LETHAL AND SUBLETHAL EFFECTS OF OIL ON FOOD ORGANISMS (EUPHAUSIID: *Thysandessa raschii*) OF THE BOWHEAD WHALE

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Final Report
Outer Continental Shelf Environmental Assessment Program
Research Unit 662

December 1985

TABLE OF CONTENTS

List of Figures

List of Tables

1. SUMMARY OF OBJECTIVES, CONCLUSIONS AND IMPLICATIONS WITH RESPECT TO OCS OIL AND GAS DEVELOPMENT

This study was contracted for the purpose of investigating the sensitivity of Arctic krill, namely the euphausiid Thysanoessa raschii (M. Sars, 1864), to the water soluble fraction (WSF) of Prudhoe Bay crude oil. The study had two primary objectives: (1) determine, through laboratory bioassays, the 96-hr LC_{50} of Prudhoe Bay crude oil WSF for T. raschii; and (2) estimate the losses to populations of T. raschii and the potential recovery rates resulting from hypothetical oil spills in the Beaufort Sea. The major concern prompting this study is the fact that euphausiids are a major food source for the endangered bowhead whale in the western Beaufort Sea.

The experimental results indicate that T. raschii sensitivities to Prudhoe Bay WSF are within the range expected, baaed on previous teats using Alaskan marine crustacea. No data could be found for this or similar species; thus, this study provides an important data point in the oil effects literature. Unlike other marine crustacea tested, raschii larvae appear to be less sensitive to oil WSF than older life stages. Gravid females were found to be the most sensitive life stage. The concentrations of WSF that resulted in euphausiid mortalities were fairly high, relative to results of studies with other species. These higher levels also produced changes in molt frequency, resulting in longer intermolt periods for adult animals.

The population loss and recovery estimates were based on scenarios supplied by NOAA, information from literature review, and several assumptions. A major impediment to estimation was a lack of distribution and abundance data for T. raschii in the Beaufort Sea, and a lack of life history information for this species in the Alaskan Arctic. A "worst case" situation was assumed, using distribution data for known euphausiid predators, to select an area of potential great risk. Conclusions for both spill scenarios were that NEGLIGIBLE to MINOR effects would result from the spills. The dissolution concentrations of oil in seawater, known vertical distribution of euphausiids, and derived LC_{50}'s for T. raschii contributed to the conclusions reached. The fact that local euphausiid populations are replenished through reproduction in other locations contributed to the conclusion that recovery of a localized population was dependent on factors other than losses due to a spill event.

A number of important data points were missing in the analyses described above. These are primarily related to the distributions, abundance, population structure and life history of T. raschii in the Beaufort Sea. As these data gaps are filled, our ability to assess impacts to natural populations of euphausiids resulting from OCS oil and gas development will improve. This study concluded that euphausiid mortalities resulting from the oil spill scenarios would be minimal; thus, bowhead whale food supplies would not be severely impacted. Other investigators have noted, however, that the predator-prey balance in Alaskan Arctic waters is delicate, and a poor year for zooplankton may increase competition between predators for this resource. An oil spill event during such a year may have more severe implication for bowheads.

2 INTRODUCTION

This project was funded through the Outer Continental Shelf Environmental Assessment Program. The purpose of the Program is the filling of information gaps in knowledge of Alaskan marine organisms and the ecological impacts of oil and gas development. Objectives of this study Included the laboratory determination of effects from various levels of the sea-water soluble fraction of Prudhoe Bay crude oil on the euphausiid *Thysanoessa raschii*, and estimation of population losses and probable recovery potential following hypothetical oil spills in the Alaskan Beaufort Sea.

3. CURRENT STATE OF KNOWLEDGE

The euphausiid *Thysanoessa raschii* is a major food item in the diets of a variety of marine fish, birds and mammals in the Beaufort Sea. *T. raschii* is important in the diets of Arctic cod, terns, gulls, jaegers, ringed seal and bowhead whale (U.S. Army COE 1984; USDI,MMS 1984). The effects of oil spills on *T. raschii* populations are of particular interest in relation to food resources for the bowhead whale, an endangered species.

The effects of petroleum hydrocarbons have been tested on a variety of Alaskan marine organisms. Lethal and sublethal effects have been investigated: however, the majority of organisms tested have been benthic or demersal invertebrates and fish (Craddock 1977: Malins et al. 1985: Rice et al. 1985). Few pelagic invertebrates have been the subject of oil-effect studies due to the difficulty of capturing and/or culturing healthy organisms; *T. raschii* has not been tested previously. Published study results indicate that pelagic organisms are more sensitive than either benthic or intertidal organisms (Rice et al. 1985); this difference is attributed to the relatively more uniform pelagic environment.

The importance of *T. raschii* in pelagic ecosystems of northern waters is well known: the bulk of studies, however, concerning distribution, abundance and other ecological characteristics of populations is for the North Atlantic and contiguous waters. The importance of this species as a food supply for key Arctic marine fish, bird and mammal species underscores the importance of increasing the knowledge of this organism's natural ecology. and the effects of oil/gas development related perturbations on local populations. The current state of knowledge concerning *T. raschii* ecology is summarized as part of Section 6, Discussion.

4. METHODS

4.1 Collection and Transportation

study objectives included the testing of adult, gravid female, egg and larval T. raschii. Three sampling periods were therefore planned in order to obtain various life stages of this species from waters near Juneau, Alaska. A late winter (March) collection was scheduled to obtain non-reproductive adults; a spring (May) collection was planned to obtain gravid females; and a late-summer (late-August) collection was designed to obtain juvenile and adult animals. The spring collection plan was designed to obtain sufficient numbers of gravid females to supply eggs and larvae for tests.

Euphausiids were collected from Auke Bay, near Juneau, Alaska, and shipped to the laboratory in Newport, Oregon. Towed bongo nets and vertically-hauled plankton nets, both with modified collection buckets, were used to capture euphausiids. Samples were sorted and maintained alive in a laboratory of the University of Alaska, Juneau. Animals were shipped via commercial air freight from Juneau to Portland, Oregon in 5-gallon plastic containers packed inside camp-type coolers with frozen "'blue ice". Containers were transported from Portland to Newport by small airplane or automobile. Shipping time ranged from 7 to 10 hours.

Details of the sampling schedule are presented in Table 4-1.

TABLE 4-1

COLLECTION DATA FOR EUPHAUSIID SAMPLING

Date	Vessel [a]	Gear [b]	Target Depth (m)	Envir. Conditions Depth (m)	Temp. (C)	Sal. (ppt)	Shipping Date	No.	Sex
9MAR85	Maybeso	RN/O	80-90	0	2.9	31.3	3/11	300	M+F
2MAY85	Maybeso	RN/O	70	0	6.0	30.0	5/11	600	F
				20	4.2	31.0			
				40	3.9	31.6			
7-8MAY85	Maybeso	RN/O	45-90	0	8.2	25.2	same as 5/11		
				50*	4.9	31.5			
21JUN85	Searcher	RN/O	45	0	9.2	23.5	6/23	6	F
				45*	6.0	31.5			
9SEP85	Maybeso	RN/V	50-70	0	9.0	22.4	9/11	300	Juv
				50*	5.9	31.5			

(a) Maybeso, research vessel of University of Alaska, Juneau, School of Fisheries and Natural Sciences

Searcher, research vessel of Auke Bay Laboratory, National Marine Fisheries Service

(b) Sampling gear: RN/O = ring net (1 meter, 560u mesh)/oblique tow
RN/V = ring net (as above)/vertical tow

* Temperature and salinity values estimated from Bruce, MeLain and Wing (1977)

TABLE 4-1 (continued)

Sampling Notes:

9MAR85 collection: - sampling location,SE of Coughlan Island
650 T. raschii collected, low mortality
during sorting, maintenance and shipping

2MAY85 collection: - sampling location, middle of Auke Bay,
SE of Coughlin 1s., and Stephens Passage
females sorted from samples
very high percentage of males and
copepods (Metridia sp.)
Approx. 500 Traschii collected,
25% were females, very high mortality
during sorting and maintenance, mostly
females, probably from low DO due to
copepod numbers

7-8MAY85 collection:
sampling location, middle of Auke Bay,
SE of Coughlin Is., Fritz Cove,Stephens
Passage
approx. 4,000 T. raschii collected,
30 - 35% females
high mortality of females during sorting

21JUN85 collection:
sampling location, SE of Coughlin Is.
greater ratio of females than May
collections

9SEP85 collection: - sampling location, same as May
65% of euphausiids in sample were
T.longipes
approx. 750 juvenile T. raschii
collected
- high mortality of smaller juveniles
during sorting, 300 shipped

4.2 Laboratory Acclimation and Culture

Euphausiids from the first shipment were initially cultured in seven-gallon glass aquaria. Observation and handling of the animals proved to be difficult with this system, however, and the euphausiids were transferred into one-gallon glass jars containing 2 liters of culture water for the final 11 days of acclimation. Subsequent shipments of euphausiids were cultured in 3.5 gal. plastic pails (27 cm diameter X 25 cm deep) containing approximately 7 liters of culture water. Euphausiids, along with the water used in shipment, were transferred into the culture vessels which were then immersed in a refrigerated water bath for temperature control and supplied with gentle aeration through 1 ml disposable glass pipets.

The shipping water was gradually replaced over a two to three day period with filtered Yaquina Bay (Oregon] water supplied to the laboratory through all PVC pipe from a 6000 gal fiberglass storage tank. Euphausiids were held at a density of approximately 10 per liter in the acclimation vessels. One- to three-day old brine shrimp (*Artemia salina*) nauplii were supplied as a source of food three times per week at a density of approximately 2000 per liter. In addition, animals in the first shipment were fed sea urchin (*Strongylocentrotus purpuratus*) plutei at a density of approximately 800 per liter on two occasions. Uneaten brine shrimp and fecal material were periodically removed by suction from the acclimation containers. Euphausiids were acclimated to a photoperiod of 16 hours light and 8 hours darkness.

4.3 Bioassay Tests

4.3.1 Flow-Through Toxicity Test System

The flow-through toxicity test system consisted of three principal components; a device to prepare the stock water-soluble fraction (WSF) in a continuous-flow mode, a toxicant diluter, and exposure aquaria or containers.

The crude oil WSF was prepared on-a continuous basis using the apparatus described by Nunes and Benville (1978). The apparatus (saturator) consisted of a 2.5 liter pyrex bottle, the top of which was removed and fitted with a stainless steel plate perforated with 1 mm diameter holes. The bottom portion of the bottle was fitted near the bottom with a constant level siphon arm for outflow of prepared WSF, and with entry and overflow ports near the top for introduction and overflow of crude oil. The cut surfaces of the top and bottom halves of the bottle were ground, and, in operation, held together with stainless steel springs.

During each dilution cycle, seawater was introduced into the top of the saturator at a rate of about 1 liter per minute. Droplets of seawater, formed by passing through the perforated stainless steel plate, subsequently passed through a 4-6 cm layer of crude oil floating on the surface of a pool of seawater in the bottom half of the saturator. The oil layer was replenished at an average rate of approximately 1 ml/min to maintain a constant composition throughout the exposure period. The more soluble components of the oil were dissolved in the seawater droplets on passage through the oil layer.

A barrel of Prudhoe Bay crude oil was supplied by NOAA. Five concentrations of the WSF and a dilution water control were prepared using an effluent type Mount-Brungs diluter (Peltier 1978) calibrated for a dilution factor of 0.60. No predilution of the stock WSF was performed. Each 30-minute cycle of the diluter delivered 500 ml of solution per test concentration to a four-way flow splitter chamber resulting in a flow of approximately 125 ml to each of four replicate aquaria per test concentration per cycle.

Small glass aquaria, 27 cm long X 12 cm wide X 15 cm high were filled to a depth of 10.5 cm and contained 3.4 liters of test solution each. In the tests of adult (Test I) and Juvenile (Test IV) euphausiids, animals were allowed to move unimpeded in the test aquaria. The overflow tubes were fitted with 1 mm plastic mesh screen to prevent the loss of animals. Aquaria were partially immersed in a water bath for temperature control.

The same test chambers were employed in tests of gravid females (Test II) and larvae {Test III), but aquaria were compartmentalized to permit testing of both stages simultaneously and to provide a mechanism for collecting and enumerating any eggs released by females during the test. Gravid females, initially eight per replicate, were confined in 8.0 cm diameter polyvinylchloride (PVC) cylinders 10.8 cm deep fitted with 1 mm mesh plastic window screen on the bottom. The cylinders were placed into pyrex dishes (11.2 cm diameter) and were supported above the bottom of the dishes by four legs 0.9 cm high. The cylinder/dish assemblies were placed at the influent ends of the rectangular test aquaria. Eggs released by the females passed through the 1 mm screen mesh and were collected in the pyrex dish. Adequate circulation in the PVC confinement chamber was accomplished by placing the chambers directly under the test solution splitter, causing the test solution to pass first through the chamber, then over the lip of the pyrex dishes and into the main compartment of the test aquaria. The rate of flow was sufficiently low that eggs were not flushed out of the pyrex dishes.

Test cages for the larval stages were constructed of 3.0 cm diameter PVC cylinders 3.6 cm deep fitted with a 210 μm Nitex *screen on* the bottom and a plastic hook cemented near the top on the outside. The larval test chambers were suspended, using the plastic hooks, in the rectangular aquaria and in operation contained test solution to a depth of approximately 1 cm.

4.3.2 Toxicity Test Procedures

The experimental design employed in tests of all life stages consisted of exposure of the euphausiids to five WSF concentrations in a logarithmic series and a control. Four replicate aquaria or animal exposure chambers were used at each treatment level. Because the number of euphausiids available for testing was limited, the total number of animals per treatment replicate varied from six to eight in the several tests performed with adults or juveniles. In the tests of larval T. raschii only five individuals were used per replicate. Although more first naupliar stage larvae were available at the time this test *was* begun, the use of more than five organisms per replicate was not considered practical due to the extreme difficulty of observing and counting this life stage without risk of losing or damaging the test specimens.

Toxicity tests with postlarval forms of T. raschii were begun by addition of euphausiids, one at a time, to each test container until all available animals were distributed to the containers. This method reduces or eliminates the "hard-to-catch" vs. "easy-to-catch" bias in toxicity testing. Prior to addition of the animals, the flow-through test system was operated for a 24-hr period to ensure the equilibration of all teat parameter.

Observations on the survival, number of molts, gross behavior, and, in the tests with gravid females, numbers of eggs released, were performed daily for up to seven days in tests with postlarval individuals. After day 8 in Test I and day 7 in Test IV, observations were made every second day. Dead animals were removed when observed and preserved in buffered 5% formalin in seawater. The absence of visible appendage movement during a 15 second observation period under a dissecting microscope was used as the criterion of death.

In tests of the larvae, eggs that were released by several females were transferred, using a Pasteur pipet, to beakers of control seawater at the approximate test temperature and salinity. "Four days after isolation of the eggs, most had hatched and free-swimming first nauplii were observed to be actively swimming near the water surface. Swimming nauplii were captured under a dissecting microscope using a Pastuer pipet *and* transferred into the larval test chambers. The latter, resting *on* the floor of a 10.0 *cm* diameter crystallizing dish containing test water, were approximately half full, and naupl i i were released under the water surface.

Daily observation of the larvae under *a* dissecting microscope was accomplished by carefully removing the larval test cages in a small (10.0 cm diameter) pyrex crystallizing dish. The dish was carefully moved into position under the suspended larval test cage, and both the cage and dish were removed from the aquarium in a manner that prevented water from draining out of the test container. The test chamber and dish were then placed onto the stage of the dissecting microscope for observation of the larvae. After observation, the larvae were returned to the test aquarium by reversing the above procedure.

The number of surviving larvae was the primary observation performed. If the number of surviving larvae was less than on the previous day, this usually correlated with the presence of a dead organism which was then removed. Occasionally, however, an organism was missing, i.e. could not be found either in the water or on the wall of the test vessel. Entrapment of larvae on the vessel wall was thought to occur occasionally as a result of changing water level in the cage as it was handled for observation. Larvae trapped at the time of beginning the observation could be flushed back into the water without apparent ill effects, but animals trapped while returning the cage to the test aquarium after making an observation may have remained on the wall *and* become dessicated. This may account for the occasional missing larva. In addition to survival, observations on the stage of development of larvae and on gross behavior were also noted.

The water quality parameters, temperature, dissolved oxygen, and pH, were recorded daily or on alternate days at the same time that biological observations were made. Measurements were made on one replicate aquarium at each treatment level. Temperature was measured using a calibrated mercury thermometer with 0.1 °C scale divisions. Dissolved oxygen was determined with a YSI Model 51B polarographic oxygen meter and probe with temperature and salinity correction. A Chemtrix Model 40E pH meter with divisions of 0.1 pH units was used for pH measurement.

In Test I, measurement of salinity was also performed in one replicate of each treatment level, but In the remaining tests only the salinity of the dilution water was determined at each observation period. In the initial test, salinity was determined by measuring the conductivity of a diluted 5 ml test water sample and obtaining the salinity from a calibration curve. In the latter tests, salinity of the dilution water was measured using specific gravity hydrometers and conversion from density to salinity by reference to U.S. Coast and Geodetic Survey *conversion* tables. At each time that water quality parameters were measured, a 500 ml sample of test solution from one replicate at each treatment level was also taken for petroleum hydrocarbons analysis.

4.3.3 Chemical Analyses

The concentrations of individual aromatic hydrocarbons in the test solutions were measured by capillary column gas chromatography (GC) after solvent extraction with methylene chloride. Test solution samples of 500 ml were siphoned from test aquaria into 500 ml brown glass bottles, sealed with teflon lined caps, and stored under refrigeration (5° C) until extraction within 7 days. Samples were extracted three times by shaking with 30 ml volumes of methylene chloride in 1000 ml separatory funnels. The methylene chloride extracts were pooled in 125 ml erlenmeyer flasks and dried by the addition of anhydrous sodium sulfate. Dried extracts were transferred to 250 ml Kadura-Danish evaporator flasks fitted with 25 ml concentrator tubes and concentrated on a steam bath to 5 ml. After cooling, the concentrator tubes were fitted with micro-Snyder columns and were further concentrated to 0.8 ml. The concentrated extracts were quantitatively transferred to 1 ml GC autosampler vials, spiked with exactly 15.90 ng of hexamethylbenzene internal standard (1.S.) in 10 µl of methylene chloride solvent, and immediately capped with teflon lined seals.

Analyses were performed using a Hewlett-Packard 5840A gas chromatography equipped with auto-sample injection, a flame ionization detector, and integration and methods calculation capability. A 30 meter Supelco SBP-5 fused silica capillary column was employed at an initial oven temperature of 30 -c held for 4 minutes, followed by temperature programming at 4 "C per minute to a final temperature of 280 •C which was held for 4 minutes. The injection temperature was 280 'C and the detector temperature was 300 •C. Analyses were performed in the splitless injection mode. The injection volume was 1 µl.

Qualitative and quantitative analyses of most major aromatic hydrocarbons in the WSF were performed by comparison with authentic reference standards using the internal standard calculation method. Response factors for each compound and the internal standard were individually determined from the analyses of standards and used to calibrate the chromatography. An average calibration factor was calculated from the standards and used to determine the approximate concentration of prominent unidentified peaks which were assumed also to be hydrocarbons. A quantitative standard containing all of the reference standards in the approximate concentration ratios actually observed in the WSF was prepared and used to spike representative seawater samples in order to establish the recovery and precision of analysis of individual compounds. Analysis of spiked seawater samples demonstrated that the recovery of most aromatic hydrocarbon waa in the range of 92-98x (Table 4-2). The average recovery of benzene was 54%; that of toluene 86x. Lower recovery of these latter compounds is to be expected because of volatilization 106s during concentration steps in the analysis. Precision of the analyses • indicated by the *percent* relative standard deviation, ranged from 0.6% to 2.1% for all compounds analyzed except benzene. The percent relative standard deviation for benzene was S.9%. The results of analyses of hydrocarbon in bioassay teat water were not corrected for recovery.

4.4 Data Analysis

All tests of significance between treatment means *in* the toxicity tests *were* performed using one-way analysis of variance (ANOVA) . An arcaine transformation was employed with percent data (survival) and untransformed data were employed in comparisons of molt frequency. When the ANOVA test indicated differences between treatment means, the "least significant difference" multiple range test (Snedecor and Cochran 1967) was used to determine when treatments differed significantly (P=) .05) from the controls. Calculation of LC_{50} concentrations of the WSF were performed using the probit method (Finney 1971), or by the binomial procedure (Stephan 1977) when the use of the probit analysis was not permitted by the data.

TABLE 4-2

ACCURACY AND PRECISION OF ANALYSIS OF AROMATIC HYDROCARBONS IN SEAWATER

Compound	Average Percent Recovery	Standard Deviation	Percent Relative S.D.
Benzene	54.0	3.2	5.9
Toluene	86.3	1.7	1.9
Ethylbenzene	95.1	2.0	2.1
p-Xylene	91.7	1.6	1.7
o-Xylene	97.8	2.1	2.1
Isopropylbenzene	92.4	1.8	2.0
n-Propylbenzene	92.6	1.3	1.4
1,3,5-Trimethylbenzene	92.6	2.0	2*1
1,2,4-Trimethylbenzene	92.6	1.6	1.7
1,2,3,4-Tetramethylbenzene	93.7	0.8	0.9
DI-Isopropylbenzene	92.9	1.s	1.6
Naphthalene	94.7	2.0	2.1
2-Methylnaphthalene	95.4	0.6	0.6
1-Methylnaphthalene	95.0	0.5	0.6

Based on analysis of 5 spiked seawater samples.

5. RESULTS

5.1 Collection and Transportation

The numbers of euphausiids collected and shipped during each collection period were presented in Table 4-1. Sufficient numbers of animals were collected for each of the tests: mortalities during shipment were fairly low. The highest mortalities experienced during handling and shipment occurred with the gravid females. Water temperatures during shipment increased generally 1 or 2° C.

Each of the shipments of animals was received at the toxicology laboratory in apparently satisfactory condition. The temperature of several representative containers in the initial shipment was found to be about 6*C, an increase of 2° over the initial shipping temperature. Gravid females received in the second shipment were in water at 4.7°C; temperature on arrival for the last shipment was 6*C. The transport water was oxygen saturated in all shipments, and the salinity was between 31 and 32 o/oo. Dead animals were found in most shipping containers upon receipt in the laboratory.

5.2 Laboratory Acclimation and Culture

A summary of water quality conditions employed during acclimation of each tested group of euphausiids is presented in Table 5-1. Holding times for postlarval animals (Tests I, II and IV) varied from 9 to 17 days. All water quality conditions were relatively constant during acclimation of Teat I and Test IV animals. Test II animals experienced greater fluctuation of temperature and dissolved oxygen. Temperature for this group, which for most of the acclimation period averaged less than 6.0°C, was elevated to the range of 6.5 to 9.4°C during two days of unusually warm weather which caused the cooling capacity of the water bath refrigeration system to be exceeded. Dissolved oxygen levels remained essentially at saturation, but the concentrations fluctuated with temperature.

TABLE 5-1

WATER QUALITY CONDITIONS DURING ACCLIMATION OF EUPHAUSIIDS

Test No.	Days held prior to testing	Temperature (°C)	Dissolved oxygen (mg/l)	pH	Salinity (0/00)
1	17	4.4 ± 0.4	8.8 ± 0.8	7.3 ± 0.2	33.1 * 0.8
II	9	6.0 ± 1.4	9.2 ± 1.5	7.6 ● 0.1	31.9 * 0.4
III	4	6.8	9.3	7.7	32.1
Iv	12	6.5 ± 0.1	9.2 ± 0.3	7.6 ± 0.1	32.2 ± 0.3

Eggs released by gravid females. were held in 250 ml beakers in a temperature controlled water bath for four days prior to use in the larval test (Test III). Hatching occurred during that period, resulting in swimming first stage nauplii. Water quality conditions were measured only at the time that larvae were removed for use in the test, but were assumed to be unchanged during the 4 day development period.

Records of mortalities for adult euphausiids received in the first shipment were not available for the first six days because counts could not readily be made in the large holding aquaria. During the last 11 days of acclimation, however, an average of 5.7 animals, representing about 2% of the culture, died per day. This is in contrast to the low mortality observed in the control (0%) and 1 0W test concentration groups (3-10%) during the subsequent 16-day test period.

For the second and third groups of acclimating postlarval euphausiids, highest mortalities occurred during the initial few days after arrival at the laboratory, but daily mortalities substantially declined thereafter. For example, of the gravid females received on May 10, 78 dead or dying animals were removed on the day of receipt. Two days later, 98 dead animals were removed; on subsequent days the numbers of dead animals found were 39, 10, 5, 3, 6, 10, and 2. The same pattern was found with the juvenile and young adult animals received in September, but the numbers of dying animals were much fewer. The daily number of dead animals removed from the culture from September 17 through September 23 were 9, 6, 2, 1, 0, 1, and 1.

5.3 Bioassay Tests

5.3.1 Test Conditions

Four tests were conducted during three time periods, or series, with Tests II and III conducted simultaneously. Water quality conditions during each of the three teat series are summarized in Table 5-2. In the first test, with adult T. raschii, mean temperatures ranged from 5.3 to 6.0 °C. Tests with gravid females and larvae (Tests II and III, respectively) had mean water temperatures ranging from 6.8 to 7.5 'C. Test IV, with Juveniles, had mean temperatures ranging from 7.2 to 7.4 °C. Mean dissolved oxygen concentrations ranged from a low of 6.8 mg/l in one treatment in the second test series to a high of 9.3 mg/l in

TABLE 5-2

HYDROCARBON CONCENTRATIONS AND WATER QUALITY CONDITIONS
DURING EUPHAUSIID BIOASSAYS

Test No. (a)	Total Measured Hydrocarbon (mg/l)	Temp. (-c)	Dissolved Oxygen (mg/l)	pH	Salinity (0/00)
1	0 (control)	5.8±0.5	9.3±0.8	7.5±0.1	30.6*2.3
	0.301±0.051	5.9±0.4	9.2±0.9	7.5*0.1	30.9±2.2
	0.543±0.072	5.8±0.4	9.2±1.0	7.4±0.2	31.1±2.0
	0.897*0.093	5.9*0.3	9.2±1.0	7.4±0.2	31.0±2.3
	1.413*0.113	5.3*0.4	9.0±1.0	7.5±0.1	30.9±2.1
	2.062±0.288	6.0±0.4	8.7±1.1	7.5*0.1	30.6±2.4
11 & III	0(control)	7.2±0.8	7.5*0.5	7.4±0.0	30.8±0.6 *
	0.054*0.043	7.5±0.8	7.1*0.5	7.4±0.0	
	0.142*0.104	7.1±0.9	7.3±0.6	7.4±0.0	
	0.620*0.176	7.0*0.9	6.8±0.5	7.4±0.0	
	1.329±0.138	6.8±0.7	7.2±0.6	7.4±0.0	
	1.956±0.301	7.4±1.0	6.9±0.5	7.4±0.0	
IV	0(control)	7.3*0.3	8.1±0.2	7.4*0.1	32.8±0.4 *
	0.191*0.126	7.3*0.4	7.9*0.4	7.4*0.1	
	0.497*0.225	7.3±0.3	7.7±0.6	7.4*0.1	
	0.74220.332	7.4*0.3	7.5±0.8	7.4$0.1	
	1.627s0.206	7.2±0.3	7.6±0.8	7.4*0.1	
	2.184±0.308	7.4±0.3	7.6*0.7	7.4*0.1	

(a) Test I: T. *raschii* adults, test begun on '-March 29, 1985"
Test II: *T. raschii* gravid females, test begun on May 19, 1985
Test III: *T. rascbii* larvae, test begun on May 19, 1985
Test IV: *T. raschii* Juveniles, test begun on September 24, 1985

•Salinity measured only at the seawater source.

the control treatment of the first test series. None of the temperature or dissolved *oxygen* differences were significant within a test series.

The mean pH in all tests was within the range of 7.4 to 7.5. Mean salinities in Test I, for individual teat concentrations ranged from 30.6 0/00 to 31.1 0/00. In Tests II, III, and IV, salinity was measured only at the seawater source; the *average* salinity in the second test series was 30.8 0/00, that of Test IV was 32.8 0/00.

5.3.2 Concentration and Composition of Prudhoe Bay WSF

The mean of total measured hydrocarbons at each treatment level in each of the three test series is also shown in Table 5-2. The highest levels in the three test series were similar; 2.06 mg/l in Test I, 1.96 mg/l in Tests II and III, and 2.18 mg/l in Test IV. Lowest test concentrations ranged from 0.054 mg/l (Tests II and 111) to 0.301 mg/l (Test I). The average concentrations of the principal components of the Prudhoe Bay water soluble fractions found in each of the three test series are shown in Table 5-3. Benzene and toluene together accounted for roughly 75% of the measured compounds.

Ethylbenzene and the three xylene isomers account for an additional 13% of the measured compounds. The remainder of the measured peaks consisted of more highly substituted benzenes, naphthalene, methyl naphthalenes, and eight unidentified peaks.

TABLE 5-3

AVERAGE CONCENTRATIONS OF AROMATIC HYDROCARBONS IN UNDILUTED WATER SOLUBLE FRACTIONS OF PRUDHOE BAY CRUDE OIL USED FOR EUPHAUSIID BIOASSAYS

Compound	Concentration (mg/l)		
	Teat I	Tests II & III	Test IV
Benzene	0.789 ± 0.134	0.7s7 ± 0.119	0.823 ± 0.126
Toluene	0.757 ± 0.128	0.698 ± 0.123	0.819 ± 0.137
Ethylbenzene	0.046 ± 0.014	0.029 ± 0.011	0.044 * 0.013
m-,p-xylene	0.141 ± 0.030	0.129 ± 0.023	0.149 ± 0.028
o-xylene	0.073 ± 0.008	0.068 ± 0.010	0.081 ± 0.013
Isopropylbenzene	0.004 * 0.001	0.003 * 0.001	0.004 ± 0.001
n-Propylbenzene	0.004 ± 0.002	0.002 ± 0.001	0.004 ± 0.002
unidentified	0.016 ± 0.003	0.014 * 0.003	0.016 ± 0.003
1,3,5-Trimethylbenzene	0.006 ± 0.001	0.005 * 0.001	0.006 ± 0.002
unidentified	0.008 ± 0.001	0.007 * 0.001	0.009 ± 0.002
1,2,4-Trimethylbenzene	0.017 ± 0.004	0.016 ± 0.003	0.018 ± 0.005
p-Cymene	0.012 * 0.001	0.011 * 0.001	0.013 ± 0.002
unidentified	0.022 ± 0.012	0.030 * 0.009	0.027 ± 0.006
unidentified	0.014 * 0.007	0.012 * 0.005	0.024 ± 0.005
unidentified	0.018 ± 0.006	0.024 ± 0.004	0.023 ± 0.004
1,2,3,4-Tetramethylbenzene	0.008 ± 0.002	0.013 * 0.003	0.004 ± 0.003
Di-isopropylbenzene + unidentified	0.055 * 0.022	0.076 ± 0.020	0.060 ± 0.014
Naphthalene	0.021 ± 0.009	0.011 ± 0.003	0.020 ± 0.009
unidentified	0.018 ± 0.004	0.024 ± 0.002	0.027 ± 0.004
unidentified	0.008 ± 0.002	0.011 ± 0.002	0.004 ± 0.002
2-Methylnaphthalene	0.012 ± 0.002	0.012 ± 0.003	0.014 ± 0.004
1-Methylnaphthalene	0.013 * 0.001	0.013 * 0.002	0.014 * 0.002

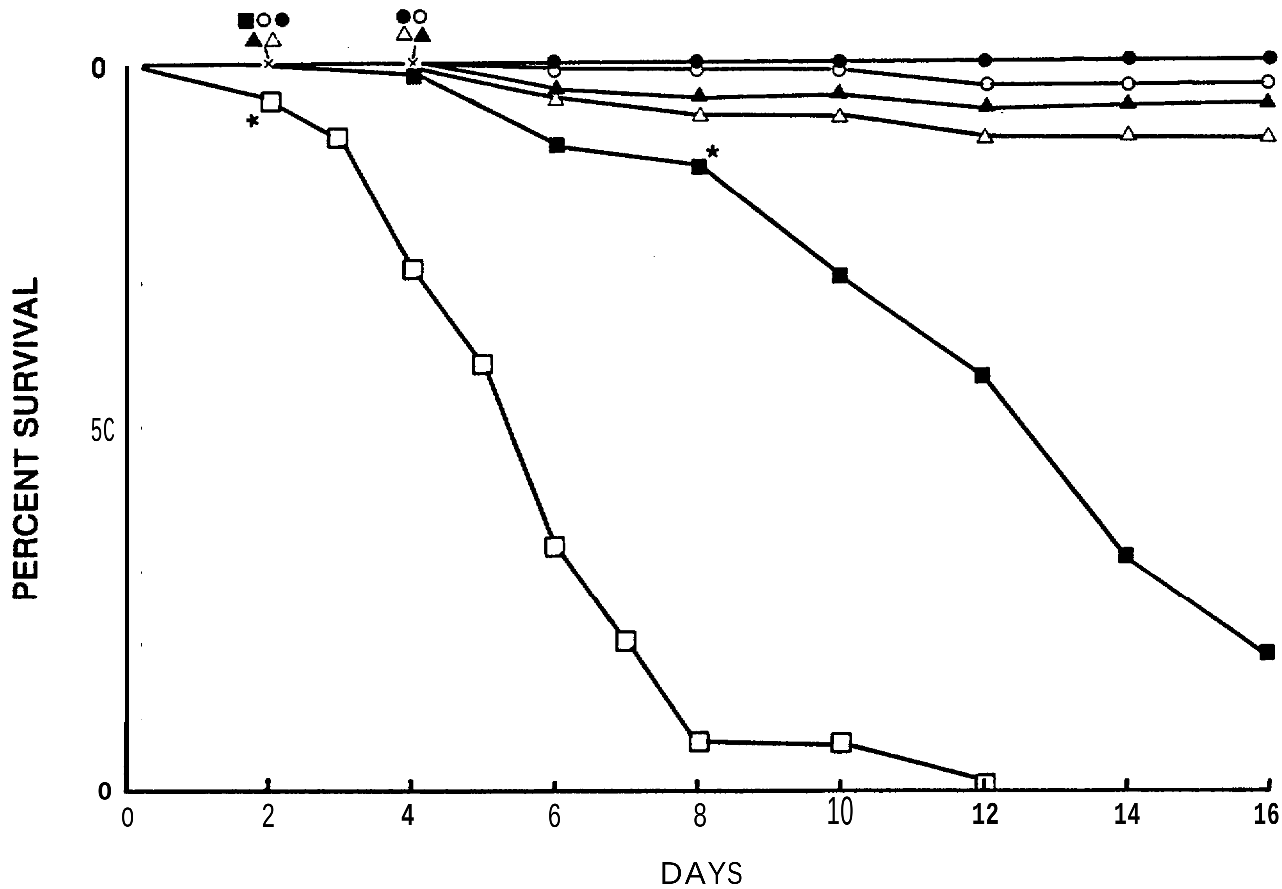
5.3.3 Effects of WSF on Euphausiid Survival

In Test I, using adult *T. raschii*, animals exposed to the highest test concentration, 2.06 mg/l TMH (total measured hydrocarbons), were severely narcotized within the initial 24-hr period, but deaths occurred gradually over a period of eight days (Figure 5-1). Survival in this group was significantly less than in controls by day 2. Euphausiids exposed to 1.41 mg/l TMH were also slightly to moderately narcotized within the initial 24 hours and generally throughout the remainder of the test. Survival in this group was significantly less than in controls on day 8, and survival continued to decrease until the end of the test on day 16, by which time only 18% of the initial number of animals had survived. Euphausiids exposed to 0.897 mg/l TMH did not experience significantly poorer survival than control animals and those at lower test concentrations and did not appear to be behaviorally affected.

In the second test, with gravid females, reduced survival occurred at the highest (1.96 mg/l) and second highest (1.33 mg/l) test concentrations as in the first test, but the effect occurred much more rapidly (Figure 5-2). Survival was significantly less than controls by day 2 at 1.96 mg/l and complete mortality was noted within 3 days. At 1.33 mg/l, survival was significantly less than in controls by day 3 and 75% mortality occurred within 5 days. Euphausiids at the third highest test level (0.62 mg/l) also experienced significantly higher mortality than controls by day 6.

Figure 5-3 pre.cents the results of WSF toxicity testing on *T. raschii* nauplii. Survival was not significantly lower at either 1.96 mg/l or 1.33 mg/l TMH compared with the controls at any time during the six day exposure period. During the naupliar test, animals were observed to progress from first to second nauplius and then to first calyptosis stage. On day 6 virtually all larvae were in the calyptosis stage. During the test, larvae were occasionally damaged or lost by adhering to the sides of the test cages, a circumstance contributing to the Steady decrease in apparant survival of the nauplii at all test levels, including the controls, during the six day test period.

A final test (Test IV) was performed using juvenile (Age 0+) *T. raschii*. The results of this last test were very similar to the initial test with adults (Test I). Euphausiids exposed to 2.18 mg/1, the highest test level, experienced a steady decrease in percent survival over the ten day period (Figure 5-4). The percent survival was first significantly less than that of the controls on day 4 of the



TOTAL MEASURED HYDROCARBONS

● CONTROL
o 0.3101 mg/l
▲ 0.543 mg/l
A 0.897 mg/l
● 1.413 mg/l
□ 2.062 mg/l

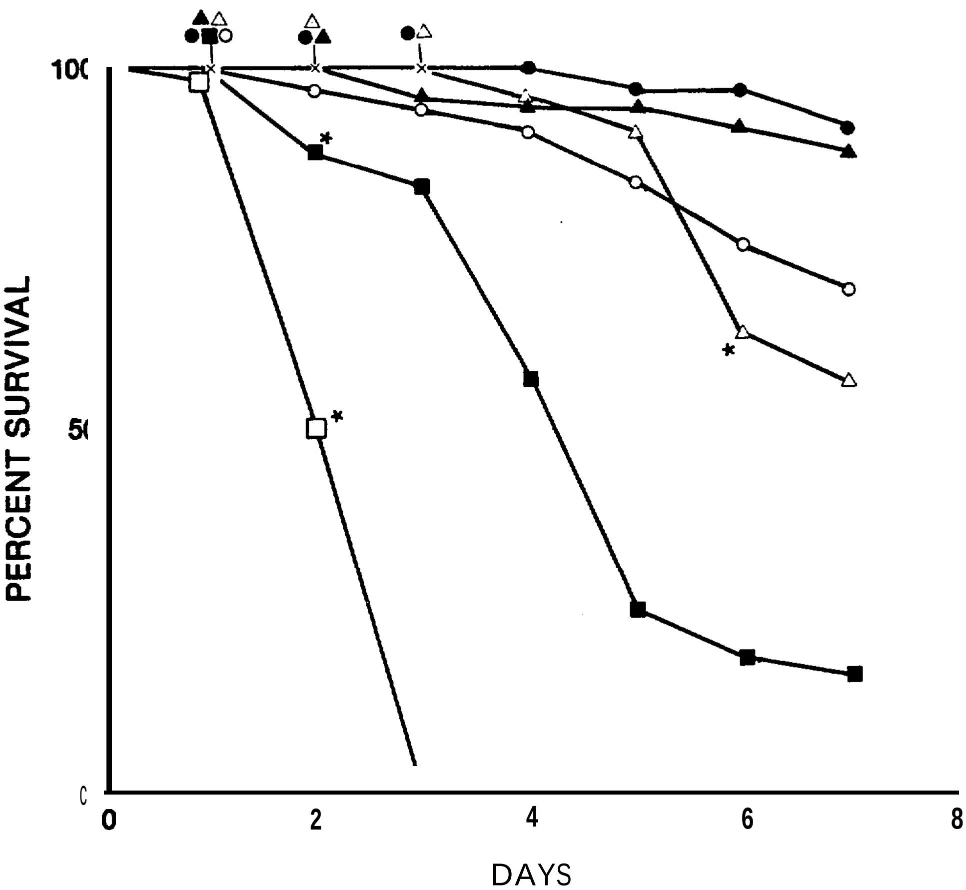
● Significant difference from control group (5% level)

EFFECTS OF OIL ON FOOD ORGANISMS OF THE BOWHEAD WHALE
NOAA/OCSEAP RU 662

EUPHAUSIID SURVIVAL AT EXPERIMENTAL LEVELS OF PRuDHOE BAY CRUDE OIL WSF

TEST I: ADULTS

1985 | FIGURE 5-1



TOTAL MEASURED HYDROCARBONS

● CONTROL
O 0.054 mg/l
A 0.142 mg/l
△ 0.620 mg/l
■ 1.329 mg/l
❑ 1.956 mg/l

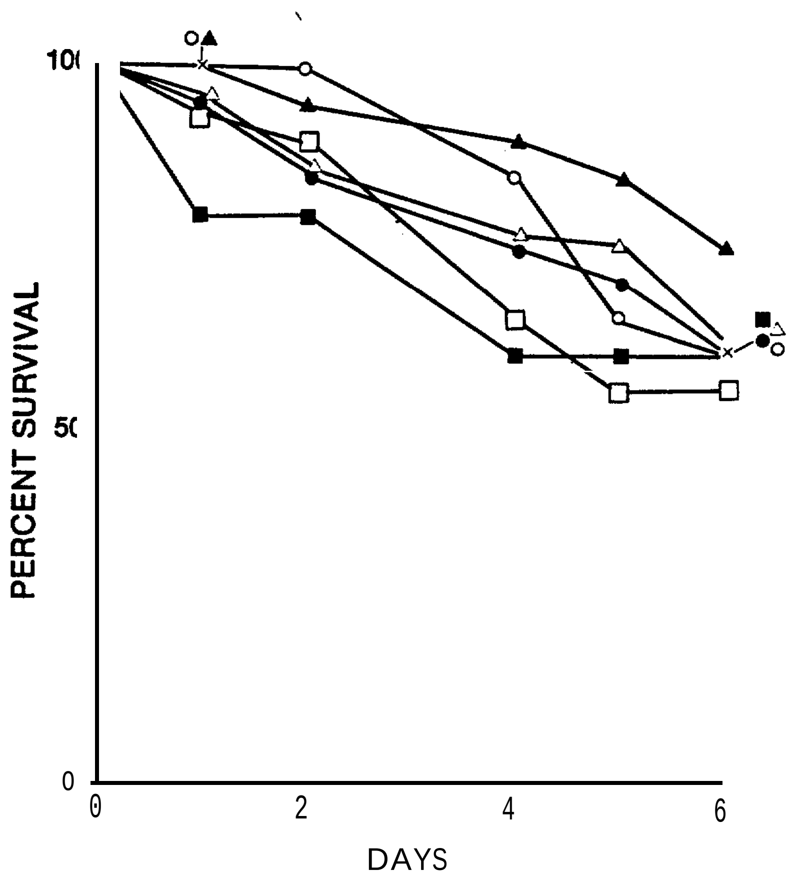
● Significant difference from control group(5% level)

EFFECTS OF OIL ON FOOD ORGANISMS OF THE BOWHEAD WHALE
NOAA/OCSEAP RU 662

EUPHAUSIID SURVIVAL AT EXPERIMENTAL LEVELS OF PRUDHOE **BAY CRUDE OIL WSF**

TEST 11: GRAVID FEMALES

FISHMAN ENVIRONMENTAL SERVICES 5-9 | 1985 | **FIGURE** 5-2



TOTAL MEASURED HYDROCARBONS

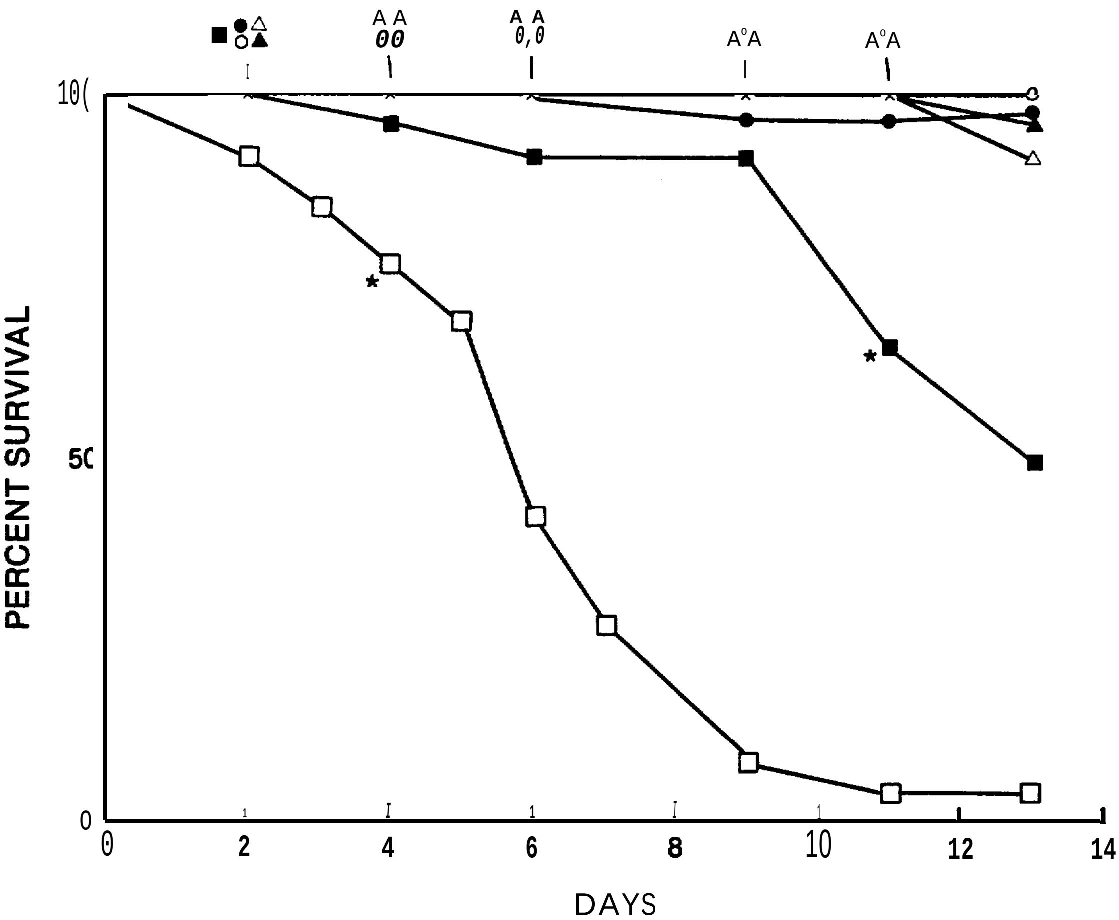
● CONTROL
O 0.054 mg/l
A 0.142 mg/l
△ 0.620 mg/l
■ 1.329 mg/l
□ 1.956 mg/l

EFFECTS OF OIL ON FOOD ORGANISMS OF THE BOWHEAD WHALE
NOAA/OCSEAP RU 562

EUPHAUSIID SURVIVAL AT EXPERIMENTAL LEVELS OF PRUDHOE BAY CRUDE OIL WSF

TEST III LARVAE

FISHMAN ENVIRONMENTAL SERVICES 5-10 | 1985 | FIGURE 5-3



TOTAL MEASURED HYDROCARBONS

● CONTROL
O 0.191 mg/l
▲ 0.497 mg/l
A 0742 mg/l
● 1.627 mg/l
□ 2.184 mg/l

Slgn,flcant difference from conlrolgroup(5°/, level)

EFFECTS OF OIL ON FOOD ORGANISMS OF THE BOWHEAD WHALE
NOAA/OCSEAP RU 662

EUPHAUSIID SURVIVAL AT EXPERIMENTAL LEVELS OF PRUDHOE **BAY CRUDE OIL WSF**

TEST IV JUVENILES

FISHMAN **ENVIRONMENTAL SERVICES** 5-11

1985

FIGURE 5-4

test, more than 50% mortality was recorded by day 6, and only one of 26 initial animals in this group survived to the end of the test on day 13. Animals exposed to 1.63 mg/l, the next highest test level, exhibited significantly reduced survival compared with controls by day 11 and 50% mortality at the end of the test on day 13. Euphausiids exposed to 0.742 mg/l did not experience reduced survival compared with controls.

LC_{50} concentrations for approximately 4, 7 and 10-day intervals in tests of all four life stages are presented in Table 5-4. Gravid females had the lowest LC_{50}'s of any stage tested, 1.37 and 0.69 mg/l for days 4 and 7, respectively. Adults and juveniles were approximately equal in sensitivity; adult LC_{50}'s ranged from 1.5[illegible] mg/l at day 10 to >2.06 mg/l at day 4, and juvenile LC_{50}'s ranged from 1.72 mg/l at day 11 to >2.18 mg/l at day 4. Larvae were the least sensitive stage; LC_{50}'s were >1.96 on both days 4 and 7.

5.3.4 Sublethal Effects of WSF on Euphausiids

A sublethal effect that could be evaluated in the adult organisms was the frequency of molting. On each day that test animals were examined for survival, the number of molts that had occurred during the previous 24 hours was recorded. After day 8 in Test I and day 7 in Test IV, aquaria were examined only every second day and the number of molts recorded, thereafter, was for a 48-hr period. At the end of the tests, the numbers of surviving adults in each test concentration each day was summed to provide a total number of animal days. Dividing this by the total number of molts found yields a molt frequency value (animal days per molt).

In Test I, euphausiids exposed to 1.41 and 2.06 mg/l had significantly longer periods between molts, 17.33 and 20.29 days/molt, respectively, compared with from 8.24 to 9.30 days/molt for controls and euphausiids exposed to 0.897 mg/l TMH and less (Table 5-5). The interval between molts of gravid female euphausiids was significantly longer than *found in* the controls at 1.96 mg/l TMH, but not at 1.33 mg/l TMH or at lower test concentrations (Table 5-6).

Juvenile euphausiids experienced the least sensitivity of WSF exposure on molting frequency. The interval between molts at 2.18 mg/l TMH at 27.80 days was significantly longer than at lower test levels and in controls, but the molt interval, 8.23 days, for the next highest test level, 1.63 mg/l, was not significantly different than the interval found for controls (Table 5-7).

TABLE 5-4

LC_{50} CONCENTRATIONS FOR I. RASCHII DEVELOPMENTAL STAGES

Test Number/ Life Stage	LC_{50} in mg/l (95% Confidence Interval) 4-day	7-day	10-day
I / Adults	> 2.06	1.76 (1.41-2.06)	1.58 (1.41-2.06)
11/ Gravid Females	1.37 (1.33-1.96)	0.69 (0.62-1.33)	---------
111/ Larvae	> 1.96	>1.96 *	--------
IV/ Juveniles	> 2.18	2.00 (1.87-2.14)	1.72 (1.60-1.83) **

* Day 6

** Day 11

TABLE 5-5

EFFECT OF OIL WSF ON ADULT *T. RASCHII* MOLT FREQUENCY DETERMINED DURING TEST I

Total measured hydrocarbons (mg/l)	Test Day * 1 2 3 4 5 6 7 8 10 12 14 16	Total molts	Total animal days	Days per molt
control	7 4 3 322 5 1142 7 3	53	460	9.06
0.301	5653 1 0 1 512 7 7 1	54	474	a. 78
0.543	510 0 1 4 3 1 211 5 6 5	53	463	8. 24
0.297	63 3 1 1 3 1 3 8 6 66	47	437	%30
1.413	3 5 2 4 0 0 1 0 2 0 1 0	18	312	17.33
2.062	6 0 1 00 0 0 0 0 0 --	7	142	20.29

TABLE 5-6

EFFECT OF OIL WSF ON GRAVID FEMALE *T. RASCHII* MOLT FREQUENCY DETERMINED DURING TEST II

Total measured hydrocarbons (mg/l)	Test Day* 1 2 3 4 5 6 7	Total molts	Total animal days	Days per molt
control	2 1 2 1 5123	26	219	8.42
0.054	2 3 0 7 110 2	25	195	7.20
0.142	2 2 3 6 6 7 2	22	210	7,50
0.620	1 1 73 36 3	24	193	8.04
1.329	32 1 2 1 02	11	116	10.6
L 956	i o o - - - -	1	48	48.0

TABLE 5-7

EFFECT OF OIL WSF ON JUVENILE *T. RASCHII* MOLT FREQUENCY DETERMINED DURING TEST IV

Tot al measured hydrocarbons (mg/l)	Test Day * 1 2 3 4 5 6 7 91113	Total molts	Total animal days	Days per molt
Control	4 1 83 2 5 3 6 10 8	50	333	6.66
0.191	1 5 72 2 7011 7 8	50	338	6.76
0.497	S 4 0 3 5 3 6 7 713	53	333	6.28
0.742	4 1 3 3 3 6 6 5 8 11	50	336	6.72
1.627	2 36 4 23 3 37 2	35	288	8.23
2. 184	1 2 1 00000 1 o	5	139	27.80

* Numbers in Test Day columns = number of molts.

Molt frequencies were not compared between life stages because of differences inherent in each stage, and some differences in test temperatures.

No attempt was made to quantitatively evaluate swimming, activity level or other gross behavior during the tests of WSF toxicity. It was readily apparent, however, that euphausiids exposed to the highest test levels in each of the three tests of postlarval animals were highly narcotized during the initial 24 hours of exposure. To a lesser extent, euphausiids exposed to the second highest levels in all three postlarval tests were similarly affected. As the tests progressed, some of the narcotized animals at this test level became progressively more affected and eventually died, but others appeared to recover. At all lower test levels, the postlarval animals generally appeared to be unaffected behaviorally in comparison to controls. Nevertheless, it seemed to the observer that control euphausiids and those at the lowest test levels (e.g. < 0.5 mg/l TMH) were more robust and healthy appearing at times, and were more successful in consuming available food organisms (based on the amount of food *remaining* in teat chambers by the next feeding time), than animals exposed at the middle test concentrations of WSF (e.g. in the range of 0.5 to 0.9 mg/l TMH).

6. DISCUSSION

6.1 Ecology of *Thysanoessa raschii*

6.1.1 Ecological Importance of *T. raschii*

Euphausiids comprise up to one-third of the zooplankton biomass in boreal waters (Mauchline and Fisher 1969). *T. raschii* averages over 30% of the total number of individual euphausiids in the northern seas (Hopkins, et al. 1978; Rogers, et al. 1979). Thus, this species represents at least one tenth of the total zooplankton biomass in these areas and more in neritic waters where it is more common (Mauchline and Fisher 1969). As a consequence, the ecological interactions of this species are of considerable importance in Arctic and subarctic coasts 1 marine environments.

Early growth stages of euphausiids apparently feed upon phytoplankton, <primarily, but not exclusively diatoms) (Mauchline and Fisher 1969; Mauchline 1980). As they mature, *T. raschii* individuals become more omnivorous; but remain primarily herbivorous as adults (Mauchline 1966). The combination of the large biomass, herbivorous nature, and vertical migration of *T. raschii* means that this species. is a major route of energy and materials transfer from the epipelagic region to the mesopelagic habitat in Arctic and subarctic waters. Its fecal pellets and moults can further transfer material to the ocean floor as well. For example, forty percent of the zinc-65 discharged by the Columbia River in the Pacific is incorporated into the exoskeleton of *Euphausia pacifica* individuals, then molted off into deeper waters (Fowler and Small 1967; Pearcy and Osterberg 1967).

Other significant ecological interactions include the synthesis of vitamin A. Euphausiids are the only group of organisms in which all members synthesize vitamin A and they have greater concentrations than all other invertebrates (Mauchline and Fisher 1969). It has been suggested that they are responsible for the bulk of naturally-synthesized vitamin A.

The key ecological significance of *T. raschii* and other euphausiid species, however, lies in the fact that they are a major source of food for marine animals higher in the food web, transforming energy and materials synthesized by its food supply, the phytoplankton, into a more utilizable form for marine fish, birds, and mammals (Table 6-1).

The importance of euphausiids in diets of subarctic Alaskan fish species is fairly well documented. Euphausiids have been found important in diets of juvenile salmon (Gosho 1977; Harris and Hartt 1977: Rogers et al. 1979), capelin (Harris and Hartt 1977; Rogers et al. 1979?, sand lance (Rogers et al. 1979), walleye pollock (Rogers et al. 1979; VTN 1980), and other species. Studies in Balsfjorden, Norway found capelin, herring, end Atlantic cod feeding extensively on Thysanoessa euphausiids (Pearcy et al. 1979).

The role of euphausiids in Alaskan Arctic fish diets has not been well documented. Fish collected in nearshore waters of the northeastern Chukchi Sea during 1983 were found to eat a variety of items, but only one species of eight examined had eaten euphausiids. Pink salmon (Oncorhynchus gorbuscha) stomach contents were less than 1% euphausiids (2 of 12 fish). The other species examined, which did not have euphausiids in their stomachs, were Arctic cod (Boreogadus saida), fourhorn sculpin (Myoxicephalus quadricornis), capelin (Mallotus villosus), saffron cod (Eleginus navaga), Pacific herring (Clupea harengus palasii), boreal smelt (Osmerus mordax), and Arctic flounder (Liopsetta glacialis). Lowry and Frost (1981) found euphausiids of minor importance in diets of Arctic cod in the Bering, Chukchi and Beaufort Seas.

Euphausiids are utilized by pelagic and nearshore birds in the Beaufort Sea (Divoky 1984; Frost and Lowry 1984). Species feeding on euphausiids include glaucous gull (Larus hyperboreus), ivory gull (Pagophila eburnea), Ross' gull (Rhodostethia rosea), Sabine's gull (Xema sabini), Arctic tern (Sterna paradisaea), black-legged kittiwake (Rissa tridactyla), thick-billed murre (Uris lomvia), red phalarope (Phalaropus fulicarius), and oldsquaw (Clangula hyemalis). Arctic tern and several of the gull species were the greatest euphausiid feeders.

Six of the seven species of baleen whales known to occur off Alaska live on euphausiids and copepods (Nemato 1970; Nishiwaki 1972). Sei, blue and bowhead whales live almost entirely on these organisms, while minke, fin, and humpback whales add small, gregarious fish, such as the euphausiid-eating capelin, other smelt, herring and sand lance, to their diets as well.

TABLE 6-1

EUPHAUSIIDS AS FOOD ITEMS OF ALASKAN ARCTIC MARINE VERTEBRATES

PREDATOR SPECIES	EUPHAUSIID REPRESENTATION IN STOMACH CONTENTS	{reference}
MAMMALS		
Bowhead whale	37% (n=5). Whales taken during Autumn, 1979 near Kaktovik.	{A}
	92% (n=2). Whales taken during Autumn, 1976 near Barrow.	{A}
Ringed seal	90% (vol., n=3). Spring (May), 1976, near Barrow.	{A}
	99% (vol., n=2). Summer (Aug-Sep), 1976, Barrow	{A}
	44% (n=16). Summer, 1980 Beaufort Lagoon	{A}
	<1% (n=8). Summer, 1980, Pingok.	{A}
	0 (n=13). Summer, 1977, Prudhoe.	{A}
	0 (n=73). Autumn (Nov), 1977 and 1978, Barrow and Prudhoe.	{A}
	2% (vol., n=24). Winter (Feb-Apr), 1979, Prudhoe.	{A}
	0 (n=34). Winter (Feb-Apr), 1978 and 1979, Barrow.	{A}
BIRDS		
Black-legged kittiwake	2%	{A}
Glaucous gull	9%	{A}
	0 (n=9). Pelagic region.	{B}
	13% (wt.): 33% (freq.), (n=9). Nearshore region.	{B}

TABLE 6-1 (continued)

Ivory gull	10%	{A}
Ross' gull	40%	{Al
Sabine's gull	10%	(A)
	13% (wt.); 17% (freq.), (n=6) Pelagic region.	{B}
	4% (wt.); 3% (freq.), (n=32) Nearshore region.	{B}
Arctic tern	18%	(Al
	35% (wt.); 22% (freq.), (n=6) Pelagic region.	(B]
	23% (wt.); 23% (freq.), (n=48) Nearshore region.	{B]
Thick-billed murre	2%	{Al
Red phalarope	5% (freq.) (n=76). Pelagic and nearshore regions combined.	(B}
Oldsquaw	17% (wt.);13% (freq.), (n=93) Nearshore region.	(B)
Fish		
Arctic cod	5%	
Pink salmon	<1% (wt.); 17% (freq.), (n=12). Pt. Lay, Chukchi Sea.	{C}

References: {A} = Frost and Lowry (1984), Beaufort Sea.
{B} = Divoky (1984), Beaufort Sea.
{C} = Fechhelm et al. (1985), Chukchi Sea.

In the Beaufort Sea, bowhead whales (*Balaena mysticetus*) and ringed seals (*Phoca largha*) are major consumers of euphausiids. Stomachs of bowhead whales have been found to contain 5-98% euphausiids, depending on location and season of capture (Frost and Lowry 1984). Whales taken near Kaktovik (5 animals) in 1979 had a mean composition of 37% euphausiids in their stomachs; 2 whales taken near Barrow in 1976 averaged 92% euphausiids in their stomachs. (Referenced locations are shown in Figure 6-l.) Ringed seals examined had 2-99% stomach content composition represented by euphausiids (Frost and Lowry 1984).

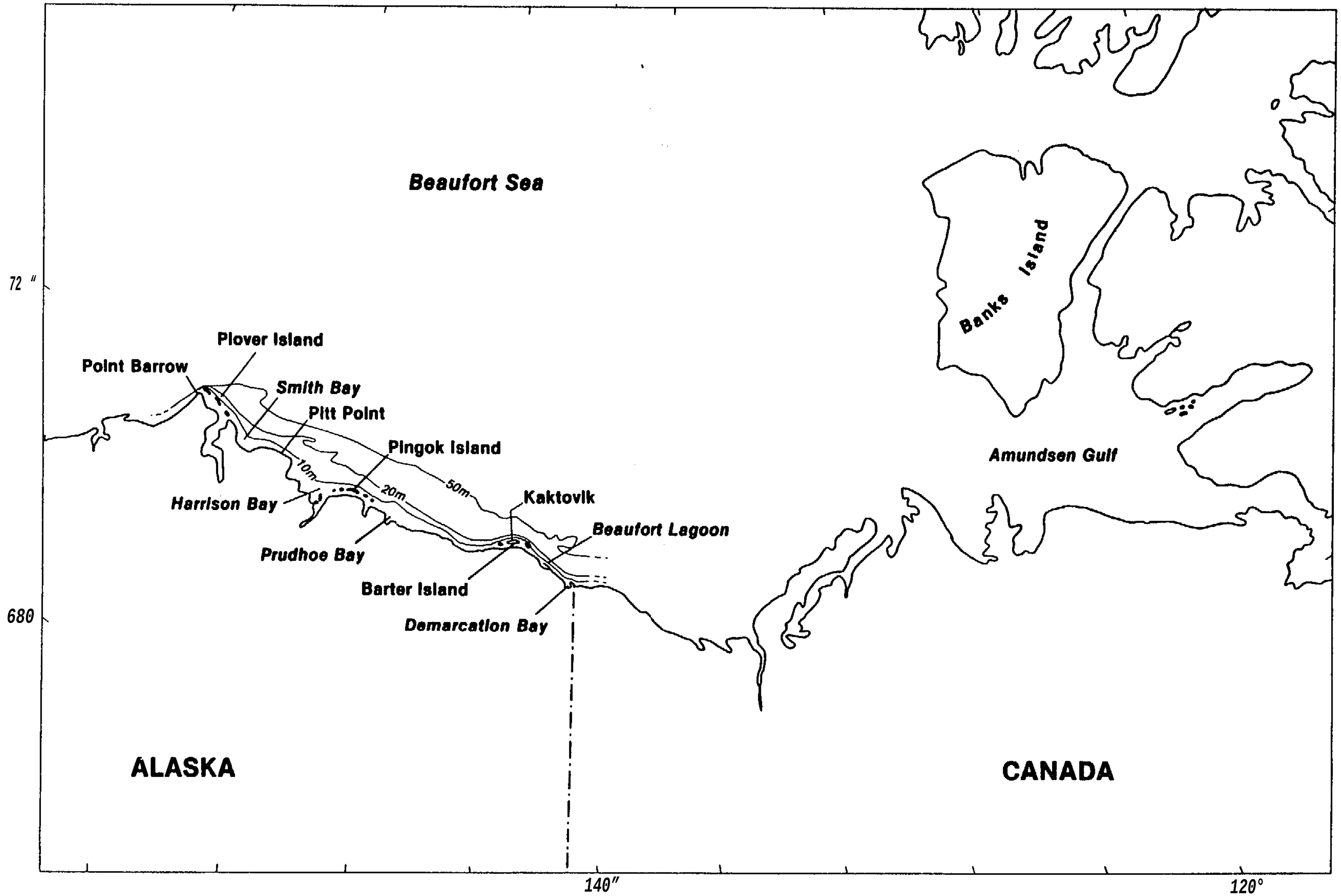
Data concerning trophic relationships of vertebrate consumers in the Alaskan Beaufort Sea were recently synthesized and summarized by Frost and Lowry (1984). These authors estimated the total quantities of food consumed annually by the major vertebrate consumers. Euphausiids represented 7%, by weight, of the 2+ million tons of estimated food consumption; copepods, Arctic cod, hyperiid amphipods and "others" represented 48%, 6%, 1% and 37%, respectively. The estimated 143,000 tons of euphausiids consumed annually are eaten by Arctic cod (65.8%), bowhead whales (31.5%), ringed seals (2.6%) and birds (less than 0.1%). Euphausiids represented 65% of annual consumption by bowhead whales, 9.7% of consumption by ringed seals, 2.5% of consumption by all marine birds, and 5% of consumption by Arctic cod.

6.1.2 Distribution of *T. raschii* within the Arctic Ocean

T. raschii is found throughout the boreal coastal waters of the world's oceans. It occurs in the North Atlantic between 40 and 70 degrees north off West Greenland to the Gulf of Maine, around Iceland, around Scotland, in the North Sea, and off Norway (Mauchline and Fisher 1969). In the Pacific it is present along the coastlines of Asia and North America, and north into the Bering and Beaufort Seas at the same latitudes (Brinton 1962; Mauchline and Fisher 1969). *T. raschii* is seldom found in oceanic waters.

Thysanoessa raschii and *T. inermis* are the only two species of euphausiids common in the Arctic Ocean (Mauchline 1980). *T. raschii* is abundant in the Barents and White Seas (Zelikman, et al. 1978; 1979; 1980), in the Sea of Okhotsk (Zhuravlev 1977), in the Bering Sea (Cooney 1977) and in the Chukchi and Beaufort Seas (Carey 1978; Homer 1981).

Typical daytime densities reported off Alaska for *Thysanoessa raschii* were 16 individuals per 1000 cubic meters in southeastern fjords (VTN 1982), 100 per 1000 cubic meters in Kodiak bays (Kendall et al. 1980: Rogers, et al.



EFFECTS OF OIL ON FOOD ORGANISMS OF THE BOWHEAD WHALE
NOAA/OCSEAP RU 662

THE BEAUFORT SEA

FISHMAN ENVIRONMENTAL SERVICES

1985 | FIGURE 6-1

1979; Vogel and McMurray 1982) and up to 510 per 1000 cubic meters in the Beaufort Sea (Homer 1981). The average density of adult T. raschii in the Beaufort was between 50 to 200 individuals per 1000 cubic meters (Carey 1978). During August and early September, 1977 densities in excess of 100 animals per 10CIO cubic meters occurred all along the Beaufort Sea coastline in waters of 20 to 80 m depth, approximately 15 to 100 km offshore (Carey 1978). Pack ice apparently inhibited collections farther offshore, thus, the offshore distribution of this species in the Beaufort Sea is unknown.

The lack of abundance and distribution data for T. raschii in the Alaskan Beaufort necessitates consideration of indirect *evidence:* bird and mammal feeding behavior and distribution. Bowhead whales are reported to feed extensively on euphausiids (primarily T. raschii), particularly in the western Beaufort (L.'-Lowry 1985, personal communication). Bowheads are found in nearshore waters along the western Beaufort during their fall westward migration. The inshore waters between Pt. Barrow and Smith Bay are utilizedannually between August and November, with most sightings (>90%) during September (Braham et al. 1983). Whales were observed feeding *in* these waters during September of 1974, 1975, 1976 and 1978; whales were observed feeding near the surface during a swarming and onshore movement of euphausiids during September, 1976 (Braham et al. 1983>. Bodfish (1936) reported bowheads consistently in water lees than 40 m, Braham et al. (1983) observed whales in water 3 to 12 m deep, with 172 of 234 sightings during August-November, 1974-78 near Pt. Barrow in water less than 12 mm Braham et al. (1983) concluded that nearshore waters are more important for feeding whales than offshore waters in the area of the Plover Islands.

The area near the Plover Islands appears to be important in terms of primary and secondary productivity, and feeding for marine birds and mammals. Divoky (1984) discussed the apparent importance of this area to marine birds. Warmer northeastward-flowing water from the Bering Sea (Bering Sea Intrusion) is a major oceanographic feature found off Pt. Barrow. Divoky attributed higher bird densi.ties in the western Beaufort to " higher prey densities associated with this warm, subarctic water. Bering Sea water meets the westward-moving Beaufort Gyre and nearshore waters, resulting in the formation of eddies in the Plover Islands and Pitt Point region. While zooplankton samples in an intrusion area produced inconclusive results related to abundance/density differences compared *with* nearby *areas,* stomach samples of Arctic terns captured while feeding at a convergence line off the Plover Islands contained mostly euphausiids (Divoky 1984). Also, major wash-ups of dead and dying T. raschii have been documented about once every 2 years during late August - early September (Divoky 1985, personal communication). The observed 2-3 inch deep windrows of beached euphausiids fed major concentrations of sea birds (mixed species flocks of about 10,000 birds). Based on bird feeding data, Divoky (September 24, 1985, personal comm. by telephone) found euphausiids distributed farther offshore (20 m and deeper) in the western Beaufort than the eastern Beaufort.

Feeding data for ringed seals (Frost and Lowry 1984) provide evidence of euphausiid distribution, and, perhaps, seasonality. Stomach contents of seals captured near Barrow were 90% euphausiids during spring (May), 1976, and 99x euphausiids during summer (Aug-Sep), 1976; no euphausiids were in stomachs of seals captured during autumn (November), 1977 and 1978, and winter (Feb-Apr), 1978 and 1979. The stomach contents of seals captured in Prudhoe Buy were Q% euphausiids during spring, 1979, summer, 1977, autumn, 1977 and 1978; and 2% during winter,1979. Stomach contents of seals taken in Beaufort lagoon during summer, 1980 were 44% euphausiids.

Moat collection programs in nearshore waters and coastal lagoons of the Beaufort and Chukchi Seas have found few or no euphausiids either in the water column or in fish stomachs (Craig and McCart 1976: Griffiths 1984; Craig et al. 1982; Craig 1984>. Exceptions include euphausiids reported in stomachs of Arctic cod taken in Beaufort Sea shallow water (5 m; Lowry, Alaska Dept. Fish and Game, October 7, 1985, personal comm. by telephone, and pink salmon in the Chukchi (Fechhelm et al. 1985).

The data summarized above suggest several points concerning T. raschii distribution in the Beaufort Sea:

1. Euphausiids are found in nearshore waters as well as deeper offshore areas.

2. The area around Pt. Barrow and the Plover Islands appears to support a major concentration of euphausiids, particularly during August - September.

3. The Bering Sea Intrusion appears to be a major factor in assumed euphausiid distribution and density. (Euphausiids associated with the intrusion, however, may represent transported Bering Sea populations [Divoky 1984]).

6.1.3 Vertical distribution patterns of T. raschii

In areas where this species has been studied, adults typically live at 200 m or less during the day and migrate toward the surface at night, while earlier life history stages are collected in the surface 25 m (Mauchline and Fisher 1969). As adults, Thysanoessa raschii migrate vertically about 100 m (Mauchline and Fisher 1969; Mauchline 1980). Light intensity apparently is the key physical parameter causing vertical migration. Clarke (1971) found that the optimal light intensities for adult euphausiids off California were 10^{-3} to 10^{-4} W/cm^2 (micro-watts). Disruption of T. raschii vertical migration may occur during mid-summer' in the Beaufort Sea due to the continuous light conditions at that time of year. While this phenomenon was not observed for euphausiids in Balsfjorden by Hopkins, et al. (1978) or Pearcy, et al. (1979), neither study was performed during the period of continuous light (Eilertsen, et al. 1981). Wiborg (1954) found, however, that vertically migrating zooplankton species appear to stop migrating during the High Arctic summer.

The association of euphausiids with isolumes results in their tendency to live within a 'restricted vertical layer of the water column during daylight hours. Extensive information is now available suggesting that euphausiids are sometimes responsible for the deep scattering layers (DSL) recorded by echo sounders (Farquhar 1971). T. raschii causes sound scattering at 100 to 200 kHz (kilohertz) (Farquhar 1977) and several studies have tracked vertical distribution of this species using 120 kHz echo sounders (Hopkins, et al. 1978; Sameoto 1976a, 1980b).

High light levels have been found to reduce the lifespan of euphausiids (Mauchline and Fisher 1969). Despite their preference for a low optimal light level, some populations of euphausiids have biochemically adapted to higher light intensities. Euphausia pacifica in Saanich Inlet, British Columbia migrates only 85 m due to the presence of an anoxic layer below (Bary, et al. 1962). This population lives in light two to three orders of magnitude greater than other populations of the same species. Boden and Kampa (1965) determined that individuals of the Saanich Inlet population have differentially deposited a screening pigment which allows them to survive the higher light levels, suggesting that some euphausiid species may possess significant amounts of genetic variability between different populations.

Obviously, T. raschii living in shallow (less than 20 m) nearshore waters will not exhibit large-scale vertical migrations. The occurence of large numbers of euphausiids in nearshore waters, such as described off the Plover Islands, may be related to reproductive swarming. Another factor in this apparent concentration of euphausiids could be the Bering Sea Intrusion. Aagaard (1984) describes cross-shelf flow, or exchange between the Beaufort Undercurrent and inshore waters over distances of 13 km. The Barrow Sea Valley, running just east of Pt. Barrow, has depths of 150+ m within S km of water <10 m deep off Pt. Barrow. Cross-shelf flow and localized upwelling events might provide a transport mechanism for euphausiids into shallow, nearshore waters.

6.1.4 Life history and fertility of T. raschii

In Balsfjorden, Norway, (approx. 69.5" N latitude) T. raschii lives for two years, three months (Falk-Petersen and Hopkins 1981). Similar periods of longevity have been found for this species in the Clyde Sea area off southwest Scotland (Mauchline 1966), in the Gulf of St. Lawrence (Berkes 1976), in the Gulf of Maine and in the central North Sea (Lindley 1980).

Spawning typically takes place in the spring at water temperatures of O to 7° C. Surface (O to 25 m) breeding swarms of T. raschii have been collected in several locations, including Alaska, during this spawning period. The duration of spawning is from two to three weeks, usually with a peak period in April or May, coinciding with the spring diatom bloom. Berkes (1976), however, found some evidence for a low level of spawning activity throughout the spring and summer, and Mauchline (1980) suggested that there might be a second spawning period in the fall in a few, favored locations. T. raschii have been reported to breed in the Beaufort Sea during the fall and early winter (Carey 1978). Falk-Petersen and Hopkins (1981) regard phytoplankton production as being more important than temperature in controlling spawning. This correlates well with the observed 1977 Beaufort Sea euphausiid densities. Distribution of T. raschii densities in excess of 100 animals per 1000 cubic meters match the areas in the Beaufort with high chlorophyll a concentrations and C^{14} uptake rates (Carey 1978).

The estimated fecundity Per T. raschii female during a breeding season is 300 to 400 eggs (Mauchline 1980); the eggs, however, are shed freely into the sea after fertilization and direct counts have not been made. The number of eggs produced is a function of the size of the female (Mauchline 1980). The eggs sink, then hatch, and the larvae migrate toward the surface. Larval euphausiids are mainly found in the top 15 to 25 m of water (Mauchline and Fisher 1969); however, as they mature, fewer and fewer are found there during daylight hours. The mortality of the egg and larval stages (nauplius, calyptopis, and furcilia) is calculated to be 98.2% (Lindley 1980).

Larvae in the Clyde Sea area become juveniles after three to four months (Mauchline 1966) and reproduction occurs the following spring. In Balsfjorden, on the other hand, the animals usually become sexually mature two years after birth, although a few mature one-year-old females have been found (Falk-Petersen and Hopkins 1981). Some Clyde Sea females reproduce in their second year as well. Thysanoessa populations from fjords in southeast Alaska have a similar lifecycle to the Balsfjorden population (Vogel, unpublished data). Beaufort Sea population are likely to be similar to those of Balsfjorden, although life history information for Beaufort Sea T. raschii is not available.

6.1.5 Feeding patterns and productivity of T. raschii

Thysanoessa raschii is almost exclusively an herbivore (Mauchline and Fisher 1969: Mauchline 1980). The growth of Thysanoessa in Balsfjorden, in terms of changes in carapace length, is closely related to primary productivity (Falk-Petersen 1981; Falk-Petersen and Hopkins 1981). Likewise, over 80% of the annual increase in individual size for Clyde Sea populations occurs between March and June during the spring diatom bloom (Mauchline 1966).

A second line of evidence for the herbivory of T. raschii hae recently been developed. Euphausiids store excess consumed food in the form of lipids. These lipids can be characterized by their source population and origin. As a consequence, the food habits by season for four euphausiid species, including T. raschii, have been described (Henderson, et al. 1982). During mid-winter T. raschii individuals in Balsfjorden lacked 20:1 and 22:1 fatty acids end wax esters (indicative of feeding upon calanoid copepods) while they were rich in 16:0 and 18:1 fatty acids and phytol, which are characteristic of phytoplankton (Sargent and Falk-Petersen 1981). It ie believed that the presence of phytol is indicative of detrital feeding during this period (Falk-Petersen, et al. 1982; Sargent and Falk-Petersen 1981). Apparently, neither T. raschii nor T. inermis fed upon Phaeocystis pouchetti, a major spring phytoplankton species in Balsfjorden, as their fatty acid composition was entirely different from this alga's (Falk-Petersen, et al. 1982).

Stomach content analyses of T. raschii indicate that this species eats detritus, phytoplankton (mainly diatoms and dinoflagellates) tintinnids and radiolarians (both microzooplankton) and that larger individual include Sagitta and small crustaceans in their diet (Mauchline 1980; Mauchline and Fisher 1969). Recently, Sameoto (1980a) found that T. raschii from the Gulf of St. Lawrence preferred to feed upon phytoplankton (except Chaetoceros atlanticum, a large, spiny diatom) and at night in the top 75 m of water. They also occasionally ate microzooplankton. Only 5% of the stomachs had copepod remains in them (as opposed to 90% of those of Meganyctiphanes norvegica, known to be carnivorous, and 22% of the stomachs of T. inermis). The highest frequency of copepod remains in the stomachs of T. raschii was during September when phytoplankton densities are low in boreal waters. Sameoto further reported that none of the stomachs of any of the three species he studied had bottom mud in them, unlike results from previous studies. Sameoto concluded that all three species preferred to feed in the water column when food was available. Daily calorie consumption in the Gulf of St. Lawrence by the average individual T. raschii was 3.1 calories during June, and 2.2 calories during December (Sameoto 1976b); this represented 1.5% of the daily phytoplankton production in June, and 60% in December.

Annual production of T. raschii is relatively uniform in the subarctic Atlantic. Lindley (1980) found that annual production for this species equalled 1.S4 mg dry weight (DW) per cubic meter off the Gulf of St. Lawrence, in the Bay of Fundy and in the Gulf of Maine, but only 1.02 mg DW m^{-3} in the central North Sea. In the Gulf of St. Lawrence proper, production of this species was 1.8 mg DW m^{-3} per year (Berkes 1977), while in Balsfjorden it was estimated to be about 1.9 mg m^{-3} yr^{-1} (Falk-Petersen 1981; Hopkins, et. al. 1978). Annual production measurements have not been made for this species in either the boreal North Pacific or the Arctic.

Individual specimens of T. raschii (Average dry weight = 10 mg) consume 1.8 µl of oxygen per hour per mg DW at 0 to 2 degrees C (Sameoto 1976b). Oxygen consumption per mg DW doubles between 5 and 15° C for T. inermis according to this study. As respiration rates for Thysanoessa raschii and T. inermis are not significantly different (Sameoto 1976b), a similar increase in metabolic rate should occur in T. raschii. Respiration rates also change with age of the animal due to the change in the surface area to body weight ratio (Harding 1977). About 6% of the total energy needs of this species is required for molting (Sameoto 1976b), much lower than the 38% necessary for molting by Euphausia superba (Ikeda 1984) or the 34% required by E. pacifica (Paranjape 1967).

6.1.6 Comparison of T. raschii and Euphausia superba

Euphausia superba is probably the single most abundant euphausiid in the world's oceans, and has been the subject of a large number of ecological studies. Comparisons of E. superba to T. raschii can increase our understanding of T. raschii biology and ecology.

E. superba occupies the same ecological niche as T. raschii . It is primarily an herbivore feeding on similarly sized particles (Boyde, et al. 1984) with similar lipid composition to T. raschii (Clarke 1984; Falk-Petersen 1981). E. superba, however, does not change to detritus feeding during the winter as do the Thysanoessa species, but rather the animals overwinter on their stored reserves, losing weight and literally shrinking throughout the winter (Ikeda 1984). Nor are its lipid reserves especially large for an animal of its size; shrinkage is the primary overwintering survival mechanism. The ecological similarity in these two animals' niches also extends to their importance as major food organisms for the pelagic food web in the region of the world's oceans where they occur (Laws 1985; Mauchline and Fisher 1966; Mauchline 1980).

Another similarity is schooling by the two species. Both species, like all euphausiids studied to date, form breeding swarms, and all species of euphausiids aggregate vertically to some extent (Mauchline 1980). Only eight or nine species, however, including both T. raschii and E. superba live in large, hollow feeding swarms outside of the breeding season (Brinton and Antezana 1984 ; Mauchline and Fisher 1966 ; Mauchline 1980). Behavior of E. superba feeding schools has now been directly observed by divers (Hamner 1984). T. raschii probably behaves similarly.

E. superba is a much larger animal than T. raschii (Average total length, or TL, of E. superba = 34 to 35 mm, Fevolden and George 1984; average TL of T. raschii = 22 to 25 mm, Mauchline and Fisher 1966). It also lives for up to 5 years (Ettershank 1984; Ikeda 1984: Marr 1962) instead of the two and a quarter of T. raschii . Annual growth and respiration rates are thus quite different for the two species. During the second year of life juvenile E. superba increase, on the average, from 2.3 mg DW to 30 mg DW (Ikeda 1984); by contrast, Juvenile T. raschii in Balsfjorden grow from 1.0 mg DW to 9.3 mg DW (Falk-Petersen 1981) . Growth rates in both species, however, are controlled by phytoplankton production (Falk-Petersen and Hopkins 1981:

Helm-Hansen and Huntley 1984). Juvenile *E. superba* (Average DW = 10 mg) have a respiration rate of 0.7 µl of oxygen hr^{-1} mg^{-1} DW at -1 to +1° C (Ikeda 1984), not the 1.8 1 per hr found by Sameoto (1976b) for *T. raschii* specimens of the same size and maturity.

Another difference between these two organisms is in their development. Due to the great depth from which the newly hatched *E. superba* nauplii must ascend (1200 to 2000 m, George 1984; Marr 1962), this species does not begin to feed until the first calyptopis stage (Brinton and Townsend 1984; George 1984; Ikeda 1984; Marr 1962: Mauchline and Fisher 1969). The first stage nauplius of *T. raschii* is an active phytoplanktivore by comparison. Since the larvae of both species are phytoplanktivorous, yet enter the surface waters after differing lengths of time for development, reproduction must be timed differently, possibly using different environmental cues.

6.1.7 Sensitivity of *T. raschii* to organic pollutants

Euphausiids have not been extensively used as bioassay organisms. Lee (1975). in a study of the effects of petroleum hydrocarbons upon marine zooplankton, included two euphausiids, *Euphausia pacifica* and *Thysanoessa raschii* , in his comparisons to two calanoid copepods, *Calanus plumchrus* and *C. hyperborealis* . Unfortunately, no specific values were given for the reactions of the two euphausiids. It may safely be inferred, however, that the euphausiids reacted similarly to the copepods when exposed to different hydrocarbons because, first, Lee commented on various differences he found using a hyperiid amphipod, *Parathemisto pacifica* , and second, Harding and Vass (1979) found similar uptake rates on a per mg DW basis by *T. raschii* and *Calanus finmarchicus* for DDT ingestion and clearance. According to Lee, most of the uptake by the copepods was within the first 24 hours and most of the clearance occurred within three days, although some remained after 28 days. Naphthalene, benzpyrene, and octadecane were successfully metabolized by the copepods. However, 500 ppb of Fuel Oil #2 caused copepod mortality and paralysis occurred at 200 to 500 ppb . Survival of copepod eggs was reduced from 75% to 40% in the presence of 80 ppb of either l-methyl naphthalene or 1,2-dimethyl naphthalene, but not in the presence of either naphthalene or mineral oil.

6.2 Effects of Crude Oil WSF on *T. raschii*.

6.2.1 Limitations of Experimental Data

Interpretation and discussion of the results from the tests described in this report must be carefully qualified. First, the euphausiids used for the tests were from a southeast Alaskan population of *T. raschii*; second, experimental temperatures were generally several degrees C higher than summer temperatures of water over the Alaskan Beaufort continental shelf; and, third, as explained in Section 6.3, the experimental concentrations of crude oil WSF and individual components may be quite different from those experienced in a real oil spill.

6.2.2 Laboratory Test Results

No test reports of the effects of crude oil WSF on euphausiids could be found in the scientific literature: the present study, therefore, represents an important contribution to the body of knowledge concerning oil fate and effects. The sensitivities of *T. raschii* life stages to oil WSF concentrations can be presented in terms of the highest "no effect" concentrations (Table 6-2). From this table, it is clear that larvae were the least sensitive, and gravid females were the most sensitive stage tested (gravid females were also the most sensitive to handling and shipping).[1] Juveniles seemed more resistant to effects of oil WSF then adults. The highest concentrations producing "no effect" on molt frequency were lowest for non-reproductive adults and highest for Juveniles.

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1. No data were obtained, however, for larval molt frequency.

TABLE 6-2

HIGHEST "NO EFFECT" WSF CONCENTRATIONS FOR *T. RASCHII* LIFE STAGES BASED ON SURVIVAL AND MOLT FREQUENCY

Test	Highest "no effect" concentration (mg/l)			
	Survival			Molt Frequency
	Day 4	Day 7	Day 10	End of Test
I. Adults	1.42	1.42	0.90	0.90
II. Gravid females	0.62	0.14	----	1.33
III. Larvae	>1.96	>1.96*	----	----
IV. Juveniles	1.63	1.63	0.74**	1.63

* Day 6
** Day 11

6.3 Comparison with Toxicity Data for other Marine Crustacea

A variety of marine crustaceans have been the subjects of laboratory bioassay tests using hydrocarbons. This discussion is focused on Alaskan species of crustacea.

6.3.1 General Considerations

Direct comparison of data generated from different tests, even of the same species, is difficult due to variation in experimental parameters. Static and flow-through tests yield different results because the hydrocarbon concentrations decrease with time during the static tests, and mixing methods may differ greatly. Exposure methods, chemical analyses, life stage and condition of test animals, and temperature are factors that can lead to differences in results and misinterpretation of data. In addressing these concerns, Rice et al. (1979, p. 552) concluded:

> "Consequently, there is little point in comparing animal sensitivities derived from experiments of different investigators, although the comparisons and conclusions within a study are usually valid."

We strongly agree with Rice et al. on the validity of comparisons between studies. It is obvious from Table 6-3 that the concentrations of aromatic hydrocarbons in undiluted WSF's of Prudhoe Bay crude oil used in this study were different from those measured by Rice et al. (1985) in their studies; concentrations in our study were lower for all aromatics reported. The relative proportions of the mono-aromatics (benzene, toluene, O-xylene) to total aromatics were similar between the studies: proportions of di-aromatics (naphthalenes) were lower in our study. Thus, even though the source of crude oil was the same (Prudhoe Bay), either the oil samples themselves, or the preparation of WSF's differed between studies.

The lack of oil WSF data for euphausiids, or any pelagic crustacean for that matter, forces us to use comparisons with other studies, using other species, for points of reference. With the preceding discussion in mind, these comparisons are not directly usable, but serve as general guidelines in the application of the _T. raschii_ bioassay data to real-world estimations. The published results of toxicity tests using Alaskan marine crustaceans and two types of Alaskan crude oil are presented in Table 6-4.

TABLE 6-3

BETWEEN-STUDY COMPARISON
OF AROMATIC HYDROCARBON CONCENTRATIONS

Component	Aromatic Hydrocarbon Concentrations (mg/l)			
	PBCO-WSF (a)	PBCO-WSF (b)	CICO-WSF (b)	Fuel Oil WSF (b)
Benzene	0.757 - 0.823	1.8	3.2	0.21
Toluene	0.698 - 0.819	2.0	2.5	0.17
o-xylene	0.068 - 0.081	0.28	0.35	0.12
m-p-xylene	0.129 - 0.149	0.58	0.78	0.17
Naphthalene	0.011 - 0.021	0.084	0.15	0.15
1-Methylnaphthalene	0.013 - 0.014	0.032	0.066	0.13
2-Methylnaphthalene	0.012 - 0.014	0.048	0.088	0.25
Ratio of all mono-aromatic to di-aromatic hydrocarbons	26.7 : 1 (b)	19.3:1	15.7:1	1.1:1

PBCO = Prudhoe Bay crude oil
CICO = Cook Inlet crude oil

(a) From this study, Test Series 2 (Tests II and III)

(b) From Rice et al. 1985; Table 2

TABLE 6-4

OIL SENSITIVITY DATA FOR ALASKAN MARINE CRUSTACEA

SPECIES (a)	OIL USED(b)	LC50 (ppm) (b)	REFERENCE	REMARKS
coonstripe shrimp, egg	CICO	}1.4(2C)	Rice, et al. 1985	96hr, flow-through
larva	PBCO	8.53(IR)	Rice et al. 1975	96hr, static
larva	CO	1.0(GC)	" "	" "
stage 1 larva	CICO	1.7(IR)	Brodersen, at al. 1977	96hr, static
adult	PBCO	1.96(IR)	Rice, et al. 197S	"
adult	CICO	2.72(IR)	Rim, et al. 1976	96hr, static
adult	CICO	1.4(GC)	" "	" "
adult	CICO	2.7(IR)	Brodersen, et al. 1977	96hr, static
gravid female	CICO	1.4(GC)	Broderson and Carls, in prep.	96hr, flow-through
humpy shrimp, adult	PBCO	1.26(IR)	Rice et al. 1975	96hr, static
adult	CICO	4.94(GC)	Rica at al. 1979	96hr, static
adult	CICO	2. 0(IR)	Brodersen, et al. 1977	96hr, static
stage 1 larva	CICO	1.7(IR)	" " "	" "
pink shrimp, adult	PBCO	2.11(IR)	Rice, et al. 197S	" "
adult	CICO	2.43(IR)	Rice, at al, 1976	96hr, stat ic
adult	CICO	4.94(GC)	Rice et al. 1979	96hr, static
dock shrimp, adult	CICO	0.01 (IR)	Rice, at al. 1975	96hr, static
kelp shrimp, adult	CICO	1.4(GC)	Rice, et al. 192S	96hr, flow-through
adult	CICO	1.86(GC)	Rice, at al. 1979	96hr, static
adult	CICO	0.95(IR)	Brodersen, et al. 1977	96hr, static
stage I larva	CICO	1.1(IR)	Brodersen, et al. 1977	96hr, static
scooter shrimp, adult	PBCO	1.94(IR)	" "	"
larva	PBCO	6.36(IR)		
adult	CICO	1.46(IR)	Rice, et al. 1976	" "
adult	CICO	4.3(IR)	Brodersen, et al. 1977	96hr, static
stage I larva	CICO	0.95(IR)	" " "	" "
grass shrimp, adult	CICO	0.87(GC)	Rice, et al. 1979	96hr, static
shrimp	CICO	0.67-1.26 (GC)	Rice, at al. 198S	96hr, flaw-through
pelagic crab and shrimp	CICO	1-5(GC)	Rice, et al. 192S	96hr, flew-through

TABLE 6-4 (continued)

crab	CICO	3D6-)10 (GC)	Rica, et al. 1985	96hr,	flea-thraugl!
king crab	PBCO	2.35(IR)	Rica, et al. 1975	96hr,	static
larva	PBCO	)6.4(IR)	" •	"	
adult	CICO	3.69(GC)	Rica, et al. 1979	96hr,	static
adult	CICO	4.2(IR)	Brodersen, et al. 1977	96hr,	static
stage I larva	CICO	0.96(IR)	' "	"	•
Tanner crab, larva	CICO	1.7(IR)	' "	"	•
purple chore crab	CICO	8.45(K)	Rica, et al. 1979	96hr,	static
hairy hermit crab	CICO	) 10. 58(GC)	" "	"	•
amphipod	CICO	)7.98(GC)	" "	"	"
mysid	CICO	)9.02(GC)	" "	"	"

(a): coonstripe shrimp (Pandalus hypsinotus)
humpy shrimp (Pandalus goniurus)
pink shrimp (Pandalus borealis]
dock shrimp (Pandalus danae)
kelp shrimp (Eualus suckleyi)
scooter shrimp (Eualus fabrici i)
grass shrimp (Crangon alaskensis)
king crab (Paralithodes camtschatica)
Tanner crab (Chionoecetes bairdii)
purple shore crab (Hemigrapsis nudus)
hairy hermit crab (Pagurus hirsuiticulus)
amphipod (Orchomene pinguis)
mysid (Acanthomysis pseudomacropsis)

(b): GC = gaa chromatography
IR = infrared spectrophotometry

All of the studies represented in the table used seawater soluble fractions of either Cook Inlet or Prudhoe Bay crude oil, and were either static or flow-through 96 hr tests. The concentrations of hydrocarbons were measured by either infrared spectrophotometry (IR) or gas chromatography (GC). IR analysis is more sensitive to paraffinic hydrocarbons than to aromatics: the aromatic components are generally agreed to be more toxic (Rice et al. 1977). Rice et al. (1979) discuss comparisons of IR and GC analyses, and conclude that comparisons cannot be made.

Hydrocarbon toxicity data for euphausiids are not available in the literature, so only comparisons with other crustaceans are possible. Shrimps and crabs, which comprise the bulk of data in the table, are in the order Decapoda, which, like the Euphausiacea, is a subgroup of the Superorder Eucarida. This taxonomic relationship somewhat validates comparisons betweeen the euphausiid T. raschii and various shrimps and crabs. The ecology of these species is also important to consider. Pelagic species tend to be more sensitive to hydrocarbons than benthic species, which in turn are more sensitive than intertidal species (Rice et al. 1985). Data for pelagic decapod larvae might be similar to data for euphausiid larvae.

6.3.2 Life Stage Sensitivities

The 96 hr LC_{50} data presented in Table 6-3 for shrimp species have the following ranges for life stages:

adults: 1.4 - 4.94 ppm (GC); 0.81 - 2.72 ppm (IR)

eggs: >1.4 ppm (GC) (one value only)

larvae: 1.0 ppm (GC) (one value only); 0.95 - 8.53 ppm (IR)

Values for adults of the crabs tested tended to be higher than the LC_{50}'s reported for adult *shrimp;* shore crab, hermit crab, mysid and amphipod LC_{50}'s were also generally higher than for adult shrimp.

The 96 hr LC_{50} values presented in this report for <u>T. raschii</u> were:

adults: > 2.06 ppm (GC)

gravid females: 1.33 - 1.96 ppm (GC)

1 arvae: > 1.96 ppm (GC)

juveniles: > 2.18 ppm (GC)

Several investigators have examined the sensitivities of shrimp life stages to oil WSF levels. Broderson and Carls (in preparation) found that eggs of coonstripe shrimp (*Pandalus hypsinotus*) end kelp shrimp (*Eualus suckleyi*) survived exposure to oil WSF if the females carrying them survived; further, larvae hatched from these eggs were physiologically more resistant to the WSF than females. Eggs from weak and dying females hatched into swimming larvae, leading the authors to conclude that the shrimp eggs were more tolerant to WSF than adult females. Since eggs of these species are carried by the female until hatching, the LC_{50}'s of the females were considered to be the important values in a real-world situation. Eggs of *T. raschii*, on the other hand, are shed into the water before hatching, and, if more resistant to oil WSF than females, may have better survival than the adults in a spill situation.

Larval shrimp and crabs are generally considered more sensitive to oil WSF than adults. First stage larvae of four shrimp species were "somewhat more sensitive" than adults in tests conducted by Broderson et al. (1977) . Each of several coonstripe shrimp larval stages (I - VI) tested by these investigators had a different sensitivity to oil WSF , ranging from 0.24 ppm for Stage VI, to 1.9 ppm for Stage IV larvae. Larvae were considered more vulnerable perhaps due to their rapid growth and frequent molting. Mecklenberg et al. (1977) found that molting larvae of king crab (*Paralithodes camtschatica*) and coonstripe shrimp were 4 to 8 times *more* sensitive to oil WSF than intermolt larvae. Exposure of molting larvae to 1.15 - 1.87 ppm WSF (IR) for as little as 6 hours reduced molt success by 10-30%, with some mortality resulting; while exposure for 24 hours or longer reduced molting success by *90-100%*, with death usually resulting. The lowest WSF test concentrations (0.15-0.55 ppm) resulted in no reduction of molting; however, many exposed larvae died after molting.

The results of tests with *T. raschii*, presented in this report, provide important information not previously available in the scientific literature. Larval *T. raschii* were found less sensitive to oil WSF than adult or Juvenile animals. Gravid female *T. raschii* appeared to be the most sensitive of life stages tested. Unfortunately, meet gravid females held in the laboratory re-absorbed their eggs before or during the bioassay tests, so data were not generated for the effects of WSF on egg survival or hatching *success*. The LC_{50}'s for *T. raschii* are within the range of GC-derived LC_{50}'s for shrimp species presented in Table 6-3 (1.4 - 4.94

ppm) and pelagic crabs and shrimp (1-5 ppm); however, these cited values are from teats using Cook Inlet crude oil, and most were static bioassays.

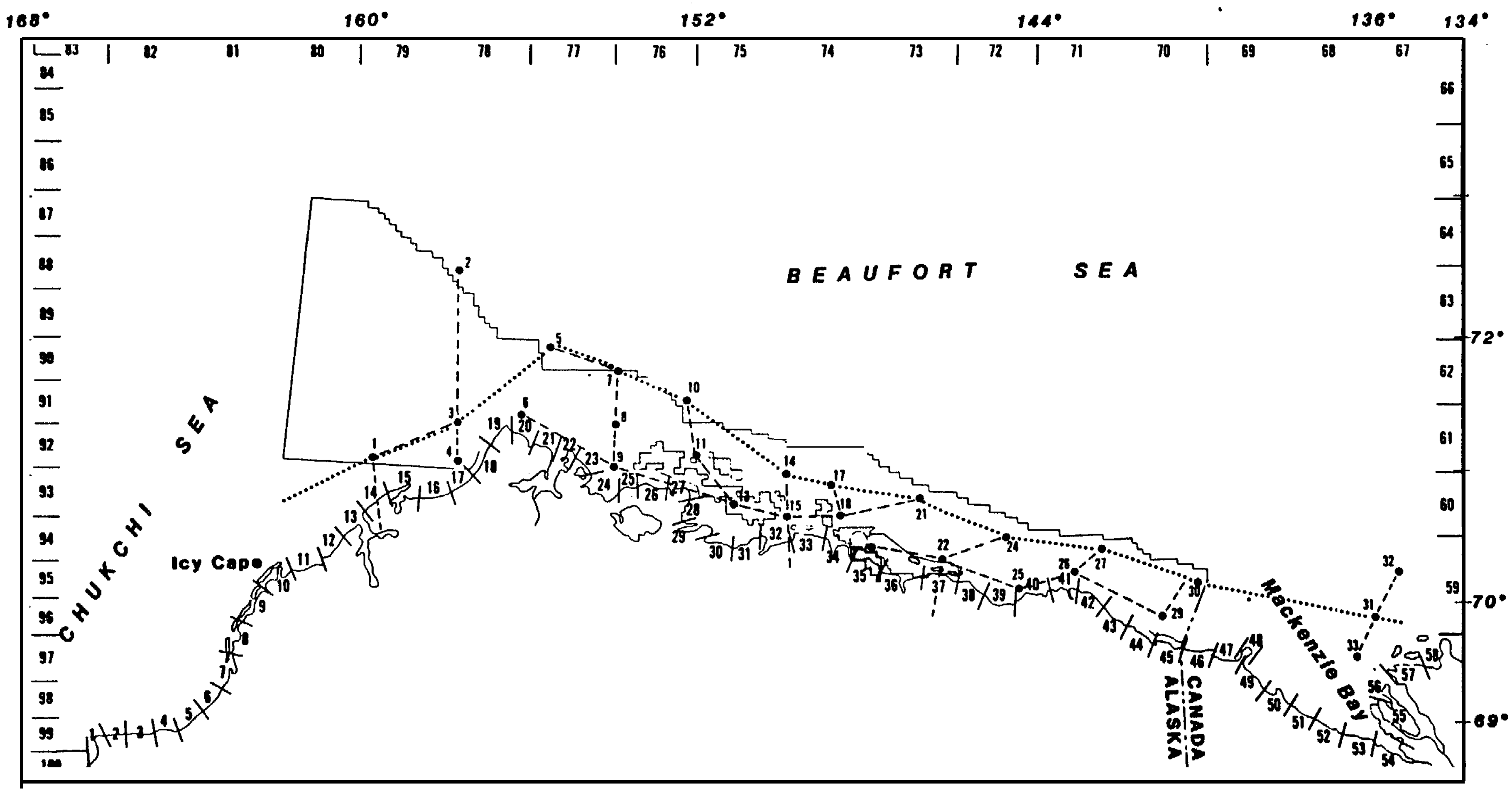
6.4 Estimates of Oil Spill Impacts to *T. raschii* Populations

6.4.1 Oil Spill Risk Analysis

An oil spill risk analysis was prepared for the southern Alaskan Beaufort Sea as part of the Environmental Impact Statement for the Diapir Field Lease Offering (MMS 1984). Review of this analysis is instructive in relation to the potential effects of oil spills on euphausiid populations. Primarily, the analysis was helpful in determining areas of high vulnerability to oil spill effects, and seasonal considerations.

Figure 6-2 shows the oil transportation routes and spill launch points used in the risk analysis. Probability estimates resulted in a total expected number of spills of 29.3 over the 40 year life of the Diapir Field: this total includes 7.8 spills expected from the proposed developments, 8.9 spills from existing leases, and 12.6 spills from production and transportation of Canadian oil in the eastern Beaufort. A 99+% chance of one or more spills of 1,000 barrels (bbl) or greater and of 10,000 bbl or greater was predicted.

Oil spill trajectory simulations were run for both the ice covered (winter) and open water (summer) seasons. The assessment of impacts to sea bird habitats included open water areas used for feeding. As seen from Figure 6-3. the area identified as the Bering Sea Intrusion has the highest probability (40+%) of oil spill contact when compared with other seabird areas. This probability approaches 60% when spills from existing leases are included. Winter spills contribute a significant amount to these probabilities. Oil spilled beneath ice cover will essentially become encapsulated in the ice, and oil trajectories thus become ice trajectories. Breakup and thaw of ice cover will release essentially fresh oil to the water. Because of the net westward flow of ice and surface currents in the nearshore Alaskan Beaufort, oil spills during winter east of Barrow become factors in spill contact risk probabilities for the Barrow area, including the Bering Sea Intrusion. The Bering Sea Intrusion area is important seabird feeding habitat as well as bowhead whale migration (and seasonal feeding) area (Figure 6-4).



DIAPIR FIELD LEASE OFFERING (June 1984)

TRACTS PREVIOUSLY LEASED

| 41 | LAND AND BOUNDARY SEGMENTS

ENDICOTT RESERVOIR

● LAUNCH POINTS (including platforms)

●- -● PIPELINES

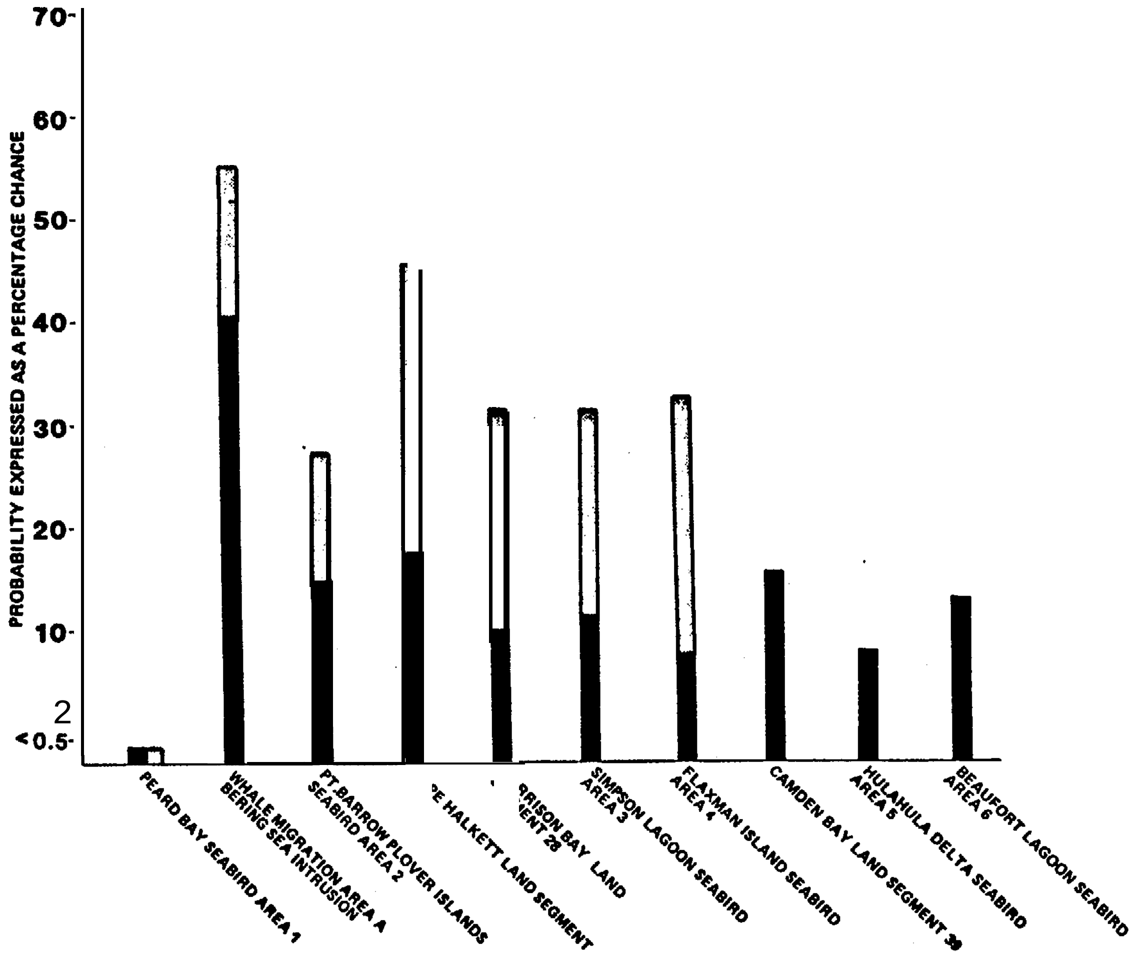
······ TANKER ROUTES

Source: MMS (1984). Diapir Field Lease Offering FEIS Figure IV-1

EFFECTS OF OIL ON FOOD ORGANISMS OF THE BOWHEAD WHALE
NOAA/OCSEAP RU 662

STUDY AREA, LAND AND BOUNDARY SEGMENTS, TRANSPORTATION ROUTES AND SPILL LAUNCH POINTS HYPOTHESIZED IN OILSPILL RISK ANALYSIS

FISHMAN ENVIRONMENTAL SERVICES | 1985 | **FIGURE 6-2**



Proposal

Proposal plus..ittirql.wing

PROBABILITY WITHIN 10 DAYS FOR OPEN-WATER SEASON OVER THE EXPECTED PRODUCTION LIFE OF THE LEASE AREA

Source: MMS (1984). Diapir Field Lease Offering FEIS Figure Iv-7

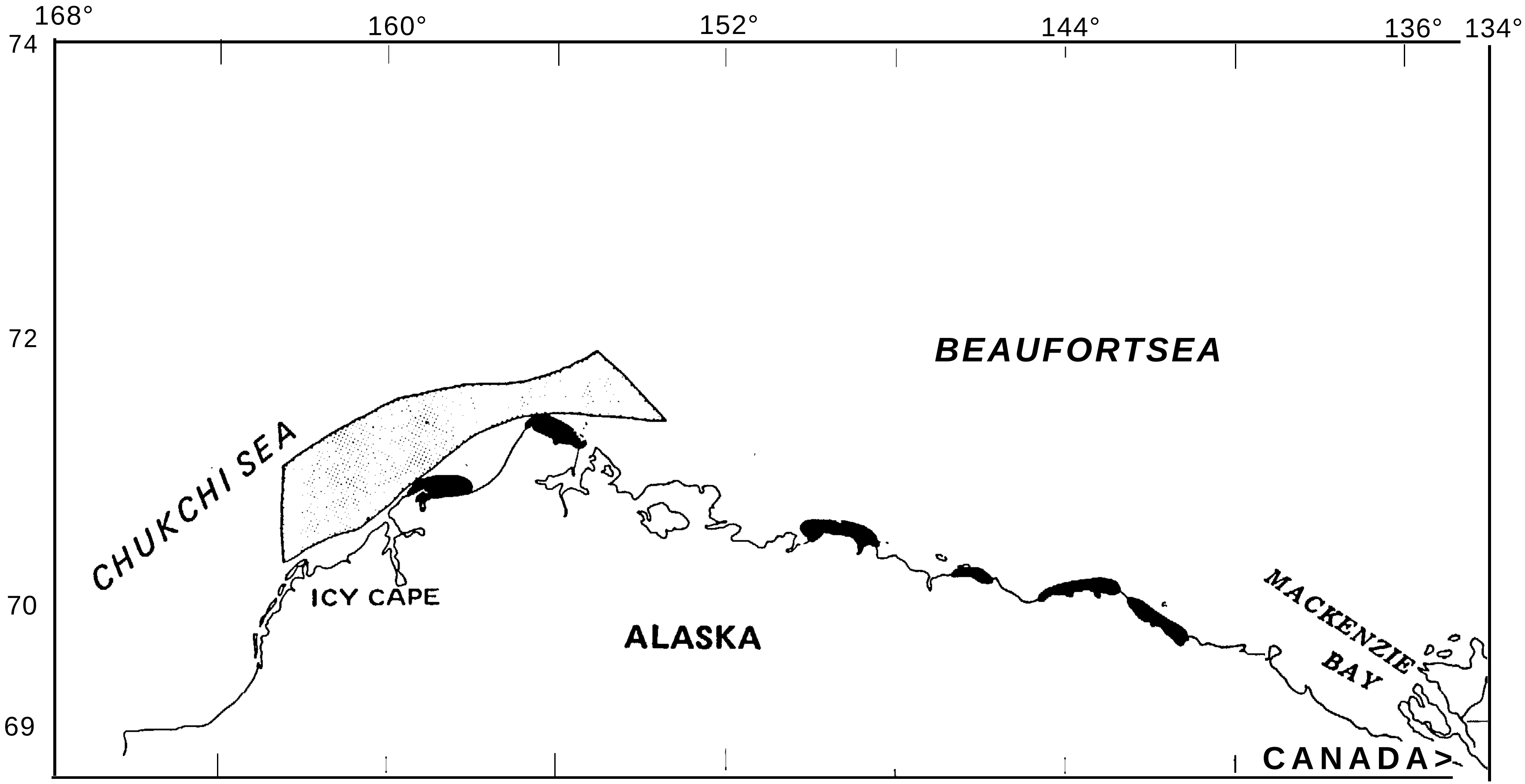
EFFECTS OF OIL ON FOOD ORGANISMS OF THE BOWHEAD WHALE
NOAA/OCSEAP RU 662

PERCENTAGE PROBABILITY OF ONE OR MORE SPILLS OF 1,000 BARRELS AND GREATER OCCURRING AND CONTACTING BIRD HABITATS

FISHMAN ENVIRONMENTAL SERVICES

1985

FIGURE 6-3



WHALE MIGRATION AREA (**Bird** Offshore Feeding **Area**)

SEABIRD FEEDING AND CONCENTRATION AREAS

Source: MMS (1984) Diapir Field Lease Offering FEIS Figure IV-9

EFFECTS OF OIL ON FOOD ORGANISMS OF THE BOWHEAD WHALE
NOAA/OCSEAP RU 662

WHALE MIGRATION AND SEABIRD FEEDING AND CONCENTRATION AREAS

'FISHMAN ENVIRONMENTAL SERVICES

1985

FIGURE 6-4

The Diapir Field EIS regarded the effect of oilspills on plankton communities to be MINOR in all cases except uncontrolled blowouts, in which case effects could be MODERATE. [2] The FEIS also concluded that contamination or loss of seasonally abundant crustaceans in the Bering Sea intrusion due to an oilspill could substantially increase sea bird mortality during the fall migration due to reduction in food resource. It was also concluded that detrimental changes in zooplankton biomass relative to bowhead whale feeding requirements would be unlikely even from a major oil spill; primarily because of plankton patchiness and rapid repopulation of plankton communities. During heavy ice years, however, when food could be limiting to vertebrate consumers, increased competition among vertebrates for reduced zooplankton populations could force bowhead whales to rapidly leave the Alaskan Beaufort and rely on stored nutrients (MMS 1984).

6.4.2 Selection of Worst Case Parameters

The use of a "worst case" situation requires some qualification. Estimation of worst case conditions relies heavily on the use of assumptions, particularly in the present study where important data are non-existent. A number of oil spills have been thoroughly documented in the past, and data are available describing the spread of oil and effects to biological units. Each spill is different, however, beginning with the characteristics of the oil involved, the general oceanographic patterns in the spill area, the population structures of biological components, and such fine-scale particulars as the weather on the day of the spill.

The attempt in the following sections is to build "worst case" situations that are based on reality: the realitiy of the Beaufort Sea and our knowledge of its environmental and biological variables. Thus, while WSF concentrations, for example, recorded during historical spills may have reached 10 or 20 ppm, the potential levels estimated for the Beaufort Sea scenarios are much less, based on experimental models.

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2. MINOR impact: A specific group of individuals of a population in a localized area and over a short time period (one generation) is affected. MODERATE impact: A portion of a regional population changes in abundance and/or distribution over more than one generation, but is unlikely to affect the regional population.

and modeling work for the Bering Sea.

Two oil spill scenarios were provided by NOAA for this assessment, with instructions to consider a "worst case" situation. The provided scenarios defined the type, duration and coverage of spills, but not the location or season. A worst case location and season therefore needed to be selected.

As indicated previously, distribution and abundance data for T. raschii are relatively non-existent for the Beaufort Sea. The evidence provided from bird and mammal studies, however, points to the area of the Bering Sea Intrusion, off Barrow, as a major feeding area for birds and mammals that are known to consume euphausiids. Work in the Canadian Beaufort indicates that zooplankton are more abundant in nearshore areas, especially areas of mixing between coastal and offshore waters (ESL 1982). In discussing the Beaufort Undercurrent (= Bering Sea Intrusion), Aagaard (1984) concluded that cross shelf flow is frequent, and links the Beaufort Undercurrent with the nearshore. For these reasons, and the results of spill contact probability presented above, the Bering Sea Intrusion area off the Plover Islands was selected as the location for a worst case spill event.

Consideration of seasons indicated that August-September would be a worst case time for a spill event. Zooplankton abundance is likely to be at its peak during this time, following the open water phytoplankton maximum. Again, bird and mammal studies indicate that large concentrations of sea birds and bowhead whales utilize the Bering Sea Intrusion area and nearshore waters east of Barrow during this time period. The observed die-off of euphausiids subsequently washed up on the Plover Islands was also during this period.

6.4.3 Oil Spill Scenarios and Impact Estimates

The information and integrations required for estimation of oil spill impacts to T. raschii are outlined below:

1. Hypothetical Oil Spill Parameters

    1. Time of year

    2. Location

    3. Quantity

4. Duration

2. Literature Review Data

   1. Hydrographic/oceanographic characteristics

   2. Behavior of hydrocarbons in seawater

   3. Biology of target species

   4. Distribution/abundance of target species

3. Experimental Results

   1. Lethal effects of WSF on target species

   2. Sublethal effects of WSF on target species

4. First Level Estimates

   1. Oil spill transport

   2. WSF distribution/concentration in water column

5. Second Level Estimates

   1. Estimate of direct mortality to target species life stages

   2. Estimate of changes in fertility/fecundity of target species population

6. Third Level Estimates

   1. Estimate of target species population losses and probable recovery potential

Two oil spill scenarios were presented for this analysis. Each scenario is detailed below in the format presented in the previous outline.

Scenario 1

Oil Spill Parameters

Time of year: late August - early September

Location: Bering Sea Intrusion off Plover Islands

Quantity: 200,000 bbl Prudhoe Bay crude oil

Duration: Instantaneous; area covered and concentrations maximum for 96 hours

Literature Review Data

Hydrographic/oceanographic characteristics: open water; nearshore wind-driven westerly currents (MMS 1984); exchange with Bering Sea Intrusion water possible (Aagaard 1984).

Hydrocarbon behavior in seawater: maximum concentrations in water column from dissolution = 0.6 ppm at 0-2 m depth, 0.2 ppm at 2-7 m depth, 0.1-0.01 ppm at >7 m depth (Thorsteinson 1984).

Water column dynamics: stratified, thermo-haline (assumed)

Distribution/abundance of *T. raschii*: unknown; maximum recorded density in Beaufort Sea = 510/1000 cu m; high seasonal densities assumed from bird and mammal research.

Biology of *T. raschii*: time of spawning unknown; fecundity = 300-400 eggs/female; eggs shed into water, sink, larvae ascend toward surface; natural mortality of eggs and larvae estimated at 98.2%; sexual maturity at age 2 (some at age 1) in Balsfjorden, Norway; euphausiids very motile, fast; form large breeding swarms, and possibly large feeding swarms (as in *Euphausea superba*).

Experimental Results

Lethal effects of WSF: 96 hr LC_{50}'s = adults: >2.06 ppm; gravid females: 1.37 ppm; larvae: >1.96 ppm; juveniles: >2.18 ppm.

Sublethal effects of WSF: longer intermolt period for adults: ≥1.41 ppm; gravid females: >1.96 ppm; juveniles: ≥2.18 ppm. Observations suggested that animals exposed to >0.5 ppm were less healthy.

First Level Estimates

The scenario parameters provided by NOAA included the maxima of sea surface areal coverage by the slick and concentrations in the water column remaining steady over a 96 hr period. Maximum spill areal coverage is assumed to be 168 sq km, with WSF concentrations greater than 0.01 ppm in an area of 407 sq km. These scenario parameters were developed and presented in the North Aleutian Shelf Synthesis report (Thorsteinson 1984). The highest concentration of WSF observed in experimental situations or predicted by spill dissolution models was 0.6 ppm. Therefore, for the First Level Estimate, an instantaneous spill of 200,000 bbl (perhaps from a tanker accident) covers 168 sq km in the area of the Bering Sea Intrusion off Plover islands, with WSF concentrations reaching a maximum of 0.6 ppm in the top few meters of the water column.

Second Level Estimates

Direct mortality of eggs, larvae or adult T. raschii is not expected as a result of this hypothetical spill. Although LC_{50} values are not available for eggs, they would likely not be exposed to hydrocarbons due to their sinking. Larval stages would probably be at the greatest risk of maximum exposure due to their ascent toward surface water; however, our tests indicate that the larvae are least sensitive to WSF of life stages tested. Adult euphausiids could certainly avoid contaminated waters if, in fact, they can detect and are repulsed by hydrocarbons. Adults, however, are not expected to be in the surface layers except, perhaps, when in breeding swarms. (Adult T. raschii in subarctic waters and in Arctic fjords of Norway are known to be vertical migrators, having little *if any* contact with surface waters. The behavior of Beaufort population, however, especially in nearshore waters, is unknown, and may prove very different.) The group at highest risk, in terms of direct mortality, is gravid females, with the highest "no effect'* WSF concentration for survival (Table 6-2) *being at* the same level as maximum WSF concentration expected during the spill scenario. Mortalities could be experienced in this group if individuals were in the surface 2 m of water for 96 hours; however, the expected concentrations are the bottom threshold for mortality. Mortality to gravid females would potentially decrease the fecundity of the local population; however, this impact is considered very minor in terms of impacts to future populations due to the high natural mortality rate of euphausiid eggs and larvae (98+%) and the mobility of local populations. The success of any particular euphausiid year class in a specific locality is more dependent on transport of individuals into the area from outside.

Indirect mortalities are quite likely as a result of increased predation on narcotized or weakened animals if they are exposed to near-surface concentrations of hydrocarbons. Interruption of molt frequency was noted at high WSF concentrations, some animals may experience this effect near the surface. The extent of these indirect mortalities and sublethal effects is impossible to estimate. estimate.

Third Level Estimates

The impact of this hypothetical oil spi11 would be NEGLIGIBLE to MINOR; that is, the greatest impact would be that a specific group of individuals of a population in a localized area over a short period of time would be affected. Population losses would likely be minimal, if any. Any effects would not be carried through to the next generation due to the replenishment of localized populations from surrounding areas. The Bering Sea Intrusion might act as a dispersal pathway for Bering Sea populations, which would seed the populations in the Beaufort Sea; euphausiid populations east of Barrow would also be dispersed into the spill area.

Scenario 2

Oil Spill Parameters

Time of year: late August - early September

Location: East of Bering Sea Intrusion off Plover Islands

Quantity: 2,000 bbl/day Prudhoe Bay crude oil

Duration: Continuous; 5 days

Literature Review Data

Hydrographic/oceanographic characteristics: open water; nearshore wind-driven westerly currents (MMS 1984); exchange with Bering Sea Intrusion water possible (Aagaard 1984).

Hydrocarbon behavior in seawater: maximum concentrations in water column from dissolution = 0.6 ppm at O-2 m depth, 0.2 ppm at 2-7 m depth, 0.1-0.01 ppm at >7 m depth; maximum concentration under slick from source to 2 km downwind = 0.6S ppm (Thorsteinson 1984).

Water column dynamics: stratified, thermo-haline (assumed); wind-driven westerly surface current.

Distribution/abundance of _T. raschii_: unknown; maximum recorded. density in Beaufort Sea = 510/1000 cu m; high seasonal densities assumed from bird and mammal research.

Biology of _T. raschii_: time of spawning unknown; fecundity = 300-400 eggs/female; eggs shed into water, sink, larvae ascend toward surface; natural mortality of eggs and larvae estimated at 98.2%; sexual maturity at age 2 (some at age 1) in Balsfjorden, Norway; euphausiids very motile, fast; form large breeding swarms, and possibly large feeding swarms (as in _Euphausea superba_).

Experimental Results

Lethal effects of WSF: 96 hr LC_{50}'s = adults: >2.06 ppm; gravid females: 1.37 ppm; larvae: >1.96 ppm; juveniles: >2.18 ppm.

Sublethal effects of WSF: longer intermolt period for adults: ≥1.41 ppm; gravid females: >1.96 ppm; juveniles: ≥2.18 ppm. Observations suggested that animals exposed to >0.5 ppm were less healthy.

First Level Estimates

The scenario parameters provided by NOAA indicate a slick size of 100 sq km, and an area of 0.8 sq km with WSF concentration greater than 0.01 ppm. These scenario parameters were developed and presented in the North Aleutian Shelf Synthesis report (Thorsteinson 19843. The highest concentration of WSF observed in experimental situations or predicted by spill dissolution models was 0.6 ppm. Therefore, for the First Level Estimate, a continuous spill of 2,000 bbl/day (perhaps from a well blowout) covers 100 sq km in the area of the Bering Sea Intrusion off Plover Islands, with WSF concentrations reaching a maximum of 0.65 ppm in the top few meters of the water column.

Second Level Estimates

The Second Level Estimate for this scenario is the same as for Scenario 1. Direct mortalities to *T. raschii* are not anticipated, or are very minor (NEGLIGIBLE).

Third Level Estimates

The Third Level Estimate for this spill scenario is the same as for Scenario 1.

7. RECOMMENDATIONS FOR FURTHER STUDIES

Several studies are recommended to further the knowledge of *T. raschii* ecology, interactions with the Arctic environment, and responses to hydrocarbons in the environment.

7.1 Ecology of *T. raschii* in the Alaskan Beaufort Sea

7.1.1 Distribution of *T. raschii* in the Alaskan Beaufort Sea

Objective. This study would describe the spatial and temporal distributions of *T. raschii* in the Alaskan Beaufort Sea, with an emphasis on nearshore and offshore waters proposed for oil and gas development. Few data presently exist concerning the distribution of this species, thus, predictions of effects of development are speculative. Diel vertical distribution is also included in the scope of this study.

Proposed Methods. Data collection should consist of acoustical surveys and net samples in specific areas during open water seasons. Attempts should be made to obtain acoustic data from the U.S. Navy for ice-covered seasons. The study design should also include following large euphausiid swarms over a several day period to describe daily distributions. Data would be analyzed and summarized to show diel and seasonal distribution.

Schedule. The study should be conducted over a period of 2 to 3 years to determine year-to-year variability.

7.1.2 Relative Abundance of *T. raschii* in the Alaskan Beaufort Sea

Objectives. The relative abundance of *T. raschii* is little known for the Beaufort Sea. Standard plankton sampling methods usually underestimate euphausiid abundance due to the inefficiency of sampling equipment. The lack of abundance data restricts the ability of investigators to estimate regional biomass, and thus, the role of euphausiids in Arctic trophic dynamics. Abundance relative to other zooplankters is also important in studies of vertebrate consumer feeding; for example, bowhead whales are thought to consume more copepods in the eastern Beaufort and more euphausiids in the western Beaufort.

Proposed Methods. Techniques for estimating density and biomass of euphausiid swarms have been developed and used in the Antarctic. Acoustics and net samples are used in this work.

Schedule. The study should be conducted during open water. Euphausiid swarms should be sampled opportunistically when they are encountered.

7.1.3 Life History Studies of Beaufort Sea Euphausiids

Objectives. No data exist describing the life history of *T. raschii* in the Alaskan Beaufort. Data collected should include: distribution (spatial and temporal) of eggs and larvae; timing of larval development; growth rates, including over winter; sex ratios of local populations or swarms; timing of spawning, and annual productivity. These data are needed in order to understand and predict the distribution, abundance and behavior of euphausiids, especially in relation to vertebrate consumer distributions, and potential oil development impacts.

Proposed Methods. Plankton sampling should be scheduled once or twice per month in specific areas in order to track the development of life stages. Samples should also be obtained from past or present feeding studies of fish, birds and marine mammals known to eat euphausiids. Major wash-ups, such as those described on the Plover Islands, should be sampled to determine age and reproductive condition of beached euphausiids.

Schedule. The study should be conducted through two consecutive open water seasons.

7.2 Study of the Bering Sea Intrusion Near Pt. Barrow

Objectives. The Bering Sea Intrusion may be an important feature of the western Beaufort Sea related to biological productivity. Seasonal concentrations of bowhead whales, sea birds, and other vertebrates have been described in the area. Oceanographic conditions in the area may be related to swarms of euphausiids and other plankters. The importance of this area, and its vulnerability to oil spill effects, needs to be assessed. The study would examine oceanographic conditions and related biological events in the area of the Bering Sea Intrusion.

Proposed Methods. CTD casts would be made along transects in order to describe the characteristics and distribution of intrusion water and other masses. Concurrent samples of chlorophyll, phytoplankton and zooplankton would be collected. Data would be synthesized to determine relationships between water masses and productivity, species composition and diversity.

Schedule. The study should be conducted over a period of several years in order to assess year-to-year variability.

7.3 Detection of and Reaction to Hydrocarbon WSF by *T. raschii*

-Objectives. Many oil effects estimates involving marine animals assume that the organism in question will be exposed to hydrocarbons if they co-occur in the water column. Few studies have examined the physiological and behavioral responses of organisms to oil in water. This study would examine the ability of T. raschii to detect crude oil WSF at various concentrations,'-and the behavioral responses to these levels. Results will add important information for future assessments of oil spill effects on euphausiid populations.

Proposed Methods. Laboratory experiments will be designed to test the detection ability of euphausiids for crude oil WSF. Once detection levels are established, additional experiments will be conducted to determine the behavioral responses of euphausids to these WSF concentrations. Possible behavioral indices might include: repulsion and flight, attraction, changes in feeding behavior, changes in locomotor behavior, changes in responses to environmental stimuli such as light, pressure and temperature.

Schedule. No specific schedule is proposed.

7.4 Additional Oil WSF Bioassays with *T. raschii*

Objectives. Additional bioassay experiments are proposed for *T. raschii* to complement the results of the present study. Important data not obtained from the present study included some longer-term effects of oil WSF. The reproductive success of adults exposed for 96 hours was not determined. It was concluded that adults (except gravid females) were fairly tolerant to all but the highest concentrations of

WSF ; however, the subsequent reproductive success of these animals was not determined. Another long-term effect might be the survival of animals exposed to WSF for 96 hours as larvae. Larvae were found to be highly tolerant to WSF, but subsequent survival might be affected. Larval molt frequency and egg survival also need testing.

Proposed Methods. Experiments will be designed in which larval and adult *T. raschii* will be exposed to various levels of crude oil WSF for 96 hours. Test animals will then be cultured in clean water and survival compared with control groups. The reproductive success of females will also be determined relative to control animals (assuming females will breed in the laboratory situation).

Schedule. A specific schedule is not proposed for this study .

8. LITERATURE CITED

Aagaard, K. 1904. The Beaufort undercurrent. In: P.W. Barnes, D.M. Schell and E. Reimnitz (eds.). The Alaskan Beaufort Sea: Ecosystems and Environments. Academic Press, Inc. Orlando.

Bary, B. Mck., W.E. Barraclough and S?. Herlinveaux. 1962. Scattering of underwater sound in Saanich Inlet, British Columbia. Nature 194: 36-37.

Berkes, F. 1976. Ecology of euphausiids in the Gulf of St. Lawrence. J. Fish. Res. Bd. Canada 33: 1894-1905.

_____. 1977. Production of the euphausiid crustacean Thysanoessa raschii in the Gulf of St. Lawrence. J. Fish. Res. Bd. Canada 34: 443-446.

Boden, B.P. and E.M. Kampa. 1964 An aspect of euphausiid ecology revealed by echo-sounding in a fjord. Crustacean 9: 155-173.

Bodfish, H.H. 1936. Chasing the bowhead. Harvard Univ. Press, Cambridge, Mass.

Boyde, C.M., M. Heyraud and C.N. Boyd. 1984. Feeding of the Antarctic krill Euphausia superba. J. Crust. Biol. 4(Sp.No.1): 123-141.

Braham, H.W., B.D. Krogman, and G. Carroll. 1983. Bowhead whale (Balaena mysticetus) migration, distribution, and abundance in the Bering, Chukchi, and Beaufort Seas, 1975-1978, with notes on the distribution and life history of white whales (Delphinapterus leucas). U.S. Dept. Commer., NOAA, OCSEAP. Final Rep. 20: 75-170.

Brinton, E. 1962. The distribution of Pacific euphausiids. Bull. Scripps Inst. Oceanogr. 8: 51-270.

----- and T. Antezana. 1984. Structures of swarming and dispersed populations of krill (Euphausia superba) in Scotia Sea and South Shetland waters during January-March 1981, determined by bongo nets. J. Crust. Biol. 4(Sp. No.1): 45-66.

----- and A.W. Townsend. 1984. Regional relationships between development and growth in larvae of Antarctic krill, Euphausia superba, from field samples. J. Crust. Biol. 4(Sp.No.1): 244-246.

Brodersen, C.C., S.D. Rice, J.W. Short, T.A. Mecklenburg, and J.F. Karinen. 1977. Sensitivity of larval and adult Alaskan shrimp and crabs to acute exposures of the water-soluble fraction of Cook Inlet crude oil. Pp. 575-578 in: API, EPA, and USCG, 1977 Oil Spill Conference (Prevention Behavior, Cont rCleanup), Proceedings. American Petroleum Institute. Washington, D.C.

Broderson, C.C. and M.G. Carls. In preparation. Sensitivity of egg, larval and adult coonstripe shrimp (Pandalus hypsinotus) to long-term exposure to the water-soluble fraction of Cook Inlet crude oil. Abstracted in: Rice et al. 1985.

Bruce, H.E., McLain, D.R., and B.L. Wing. 1977. Annual Physical and Chemical Oceanographic Cycles of Auke Bay, Southeastern Alaska.NOAA Tech. Rept. NMFS SSRF-712.

Carls, M.G. and S.D. Rice. 1980. Toxicity of oil-well drilling muds to Alaskan larval shrimp and crabs. NOAA/OCSEAP RU 72, Final Report, 18 Dec. 1980.

Carey, A.G., Jr. (cd.) 1978. Environmental Assessment of the Alaskan Continental Shelf, Beaufort/Chukchi Interim Synthesis Report, NOAA/OCSEAP.

Clarke, A. 1984. Lipid content and composition of Antarctic krill, Euphausia superba Dana. J. Crust. Biol. 4(Sp.No.1): 285-294;

Clarke, W.D. 1971. Comparison of different investigative techniques for studying the deep scattering layers. In: G.B. Farquhar (cd.). Biological Sound Scattering in the Ocean, pp. 550-562.

Cooney, R.T. 1977. Zooplankton and micronekton studies in the Bering-Chukchi/Beaufort Seas. NOAA/OCSEAP RU 426, Annual Report.

Craddock, D.R. 1977. Acute toxic effects of petroleum on Arctic and Subarctic marine organisms. In: D.C. Malins (cd). Effects of Petroleum on Arctic and Subarctic Marine Environments and Organisms. Vol. II: Biological Effects. Academic Press, New York.

Craig, P.C. 1984. Fish use of coastal waters of the Alaskan Beaufort Sea: A review. Trans. Amer. Fish. Soc. 113: 265-282.

Craig, P.C. and P. McCart. 1976. Fish use of nearshore coastal waters in the western Arctic: emphasis on anadromous species. In: D.W. Hood and D.C. Burrell (eds.). Assessment of the Arctic Marine Environment: Selected Topics. Univ. of Alaska. Institute of Marine Science. Occas. Publ. No. 4. Fairbanks, AK.

Craig, P.C., W.B. Griffiths, L. Haldorson, and H. McElderry. 1982. Ecological studies of Arctic Cod (Boreogadus saida) in Beaufort Sea coastal waters, Alaska. Can. J. Fish. Aquat. Sci. 39: 395-406.

Divoky, G.J. 1984. The pelagic and nearshore birds of the Alaskan Beaufort Sea: biomass and trophies. In: P.W. Barnes, D.M. Schell and E. Reimnitz (eds.). The Alaskan Beaufort Sea: Ecosystems and Environments. Academic Press, Inc.

Eilertsen, H.C., S. Falk-Petersen, C.C.E. Hopkins and K. Tande. 1981. Ecological investigations on the plankton community of Balsfjorden, northern Norway. Program for the project, study area, topography, and physical environment. Sarsia 66: 25-34.

ESL Environmental Sciences, Ltd. 1982. Biological impacts of three oil spill scenarios in the Beaufort Sea. Pallister Resource Management, Ltd. Ontario.

Ettershank, G. 1984. A new approach to the assessment of longevity in the Antarctic krill Euphausia superba. J. Crus. Biol. 4(Sp.No.1): 295-305.

Falk-Petersen, S. 1981. Ecological investigations *on* the zooplankton community of Balsfjorden, northern Norway: seasonal changes in body weight and the main biochemical composition of Thysanoessa inermis (Kroyer), T. raschii (M. Sars), and Meganyctiphanes norvegica (M. Sars) in relation to environmental factors. J. Exp. Marine Biol. Ecol. 49: 103-120.

_____ and C.C.E. Hopkins. 1981. Ecological investigations on the zooplankton community of Balsfjorden, northern Norway: population dynamics of the euphausiids Thysanoessa inermis (Kroyer), T. raschii (M. Sars) and Meganyctiphanes norvegica (M. Sars) in 1976 and 1977. J. Plankton Res. 3: 177-192.

--___, J.R. Sargent, C.C.E. Hopkins, and B. Vaja. 1982. Ecological investigations on the zooplankton community of Balsfjorden, northern Norway: lipids in the euphausiids Thysanoessa raschii and T. inermis during spring. Mar. Biol. 68: 97-102.

Farquhar, G.B. (cd.). 1971. Biological Sound Scattering inthe Ocean. Mawry Center for Ocean Science, U.S. Dept. of the Navy.

----- ___. 1977. Biological sound scattering in the ocenas: a review. In: N.R. Andersen and B.J. Zahuranec (eds). Oceanic Sound Scattering Prediction. Marine Science, Vol. 5: 493-S27. Plenum Press.

Fechhelm, R.G., P-C. Craig, J.S. Baker, and B.J. Gallaway. 1985. Fish distribution and use of nearshore waters in the northeastern Chukchi Sea. U.S. Dep. Commer., NOAA, OCSEAP Final Rep. 32: 121-298.

Fevolden, S.E. and R.Y. George. 1984. Size frequency pattern of Euphausia superba in the Antarctic Peninsula waters in the austral summer of 1982. J. Crust. Biol. 4(Sp.No.1): 107-122.

Finney, D.J. 1971. Probit analysis. 3rd cd., Cambridge Univ. Press. London.

Fowler, S.W. and L.F. Small. 1967. Sinking rates of euphausiid fecal pellets. Limnol. Oceanogr. 17: 293-296.

Frost, K.J. and L.F. Lowry. 1984. Trophic relationships of vertebrate consumers in the Alaskan Beaufort Sea. In: P.W. Barnes, D.M. Schell and E. Reimnitz (eds.). The Alaskan Beaufort Sea: Ecosystems and Environments. Academic Press, Inc.

George, R.Y. 1984. Ontogenetic adaptations in growth and respiration of Euphausia superba in relation to temperature and pressure. J. '-Crust. Biol. 4(Sp.No.1): 252-262.

Gosho, M.E. 1977. The food and feeding habits of Juvenile pink salmon in the estuaries of Kodiak Island, Alaska. M.S. Thesis, Univ. of Washington.

Griffiths, W.B. 1984. Fish. In: J.C. Truett (cd.). Environmental characterization and biological use of lagoons in the eastern Beaufort Sea. U.S. Dept. Commer. NOAA. OCSEAP Final Rep. 24: 325-368.

Hamner, W.M. 1984. Aspects of schooling in Eupausia superba. J. Crust. Biol. 4(Sp. No.1): 67-74.

Harding, G.C.H. 1977. Surface area of the euphausiid Thysanoessa raschii and its relation to body length, weight, and respiration. J. Fish. Res. Bd. Canada 34: 25S-231.

----- and W.P. Vass. 1979. Uptake from seawater and clearance of p,p'-DDT by marine planktonic crustacea. J. Fish. Res. Bd. Canada 36: 247-254.

Harris, C.K. and A.C. Hartt. 1977. Assessment of pelagic and nearshore fish in three bays on the east and south coasts of Kodiak Island, Alaska. NOAA/OCSEAP RU 485, Final Report.

Henderson, R.J., S. Falk-Petersen and J.R. "Sargent. 1982. The composition and biosynthesis of lipids in Thysanoessa raschii from the Clyde estuary, Scotland. Mar. Biol. 70: 7-12.

Helm-Hansen, O. and M. Huntley. 1984. Feeding requirements of krill in relation to food sources. J. Crust. Biol. 4(Sp. No.1): 156-173.

Hopkins, C.C.E., S. Falk-Petersen, K. Tande and H.C. Eilertsen. 1978. A preliminary study of zooplankton sound scattering layers in Balsfjorden: structure, energetic and migrations. Sarsia 63: 255-264.

Homer, R. 1981. Beaufort Sea plankton studies. In: U.S. Dept. Commer., NOAA, OCSEAP Final Rept. 13.

Ikeda, T. 1972. Chemical composition and nutrition of zooplankton in the Bering Sea. In: A.Y. Takeouti (cd.) Biological Oceanography of the Northern North Pacific. P. 433-442.

-----. 1984. Sequences in metabolic rates and elemental composition (C,N,P) during the development of Euphausia superba Dana and estimated food requirements during its life span. J. Crust. Biol. 4(Sp.No.1): 273-284.

Kendall, A.W., Jr., J.R. Dunn, R.J. Wolotira, Jr., J.H. Bowerman, Jr., D.B. Dey, A.C. Matarese and J.E. Munk. 1980. Zooplanton, including ichthyoplankton and decapod larvae, of the Kodiak Shelf. Northwest Fisheries Center, Nat. Marine Fisheries Serv., NWAFC Processed Rept. 80-8.

Laws, R.M. 1905. The Ecology of the Southern Ocean. Amer. Sci. 73(l): 26-40.

Lee, R.F. 1975. The fate of petroleum hydrocarbons in marine zooplankton. In: Proceedings of the 1975 Conference on Prevention and Control of Oil Pollution, March 25-27, American Petroleum Inst., pp. 549-553.

Lindley, J.A. 1980. Population dynamics and production of euphausiids. II. Thysanoessa inermis and T. raschii in the North Sea and American coastal waters. Mar. Biol. 59: 225-233.

Lowry, L. 1985. Telephone conversation. October 7. 1985. Alaska Department of Fish & Game.

Lowry, L.F. and K.J. Frost. 1981. Distribution, growth, and foods of Arctic Cod (Boreogadus saida) in the Bering, Chukchi, and Beaufort Seas. Canadian Field-Naturalist 95(2): 186-191.

Malins, D. C., H. O. Hodgins, U. Varanasi, S.-L. Chan, B. B. McCain, D. D. Weber, and D. W. Brown. 1985. Sublethal effects of petroleum hydrocarbons and trace metals, including biotransformations, as reflected by morphological, chemical, physiological, and behavioral indices. U.S. Dept. Commer., NOAA, OCSEAP Final Rep. 29: 1-229.

Marr, J.W.S. 1962. The natural history and geography of the Antarctic krill (Euphausia superba Dana). Discovery Rept. 32: 33-464.

Mauchline, J. 1966. The biology of Thysanoessa Raschii (M. Sars), with a comparison of its diet with that of Meganyctiphanes norvegica (M. Sars). In: H. Barnes (cd.). Some Contemporary Studies in Marine Sciences. pp. 493-510.

----- . 1980. The biology of Mysids and Euphausiids. Adv. In Marine Biology, Academic Press.

_____ and L.R. Fisher. 1969. The Biology of Euphausiids. Adv. in Marine Biology. Academic Press.

Mecklenburg, T.A., S.D. Rice, J.F. Karinen. 1977. Molting and survival of king crab (Paralithodes camtschatica) and coonstripe shrimp (Pandalus hypsinotus) larvae exposed to Cook Inlet crude oil water-soluble fraction. Pp. 221-228. In: D.A. Wolfe (cd.). Fate and Effects of Petroleum in *Marine* Organisms and Ecosystems, Proceedings. Permagon Press. New York.

Minerals Management Service, Alaska OCS Region. 1984. Diapir field lease offering (June 1984) Final Environmental Impact Statement, Vol. 1. U.S. Dept. Interior.

Nemato, T. 1970. Feeding patterns of baleen whales in the ocean. In: J.H. Steele (cd.). Marine Food Chains, Univ. of California, Berkeley, pp. 241-252.

Nishiwaki, M. 1972. General biology. In: S.H. Ridgway, (cd.). Mammals of the Sea: Biology and Medicine. C.C. Thomas, pp. 3-204.

Nunes, P. and P.E. Benville. 1978. Acute toxicity of the water soluble fraction of Cook Inlet crude oil to the manila clam. Mar. Pollut. Bull. 9:324-331.

Paranjape, M.A. 1967. Molting and reparation of euphausiids. J. Fish. Res. Bd. Canada 24: 1229-1240.

Pearcy, W.G., C.C.E. Hopkins, S. Gronvik and R.A. Evans. 1979. Feeding habits of cod, capelin and herring in Balsfjorden, northern Norway, July-August 1978: The importance of euphausiids. Sarsia 64: 269-277.

----- and C.L. Osterberg. 1967. Depth, diel, seasonal and geographic variations in zinc-65 of midwater animals off Oregon. Int. J. Oceanol. Limnol. 1: 103-116.

Peltier, W. 1978. Methods for measuring the acute toxicity of effluents to aquatic organisms. U s . Environmental Protection Agency, Cincinnati. Publ. No. EPA-600/4-78-012. 52 pp.

Percy, J.A. and F.J. Fife. 1981. The biochemical composition and energy content of Arctic marine macrozooplankton. Arctic 34: 307-313.

Rice, S.D., J.W. Short, C.C. Broderson, T.A. Mecklenburg, D.A. Moles, C.J. Misch, D.L. Cheatham, and J.F. Karinen. 1975. Acute toxicity and uptake-depuration studies with Cook Inlet crude oil, Prudhoe Bay crude oil, No. 2 fuel oil and several subarctic marine organisms. N.W. Alaska Fisheries Center, NMFS, NOAA, U.S. Dept. of Commerce, Auke Bay Fisheries Laboratory. Processed Report, 144p.

Rice, S.D., J.W. Short. and J.F. Karinen. 1976. Toxicity of Cook Inlet crude oil and No. 2 fuel oil to several Alaskan marine fishes and invertebrates. In: Sources, effects and sinks of hydrocarbons in the aquatic environment. The American Institute of Biological Sciences, Washington, D.C. PP. 395-406.

Rice, S.D., J.W. Short, and J.F. Karinen. 1977. Comparative oil toxicity and comparative animal sensitivity. In: D.A. Wolfe, (cd.), Fate and Effects of Petroleum Hydrocarbons in Marine *Organisms* and Ecosystems. Pp. 78-94. Permagon Press. N.Y.

Rice, S.D., D.A. Moles, T.L. Taylor, and J.F. Karinen. 1979. Sensitivity of 39 Alaskan marine species to Cook Inlet crude oil and No. 2 fuel oil. Pp. 549-554 in: API, EPA, and USCG, 1979 Oil Spill Conference (Prevention, Behavior, Control, Cleanup), Proceedings. Washington, D.C., American Petroleum Institute. 728 p.

Rice, S.D., D.A. Moles, J.F. Karinen, S. Kern, M.G. Carls, C.C. Brodersen, J.A. Gharrett, and M.M. Babcock. 1985. Effects of petroleum hydrocarbons on Alaskan aquatic organisms: a comprehensive review of all oil-effects research on Alaskan fish and invertebrates conducted by the Auke Bay Laboratory, 1970-81. U.S. Dept. Commer., NOAA, OCSEAP Final Rep. 29: 311-427.

Rogers, D.E., D.J. Rabin, B.J. Rogers, K. Garrison and M.E. Wangerin. 1979. Seasonal composition and food web relationships of marine organisms in the nearshore zone off Kodiak Island - including ichthyoplankton, meroplankton (shellfish), zooplankton and fish. NOAA/OCSEAP RU 553, Annual Report, 30 Sept. 1979.

Sameoto, D.D. 1976a. Distribution of sound scattering layers caused by euphausiids and their relationship to chlorophyll a concentration in the Gulf of St. Lawrence estuary. J. Fish. Res. Bd. Canada 33: 681-687.

..... " 1976b. Respiration rates, energy budgets, and molting frequencies of three species of euphausiids found in the Gulf of St. Lawrence. J. Fish. Res. Bd. Canada 33: 2568-2576.

..... . 1980a. Relationships between stomach contents and vertical migration in Meganyctiphanes norvegica, Thysanoessa raschii, and T. inermis (Crustacea Euphausiacea }. J. Plankton Res. 2: 129-143.

..... . 1980b. Quantitative measurements of euphausiids using a 120 kHz sounder and their in situ orientation. Can. J. Fish. Aquat. Sci. 37: 693-702.

Sargent, J.R. and S. Falk-Petersen. 1981. Ecological investigations on the zooplankton community in Balsfjorden, northern Norway: lipids and fatty acids in Meganyctiphanes norvegica, Thysanoessa raschii, and T. inermis during mid-winter. Mar. Biol. 62: 131-137.

Snedecor, G.W. and W.G. Cochran. 1967. Statistical methods. 6th ed. Iowa State Univ. Press. Ames, Iowa.

Stephan, C.W. 1977. Methods for calculating an LC50. pp. 6S-84, In: F.L. Mayer and J.L. Hamelink (eds.). Aquatic toxicology and hazard evaluation. Am. Soc. Testing Mater., Philadelphia.

Thorsteinson, L.K. (cd.) 1984. The North Aleutian Shelf Environment and Possible Consequences of Offshore Oil and Gas Development: Proceedings of a Synthesis Meeting. U.S. Dept. Commer. NOAA/OAD.

Us. Army Corps of Engineers, Alaska District. 1984. Endicott development project. Final Environmental Impact Statement,Vol. 1.

Vogel, A.H. and G. McMurray. 1982. Seasonal population density distribution of copepods, euphausiids, amphipods, and other holoplankton on the Kodiak Shelf. NOAA/OCSEAP RU 608, Final Report.

VTN. 1980. Boca de Quadra baseline report, Quartz Hill Molybdenum Project, Southeast Alaska. U.S. Borax & Chemical Corp. Los Angeles, CA.

VTN. 1982. Boca de Quadra and Wilson Arm/Smeaton Bay Monitoring Study, Quartz Hill Molybdenum Project. Southeast Alaska. U.S. Borax & Chemical Corporation.

Wiborg, K.F. 19S4. Investigations on zooplankton in coastal and offshore waters of western and northwestern Norway. Rept. Norwegian Fish. Marine Invest. 11: 1-246.

Zelikman, E.A., I.P. Lukashevich and S.S. Drobysheva. 1978. Aggregative distribution of Thysanoessa inermis (Kroyer) and T. raschii (M. Sars) (Euphausiacea) in the Barents Sea. Oceanology 18: 709-713.

_____, _____ and ____. 1979. Year-round diurnal vertical migrations of the euphausiids Thysanoessa inermis and T. raschii in the Barents Sea. Oceanology 19: 82-8S.

-----, -----, ----- and A.A. Degtereva. 1980. Fluctuations in the number of eggs of the Barents Sea crustaceans Thysanoessa inermis Kr. and T. raschii (M. Sara) (Euphausiacea). Oceanology 20: 716-721.

Zhuravlev, V.M. 1977. Species composition arid character of distribution of euphausiids in the Sea of Okhotsk. Oceanology 17: 81-83.

ACKNOWLEDGEMENTS

This study was funded, wholly, by the Minerals Management Service, Department of the Interior through an Interagency Agreement with the National Oceanic and Atmospheric Administration, Department of Commerce, as part of the Alaska Outer Continental Shelf Environmental Assessment Program.

Dr. Carol-Ann Manen was the Contracting Officer's Technical Representative for this project; her support and assistance are gratefully acknowledged. The untiring efforts of Mr. Yoji Endo, Juneau, Alaska, provided live, sorted euphausiids for the project. The cooperation and efforts of University of Alaska, Juneau staff and the skipper of the Maybeso enabled collection of live euphausiids. The cooperation of Dr. Bruce Wing, National Marine Fisheries Service, Auke Bay Laboratory, is also acknowledged for collection time during a sampling cruise.