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ABSTRACT: In a 4-year study I assessed impacts of offshore placer gold mining on adult red king crabs *Paralithodes camtschaticus* in the northeastern Bering Sea near Nome, Alaska. From June to October 1986–1990, nearshore mining with a bucket-line dredge to depths of 9 to 20 m removed 1.5 km^2 and about 5.5×10^6 m^3 of substrate. Crabs were offshore of the study area when mining occurred but were in the mining vicinity during the ice-covered months of March and April, which was the primary time data on crab abundance and prey were obtained. Comparisons between mined and unmined stations revealed that mining had a negligible effect on crabs. Crab catches, size, sex, quantity, and contribution of most prey groups in stomachs were similar between mined and unmined areas. However, a few ROV observations indicated that crab abundance was lower in mined areas. Also, plants (mainly eelgrass *Zostera marina*) and hydroids, which accumulated in mining depressions, were more common in crab stomachs from mined areas. The preponderance of food consumed by crabs throughout the mined and unmined regions was unidentified fishes. Mining effects were analyzed in the context of the small size of the area disturbed, the dynamic nature of the benthic habitat in the region, and the opportunistic feeding habits of the crabs.

INTRODUCTION

Small, unregulated placer mining at the turn of the century and more recent (1970s and 1980s) short-term exploratory endeavors have typified coastal marine mining activity in Alaskan waters (R. Baer, U.S. Department of the Interior, Bureau of Mines, Juneau, personal communication). Only one Alaskan marine mining project on the continental shelf has been environmentally monitored. That project, known as the Nome Offshore Placer Project, assessed the effects of placer gold mining in the shallow waters of Norton Sound in the northeastern Bering Sea. Mining took place between 1986 and 1990; monitoring occurred between 1986 and 1991. Generally, monitoring of marine mining and dredging includes tailing discharge rates, chemical analyses, turbidity, and trace-metal bioaccumulation and biomagnification (Ellis 1988), and most environmental monitoring programs include quantification of benthic organisms as an index to assess the effects of mining. Infaunal invertebrates are most frequently sampled (e.g., Swartz et al. 1980; Jones and Candy 1981; Poiner and Kennedy 1984; Ellis and Hoover 1990a, 1990b; Kenny and Rees 1996). Some investigations utilized large motile epifauna, such as crabs, in their monitoring studies (Stevens 1981; also see Poling and Ellis 1993; Ellis et al. 1994; Johnson et al. 1998; Stone and Johnson 1998 for review of monitoring programs associated with submarine tailings disposal). The red king crab *Paralithodes camtschaticus* (family Lithodidae) supports commercial and noncommercial (subsistence) fisheries in Norton Sound that encompass the mining area off Nome. Consequently, this species was the choice of regulatory agencies and special interest groups to evaluate the effects of mining on marine benthos. Ideally, a long-lived, benthic organism of limited or no mobility would be most appropriate for monitoring; however, no such organism inhabits this dynamic nearshore environment.

This study was designed to evaluate the potential effect of mining activity on red king crabs in northwestern Norton Sound near Nome. Specific objectives were to examine their relative abundance, distribution, and prey. The potential effects of mining on this crab species are also addressed in Jewett (1997) and Jewett et al. (1999).

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Study Area

This study was conducted from 1986 to 1993 within the 88 km^2 of State of Alaska offshore mining leases in northwestern Norton Sound adjacent to the city of Nome. The lease area extends from 64° 26' N northward to the southern coastline of the Seward Peninsula. The southern boundary generally follows the 20-m depth contour. The eastern boundary is due south, midway between the mouths of the Snake and Nome Rivers (165° 22' W), and the western boundary is due south, midway between the mouths of Cripple Creek and Penny River (165° 46' W; Figure 1). The westward flow of water along the south coast of the Seward Peninsula varies in intensity and extent (Hood et al. 1974; Muench et al. 1981). Surface currents in the region typically range from 5 to 20 $cm \cdot s^{-1}$, but current speeds up to 100 $cm \cdot s^{-1}$ may occur in the Nome vicinity (Nelson and Hopkins 1972). Bottom current speeds are generally 10–20 $cm \cdot s^{-1}$ (Muench et al. 1981). Tidal fluctuations are minimal (Pearson et al. 1981), but major storms can cause dramatic fluctuation in sea level. Numerous storms are prevalent, particularly during the fall months. For example, during October and November 1989 and 1990, peak easterly winds of over 47 $km \cdot h^{-1}$ were observed at Nome for 9 and 24 d, respectively (NOAA, Local Climatological Data Monthly Summary). A severe storm battered the region on October 5, 1992, with winds to 94 $km \cdot h^{-1}$ (Nome Nugget 1992) and disrupted the nearshore habitat to depths of at least 12 m (personal observation). Surface sediments in the vicinity of the study area consist of a mosaic of sediment types including relict gravel and sand from residual lag deposits along with modern sediments of very fine sand- and silt-sized particles from the Yukon River (Drake et al. 1980; Hess and Nelson 1982; Naidu 1988). The fine sand and silt substrate overlying the more permanent cobble substrate is transient in nature and subject to redistribution by storms, currents, and ice gouging. Wave-induced nearshore currents move fines both east and west, but the net nearshore sand transport is to the west approximately 5×10^5 $m^3 \cdot y^{-1}$ (Drake et al. 1980; Tetra Tech 1980). In the ice-free months of June through November bottomwater tem-

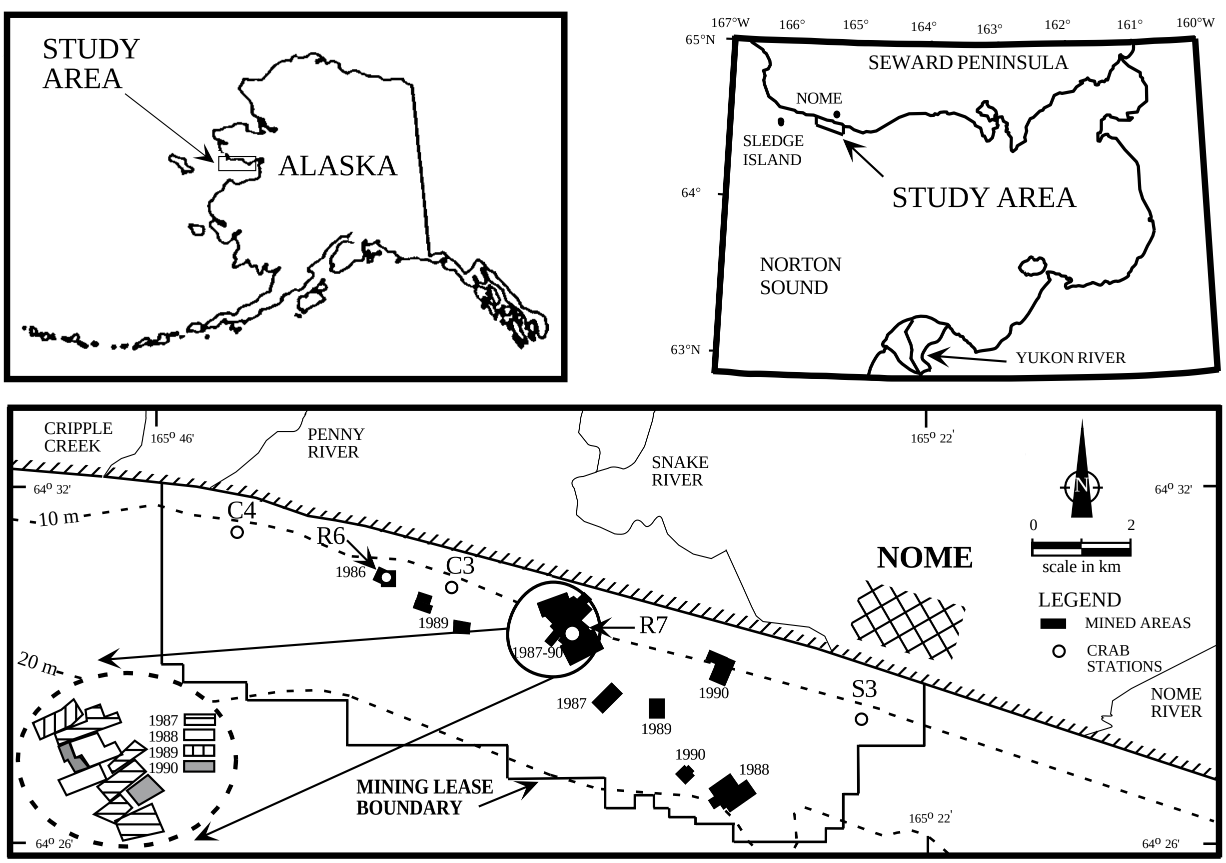

Figure 1. Map of the Nome Offshore Placer Project showing mining lease boundary, areas mined by year, and 5 stations surveyed for red king crabs.

peratures typically range from near 0 to 12°C and salinities from 21 to 34‰. During ice-covered months of December through May bottom temperatures range from -1.8 to 1.5°C and salinities from 32 to 34‰ (Hood et al. 1974; Muench et al. 1981; Jewett, unpublished). Ice thickness is variable and may approach 1.2 m. The seaward edge of the ice generally extends to the 20-m isobath and may be anchored by ice keels especially in the region from 10 to 20 m (Thor and Nelson 1981). Ice gouging takes place sporadically and trends east to west; gouges normally are <25 m wide and cut <0.5 m deep into the substrate (Thor and Nelson 1981). Bioturbation by numerous benthic invertebrates, demersal fishes, and occasionally Pacific walrus *Odobenus rosmarus divergens* also takes place (Jewett and Feder 1980; Nelson et al. 1981; Klaus et al. 1990).

Mining Overview

Mining in the Nome Offshore Placer Project was conducted in northwestern Norton Sound in ice-free months (June–October) by Western Gold Exploration & Mining Company (WestGold) with the world's largest bucket-line mining dredge, the BIMA. The BIMA's dimensions were approximately 110 m long, 43 m wide, and 45 m high; an 88-m long bucket ladder contained 134 buckets, each of which had a 0.85-m^3 capacity. Variable substrate types were mined, targeting residual lag deposits, materials processed onboard, and tailings returned to the excavation site. Mining took place in water depths of 9 to 20 m. The approximate locations and extent mined from 1986 through 1990 are shown in Figure 1. The area mined was within an 88-km^2 lease area, covered 1.5 km^2, and removed 5.5×10^6 m^3 of substrate (Howkins 1992). The average area mined was 0.300 km^2; the average volume mined was 1.1×10^6 m^3. The annual area and volume mined ranged from 0.093 km^2 and 3.1×10^5 m^3 in 1986 to 0.583 km^2 and 2.0×10^6 m^3 in 1988. The Nome Offshore Placer Project ceased operation on September 20, 1990, after extracting nearly 3,800 kg of gold (Howkins 1992).

Norton Sound Red King Crab Overview

The red king crab is 1 of 3 commercially exploited king crab species in the northern Pacific Ocean. It was once the most valuable fishery resource on the Alaskan continental shelf (Otto 1990). Norton Sound supports the northernmost commercial and subsistence fisheries for this species (Powell et al. 1983; Lean and Brennan 1995), and in 1994 the Norton Sound summer red king crab commercial fishery was designated "super-exclusive" by the North Pacific Fishery Management Council (Natcher et al. 1999). The stock within Norton Sound is unique because it: (1) is separate from other stocks in the Bering Sea (Seeb et al. 1989), (2) lives under ice for 5–6 months a year (Dupré 1980), and (3) is confined to waters <31 m in depth. The crab population within the sound is relatively small. A population assessment in August 1996 placed the total number of legal males (>121 mm carapace width [CW]) at 0.5 million crabs (Lean and Brennan 1997). Migrations of the Norton Sound crabs typically follow north–south or northeast–southwest patterns (Powell et al. 1983). The greatest recorded migration rate in the sound is 61 km in 46 d (Powell et al. 1983), and the crabs could conceivably traverse the full 250-km length of the sound in a seasonal migration. Adult male red king crabs, monitored under ice with ultrasonic biotelemetry, had an average net movement of approximately 0.26 $km \cdot d^{-1}$ in the nearshore region near Nome (Rusanowski et al. 1990). The distance traveled or activity rates for adult female red king crabs in a Southeast Alaska estuary ranged from 0.056 $km \cdot d^{-1}$ during winter to 0.090 $km \cdot d^{-1}$ during spring (Stone et al. 1992).

Commercial and subsistence fisheries for king crabs in Norton Sound occur in summer/fall and winter. The commercial summer/fall fishery is traditionally centered in the northwestern portion of the sound, south and east of Sledge Island (Wolotira et al. 1977; Powell et al. 1983). The summer commercial harvest between 1986 and 1991 averaged (± SE) 96,000 ± 18,036 males averaging 1.4 ± 0.02 kg; an average of 6 ±1.6 vessels participated, although no fishing took place in 1991 (Lean and Brennan 1995). In winter a small commercial fishery and a large subsistence fishery take crab through the ice adjacent to coastal villages, particularly Nome (Powell et al. 1983; Lean and Brennan 1995). The average (1986–1991) winter harvests during my study were 1,910 ± 627 males in the commercial fishery and 6,865 ±1,253 crabs (both sexes) in the subsistence fishery (Lean and Brennan 1995).

Limited life history information on king crabs within Norton Sound (Wolotira et al. 1977; Powell et al. 1983; Jewett et al. 1990; Otto et al. 1990) indicates the species behaves similarly to populations elsewhere (see Jewett and Onuf [1988] for reviews of red king crab life history). A northeasterly migration of adult and subadult crabs into coastal waters of Norton Sound happens in late fall and winter (Powell et al. 1983). Reproductive activities (i.e., embryo hatching, adult female molting, grasping, mating, and egg extrusion) peak while crabs are nearshore, particularly from March through May when some ice is still prevalent (Powell et al. 1983; Otto et al. 1990). The adult crabs migrate offshore during nearshore ice breakup (usu-

Table 1. Stations where king crabs were surveyed in the Nome Offshore Placer Project, 1986–1990.

Stations	Survey Method	Latitude	Longitude	Depth (m)
Unmined				
S3	ROV, Scuba	64° 29' 25"	165° 24' 67"	10–12
C3	Pots, ROV, Scuba	64° 30' 47"	165° 36' 35"	10–12
C4	Pots	64° 31' 03"	165° 45' 00"	12
Mined				
R6	Pots, ROV, Scuba	64° 31' 03"	165° 38' 40"	10–12
R7	Pots, ROV, Scuba	64° 30' 19"	165° 33' 16"	10–12

ally May) when temperatures increase and salinities decrease (Muench et al. 1981; Powell et al. 1983). Thus, most adult crabs were offshore when gold mining took place in nearshore waters near Nome. Trawl surveys in Norton Sound in August 1985 and 1988 indicated most adult males were widely dispersed between 18 and 31 m, where bottom temperatures were 2.8 to 9.5°C (Stevens 1989; Stevens and Haaga 1992). The optimal ranges of temperatures and salinities for red king crabs are -1.8 to 9.5°C and 26–34‰ (Jewett and Onuf 1988). Female crabs in Norton Sound mature at smaller sizes than in populations to the south (Otto et al. 1990). The estimated size at 50% maturity for females in Norton Sound is 71.4 mm carapace length (CL) compared with 88.8 mm CL in Bristol Bay and 102.1 mm CL near the Pribilof Islands (Otto et al. 1990). Males are also assumed to mature at smaller sizes because maturity of both sexes is attained at similar sizes elsewhere (Jewett and Onuf 1988). King crabs elsewhere utilize a wide array of food (Jewett and Feder 1982), and no differences exist in feeding between sexes (e.g., Kulichkova 1955; McLaughlin and Hebard 1961; Jewett and Feder 1982).

METHODS

Sampling and observations of crabs in Norton Sound were made at 2 mined (R6 and R7) and 3 unmined (S3, C3 and C4) stations to determine crab abundance and food consumption (Figure 1; Table 1). Although numerous sites were mined between water depths of 9–20 m over the 5-year mining period, only R6 and R7 were monitored because they were initially mined and represented the longest temporal data sets. Station R6 was mined in 1986 and R7 in 1987–1990. The mined area in the vicinity of stations R6 and R7 was approximately 0.75 km^2. Water depths at all 5 stations were 10–12 m. The mined stations were positioned in the middle of the mined areas, a distance of at least 0.5 km to the periphery. Stations from the unmined area were selected without known bias from a sampling grid. Positioning was obtained with a Motorola Mini-Ranger III and a portable Loran C unit.

Crab abundance was primarily determined by capturing crabs in baited pots and secondarily by in situ observations with remotely operated vehicles (ROV) and scuba. Crabs were collected with pots through the ice at 2 mined (R6 and R7) and 2 unmined (C3 and C4) stations during March and early April. Crabs were caught from 1987 to 1990 to determine abundance; subsets of crabs caught from 1987 to 1989 were examined for food consumption. Occasionally, all 4 stations could not be fished, mainly because of poor ice conditions (e.g., ridges). Therefore, 2 holes were fished approximately 200 m apart in a north–south orientation at station R6 (R6a and R6b) in 1987, R7 (R7a and R7b), and in 1990 C3 (C3a and C3b). Collections were made with conical, top-loading commercial pots (1.5-m base diameter) or rectangular, side-loading commercial pots that were generally soaked 12–24 h, which minimized the digestion time of stomach contents. All pots had 7.6-cm stretched mesh and were baited with chopped, frozen Pacific herring *Clupea pallasi* placed in 2 plastic perforated containers (9 L); the bait was changed approximately every 48 h. A slipknot was tied to each pot line as a mechanism to detect disturbance or pot tampering at all fishing stations. Catch data from disturbed pots were not included in the data set. Bottom temperature and salinity were recorded with a YSI Model 33 S-C-T meter the first time a pot was fished at each station over the 2-week period in each year.

Carapace lengths from the eye orbit to the median posterior margin of the carapace, weights, and sex of all pot-captured crabs were determined immediately after capture. Exoskeletal condition indexed molt condition of crabs. Individuals that molted during the past year (new-shell crabs) had exoskeletons with few abrasions and relatively small attached epifauna (Gray and Powell 1966). Crabs that failed to molt during the year (old-shell crabs) had exoskeletal abrasions and larger attached epifauna. Observations on female reproductive stages were also noted. Crab sex ratios in mined and unmined areas were compared. Crabs caught for abundance determination were marked with a rubber band or a colored wire around the base of a rear appendage and released. Crabs subsequently captured in pots were examined for mark identifications.

Crab abundance was also determined by under-ice observations at R6, R7, S3, and C3 using high-density color videotape in March 1986–1988 and in June 1988. Videotape recording was accomplished with ROVs: a Benthos Mini-Rover was used in 1986, and a Deep Ocean Engineering Phantom 300 was used in 1987–1988. All-terrain vehicles, snowmachines, a Weatherport shelter, and a 1.8-kW portable generator provided needed support. At each station, a hole large enough to accommodate the ROV was cut through the ice. The Weatherport shelter was set up to house the electronic and ROV control equipment.

The ROV observations with a support vessel were also made in open water on June 11 and 12, 1988. In both seasons the ROV was used to count crabs along 4 transects, generally following N, S, E, and W compass headings for a distance of up to 140 m. Occasionally the target compass heading and maximum transect distance could not be obtained because of the presence of grounded ice. When this happened a different heading or shorter distance was surveyed. Transect width, based on visibility, was approximately 2 m. Videotape records and a log of physical and biological observations were maintained along each transect. Crab sex could not be determined with the ROV.

Crab abundance was also determined by divers in open water during June 1986 and 1987. Divers counted and sexed crabs along 50-m transects, generally following the 4 main compass headings. Each station was marked by a buoy. A transect line was attached to the buoy's anchor and was set and retrieved from the dive vessel. The transect line was marked at 1-m intervals to provide accurate seafloor positioning during observations. Transect width, based on visibility, was about 4 m. Divers recorded substrate type, water depth, and crab sightings relative to the position along a transect. No crabs were collected.

Laboratory

Crab stomachs were preserved in 10% buffered formalin and shipped for processing at the Institute of Marine Science, University of Alaska Fairbanks. Stomach contents were sorted and identified to the lowest practical taxon. Most of the eyed eggs in stomachs contained unidentified fish embryos. All eyed eggs were assumed to be from fishes, based on the relatively large size of the eggs. Measurements of these eggs ranged from 1.6–2.0 mm diameter, whereas red king crab eggs do not exceed 1.2 mm diameter in the most advanced stage of development (Matsuura and Takeshita 1985). Detailed examination of fish remains took place in 1988 to determine the frequency of eggs and bones with tissue. Prey taxa from each stomach were identified and weighed (blotted wet weight) to the nearest milligram. Counts of each taxon were not made in most cases because of the triturated condition of stomach contents. The percent frequency of occurrence was calculated as the proportion of stomachs containing various food items relative to the total number of stomachs examined. A food index (FI) was calculated for each prey group with frequency of occurrence and weight (FI = frequency of occurrence proportion $\times$ weight proportion $\times$ 100). Most studies on crustacean feeding examine frequency of occurrence and weight of prey items (e.g., Elner 1981; Jewett and Feder 1982; Pearson et al. 1984; Comoglio et al. 1990). Frequency of occurrence analysis provides a semiquantitative view of the extent that a group of animals feed on a particular item. This method tends to favor taxa with easily recognizable hard parts and long digestive time in stomachs and small organisms that contribute little food value. Gravimetric or volumetric analyses provide a quantitative approach to the importance of various prey but also favor slowly digested items. A similar approach to the FI, which incorporates multiple measures, was used by Stevens et al. (1982) with Dungeness crabs *Cancer magister*. Using percentage frequency of occurrence, percentage numerical composition, and percentage gravimetric composition, they calculated an index of relative importance for each prey taxon.

General Design Considerations

Two limitations are inherent in interpreting the effects of mining on red king crabs. First, no premining assessments of the crab resource in the mining vicinity were made to compare with the postmining survey data in a BACI (Before–After, Control–Impact) design (Stewart–Oaten 1996). As a result, I relied largely on postmining comparisons of mined versus unmined sites to infer impacts. This After, Control-Impact design suffers in that making inference with respect to impacts, based on differences between mined and unmined sites, rests on the assumption that the crab parameters measured would have been similar in the absence of mining (Stewart–Oaten 1996). This assumption is untestable.

The second limitation of this study is the weight placed on pot capture as an appropriate means to assess mining effects on this crab resource. I assumed that crabs captured in a mined area were not attracted

Table 2. Average catch per unit effort (CPUE) of red king crabs through the ice at mined and unmined stations in the area offshore of Nome.

Date	Stations: Mined[a]	Stations: Unmined	Pot Retrievals[b]	Average Crab CPUE[c] (± 1 SE): Males	Females	Both Sexes
1987						
Mar 27–Apr 9	R6a		15	4.3 (0.92)	0.3 (0.13)	4.6 (0.95)
	R6b		15	6.2 (1.02)	0.2 (0.14)	6.4 (1.08)
		C3	10	5.3 (1.36)	0.5 (0.27)	5.8 (1.30)
		R7[d]	14	4.2 (1.44)	<0.1 (0.04)	4.3 (1.44)
1988						
Mar 22–Mar 31	R6		14	3.8 (0.86)	0.1 (0.11)	3.9 (0.87)
	R7		15	4.5 (1.45)	0	4.5 (1.45)
		C3	15	3.4 (0.84)	0.2 (0.15)	3.6 (0.86)
		C4	9	9.2 (1.97)	0	9.2 (1.97)
1989						
Mar 23–Apr 5	R6		18	2.8 (0.94)	0.6 (0.28)	3.4 (1.03)
	R7		18	7.7 (1.81)	<0.1 (0.07)	7.8 (1.81)
		C3	18	6.6 (0.87)	<0.1 (0.05)	6.6 (0.89)
		C4	17	8.4 (1.39)	0	8.4 (1.39)
1990						
Mar 21–Apr 10	R7a		14	1.6 (0.55)	0.5 (0.38)	2.1 (0.84)
	R7b		12	4.1 (1.71)	0.4 (0.19)	4.5 (1.79)
		C3a	14	5.2 (1.10)	0.1 (0.10)	5.3 (1.12)
		C3b	10	5.4 (1.58)	0.1 (0.10)	5.5 (1.54)

[a] Stations ending with a and b are 200 m apart.
[b] Number of times a pot was fished at a particular station.
[c] Catch standardized to 24-h effort.
[d] Before R7 was mined.

from an adjacent unmined area. No data are available on the distance king crabs can be attracted to baited pots, although Stone et al. (1992) suggested that this species in Southeast Alaska may travel several kilometers when attracted to concentrated fish waste disposed by local fisherman. However, given the relatively limited net daily movement of adult king crabs in winter ($\bar{x}$ = 0.26 km·d^{-1} [Rusanowski et al. 1990]; $\bar{x}$ = 0.056–0.066 km·d^{-1} [Stone et al. 1992]) and the distance from the periphery of the mined area to the baited pot (~0.5 km), I assumed that crabs captured in a mined area were not attracted from an unmined area.

Statistical Analyses

Crab catch per unit effort (CPUE; catch per pot) was standardized to a 24-h period. Feeding and CPUE data were used for testing various hypotheses concerning the effects of mining activity on crabs. Data were compared between mined and unmined areas. Feeding data from male and female crabs were combined in all statistical analyses because previous studies did not reveal differences in feeding (McLaughlin and Hebard 1961; Jewett and Feder 1982). All sizes of crabs were combined in the feeding analyses because the range of sizes was small and most were of adult size. Possible effects of dredging activities were examined by testing the following null hypotheses:

- the relative abundance (H_{01}) and sex composition (H_{02}) of king crabs are not significantly different between mined and adjacent unmined areas; and
- food quantity (H_{03}) and composition (H_{04}) in king crab stomachs are not significantly different between mined and adjacent unmined areas.

Parametric analysis of variance (ANOVA) was applied to the CPUE data. Due to heterogeneity of variances, nonparametric rank tests were used for comparing the total biomass of stomach contents, FI values and biomass of predominant prey groups, and catches of male and female crabs. Determination of statistical significance was set at $\alpha = 0.05$. In multiple

Table 3. Two-way ANOVA test results on abundance of king crabs as indexed by pot catches in mined and unmined areas in the offshore Nome vicinity, 1987–1990.

Source of Variation	df	MS effect	*F*-statistic	*P*-value	Power
Year	3	53.61	2.14	0.096	0.295
Treatment	1	87.59	3.49	0.062	0.332
Interaction	3	20.20	0.81	0.492	0.050
Error	220	25.07			

nonparametric tests, the Bonferroni-corrected significance level of $\alpha^* = \alpha/n$ (Rice 1995) was used to ensure that comparisons have an experiment-wise error rate of $\alpha_e = 0.05$. Statistical procedures were performed mainly with STATISTICA software (StatSoft 1994). Simulations with the bootstrap technique (Efron and Tibshirani 1993) were used to estimate the sampling distribution of the FI values with 1,000 resamplings with replacement of the crab feeding database. Approximate 95% confidence intervals for bootstrapped FI means were calculated with the 2.5% and 97.5% interval estimates. Food index values were calculated separately for each year and then for all years pooled together. The approximate confidence intervals were used to demonstrate differences between mean FI values for mined and unmined stations within each year. These confidence intervals were not corrected for the number of comparisons made as they were intended to provide a rough characterization of the importance of prey items to crabs. The similarity between prey groups from mined and unmined areas was thus determined by the overlap or no overlap of confidence intervals ($\alpha = 0.05$ for individual comparisons) between treatments. The estimated power of the parametric tests followed Peterman (1990).

RESULTS

Relative Abundance of Crabs

Pot Surveys

Throughout the pot surveys in March and April of 1987–1990 bottom temperature ranged between -1.8 and 0°C and salinity between 28.4 and 31.5‰. Over the 4-year period, 228 pot retrievals were made with 121 in the mined area and 107 in the unmined area. The standardized (and actual) number of crabs captured totaled 571 (492) at mined and 646 (554) at unmined stations and averaged 4.7 ± 0.47 at mined and 6.0 ± 0.47 at unmined stations. Of 768 crabs marked, none were recaptured over the period of 1–3 weeks. Two-way ANOVA comparisons, with year and mining treatment (mined or unmined) as factors, tested H_{01} (no difference in crab abundance between mined and unmined areas). Test results with CPUE values (Table 2) revealed that year, treatment, and interaction (effects between year and treatment) were not significant ($P > 0.05$; Table 3), so, the null hypothesis was accepted.

The overall male : female ratio of the catches approximated 25:1. At mined stations 538 males and 33 females were caught; at unmined stations 632 males and 14 females were caught. Testing revealed no significant difference in catches of male and female crabs between mined and unmined stations ($P = 0.171$; Mann–Whitney *U*-test), so the null hypothesis (H_{02}) of similar sex ratios in mined and unmined areas was accepted. There was no significant difference in catches of male and female crabs between years ($P = 0.427$; Kruskal–Wallis ANOVA).

ROV and Scuba Surveys

The ROV and scuba surveys found few crabs. In the 3 years of ROV surveys in March, 19 crabs were observed in 6,539 m^2 of area surveyed. In the unmined areas this represented 13 crabs in 3,435 m^2 or 0.0038 crabs $\cdot m^{-2}$ and in the mined areas 6 crabs in 3,104 m^2 or 0.0019 crabs $\cdot m^{-2}$ (Table 4). Observations of crabs in ROV surveys were too few to allow statistical comparison. In the June scuba and ROV surveys, only 2 crabs, a grasping pair, were encountered in 9,588 m^2. Of the 21 crabs observed in the underwater surveys, 16 (nearly 76%) were located on coarse substrates of cobble to boulder, the remainder on sand or mud (Table 4). Many of these crabs were feeding.

Prey Composition of Crabs

A total of 278 crabs (264 males and 14 females) were collected for stomach analysis in March and April 1987–1989. This included 155 (144 males and 11 females) from mined areas and 123 (120 males and 3 females) from unmined areas (Table 5). Size of these crabs (both sexes; 1987–1989) from mined and unmined areas was

Table 4. Abundance of king crabs in mined and unmined areas off Nome as determined from ROV and scuba surveys.

	Mined				Unmined			
Year	Station	Area (m^2) Surveyed	Crabs Sighted	Substrate[a]	Station	Area (m^2) Surveyed	Crabs Sighted	Substrate[a]
March ROV Surveys:								
1986					S3	1,480	5[b]	Coarse[c]
							1	Mud
1986					R6[d]	640	0	
1987					S3	362	1	Mud
							2	Cobble
1987					C3	485	0	
1987	R6	881	1	Cobble				
1987					R7[d]	468	4	Cobble
1988	R6	1,081	1	Cobble				
1988	R7	1,142	1	Sand				
			3	Cobble				
Totals		3,104	6			3,435	13	
June Scuba (1986–1987) & ROV (1988) Surveys:								
1986					S3	1,600	0	
1986					C3	800	0	
1986					R6[d]	800	2[b]	Sand
1987					S3	1,600	0	
1987					C3	800	0	
1987	R6	800	0					
1987					R7[d]	800	0	
1988	R7	560	0					
1988					S3	560	0	
1988					C3	1,268	0	
Totals		1,360	0			8,228	2	

[a] Substrate on which crabs were found.
[b] Includes grasping pair.
[c] Coarse = cobble to boulders
[d] Before area was mined.

not significantly different ($t = 1.890, P = 0.06$, df = 276, power = 0.34); those from the mined area averaged 101 (±1.2) mm CL, and those from the unmined area averaged 105 (±1.2) mm CL. All males were assumed to be adults based on their size ($\bar{x}$ = 104 ±0.8 mm CL; Powell et al. 1983). Most males were new-shell crabs. Females comprised 9 adults ($\bar{x}$ = 77 ±2.4 mm CL) and 5 juveniles ($\bar{x}$ = 71 ±1.8 mm CL). Of the female adults, 4 were carrying uneyed, purple eggs (indicative of recent spawning), 4 were carrying eyed, orange-brown eggs (indicative of eggs near hatching), and 1 had no eggs. All juveniles had dark purple internal ova.

Approximately 89% of all crabs examined, 84.6% from unmined areas and 92.3% from mined areas, contained food. No differences were observed in the weight of stomach contents from the mined and unmined areas in any of the years (Mann–Whitney *U*-test: $P = 0.695$ for 1987; $P = 0.448$ for 1988; $P = 0.372$ for 1989) or when all years were pooled (Mann–Whitney *U*-test: $P = 0.269$ for 1987–1989). Thus, the null hypothesis (H_{03}) was accepted.

Thirty-three crab prey taxa (excluding unidentified animal tissue, unidentified tissue, and sediment) were identified in 1987–1989 (Table 6). The most important food groups, in terms of the Food Index (FI), in crabs from mined and unmined areas were teleost fishes and sea urchins (Strongylocentrotidae); those of lesser importance were sand dollars (Echinarachniidae), sea stars (Asteroidea), bivalves, hydroids and plants (Table 7). The FI and weights of the 7 most predominant food

Table 5. Total number of king crabs examined for stomach analyses from mined and unmined stations by year. Number of empty stomachs are in parenthesis.

	Mined Stations			Unmined Stations			
Year	R6	R7	All	C3	C4	R7[a]	All
1987	58 (4)		58 (4)	10 (0)	16 (2)	7 (1)	33 (3)
1988	28 (3)	28 (2)	56 (5)	28 (13)	26 (2)		54 (15)
1989	21 (2)	20 (1)	41 (3)	19 (0)	17 (1)		36 (1)
1987–89	107 (9)	48 (3)	155 (12)	57 (13)	59 (5)	7 (1)	123 (19)

[a] Before R7 was mined.

groups were compared. The distribution of the FI values of these 7 food groups were simulated with the bootstrap method. Comparisons between mined and unmined groups revealed no significant differences ($P \leq 0.05$; overlapping 95% confidence intervals) in FI values for most of these food groups between mined and unmined areas (Table 8). The only instances in which significant differences were apparent were with plants and hydroids. Plants, which consisted of mainly eelgrass *Zostera marina*, had greater FI values at mined stations in 1988 and in all years combined (1987–1989). Hydroids had greater FI values at mined stations in 1987. The overlap of confidence intervals was marginal for the comparison of hydroids in 1988. The Kruskal–Wallis ANOVA test on the weights of the 7 food groups was significant at $\alpha/n = 0.05/22 = 0.0023$. The weights of all major groups, except plants and hydroids, were not significantly different between mined and unmined stations in each year and in all years combined (Table 9). The weights for plants and hydroids were greater at mined areas in 1988 and for all years combined. Therefore, the null hypothesis (H_{04}) of no difference in prey composition between mined and unmined areas was accepted for the predominant prey groups, except plants and hydroids.

Fishes were the predominant food group throughout the study (Tables 6, 7). Their remains were typically bone fragments, tissue, and eyed eggs. The identity of fish prey/carrion was not determined due to the poor condition of the digested fish remains and absence of scales or otoliths. Size of eggs in stomachs was 1.6–2.0 mm diameter. Bone fragments suggested that fishes of widely ranging sizes were consumed. In 1988 fishes were consumed in nearly equal amounts in mined versus unmined areas, 50% versus 46% frequency of occurrence and 40% versus 46% by weight. Bones with tissue were most frequently found: 79% from mined areas and 76% from unmined areas. Stomachs containing only eyed fish eggs and no other fish remains were found in 39% of the fish-eating crabs from mined areas and in 48% of the unmined areas. In mined areas 18% of the fish-eating crabs contained bones, tissue and eggs versus 24% in unmined areas.

Sea urchin *Strongylocentrotus droebachiensis* and sand dollar *Echinarachnius parma* remains were skeletal and no whole specimens were found. Crabs containing sand dollars often had a green tint on their mouthparts and the crushing margin of the chela (pulverized sand dollars are green, personal observation). Sea stars in crab stomachs were not identifiable to species.

Plant material (mainly eelgrass) and hydroids were taken by crabs in greater quantities in mined areas, although their weight was always low. Of the bivalve mollusks in stomachs, only *Yoldia* sp. and *Serripes groenlandicus* were identified. Crustacean remains included barnacles (Cirripedia), amphipods (Amphipoda), and hermit crabs (Paguridae). Sediment was common in stomachs; however, it is not known if it was a food component or if it was taken incidentally with prey items. Nevertheless, it is presented in Tables 6 and 7 to show its relative value.

DISCUSSION

Mining operations off Nome resulted in considerable localized substrate alteration. Bottom relief at mined Station R6 initially had depressions to depths of 17 m and mounds to 6 m, but from 1987 through 1991 showed continued smoothing, that is, erosion of tailings piles and shoaling of depressions left by the mining operation (Jewett et al. 1999). In contrast, relief at unmined areas was low and did not change throughout all years. Mining destabilized the sediments so that fines were redistributed by local currents and sea conditions. In general, the turbidity plume derived from mining activities indicated that solids suspended from dredging were transported downcurrent and mainly settled out within 0.5 km (personal observation). Side-scan sonar surveys made in the mined areas encompassing Station R6 (1987–1991) and Station R7 (1987–1989) revealed that fine sandy silt substrate (smooth substrate), generally predominated followed by gravel (very coarse) substrate (Jewett et al. 1999). At R6, where mining

Table 6. Percent by weight and frequency of prey taxa in red king crab stomachs from mined and unmined areas in the area offshore of Nome, 1987–1989.

	Mined		Unmined	
Prey Taxa	% Weight	% Frequency	% Weight	% Frequency
Hydrozoa	0.38	31.06	0.14	14.66
Polychaeta (unidentified)	0.01	3.00	<0.01	<0.01
Polynoidae	0.01	3.11	<0.01	<0.01
Pectinariidae	0.13	4.97	0.04	1.72
Mollusca (unidentified)	<0.01	0.62	<0.01	0.86
Bivalvia (unidentified)	0.15	6.21	0.03	1.72
Nuculanidae (unidentified)	0.05	0.62	<0.01	<0.01
Yoldia sp.	0.05	0.62	<0.01	<0.01
Cardiidae (unidentified)	0.36	2.48	0.57	5.17
Serripes groenlandicus	<0.01	0.62	<0.01	<0.01
Gastropoda (unidentified)	0.04	3.11	<0.01	0.86
Trochidae (unidentified)	<0.01	0.62	<0.01	0.86
Cylichna alba	<0.01	0.62	<0.01	<0.01
Crustacea (unidentified)	1.36	7.45	1.36	2.59
Balanus sp.	0.01	1.86	<0.01	<0.01
Amphipoda (unidentified)	0.15	8.07	0.45	1.72
Protomedeia sp.	<0.01	0.62	<0.01	<0.01
Anonyx sp.	0.01	0.62	<0.01	<0.01
Caprellidae	<0.01	0.62	<0.01	<0.01
Decapoda (unidentified)	0.08	1.24	0.12	1.72
Paguridae	0.56	0.62	<0.01	<0.01
Echiura	<0.01	0.62	<0.01	<0.01
Bryozoa	0.10	3.73	0.02	1.72
Echinodermata (unidentified)	0.29	1.24	<0.01	<0.01
Strongylocentrotus droebachiensis	13.83	13.04	10.39	16.38
Echinarachnius parma	0.44	6.21	10.28	10.34
Ophiuroidea (unidentified)	<0.01	0.62	<0.01	<0.01
Diamphiodia craterodmeta	0.04	1.24	<0.01	<0.01
Asteroidea	5.43	3.11	6.28	4.31
Urochordata	0.46	0.62	<0.01	<0.01
Teleostei[a]	28.31	33.54	33.49	38.79
Unidentified animal tissue	1.20	6.21	<0.01	<0.01
Phaeophyta	<0.01	0.62	<0.01	<0.01
Zostera marina	1.14	26.71	0.09	5.17
Unidentified tissue	44.39	78.26	35.76	59.48
Sediment	0.90	13.66	0.72	6.03

[a] Includes fish eggs.

occurred only once (1986), there was a decrease in smooth substrate over time (53–39%). However, at R7, where mining took place annually, smooth substrate remained the predominant feature (45–65%), with no apparent trend. In contrast, sonographs of the reference area that included Station S3 revealed very coarse (47–55%) and smooth (43–50%) features predominated in similar proportions in the 2 survey years (1985 and 1989). Analyses of sediment granulometry generally corroborated the side-scan sonar results. For example, on sand substrates there was more mud at mined than at unmined stations (Jewett et al. 1999). Although physical disturbance of the mined seabed at R6 was only about 0.09 km^2, substantial alteration was still apparent 5 years after the 1986 mining event. A small (0.13 km^2) experimental gravel dredging study in the North Sea revealed considerable sediment transport during the first 2 years following dredging (Kenny and Rees 1996). Although the dredging scars in that study had virtually disappeared after 2 years, benthic biomass was still substantially reduced because of increased sediment disturbance caused by tide and wave action.

Natural disturbances on the bottom are a common phenomenon in the lease area. Gross littoral drift (mainly sand) in the nearshore vicinity of Nome was calculated to be approximately 5×10^5 m$^3 \cdot$y^{-1} (Tetra Tech 1980). Side-scan images corroborate that fine

Table 7. Comparison of food indices (FI = frequency of occurrence proportion × weight proportion × 100) of prey groups in king crab stomachs from mined and unmined areas in the area offshore of Nome, 1987–1989.

	1987		1988		1989	
Prey Group	Mined	Unmined	Mined	Unmined	Mined	Unmined
Hydrozoa	0.08	<0.01	0.21	0.03	0.12	0.04
Polychaeta	0.08		<0.01	<0.01	<0.01	
Bivalvia	0.08	<0.01	0.08	0.15	0.04	
Gastropoda	0.01			<0.01		
Crustacea (unid.)	<0.01	<0.01	0.12	<0.01	0.48	0.49
Cirripedia		<0.01	<0.01			
Amphipoda	<0.01	<0.01	<0.01	<0.01	0.08	0.05
Decapoda					0.06	
Bryozoa			0.02	<0.01	<0.01	
Echinodermata (unid.)	0.01				<0.01	
Strongylocentrodidae	1.01	5.78	0.36	2.08	3.64	0.78
Echinarachniidae	0.20	6.30		0.16		
Ophiuroidea	0.01					
Asteroidea	0.03	0.50		0.39	1.91	
Urochordata					0.05	
Teleostei	8.49	2.90	20.05	21.24	2.54	13.30
Plant	0.01	0.01	1.61	0.01	0.01	
Sediment	0.25	0.11	0.14	0.03	0.01	0.03

sand/mud (smooth substrate) is continuously redistributed in the study area by storms, ice, and currents, resulting in modification of the surficial substrate (Jewett et al. 1999). Strong winds and storms in Norton Sound vary annually in intensity and frequency, and the project area is commonly affected by these conditions. For example, exceptionally high storm-force winds existed in Norton Sound between July 1, 1990, and June 30, 1991. The peak surface winds at Nome exceeded 47 km·h^{-1} for 79 d from July 1990 through June 1991. During October and November 1990 there were 24 d that had peak easterly winds over 47 km·h^{-1} (NOAA Local Climatological Data Monthly Summaries). These winds battered the northern coastline (personal observation) and presumably disrupted the nearshore subtidal habitat. The ROV observations in March, 1986–1988, revealed grounded and gouging ice to be pervasive throughout the study area, but most commonly at depths of <7 m. As a consequence of this ice activity, sessile organisms, such as sponges, hydroids, and bryozoans, at shallower depths, were less common than in deeper waters (>7 m) where lush growth of these organisms was evident.

Habitat Use

Crab movements at R7 and C3 were related to seafloor substrate type by comparing side-scan sonar records with tracking data of ultrasonic-tagged crabs over 10 d (Rusanowski et al. 1988). Superimposition of crabs at 141 contact points on side-scan images revealed that 62% of the crabs occurred on cobble and 38% on fine sediment. The proportions of substrates utilized were similar at mined and unmined stations. Scuba and ROV observations in the present study supported these findings, 76% of the crabs being present on cobble and 24% on fine sediments. Therefore, the data tend to support a preference for coarser substrate by red king crab. Because mining resulted in more fines at the sand-sediment surface, there may have been some avoidance of mined areas. The pot surveys in March and April did not demonstrate a significant avoidance response to mining-related activities, although the few ROV observations gave the impression that crabs preferred unmined to mined areas. Little credence is given to the ROV finding because it was inadequate for statistical comparison; only 19 crabs were observed in the 3 years of filming. Recent laboratory findings revealed that ovigerous Tanner crabs *Chionoecetes bairdi* exposed to gold mine tailings spent significantly less time on tailings than on control sediments, presumably due to the inability to bury in the more compact tailings (Johnson et al. 1998). However, king crabs, unlike Tanner crabs, do not bury in sediments, thus, king crab avoidance of mined areas is less probable.

No assessment of impacts were made on larval or juvenile crabs. No juveniles (<64 mm CL) were encountered on the various substrates in the study area, although a variety of sampling methods were used (pots, ROV, scuba, and airlifts for infauna and small epifauna; Jewett 1997; Jewett et al. 1999). The absence of juvenile crabs in the nearshore region of Norton Sound dif-

Table 8. Bootstrapped 95% confidence intervals of food index (FI) values for predominant king crab prey groups. The central FI values are from the original data. The significance level is not corrected for the number of multiple comparisons.

Year	Treatment	Prey Groups	Lower Bound	FI Value	Upper Bound
1987	Mined	Fishes	2.730	8.490	16.740
		Sea Urchins	<0.010	1.010	3.920
		Sand Dollars	0.010	0.200	0.760
		Bivalves	<0.010	0.080	0.310
		Hydroids	0.020	0.080*	0.210
		Sea Stars	0.000	0.030	0.330
		Plants	0.001	0.009	0.025
	Unmined	Sand Dollars	0.170	6.300	17.100
		Sea Urchins	0.190	5.780	19.580
		Fishes	0.200	2.900	9.980
		Sea Stars	0.000	0.500	3.140
		Bivalves	0.000	<0.010	0.020
		Hydroids	0.000	<0.010*	0.006
		Plants	0.000	0.008	0.039
1988	Mined	Fishes	9.660	20.050	32.110
		Plants	0.777	1.612*	2.804
		Sea Urchins	0.000	0.360	1.930
		Hydroids	0.075	0.210	0.390
		Bivalves	0.010	0.080	0.280
		Sea Stars		NA	
		Sand Dollars		NA	
	Unmined	Fishes	9.380	21.240	34.470
		Sea Urchins	0.030	2.080	6.180
		Sea Stars	0.000	0.390	2.190
		Sand Dollars	<0.010	0.160	0.770
		Bivalves	0.010	0.150	0.470
		Plants	<0.010	0.012*	0.07
		Hydroids	<0.010	0.030	0.077
1989	Mined	Sea Urchins	0.290	3.640	10.210
		Fishes	0.300	2.540	7.950
		Sea Stars	<0.010	1.910	6.960
		Hydroids	0.010	0.120	0.390
		Bivalves	<0.010	0.040	0.200
		Sand Dollars		NA	
		Plants	<0.010	0.006	0.020
	Unmined	Fishes	3.750	13.300	27.600
		Sea Urchins	<0.010	0.780	3.000
		Hydroids	<0.010	0.040	0.130
		Bivalves		NA	
		Sand Dollars		NA	
		Sea Stars		NA	
		Plants		NA	
1987–89	Mined	Fishes	5.540	9.930	15.330
		Sea Urchins	0.170	1.240	3.010
		Plants	0.142	0.321*	0.593
		Sea Stars	<0.010	0.190	0.780
		Hydroids	0.060	0.130	0.230
		Bivalves	0.020	0.070	0.180
		Sand Dollars	<0.010	0.030	0.100
	Unmined	Fishes	6.620	12.340	19.620
		Sea Urchins	0.650	2.640	5.850
		Sand Dollars	0.070	0.930	2.860
		Sea Stars	<0.010	0.240	1.070
		Bivalves	<0.010	0.040	0.120
		Hydroids	<0.010	0.020	0.040
		Plants	<0.010	0.006*	0.02

NA = Not applicable because the prey group was not present in stomachs for that treatment.
* = Comparison is significantly different at $\alpha = 0.05$.

Table 9. Kruskal–Wallis one-way ANOVA test results (*P*-value) of biomass comparison of king crab prey groups from mined and unmined areas. The significance level of these tests was corrected by the Bonferroni method; therefore, test results are significant at $\alpha = 0.0023$.

	Predominant Prey Groups						
Years	Plants	Hydroids	Bivalves	Sea Urchins	Sand Dollars	Sea Stars	Fishes
1987	0.6333	0.0344	0.2110	0.0090	0.3363	0.2681	0.6018
1988	< 0.0001[a]	0.0013[a]	0.9013	0.1698	NA	NA	1.0000
1989	NA	0.4093	NA	0.2175	NA	NA	0.0380
1987–89[b]	< 0.0001[a]	0.0004[a]	0.2101	0.1553	0.2839	0.7042	0.3427

NA = Not applicable because the prey group was not present in crab stomachs for each treatment group.
[a] Mined > unmined.
[b] These comparisons are based on the pooled data for all years.

fers from southern populations in the southeast Bering Sea and Gulf of Alaska where young red king crabs commonly occur inshore (Jewett and Onuf 1988). Presumably low bottomwater salinities (as low as 16‰ in 1988) occur in the study area during the summer, which precludes year-round presence of juvenile crabs.

Crab mortality associated with entrainment or burial was probably of minor importance in the present study, unlike the major dredging impacts to Dungeness crabs and associated biota elsewhere (Stevens 1981; McGraw et al. 1988). Presumably, entrainment and burial were negligible because most adult crabs had moved offshore by the time mining commenced in June. Upon ice breakup, typically in May, adult crabs begin their migration offshore to deeper waters. Crabs tagged with sonic tags in early June, after the ice receded, migrated offshore 2–4 km within 1–2 d of their release, demonstrating their offshore movement (Rusanowski et al. 1990). This exodus to offshore waters is reflected in the paucity of crabs (2) found in the June ROV and scuba surveys compared to the 19 crabs found in March ROV surveys (Table 4).

The failure of any of the 768 marked crabs to be recaptured could be due to: (1) loss of marks (rubber bands or colored wires) on the crabs so that the crabs subsequently re-entered pots undetected, or (2) the population was so mobile that the probability of catching a marked crab was small. Red king crab tagging studies in Norton Sound have reported that tagged crabs do re-enter baited pots (e.g., Powell et al. 1983). Therefore, the most probable explanation is that the crabs were sufficiently mobile, even in winter, to preclude recapture. Tracking of sonic-tagged crabs under ice showed that, although the average net movement was only 0.26 $km \cdot d^{-1}$, the average distance traveled haphazardly was approximately 1 $km \cdot d^{-1}$ (Rusanowski et al. 1990). Because the pots were positioned in an environment where constant, intense westerly currents prevail, only crabs immediately downcurrent of the baited pots would have been lured to the pots (Zhou and Shirley 1997).

The paucity of females (25 males/female) in pot collections is presumably due to their behavior during the March–April reproductive period. Few females ($\bar{x}$ = 23 males/female) were also caught during these months in pot surveys conducted by the Alaska Department of Fish and Game between 1983 and 1995 (Brennan and LaFlamme 1995). In contrast, the sex ratio in deeper waters of Norton Sound during August averaged 2.4 males/female in National Marine Fisheries Service trawl surveys of 1985, 1988, 1991, and 1996 (Fair 1997). Feeding by molting females is curtailed during the molting and mating period (Powell and Nickerson 1965); consequently, few females entered the baited pots.

Prey Composition

King crab feeding data corroborated the CPUE data: significant differences between mined and unmined stations were not apparent. The data showed that none of the 7 most predominant food groups in crabs were less important at mined than at unmined stations, even though an assessment of benthic infauna and small epifauna in the study area revealed that numerically predominant families, many of which were king crab prey, were reduced in mined areas (Jewett et al. 1999). Crabs were observed via ROV feeding in mined areas, and apparently they were able to find ample food there, even though there may have been some foraging in unmined areas. There are numerous accounts of predatory and scavenging crabs, as well as other organisms, feeding on the benthos in disturbed areas (e.g., Caddy 1972; Eleftheriou and Robertson 1992; Collie et al. 1997).

King crabs are opportunistic omnivores with a preference for animal food. They take a wide variety of prey, most often mollusks (mainly bivalves), crustaceans (mainly barnacles, amphipods, and assorted crabs), and echinoderms (mainly brittle stars, sand dollars, and sea urchins; see Jewett and Onuf 1988 for review). Their opportunistic feeding strategy presumably enables them to switch between prey when a particular food resource becomes depleted. As examples of their prey diversity, adult and subadult king crabs examined from shallow waters (5–15 m) near Kodiak Island, Alaska, had 53 different prey taxa in their stomachs (Feder and Jewett 1981; Jewett and Feder 1982). These crabs were feeding on a variety of substrates including mud, sand, and coarse bottoms with and without attached epifauna. In the Nome study area, foods identified in crabs found on coarse substrates included sessile organisms, such as hydroids, bryozoans, and urochordates, whereas foods from crabs on soft substrates included polychaetes, bivalves, amphipods, and sand dollars. Prey in common from both substrates included gastropods, crustaceans other than amphipods, sea urchins, sea stars, fishes, and fish eggs.

Fishes and fish eggs were the predominant component of the diet in mined (33.5% frequency of occurrence) and unmined areas (38.8% frequency of occurrence) in all years. There are numerous accounts of king crabs feeding on fishes (Jewett and Feder 1982), but none listed fishes as an important component of the diet. The frequency of occurrence of fishes within king crabs elsewhere ranged from 4 to 13% (Cunningham 1969; Pearson et al. 1984) in the southeastern Bering Sea, 5% on the west Kamchatka shelf (Feniuk 1945), and 8% on the west coast of South Sakhalin Island (Kulichkova 1955). The most likely candidates of fish prey in the study area, based upon their abundance, ubiquity, and life history in Norton Sound, are saffron cod *Eleginus gracilis,* sculpins (Cottidae), and Pacific sand lance *Ammodytes hexapterus* (Wolotira et al. 1977; Barton 1978).

Demersal trawl surveys in Norton Sound determined that saffron cod was the most abundant fish species present in the late 1970s (Wolotira et al. 1977; Sample and Wolotira 1985). Adult saffron cod generally move inshore in winter when king crabs are present and spawn demersally under coastal sea ice in 2–10 m of water (Wolotira 1985). Their eggs are demersal and slightly adhesive to coarse substrates. Their size (1.5–2.0 mm diameter) matches the size of eggs taken from crab stomachs. Saffron cod in western Alaska waters have a high rate of natural mortality. Approximately 60–80% of the population dies annually, and <1% of the stock survives past the age of 5 years (Wolotira 1985). Therefore, deposition of eggs on the bottom, combined with a high natural mortality rate, makes saffron cod a probable food source for crabs in winter.

Although sculpins are among the most abundant fishes in Norton Sound (Wolotira et al. 1977), nothing is known about their natural mortality. Sculpins inhabit coastal waters near Nome where they spawn under the ice during winter, attaching large (2–3 mm) eggs in clusters among rocks (Hart 1973; Eschmeyer et al. 1983). Some fish eggs taken by crabs in the study area are probably those of sculpins.

Sand lance spawn in shallow subtidal regions along the Alaskan coast, inclusive of Norton Sound, burrowing into coarse sand substrates or fine gravel (Dick and Warner 1982; personal observation). Sand lance are abundant off Nome (Barton 1978), and they were occasionally found when sampling the benthos (Jewett 1997). On several occasions I observed them emerging from the substrate when diving in the study area. The abundance and burrowing habits of sand lance make it vulnerable to capture by Dungeness crabs along the Washington coast (Stevens et al. 1982) and presumably by king crabs. Sand lance eggs were probably not taken by crabs because eggs of this fish (0.9–1.2 mm in diameter; Healey 1984) are smaller than the eggs found in king crab stomachs.

Prey of secondary importance to crabs were the echinoids *Strongylocentrotus droebachiensis* and *Echinarachnius parma* and sea stars. Both echinoids were frequently observed throughout the study area. Benthic sampling revealed significantly more *E. parma* on unmined sand substrates (Jewett et al. 1999), whereas *S. droebachiensis* had significantly greater abundance, albeit low (4 urchins$\cdot$m^{-2}), on unmined cobble substrates (author's unpublished data). Urchins typically had a rock on their aboral surface, which appeared to prevent their tumbling over the substrate under prevailing strong currents. Sand dollars were visible at the sediment surface and slightly buried (<1 cm). Their trails were often visible in the fine sandy silt at depths exceeding 10 m. Although both species are taken by king crabs (Feniuk 1945; Kun and Mikulich 1954; Cunningham 1969), *S. droebachiensis* is typically the more common echinoid eaten (Kulichkova 1955; Tarverdieva 1976; Pearson et al. 1984). When *S. droebachiensis* was consumed in appreciable amounts, crabs were mainly feeding nearshore (e.g., Tarverdieva 1979; Feder and Jewett 1981; this study). Crabs taken from the deeper waters of Norton Sound in 1976 and 1985 did not contain *S. droebachiensis* (Jewett et al. 1990), even though it was one of the predominant members of the epifaunal community (Hood et al. 1974; Feder and Jewett 1978). Other prey, such as bivalves and brittlestars, were more common in crabs from the deeper waters of Norton Sound (Jewett et al. 1990). Also, *E. parma* was rarely taken by crabs in deeper waters of Norton Sound outside the lease area (Jewett et al. 1990).

Sea stars (Asteroidea) in crab stomachs were not identifiable to species. However, 11 species of sea stars were identified in Norton Sound by Feder and Jewett (1978). Sea stars are reported as king crab food elsewhere, but never in appreciable quantities (e.g., McLaughlin and Hebard 1961; Tarverdieva 1976; Feder and Paul 1980; Feder and Jewett 1981; Jewett and Powell 1981; Jewett and Feder 1982).

Hydroids were ubiquitous throughout the study area on coarse substrates in mined and unmined areas. However, their presence in crab stomachs was significantly more common in mined areas. These sessile organisms are reported in stomachs of king crabs elsewhere (e.g., Tsalkina 1969; Tarverdieva 1976; Feder and Paul 1980; Pearson et al. 1984). Eelgrass was the plant material most often consumed by crabs in mined areas. No eelgrass existed within the study area, although beds of eelgrass existed upcurrent from the study area (Barton 1978). The significance of plant material as a king crab food item is variable. For example, plant remains, mainly *Laminaria* and *Phyllospadix*, amounted to more than 80% of the weight of stomach contents of 16 king crabs (*Paralithodes brevipes*) off the West Kamchatka Shelf (Kun and Mikulich 1954). Conversely, plant material only accounted for about 3% of the food weight in 713 red king crabs near Kodiak Island (Feder and Jewett 1981; Jewett and Feder 1982) and about 1% of the food weight in this study. Observations with the ROV at the mined areas during March 1988 revealed unusual accumulations of assorted debris, including hydroids and eelgrass, within depressions in dredged areas. These depressions acted as catch basins for material loosened by mining or natural disturbances, thereby providing a readily available food source for crabs.

It is not known if the high incidence of sediment in crab stomachs represents deliberate ingestion for the attached and associated bacteria, diatoms, foraminiferans, and meiofauna (Rice 1980) or attendant ingestion when taking larger organisms. Most king crab researchers tend to adhere to the notion of attendant ingestion (e.g., Feniuk 1945; Cunningham 1969; Tarverdieva 1976; Pearson et al. 1984).

CONCLUSIONS

Based on the relatively small area affected by mining (about 1.5 km^2), the high natural dynamics of the region (i.e., current scour, storms, ice gouging, bioturbation), the relatively high mobility (average 0.26 $km \cdot d^{-1}$ net movement under ice nearshore), and opportunistic feeding habits (at least 33 prey taxa) of red king crabs, this investigation revealed few mining effects on this crab species. No significant differences were found between mined and unmined areas regarding crab catches, crab sex and size composition, and prey quantity and only minor differences were detected in prey composition between the 2 treatments. The only possible negative effect, reduced crab density at mined locations, may have been due to inadequate sample size or actual population differences. Although essentially no mining effects to king crabs were noted, these findings should not be construed to mean mining is appropriate in king crab habitat. The conjecture is that the probability of detecting effects to crabs would greatly increase if a substantially greater area is mined.

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