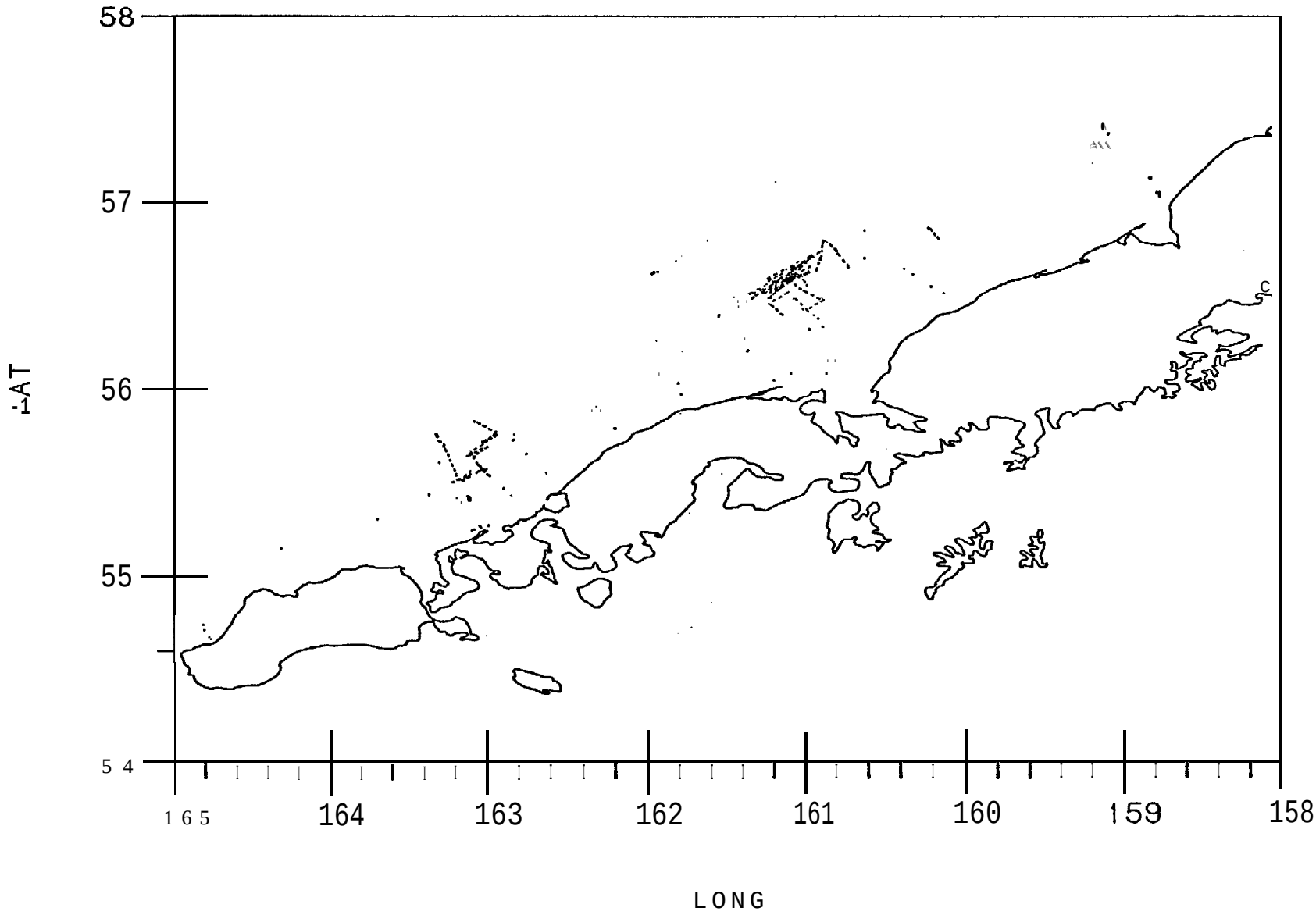


Figure 2. --Station locations during the August 1982 cruise. NOAA ship Miller Freeman.

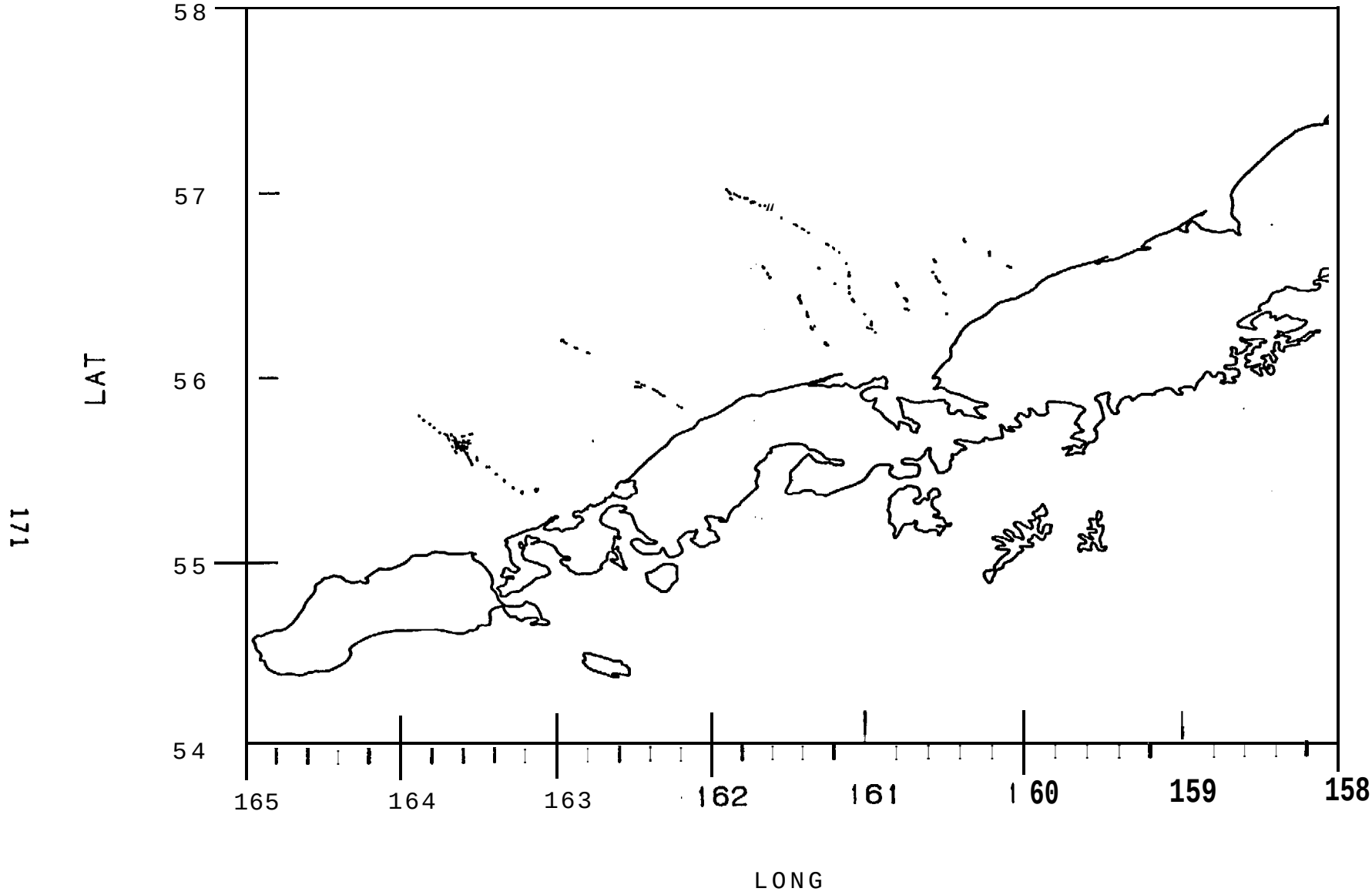


Figure 3. Station locations during the October 1982 cruise. NOAA ship Discoverer.

Table 1. Ship operations accomplished during NOAA/OCSEAP cruises RP-4-MF-82A, LEG I, June, 1982; RP-4-MF-82A, LEG III, August, 1982; RP-4-DI-82B-LEG 1A, October, 1982.

Operation	Number per cruise		
	Jun 82	Aug 82	Ott 82
Try net trawls	93	198	72
Diver sled tows	16	0	0
Drift dives (no sled)	8	19	5
TV tows	18 (8.3 h)	4 (3 h)	0
Grabs	20	35	18
CTD ' s	18	75	75

before freezing. From large catches on the June and August cruises, portions of juvenile king crabs caught were measured and then maintained in live tanks for shipboard experiments. Because of their extremely small size (CW <20 mm) most tanner crab, C. bairdi, were not measured individually but were counted and weighed as a batch before freezing.

In 1983 juvenile king crab (CL <30 mm) were collected and frozen for Battelle during the NOAA/OCSEAP North Aleutian Shelf cruises. These crab were used in determining dietary composition by visual examination and in the immunoassay. During May, 1983, additional potential prey items were collected near the Pribilof Islands and prepared for the immunoassay.

CARAPACE SIZE/MAXIMUM STOMACH VOLUME RELATIONSHIP

Equations relating the carapace size to the stomach volume were developed for king and tanner crab, C. bairdi, after Hill (1976). These equations were necessary to calculate stomach fullness by volume in later analyses. Before dissection of individual crabs, measurements of wet weight, sex, carapace length, carapace width, and shell condition were made as required for OCSEAP-specified NODC digital data files. After these measurements, the carapace of a thawed crab was carefully dissected from its body. The muscle and other tissue were removed from the outside of the stomach, and the stomach ligatured first at the oesophagus and secondly between the foregut and the midgut posterior to the filter chamber. After cutting of the oesophagus and intestinal tract, the ligatured stomach with its contents was removed. In a graduate cylinder the volume displaced by the stomach with its contents was measured to the nearest 0.5 ml (0.1 ml for smaller stomachs). With a syringe clean seawater was injected into the stomach through the cut end of the filter chamber until the stomach wall became smooth and taut and water began to leak along the syringe. The displacement volume of the stomach with its contents plus injected water was then measured. After opening the stomach and washing the contents into formalin, the displacement volume of the stomach wall alone was measured. The maximum stomach volume. V_{max}, was calculated by subtracting the volume of the stomach wall alone, V_s, from the volume of the stomach with contents and injected water, $V_{s,c,w}$, i.e.,

$$V_{max} = V_{s,c,w} - V_s.$$

Regression analysis was used to relate carapace size to the maximum stomach volume. As a measure of carapace size, carapace length was used for king crab and carapace width for tanner crab.

STOMACH CLEARANCE RATES

Stomach clearance rates for juvenile king crab were determined for several prey types. To determine how quickly the quantity of contents naturally-present in the stomach decreased, juvenile king crabs from large catches in June and August were used. A portion of these large catches were frozen immediately, and the rest held without food in a live tank at ambient seawater temperature (8–9 C). During holding in June, the live tank was periodically siphoned to remove feces and regurgitated shell. In August, the crabs were held in baskets that separated the crabs from any regurgitated or defecated material. At selected time intervals after capture, subsamples of the captive crabs were removed from the live tank and frozen. Later the volume and dryweight of the gut contents of these crabs were determined,

The volume of stomach contents was determined by subtracting the displacement volume of the stomach wall alone, Vs, from that of the intact, ligatured stomach with its contents, $V_{s,c}$. Dividing the resulting volume by the maximum stomach volume, V_{max}, and multiplying by 100, gave the percentage stomach fullness, F, by volume. Thus,

$$F = \frac{V_{s,c} - V_s}{V_{max}} 100.$$

For June samples determination of clearance rates by plotting percentage stomach fullness against time was confounded by the large volumes of clear liquid that still occurred in stomachs after solid material disappeared, and to avoid this confounding the dry weight of the stomach contents and the volume of the solid material alone were determined. After determining sex, wet weight, and carapace length, of thawed crabs from August, the stomachs and their contents were transferred to graduated and tared centrifuge tubes. After 1 h of settling, the total volume of liquid and solids and the volume of solids alone were recorded. Settling for 16 h did not change the volume noted after 1 h. After noting the volumes and the occurrence of sand, floe, soft tissue, or hard parts, the stomach contents were dried at 60 C to constant weight. The

percentage of the maximum stomach volume occupied by solid material was calculated, and the dry weight standardized by dividing it by the crab's wet weight. The stomach contents preserved in June were similarly reanalyzed, except that the addition of preservative precluded measurement of total volume including the liquid.

To determine stomach clearance rates for specific prey items, crabs from large trawls in August were held without food in the ship's live tank. Seven days after isolation examination of the stomachs of 5 crabs confirmed that all were empty except for liquid and that crabs held at least 7 days could be used in the experiment. After 7-12 days without food crabs were removed and their sex, wet weight, carapace length and width, and shell condition determined. Individual juvenile king crab were tagged and placed into individual containers with seawater to be given a specific prey item. Individual crabs were presented with one of the following: pandalid shrimp, juvenile gadid fish (2-3 cm), barnacles (*Balanus* sp), small mussels (*Mytilus edulis*, <2 cm long), shucked and diced clam (*Spisula polynyma*: siphon, foot, and adductor), tube worms (Sabellidae), and snails. With the exception of the mussels these or similar prey types had been identified in crab stomachs in June. Whole mussels were used in place of the small clams, e.g., *Tellina* sp, which were preferred but not obtained in sufficient number during the survey.

The protocol was as follows: During daylight a tagged and measured crab was transferred from isolation to an individual container with seawater. After 0.5 h of acclimation, a known number and volume of a specific prey item were added. The containers were examined every 10 to 15 min. If a crab had eaten more than half the food, the crab was removed and it was determined by formal randomization whether to freeze the crab immediately or transfer it to isolation for a prespecified time interval. Any crabs that had not eaten within 1.5 h after food introduction did not enter the analysis for that food. After removing a crab, the remaining food was recovered and its volume measured to confirm that the crab had, indeed, ingested the food.

The live tank had flowing seawater at 0.0 to 0.3 C above ambient sea surface temperature (8–9 C). After 1.5 h, seawater in the static feeding containers rose less than 0.9 C. The bottom temperature at capture varied between 5 and 6 C.

In the laboratory, the stomachs from thawed crabs were removed and the contents transferred to graduated and tared centrifuge tubes. As described above the total volume of liquid and solids and that of solids alone were determined before drying the contents to constant weight.

SHIPBOARD OBSERVATIONS OF FEEDING BEHAVIOR

On shipboard the feeding behavior of juvenile king crab was observed during the clearance rate experiment and later filmed in a large glass-fronted aquarium with flowing ambient seawater. Special note was taken of how crabs handled prey items during ingestion.

DIEL FEEDING CHRONOLOGY

In areas of high crab density continuous trawling from 23 to 72 hours was conducted to collect crabs for determination of diel feeding chronologies. Generally, two or three trawls took place within 2 h, and the samples taken within each 2-h period of the 24-h cycle were pooled.

Stomach fullness determined as described above was plotted against time of day and the plot examined for periods of high fullness. Because this method proved inadequate due to high volumes of liquid in otherwise empty stomachs, preserved and frozen stomachs were analyzed as decribed above to obtain the percentage of maximum stomach volume occupied by solids and dry weight of stomach contents standardized by the wet weight of the crab. Plots of these two variables against time of day were examined for periods of high stomach contents.

DAILY RATION

Using the diel feeding chronologies and equations for the clearance rates of all items naturally present in the king crab stomachs, daily rations for June and August were calculated following a modification of the technique of Elliott and Persson (1978). The diel feeding chronologies gave the dry weight (mg/g crab wet weight) of stomach contents for each 2 h period of the 24 h cycle. To determine the amount of food consumed during each 2–hour interval, the following equation from Elliott and Persson (1978) was used.

$$C_t = S_t - S_o + A$$

where t = midpoint of the 2-h -interval,

C_t = amount of food consumed,
S_o = amount of food at the beginning of the interval,
St = amount of food at the end,
and A = the amount of food evacuated from the stomach during the interval.

The amount evacuated is given by the following equation:

$$A = 1/2 (S_o + S_t) - S_r,$$

where $S_r = 1/2 (S_o + S_t) e^{-Rt}$
R = the decay constant
and t = 2 h.

Values for So and St were taken from the dry weight data in the diel feeding chronologies, and A was calculated using the multi-compartmental clearance rate equation given in Table 2 in place of the term, e^{-Rt}, used by Elliott and Persson (1978). By summing the twelve C_t values for each 2-hour period of the day the daily ration was calculated. Later the daily ration was converted to caloric equivalents using the dietary composition data and caloric values of prey items.

DIETARY COMPOSITION

The Frequency of Newly Discovered Prey as a Function of the Number of Stomachs Examined

To determine the optimal number of stomachs to examine in detail for dietary composition, 25 stomachs were examined from one station with a large catch of 192 juvenile king crabs. Following Vesin et al. (1981) the number of newly discovered prey items was plotted against the number of additional stomachs examined.

Dietary composition from Visual Examination of Stomach Contents

Stations for the examination of stomach contents of juvenile king crab (CL = 53-80 mm) were chosen by two criteria. First, the stations were occupied at or near a feeding peak evidenced in the diel feeding chronology. Secondly, the number of crabs at the stations approached the optimal number determined from above. Most juvenile crabs visually

Table 2. **Clearance rates for all items naturally present in the stomachs of juvenile** king crab. V = proportion of the initial value for the volume of sol ids as a percentage of maximum stomach volume. This average initial value of solids volume was 23.1 (± 2.4 SD) %. W= proportion of the initial value for the gram dry weight of stomach contents per gram crab wet weight. The average initial value for the dry weight was 2.91 (± 1. 51) mg dry weight/g crab wet weight. T = time in hours after isolation. $\bar{T}$ = mean life, the reciprocal of the decay constant.

Basis	No. of time intervals	Equation	R^2	$\bar{T}$ in the compartments	Time (h) to 10% of initial	Time (h) to 5% of initial
Volume	14	$V=0.191e^{-1.190T}+0.856e^{-0.0930T}$	87.9	0.84 10.8	23.2	30.6
Dry weight	18	$W=0.287e^{-1.134T}+0.551e^{-0.148T}+0.226e^{-0.0217T}$	93.1	0.88 6.8 46.1	38.0	69.5

examined entered the dry weight analysis discussed below, and in some cases also entered the immunoassay. Thus, for larger juveniles both visual and immunological analyses were performed on the same stomachs. The smallest juvenile king crab (CL <30 mm) from both 1982 and 1983 were randomly assigned either to visual examination or to the immunoassay because the stomach volumes of the smallest juveniles proved too small for both analyses to be done on the same stomach.

Stomach contents were examined under a dissecting scope, sorted, and the prey items identified to the lowest taxa possible. For stomachs entering dry weight analyses all items were sorted and added to a pooled sample in a tared vial for drying to constant weight. Because of grinding by the crab's gastric mill, counting the number of prey items proved impossible.

The percentage frequency of occurrence was calculated by dividing the number of stomachs in which a prey item was observed by the number of stomachs examined and multiplying by 100. Another measurement of dietary importance calculated was the percentage of all occurrences for each prey item, i.e., the number of occurrences of a prey item divided by the total number of all occurrences of all prey items multiplied by 100.

To correct estimates of dietary composition for overestimation of the importance of items with hard tissue and, therefore, long gut residence . times, the percentage of all observed occurrences were corrected following Peterson and Bradley (1978). Estimates of gut residence time came from the shipboard clearance rate experiments. Residence times for items not determined experimentally were estimated by their similarity to those so determined. From the number of stomachs containing floe during the clearance rate experiments, the residence time for floe was found to be 90 h. To correct for gut residence times, the percentage of all occurrences of each item was divided by its gut residence time to determine the relative dietary proportion. Summing the relative proportions and then dividing individual relative proportions for each item by the resulting sum gave the corrected proportion of the diet each item represents. In calculating the percentage of diet totals that both included and excluded floe and sand were used.

Dietary Composition from Dry Weights of Prey items

Because dry weights are the appropriate measure of bulk for conversion to caloric intake (Hyslop, 1980), the percentage of the diet of juvenile king crab contributed by each prey item was determined by dry weight of each prey item. From the stomachs visually examined above, prey items were sorted into tared vials for drying at 60 C to constant weight. To

obtain sufficient weights all the stomachs at a station were pooled into one sample. Dividing the dry weights of individual prey items by the total dry weight of all items and multiplying by 100 gave dietary composition as a percentage of total dry weight. Because floe and sand proved a substantial proportion of the dry weight, calculations were done both including and excluding floe and sand.

CALORIC INTAKE

To determine caloric intake the dry weights for each item needed to be converted to caloric equivalents. However, simple conversion of dry weights of stomach contents to calories was not possible without an estimate of the intake of soft tissue, Caloric values are determined on the soft tissue of marine invertebrates after the shell or other hard parts have been removed. Because the dry weights of prey items were determined almost exclusively by weighing hard tissue, such as shell, estimating the dry weight of soft tissue ingested from the dry weights of hard parts was necessary before conversion to calories was possible. For a number of potential prey items collected from the Bering Sea, the soft tissue was separated from the hard tissue, and both dried at 60 C in tared containers to constant weight. Soft tissue/hard tissue conversion factors were calculated by dividing the dry weight of the soft tissue by the dry weight of the hard tissue. Conversion factors for prey items not determined experimentally were estimated by their similarity to those items for which data exists. Floe was assumed to be essentially soft tissue and assigned a scft tissue/hard tissue ratio of 1.000.

To obtain dietary composition on the basis of soft tissue dry weights, the dry weight for each prey item was multiplied by its soft tissue/hard tissue ratio, the resulting soft tissue dry weights summed to obtain a total, and the percentage of the diet calculated based on that total. Correction for gut residence time followed the same procedure described above for dietary composition as percentage of all occurrences.

To obtain the energetic contribution to the diet made by each prey item, the corrected percentage of diet on the basis of total scft tissue dry weight was multiplied by the daily ration (mg/g crab wet weight) to yield the soft tissue dry weight for each item. Then these soft tissue dry weights were multiplied by the calcric values (calcries/mg dry weight) to obtain the calcries ingested from each prey item. Caloric values came either from the literature or from new determinations done on specimens collected frcm the Bering Sea. These new determinations of calcric value were done by standard bomb calorimetry with benzoic acid standards at

Battelle's Pacific Northwest Division in Richland, Washington.

After multiplication of the soft tissue dry weights by the caloric values, summing the caloric intakes for all items gave the daily ration in calories per g crab wet weight per day. The percentage of this total caloric intake that each item contributed was then calculated.

IMMUNOASSAY

Because the grinding of the crab's food by the gastric mill (Warner, 1977) renders prey unidentifiable, visual examination of gut contents suffers bias. To identify prey entirely missed by conventional analysis, immunological examination of gut contents modified from Feller et al (1979) was performed. Briefly, probable macro and meiofaunal prey items were collected as described above. On shipboard these organisms were isolated in seawater filtered to 45 microns. After up to 7 days to clear their stomachs of foreign protein the isolated organisms were flash frozen. In the laboratory, whole organism extracts were prepared by grinding frozen prey in a chilled buffer solution. Protein concentrations in the extracts were determined spectrophotometrical ly against albumin standards. Following standard protocols (Kenny, 1971) extracts of known protein concentration were injected into rabbits to produce antisera of varying specificity.

To determine self and cross reactions and reactions between the antisera and gut contents, standard Ouchterlony (double immuno diffusion precipitin) tests were performed. In this test the antigen and the antisera were allowed to diffuse towards each other through a supporting medium of 0.5 percent agarose gel on glass microscope slides for 48 hours. When a soluble antigen (prey organism extract or stomach contents) reacted with its specific antibody (antisera to prey organisms), a precipitate was formed where they met in optimal proportions. The opaque precipitin lines were then stained with Coomassie Brilliant Blue R and counted. Based on the number of precipitin reaction lines encountered, a matrix table of self and cross reactions was developed similar to Feller's.

RESULTS

LOCATION AND COLLECTION OF JUVENILE CRABS

Juvenile king and tanner crabs varied in their spatial and temporal distribution. In June, August, and October, no juveniles of the tanner crab, C. opilio, and only minimal numbers of adults were captured. In June trawling produced only 56 adult C. opilio, 50 of which occurred in one trawl at the extreme western end of the study area near Unimak Pass. The study area apparently does not contain juvenile C. opilio, and the tanner crab mentioned in the rest of this report are C. bairdi.

Juvenile tanner crab, C. bairdi (CW <20 mm), were most abundant near Amak Island at depths of 55-65 m in June, 65-75 m in August, and over 80 m in October. Over 2000 of C. bairdi were less than 20 mm CW whereas less than 50 were greater than 20 mm CW.

Juvenile king crab were concentrated off Port Moller and Cape Seniavin. In June, August, and October only adult king crab occurred west of Nelson Lagoon. Off Port Moller, juvenile king crab were deeper in August (65 to 75 m) than in June (55 to 65 m). In contrast to the hundreds of juvenile king crab taken off Port Moller in June and August, only one juvenile king crab was taken in October.

Diver sled tows covered the areas shoreward of 20 m in June, but divers sighted no pods or solitary king crab or tanner crab. The high-energy sandy nearshore areas along the north side of the Alaska Peninsula do not appear to offer good habitat for juvenile crab. Among boulders divers did find 4 juvenile king crab (CL <20 mm) at approximately 18 m near Amak Island.

TV tows off Cape Seniavin and Port Moller revealed that juvenile king crab occurred on sandy bottoms where large numbers of ascidians and sponges were growing on the large tubes of polychaete worms. The crabs were not aggregated or podded, but solitary. All TV tows occurred during daylight. Because this survey was not specifically designed to compare TV

tows and trawling as techniques for assessing distribution and abundance, little can be said concerning the relative effectiveness of the two techniques in determining distribution. Clearly, the TV tows were most valuable in giving a visual record for characterizing the habitat of the juvenile king crab and should be considered capable of providing information not obtainable from trawling.

Most of the juvenile king crab collected were between 50 and 80 mm CL. King crab less than 20 mm CL were collected by divers or trawls in rocky areas off Nelson Lagoon and near Amak Island. Trawls in these rocky areas tore the nets, and the small juveniles were picked off the torn netting. Of king crab less than 20 mm CL one was taken in June; eight, in August; and one, in October. Two additional king crabs collected were between 20 and 40 mm CL: the remaining king crab were above 48 mm CL. During 1983 other NOAA/OCSEAP investigators collected and froze 63 specimens of juvenile king crab (CL = 5-29 mm) for use in the immunoassay.

The lack of juvenile king crab off Port Moller in October was unexpected but may have been related to oceanographic events. In October warm water (>7 C) extended to the 75-m isobath due to storms with west winds in September. The crabs may have moved in response to the extension of the warm water mass. The smaller shifts of juvenile king and tanner crab from 55-65 m in June to 65-75 m in August may also have been due to seaward extension of the frontal zone in August. A more systematic effort would be necessary to demonstrate that the juvenile crabs migrate seaward and shoreward before the frontal zone of the coastal water mass located approximately at the 50–m isobath.

CARAPACE SIZE - MAXIMUM STOMACH VOLUME RELATIONSHIP

In June, 262 of the 319 king crabs (CL = 33–129 mm) that were dissected had intact stomachs and were used in the regression analysis. The following power function proved to relate the maximum stomach volume, V (ml), to the carapace length, L (mm):

$$V = 2.22 \times 10^{-5} L^{2.87}$$

or in $V = -10.716 + 2.87 \text{ in } L$.

The R-squared was 76.6%. Equations for the separate sexes did not differ significantly so that data from both sexes were pooled to produce the above equation. Shell condition also did not prove to be a significant variable.

For tanner crab, C. bairdi, the following power function related maximum stomach volume, V (ml), to carapace width, W (mm):

$$V = 2.68 \times 10^{-5} W^{2.69}$$

$$\text{or } \ln V = -10.527 + 2.69 \ln W.$$

Ninety-two out of 133 tanner crabs (CW = 27-153 mm) were successfully dissected and entered the analysis. The R-squared was 79.8%.

These equations differ substantially in mathematical form from that given by Cummingham (1969) and cited and used by Jewett and Feder (1982) for adult king crab. The equation appearing in Jewett and Feder (1982) has a typographical error and is really a second order quadratic. Thus, Jewett and Feder's equation is only a good fit over a specific size range, and for king crabs below 70 mm CL actually gives increasing stomach volumes for-decreasing carapace lengths. Most allometric relationships in crustaceans are power functions so that it was not surprising that regression analysis confirmed a power function relating carapace size and stomach volume. The power functions presented here are more appropriate models than the quadratic best fit model given by Cummingham (1969) and used by Jewett and Feder (1982).

The above equations were used to calculate the maximum stomach volume from the carapace size of crabs measured in the laboratory. The maximum stomach volume was then used in calculations of percentage stomach fullness and other statistics.

STOMACH CLEARANCE RATES

Clearance Rate for all Items Naturally Present

To obtain a decay curve describing the passage of food from the gut, 85 juvenile king crab, 61.3 (± 6.6 SD) mm CL, were kept in June without food in ship's live tank and sacrificed at intervals of T = O, 1, 2, 4, 8, 12, 16, 24, 40, 72, and 121 h. In August 58 juvenile king crabs, 64.3 (±8.1) mm CL, were sacrificed at T = O, 8, 12, 24, and 48 h. Stomach fullness as a percentage of the maximum stomach volume was determined for the June samples using the total volume of the gut and its contents.

Stomach fullness plotted against time after isolation proved not to describe adequately the passage of solid material from the gut because large amounts of liquid were still present in otherwise empty stomachs. In fact, the volume of liquid actually increased with time after -isolation (Table 3), and otherwise empty stomachs contained enough liquid to maintain 25 to 30% stomach fullness after 130 h. The liquid was clear to light brown and without floe or the cloudiness indicating fine particulate matter. Apparently the crab maintains a minimum level of digestive fluid in its gut. To avoid confounding the determination of clearance rates by this liquid, the volume of solid material in the stomach and the dry weight of the stomach contents were determined.

Both the volume of solids and the dry weight of stomach contents fell exponentially with time after isolation (Figure 4, Table 2). A two-compartmental model described the decrease in the volume of solids and a three-compartmental model, the loss of dry weight (Table 2). The exponential decay curves were used later to calculate daily ration following Elliott and Persson (1978). Dry weight of stomach contents proved to be a better measure of stomach clearance rates than volume.

Evidence for several compartments rather than one in the exponential decay curves comes from two sources: information concerning variation in gut residence times of different materials (Hill, 1976; Carter and Steele, 1982) and graphical analysis of the data here. Whereas many models of stomach clearance assume a one–compartmental exponential decay curve, it is not reasonable to accept the implication of a one-compartmental model that all the materials in the stomach are digested and passed out at the same rate. Hill (1976) and Carter and Steele (1982) reported that in the stomachs of crabs and lobsters soft tissue is lost in hours while hard parts from bivalves and echinoderms remain for days. Thus knowing that clearance rates do vary among different tissues, it is reasonable to expect that a decay curve describing the passage of a mixture of materials from the stomach would be the outcome of different clearance rates acting on different materials initially present in different proportions. The king crab stomachs examined for this analysis contained floe, sand, soft tissue, shell fragments from small bivalves and gastropod, and sand dollar tests. Finding multi-compartmental exponential models for stomach clearance meets this reasonable expectation.

Graphical analysis indicated the number of compartments in the specific decay curves. If the appropriate model for the exponential decay had only one compartment, then plotting natural logarithm of the dependent variable, e.g., the dry weight, against time would give a straight line. For a two-compartmental model such a plot would show a straight line

Table 3. Stomach fullness as a function of time after isolation. Stomach fullness is expressed as the percentage of maximum stomach volume occupied by the total or liquid portion of stomach contents.

Time after isolation (h)	Stomach fullness by volume %	
	Total contents	Liquid contents
0	**48.3**	**30.1**
8	**30.9**	**22.0**
12	**23.7**	**16.2**
24	**24.9**	**24.4**
48	**28.3**	**28.3**

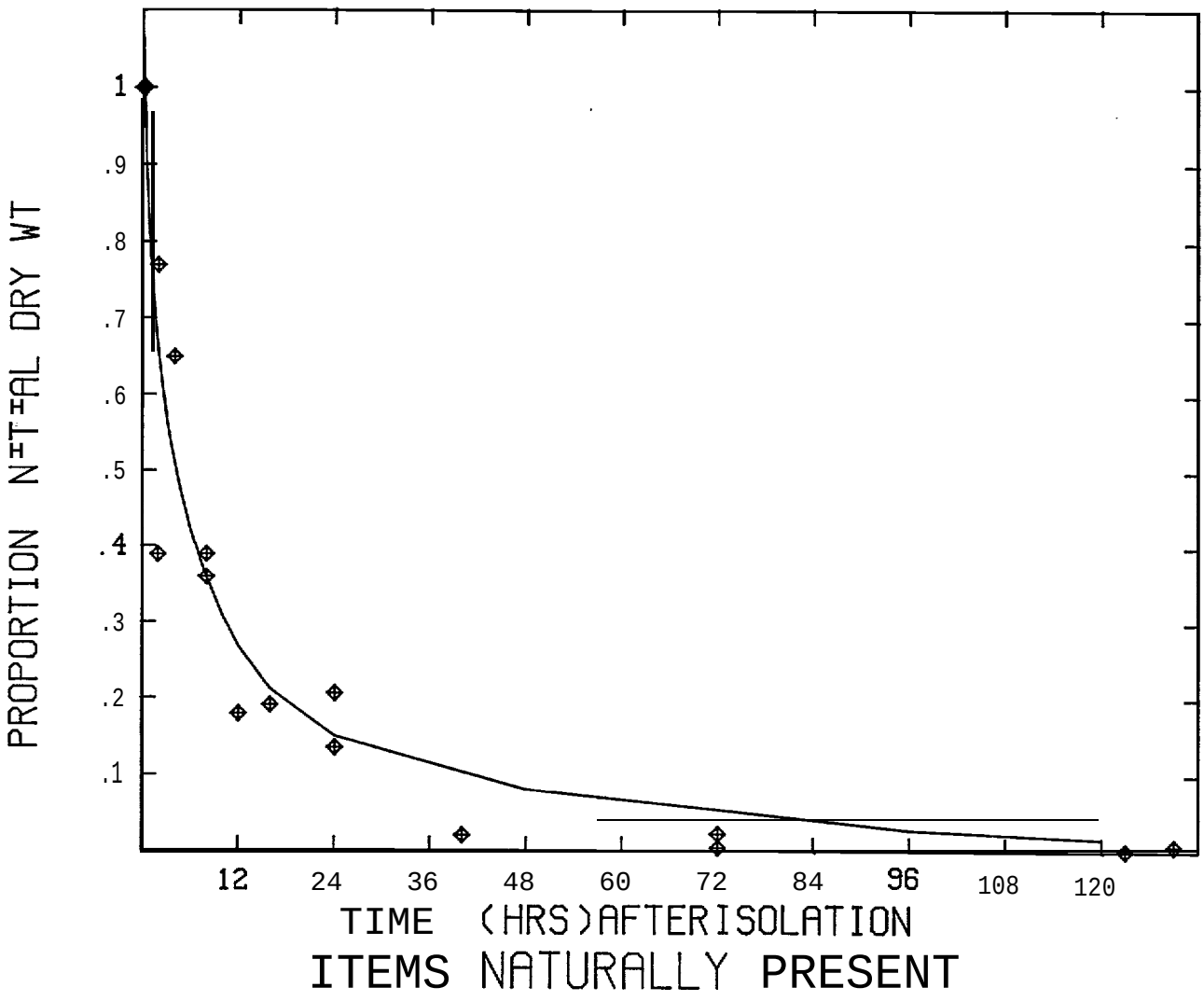


Figure 4. Decay curve for the clearance of all items naturally present in the stomachs of juvenile king crab. The proportion of the initial value for grams dry weight of stomach contents per grams crab wet weight vs. the time in hours after isolation.

falling to an inflection point where another straight line of shallower slope would continue. Similarly, for a three-compartmental model the plot would show three straight lines meeting at two inflection points. For clearance rates of all items naturally present and of specific prey items such plots were used to indicate the appropriate number of compartments and to estimate starting values for a reiterative curve fitting program. The FIT program developed by Battelle Pacific Northwest Laboratories was then used to evaluate the parameters of multi-compartmental exponential decay curves.

Beyond 48 h the volume of solids had fallen below the minimum measurable volume (0.1 ml). If smaller volumes could have been measured, a three-compartmental exponential model might also have described the volume decay curve. In contrast to volume, the dry weight of stomach contents did not fall below the minimum measurable amount. The coefficient and decay constant for the first compartment in the volume curve agree well with those in the dry weight curve. Also, the parameters of the second compartment in the volume curve approximate a combination of the parameters of the second and third compartments of the dry weight curve. Given this agreement, dry weight of stomach contents is the better basis for determining clearance rates than volume on two counts: the better measurements for dry weight than solids volume with extremely low stomach contents and the better fit of the dry weight curve. Similarly, dry weight also proved a better measure for determining clearance rates for specific prey items and the diel feeding chronology described in the next sections.

The parameters of the exponential model have definite biological meaning. The decay constants and their reciprocals, the mean life, indicate how long material remains in a given compartment. Thus from Table 2, material remains in the first compartment less than 1 h; in the second compartment, about 7 h; in the third, 46 h. The coefficients also can be interpreted. Because the dry weight is expressed as a proportion of the standardized dry weight initially present, W = 1,000 at T = O by definition. Note that the coefficients of the three compartments in Table 2 sum to 1.064. The coefficients represent the proportion of total dry weight that is in each compartment at T = O. There are three possible biological interpretations of the coefficients. Under the first interpretation, the coefficients represent the proportions at T = O of different classes of material (either tissue types, e.g., soft tissue, hard tissue,. or prey types, e.g., worms, crustaceans, molluscs). Under this first interpretation then soft tissue would be assigned to the first compartment, Soft tissue would have been slightly less than 30% of the original material and have essentially disappeared after 0.9 h, the mean

life of the compartment. Similarly, hard tissue would be assigned to the third compartment. This third compartment would have constituted 23% of the material originally present and had a mean life of 46 h. Under the second interpretation, the compartments represent processes, such as, digestion and active passage of indigestible material, rather than kinds of materials or tissues. Here the compartments might represent the order of the dominant processes, e.g. first the digestion of soft tissue, then the breakdown of more refractory material and finally the evacuation of indigestible material. Under the third interpretation the compartments are seen to represent some combination of process and material.

More experimental work would be necessary to confirm one or the other of these interpretations. They are presented because all three have practical implications. If the compartmental coefficients indicate the proportion of tissue type initially present, or the predominant digestive process. then a potential method exists for estimating the time at which the crabs fed from a decay curve such as in Figure 4 and Table 2. A high proportion (high coefficient) in the first compartment would indicate recent feeding whereas a low proportion in the first compartment would indicate less recent feeding.

Clearance Rates for Specific Prey Items

On shipboard starved juvenile king crabs fed readily on shucked and diced clam, juvenile fish, shrimp and barnacles, less readily on tube worms, only slightly on mussels. Crabs did not eat the snails. For mussels the number of crabs eating was not sufficient to determine clearance rate. The clearance rate for the sabellid worm is based on much fewer data points than those for the other items and, therefore, should be considered tentative.

For the proportion of the initial grams dry weight of stomach contents per gram crab wet weight, multi-compartmental models described the exponential decay (Figures 5-8, Table 4). As previously described, graphical analysis indicated the number of compartments and Battelle's FIT program evaluated the parameters. Because only a small number of crabs consumed tube worms, the exponential decay model for tube worms (Table 4) is based on data only to 12 h and may have shown more than one compartment if it could have been followed longer. An example of how the individual compartments combine to give an overall decay curve appears in Figure 8.

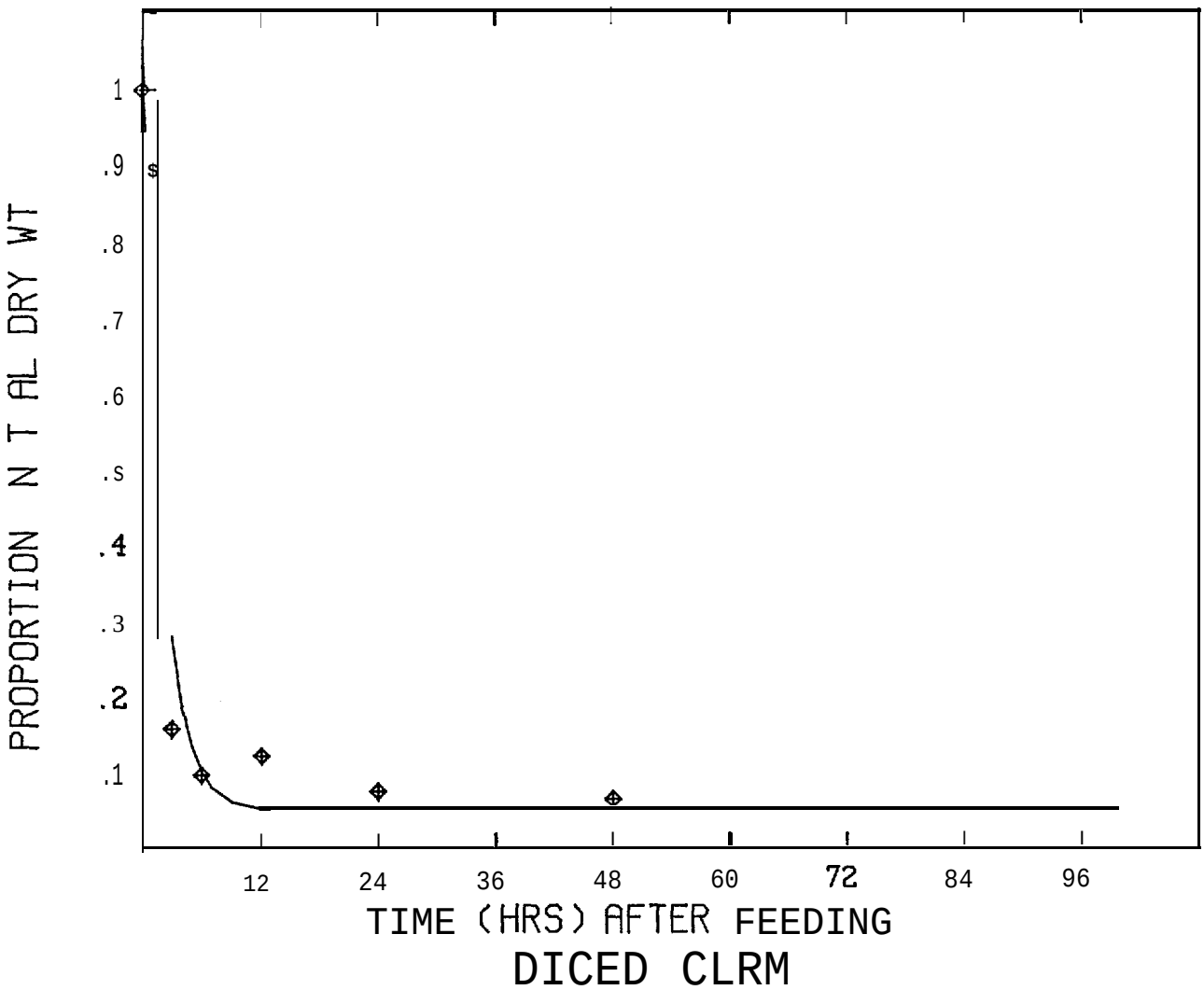


Figure 5. Exponential decay curve for stomach contents in juvenile king crab fed diced clam. The dependent variable is the proportion of the grams dry weight of stomach contents per gram crab wet weight at time = O. See Table 4 for equations.

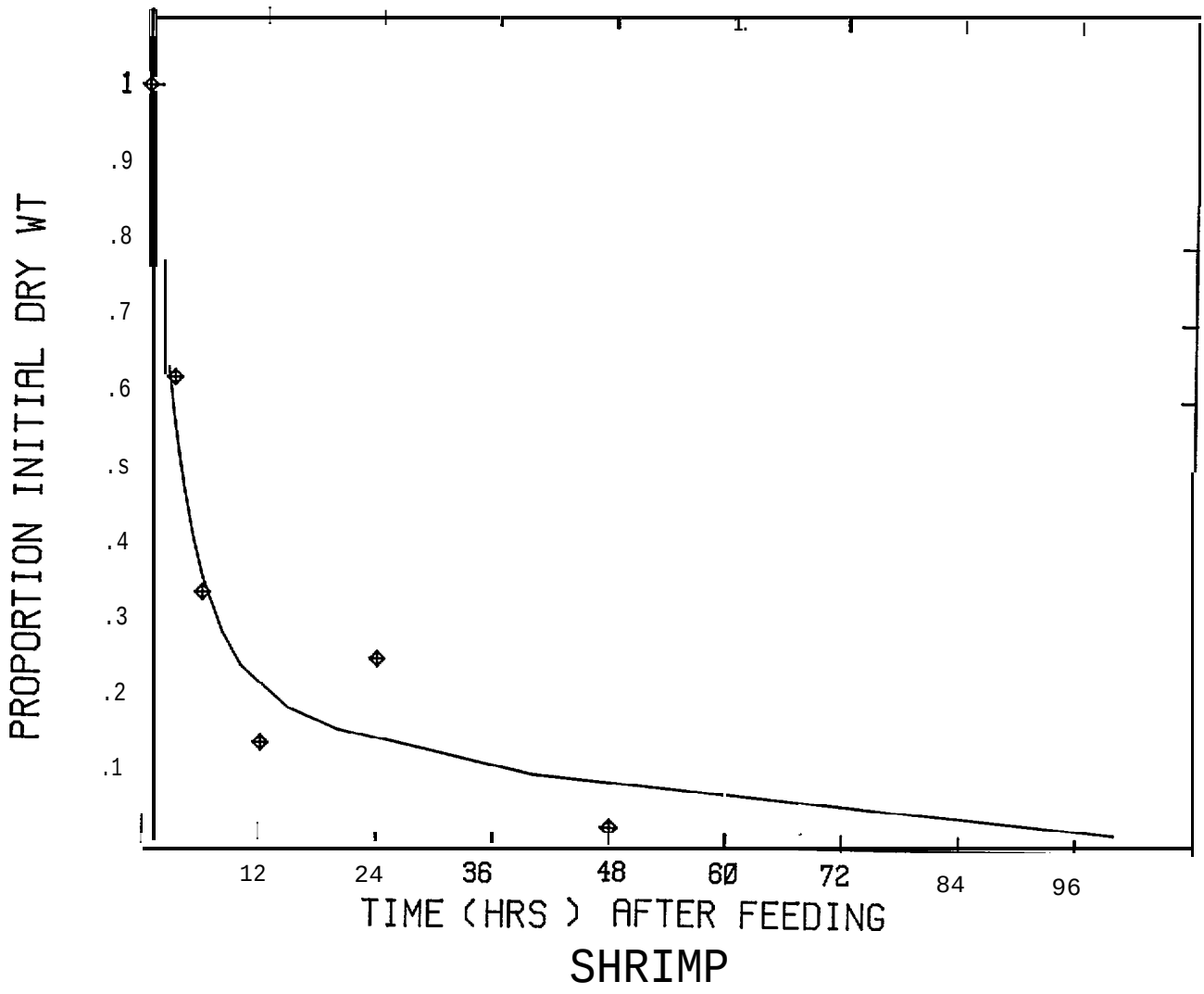


Figure 6. Exponential decay curve for stomach contents in juvenile king crab fed shrimp. The dependent variable is the proportion of the grams dry weight of stomach contents per gram crab wet weight at time = 0. See Table 4 for equations.

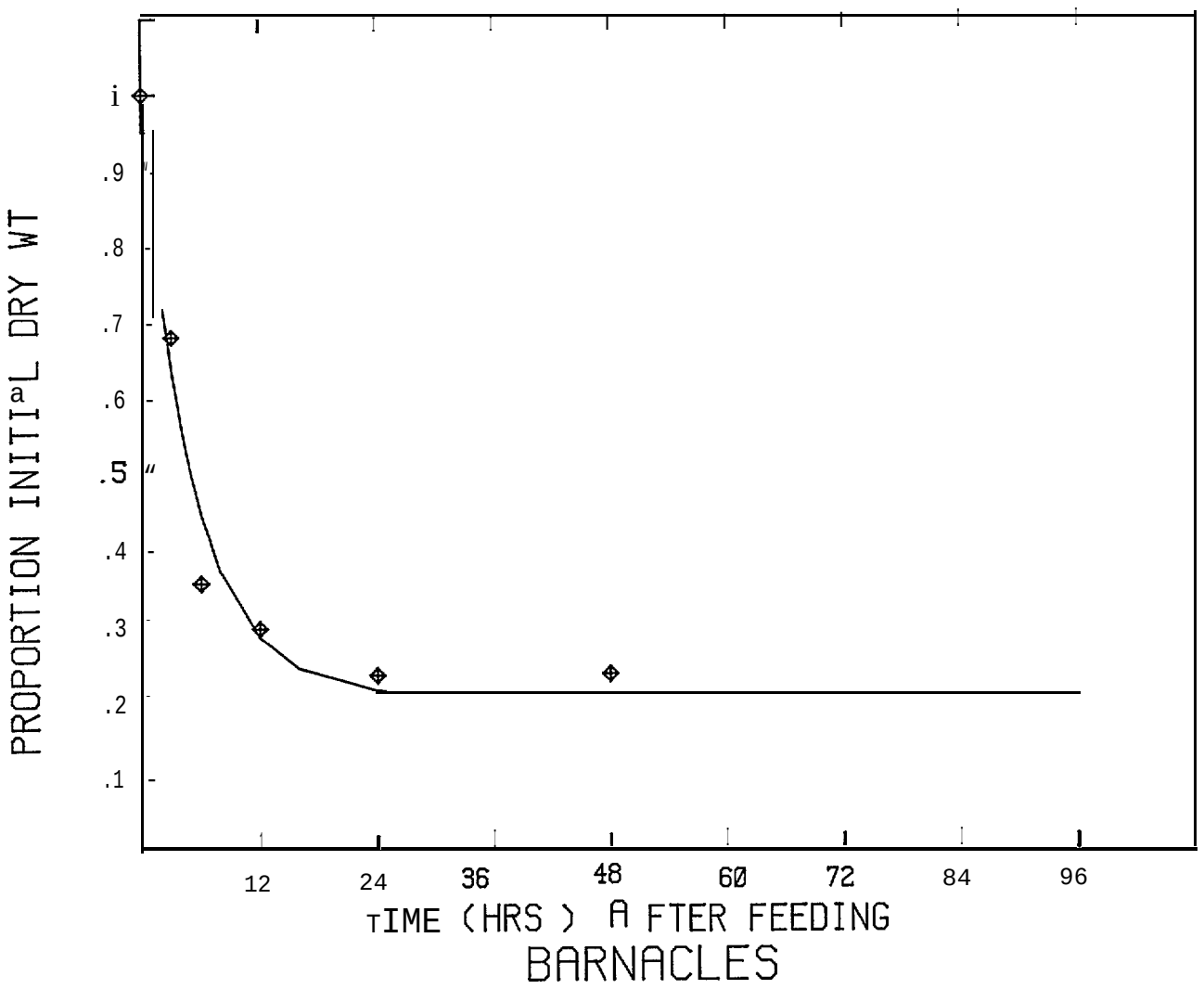


Figure 7. Exponential decay curve for stomach contents of juvenile king crab fed barnacles. The dependent variable is the proportion of grams dry weight of stomach contents per gram crab wet weight at time = 0. See Table 4 for equations.

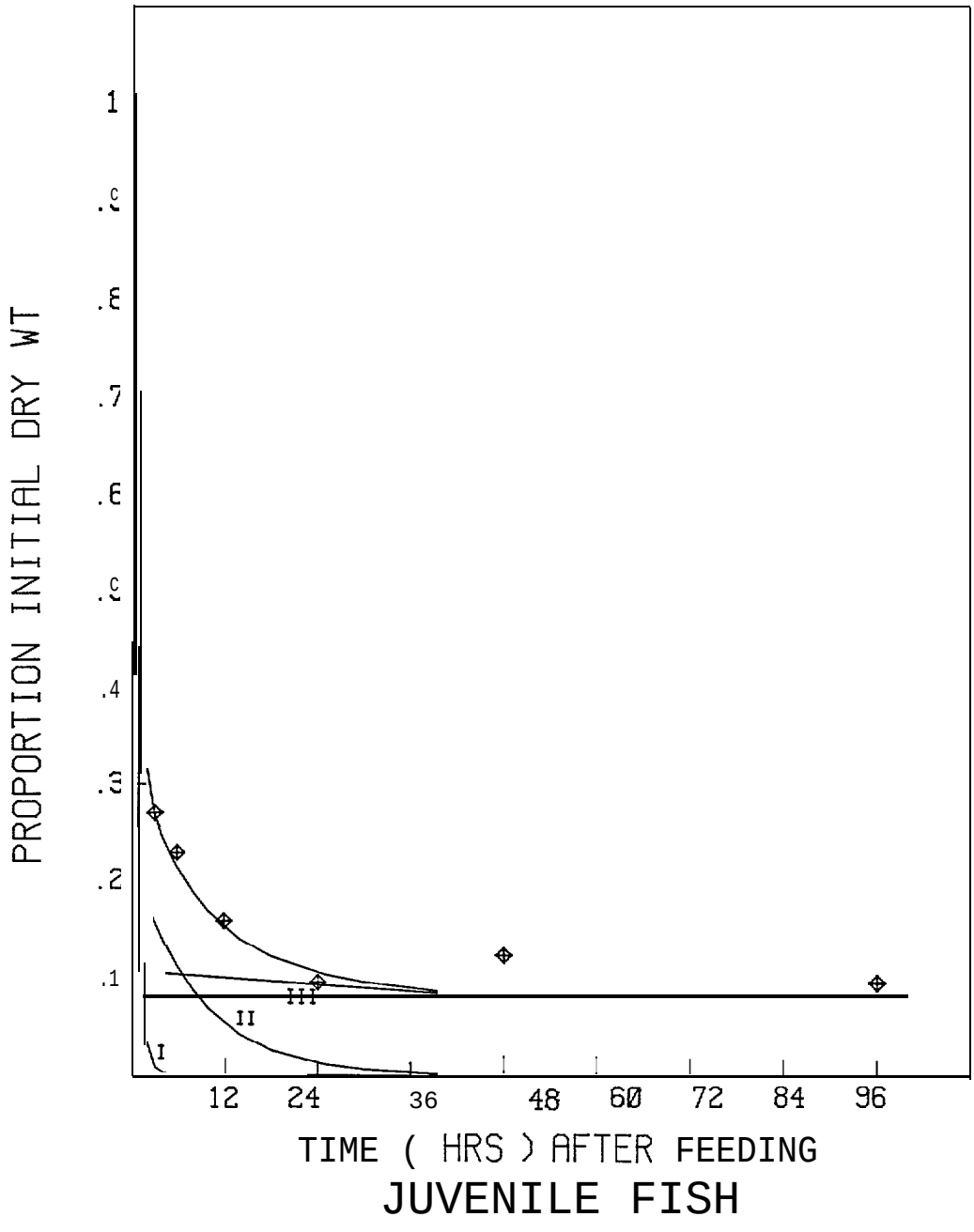


Figure 8. Exponential decay curve for stomach contents of juvenile king crab fed juvenile fish. The dependent variable is the proportion of grams dry weight of stomach contents per gram crab wet weight at time = O. Decay curves for each compartment are plotted individually and label led with Roman numerals. See Table 4 for equations.

Table 4. Stomach clearance rates for specific prey items fed to juvenile king crab. W = proportion of initial g dry weight/g crab wet weight, T = time in h after feeding or isolation, $\bar{T}$ = mean life, the reciprocal of the decay constant.

Prey	Avg. dry Wt (g) @ t = o	Equation	R^2	$\bar{T}$ by (h) compartment	Time (h) to 10% of initial	Time (h) to 5% of initial
Diced clam	0.425	$W=1.003e^{-0.494T}+0.0518e^{-0.0000022T}$	92.9	2.0 4.5X105	6.1	asymptotic to 5% @ 11 h
Shrimp	0.212	$W=0.763e^{-0.0271T}+0.233e^{-0.0224T}$	96.6	3.69 44.5′	37.5	68.5
Barnacles	0.180	$W=0.598e^{-0.225T}+0.192e^{-0.128T}+0.200e^{-0.000033T}$	**97.6**	**4.45** 7.84 $3.0x10^4$	asymptotic to 20% @ 48 h	
Juvenile fish	0.525	$W=0.666e^{-1.518T}+0.229e^{-0.121T}+0.106e^{-0.0058T}$	99.8	0.66 8.23 172.0	26.5	129.5
Tube worm	0.502	$W=0.912e^{-0.204T}$	99.5	4.9	10.8	14.2

A comparison of the equations in Table 4 shows that the overall clearance rates, the number of compartments, and the relative size and mean life of the compartments clearly varied with prey type. The diced clam represented soft tissue with no hard parts and had by far the fastest clearance rate. The decay model for diced clam shows that the first compartment contains almost 100% of the material and has a very low mean life, 2.0 h. Other items showed substantial amounts of material in their second and third compartments and lower clearance rates due primarily to longer mean life in the second and third compartments. Shrimp with an exoskeleton but no heavily calcified parts had two compartments whereas barnacles and juvenile fish with calcified parts (barnacle plates and fish bone) had three compartments. Note that the decay constants in the first compartments (Table 4) are quite comparable for shrimp and barnacles but are much higher for clam and fish. If the first compartment represents digestion of soft tissue, shrimp and barnacles with their crustacean exoskeleton might be expected to have similar decay constants when compared to each other but slower decay constants when compared with prey types having more exposed soft tissue.

If the coefficients for each compartment represent the proportions of tissue types present at T = O, then for barnacles and fish 20% and 10%, respectively, of the ingested material have very long stomach residence times. For lobsters, Homarus americanus, Carter and Steele (1982) found that barnacle plates and bivalve shells remain in the stomach for 180 days. Because' the stomach clearances for the king crab were studied for only 4 days, the third compartment for barnacles appears almost indefinite (mean life = about 1000 d). Even so, this estimate for barnacles is not totally unimaginable given Carter and Steele's (1982) findings.

Conventional determinations of dietary composition are biased in favor of those items with long stomach residence times (Peterson and Bradley, 1978)., and clearance rates for specific prey items were needed to provide gut residence times for corrections of the relative importance of prey items in the diet of juvenile king crab. The occurrence of multi-compartmental models makes it inappropriate to use mean life, the reciprocal of the decay constant, as a measure of stomach residence time because no legitimate way is known to combine the mean lives from several compartments into one number. Instead, the time required for the dry weight to fall to 5% of initial value was taken as a measure of stomach residence time. Such estimates can be readily calculated from the exponential equations and appear in Table 4. Stomach residence times of prey items not studied were estimated by their similarity to those studied.

Estimating an appropriate residence time for shell fragments appears problematic but a reasonable estimate is possible. Carter and Steele (1982) found that shell fragments remained in lobster stomachs 90 to 180 d (2160 to 4320 h). Hill (1976) observed no decrease in the weight of shell fragments in the stomachs of the crab, Scylla serrata, during 8 days of observations while soft tissue fell to 5% of its initial level in 12 h and fishbone, to less than 5% in about 3.5 days (about 84 h). Here barnacle tissue reached 5% of its initial dry weight at 3.0×10^4 h, i.e., 1250 days. Hard tissue, such as barnacle plates and molluscan shell fragments, appear to remain indefinitely in crab stomachs. Hill suggests that crabs regurgitate shell rather than evacuate it into the lower digestive system. Pearson and Olla (1977) and Pearson et al (1979) have seen captive blue crab, Callinectes sapidus, and Dungeness crab, Cancer magister, periodically regurgitate shell when held on an ad libitum diet of blue mussels. During shipboard holding of juvenile king crab regurgitation of shell and sand dollar test fragments was observed. These observations suggest that shell fragments and other hard tissue remain indefinitely in crab stomachs accumulating to some threshold volume at which point the crab regurgitates the entire volume. If so, the problem becomes one of determining the time frame within which the regurgitation will normally occur. On shipboard juvenile king crabs held without food regurgitated shell beginning 4 days after capture and continuing each night until the crabs were used in an experiment at 12 days after isolation. Five crabs sacrificed 7 days after isolation had no visible shell fragments in their guts, but dry weights of stomach contents for these individuals were not determined. Both Hill's (1976) data and that presented here indicate shell fragments have a longer stomach residence time than fish bone. In light of the available information, a stomach residence time for hard tissue such as shell fragments appears to be more than 5.4 days and could be on the order of 135 days for crustaceans continuing to feed on soft tissue. The shipboard observations on regurgitation and visual examination of the stomachs would indicate a residence time between 4 and 7 days. The exponential model would indicate one of 1250 days. The harmonic mean of these four estimates is 10.7 days. This latter value was used in corrections for gut residence times.

SHIPBOARD OBSERVATIONS OF FEEDING BEHAVIOR

On shipboard, juvenile king crabs selectively ingested only certain parts of some prey. Crabs ate the fleshy portions of the shrimp and juvenile fish, leaving the heads. Similarly, crabs ingested little of the barnacle plates and mussel shell. Crabs scraped the soft tissue from the

hard parts with the palps and then dropped the cleaned hard parts. Only small fragments of plate or shell were ingested. Previously Pearson et al (1979,1981) have seen similar selective feeding on soft tissue and discarding of hard parts by the Dungeness crab, C. magister. The implication of the selective ingestion observed in the juvnenile king crab is that in actively selecting soft tissue and rejecting hard tissue, the crab is not ingesting prey items in proportion to the occurrence of hard parts of those items in the stomach. For example, juvenile king crab could well be consuming more clams than the presence of shell fragments indicates.

DIEL FEEDING CHRONOLOGY

Diel feeding chronologies were determined for June and August (Figures 9, 10 and 11). In June juvenile king crab were not sampled at every hour of the day, but in August 25 crabs were obtained in each 2-h period of the 24-h cycle. In October only one juvenile king crab greater than 20 mm CL was collected. Consequently, the best estimate of the diel feeding chronology for juvenile king crab came from August. For tanner crab the sample sizes for crabs greater than 20 mm CW were inadequate to construct a diel feeding chronology. Tanner crab less than 20mm CW had extremely small stomach volumes (<0.08 ml) that precluded this type of analysis.

In June the volume of solid material in the stomachs of juvenile king crab averaged 18% of the maximum stomach volume, and the dry weight of the stomach contents, 1.63 mg dry weight per g crab wet weight (Table 5). In August the volume of solids in the stomach averaged 10% of the maximum stomach volume and the dry weight of the stomach contents, 2.89 mg dry weight per g crab wet weight (Table 6). Because of the low sample size and consequent high variance, there was no significant difference in June with time of day for the volume of solid stomach contents or the dry weight. Ignoring those times of day with less than 10 samples stomach fullness decreased during mid-day in June but again not significantly. In August the volume and dry weight of stomach contents both varied significantly with time of day. In June and August volume and dry weight of stomach contents did not vary significantly with sex.

Patterns in the diel feeding chronologies were similar in June and August. The average amount of food in the stomach was higher in August (Figures 9, 10, and 11). Two feeding peaks occurred. The feeding period between 1300 and 1800 h showed higher amounts of stomach contents than that between 0000 and 0800 h.

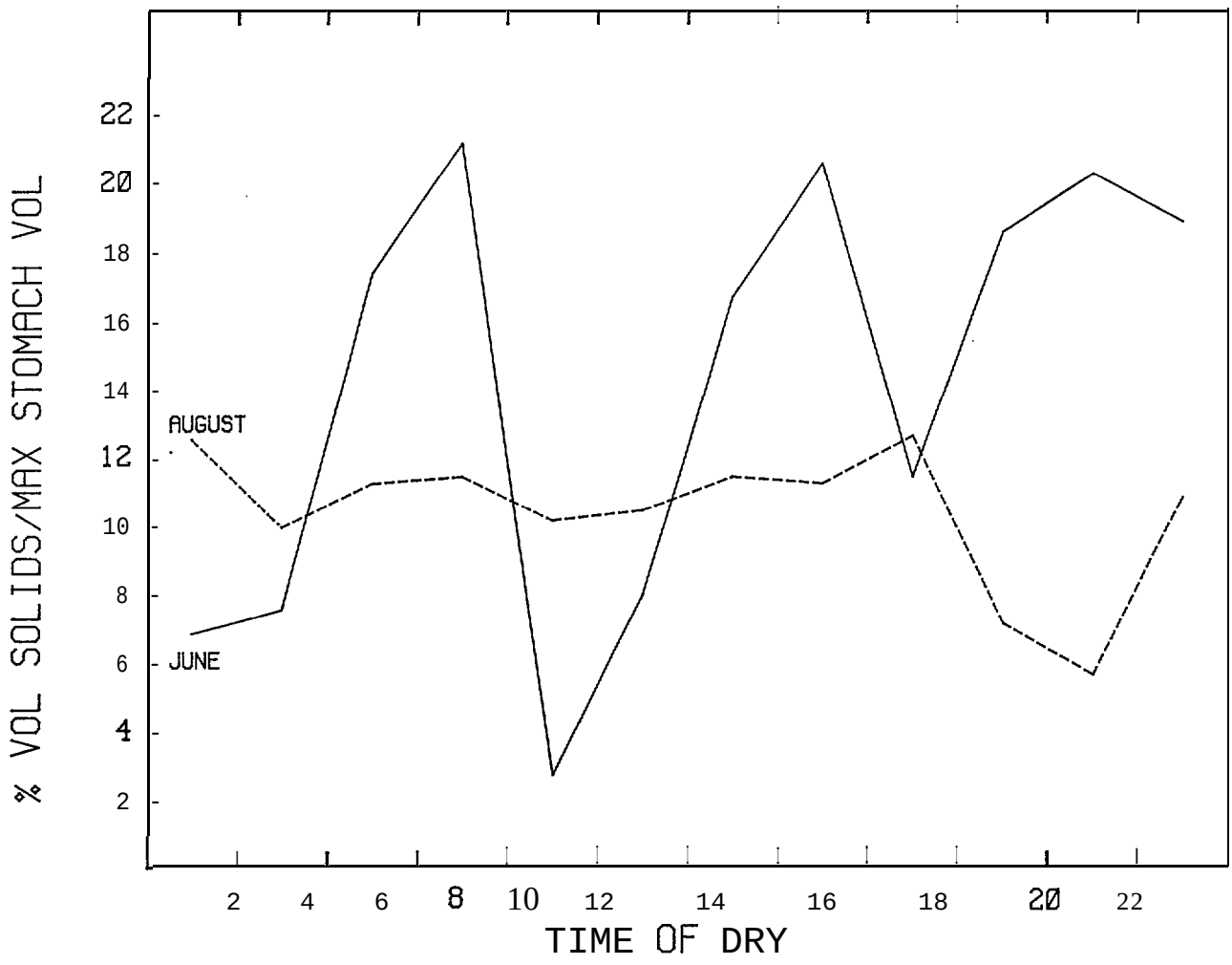


Figure 9. Volume of solids in stomach as a percentage of maximum stomach volume vs. time of day for juvenile king crab.

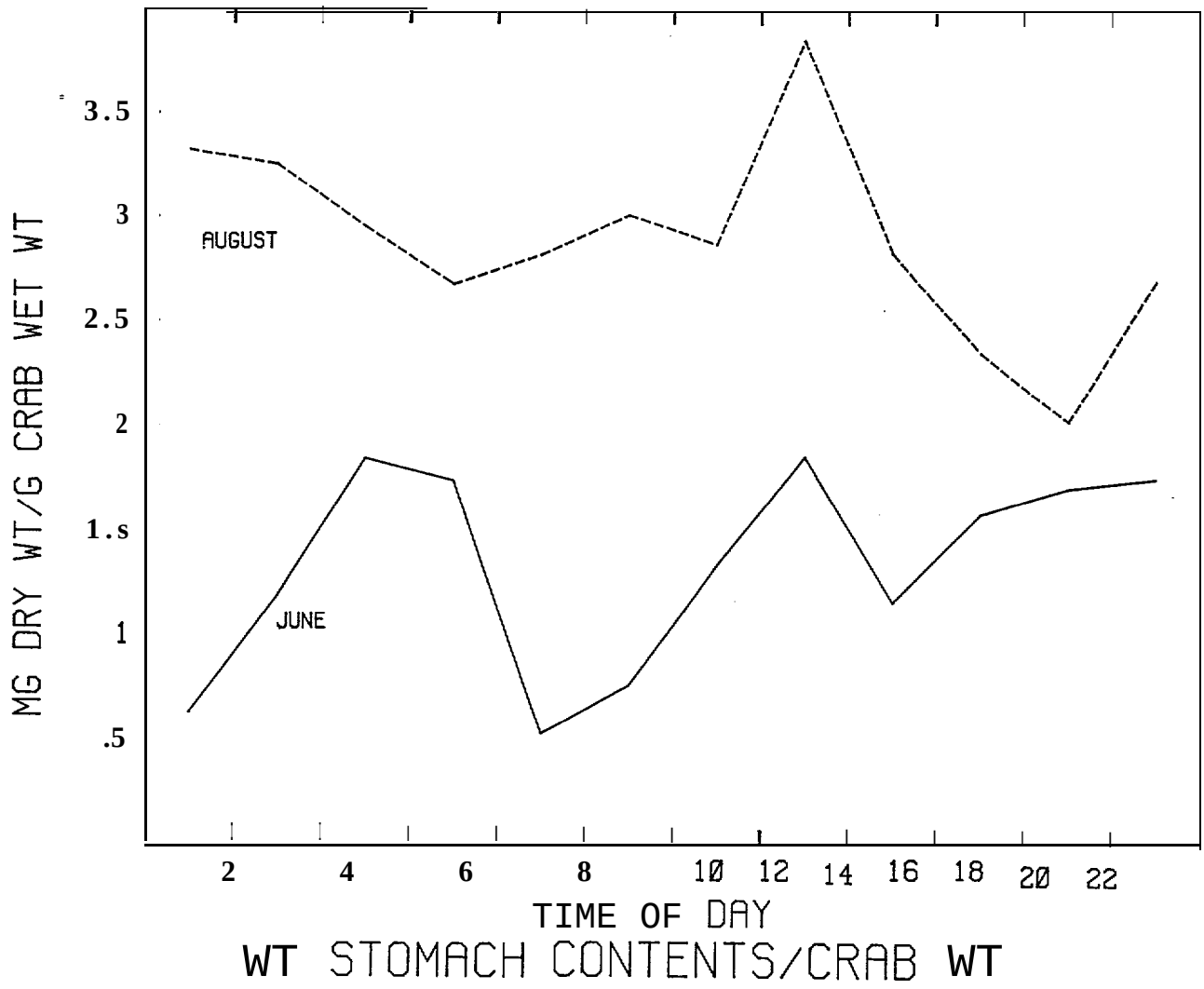


Figure 10. Standardized dry weight of stomach contents (mg dry weight/g crab wet weight) vs. time of day for juvenile king crab.

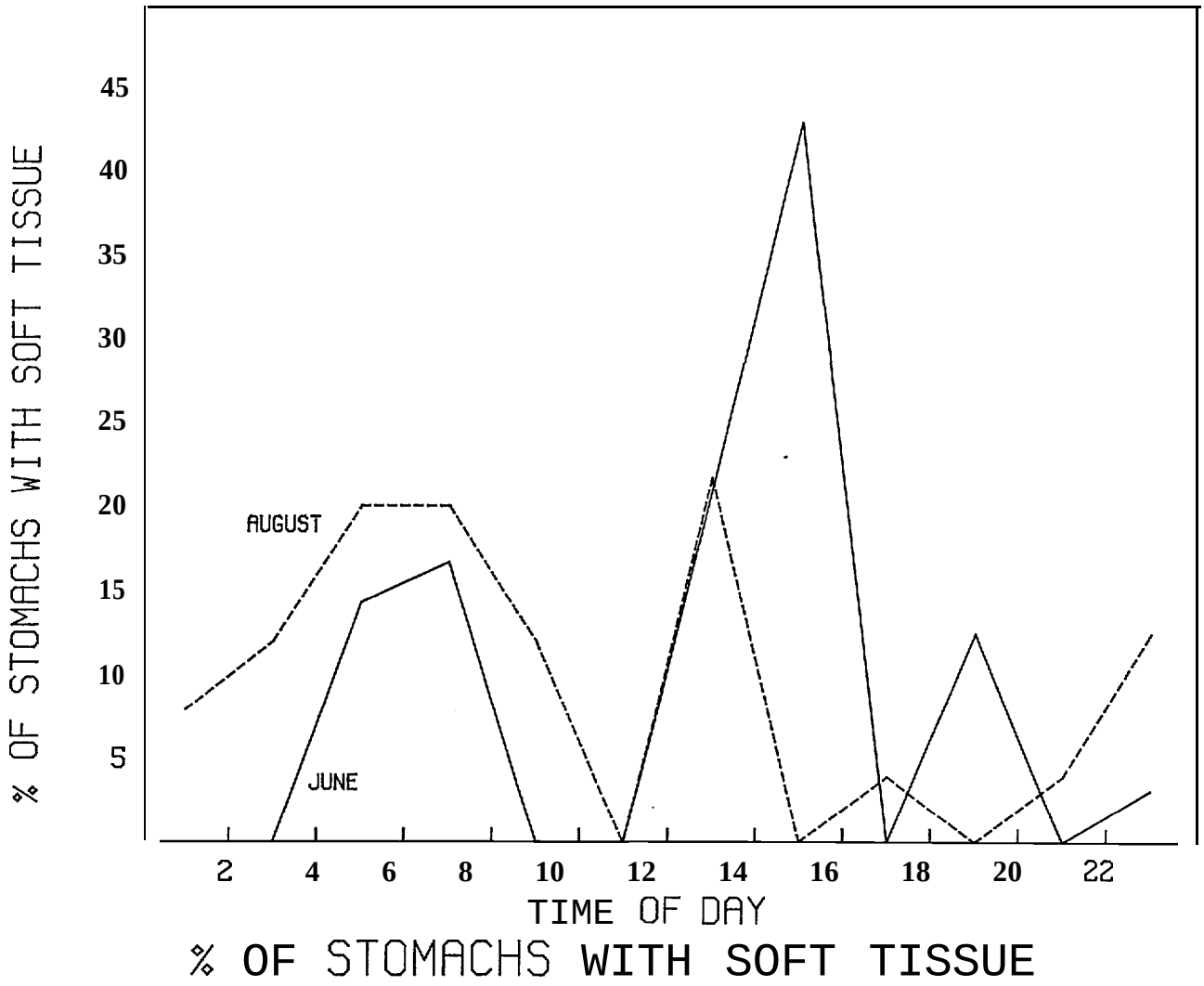


Figure 11. Percentage of stomachs with soft tissue vs. time of day for juvenile king crab.

Table 5. Diel feeding chronology from June, 1982, for juvenile kingcrab (≤ 90 mm CL). Mean carapace length 64.5 (± 8.8) mm. Time of day is midpoint of 2-h period. Duration of trawling was 24 h.

Time of day	N	Volume of solids as % maximum Stomach volume x ± SD		mg dry weight stomach contents per g crab wet weight x ± SD	
0100	4	6.8	3.0	0.635	0.230
0300	1	7.5		1.195	
0500	28	17.3	12.9	1.845	1.480
0700	18	21.1	13.3	1.742	1.030
0900	1	2.7		0.539	
1100	2	7.9	4.3	0.776	0.027
1300	24	16.6	14.5	1.346	1.310
1500	7	20.5	9.9	1.863	1.010
1700	4	11.4	7.3	1.176	1.030
1900	8	18.5	10.5	1.596	0.695
2100	22	20.2	14.7	1.723	1.210
2300	31	18.8	15.6	1.772	1.380
Overal 1	150	17.9	13.5	1.630	1.240

Table 6. Diel feeding chronology from August 1982, for juvenile king crab (≤ 90 mm CL). Mean carapace length 63.8 (± 8.3) mm. Time of day is midpoint of 2-h period. Duration of trawling was 70 h.

Time of day	N	Volume of solids as % maximum Stomach volume x ± SD		mg dry weight stomach contents per g crab wet weight x ± SD	
0100	25	12.5	10.5	3.32	1.93
0300	25	9.9	6.5	3.25	1.41
0500	25	11.2	7.8	2.95	1.30
0700	25	11.4	7.3	2.68	1.21
0900	25	10.1	6.6	9.82	1,47
1100	25	10.4	7.0	3.01	1.23
1300	23	11.4	6.9	2.87	1.27
1500	25	11.2	8.8	3.85	1.95
1700	25	12.6	9.5	2.83	1.42
1900	25	7.1	3.4	2.36	0.83
2100	25	5.6	3.6	2.04	0.77
2300	24	10.8	7.0	2.71	1.19
Overall	297	10.3	7.5	2.89	1.42

These results are comparable to those of Tarverdieva (1978) for red king crab in Bristol Bay during September. The two peaks in feeding found by Tarverdieva (op. cit.) also occurred at 0300 and 1300 h but in contrast to the findings here the nocturnal peak was higher than the diurnal one. During the long photoperiods of June, a nocturnal feeding rhythm present, at other seasons may break down.

The dry weight of stomach contents standardized by crab wet weight was a clearer indicator of diel changes than the volume of solid contents as a percentage of maximum stomach volume. The percentage of stomachs with soft tissue followed the diel trends in dry weight of stomach contents (Figure 11).

DAILY RATION

Using the diel feeding chronologies and the clearance rate equation from Table 2, daily rations in June and August were calculated. Juvenile king crabs in August consumed slightly less than twice the dry weight of material consumed in June (Tables 5 and 6). The June daily ration for juvenile king crab was 6.30 mg dry weight per g crab wet weight per day; the August daily ration, 11.92 mg dry weight per g crab wet weight per day.

The daily ration determined by Tarverdieva (1978) for adult king crab was 3.1 mg/g crab wet weight, about 1/4 to 1/2 of the daily rations. The difference between the calculations here and Tarverdieva's could be a reflection of seasonal differences. More likely it is due to correction for clearance rate in the calculations.

From the daily rations, dietary composition data and caloric equivalents from the literature, a schedule of the energy derived from various prey items was calculated and appears in a following section.

DIETARY COMPOSITION

The Frequency of Newly Discovered Prey as a Function of the Number of Stomachs Examined

Following Vesin et al. (1981), the frequency of newly-discovered prey

as a function of the number of stomachs examined was determined. In 25 stomachs of juvenile king crab from a single station a total of 25 prey items was observed. Examination of 19 stomachs gave 95% of the total number of identified prey items (Figure 12). Thus, 19 is the optimal number of stomachs to examine per sampling unit. Vesin et al. (1981) found that for capelin, Mallotus villosus, examining beyond 10 to 15 stomachs added no new information that influenced overall estimates of dietary composition.

Dietary Composition by Visual Examination of Stomach Contents

The frequency of occurrence, i.e., the percentage of stomachs in which a prey item occurs, gives a crude qualitative view of the extent to which an animal population feeds on a particular item but does not indicate the relative amount or bulk of that item in the stomach or the diet (Hyslop, 1980). In the overall diet of juvenile king crab (CL = 53 to 80 mm), clams, snails, sand dollars, crustaceans and polychaetes rank in that order by frequency of occurrence (Table 7). The major differences in frequency of occurrence between June and August were, first, that sand dollars occurring in 75% of the stomachs in June dropped to 33% in August and, secondly, that Tellina sp in August replaced Cyclocardia cebricostata as the important bivalve.

Dietary composition expressed as the percentage of total number of visually observed occurrences by all items appears in Table 8. For this measure gastropod rank first at 21% in the overall diet followed by pelecypods at 19%, crustaceans at 11%, echinoderms at 10%, polychaetes at 6%, and other taxa at 4.%. Again the major difference between June and August is a decrease in the extent to which sand dollars occur in stomachs.

Frequency of occurrence analyses overestimate the importance of taxa possessing hard tissues that have long residence times in the gut. Dietary composition was corrected for gut residence time following Peterson and Bradley (1978). An example of the calculations appears in Table 9. The uncorrected and corrected dietary compositions appear in Tables 10 and 11. Whereas bivalves, snails and sand dollars dominated the uncorrected dietary composition, polychaetes, a soft bodied prey with short gut residence time, dominated the corrected dietary composition of the larger juvenile king crab.

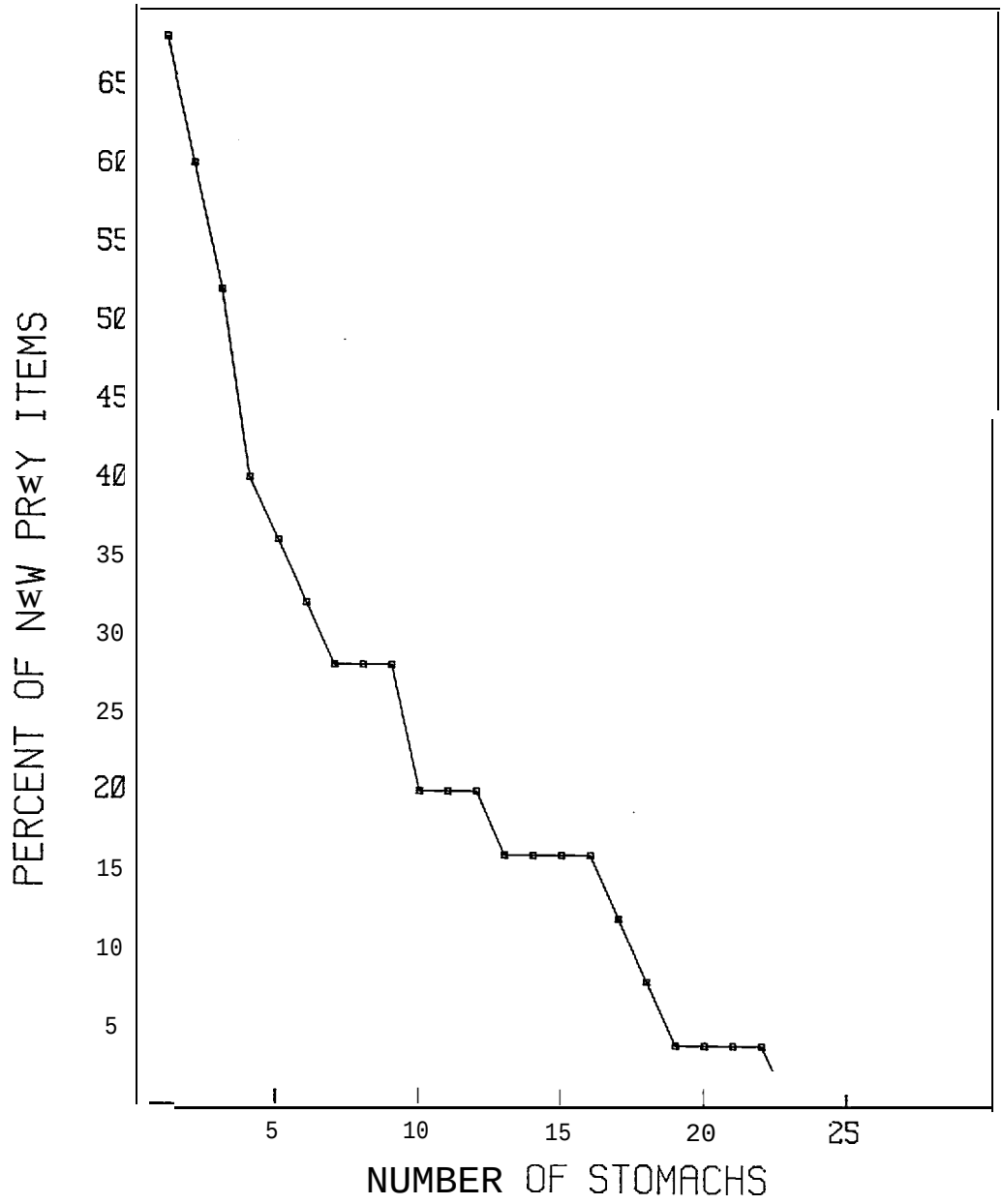


Figure 12. The frequency of newly discovered prey items as a function of the number of stomachs examined. Examination of 25 stomachs of juvenile king crab from one station gave a total of 25 prey items.

Table 7. Percentage frequency of occurrence of prey items visually observed in stomachs of juvenile king crab (CL = 53 to 80 mm). See Figure 15 for locations of stations.

Prey item	% of stomachs with prey item						
	Station C57	Station C91	June Cruise	Station 679	Station B100	August Cruise	Overal 1
GASTROPOD	100	74	87	82	81	81	86
Neptunea sp	0	0	0	0	6	4	1
Oenopota sp	64	16	43	45	25	33	39
Retusa obtusa	20	0	11	0	6	4	8
Naticidae	0	0	0	18	19	18	7
Neverita nana	16	0	9	36	0	15	11
Trochidae	0	0	0	0	6	4	1
Solariella sp	64	63	64	73	56	63	63
Others	0	10	4	36	12	22	11
PELECYPODS	100	79	91	100	100	100	94
Cyclocardia cebri costata	92	74	84	0	19	11	56
Tellina sp	24	10	18	100	100	100	49
Spisula polynyma	60	5	36	18	12	15	28
Others	0	5	2	0	0	0	1
CRUSTACEANS	44	63	52	82	69	74	60
Balanus sp	8	0	4	18	12	15	8
Amphipods	0	0	0	9	6	7	3
Paguridae	36	5	23	0	0	0	14
Ostracod ??	0	0	0	45	56	52	20
Others	0	58	25	45	31	37	30
POLYCHAETES	32	68	48	54	25	37	44
Pectinaria sp	0	37	16	27	12	18	17
Sabellidae	0	26	11	27	12	18	14
Others	32	5	20	0	0	0	13

Table 7. Continued

Prey item	% of stomachs with prey item						
	Station C57	Station C91	June Cruise	Station B79	Station B100	August Cruise	Overall
ECHINODERMS							
Echinarachuics parma	92	100	95	54	19	33	72
MISCELLANEOUS							
Hydroid	0	5	2	27	25	26	11
Bryozoan	0	5	2	18	19	18	8
Plant matter	0	5	2	9	6	7	4
Fish	8	0	4	0	6	4	4
Floc	100	100	100	100	100	100	100
Sand	100	100	100	100	100	100	100
Number of stomachs	25	19	44	11	16	27	71

Table 8. Uncorrected species composition of the diet of juvenile king crab. (Frequency of occurrence as% of total number of visually observed occurrences by all items.) Totals for calculation include floe and sand.

Prev item	Diet composition as % of all observed occurrences		
	June	August	Overal 1
GASTROPOD	*	*	*
Neptunea sp	0.0	0.5	0.2
Oenopota sp	6.4	4.6	5.6
Retusa obtusa	1.7	0.5	1.2
Naticidae	0.0	2.6	1.0
Neverita nana	1.3	2.0	1.6
Trochidae	0.0	0.5	0.2
Solariella sp	9.4	8.7	9.1
Others	0.7	3.1	1.6
PELECYPODS	*	*	*
Cyclocardia cebricostata	12.4	1.5	8.1
Tellina sp	2.7	13.8	7.1
Spisula polynyma	5.4	2.0	4.0
Others	0.3	0.0	0.2
CRUSTACEANS	*	*	*
Balanus sp	0.7	2.0	1.2
Amphipods	0.0	1.0	0.4
Paguridae	3.3	0.0	2.0
Ostracod ??	0.0	7.1	2.8
Others	3.7	5.1	4.2
POLYCHAETES	*	*	*
Pectinaria sp	2.3	2.6	2.4
Sabellidae	1.7	2.6	2.0
Others	3.0	0.0	1.8
ECHINODERMS			
Echinarachnius parma	14.0	4.6	10.3
MISCELLANEOUS			
Hydro i d	0.3	3.6	1.6
Bryozoan	0.3	2.6	1.2
Plant matter	0.3	1.0	0.6
Fish	0.7	0.5	0.6
Floe	14.7	13.8	14.3
Sand	14.7	13.8	14.3

Table 9. Dietary composition (% frequency of all visually observed occurrences) from visual examination of stomach contents of juvenile king crab corrected for gut residence times and including floe and sand - June cruise.

Taxa	A Uncorrected diet. comp. %	B Residence time h	C Relative comp. (A/B)	0 Corrected diet. comp. %
GASTROPOD	*	*	*	*
Neptunea sp	0.0000	259	0.000000	0.0000
Oenopota sp	6.3545	259	0.024535	2.1967
Retusa obtusa	1.6722	259	0.006457	0.5781
Naticidae	0.0000	259	0.000000	0.0000
Neverita nana	1.3378	259	0.005165	0.4625
Trochidae	0.0000	259	0.000000	0.0000
Solariella sp	9.3645	259	0.036157	3.2372
Others	0.6689	259	0.002583	0.2312
PELECYPODS	*	*	*	*
Cyclocardia cebricostata	12.3746	259	0.047778	4.2778
Tellina sp	2.6756	259	0.010330	0.9249
Spisula polynyma	5.3512	259	0.020661	1.8498
Others	0.3344	259	0.001291	0.1156
CRUSTACEANS	*	*	*	*
Balanus sp	0.6689	259	0.002583	0.2312
‘ d s	0.0000	68	0.000000	0.0000
Paguridae	3.3445	68	0.049184	4.4036
Ostracod ??	0.0000	68	0.000000	0.0000
Others	3.6789	68	0.054102	4.8439
POLYCHAETES	*	*	*	*
Pectinaria sp	2.3411	14	0.167224	14.9722
Sahel 1 idae	1.6722	14	0.119446	10.6944
Others	3.0100	14	0.215002	19.2499
ECHINODERMS				
Echinarachnius parma	14.0468	259	0.054235	4.8558
MISCELLANEOUS				
Hydroid	0.3344	11	0.030404	2.7222
Bryozoan	0.3344	11	0.030404	2.7222
Plant matter	0.3344	24	0.013935	1.2477
Fish	0.6689	130	0.005145	0.4607
Floe	14.7157	90	0.163508	14.6394
Sand	14.7157	259	0.056817	5.0871
TOTAL	100.00	--	1.6765	100.00

Table 10. Dietary composition of juvenile king crab (% frequency of all visually observed occurrences). Floe and sand are included in the calculations. Corrections for gut residence times as illustrated in Table 9.

Prey Item	June		August		Overal 1	
	Uncorrected	Corrected	Uncorrected	Corrected	Uncorrected	Corrected
GASTROPOD	*	*	*	*	*	*
Neptunea sp	0.0000	0.0000	0.5102	0.1273	0.2020	0.0606
Oenopota sp	6.3545	2.1967	4.5918	1.1453	5.6566	1.6962
Retusa obtusa	1.6722	0.5781	0.5102	0.1273	1.2121	0.3635
Naticidae	0.0000	0.0000	2.5510	0.6363	1.0101	0.3029
Neveri ta nana	1.3378	0.4625	2.0408	0.5090	1.6162	0.4846
Trochidae	0.0000	0.0000	0.5102	0.1273	0.2020	0.0606
Solariella sp	9.3645	3.2372	8.6735	2.1633	9.0909	2.7260
Others	0.6689	0.2312	3.0612	0.7635	1.6162	0.4846
PELECYPODS	*	*	*	*	*	*
Cyclocardia cebricostata	12.3746	4.2778	1.5306	0.3818	8.0808	2.4231
Tellina sp	2.6756	0.9249	13.7755	3.4359	7.0707	1.1201
Spisula polynyma	5.3512	1.8498	2.0408	0.5090	4.0404	1.2116
Others	0.3344	0.1156	0.0000	0.0000	0.2020	0.0606
CRUSTACEANS	*	*	*	*	*	*
Balanus sp	0.6689	0.2312	2.0408	0.5090	1.2121	0.3635
Amphipods	0.0000	0.0000	1.0204	0.9694	0.4040	0.4615
Paguridae	3.3445	4.4036	0.0000	0.0000	2.0202	2.3073
Ostracod??	0.0000	0.0000	7.1429	6.7857	2.8283	3.2302
Others	3.6789	4.8439	5.1020	4.8469	4.2424	4.8453
POLYCHAETES	*	*	*	*	*	*
Pectinaria sp	2.3411	14.9722	2.5510	11.7710	2.4242	13.4483
Sahel 1 idae	1.6722	10.6944	2.5510	11.7710	2.0202	11.1069
Others	3.0100	19.2499	0.0000	0.0000	1.8182	10.0862
ECHINODERMS	*	*	*	*	*	*
Echinarachnius parma	14.0468	4.8558	4.5918	1.1453	10.3030	3.0895
MISCELLANEOUS						
Hydroid	0.3344	2.7222	3.5714	20.9739	1.6162	11.4107
Bryozoan	0.3344	2.7222	2.5510	14.9813	1.2121	8.5580
Pl ant matter	0.3344	1.2477	1.0204	2.7466	0.6061	1.9612
Fish	0.6689	0.4607	0.5102	0.2535	0.6061	0.3621
Floe	14.7157	14.6394	13.7755	9.8877	14.3434	12.3774
Sand	14.7157	5.0871	13.7755	3.4359	14.3434	4.3010

Table 11. Dietary composition of juvenile king crab (% frequency of all visually observed occurrences). Floe and sand are excluded from the calculations.

Prey Item	June		August		Overal 1	
	Uncorrected	Corrected	Uncorrected	Corrected	Uncorrected	Corrected
GASTROPOD	*	*	*	*	*	*
Neptunea sp	0.0000	0.0000	0.7042	0.1468	0.2833	0.0727
Oenopota sp	**9.0047**	2.7363	6.3380	1.3213	7.9320	2.0356
Retusa obtusa	2.3697	0.7201	0.7042	0.1468	1.6997	0.4362
Naticidae	0.0000	0.0000	3.5211	0.7340	1.4164	0.3635
Neverita nana	1.8957	0.5761	2.8169	0.5872	2.2663	0.5816
Trochidae	0.0000	0.0000	0.7042	0.1468	0.2833	0.0727
Solariella sp	13.2701	4.0324	11.9718	2.4957	12.7479	3.2715
Others	0.9479	0.2880	4.2254	0.8808	2.2663	0.5816
PELECYPODS	*	*	*	*	*	*
Cyclocardia cebricostata	17.5355	5.3286	2.1127	0.4404	11.3314	2.9080
Tellina sp	3.7915	1.1521	19.0141	3.9638	9.9150	2.5445
Spisula polynyma	7.5829	2.3042	2.8169	0.5872	5.6657	1.4540
Others	0.4739	0.1440	0.0000	0.0000	0.2833	0.0727
CRUSTACEANS	*	*	*	*	*	*
Balanus sp	0.9479	0.2880	2.8169	0.5872	**1.6997**	0.4362
' d s	0.0000	0.0000	1.4085	1.1183	**0.5666**	0.5538
Paguridae	4.7393	5.4853	0.0000	0.0000	**2.8329**	2.7690
Ostracod??	0.0000	0.0000	**9.8592**	7.8283	**3.9660**	3.8766
Others	5.2133	6.0338	**7.0423**	5.5916	**5.9490**	5.8149
POLYCHAETES	*	*	*	*	*	*
Pectinaria sp	3.3175	18.6500	**3.5211**	13.5797	**3.3994**	16.1394
Sahel 1 idae	2.3697	13.3214	**3.5211**	13.5797	**2.8329**	13.4495
Others	4.2654	23.9786	**0.0000**	0.0000	**2.5496**	12.1045
ECHINODERMS		*	*	*	*	
Echinarachnius parma	19. 905;	6.0486	6.3380	1.3213	**14.4476**	3. 707;
MISCELLANEOUS						
Hydroid	0.4739	3.3909	4.9296	24.1965	**2.2663**	13.6940
Bryozoan	0.4739	3.3909	3.5211	17.2832	**1.6997**	10.2705
Plant matter	0.4739	1.5542	1.4085	3,1686	**0.8499**	2.3537
Fish	0.9479	0.5738	0.7042	0.2925	**0.8499**	0.4345
Flocculent	*	*	*	*	*	*
Sand	*	*	*	*	*	*

The frequency of occurrence and dietary composition from visual examination for yearling juvenile king crab (CL = 9-.25 mm) appear in Table 12. The relative rankings of the major taxa, pelecypods, gastropod, echinoderms and crustaceans, are essentially the same as for the larger juvenile crabs, except that polychaetes and other soft bodied prey were not visually observed in the smallest juveniles. Most yearling king crab had stomachs full of floe and sand with little or nothing else discernible.

Dietary Composition from Dry Weights of Prey Items

Dietary composition based on dry weights of prey items in pooled stomach samples of juvenile king crab (CL = 53-80 mm) appears in Table 13. Floe constituted a substantial proportion of the dry weight of the stomach contents (36% in June, 64% in August, 54% overall). Excluding the floe, sand dollars dominated the dry weight of stomach contents in June followed in rank by clams, gastropod, polychaetes and crustaceans. In August bivalves replaced sand dollars as the dominant class in the stomach contents by dry weight (excluding floe). Overall the dry weight of stomach contents excluding floe was dominated by sand dollars followed by clams, gastropod, polychaetes, and crustaceans.

The above dry weights were measured almost exclusively on hard parts such as bivalve shells, sand dollar tests, and barnacle plates. To estimate the dry weight of soft tissue ingested the soft tissue/hard tissue ratios and dry weights in Tables 14 and 15 were used. Among the bivalves thick shelled species, such as Cyclocardia sp, had soft/hard ratios on the order of 0.05 whereas thin shelled species had ratios between 0.15 and 0.20. Among the gastropod the thick shelled species also had ratios distinctly different from the thin shelled species. For the polychaetes, little soft tissue was found and polychaete dry weights were determined by weighing the sand tubes and large cephalic spines of the Pectinaria sp and the parchment tubes of the Sabellidae. Therefore, the soft tissue dry weights for these soft bodied prey were estimated using the soft tissue to hard part ratios determined in the laboratory.

Dietary composition based on soft tissue dry weights in stomachs of juvenile king crab appears in Tables 16 and 17. Floe, which is predominantly unrecognizable organic matter, constitutes over 80% of the dry weight in the June, August and overall diets whether uncorrected or corrected for gut residence time. Excluding the floe and correcting for gut residence times yields an estimated dietary composition dominated by

Table 12. Dietary composition (% frequency of occurrence as % of stomachs with item and as % of total occurrences by all items) from visual examination of yearling juvenile king crab (CL = 9-25 mm, N = 24).

Prey item	% of stomachs with item	% of all observed occurrences	
		Including floe + sand	Excluding floe & sand
FORAMINIFERA	4.2	1.4	3.2
GASTROPOD			
Naticidae	8.3	2.8	6.4
Trochidae	8.3	2.8	6.4
Other	12.5	4.2	9.7
PELECYPODS	41.7	13.9	32.2
CRUSTACEANS			
Barnacles	8.3	2.8	6.4
Copepods	4.1	1.4	3.2
Amphipods	8.3	2.8	6.4
Other	12.5	4.2	9.7
ECHINODERMS			
Echinarachnius parma	20.8	6.9	16.1
FLOC	91.7	30.6	--
SAND	79.2	26.4	--

Table 13. Dietary composition (% of total dry weight of all prey items in pooled stomach samples) of juvenile king crab (CL = 53-80″ mm). These percentages are-not corrected for gut residence time.

Prey i tern	June		August		Overal 1	
	With floe + sand	Without floe + sand	With floe + sand	Without floe + sand	With floe + sand	Without floe + sand
GASTROPOD	*	*	*	*	*	*
Neptunea sp	0.0000	0.0000	0.0094	0.041	0.0058	0.017
Oenopota sp	0.2452	**0.4560**	0) 1320	0.588	0.1769	0.509
Retusa obtusa	0.0000	0.0000	0.0008	0.003	0.0005	0.001
Naticidae	0.0000	0.0000	0.0312	0.137	0.0192	0.055
Neverita nana	0.0000	0.0000	0.1528	0.670	0.0939	0.270
Trochidae	0.0000	0.0000	0.2930	1.285	0.1802	0.519
Solariella sp	1.0755	2.0000	0.9719	4.261	1.0118	2.913
Others	0.0075	0.0139	0.3749	1.644	0.2334	0.672
PELECYPODS	*	*	*	*	*	*
Cyclocardia cebricostata	3.4930	6.4955	0.2058	0.902	1.4714	4.237
Tellina sp	0.0871	0.1620	13.9505	61.163	8.6128	24.798
Spisula polynyma	0.2216	0.4120	0.4910	2.153	0.3873	1.115
Others	0.1220	0.2269	0.0000	0.000	0.0470	0.135
CRUSTACEANS	*	*	*	*	*	*
Balanus sp	0.0000	0.0000	1.2002	5.262	0.7381	2.125
' d s	0.0000	0.0000	0.0148	0.065	0.0091	0.026
Paguridae	0.0274	0.0509	0.0000	0.000	0.0105	0.030
Ostracod ??	0.0000	0.0000	0.0546	0.239	0.0336	0.097
Others	0.2241	0.4167	0.1107	0.485	0.1543	0.444
POLYCHAETES	*	*	*	*	*	*
Pectinaria sp	0.5042	0.9375	1.0880	4.770	0.8632	2.485
Sahel 1 idae	0.5689	1.0579	0.3437	1.507	0.4304	1.239
Others	0.0012	0.0023	0.0000	0.000	0.0005	0.001
ECHINODERMS						
Echinarachnius parma	47.1400	87.6594	2.7784	12.181	19.8584	57.177
MISCELLANEOUS						
Hydroid	0.0025	0.0046	0.0242	0.106	0.0158	0.046
Bryozoan	0.0012	0.0023	0.0132	0.058	0.0086	0.025
Plant matter	0.0336	0.0625	0.0132	0.058	0.0211	0.061
Fish	0.0212	0.0394	0.5526	2.423	0.3480	1.002
Floe	36.2475	*	64.5868	*	53.6757	*
Sand	9.9762	*	12.6045	*	11.5926	*

Table 14. Soft tissue to hard tissue ratios for possible prey items from laboratory determinations.

Organism	Size mm	No. of Pooled Samples	$\bar{X} \pm SD$ % shell or hard part wet weight	$\bar{X} \pm SD$ % shell or hard part dry weight	$\bar{X} \pm SD$ Soft/hard ratio dry weight
GASTROPOD					
Solariella sp	5-7	8	68.7 ± 3.0	88.2 ± 1.5	0.1341 ± 0.0195
Oenopota sp	8-29	3	84.6 ± 3.2	95.8 ± 0.6	0.0439 ± 0.0067
Propebella sp	9-18	1	81.7	95.4	0.0487
Boreotrophon sp	12-24	3	80.1 ± 1.2	94.8 ± 0.5	0.0548 ± 0.0053
Natica clausa	5-32	3	55.8 ± 14.1	76.8 ± 10.7	0.3196 ± 0.1956
PELECYPODS					
Cyclocardia sp	5-13	8	81.8 ± 1.2	95.0 ± 0.6	0.0528 ± 0.0068
Laevicardium sp	5-6	2	54.1	81.2	0.1737
Nucula tenuis	"2	1	79.7	94.2	0.0617
Astarte sp	32-39	1	77.4	94.4	0.0594
Spisula polynyma	4-8	1	53.7	87.2	0.1473
CRUSTACEANS					
Barnacles	8-15	2	81.8	95.9	0.0428
Amphipods	3-5	1	ND	75.2	0.3301
Paguridae	-30	1	ND	69.0	0.4498
POLYCHAETES					
Pectinaria sp[a/]	5-8	2	ND	74.6	0.3592
Sabellidae[b/]	~10	2	ND	78.6	0.2882
ECHINODERMS					
Echinarachnius parma[c/]	30-50	1	ND	95.5	0.0473

[a/] Soft worm vs. cephalic spines and sand tube.

[b/] Soft worm vs. parchment tube with minimal adhering sand.

"Viscera vs. test.

Table 15. Dry weights of prey items in pooled stomachs of juvenile king crab (CL = 53-80 mm).

	Dry weight (g) in stomachs			Soft/hard ratio
	June	August	Overal 1	
GASTROPOD	*	*	*	*
Neptunea sp	0.0000	0.0012	0.0012	0.0439
Oenopota sp	0.0197	0.0172	0.0369	0.0439
Retusa obtusa	0.0000	0.0001	0,0001	0.3196
Naticidae	0.0000	0.0040	0.0040	0.3196
Neverita nana	0.0000	0.0196	0.0196	0.3196
Trochidae	0.0000	0.0376	0.0376	0,1341
Solariella sp	0.0864	0.1247	0.2111	0.1341
Others	0.0006	0.0481	0.0487	0.1202
PELECYPODS	*	*	*	*
Cyclocardia cebricostata	0.2806	0.0264	0.3070	0.0528
Tellina sp	0.0070	1.7900	1.7970	0.1737
Spisula polynyma	0.0178	0.0630	0.0808	0.1473
Others	0.0098	0.0000	0.0098	0.0981
CRUSTACEANS	*	*	*	*
Balanus sp	0.0000	0.1540	0.1540	0.0428
Amphipods	0.0000	0.0019	0.0019	0.3301
Paguridae	0.0022	0.0000	0.0022	0.4498
Ostracod ??	0.0000	0.0070	0.0070	0.3900
Others	0.0180	0.0142	0.0322	0.3900
POLYCHAETES	*	*	*	*
Pectinaria sp	0.0405	0.1396	0.1801	0.3592
Sabellidae	0.0457	0.0441	0.0898	0.2882
Others	0.0001	0.0000	0.0001	0.3237
ECHINODERMS				
Echinarachnius parma	3.7868	0.3565	4.1433	0.1432
MISCELLANEOUS				
Hydroid	0.0002	0.0031	0.0033	0.1000
Bryozoan	0.0001	0.0017	0.0018	0.1000
Plant matter	0.0027	0.0017	0.0044	1.0000
Fish	0.0017	0.0709	0.0726	0.1000
Floe	2.9118	8.2872	11.1990	1.0000
Sand	0.8014	1.6173	2.4187	0.0000

Table 16. Dietary composition (% of total soft tissue dry weight of prey items in pooled stomachs) of juvenile king crab (CL = 53-80 mm). Data for this table were calculated with soft tissue/hard tissue ratios from Tables 14 and 15. Percentages were calculated including floc and sand. Correction is for gut residence times.

	% of Diet					
	June		August		Overal 1	
Prey Item	Uncorrected	Corrected	Uncorrected	Corrected	Uncorrected	Corrected
GASTROPOD	*	*	*	*	*	*
Neptunea sp	0.0000	0.0000	0.0006	0.0002	0.0004	0.0002
Oenopota sp	0.0245	0.0091	0.0086	0.0030	0.0132	0.0046
Retusa obtusa	0.0000	0.0000	0.0004	0.0001	0.0003	0.0001
Naticidae	0.0000	0.0000	0.0146	0.0050	0.0104	0.0036
Neveri ta nana	0.0000	0.0000	0.0713	0.0246	0.0509	0.0179
Trochidae	0.0000	0.0000	0.0574	0.0198	0.0410	0.0144
Solariella sp	0.3287	0.1216	0.1904	0.0656	0.2300	0.0808
Others	0.0020	0.0008	0.0658	0.0227	0.0476	0.0167
PELECYPODS	*	*	*	*	*	*
Cyclocardia cebricostata	0.4203	0.1555	0.0159	0.0055	0.1317	0.0463
Tellina sp	0.0345	0.0128	3.5399	1.2191	2.5361	0.8910
Spisula polynyma	0.0744	0.0275	0.1057	0.0364	0.0967	0.0340
Others	0.0273	0.0101	0.0000	0.0000	0.0078	0.0027
CRUSTACEANS	*	*	*	*	*	*
Balanus sp	0.0000	0.0000	0.0750	0.0258	0.0536	0.0188
' d S	0.0000	0.0000	0.0071	0.0094	0.0051	0.0068
Paguridae	0.0281	0.0396	0.0000	0.0000	0.0080	0.0108
Ostracod??	0.0000	0.0000	0.0311	0.0408	0.0222	0.0297
Others	0.1992	0.2806	0.0631	0.0827	0.1020	0.1365
POLYCHAETES	*	*	*	*	*	*
Pectinaria sp	0.4127	2.8245	0.5709	3.6374	0.5256	3.4161
Sabellidae	0.3736	2.5572	0.1447	0.9219	0.2103	1.3666
Others	0.0009	0.0063	0.0000	0.0000	0.0003	0.0017
ECHINODERMS	*	*	*	*	*	*
Echinarachnius parma	15.3840	5.6911	0.5812	0.2002	4.8206	1.6936
MISCELLANEOUS						
Hydro i d	0.0006	0.0049	0.0035	0.0286	0.0027	0.0222
Bryozoan	0.0003	0.0025	0.0019	0.0157	0.0015	0.0121
Plant matter	0.0766	0.3058	0.0194	0.0719	0.0357	0.1355
Fish	0.0048	0.0036	0.0807	0.0554	0.0590	0.0413
Floe	82.6066	87.9420	94.3507	93.5101	90.9896	91.9923
Sand	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

Table 17. Dietary composition (% of total soft tissue dry weight of prey items in pooled stomachs)' of juvenile king crab (CL= 53-80 mm). Data for this table were calculated with soft tissue/hard tissue ratios from Tables 14 and 15. Percentages were calculated excluding f loc and sand. Correction is for gut residence times.

			August		Overal 1	
Prey i tern	Uncorrected	Corrected	Uncorrected	Corrected	Uncorrected	Corrected
GASTROPODS	*	*	*	*	*	*
Neptunea sp	0.0000	0.0000	0.0106	0.0032	0.0047	0.0019
Oenopota sp	0.1411	0.0753	0.1522	0.0456	0.1460	0,0578
Retusa obtusa	0.0000	0.0000	0.0064	0.0019	0.0029	0.0011
Naticidae	0.0000	0.0000	0.2576	0.0772	0.1152	0.0456
Neverita nana	0.0000	0.0000	1.2625	0.3784	0.5647	0.2234
Trochi dae	0.0000	0.0000	1.0162	0.3045	0.4545	0.1798
Solariella sp	1.8899	1.0088	3.3701	1.0100	2.5519	1.0095
Others	0.0118	0.0063	1.1652	0.3492	0.5277	0.2088
PELECYPODS	*	*	*	*	*	*
Cyclocardia cebricostata	2.4166	1.2900	0.2809	0.0842	1.4612	0.5781
Tellina sp	0.1983	0.1059	62.6621	18.7797	28.2384	11.1315
Spisula polynyma	0.4277	0.2283	1.8702	0.5605	1.0729	0.4244
Others	0.1568	0.0837	0.0000	0.0000	0.0867	0.0343
CRUSTACEANS	*	*	*	*	*	*
Balanus sp	0.0000	0.0000	1.3284	0.3981	0.5942	0.2351
Amphipods	0.0000	0.0000	0.1264	0.1443	0.0565	0.0852
Paguridae	0.1614	0.3282	0.0000	0.0000	0.0892	0.1344
Ostracod ??	0.0000	0.0000	0.5502	0.6280	0.2461	0.3708
Others	1.1451	2.3281	1.1161	1.2740	1.1321	1.7058
POLYCHAETES	*	*	*	*	*	*
Pecti naria sp	2.3729	23.4334	10.1059	56.0310	5.8318	42.6803
Sabellidae	2.1483	21.2155	2.5614	14.2017	2.3330	17.0745
Others	0.0053	0.0521	0.0000	0.0000	0.0029	0.0214
ECHINODERMS						
Echinarachnius parma	88.4515	47.2158	10.2886	3.0835	53.4860	21.1590
MISCELLANEOUS						
Hydroid	0.0033	0.0410	0.0625	0.4409	0.0297	0.2771
Bryozoan	0.0016	0.0205	0.0343	0.2418	0.0162	0.1511
Plant matter	0.4404	2.5370	0.3426	1.1081	0.3966	1.6934
Fish	0.027'7	0.0295	1.4289	0.8532	0.6545	0.5158
Floe	*	*	*	*	*	*
Sand	*	*	*	*	*	*

polychaetes in both June and August and overall. In the corrected overall diet, four taxa, Pectinaria sp (a polychaete), sand dollars, sabellid polychaete worms, and the clam, Tellina sp, account for 92% of the soft tissue dry weight. Comparing June and August shows the June diet dominated by polychaetes (45%) and sand dollars (47%) and the August diet dominated by polychaetes (70%) and clams (19%).

CALORIC INTAKE

Caloric intake was calculated with values from the literature (Table 18) and from laboratory determinations (Table 19). Attempts to determine the caloric values for-whole sand dollars both before and" after digestion with 0.01 M HCL failed because of incomplete combustion of the sample even after mixing with benzoic acid. The caloric value for sand dollars used in the calculations was from bomb calorimetry of viscera after dissection from the test (Table 19).

Using the June and August alai'ly rations, 6.30 and 11.92 mg dry weight per gram crab wet weight per day, and the corrected dietary composition based on soft tissue dry weights. (Table 16 and 17) the daily rations were converted to calories. Floe dominated the dry weight of stomach contents and, being organic matter, has caloric value. Clearly, floe must be considered in estimating the daily intake of calories, but how floe should be considered in such estimation was not obvious.

One can consider the source of the floe to be one of two extremes. At one end floe is taken to derive entirely from unidentified prey items different from those already identified and for which soft tissue dry weights were calculated. At this extreme the caloric value of the floe is in addition to that of the identified prey items and must be included in any calculations of total caloric intake. At the other extreme floe is taken to derive entirely from the soft tissue of the prey items already identified and for which soft tissue dry weights have been taken into account. At this extreme the caloric value of the floe is equal to that calculated from the soft tissue dry weights of the identified prey and should not be included in any calculations of total caloric intake.

To encompass these extremes total caloric intake was estimated under three assumptions: first, that floe could not be attributed to any of the other items already identified and had a caloric value equal to the mean of all the invertebrates identified as prey items: secondly, that floe was diluted by inorganic matter or derived equally from known and unknown prey

Table 18. Caloric values of marine Organisms selected from the literature.

Organism	Caloric Value CAL/g dry weight Spring	Summer	Reference
Annelida			
Lumbringereis fragil is	4857		Brawn et al. 1968
Terebel lids	4141		Brawn et al. 1968
Nepthys	4061		Brawn et al. 1968
Aphrodita hastata	3438		Brawn et al. 1968
Maldanid	3276	3549	Brawn et al. 1968
Pectinaria hypoborea	3242	3620	Brawn et al. 1968
Pherusa plumosa	2660		Brawn et al. 1968
' s - e r	2127		Brawn et al. 1968
Nichamache sp		3561	Brawn et al. 1968
	Annual Mean		
Lumbrinereis fragilis	4565 (4359-481 0)		Tyler 1973
Nephtys incisa	3984 (3773-4156)		Tyler 1973
Praxillella praetermissa	**2365**		
Aphrodita hastata	**2638 (1914-3407)**		
Mollusca			
Bivalves (no shell)	Summer	Spring	
Yoldia thraciaeformis	4783	4452	Brawn et al. 1968
Yoldia sapotilla	4778		Brawn et al. 1968
Clinocardium ciliatum	4453		Brawn et al. 1968
Yoldia sapotilla	4216 (3880-4555)		Tyler 1973
Nuclulana sp	4184		Tyler 1973
Venericardia borealis	3678 (3400-4202)		Tyler 1973
Artica islandica	4031 (3684-4276)		Tyler 1973
Astarte undata	4234 (3734-4521)		
Modiolus sp	4600 ± 7		Cummins & Wuycheck 1971
Dentalidae			
' Dentalium entale (tooth shell)	**4560**		Tyler 1973
Gastropod			
Thais lapilus (Dog Whelk)	4595		Brawn et al. 1968
Natica clausa (Little Moon Snai 1)	4392		Brawn et al. 1968
Thais lamellosa (Dog Whel k)	5377		Paine 1964
Scaphander punctostrians (Striated canoe shell)	3336		Brawn et al. 1968
Colus stimpsoni (Neptune Shell)	4587		Tyler 1973.

Table 18. Continued

Organism	Caloric Value CAL/g dry weight Spring	Summer	Reference
Hydroids			
Hydra littoralis (freshwater)	6034 ± 146 ash free		Slobodkin & Richman 1961
Chlorohydra viridissima	5729 ± 247 ash free		Slobodkin & Richman 1961
Echinoderms			
(corrected for $CaCo_3$	Summer	Spring	
Asterias vulgaris	2551	2014	Brawn et al. 1968
Strongylocentrotus droehbachiensis		883	Brawn et al. 1968
Crustaceans			
Barnacles			
Balanus cariosus (no plates)	4596		Paine 1974
Eliminius modestus	5423 ± 212		Cummins & Wuycheck 1971
Amphipods	3761		Brawn et al. 1968
Unicola levcopis	2147 (1845-2512)		Tyler 1973
Leptochei rus pinguis	2740 (2319-3348)		Tyler 1973
Shrimp			
Spirontocaris sp	4423	4065	Tyler 1973
Pandalus montagui	4610 (4390-4345)		Tyler 1973
Pandalus montagui	4740		Brawn et al. 1968
Crab	4958		Tyler 1973
Hyas araneus	2610		Brawn et al. 1968
Uca pugnax			
small whole animal	2791.7		Cummins & Wuycheck 1971
medium whole animal	2841.8		Cummins & Wuycheck 1971
large whole animal	1909.6		Cummins & Wuycheck 1971
Mixed algae species	4477		Moshiri & Cummins 1969
Diatoms			
Navicula minima	3218		Cummins & Wuycheck 1971
Navicula sp	4918		Cummins & Wuycheck 1971
Nitzschia paradora	3280		Cummina & Wuycheck 1971

Table 19. Caloric values of tissue from laboratory determinations.

Organism	Calories/g dry wt	Calories/g ash free dry wt
Cyclocardia sp small	4340	4790
Cyclocardia sp large	3810	4650
Sabellid tube worms	3170	4420
Natica clausa	4620	4970
Astarte sp	4710	4930
Oenopota sp	4510	4900
Solariella sp	3730	4430
Sand dollar viscera	2110	4590
Sand dollar*		
dried	230	1560
	360	2310
dried + digested	56	970

*Not enough material to support complete combustion of sample even after mixing with benzoic acid.

and, therefore, had a caloric value one half that used under the first assumption: thirdly, that floe derived totally from the prey items already identified and could be ignored in the calculations. Under the first two assumptions, the corrected dietary composition calculated with floe included (Table 16) was used. Under the third assumption the corrected dietary composition calculated without floe (Table 17) was used. Under the three assumptions, the June daily ration equaled 29.6, 15.9, and 17.5 calories per g crab wet weight per day, respectively (Tables 20, 21, and 22). Similarity, the August daily ration equaled 58.1, 30.4, and 42.2 calories per g crab wet weight per day (Tables 23,24, and 25).

The energetic contribution of each prey item to the total caloric intake appears in the last column in Tables 20-25. Even after halving the caloric value of the floe, between 87 and 91% of the total caloric intake of juvenile king crabs still resides in floe. If one considers floe to derive from the identified prey, then polychaetes and sand dollars constitute 52% and 36%, respectively, of the total caloric intake in June (Table 22) whereas polychaetes and the clam, Tellina sp, constitute 64% and 24% of the caloric intake in August.

IMMUNOASSAY

Antisera from 29 species of potential prey items collected during the August and October cruises were produced. After an initial visual examination of juvenile king crab stomach contents, an additional 8 antisera were produced from prey items collected from Sequim Bay and from a subsequent NOAA/OCSEAP cruise during May of 1983. In the table of self and cross reactions (Table 26) numbers of self reaction lines ranged from 4 lines for several species of polychaetes and nematodes to 11 lines for the king crab. Cross reactions were also evident as expected, particularly among species closely related phylogenetically.

Before analysis of the smallest juvenile king crab, the immunoassay method and microscopic examination were compared in examining gut contents from larger juvenile king crab (CL >50 mm). Twenty stomachs of larger juvenile king crab collected in June 1982 were examined and a species list and frequency of occurrence table developed (Table 27). Extracts of the stomach contents without solid material were saved for the immunoassay. Immunological tests were then conducted on the stomach contents of the same 20 crabs examined visually.

Prey item	Corrected % of diet	Dry wt (mg)	Calories per mg dry wt	Calories per prey item	% of total calories
GASTROPODS	*	*	*	*	*
Neptunea sp	0.0000	0.00000	4.494	0.0000	0.0000
Oenopota sp	0.0091	0.00057	4.510	0.0026	0.0087
Retusa obtusa	0.0000	0.00000	4.494	0.0000	0.0000
Naticidae	0.0000	0.00000	4.620	0.0000	0.0000
Neverita nana	0.0000	0.00000	4.620	0.0000	0.0000
Trochidae	0.0000	0.00000	3.730	0.0000	0.0000
Solariella sp	0.1216	0.00766	3.730	0.0286	0.0964
Others	0.0008	0.00005	4.494	0.0002	0.0007
PELECYPODS	*	*	*	*	*
Cyclocardia cebricostata	0.1555	0.00980	4.340	0.0425	0.1434
Tellina sp	0.0128	0.00080	4.530	0.0036	0.0123
Spisula polynyma	0.0275	0.00173	4.530	0.0079	0.0265
Others	0.0101	0.00064	4.530	0.0029	0.0097
CRUSTACEANS	*	*	*	*	*
Balanus sp	0.0000	0.00000	4.596	0.0000	0.0000
[illegible]d. s	0.0000	0.00000	4.002	0.0000	0.0000
Paguridae	0.0396	0.00249	3.944	0.0098	0.0331
Ostracod ??	0.0000	0.00000	4.510	0.0000	0.0000
Others	0.2806	0.01768	4.510	0.0797	0.2689
POLYCHAETES	*	*	*	*	*
Pectinaria sp	2.8245	0.17794	3.242	0.5769	1.9457
Sabellidae	2.5572	0.16110	3.170	0.5107	1.7225
Others	0.0063	0.00040	3.503	0.0014	0.0047
ECHINODERMS					
Echinarachnius parma	5.6911	0.35854	2.110	0.7565	2.5516
MISCELLANEOUS					
Hydroid	0.0049	0.00031	5.724	0.0018	0.0060
Bryozoan	0.0025	0.00016	5.724	0.0009	0.0030
Plant matter	0.3058	0.01927	4.477	0.0862	0.2909
Fish	0.0036	0.00022	5.086	0.0011	0.0038
Floe	87.9420	5.54035	4.970	27.5355	92.8717
Sand	0.0000	0.00000	0.000	0.0000	0.0000
TOTALS	100.0	6.30	--	29.649	100.0

Table 20. Caloric intake from various prey items based on June daily ration of juvenile king crab. Calculations include floe with an estimated caloric value of 4.970 calories/mg dry weight.

Table 21. **Caloric intake from various** prey items based on **June daily ration of juvenile king** crab. **Calculations include floe with an estimated caloric value of 2.485 calories/mg** dry weight.

Prey item	Corrected % of diet	Dry wt (mg)	Calories per mg dry wt	Calories per prey item	% of total calories
GASTROPOD	*	*	*	*	*
Neptunea sp	0.0000	0.00000	4.494	0.0000	0.0000
Oenopota sp	0.0091	0.00057	4.510	0.0026	0.0162
Retusa obtusa	0.0000	0.00000	4.494	0.0000	0.0000
Naticidae	0.0000	0.00000	4.620	0.0000	0.0000
Neveri ta nana	0.0000	0.00000	4.620	0.0000	0.0000
Trochidae	0.0000	0.00000	3.730	0.0000	0.0000
Solariella sp	0.1216	0,00766	3.730	0.0286	0.1799
Others	0.0008	0.00005	4.494	0.0002	0.0013
PELECYPODS	*	*	*	*	*
Cyclocardia cebricostata	0.1555	0.00980	4.340	0.0425	0.2677
Tellina sp	0.0128	0.00080	4.530	0.0036	0.0229
polynyma	0.0275	0.00173	4.530	0.0079	0.0494
Others	0.0101	0.00064	4.530	0.0029	0.0181
CRUSTACEANS	*	*	*	*	*
Balanus sp	0.0000	0.00000	4.596	0.0000	0.0000
' d s	0.0000	0.00000	4.002	0.0000	0.0000
Paguri dae	0.0396	0.00249	3.944	0.0098	0.0619
Ostracod ??	0.0000	0.00000	4.510	0.0000	0.0000
Others	0.2806	0.01768	4.510	0.0797	0.5020
POLYCHAETES	*	*	*	*	*
Pecti naria sp	2. %245	0.17794	3.242	0.5769	3.6326
Sahel 1 idae	2.5572	0.16110	3.170	0.5107	3.2157
Others	0.0063	0.00040	3.503	0.0014	0.0087
ECHINODERMS					
Echinarachnius parma	5.6911	0.35854	2.110	0.7565	4.7636
MISCELLANEOUS					
Hydroid	0.0049	0.00031	5.724	0.0018	0.0112
Bryozoan	0.0025	0.00016	5.724	0.0009	0.0056
Plant matter	0.3058	0.01927	4.477	0.0862	0.5431
Fish	0.0036	0.00022	5.086	0.0011	0.0072
Floe	87.9420	5.54035	2.485	13.7678	.86.6933
Sand	0.0000	0.00000	0.000	0.0000	0.0000
TOTALS	100.0	6.300	--	15.881	100.0

Table 22. **Caloric intake from various** prey items based on June daily ration of juvenile king crab. Calculations exclude floe.

Prey item	Corrected % of diet	Dry wt (mg)	Calories per mg dry wt	Calories per prey item	% of total calories
GASTROPOD	*	*	*	*	*
Neptunea sp	0.0000	0.00000	4.494	0.00000	0.0000
Oenopota sp	0.0753	0.00474	4.510	0.02140	0.1220
Retusa obtusa	0.0000	0.00000	4.494	0.00003	0.0000
Naticidae	0.0000	0.00000	4.620	0.00000	0.0000
Neverita nana	0.0000	0.00000	4.620	0.00000	0.0000
Trochidae	0.0000	0.00000	3.730	0.00000	0.0000
Solariella sp	1.0088	0.06356	3.730	0.23706	1.3521
Others	0.0063	0.00040	4.494	0.00178	0.0102
PELECYPODS	*	*	*	*	*
Cyclocardia cebricostata	1.2900	0.08127	4.340	0.35271	2.0117
Tellina sp	0.1059	0.00667	4.530	0.03021	0.1723
Spisula polynyma	0.2283	0.01438	4.530	0.06515	0.3716
Others	0.0837	0.00527	4.530	0.02389	0.1362
CRUSTACEANS	*	*	*	*	*
Balanus sp	0. 0000	0.00000	4.596	0.00000	0.0000
Amphipods	0.0000	0.00000	4.002	0.00000	0.0000
Paguridae	0.3282	0.02067	3.944	0.08154	0.4651
Ostracod ??	0.0000	0.00000	4.510	0.00000	0.0000
Others	2.3281	0.14667	4.510	0.66148	3.7728
POLYCHAETES	*	*	*	*	*
Pectinaria sp	23.4334	1.47630	3.242	4.78617	27.2981
Sabellidae	21.2155	1.33658	3.170	4.23695	24.1656
Others	0.0521	0.00328	3.503	0.01151	0.0656
ECHINODERMS					
Echinarachnius parma	47.2158	2.97459	2.110	6.27639	35.7976
MISCELLANEOUS					
Hydroid	0.0410	0.00258	5.724	0.01479	0.0844
Bryozoan	0.0205	0.00129	5.724	0.00739	0.0421
Plant matter	2.5370	0.15983	4.477	0.71557	4.0813
Fish	0.0295	0.00186	5.086	0.00945	0.0539
Floe	*	*	4.970	*	*
Sand	*	*	0.000	*	*
TOTAL	100.0	6.30	--	17.533	100.0

Table 23. Caloric intake from various prey items based on August daily ration of juvenile king crab. Calculations include floe with an estimated caloric value of 4.970 calories/mg dry weight.

Prey item	Corrected % of diet	Dry wt (mg)	Calories per mg dry wt	Calories per prey item	% of total calories
GASTROPOD	*	*	*	*	
Neptunea sp	0.0002	0.0000	4.494	0.0001	0.0002
Oenopota sp	0.0030	0.0004	4.510	0.0016	0.0027
Retusa obtusa	0.0001	0.0000	4.494	0.0001	0.0001
Naticidae	0.0050	0.0006	4.620	0.0028	0.0047
Neverita nana	0.0246	0.0029	4.620	0.0135	0.0233
Trochidae	0.0198	0.0024	3.730	0.0088	0.0151
Solariella sp	0.0656	0.0078	3.730	0.0292	0.0501
Others	0.0227	0.0027	4.494	0.0121	0.0209
PELECYPODS	*	*	*	*	*
Cyclocardia cebricostata	0. 0055	0.0007	4.340	0.0028	0.0049
Tellina sp	1.2191	0.1453	4.530	0.6583	1.1323
Spisula polynyma	0.0364	0.0043	4.530	0.0196	0.0338
Others	0.0000	0.0000	4.530	0.0000	0.0000
CRUSTACEANS	*	*	*	*	*
Balanus sp	0.0258	0.0031	4.596	0.0142	0.0244
' d s	0.0094	0.0011	4.002	0.0045	0.0077
Paguridae	0.0000	0.0000	3.944	0.0000	0.0000
Ostracod ??	0.0408	0.0049	4.510	0.0219	0.0377
Others	0.0827	0.0099	4.510	0.0445	0.0765
POLYCHAETES	*	*	*	*	*
Pectinaria sp	3.6374	0.4336	3.242	1.4056	2.4178
Sahel 1 i dae	0.9219	0.1099	3.170	0.3484	0.5992
Others	0.0000	0.0000	3.503	0.0000	0.0000
ECHINODERMS					
Echinarachnius parma	0.2002	0.0239	2.110	0.0503	0.0866
MISCELLANEOUS					
Hydro i d	0.0286	0.0034	5.724	0.0195	0.0336
Bryozoan	0.0157	0.0019	5.724	0.0107	0.0184
Plant matter	0.0719	0.0086	4.477	0.0384	0.0660
Fish	0.0554	0.0066	5.086	0.0336	0.0578
Floe	93.5101	11.1464	4.970	55.3976	95.2864
Sand	0.0000	0.0000	0.000	0.0000	0.0000
TOTAL	100.0	11.920	--	58.138	100.0

Table 24. Caloric intake from various prey items based on August daily ration of juvenile king crab. calculations include floe with an estimated caloric value of **2.485 calories/mg** dry weight.

Prey item	Corrected % of diet	Ory wt (mg)	Calories per mg dry wt	Calories per prey i tern	% of total calories
GASTROPOOS	*	*	*	*	*
Neptunea sp	0.0002	0.0000	4.494	0.0001	0.0003
Oenopota sp	0.0030	0.0004	4.510	0.0016	0.0052
Retusa obtusa	0.0001	0.0000	4.494	0.0001	0.0003
Naticidae	0.0050	0.0006	4.620	0.0028	0.0092
Neverita nana	0.0246	0.0029	4.620	0.0135	0.0444
Trochidae	0.0198	0.0024	3.730	0.0088	0.0289
So lariella sp	0.0656	0.0078	3.730	0.0292	0.0959
Others	0.0227	0.0027	4.494	0.0121	0.0398
PELECYPODS	*	*	*	*	*
Cyclocardia cebricostata	0.0055	0.0007	4.340	0.0028	0.0092
Tellina sp	1.2191	0.1453	4.530	0.6583	2.1627
Spisula polynyma	0,0364	0.0043	4.530	0.0196	0.0644
Others	0.0000	0.0000	4.530	0.0000	0.0000
CRUSTACEANS	*		*		*
Balanus SP	0.0258	0.003:	4.596	0.014;	0.0466
' . d. s	0.0094	0.0011	4.002	0.0045	0.0148
Paguridae	0.0000	0.0000	3.944	0.0000	0.0000
Ostracod ??	0.0408	0.0049	4.510	0.0219	0.0719
Others	0.0827	0.0099	4.510	0.0445	0.1462
POLYCHAETES	*	*	*	*	*
Pectinaria sp	3.6374	0.4336	3.242	1.4056	4.6178
Sahel 1 idae	0.9219	0.1099	3.170	0.3484	1.1446
Others	0.0000	0.0000	3.503	0.0000	0.0000
ECHINODERMS					
Echinarachnius parma	0.2002	0.0239	2.110	0.0503	0.1652
MISCELLANEOUS					
Hydroid	0.0286	0.0034	5.724	0.0195	0.0641
Bryozoan	0.0157	0.0019	5.724	0.0107	0.0352
Plant matter	0.0719	0.0086	4.477	0.0384	0.1262
Fish	0.0554	0.0066	5.086	0.0336	0.1104
Floe	93.5101	11.1464	2.485	27.6988	90.9977
Sand	0.0000	0.0000	0.000	0.0000	0.0000
TOTAL	100.0	11.920	..	30.439	100.0

Table 25. Caloric intake from various prey items based on August daily ration of juvenile king crab. Calculations exclude floe.

Prey item	Corrected % of diet	Dry wt (mg)	Calories per mg dry wt	Calories per prey item	% of total calories
GASTROPODS	*	*	*	*	*
Neptunea sp	0.0032	0.00038	4.494	0.0017	0.0040
Oenopota sp	0.0456	0.00544	4.510	0.0245	0.0581
Retusa obtusa	0.0019	0.00023	4.494	0.0010	0.0024
Naticidae	0.0772	0.00920	4.620	0.0425	0.1007
Neverita nana	0.3784	0.04510	4.620	0.2084	0.4936
Trochidae	0.3045	0.03630	3.730	0.1354	0.3208
Solariella sp	1.0100	0.12039	3.730	0.4491	1.0638
Others	0.3492	0.04163	4.494	0.1871	0.4431
PELECYPODS	*	*	*	*	*
Cyclocardia cebricostata	0.0842	0.01004	4.340	0.0436	0.1032
Tellina sp	18.7797	2.23854	4.530	10.1406	24.0213
Spisula polynyma	0.5605	0.06681	4.530	0.3027	0.7169
Others	0.0000	0.00000	4.530	0.0000	0.0000
CRUSTACEANS	*	*	*	*	*
Balanus sp	0.3981	0.04745	4.596	0.2181	0.5166
' d s	0.1443	0.01720	4.002	0.0688	0.1630
Paguridae	0.0000	0.00000	3.944	0.0000	0.0000
0s traced ??	0.6280	0.07486	4.510	0.3376	0.79'38
Others	1.2740	0.15186	4.510	0.6849	1.6224
POLYCHAETES	*	*	*	*	*
Pectinaria sp	56.0310	6.67890	3.242	21.6530	51.2922
Sahel 1 idae	14.2017	1.69284	3.170	5.3663	12.7118
Others	0.0000	0.00000	3.503	0.0000	0.0000
ECHINODERMS					
Echinarachnius parma	3.0835	0.36755	2.110	0.7755	1.8371
MISCELLANEOUS					
Hydroid	0.4409	0.05255	5.724	0.3008	0.7125
Bryozoan	0.2418	0.02882	5.724	0.1650	0.3908
Plant matter	1.1081	0.13208	4.477	0.5913	1.4008
Fish	0.8532	0.10170	5.086	0.5172	1.2252
Floe	*	*	4.970	*	*
Sand	*	*	0.000	*	*
TOTAL	100.0	11.920	--	42.215	100.0

Table 26. Matrix of self and cross reactions between prey items from immunological testing with micro- ouchterlony-doub le-di ffusion-in-agar technique.

		Extract																					
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
1.	Axiothel la rubrocincta	9	1	1	0	1	2	1	1	0	1	1	1	2	2	0	1	0	0	0	1	0	1	1
2.	Pista elongata	0	4	0	1	1	1	0	1	0	o	0	0	0	0	0	0	0	0	0	0	0	1	ᵕ
3.	Harmothoe imbricata	1	2	5	0	1	2	0	2	0		1		1		1		1	0	0	0	0	0	G
4.	U/K sabel 1 idae polychaete	1	1	2	5	2	2	2	2	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0
5.	Ophelia limacina	1	1	1	2	5	1	1	2	0		1	1	1	1	0	0	0	0	0	0	0	0	0
6.	U/K glyceride polychaete	2	3	24	4	8	3	3	I	3	2	3	1	3	3	3	2	3	0	0	2	1		
7.	Pectinaria sp	1	2	0	1	1	1	9	1	0	1	0	1	1	0	0	0	0	0	0	0	0	G	
8.	U/K oligochaetes	2	2	2	4	4	5	1	8	2	3	4	3	4	3	3	1	1	2	0	0	0	0	
9.	U/K nematodes	0	0	0	0	00		1	1	4	0	0	0	0	1	1	0	1	1	0	0	0	0	
10.	Spisula polynyma	32	3	3	1	2	2	10		7	6	6	4	2	2	2	3	1	2		0	1	1	
11.	Tellina lutes	11		12		1	1		120		1	7	2	2	1	0	0	0	0					
12.	Cyclocardia cebricostata	1		1122			12		1	1	2	1	5	3	0	11	3	3	0	00	0	0	1	0
13.	Solariella sp	2	2	1	1	1	2	0	3	0	2	2	3	6	1	1	1	1	1	0	1	0	0	
14.	U/K hermit crab	22		2	2	1		10	2	0	2	2	1	1	7	2	3	8	4	4	0	0	0	
15.	Balanus sp.	21		12		1	2	0		10	1	2	1	0	3	9	2	5	2	0	0	1	0	
16.	U/K cumacean	10	0	00		1	1	1	1	0	0	0	1	1	1	9	2	2	0	0	0	0		
17.	Paralithoides camtschatica	5		11			110020			3	2	2	2	2	3	2	Q	4	1	0	1	O		
18.	Chi onoecetes bai rdi	1		113		1		1100		3	2	3	2	2	2	2	7	7	0	0	1	0		
19.	U/K bryozoans	000		0		0		00		00	0	2	0	0	0	0	0	0	5		0	0	0	
20.	U/K diatoms	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	6	0	0		
21.	Dendraster exentricus	1		10		10	0	2		00	2	1	1	0	0	3	1	1	1	1	0	11	0	
22.	U/K gadidae fish	100		0		0		00		00	1	2	0	1	"0	2	0	2	1	0	1	0	5	

Table 27. Results of visual examination of stomach contents of king crab >50 mm C.L. Station C-57, June 1982. X = item detected visually.

Prey item	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
Pectinaria sp	×						X			×		×	X							
Spisula polynyma	×				×			X			X	×				×				
Tellina sp		×				×	%						×				×			
Cyclocardia sp	X			X	×	×	×	X	×	×		×	×		×	×	×	×	×	X
Solariella sp					×		×	X			×	×				×		×	×	X
Oenopota sp	X			X	×		×	X		×		×			×					
Retusa sp										×										
U/K Trochidae fam.				×		×			×	×					×					×
U/K Naticidae fam.				×				×												
U/K gastropod																			X	
Hermit crab												X								
King crab														×						
U/K crustacean															×					
Balanus sp			X	×																
U/K hydroid										×				×						

There was an average of four prey antisera per crab stomach showing precipitin lines. However, these lines were not always strong and distinct. Moreover, there were only 2 lines at the most showing for these reactions. More precipitin lines were expected (Feller, personal communication) and more needed to confirm a positive predator-prey interaction using Feller's algorithm.

There were several possible explanations for the number of precipitin lines being lower than expected. First, during handling and long-term storage in a freezer, the antigenic protein may have broken down causing the loss of specificity needed to confirm the predator-prey interaction. Immunoassay were performed on several stomachs collected during May and June cruises of 1983. These stomachs had not been stored long prior to the immunoassay. The results were similar. There were few precipitin lines showing and those not very distinct. The problem was not due to handling and storage.

Secondly, the titre (antibody concentration) of the antisera may have been too low. Prey extracts and homologous antisera had produced many precipitin lines, as shown in Table 26; however, the stomach contents may readily have been diluted by digestive secretions in the foregut. Serial dilutions and analysis of antisera indicated the titre was sufficiently high. Similarly, dilution of antigenic material to a probable level found in the gut showed positive precipitin results when tested with its respective antisera. Also, the total protein concentrations of crab stomachs examined was as high as the original antigenic material.

Thirdly, the antigenic determinants (the separate combining sites on the surface of the protein) could have been rapidly denatured due to digestive processes. Two pieces of evidence support this explanation. The first came from one king crab observed feeding on sabellid polychaetes during a shipboard experiment in June of 1983 and flash frozen at that time. When the gut was dissected, the tissue and worm tube could readily be seen. Immunological tests were run on the stomach contents. Two precipitin lines were observed between the stomach contents and the sabellid polychaete antisera. Reaction lines were not very distinct, and 5 lines (the self reaction number for sabellid polychaetes) were expected because the tissue ingested was fresh and still obviously present in the gut.

The other evidence came from a supplemental feeding experiment performed to address the question of how long particular antigenic determinants remain viable in the digestive tract of a crustacean predator. Live red rock crab, Cancer productus, were collected in Sequim Bay and held in the laboratory for 3-4 days to clear their gut contents.

They were then fed thawed juvenile gadid fish which had been collected previously from Bristol Bay during the August 1982 cruise. The time of feeding was noted for each crab. The crabs were frozen whole at preset time intervals of 1.5, 4, 8, and 24 hours after being fed. Also frozen were other red rock crabs that had not been fed and, therefore, had empty guts (T = 0). Visual examination of the stomach contents of the experimental crab showed that at T = 1.5 hours, fish in the gut were still recognizable as such. Fish were still present at T = 4 and 8 hours, but the contents were ground to a fine paste. At 24 hours the gut was empty in some crabs, others still had a small amount of finely ground paste. At T = 0 the crabs, indeed, had empty stomachs. Ouchterlony tests were performed using these stomach contents to demonstrate whether or not antigenic determinants within the gut declined over time due to digestion processes. The fish antisera (Ah) was placed in the center well of the slide. The fish antigen (Ag) was placed in an outer well. The time series stomach contents were also placed in surrounding outer wells in a manner that would easily show disappearance or retention of the precipitin lines.

As shown in Figure 13A, the fish antisera - antigen reaction had 5 self reaction lines as expected. The two inner precipitin lines continue through the T = 1.5 hour stomach contents and T = 4 well. One precipitin line continues through to T = 8. There were no lines at T = 24 hours and as expected none at T = 0. The three outer precipitin lines between the fish Ag and Ab were absent from stomachs throughout the time series. The antigenic determinants for these 3 lines no longer existed after 1.5 hours of digestion. There were 2 determinants that survived longer; however, all antigenic material was gone at .24 hours. The information obtained from this experiment correlated with the visual examination of the gut contents. There was little, if any fish remaining in the gut at 24 hours and no precipitin lines to indicate otherwise.

This feeding experiment was conducted with red rock crab because live king crab were not available at Sequim. Hence any conclusions made should be tentative until feeding experiments can be carried out with king crab and other prey items in addition to fish. With this caveat, the indications are still strong that the antigenic material necessary for detection in the gut degrades with time. Moreover, some antigenic determinants break down after a very short time in the foregut of crabs. The loss of antigenicity correlates with the visually observed residence time of the fish in the gut. This may be true for other soft bodied prey species as well.

Feller et al (1979) designed an algorithm to assure that precipitin lines observed were correctly attributed to the presence of the prey

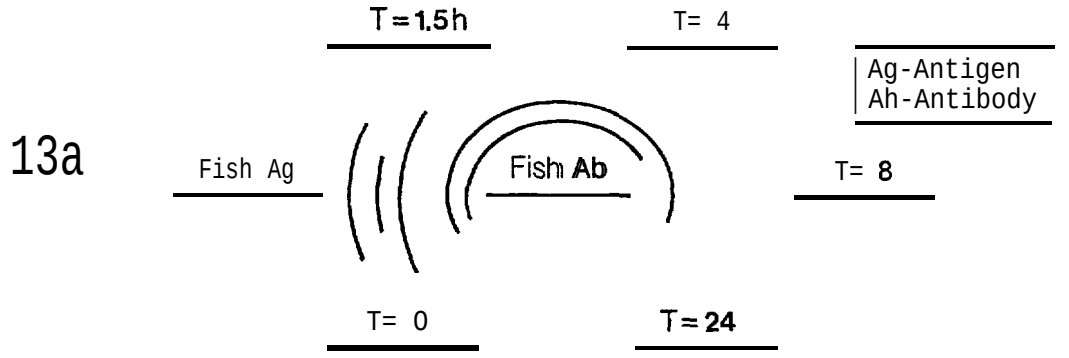
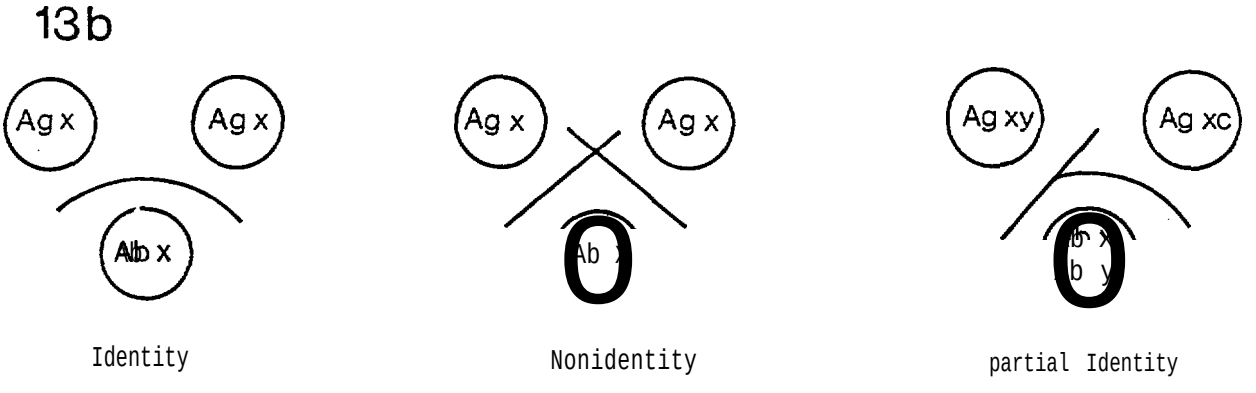
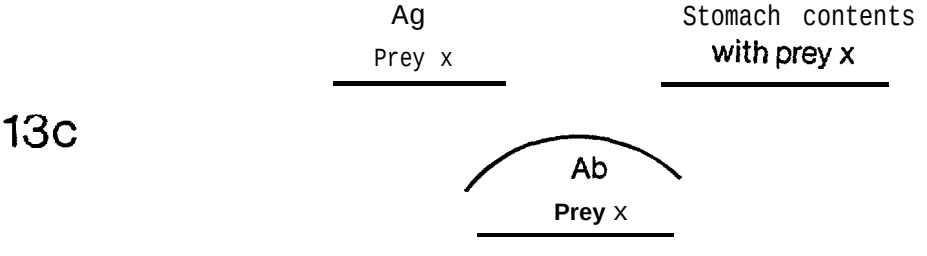


Figure 13a. Loss of precipitin reaction lines for fish antigens with time spent in crab foreguts.



13b. Precipitin reaction lines of identity, nonidentity, and partial identity.



13C. Example of positive reaction between stomach contents and prey item. A line of identity is formed.

being tested rather than to cross reactions. The algorithm is by design relatively conservative. Because only one or two reaction lines were occurring, any antisera that had a cross reaction of 2 or more with king crab (see Table 26, column 17) would automatically be eliminated from consideration as a prey item. Suet-I antisera included Spisula sp, hermit crab, Balanus, and gadid fish - food items which visual examination of gut contents had demonstrated as present in the gut. An example of the application of Feller's algorithm is given in Figure 14.

In any given antigen there may be antigenic determinants that will survive longer when subjected to digestive processes as evidenced by the 2 out of 5 remaining precipitin lines from the king crab that fed on the sabellid polychaete. The few precipitin lines that did occur in king crab stomachs were related to strong antigenic determinants. How long they remain is determined by the digestive processes of a particular organism and the composition of the antigenic determinant.

Because of rapid digestion in the guts of crab, it was apparent that Feller's algorithm of counting the number of precipitin lines and subtracting cross reactions was not going to suffice for this study. Because there was information to be obtained from the precipitin reactions, Feller's algorithm was replaced with a different approach that experimentally determined the type of precipitin reaction. According to Roitt (1971), there are three basic patterns (Figure 13b) of precipitation that can be obtained in Ouchterlony tests:

(a) The REACTION OF IDENTITY - this occurs between identical antigenic determinants, causing the precipitin lines to fuse giving a continuous arc.

(b) The REACTION OF NONIDENTITY - this occurs where two antigens do not contain any common antigenic determinants, causing the precipitin lines to form independently and cross without any interaction.

(c) The REACTION OF PARTIAL IDENTITY - this occurs where partially related antigens have one common determinant giving a continuous line of identity. An extra determinant in one of the antigens gives a line of nonidentity causing a spur to form.

To separate positive predator-prey interactions from potential cross reactions Feller's algorithm was replaced with more immunoassay tests using lines of identity and nonidentity. The procedure for all the crab stomachs was first to test the stomach contents against all the antisera. Any antisera that showed a positive reaction with contents was retested

Algorithm Example

Number of reaction lines observed in stomach contents of king crab

hermit crab - 2
Spisula sp - 2

Step 1 Rank the potential prey taxa based on a ratio of:

$$\frac{\text{\# of lines observed in the gut of sample crab}}{\text{\# of lines observed in self reaction (See Table 3)}}$$

hermit crab	2/7	.29	1
Spisula sp	1/7	.14	2

Step 2 Eliminate cross reactions that may have been due to cross reactions with the predator (king crab)

Antiserum by rank	# reaction lines observed between king crab and antisera	# of lines due to cross reactions with king crab		
HERMIT CRAB	2	8	=	NEG
SPISULA SP	1	3	=	NEG

Step 3 Eliminate cross reactions that may have been due to cross reactions with other prey in the gut.

Figure 14. An example of the algorithm for eliminating false detections due to immunological cross reactions.

against its respective antigen and stomach contents, and the reaction examined for lines of identity (see Figure 13c).

Tables 28 and 30 give the results of these tests. X's indicate that precipitin lines were present on the first test. Underlined X's indicate that the second test showed a positive line of identity, confirming that prey item existed in the stomach. X's not underlined may or may not be prey items. Present immunological evidence can neither confirm nor deny their being prey items. Only those items showing a positive reaction after retesting are considered to have been detected for this report.

For the larger juvenile king crabs (CL >50 mm) (Tables 27 and 28), the immunoassay detected a maldanid polychaete, the clam, Spisula polynyma, pagurid crab, and a tunicate in stomachs where these items were undetected by visual examination. For Spisula polynyma, the immunoassay detected this clam in 4 cases where it was not detected visually. Visual examination detected S. polynyma in 5 cases where the immunoassay did not detect the clam or failed to give a positive detection when retested for lines of identity.

For yearling juvenile king crab (CL <30 mm) (Tables 29 and 30), the immunoassay added 5 prey items not detected visually: three polychaetes, an oligochaete, and a nematode. These new items are all soft bodied prey: two are meiofaunal. A total of 8 prey were detected visually and 10 immunologically. Five items were detected immunologically but not visually and three visually but not immunologically. For items detected both immunologically and visually, the frequency of occurrence increased by using the immunoassay. For yearling king crab collected on the North Aleutian Shelf cruise in September 1983, nothing could be visually distinguished in the stomachs except floe and sand. Among these crabs the immunoassay detected a maldanid polychaete, a glycerid polychaete, oligochaetes, the clam, Cylcocardia cebricostata, a pagurid crab, and sand dollars.

Table 28. Immunoassay precipitin reactions from stomachs of juvenile king crab 50-90 mm C. L., station C-57, June 1982. Crab numbers match those in Table 27.

Antisera	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	2
Arr ,ndia brevis																					
Axi othel la rubrocineta	X	X		X		X	X	X			X	X	X	X	X		X		X	X	
Pista elongata																					
Harmothoe imbricata														X							
U/K sabel lidpolychaete		X										X									
Nereis vexi 1 loss																					
Naineris dendritica							X														
Lumbri neris tetrauna																					
U/K polychaetes			X									X									
Spisula polynyma	X		X	X	X	X	X			X	X	X	X			X		X	X	X	
Iellina lutes															X	X	X			X	
Solariella sp					X		X									X				X	
Fusitriton sp							X									X					
Corophium amphipod																					
Crangon shrimp																					
U/K hermit crab	X	X	X	X	X		X	X	X	X	X	X		X			X		X	X	X
Balanus sp												X									
Leptochel ia savignyi																					
King crab	X		X		X		X	X	X		X	X	X	X	X	X	X	X	X	X	
Tanner crab																X					

Ant i sera	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	2(
U/K brittle star																				
U/K sea urchin												X								
U/K tunic ate						X								X	X					
U/K hydroi d												X			X					
U/K bryozoan																				
U/K diatoms															X					
U/K gadidae fish															X					

X - indicates at least one precipitin 1 ine between stomach contents and antisera.

- indicates "1 ine of identity" between antigen and stomach contents and the probable presence of the prey i tern.

Table 29. Results of visual examination of stomach contents of juvenile king crab < 40 mm C. L.

Prey item	100	101	104	106	108	109	112	114	116	132(a)	134(a)	136(a)	138(a
U/K bivalve	x												
U/K gastropod				x									
Trothidae fare.			x										
Naticidae fare.					x	X	X						
U/K crustacean		x	x					X					
U/K copepod													
U/K barnac 1 e					x		X						
Caprel 1 id amphipod					x		X						
U/K echinoid		x											
Foramini fera													
Sand	x	x	x	x	x	X	X	X	X	X	X		X
Floe	x	x	x	x	X	X	X	X		X	X	X	X

(a) These crab were collected during September of 1983.

Table 30. Immunoassay precipitin reactions from stomachs of juvenile king crab <40 mm C. L.

Antisera	Crab # 102	103	105	107	110	111	113	115	133(a)	135(a)	137(a)	139(a)
Axiothella rubrocincta			X	X		X				X		
Pista elongata												
Harmothoe imbricata				X	X	X				X		
Fare. Sahelidae					X							
Ophelia limacina			X		X		X					
Fare. Glyceride		X	X	X	X	X	X		X	X	X	X
Pectinaria sp		X			X	X	X			X		
U/K 01 igochaetes		X	X	X	X	X	X			X	X	
U/K nematodes					X							
Spisula polynyma	X	X	X									
Tellina lutes												
Cyclocardia cebricostata		X	X	X	X	X				X		
Solariella sp			X	X		X				X		
U/K hermit crab	X	X	X	X	X	X	X			X	X	
Balanus SP			X	X	X	X					X	
U/K cumacean		X	X		X	X					X	
Red king crab	X	X	X	X	X	X	X		X	X	X	X
Tanner crab	X	X	X		X	X	X		X	X	X	
U/K bryozoans			X									
U/K diatoms					X							
Sand dollar	X	X	X	X	X	X		X		X	X	
Gadidae fish										X	X	

X - Indicates at least one precipitin line between stomach contents and antisera.

\- "Line of identity" between antigen and stomach contents indicating probable presence of prey item.

(a) - These crab were collected during September of 1983.

DISCUSSION

IMMUNOASSAY

The immunological examination of stomach contents as applied here provided evidence that juvenile king crab consume prey items overlooked by conventional visual examination of gut contents and that these overlooked prey were soft-bodied, readily-digested organisms. As expected, the value of the immunoassay was greatest for the smallest juvenile king crab.

The immunoassay suffered some lack of sensitivity apparently due to low gut residence times of antigenic determinants. Because of the rapid breakdown of antigenic determinants in crab stomachs, the extent to which the smallest juvenile crabs depend on soft bodied macro and meiofaunal prey could well be underestimated here.

Further use of this immunoassay for king crabs and other crustaceans should be enhanced by experimental determination of gut residence times of the antigenic determinants. Particularly important would be the determination whether there is substantial enough variation in gut residence times of antigenic determinants with prey type to be a significant source of bias. If prey types do vary substantially in the gut residence times of their antigenic determinants, then correction of dietary composition determined by immunoassay would follow the procedures used here for correction of dietary composition determined by visual examination.

Replacing the algorithm for eliminating reactions that may be cross–reactions with the retesting for lines of identity after initial screenings proved to be a better method for juvenile king crab although more time consuming. Retesting for lines of identity reduces potential loss of information due to the conservative nature of the algorithm. More study is needed to develop an improved experimental approach to the elimination of cross reactions.

Other experimental studies to refine the immunoassay would include the following: time studies of the decay of mixtures of antigenic determinants using prey with no cross reactions; feeding experiments to determine the effects of digestive processes on changes in the antigenic determinants;

development of unique antigens to decrease cross reactions; and investigation of other immunological approaches.

Any immunoassay suffers two problems in a diverse prey community. Because antisera were not prepared for all possible prey species, it is still possible that even with the retesting for lines of identity that some positive reactions are due to another immunologically related but untested prey. Also, because antisera were prepared only for the probable, not all possible, prey, some prey may remain undetected. The import of these considerations is that the immunoassay like visual examination may be overlooking prey items.

The immunoassay provided evidence that juvenile king crab, especially, the smallest juveniles (CL <30 mm), consume soft-bodied prey types overlooked by conventional visual examination. In so doing, however, it proved more time consuming, more expensive, and more complicated in its application and interpretation than expected. The results here indicate that immunological examination of stomach contents needs to be thoughtfully applied and in specific situations will require supplemental experimental work to support and refine its application. Immunological examination proved valuable in this study and in future should be seriously considered, especially, for small-sized predators, as a supplement to conventional visual examination of stomach contents. Further development of immunological approaches to stomach contents analysis is necessary to increase their effectiveness and value.

POTENTIAL BIAS IN DETERMINATIONS OF DIET

The greatest difficulty in this study was in obtaining unbiased estimates of dietary composition, and correction of bias was the driving force behind the technique development and supplemental laboratory determinations. Determining the number of a given prey type in crab stomachs proved impossible because shells and tests were often ground too finely to distinguish individuals. Indeed, during the clearance rate determinations, particle size of stomach contents fell rapidly with time and is, therefore, a potential indicator of when the animal fed. Dry weights proved more meaningful than volume in the diel feeding chronology and were, of course, more appropriate for conversion to caloric content (Hyslop, 1980) after estimating the amount of soft tissue ingested from dry weight of hard parts in the gut.

A presently uncorrectable source of bias with king crab is the loss of prey hard parts during ingestion. Three lines of evidence suggest that

juvenile king crabs may depend on clams, especially Spisula polynyma, to a greater extent than data here indicate. First, juvenile king crabs were directly observed scraping the flesh from bivalve shells rather than ingesting shell along with the flesh. Secondly, whereas most of the shell of small clams, such as, Cyclocardia cebricostata were observed in the gut, only bits of the shell margin of Spisula polynyma were found. Thirdly, the immunoassay detected Spisula sp in the stomachs of the larger juveniles where visual examination did not. Given the rapid clearance rate for clam soft tissue determined in shipboard experiments and the three considerations above, the contribution of Spisula to the crab's diet is probably underestimated here.

COMPARISON OF VARIOUS METHODS FOR DETERMINING DIETARY COMPOSITION

For the June, August, and overall diets of juvenile king crab (CL = 53 to 80 mm) comparisons of dietary composition determined by visual examination, dry weights and caloric intake appear in Tables 31, 32, and 33. The major problem in all estimates of dietary composition from stomach analysis is that what is found in the stomach is not directly representative of what occurs in the diet. Corrections done here were designed to estimate the relative contribution of prey items to the diet rather than just to the contents of stomachs.

The findings here agreed with Hyslop (1980) that the frequency of occurrence method gives only a crude qualitative view of dietary composition, suffers greatly when food items are not readily identifiable, and is not an indicator of the amount or bulk of food consumed. Perhaps the most fruitful way to view the frequency of occurrence data is to see it as indicating whether a given prey is consumed by most, some, or only a few of the juvenile crab population.

In contrast to the frequency of occurrence method, the gravimetric approach using dry weights, although more tedious and time consuming, gives the best indication of the amount of food consumed and is necessary for determination of caloric intake (Hyslop, 1980). In interpreting the relative importance of prey items in the diet, more credence was given to rankings of dietary importance based on dry weights and calories than those based on frequency of occurrence.

Perception of what prey were most important changed after correction for gut residence times, estimation of soft tissue dry weights and conversion to caloric equivalents. The major effect of such corrections was to show that, excluding floe, molluscs and echinoderms dominate

Table 31. Comparison of June dietary composition of juvenile king crab estimated by various methods.

	By visual examination			By dry weight			Z%%R%-
	% of stomachs	% of al 1 occurrences Uncorrected	Corrected*	% of dry wt	% of tissue dry wt Uncorrected	Corrected*	
Gastropod	87	19.5 (27.5)	6.7 (8.4)	**1.3 (2.5)****	0.4 (2.0)**	0.13 (1.1)**	0.10 (1.5)**
Pelecypods	91	20.8 (29.4)	7.2 (8.9)	**3.9 (7.3)**	0.6 (3.2)	0.20 (1.7)	0.19 (2.7)
Crustaceans	52	7.7 (10.9)	9.5 (11.8)	**0.2 (0.5)**	0.2 (1.3)	0.32 (2.6)	0.30 (4.2)
Polychaetes	48	7.0 (10.0)	44.9 (56.0)	1.1 (2.0)	0.8 (4.5)	5.39 (44.7)	3.67 (51.5)
Echinoderms	95	14.0 (19.9)	4.8 (6.0)	47.1 (87.6)	15.4 (88.4)	5.69 (47.2)	2.55 (35.8)
Other	32	1.6 (2.4)	7.2 (8.9)	0.1 (0.1)	0.1 (0.5)	0.32 (2.6)	0.30 (4.3)
Floe	100	14.7	14.6	36.2	82.6	87.9	92.9
Sand	100	14.7	5.1	10.0	0	0	0

*Corrected for gut residence times.
**Calculated using totals without floc and sand.

Table 32. Comparison of August dietary composition of juvenile king crab estimated by various methods.

	By visual examination			By dry weight			5%%%%- -
	% of stomachs	% of al 1 occurrences Uncorrected	Corrected*	% of dry wt	of tissue dry wt Uncorrected	Corrected*	
Gastropod	81	22.5 (31.0)	5.6 (6.4)	2.0 (8.6)**	**0.4 (7.2)****	0.14 (2.2)**	0.11 **(2.5)****
Pelecypods	100	17.3 (23.9)	4.3 (5.0)	14.6 (64.2)	**3.7 (64.8)**	1.26 (19.4)	**1.17 (24.8)**
Crustaceans	74	15.3 (21.1)	13.1 (15.1)	1.4 (6.0)	0.2 (3.1)	0.16 (2.4)	**0.15 (3.1)**
Polychaetes	37	5.2 (7.0)	23.5 (27.2)	1.4 (6.3)	0.7 (12.7)	4.56 (70.2)	**3.02 (64.0)**
Echinoderms	33	4.6 (6.3)	1.1 (1.3)	2.8 (12.2)	0.6 (10.3)	0.20 (3.1)	**0.09 (1.8)**
Other	48	7.7 (10.6)	39.0 (44.9)	0.6 (2.6)	0.1 (1.9)	0.17 (2.6)	**0.18 (3.7)**
Floe	100	13.8	9.9	64.6	94.4	93.5	**95.3**
Sand	100	13.8	3.4	12.6	0	0	**0**

*Corrected for gut residence times.
**Calculated using totals without floc and sand.

Table 33. Comparison of overal 1 dietary composition of juvenile king crab estimated by various methods.

	By visual exami nation			By dry weight		
	% of stomachs	% of al l occurrences		% of dry wt	of tissue dry wt	
		Uncorrected	Corrected*		Uncorrected	Corrected*
Gastropod	86	20.8 (28.9)**	6.2 (7.4)**	1.7 (5.0)**	0.4 (4.4)**	0.14 (1.7)
Pelecypods	94	19.4 (27.2)	5.8 (7.0)	10.5 (30.3)	2.8 (30.8)	0.97 (12.2)
Crustaceans	60	10.7 (15.0)	11.2 (13.4)	0.9 (2.7)	0.2 (2.1)	0.20 (2.5)
Polychaetes	44	6.3 (8.8)	34.7 (41.7)	1.3 (3.7)	0.7 (8.2)	4.78 (59.8)
Echinoderms	72	10.3 (14.4)	3.1 (3.7)	19.8 (57.2)	4.8 (53.5)	1.69 (21.2)
Other	11	4.0 (5.7)	22.3 (26.8)	0.4 (1.1)	0.1 (1.1)	0.21 (2.6)
Floe	100	14.3	12.4	53.7	91.0	92.0
Sand	100	14.3	4 . 3	11.6	0	0

*Corrected for gut residence times.
**Calculated using totals without floe and sand.

stomach contents but soft-bodied polychaete worms are the major food of juvenile king crab.

The results of correction for differential gut residence were sensitive to the values determined for gut residence time. Note the rise in the dietary importance of the miscellaneous category of food items in August (Table 32). An increase in their frequency of occurrence in August coupled with low gut residence times means a high corrected percentage of all occurrences. Whereas frequency of occurrence after correction was high, dietary importance by dry weight was quite low. These results suggest two alternative explanations. In August a greater number of crabs could have been consuming a greater number of miscellaneous items but only in small amounts. Alternatively, the gut residence times for these miscellaneous items could have been underestimated. More experimental effort in determining stomach clearance rates for a larger set of potential prey items would have been desirable.

Less dramatic than changes brought through correction for gut residence time were changes in relative ranking in the diet after estimation of soft tissue dry weights from the dry weights of hard parts in stomachs and soft tissue/hard tissue ratios. Floe increases in the overall diet from 54% of the dry weight of stomach contents to 91% of the estimated dry weight of soft tissue (Table 33). Correction for gut residence time increases floe contribution to 92% of the total corrected dry weight of soft tissue. Excluding floe, only polychaetes increase in relative ranking after estimation of soft tissue dry weight but not dramatically so. It is after correction for gut residence times that polychaetes come to dominate the dietary composition based on tissue dry weight.

Comparing the corrected dietary compositions determined by frequency of occurrence, soft tissue dry weight and caloric intake (columns 3, 6, and 7 in Tables 31 and 32) clearly indicates two things: First, a substantial proportion of the bulk of the food ingested resides in the floe and, secondly, soft-bodied polychaete worms are a substantially more important dietary component than previously supposed. Every stomach examined contained floe, which constituted 54% of the overall dry weight of stomach contents. In terms of corrected soft tissue dry weight and caloric intake, over 90% of the diet of juvenile king crab derives from whatever prey items contribute to the floe found in the stomachs,

Polychaetes are the dominant prey taxa in the crab diet by frequency of occurrence, soft tissue dry weight and caloric intake. Except for echinoderms, dietary composition by soft tissue dry weight parallels dietary composition by caloric intake. The caloric values of the prey

items generally fall between 4000 and 5000 calories per g dry weight. This similiarity of caloric values produced the parallel rankings between soft tissue dry weight and caloric intake. Echinoderms were the exception to the parallel ranking because their caloric value was about half the average of the other prey items.

Whereas the dietary composition by soft tissue dry weight and that by caloric intake are similiar, dietary composition by frequency of occurrence differs from both of the former. In August the prey taxa rank by caloric intake in the following order: polychaetes >> clams >> other > crustaceans > gastropod > echinoderms. In contrast in August prey taxa rank by corrected frequency of occurrence in this order: other > polychaetes > crustaceans > gastropod > clams > echinoderms. In June the rankings by caloric intake are as follows: polychaetes >> echinoderms >> other = crustaceans > clams > gastropod; and by frequency of occurrence: polychaetes >> crustaceans > other = clams = gastropod > echinoderms. The different results from the frequency of occurrence and gravimetric-caloric methods reinforce Hyslop's (1980) statement that frequency of occurrence data suffer when prey is not readily identifiable and that frequency of occurrence data is a poor indicator of the bulk of food consumed.

THE FOOD OF JUVENILE KING CRAB

What are the most important items in the diet of juvenile king crab? The answer depends upon the meaning one assigns to the large proportion of floe found in the stomach contents. If one regards the floe as soft tissue from largely unknown organisms that are a different set from those visually identified and whose hard parts were weighed, then one must conclude that the prey items comprising over 80% of the diet by dry weight and over 90% by caloric intake are unknown. If one regards the floe as organic matter derived from prey items identified visually and in rough proportion to the weights determined, then one may conclude that four items dominate the diet of the larger juvenile king crab (CL = 53-80 mm). In order these dominant items are (1) the polychaete, Pectinaria sp, (2) a sabellid polychaete, (3) the sand dollar, Echinarachnius parma, and (4) the clam, Tellina sp. The polychaetes constituted more than 50% of the diet by weight and calories in both June and August. The sand dollar was energetically important in June but not in August whereas Tellina sp was important in August. Juvenile king crab appear to be a predator on small, lowly motile benthic organisms that reside at or just below the surface of the sediment.

The assumption that, at least for the larger juvenile king crab, the floe is composed mainly of the soft tissues of prey items identified visually is more reasonable than the assumption" that floe derives mainly from a different and unknown set of prey items. The main evidence for the position comes from the immunoassay. For the larger juvenile crab the immunoassay detected the same polychaetes and clams detected visually but often did so in stomachs where the items were, in fact, not detected visually. This result indicates the presence of soft tissue from the prey items amid the visually unrecognizable organic matter. Also, for the larger juvenile crabs, of the two items that the immunoassay detected beyond those detected visually one was a polychaete. Furthermore. as discussed above concerning the clam, Spisula polynyma, the crabs may be ingesting the meat of clams in greater amounts than the presence of hard parts in the stomach indicates. For the larger juvenile" king crab (CL = 53-80 mm) the floe comes mainly from polychaetes and clam tissue and not from some totally different, unknown set of prey items. This position implies that the most reasonable estimates of daily caloric intake were those calculated without floe, 17.5 and 42.2 calories/g crab wet weight/day in June and August.

The situation for the yearling king crab (CL <30 mm) appears somewhat different from that of the larger juveniles. Floe and sand were often the only visually discernible items in stomachs of yearling king crab. The immunoassay results indicate that the diet of yearling king crab includes a greater proportion of prey items that may not be detected visually and includes items not observed in the larger juveniles. Bivalves, gastropod, sand dollars, barnacles, and small crustaceans were detected both visually and immunologically in yearling king crab and also occur in the diet of the larger juveniles. In addition to these items, the immunoassay detected three polychaetes, (Pectinaria sp, a maldanid, and a glycerid), oligochaetes, and nematodes not detected visually. The immunological evidence suggests that yearling king crab depend more than the larger juveniles on small soft bodied prey including meiofaunal groups not evident in the diet of the larger juveniles.

The dietary differences between June and August have been considered in this study to be seasonal or temporal changes. However, the possibility that the observed differences were due to differences in geographical location or depth may be equally a factor because precisely the same stations were not repeated in August as in June. All stations contributing to the data considered here occurred off Port Moller and were more than one but less than 20 nautical miles apart (Figure 15). Depths in June were 58-65 m and in August, 64-71 m. Examination of Table 7

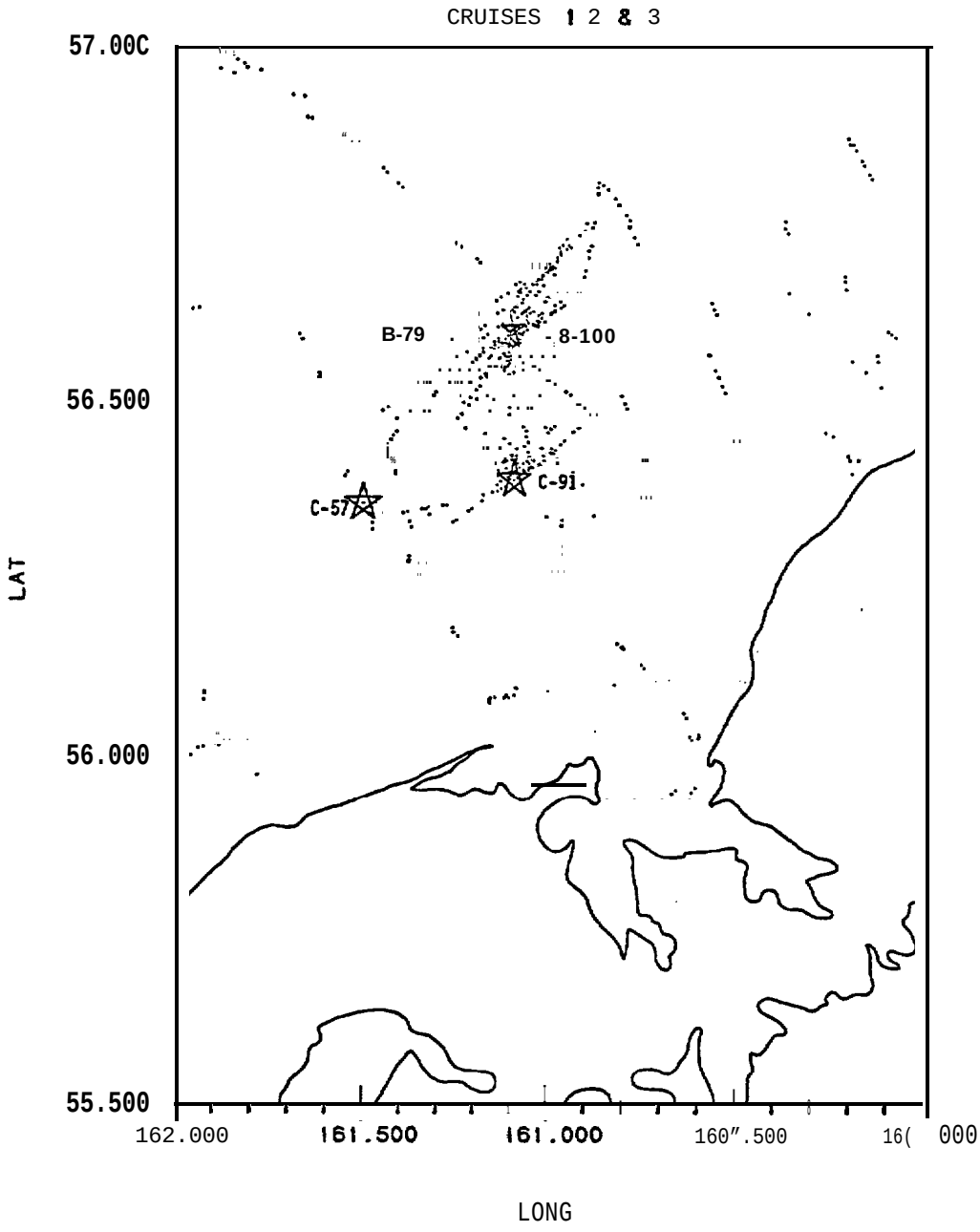


Figure 15. Station locations near Port Moller during June, August, and October, 1982.

shows high similarity between the stations from August and less similarity between the stations from June.

The results confirm the hypothesis that juvenile king crab depend upon soft-bodied readily digested prey items to a greater extent than previously thought and indicate that polychaete worms are a consistent and substantial proportion of the crab's diet by bulk and by energy. The diet of the smallest juveniles contains soft-bodied meiofaunal groups detected immunologically but not observed in the diet of larger juveniles.

POTENTIAL IMPACTS FROM OIL AND GAS DEVELOPMENT ON JUVENILE CRABS

Potential impacts from oil and gas development could derive from habitat disturbance, exposure to contaminants from platform discharges, and oil spills. The assessment of risk from these potential impacts requires judgments concerning, first, the manner and extent to which disturbance and contaminant exposure is likely to occur and, secondly, the direct and indirect consequences likely given the anticipated extent of disturbance and exposure. The potential impacts differ with life stage. This study was concerned with evaluating possible impacts on juvenile king crab. Because of their different habitats and diets, impacts are assessed separately for the smallest juveniles (CL <30 mm) and the larger juveniles (CL >40 mm).

Assessment of impacts requires consideration of the highly aggregated or clumped distribution of juvenile king crab. The larger juveniles (CL >40 mm) were essentially exclusively concentrated off Port Moller in water depths of 45 to 75 m. In this region larger juvenile king crab appear to aggregate along the seaward side of an oceanographic structural front now being studied by other NOAA/OCSEAP investigators. The temporal changes in the distribution of the larger juveniles may be related to movements in the front's position. The thought that the shallow nearshore zone north of the Alaska Peninsula held abundant juvenile king crab was not confirmed by this survey for the larger juveniles. The smallest juvenile king crab do occur in the nearshore zone amid patches of cobble and rock with abundant epifauna. These patches provide food and shelter from predation in an area of open, high-energy sandy bottoms. More detailed information on the distribution of juvenile crabs along the North Aleutian Shelf will come from another NOAA/OCSEAP study now in progress. The current perception of juvenile crab distribution indicates that for the smallest juveniles impacts from disturbance and platform discharges are unlikely whereas impacts from oil spills need consideration. For the larger juveniles (CL >40 mm) potential effects from disturbance, discharges and

spills need consideration.

The effects of oil spills in the nearshore zone are well documented (see Clark, 1982). Incorporation of oil into the subtidal sediment and its subsequent loss are functions of the circumstances of the particular spill and the energy of the nearshore zone. Because of its high energy the nearshore zone of the North Aleutian Shelf appears likely to have oil incorporated into and readily lost from subtidal sand following a spill. Whereas prediction of the probable occurrence, magnitude and extent of an oil spill reaching the nearshore subtidal habitats of the smallest juvenile king crab is beyond the scope of this study, there is little doubt that should a significant spill reach the nearshore zone there could be substantial acute, lethal and sublethal effects. Substantial immediate effects including the oiling and mortality of intertidal crabs occurred during the AMOCO CADIZ spill (See review by Conan et al, 1981). Substantial mortality of juvenile king crab would require water column concentrations of 4.2 ppm total hydrocarbons by IR, the 96-h LC_{50} for moribundity found by Brodersen et al (1977) for juvenile king crab exposed to WSF of Cook Inlet crude oil. The concentrations of oil in the sediment that would produce mortality in the juvenile king crab are not known. If a spill should produce acute mortality in the smallest juvenile king crab, any substantial loss of yearling crab could be felt as decrease in year class strength in the commercial fisheries 8 years later when the crabs would have reached harvestable size.

Chronic indirect effects persisting beyond a spill could derive from loss or reduction in the macro or meiofaunal food of the smallest juveniles. Meiofaunal groups vary considerably in their resistance to oil contamination and can recover quickly (Giere, 1979). In studying a refinery effluent Dicks and Hartley (1982) report that oligochaetes had decreased density at stations near the refinery and showed a gradient in density paralleling that of sediment concentrations of aliphatic hydrocarbon. The immunoassay identified oligochaetes as a dietary item for the smallest juvenile crab. In subtidal recruitment studies Vanderhorst (Unpublished data; see Vanderhorst, 1984) found significant reductions in the numbers of species of polychaetes, mollusks and crustaceans recruiting into sand contaminated with crude oil at total oil levels initially at 2000 ppm and falling to below 1000 ppm in 3 months. Densities of a crustacean and a polychaete selected a priori for detailed analysis were reduced to 1/4 and 1/3, respectively, of the densities in control sand. From intertidal recruitment studies Vanderhorst et al. (1981) predicted full recovery of the infauna to take 31 months following an initial contamination of the sand at 1800 ppm. An oil spill in the shallow nearshore zone can reasonably be expected to reduce the density of food important to juvenile crabs, but prediction of the extent of such restriction in the crab's food supply requires prediction of the salient features of such a spill.

supply requires prediction of the salient features of such a spill.

Restricted food supply can stop growth in marine organisms (Edwards and Huebner, 1977), and retarded growth rates in rock lobster, Jasus lalandii, correlate with the biomass of its principal prey (Newman and Pollock, 1974). Because juvenile lobsters prey upon a restricted size range of small prey, their growth rates are more heavily influenced by the availability of smaller prey than are the growth rates of the adults (Pollock, 1979; Griffiths and Seiderer, 1980). Juvenile king crab are probably also more heavily influenced by the availability of small prey. For juvenile king crab a restriction in food supply can be reasonably expected to retard growth if alternative food is not available or taken. Following the AMOCO CADIZ spill retarded growth was reported for flatfish in one of the heavily contaminated estuaries and edible crab catches were depressed for a year (Maurin, 1981). The expectation that an oil spill in the nearshore zone would retard growth of juvneile king crab through depression of its infaunal prey appears reasonable.

The larger juvenile crab (CL >40 mm) occur on soft bottoms at 45 to 70 m in a relatively small area off Port Moller and could potentially be impacted by physical disturbance, platform discharges, and oil spills. Physical disturbance of the bottom occurs around platforms and is localized. In the vicinity of platforms the effects of disturbance on benthic infauna are usually not clearly separable from effects due to sediment burdens of contaminants (Addy et al., 1978; Dicks and Hartley, 1982). Near platforms in the North Sea oil field in 70 m, Addy et al. (1978) did observe decreased densities of polychaete worms so that the reduction of a food item important to the diet of juvenile crabs could make the vicinity of platforms energetically unrewarding. On the other hand, Wolfson et al (1979) report increases in the density of tube-dwelling polychaetes in the vicinity of an oil platform in California. In a shallow Texas bay in which high turbidity appeared to enhance sedimentation of hydrocarbons, Armstrong et al (1979) found the density of benthic infauna depressed in the vicinity of the outfall of an oil separator platform. Depression of infaunal density appeared to occur where the sedimentary concentration of naphthalenes exceeded 2 ppm. The magnitude of exploration, development and production in the relatively small area off Port Moller in which the juvenile crabs concentrate needs to be predicted before one can assess whether disturbance and production discharges constitute a significant potential impact.

A potential benefit that king crab could derive from oil platforms is an increase in habitat. The smallest juvenile blue king crab (CL <30 mm) near the Pribilof Islands have been found predominantly in shell hash (Armstrong and Pearson, unpublished data). Juvenile red king crab (CL <30

mm) also occur in similiar habitat as well as others offering shelter (Fishman and Armstrong, personal communication). Under an oil platform off California, Wolfson et al (1979) found shell hash from mussels with a mean depth of 3 m. If such shell piles develop under platforms in the Bering Sea, they could offer increased habitat for the recruitment of the smallest juvenile king crab in an otherwise predominantly sandy area.

If an oil spill reaches the area of juvenile crab abundance off Port Moller, potential indirect effects from spilled oil even to the 40-70 m depths where the larger juveniles occur cannot be dismissed although direct lethal effects seem unlikely. Studies after the TSESIS oil spill in the Baltic Sea demonstrate that hydrocarbons from spilled oil can reach deep soft bottoms to produce observable effects on the benthic infauna (Kineman et al., 1980). Following the TSESIS spill hydrocarbons were sedimented to the 30-40 m bottom after attachment to particulate and through incorporation into copepod fecal pellets (Boehm et al., 1980). The contaminated particulate and fecal pellets were not apparently incorporated immediately into bottom sediments because elevated burdens were not found in surface sediment grabs. Rather the depositing matter accumulated in the nepheloid layer at the water/sediment interface. Hydrocarbon concentrations in material recovered from sediment traps , ranged up to 3.276 mg/g for aliphatics and 3.624 mg/g for aromatics. The main effect of the contaminated sediment was the disappearance of the amphipods perhaps through emigration and depression of meiofaunal densities (Elmgren et al., 1980). Densities of other infauna appeared unaffected. Small crustaceans were 2 to 3% of the diet of the larger juvenile king crab so that the crab does not appear to be highly vulnerable to their loss.

Other events following the TSESIS spill have implications for juvenile king crab. Whereas the densities of the clam, Macoma balthica, were not reduced, the clam did accumulate high burdens of hydrocarbons even at stations with little or no hydrocarbon burden in the surface sediment (Boehm et al., 1980). The clams were apparently accumulating hydrocarbons from the contaminated floe in the nepheloid layer. The burdens rose, fell and rose again 10 months after the spill. The surprising rise in the course of apparent deputation was attributed to the reintroduction of contaminated floe by bottom currents.

Juvenile king crab in August gained 25% of their caloric intake from clams so that potential accumulation of hydrocarbons in clam tissue raises the question of hydrocarbon accumulation in the crabs. Whereas mollusks can accumulate hydrocarbons from contaminated sediment, sediment-dwelling polychaetes, the major food of the juvenile king crab, do not accumulate hydrocarbons from food or sediment (Neff and Anderson, 1981). Two crabs

have been shown to readily and rapidly metabolize hydrocarbons gained from contaminated food (Corner et al, 1973; Lee et al., 1976,1977). Other crabs have been found to have enzyme systems capable of metabolizing hydrocarbons (Lee et al, 1976,1977; Varanasi and Malins, 1977). The fiddler crab, Uca pugnax, has been reported to lack the ready ability to metabolize hydrocarbons and field populations burrowing into sediment heavily contaminated with oil maintained body burdens of hydrocarbons between 180 and 280 ppm over 4 years (Burns, 1978). Based on the general ability of crabs to metabolize hydrocarbons, the king crab can also be expected to metabolize hydrocarbons, but its ability to do so has not been experimentally demonstrated and needs study before definitive assessment of the likelihood of hydrocarbon accumulation can be made.

Potential accumulation of hydrocarbon body burdens also raises the spectre of taste tainting of the commercially valuable adult king crab. After 48-h exposure to two crude oils layered on the water surface, thresholds at which taste panels detected tainting of cooked meat ranged from 49 to 160 ppm for penaeid shrimp and from 620 to 1250 ppm for blue crab, Callinectes sapidus (Knieper and Culley, 1975). Lobsters accidently exposed to diesel oil for 24 h showed taste tainting with 12–16 ppm total hydrocarbons in the cooked and canned meat (Paradis and Ackman, 1975). These findings suggest that taste tainting in crustaceans may require a high exposure level.

In assessing the likelihood of taste tainting in king crab two questions need to be addressed. First, what levels of hydrocarbon accumulation are likely? Secondly, do such levels produce taste tainting. The findings of Lee et al (1976,1977) that crabs rapidly metabolize and excrete hydrocarbons and those of Neff and Anderson (1981) that crustacean muscle tissue accumulates low levels of hydrocarbons that are rapidly released suggest that accumulation and any attendant tainting may be transient in the king crab. There are no accumulation and taste tainting data specifically for the king crab so that definite statements on the likelihood of taste tainting in king crab can not presently be made. Taste tainting is not readily predictable from hydrocarbon concentrations in the cooked meat (Mac Intyre, 1982) so that taste panel testing is necessary if king crab prove capable of accumulating hydrocarbons.

CONCLUSIONS AND RECOMMENDATIONS

Juvenile red king crab, Paralithodes camtschatica (CL >40 mm), were concentrated off Port Moller whereas juvenile tanner crab, Chionoecetes bairdi (CW <20 mm) were concentrated in the Amak Island Black Hill Region. Juvenile tanner crab, C. opilio, were not found in the study area. Both the juvenile king and tanner crab, C. bairdi, were in deeper water in August 1982 than in June 1982. The smallest juvenile king crab (CL <30 mm) were found in shallow nearshore areas amongst cobble and rock with abundant epifauna. The apparent concentration of the larger juvenile king crab along an oceanographic front and their movement with changes in the front's position and the habitat needs of the smallest juvenile king crab warrant more study.

Power laws describe the relationships between carapace size and maximum stomach volume in both king and tanner crab. Sex and shell condition did not affect the relationship. Our model differs substantially from that currently used by other workers.

Shipboard experiments showed that the clearance of contents from the stomachs of juvenile king crab was best described by multi-compartmental exponential decay models. Stomach residence time calculated from these models showed considerable variation with prey type. Soft tissue, such as, shucked clam, falls to 5% of its initial dry weight in the gut in 11 h whereas hard tissue, such as barnacle plate, remains in the stomach almost indefinitely (10^4 h) unless regurgitated.

For juvenile king crab (CL = 53-80 mm) collected in June the volume of solid material in the stomach averaged 18% of the maximum stomach volume and the dry weight of the stomach contents, 1.63 mg dry weight per g crab wet weight. In August the volume of solids averaged 10% of the maximum stomach volume, and the dry weight of the stomach contents 2.89 mg dry weight per g crab weight. In August, the volume and dry weight of stomach contents varied significantly with time of day. In June and August there were two feeding periods. During the period between 1300 h and 1800 h crabs showed greater stomach contents than those collected between 0000h and 0800h.

Using the diel feeding chronologies and the multi-compartmental exponential decay function for the evacuation of stomach contents, the daily rations of juvenile king crab were calculated to be 6.30 and 11.92 mg dry weight per g crab wet weight per day in June and August, respectively.

Using several methods to determine dietary composition gave a more complete picture of the crab's diet than reliance on one method alone. Visual examination of stomach contents gave dietary composition by frequency of occurrence. Measuring dry weights of the hard parts of prey items and estimating soft tissue intake with appropriate ratios gave a measure of dietary composition by bulk that was converted to dietary composition in terms of caloric intake. The immunoassay determined the extent to which readily digested prey items detectable immunologically went undetected by visual examination.

Examination of stomach contents alone does not indicate relative importance in the diet because such examinations are biased in favor of prey items with long stomach residence times. For the juvenile king crab correction of dietary composition for gut residence times profoundly changes the perceived dietary importance of certain prey types. After correction for gut residence times molluscs and echinoderms, whose hard parts dominate stomach contents, become of lesser dietary importance whereas soft bodied polychaete worms become the first-ranking dietary i tern. The results indicate that future dietary studies involving crabs will be obligated to consider and correct for gut residence times. More experimental effort to determine gut residence times for more prey types would have been desirable in this study.

For juvenile king crab (CL = 53-80 mm), floe, i.e., unidentifiable amorphous organic matter, constitutes the major bulk of the stomach contents. Assuming that this floe derived mainly from prey items whose hard parts were weighed, and after correcting for gut residence times, four taxa (two polychaetes, a sand dollar, and a clam) accounted for 92% of the soft tissue dry weight in the diet. The immunoassay results supported the reasonableness of the above assumption. Under this assumption the caloric intakes were 17.5 and 42.2 calories per g crab wet weight per day in June and August, respectively. Energetically two polychaetes, Pectinaria sp. and a sabellid, constituted over 50% of the caloric intake in June and August. The sand dollar, Echinarachnius parma, constituted 36% of the caloric intake in June but only 2% in August. Bivalves constituted 3% of the caloric intake in June but 25% in August. The major bivalve in the August diet was a small, thin-shelled clam, Tellina sp. Juvenile king crab appear to be predators of small, poorly motile benthic organisms living at or just beneath the sedimentary

surface.

The smallest juvenile king crab consume meiofaunal taxa not observed in the larger juveniles. For the yearling king crab (CL <30 mm) visual examination of the stomach contents was not as revealing as hoped. The immunoassay did detect polychaetes, oligochaetes and nematodes not detected visually and not seen visually or immunologically in the stomachs of the larger juvenile crabs.

The immunoassay indicated that juvenile king crab, especially the smallest juveniles (CL <30 mm) consume soft-bodied prey types overlooked by conventional analyses of stomach contents. To separate positive detections from those due to cross reactions the mathematical algorithm used by Feller'et al. (1979) proved inadequate and was replaced by successive retesting to examine lines of identity, nonidentity, and partial identity. Also, the antigenic determinants responsible for the immunological reaction between prey item proteins and the antisera proved to be rapidly digested in crab stomachs. Because of this loss of antigenicity and other factors, the immunoassay may be overlooking prey items. The immunoassay can be considered a potentially valuable and, for small predators, a possibly necessary supplement to conventional analyses of stomach contents. However, it is not a substitute for these latter analyses and needs thoughtful application. The immunological examination of stomach contents definitely needs further technical refinement. and its future application in specific situations will require supplemental experimental support.

The main perceptions from this study are that the problems inherent in stomach analysis require the integration of several methods to determine dietary composition and that failure to correct for biases can give substantially misleading results.

Potential impacts from oil and gas development could derive from habitat disturbance and exposure to contaminants from platform discharges and oil spills, The assessment of risk from these potential impacts requires judgments concerning, first, the manner and extent to which disturbance and contaminant exposure are likely to occur and, secondly, the direct and indirect consequences likely given the anticipated extent of disturbance and exposure. The current perception of juvenile crab distribution suggests that there are differences between the smallest juvenile (CL <30 mm) and the larger juvenile king crab (CL >40 mm) in the likely impacts. Because of the shallow nearshore distribution of the smallest juveniles, impacts from disturbance and platform discharges are unlikely whereas impacts from oil spills need consideration. Because of the concentration of the larger juveniles off Port Moller in depths of 40

to 70 m, potential effects from disturbance and platform discharges need consideration whereas direct effects from oil spills seem unlikely.

Chronic indirect effects persisting beyond an oil spill could derive from loss or reduction in the macro or meiofaunal food of the smallest juvenile king crab. An oil spill in the shallow nearshore zone can reasonably be expected to reduce the density of food important to juvenile crabs, but prediction of the extent of such restriction in the crab's food supply requires prediction of the salient features of such a spill. Based on findings with other crustaceans a restriction in food supply can be reasonably expected to retard growth in juvenile king crab if alternative food is not available or taken.

The magnitude of exploration, development and production in the relatively small area off Port Moller in which the larger juvenile king crab concentrate needs to be predicted before one can assess whether disturbance and production discharges constitute a significant potential impact for the larger juveniles. Whereas the major food items of the juvenile king crab, polychaete worms, have been shown to accumulate little hydrocarbon burdens from contaminated food or sediment, bivalves, a lesser but still significant food of the crabs, do accumulate hydrocarbons. Whereas crabs in general appear readily capable of metabolizing hydrocarbons, the present lack of specific information on accumulation and metabolism of hydrocarbons by king crab precludes definitive assessment of hydrocarbon accumulation in king crab.

ACKNOWLEDGEMENTS

Human endeavors can be satisfying despite obstacles when the spirit of cooperation is high. We feel privileged to have received such satisfying cooperation from all the NOAA personnel who worked with us. We are greatly indebted to the officers and crews of the NOAA ships MILLER FREEMAN and DISCOVERER. The support and cooperation given us by the personnel of the NOAA Diving Office was beyond what they needed to give and is well appreciated. The interest and thoughtful support of the NOAA/OCSEAP personnel in the Juneau offices is appreciated, especially that of Mr. Lyman Thorsteinson, the NOAA technical representative.

For their technical assistance at various stages, we thank S. L. Kiesser and D. L. McQuerry of Battelle's Marine Research Laboratory in Sequim, Washington, and D. Elliott of Battelle's Northwest Division in Richland, Washington.

For providing the extra yearling king crab in 1983, we thank Dr. David Armstrong of the University of Washington and Dr. Paul Fishman of VTN, Inc.

Special thanks go to Dr. Robert Feller of the University of South Carolina and Dr. Ralph Elston of Battelle's Marine Research Laboratory for their invaluable assistance with the immunoassay. We thank Drs. R. Feller, J. W. Anderson, and G. Roesijadi for comments on the draft report.

We are deeply indebted to the Office Support Group at Battelle's Marine Research Laboratory.

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