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Impacts of Oil Pollution and Prince William Sound Studies: Bibliography of 1960-91 Publications and Reports, Auke Bay Laboratory

by

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INTRODUCTION

This bibliography lists 137 publications and reports authored by staff members of the Auke Bay Fisheries Laboratory (ABL) and was compiled in response to the numerous information requests following the 1989 *Exxon Valdez* oil spill. It covers research done in the early 1960s from the Olsen Bay Field Station in Prince William Sound (including some post-1964 earthquake studies), work conducted along the Alaska Peninsula, and laboratory research on the effects of petroleum hydrocarbons on many of Alaska's fish and shellfish (primarily temperate or subarctic species).

The listing is organized into three parts: BIBLIOGRAPHY, ABSTRACTS, and INDEXES. The BIBLIOGRAPHY and ABSTRACTS sections are each subdivided into 1) Effects of Oil, 2) Prince William Sound and Related Papers/Reports, and 3) 1992 Addendum containing two manuscripts in preparation, then arranged alphabetically by author and coauthor(s) and chronologically by year. The INDEXES section is arranged alphabetically under 1)Keyword and 2)Author.

Each bibliographic entry has a corresponding abstract entry as originally written by the authors of that publication or report, with the following exceptions: abstracts or summaries for 11 entries were written specifically for this Technical Memorandum; and lengthy abstracts were shortened by the compilers, who accept all responsibility for interpretation.

A limited number of all reports and publications listed in this bibliography are available from:

Library
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All the reports and publications (except those in the 1992 Addendum) are also available from:

Oil Spill Public Information Center
645 G Street
Anchorage, AK 99501.

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1992 Addendum

These two manuscripts represent research conducted before the Exxon Valdez oil spill; both manuscripts are currently in draft form and nearing completion.

136 Karinen, J. F., M. M. Babcock, D. W. Brown, W. D. MacLeod, Jr., L. S. Ramos, and J. W. Short. In Preparation. Hydrocarbons in intertidal sediments and mussels from Prince William Sound, Alaska, 1977-1980: Characterization and probable sources. National Marine Fisheries Service, Auke Bay Laboratory.

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ABSTRACTS

Effects of Oil

1 Babcock, M. M. 1985. Morphology of olfactory epithelium of pink salmon, Oncorhynchus gorbuscha, and changes following exposure to benzene: A scanning electron microscopy study. In J. S. Gray and M. E. Christiansen (editors), Marine Biology of Polar Regions and Effects of Stress on Marine Organisms, p. 259-267. John Wiley & Sons, Chichester, England.

The pink salmon fishery is the most valuable fishery in Prince, William Sound, Alaska (USA), and this resource may be damaged by oil pollution from tankers or discharges from a ballast-water treatment plant near Valdez. Because juvenile pink salmon school along shallow estuarine shorelines of Prince William Sound several weeks before migrating to oceanic feeding grounds, they are vulnerable to oil pollutants from these sources. Benzene, a major component of crude oil and the effluent from the treatment plant, is water soluble and toxic to fish. To determine the histopathological effects of benzene on olfactory rosettes of pink salmon, I exposed juveniles to sublethal concentrations of benzene in seawater. Fish were exposed in seawater to 4.3 ppm benzene for 12 d or to one of four concentrations ranging from 0.15 to 4.40 ppm benzene for 29 d. (The 96-h LC_{50}=8.47 ppm). Olfactory rosettes from these fish were examined with scanning electron microscopy. Rosettes from fry exposed to >0.15 ppm benzene had exhausted mucous cells. Olfactory lamellae of fry exposed to ??????ppm benzene had altered distribution of cilia. Lamellae of fish exposed to 4.3 ppm benzene 12 d had patchy losses of cilia; lamellae of fish exposed 29 d to concentrations of benzene ??????ppm had a generalized loss of cilia. Exhausted mucous cells and loss of cilia on the olfactory lamellar surfaces could change circulation of water through the olfactory rosettes or otherwise interfere with normal chemosensory reception and consequently affect homing, traditional migratory patterns, feeding activity, and avoidance of predators.

2 Babcock, M. M., and J. F. Karinen. 1988. Reproductive success in Tanner (Chionoecetes bairdi) and Dungeness (Cancer magister) crabs held on oiled sediment. J. Shellfish Res. 7:109.

Gravid female Tanner (Chionoecetes bairdi) and Dungeness (Cancer magister) crabs were held on one of several concentrations (0-8.9 µl Cook Inlet crude oil/gm sediment) of oiled sediment through one complete reproductive cycle. These two species of commercially important crabs exhibit different behavioral characteristics while carrying eggs. Brooding Dungeness crab females consistently bury in the sediments while gravid Tanner crab females rarely bury. Because of differences in behavior, we predicted dissimilar responses to oiled sediments.

Dungeness crabs held on all doses of oiled sediments produced significantly fewer numbers of larvae than did control crabs. Larvae from crabs in high-dose tanks survived significantly shorter periods than did larvae from the control, low- and mid-dose tanks. Eggs from crabs in high-dose tanks had significantly elevated levels of aromatic and aliphatic hydrocarbons, compared with eggs from control crabs.

Production of larvae and viability of larvae of Tanner crabs held on oiled sediments showed no differences from that of control crabs. Likewise, there was no significant uptake of hydrocarbons in eggs over control levels.

Intimate contact of gravid Dungeness crabs with sediment-absorbed oil and oil present in interstitial waters in polluted habitat could reduce reproductive success in this species.

3 Benville, P. E., and S. Korn. 1977. The acute toxicity of six monocyclic aromatic crude oil components to striped bass (Morone saxatilis) and bay shrimp (Crago franciscorum). Calif. Fish Game 63:204-209.

The acute toxicities of benzene, toluene, ethylbenzene, p-xylene, m-xylene, and o-xylene were determined for striped bass and bay shrimp by static bioassay. The 96-h LC_{50}, ranged from 2.0 to 11 µl/l (ppm) for striped bass and from 0.49 to 20 µl/l (ppm) for bay shrimp. Solubilities of these aromatics were determined by gas chromatography in 16°C (61°F) seawater with a salinity of 25% as part of our procedure for dosing the animals. The solubilities were 1400, 330, 180, 180, 210, and 230 µl/l (ppm), respectively, which is high enough to be lethal to striped bass and bay shrimp. The toxic effect of the aromatics was more latent in shrimp than in fish as demonstrated by the difference in the 24- and 96-h tests.

4 Brodersen, C. 1987. Rapid narcosis and delayed mortality in larvae of king crabs and kelp shrimp exposed to the water-soluble fraction of crude oil. Mar. Environ. Res. 22:233-239.

Sensitivity of larval Paralithodes camtschatica and Eualus suckleyi exposed 20 min-96 h to the water-soluble fraction (WSF) of crude oil was determined. Swimming cessation in half the animals occurred within 20 min exposure to 2 ppm WSF for shrimp larvae and only 0.5 ppm for crab larvae. Half the larvae of both species died after 6 h exposure to 8 ppm or 24 h exposed to 2-4 ppm, but deaths did not occur until several days after exposure ended. In the field, most non-swimming larvae would probably die as well.

5 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. In 1977 Oil Spill Conference (Prevention, Behavior, Control, Cleanup), p. 575-578. American Petroleum Institute, Washington, DC.

The sensitivity of adult and larval Alaskan shrimp and crabs to the water-soluble fraction (WSF) of Cook Inlet crude oil was measured by tests using 96-h static bioassays at the water temperatures that these animals normally encounter. Larval crustaceans were found to die more slowly than adults, making it necessary to measure sensitivity in terms of concentrations causing moribundity (death imminent) instead of in terms of concentrations causing death during exposure. Cessation of motion and reaction indicated moribundity in adults, and cessation of swimming indicated moribundity in larvae exposed for 96 h. Ninety-six hour LC_{50}'s for moribundity for stage I larvae ranged from 0.95 to 1.8 ppm depending on species, while 96-h LC_{50}'s for adults ranged from 1.9 to 4.2 ppm oil. Sensitivities for stage I-VI larvae of coonstripe shrimp ranged between 0.24 ppm to 1.9 ppm.

Larvae were more sensitive to oil than adults. The sensitivity of larvae depended on species and developmental stage. Larvae are probably more vulnerable than adult to oil exposure because of greater sensitivity to oil and greater susceptibility to predation. Cold-water species may be particularly vulnerable because of increased time spent as developing larvae.

6 Carls, M. G. 1987. Effects *of* dietary and water-borne oil exposure on larval Pacific herring ***(Clupea harengus pallasi).*** Mar. Environ. Res. 22:253-270.

Pacific herring (Clupea harengus pallasi) larvae were exposed either directly to the water-soluble fraction (WSF) of crude oil or indirectly via oil-contaminated prey (OCP) (Artemia salina) for ??28 days, to determine the relative effects of diet and water as routes of contamination. Larvae were affected rapidly by 0.9 ppm WSF, which caused high larval mortality, reduced swimming ability and rapid reduction in feeding rates. Larval length was significantly reduced by 0.7 ppm WSF in 7 days and by 0.3 ppm WSF within 14 days. The WSF exposure also caused similar reductions in larval weights. Highly contaminated prey (6 ppm prey exposure) caused significant mortality, but surviving larvae appeared robust. The OCP did not affect swimming, feeding, or growth. Exposure of larvae was not significantly extended by OCP, which rapidly depurated WSF in clean water (98% in 1 day). Therefore, OCP is probably not an important source of low molecular weight petroleum contamination to larval fish in the marine environment.

7 Carls, M. G. 1978. Some toxic and behavioral effects of number 2 fuel oil on the eggs and larvae of Scomber scombrus L. and Gadus morhua L. M.S. Thesis, Dalhousie Univ., Halifax, Nova Scotia, 96 p.

Acute toxic and behavioral effects of No. 2 fuel oil on mackerel and cod eggs and larvae were studied. Abbreviated ranges of compounds obtained from the fuel oil were also tested. Maximum exposure to the oil was 139+30 h for mackerel and 278+60 h for cod. Oil loss (determined fluorimetrically) was exponential or nearly exponential. Mean exposure concentrations ranged from 0.00 to 16.22 ppm oil.

Based on mortality, effective oil concentrations (EC's) for mackerel larvae were 0.28 after 96 h of exposure, but dropped to 0.10 ppm after 480 h (predicted). EC's for cod larvae at 5.9°C were not statistically different from those for the mackerel larvae (0.36 ppm, 96 h; 0.15 ppm, 480 h) but were significantly less for cod larvae at 2°C (0.18 ppm 96 h; 0.07 ppm, 480 h). Egg mortality due to the oil was not significant, but developing embryos were significantly damaged as shown by post-hatching mortality (mackerel).

Effective concentrations were less when calculated from behavioral data, but eventually converged with those calculated from LT_{50}'s (mortality data). The relationship could be demonstrated by calculating the ratio EC_{ET50}/EC_{LT50}: at 96, 480, and 1000 h these ratios were 0.33, 0.53, and 0.64 for No. 2 fuel oil (cod larvae).

Although increased measurement sensitivity might account for some of the observed sensitivity, this study suggests mackerel and cod larvae are more sensitive to oil than previous reports have indicated.

An interpretative model describing the relationship between the rates of loss and rates of effect of individual oil components was formulated.

8 Carls, M. G., and S. Korn. 1985. Sensitivity of Arctic marine amphipods and fish to petroleum hydrocarbons. Can. Tech. Rep. Fish. Aquat. Sci. 1368:11-26.

We determined the sensitivities of six circumpolar benthic species (amphipods Anonyx nugax, Boeckosimus nanseni, and Gammaracanthus loricatus; a mysid, Mysis relicta; Arctic cod Boreogadus saida; and a sculpin, Oncocottus hexacornis) to water-soluble fractions (WSF) of Cook Inlet crude oil and naphthalene in separate tests. Exposures were flow-through and lasted 40 days. Median lethal concentrations (LC_{50}'s) of WSF ranged from 1.6 to 3.8 ppm total aromatics. Naphthalene assays were conducted at several temperatures (1.5 to 9.6°C) to study temperature effects on sensitivity to hydrocarbons. LC_{50}'s ranged from 1.35 to 3.35 ppm. General relationships between exposure temperatures and LC_{50}'s were not found. In the absence of toxicants, upper lethal temperatures for the crustaceans were surprisingly high: 17-24°C, suggesting the assay temperatures in themselves were not particularly stressful.

We compared the sensitivities of these Arctic marine species to the sensitivities of temperate species previously tested at the Auke Bay Laboratory using the same flow-through procedures and toxicants. We concluded that Arctic species are about equal in sensitivity to temperate species. However, their habitat is more vulnerable to the effects of petroleum hydrocarbon pollution than temperate habitats because colder temperatures lead to slower losses of hydrocarbons from volatilization and biodegradation, and oil entrapment under sea ice can result in very lengthy exposures.

9 Carls, M. G., and S. D. Rice. 1990. Abnormal development and growth reductions of pollock Theragra chalcogramma embryos exposed to water-soluble fractions of oil. Fish. Bull., U.S. 88:29-37.

Exposure of developing pollock Theragra chalcogramma embryos to static water-soluble fractions (WSF) of Cook Inlet crude oil in seawater slowed initial development, produced shorter larvae, and caused morphological abnormalities including membranous vesicles; body curvatures; deformations of yolk, eye, brain, jaw, intestine, and pericardial sac; absence of lower jaw; fin erosion; yolksac bloating; and light pigmentation. These abnormalities were retained after hatch, and in many cases became more pronounced as developing structures failed to form properly. The median concentration of WSF that caused abnormalities (AB_{50}) was 2.1+0.1 ppm. Exposure during embryonic development reduced prehatch survival by a maximum of 26%, and caused high mortality after hatch. The median lethal concentration (1.8+0.6 ppm) was not significantly different than the AB_{50}. Although exposed pollock embryos generally survived to hatching, larvae were malformed, smaller, and had poorer survival potential than controls.

10 Carls, M. G., and S. D. Rice. 1988. Sensitivity differences between eggs and larvae of walleye pollock (Theragra chalcogramma) to hydrocarbons. Mar. Environ. Res. 26:285-297.

Exposure of embryonic and larval walleye pollock (Theragra chalcogramma) to the water-soluble fractions (WSF) of Cook Inlet crude oil during embryonic development caused mortality and a variety of morphological abnormalities. Median WSF concentrations (1.8 ppm) which caused mortality after hatch did not differ significantly from those causing morphological abnormalities (1.6 ppm). Pollock larvae exposed to WSF did not develop abnormalities, but swimming and survival were significantly affected within 4 h of exposure. The LC_{50} for larvae dropped from 1.9 ppm on day 4 to 0.9 ppm on day 10.

The tissue of developing pollock larvae bioaccumulated significantly more dissolved toluene and naphthalene than those of embryos. Consequently, when exposed to equal concentrations of WSF, larval tissues are exposed to much higher hydrocarbon concentrations than embryonic tissues. On the basis of internal tissue concentrations, larvae were less sensitive than eggs, but the opposite conclusion is reached if external (WSF) concentrations are used for estimation of sensitivity.

11 Carls, M. G., and S. D. Rice. 1984. Toxic contributions of specific drilling mud components to larval shrimp and crabs. Mar. Environ. Res. 12:45-62.

Toxicities of six drilling muds, mud fractions (supernatants and suspensions) and common mud components (barite, bentonite, and ferrochrome lignosulfonate) were tested with stage I larvae of six species of shrimp and crab. The drilling muds we tested were not very toxic to these larvae: LC_{50}'s for supernatants ranged from 0.6 to 82% (vol/vol). Shrimp larvae were slightly more sensitive than crab larvae.

Drilling muds were not rapidly toxic, in contrast to toxicants such as the water-soluble fractions of oil. Suspensions were more toxic than supernatants and toxicity was greatest when particulates remained suspended: for example, the toxicity of used Cook Inlet mud was primarily due to suspended solids (88%) rather than chemical toxicity. Ferrochrome lignosulfonate was relatively toxic alone, but accounted for only about 6% of the toxicity of used Cook Inlet mud suspensions. Contributions of particulates to mud toxicities varied considerably. Barite and bentonite were not very toxic when tested alone. The toxicity of one mud was caused by its high alkalinity.

12 Carls, M. G., and S. D. Rice. 1981. Toxicity of oil-well drilling muds to Alaskan larval shrimp and crabs. In Environmental Assessment of the Alaskan Continental Shelf. Final Reports of Principal Investigators, Vol. 11 Biological Studies, p. 1-35. U.S. Dep. Commer., NOAA. Available Arctic Environmental Assessment Center, 222 W. 8th Ave., No. 56, Anchorage, AK 99513.

The toxic nature of drilling muds is very different from the toxic nature of crude oil. Drilling muds affect larval crustacean swimming ability and survival slowly, whereas the effects of oil are very rapid. The water-soluble fractions of, drilling muds are stable in solution, but oil WSF's are not. The slow nature of the drilling-mud toxicity suggests the toxic components are not very active as chemical poisons, but cause extra larval energy expenditure to maintain homeostasis. Crustacean larvae are more sensitive to drilling muds than adult crustaceans and fish by approximately an order of magnitude. However, drilling muds are not particularly toxic: toxic concentrations ranged from 4 to 40 ppt. Water-column concentrations of drilling muds capable of causing toxicity are probably brief and limited to distances <3 m from the point of platform discharge.

13 Collodi, P. 1983. Effect of petroleum hydrocarbons on hepatic aryl hydrocarbon hydroxylase activity in coho salmon (Oncorhynchus kisutch). M.S. Thesis, Univ. Alaska, Juneau, 120 p.

Coho salmon were exposed to the water soluble fraction (WSF) of Cook Inlet crude oil for a maximum of 30 days. This exposure, in both freshwater and sea water, resulted in a greater than three-fold increase in hepatic aryl hydrocarbon hydroxylase enzyme activity between two and five days of exposure. Persistence of the induced enzyme activity was dependent on the length and the concentration of WSF exposure. Handling stress had no effect on AHH activity, but starvation caused a decrease in activity.

14 Collodi, P., M. S. Stekoll, and S. D. Rice. 1984. Hepatic aryl hydrocarbon hydroxylase activities in coho salmon (Oncorhynchus kisutch) exposed to petroleum hydrocarbons. Comp. Biochem. Physiol. C Comp. Pharmacol. 79:337-341.

Coho salmon exposed to the water soluble fraction (WSF) of Cook Inlet crude oil for a maximum of 30 days showed a greater than three-fold increase in hepatic aryl hydrocarbon hydroxylase activity. The initial increase in enzyme activity appeared between 2 and 5 days of exposure and increased as a function of increased exposure time. Persistence of the induced enzyme activity was dependent on the length and the concentration of WSF exposure.

15 Evans, D. R., and S. D. Rice. 1974. Effects of oil on marine ecosystems: A review for administrators and policy makers. Fish. Bull., U.S. 72:625-638.

A broad selection of literature on the effects of oil on marine ecosystems is reviewed. The focus is on studies on crude oil, and should be a useful reference for administrators and policy makers involved in decisions concerning petroleum developments and related activities. The characteristics of crude oil and factors modifying its impact on the marine environment are discussed. Most research on the toxicity of oil has dealt with acute effects and data on long-term impacts at the community level are inconclusive. It is concluded that chronic low-level pollution is potentially more damaging to ecosystems than isolated catastrophic spills.

16 Gharrett, J. A. 1986. Effects of a hydrocarbon-contaminated diet on survival, feeding, growth, and molting of juvenile red king crab, Paralithodes camtschatica (Tilesius). M.S. Thesis, Univ. Alaska, Juneau, 178 p.

Juvenile red king crab (Paralithodes camtschatica Tilesius) were fed diets containing mono- and di-aromatic hydrocarbons of up to 25 ug oil/g wet Mytilus, or unoiled food for 6 months.

Hydrocarbons were rapidly accumulated in tissues, in a non-selective manner with respect to individual aromatic compounds. HP tissue always had higher levels-of aromatics than muscle, but tissue levels never exceeded those in food. Aromatics were rapidly eliminated. A combination of low oil ingestion rate, and active metabolism and/or excretion prevented crabs from accumulating higher hydrocarbon concentrations than the food. Because crabs are able to maintain low hydrocarbon burdens, treatment regimes had no significant affect on survival, or any parameter of feeding, growth, molting, or morphometrics.

17 Gharrett, J. A., and S. D. Rice. 1987. Influence of simulated tidal cycles on aromatic hydrocarbon uptake and elimination by the shore crab Hemigrapsus nudus. Mar. Biol. 95:365-370.

Intertidal crab Hemigrapsus nudus were used in laboratory experiments to determine the influence of periodic exposure to air on the toxicity, uptake, and elimination of two aromatic hydrocarbons, toluene and naphthalene. Three tidal cycles were simulated: i.e., crabs spent 0, 33, and 66% of the time in air and the remainder of the time in toxicant or seawater solutions. Naphthalene was 10 to 20 times more toxic than toluene and was accumulated faster and to higher concentrations than was toluene. Exposure to air 66% of the time reduced mortality as well as the rate at which toluene and naphthalene were accumulated and lost. Once crabs had accumulated the toxicants, however, elimination was hindered by exposure to air, even for the somewhat volatile compound toluene.

18 Gharrett, J. A., S. D. Rice, and M. S. Stekoll. 1985. Influence of an oil-contaminated diet on feeding rates, growth, and molting success of juvenile red king crabs, Paralithodes camtschatica. In Proceedings of the International King Crab Symposium, January 1985, Anchorage, Alaska, p. 371-375. Univ. Alaska, Fairbanks. Alaska Sea Grant Coll. Program, Alaska Sea Grant Rep. 85-12.

Feeding rates and molting success are sensitive indicators of the general condition of crabs. We concluded that daily consumption of oil-contaminated food was not detrimental to juvenile red king crabs over a 6-mo period, during which rapid growth and molting occurred. Aromatic hydrocarbon uptake was detected in the samples of the digestive gland taken early in the exposure. Accumulation of high concentrations in crab tissues was not observed. However, the long-term effects of exposure to oil contaminated food or sediment in the environment are unknown, and the small amounts of uptake and the trend of decreased feeding rates are cause for concern.

19 Karinen, J. F. 1988. Sublethal effects of petroleum on biota. In D. G. Shaw and M. J. Hameedi (editors),

Environmental Studies in Port Valdez, Alaska: A Basis for Management, p. 293-328. Springer-Verlag, Heidelberg.

Aromatic hydrocarbons in sediments, water, and biota of Port Valdez near the ballast diffuser are similar, in composition and concentration, to other oil impacted environments, and sublethal effects of biota of Port Valdez are probably detectable at this time.

20 Karinen, J. F. 1985. Occurrence of juvenile king crabs, Paralithodes camtschatica (Tilesius), in Auke Bay, Alaska, on sediments with relatively high concentrations of aromatic hydrocarbons. In Proceedings of the International King Crab Symposium, January 1985, Anchorage, Alaska, p. 377-387. Univ. Alaska, Fairbanks. Alaska Sea Grant Coll. Program, Alaska Sea Grant Rep. 85-12.

In the northeastern corner of Auke Bay, Alaska, juvenile king crab gather in pods and under slate rocks; it is also the location of two marinas and two docks. Marina activity may increase concentrations of hydrocarbons, metals, and synthetic organic compounds in sediments and organisms, which may affect the occurrence, health, and reproduction of these crabs; The purpose of this study was to examine the relationship of marina sediments and king crab populations in northeastern Auke Bay.

Observations on the occurrence and abundance of crabs in Auke Bay had been made by divers over a 12-year period. Determination of hydrocarbons in sediments and in the pink scallop Chlamys spp., a prey item for king crabs, from the northeastern corner of Auke Bay had been carried out in 1982 and 1983 as part of the preparation for an environmental-impact statement on marina expansion. Growth of juvenile red king crabs from the study area and from adjacent areas of Auke Bay were estimated and compared.

Year-to-year abundance of juvenile king crabs in the study area appeared to be constant, though abundance of adults had declined with time. The marina area showed a relatively high concentration of aromatic hydrocarbons in sediments, probably primarily from the marinas. Growth information from other studies indicated reduced growth rates for juvenile king crabs in the study area when compared with crabs in other areas.

Juvenile king crabs may continue to appear in the study area because circulation patterns carry larvae to the northeastern corner. Lower growth rates in the study area may be due to oil exposure.[1]

21 Karinen, J. F. 1980. Petroleum in the deep sea environment: Potential for damage to biota. Environ. Int. 3:135-144.

[1]This summary was written specifically for this Technical Memorandum by Nancy Barr, ABL.

Information on the fate, persistence and biological impact of petroleum hydrocarbons in shallow marine environments, coupled with recent data on hydrocarbons in offshore sediments and the biology of deep sea organisms, have provided new perspectives on the potential impact of oil on the deep sea environment. A review of literature on petroleum hydrocarbons in deep sea sediments, mechanisms for transport of petroleum to the deep sea floor, interaction of petroleum hydrocarbons and particulate matter, and the physiology and metabolism of deep sea fish and crustaceans has resulted in the following conclusions:

1. Hydrocarbons of apparent anthropogenic origin are accumulating in bottom sediments of coastal margins and in deeper offshore waters at unknown rates.
2. Several mechanisms exist for their rapid transport of petroleum hydrocarbons to the deep sea floor.
3. Petroleum hydrocarbons are intimately associated with particulate matter in the sea, behaving much the same as natural biogenic material and can potentially modify or interrupt natural processes.
4. The unique physiology of deep water life forms increases potential adverse impacts of petroleum hydrocarbons.
5. There is a need to determine trends of temporal and spatial deposition of hydrocarbons in deep sea sediments and evaluate the biological impact of this introduction of xenobiotic compounds on the largest environment on earth.

22 Karinen, J. F. 1977. Assessing oil impacts with laboratory data applications, limitations, and needs. In B. Melteff (editor), Oil and Aquatic Ecosystems, Tanker Safety and Oil Pollution Liability. Proceedings of the Cordova Fisheries Institute, April 1-3, 1977, Cordova, Alaska, p. 99-110. Univ. Alaska, Fairbanks, Alaska Sea Grant Rep. 77-8.

This paper outlines some of the problems associated with the utilization of laboratory data to assess the impact of oil in the environment and some of the considerations which we should make in trying to apply the toxicity and sublethal effects data. In applying these results-to the environment to determine what the actual effects of oil exposure will be, there are both biological as well as chemical considerations which we must make. This paper deals more with the chemical aspects rather than the biological aspects and is limited to a consideration of the behavior of oil in water and some chemical factors influencing the application of laboratory effects data toward assessing oil impacts.

23 Karinen, J. F., and S. D. Rice. 1974. Effects of Prudhoe Bay crude oil on molting Tanner crabs, ***Chionoecetes bairdi.*** Mar. Fish. Rev. 36(7):31-37.

Premolt and postmolt juvenile male Tanner crabs, ***Chionoecetes bairdi,*** from Alaska waters were exposed to Prudhoe Bay crude oil in static bioassays in the laboratory. Crabs in both stages were similarly susceptible to crude oil; the estimated 48-h Tlm (median tolerance limits) values were 0.56 ml oil/liter. Molting success decreased with increasing exposure of crabs to oil, and newly molted crabs autotomized limbs during exposure to oil. Relating the results of our study to the known behavior of crabs and the documented behavior of oil spills in the ocean suggests that oil spilled in Alaska waters would harm the Tanner crab resources. The impact on all crab resources of chronic low-level oil pollution from the ballast water discharged into Prince William Sound is unknown. This study further illustrates our present state of ignorance concerning the biological effects of oil in the marine environment.

24 Karinen, J. F., S. D. Rice, and M. M. Babcock. 1990. Reproductive success in Dungeness crab ***(Cancer magister)*** during long-term exposures to oil-contaminated sediments. In Outer Continental Shelf Assessment Program, Final Reports of Principal Investigators, Vol. 67, p. 435-461. U.S. Dep. Commer., NOAA. Available Arctic Environmental Assessment Center, 222 W. 8th Ave., No. 56, Anchorage, AK 99513.

Dungeness crab ***(Cancer magister)*** habitat in the nearshore waters of Alaska may be at risk from oil pollution. Transport of crude oil and expanded exploratory drilling in Alaskan waters increase the likelihood of accidental contamination of coastal sediments, and oil absorbed by the sediments is likely to persist for years in subarctic and Arctic waters. In contrast to other commercially important Alaskan crabs, Dungeness crabs completely bury themselves, particularly when spawning and incubating their eggs. Therefore, their eggs are in direct contact with sediments for extended periods and are vulnerable to any xenobiotics contaminating the habitat.

In Phase 1 of this study, we exposed adult female crabs to three dose levels of oiled sediments for one complete reproductive cycle (10 months) to determine effects on survival, uptake of hydrocarbons, hatching success, and viability of larvae. Crabs were exposed to 0, 1.2, 3.7, or 8.6 µ1 Cook Inlet Crude oil per gram of sediment. Hatching began in mid-April, and larvae were captured in a trap attached to the outlet of each tank. At three different times during the hatching period, we tested larvae, to determine viability.

Dosed crabs produced significantly ($0.025<P<0.05$) lower numbers of larvae than control crabs. Control crabs produced a mean of 368,700 larvae/crab, and the low, mid, and high doses produced 225,500, 303,900, and 268,100 larvae/crab, respectively. Larvae from the high-dose tanks survived for significantly ($P<0.005$) shorter periods (3.1 days) than larvae from the control tanks and low- and mid-dose tanks (5.3 days). Eggs from crabs in the high-dose tanks had significantly elevated levels of aromatic and aliphatic hydrocarbons.

In Phase 2, we studied the effects of oiled-sediment exposures on mating and molting. The experimental tanks contained old (held over from Phase 1) control, old mid-dose, old high-dose, fresh high-dose, and new control sediments. Female crabs from Phase 1 exposures and previously unexposed male crabs were used in the old sediment tanks. Previously unexposed male and female crabs were placed on new sediments.

Clasping behavior and successful molting were low in all old-dose experimental conditions, and completely absent in crabs in the new high-dose tanks, but occurred in 75% of the pairs in the new control tank. The low rate of clasping and molting in all old, 14-month exposures was probably caused by a combination of confinement, diet, and oil. The briefer, 4-month exposure to freshly oiled sediment completely inhibited clasping behavior and molting.

Fifty-five percent of the female crabs that had not molted subsequently spawned and established fertile clutches. At the termination of the exposures, examination revealed the presence of fresh sperm in the spermathecas of over 90% of the females, indicating these females had copulated in the hard-shelled condition. We believe that spawning without molting is an adaptive response for using energy reserves that may have been depleted by a combination of stressors.

Exposure to oiled sediments results in lower reproductive activity in Dungeness crabs, and the larvae produced are not as robust. Therefore, over a period of time, the presence of oil in the habitat substrate may lower population densities.

25 Korn, S., N. Hirsch, and J. W. Struhsaker. 1977. The uptake, distribution, and depuration of ^{14}C benzene and ^{14}C toluene in Pacific herring, ***Clupea harengus pallasi.*** Fish. Bull., U.S. 75:633-636.

Benzene and toluene are water-soluble and toxic monoaromatic components of petroleum. In this study, a comparison of the uptake, distribution, and depuration of ^{14}C benzene and ^{14}C toluene in Pacific herring, ***Clupea harengus pallasi,*** was undertaken to determine which of these may pose the greatest problem.

Adult herring in non-spawning condition were exposed to 100 ppb ^{14}C benzene or 100 ppb ^{14}C toluene. Exposures were static and lasted 48 h. In all tissues, toluene accumulated to higher levels than did benzene, despite the faster loss of toluene from test solutions. Highest accumulations were found in the gall bladder (34 nl/g toluene and 3.1 nl/g benzene). This was 340 times (toluene) and 31 times (benzene) initial concentrations in the test solutions. Other tissues exhibited lower levels with immature gonads showing the lowest. Accumulation was rapid with toluene peaking before 24 h and benzene within 1-2 d. Depuration of tissues except gallbladder, intestine and pyloric caeca, was also rapid--within 1-2 d after termination of exposures.

Toluene is more toxic and probably has greater sublethal effects than benzene.

26 Korn, S., N. Hirsch, and J. W. Struhsaker. 1976. Uptake, distribution, and depuration of ^{14}C-benzene in northern

anchovy, ***Engraulis mordax,*** and striped bass, Morone saxatilis. Fish.,Bull., U.S. 74:545-551.

The uptake, distribution, and depuration of water-soluble, monocyclic hydrocarbon contained in petroleum and refined products was studied in two species of marine fish. Mature northern anchovy, ***Engraulis mordax,*** and juvenile striped bass, ***Morone saxatilis,*** were exposed to sublethal concentrations of ^{14}C-benzene for 48 h. Residues in tissues exhibiting a high lipid content or representing apparent major metabolic sites were measured during the exposure and afterwards when the fish were transferred to clean seawater. Fish exhibited a rapid uptake over a wide range of benzene concentrations in the water column. Accumulation in anchovy was considerably greater than in striped bass. Results indicate that the pathway of hydrocarbons through the liver, gallbladder, intestines, and colon is a major depuration route. Residues were depurated rapidly after cessation of exposure; in striped bass tissues most residues were undetectable by 7 days.

27 Korn, S., D. A. Moles, and S. D. Rice. 1979. Effects of temperature on the median tolerance limit of pink salmon and shrimp exposed to toluene, naphthalene, and Cook Inlet crude oil. Bull. Environ. Contam. Toxicol. 21:521-525.

We measured the effects of temperature on the TLm's of pink salmon (Oncorhynchus gorbuscha) fry and shrimp (Eualus spp. and Pandalus goniurus) exposed to toluene, naphthalene, and the water-soluble fraction (WSF) of Cook Inlet crude oil. Static exposures were used, in which the initial concentration of the toxicant declines with time, a situation that would also occur with an oil spill. Both the persistence of oil and the physiology of animals are affected by temperature, and the measured TLm's are the net result of both variables operating simultaneously.

28 Korn, S., and S. Rice. 1981. Sensitivity to, and accumulation and depuration of, aromatic petroleum components by early life stages of coho salmon (Oncorhynchus kisutch). Rapp. P.-V. Reun. Cons. Int. Explor. Mer 178:87-22.

Coho salmon eggs, alevins, and fry were exposed to toluene, naphthalene, and 2-methyl-naphthalene in a series of short-term toxicity and hydrocarbon-uptake studies to determine whether acute toxicity is related to uptake-depuration patterns. Uptake studies used radiolabeled compounds and radiometric analyses. The time to reach maximum tissue concentrations of these hydrocarbons was determined from long-term exposures.

Sensitivity to the aromatics increased from egg to fry with the greatest increase in sensitivity between the egg and early alevin. The rates of uptake and depuration of the aromatic hydrocarbons also increased during the development from egg to fry. Eggs had the slowest rates of uptake and depuration.

Eggs required 10 days to accumulate stable tissue concentrations of toluene and naphthalene; alevins required 36 h (both toxicants); fry, 3 h (toluene) and 10 h (naphthalene). The rate of uptake and toxicity was higher with increased ring size and increased substitution (2-methyl-naphthalene > naphthalene > toluene).

Eggs were more tolerant than alevins and fry to short-term exposures of aromatic hydrocarbons probably because the chorion prevented rapid uptake. The amount of yolk also influenced sensitivity because aromatic hydrocarbons were selectively partitioned into the yolk, thus reducing availability of the hydrocarbons to the embryo and resulting in lower toxicity.

Although eggs take up hydrocarbons at a slow rate, they may accumulate lethal levels of hydrocarbons during long-term exposures and, therefore, would be more sensitive to hydrocarbons than indicated by short-term experiments.

29 Korn, S., S. D. Rice, D. L. Cheatham, and D. W. Brown. 1985. Contribution of phenol and p-cresol to the toxicity of crude oil to pink salmon ***(Oncorhynchus gorbuscha)*** fry and kelp shrimp ***(Eualus suckleyi).*** In F. J. Vernberg, F. P. Thurberg, A. Calabrese, and W. B. Vernberg (editors), Marine Pollution and Physiology: Recent Advances, p. 447-458. Univ. South Carolina Press, Columbia, SC.

Concentrations of phenolic compounds in the WSFs of Cook Inlet crude oil, Prudhoe Bay crude oil, and No. 2 fuel oil ranged from 0.040 to 0.088 ppm. Concentrations of phenol that killed 50% of the animals in 96 h (the 96-h LC_{50}) was 3.7 ppm for pink salmon and 10.3 ppm for kelp shrimp, LC_{50}s for p-cresol were 3.4 ppm for pink salmon and 7.4 ppm for kelp shrimp. In 24 h, salmon and shrimp accumulated 11-22 times the initial exposure concentration of phenol and p-cresol. Both compounds were completely eliminated from pink salmon by day 7 or less. Shrimp depurated the compounds slower than pink salmon.

Phenol and p-cresol contributed less to the toxicity of the WSF than toluene and naphthalene. Although toluene is one-half as toxic as phenol, its concentration in the WSF is 50 times higher than the concentration of phenol. Naphthalene, which is 3-10 times more toxic than phenol, had concentrations in the WSF that were 2-7 times higher than the concentration of phenol. Furthermore, the phenols accumulated slowly and are eliminated rapidly. We, therefore, conclude phenols do not contribute substantially to the toxicity of the WSF of crude oil.

30 Korn, S., J. W. Struhsaker, and P. Benville. 1976. Effects of benzene on growth, fat content, and caloric content of striped bass, ***Morone saxatilis.*** Fish. Bull., U.S. 74:694-698.

Juvenile striped bass were exposed to constant concentrations of benzene to determine whether sublethal levels would inhibit efficient energy utilization by the fish as measured by growth (wet weight, dry weight), fat content, and caloric content. Thirty-five fish were maintained up to 4 weeks in each of nine aquariums; three aquariums at 3.5 µl/liter benzene, three at 6 µl/liter benzene, and three at 0 µl/liter benzene as controls. Fish were monitored daily and seven fish were sampled from each aquarium at 0, 7, 14, 21, and 28 days, and weighed (wet and dry); three fish from each group were subjected to caloric analysis, and four to fat analysis.

Initial exposure to benzene caused hyperactivity among fish at the high benzene level and moderately elevated activity levels at the lower level of exposure. Fish exposed at the high concentration attempted to feed, but could not locate food pellets; fish at lower concentrations consumed 50% of the food offered. By the end of the study, high-dose-level fish consumed 50% of their ration and low-level fish fed normally. Wet weights, dry weights, and fat content decreased with increased benzene exposure.[1]

31 Lauren, D. J., and S. Rice. 1985. Significance of active and passive depuration in the clearance of naphthalene from the tissues of ***Hemigrapsus nudus*** (Crustacea: Decapoda). Mar. Biol. 88:135-142.

Adult male crabs ***Hemigrapsus nudus*** were exposed statically in seawater to ^{14}C-naphthalene for 12 h followed by up to 156 h of depuration. Uptake was rapid, and by 12 h the digestive gland had accumulated 105 times the water ^{14}C, while other tissues had accumulated less than 15 times. Depuration was rapid at first, but slowed by 12 h post-exposure. After 156 h of depuration, the parent naphthalene that remained was found mainly in the digestive gland and muscle. However, the highest percentages of naphthalene metabolites were found in the gills, muscle, and hemolymph. Metabolites were retained to a greater degree than the parent compound. Because no significant difference in depuration rate was found between control individuals injected with ^{14}C-naphthalene and those with their nephropores and anus blocked, it was concluded that the gills are the major route of naphthalene elimination. Thin layer chromatography (TLC) of extracts of depurated ^{14}C-naphthalene indicated that <10% of the total naphthalene depurated was composed of metabolites. In-vitro mixed function oxygenase (MFO) activity was assayed on 15,000 g tissue homogenates, using diphenyloxazole as the terminal electron acceptor. Specific activity of the gills was 2 to 4 times that of the antennal glands, and no activity was detected in either muscle, digestive glands, or cardiac and pyloric stomachs. MFO activities were very low compared to fish or mammals. It was concluded that metabolism of naphthalene plays a minor role in the reduction of naphthalene levels, with the major role being played by simple diffusion of unmetabolized napthalene across a concentration gradient. This occurs across the tissue with the largest body-to-water surface area--the gill.

32 Mecklenburg, T. A., S. D. Rice, and 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. In D. A. Wolfe (editor), Fate and Effects of Petroleum Hydrocarbons in Marine Ecosystems and Organisms, p. 221-228. Pergamon Press, New York.

Larvae of coonstripe shrimp and king crab were exposed to solutions of the water-soluble fraction (WSF) of Cook Inlet crude oil in a series of bioassays on intermolt stages I and II and the molt period from stage I to stage II. Molting larvae were more sensitive than intermolt larvae to the WSF, and molting coonstripe shrimp larvae were more sensitive than molting king crab larvae. When molting larvae were exposed to high concentrations of the WSF (1.15-1.87 ppm total hydrocarbons) for as little as 6 h, molting success was reduced by 10-30% and some deaths occurred. When larvae were exposed to these high concentrations for 24 h or longer, molting declined 90-100% and the larvae usually died. The lowest concentrations tested (0.15-0.55 ppm total hydrocarbons) did not inhibit molting at any length of exposure, but many larvae died after molting. lethal concentrations (LC_{50}'s) based on 144 h of observation for molting coonstripe shrimp and 120 h for molting king crab were much lower than the 96-h LC_{50}'s, showing that the standard 96-h LC^{50} is not always sufficient for determining acute oil toxicity. Although our LC_{50}'s for intermolt larvae are higher than levels of petroleum hydrocarbons reported for chronic and spill situations, some of our LC_{50}'s for molting larvae exposed 24 h and longer are similar to or below these environmental levels. Comparisons of sensitivity to oil between different crustacean species or life stages should be based on animals tested in the same stage of the cycle, such as intermolt.

33 Merrell, T. R. 1988. Fisheries resources. In D.G. Shaw and M. J. Hameedi (editors), Environmental Studies in Port Valdez, Alaska: A Basis for Management, p. 203-224. Springer-Verlag, New York.

Pink, chum, and coho salmon and Pacific herring are the most important fisheries resources in Port Valdez from both commercial and recreational standpoints. Early life stages of these species are the most vulnerable to oil pollution: pink and chum salmon eggs in intertidal spawning streambeds, and fry during early marine life; coho salmon smolts during their seaward migration through Port Valdez; and Pacific herring eggs and larvae during their first few weeks of life before they have dispersed away from spawning sites.

The new Solomon Gulch Hatchery is expected to reach full production of salmon by 1989, when more than 6 million pink, 324,000 chum, and 60,000 coho salmon will return each year as adults. Most of the pink and chum salmon will be caught by common property commercial net fisheries, and most of the coho salmon by sport fishermen. Unless a catastrophic oil spill occurs in Port Valdez, or concentrations of toxic components from the treated tanker ballast effluent become substantially higher in Port Valdez than at present, it is unlikely that oil pollution will have significant adverse impacts on hatchery or natural stocks of salmon, herring, or other fishery resources.

The possibility of eventual subtle indirect effects of hydrocarbons on salmon and herring, and their habitat, cannot be ruled out, however. Hydrocarbon concentrations from the ballast effluent are gradually increasing in sediment and water and could eventually have harmful effects, such as altering migratory behavior of juvenile and adult salmon, or diminishing the abundance of prey species upon which salmon and herring are dependent during early sea life.

34 Moles, A. 1980. Sensitivity of parasitized coho salmon fry to crude oil, toluene, and naphthalene. Trans. Am. Fish. soc. 109:293-297.

The effect of parasitism by glochidia of Anodonta oregonensis (a freshwater mussel) on the sensitivity of coho salmon fry, Oncorhynchus kisutch, to oil was determined by exposing fry with different levels of parasitism to several concentrations of either the water-soluble fraction of Prudhoe Bay Crude oil or the aromatic hydrocarbons toluene and naphthalene. Fry infested with 20-35 glochidia were significantly ($P < 0.05$) more sensitive to each of the toxicants than uninfested fish. Sensitivity increased linearly with increased parasite numbers. Interpretation and application of results of toxicity tests should take into account the kinds and intensities of parasitism found both in the test animals and in the wild populations of fish.

35 Moles, D. A. 1977. Effect of parasitism by glochidia of Anodonta oregonensis Lea on the sensitivity of coho salmon fry, ***Oncorhynchus kisutch*** Walbaum, to the water-soluble fraction of Prudhoe Bay crude oil and the effect of crude oil on the development of the glochidium. M.S. Thesis, Univ. Alaska, Juneau, 50 p.

Larvae of the freshwater mussel Anodonta oregonensis Lea are incubated amongst the branchial lamellae of the mother and when released, glochidia become protelean parasites on fins of fish such as coho salmon.

Ninety-six hour static bioassays using the water soluble fractions (WSF) of Prudhoe Bay crude oil and benzene were conducted on the adult mussels to determine the sensitivity of the mussels to the toxicants. Crude oil water-soluble fraction had no lethal effect and the median tolerance limit (TLm) for mussels in benzene was 500 ppm.

Exposing egg bearing mussels to the water-soluble fraction (WSF) of Prudhoe Bay crude oil for 96-h and subsequently holding the mussels in the laboratory for two months resulted in an inhibition of the development of the glochidia. The eggs of mussels exposed to oil concentrations of 2.4 ppm total aromatics had nearly completed development while mussels exposed to 10.94 ppm still carried fertilized eggs.

Coho salmon fry were inoculated with glochidia at three levels of infestation (10-45, 46-65, and 66-100 parasites per fish) and exposed to concentrations of Prudhoe Bay WSF ranging from 0.95 ppm to 11.73 ppm total aromatics for 96 h. TLm's ranged from 10.38 ppm total aromatics for non-parasitized fish to 2.26 ppm for heavily (66-100) parasitized fish.

The conclusions of the study are: 1) adult freshwater mussels are highly tolerant to oil pollution, 2) the development of glochidia incubating in the adult mussel can be inhibited by exposure to crude oil WSF with the degree of inhibition increasing with increasing oil concentration and, 3) the greater the number of glochidia on coho salmon fry, the greater the sensitivity of the salmon to water-soluble fraction of Prudhoe Bay crude oil.

36 Moles, A., M. M. Babcock, and S. D. Rice. 1987. Effects of oil exposure on pink salmon, ***Oncorhynchus gorbuscha,*** alevins in a simulated intertidal environment. Mar. Environ. Res. 21:49-58.

Pink salmon, Oncorhynchus gorbuscha, alevins (5 and 60 days after hatching) were continuously or intermittently exposed for 30 days to the water-soluble fraction (WSF) of Cook Inlet crude oil in fresh water or in a simulated freshwater-seawater cycle. Alevins exposed to 0.7-2.4 mg/liter WSF in the simulated tidal cycle were more sensitive to oil, had reduced yolk reserves, and accumulated more hydrocarbons than did alevins exposed to the same concentrations in fresh water. Alevins in fresh water were more sensitive to continuous than to intermittent exposures. In all exposures, 60-day alevins were more severely affected than were 5-day alevins.

37 Moles, A., S. Bates, S. D. Rice, and S. Korn. 1981. Reduced growth of coho salmon fry exposed to two petroleum components, toluene and naphthalene, in fresh water. Trans. Am. Fish. Soc. 110:430-436.

Coho salmon, Oncorhynchus kisutch, fry were exposed for 40 days to stable, sublethal concentrations of toluene or naphthalene in fresh water. All fry were fed equal daily rations of Oregon[2] Moist Pellet Formula II. Dry weights, wet weights, and lengths of fry exposed to the two highest concentrations of each toxicant for 40 days were significantly less than controls ($P < 0.01$). Growth per day, determined from weights and lengths, decreased linearly with increased concentrations. Fry exposed to

[2]Reference to trade names does not imply endorsement by National Marine Fisheries Service, NOAA:

naphthalene had a slower growth rate than fry exposed to equivalent concentrations (percentage of the 96-h median lethal concentration of LC_{50}) of toluene. Concentrations 18% of the LC_{50} of naphthalene and 26% of the LC_{50} of toluene had no effect on dry weight, wet weight, or length of exposed fry.

38 Moles, A., and S. D. Rice. 1983. Effects of crude oil and naphthalene on growth, caloric content, and fat content of pink salmon juveniles in seawater. Trans. Am. Fish. Soc. 112:205-211.

Juvenile pink salmon Oncorhynchus gorbuscha were exposed for 40 days to stable, sublethal concentrations of naphthalene and the water-soluble fraction of Cook Inlet crude oil. All fish were fed equal daily rations of Oregon Moist Pellet Formula II. Change in length of the fish was not a sensitive measure of toxicity. Fish exposed for 40 days to concentrations of toxicants as low as 33% of the 96-h LC_{50} weighed significantly less than control fish ($P < 0.05$). Juveniles exposed to the water soluble fraction of crude oil had slower growth rates than those exposed to the same concentration (percentage of the LC_{50}) of naphthalene. Fish exposed to either naphthalene or the water-soluble fraction of crude oil had decreased caloric content; however, fat content of the fish was not affected. Chronic marine oil pollution at a concentration as low as 0.40 mg/liter total aromatic hydrocarbons could reduce growth of juvenile pink salmon.

39 Moles, A., S. D. Rice, and S. Andrews. 1985. Continuous-flow devices for exposing marine organisms to the water-soluble fraction of crude oil and its components. Can. Tech. Rep. Fish. Aquat. Sci. 1368:53-61.

The devices produced stable concentrations of aromatic hydrocarbons that can be used in continuous-flow toxicity tests. The crude-oil mixing device produces a stable water-soluble fraction of 2.5 mg/l total aromatic hydrocarbons for 30-40 days. The device uses a gentle flow of water to dissolve aromatic components in a layer of crude oil floating on a 2-m column of seawater. Because the water does not pick up oil droplets as it passes through the column, a water-soluble fraction is produced rather than a dispersion. The other device, a syringe pump, introduces compounds directly into a water stream and produces a stable solution of monoaromatic hydrocarbons of any desired concentration or mixture up to the maximum solubility of the compounds.

40 Moles, A., S. D. Rice, and S. Korn. 1979. Sensitivity of Alaskan freshwater and anadromous fishes to Prudhoe Bay crude oil and benzene. Trans. Am. Fish. Soc. 108:408-414.

The sensitivity of various species and life stages of Alaskan freshwater and anadromous fishes to benzene and the water-soluble fraction of Prudhoe Bay crude oil was determined with 96-h toxicity tests. Freshwater juveniles of the six salmonid species tested had similar sensitivities: Median tolerance limits (TLm's) for crude oil ranged from 2.7 to 4.4 mg/liter; TLm's of benzene ranged from 11.7 to 14.7 µl/liter. Threespine sticklebacks and, to a lesser extent, slimy sculpins were more tolerant than salmonids. Eggs of pink salmon and coho salmon were quite tolerant to crude oil (TLm > 12 mg/liter) and benzene (TLm = 339-542 µl/liter). Emergent fry were the most sensitive freshwater stage (crude oil TLm = 8.0 mg/liter; benzene Tlm = 12.3-17.1 µl/liter). Out-migrant salmonids tested in seawater were twice as sensitive as out-migrant salmonids tested in fresh water, apparently because of the additional stress of entering seawater and the physiological changes associated with this transition. Seawater sensitivities were 1.1-3.6 mg/liter for crude oil and 5.5-8.5 µl/liter for benzene.

41 Myren, R. T., and J. J. Pella. 1977. Natural variability in distribution of an intertidal population of ***Macoma balthica*** subject to potential oil pollution at Port Valdez, Alaska. Mar. Biol. 41:371-382.

Natural variability in the abundance of an intertidal population of the lamellibranch Macoma balthica (Linnaeus, 1758) was measured during 1971 and 1972 in a study area near the proposed oil storage and tankship loading facility at the southern terminus of the Trans-Alaska pipeline in Port Valdez, Alaska. M. balthica were divided for analysis into a large and a small size category. Small temporal changes in population densities throughout the entire study area were detected for both size categories over several of the 7 sampling times of the 2-year period. Large and persistent differences in density were found among elevation contour intervals for either size category. Densities of both size categories were more stable at the higher elevations of the study site. Large M. balthica were more homogeneously distributed along a given elevation contour interval than the small category. Mobility and time available to redistribute at a horizontal location would explain the more homogeneous distribution of large M. balthica if competition for food resources exists.

42 O'Clair, C. E., J. L. Hanson, J. S. MacKinnon, J. A. Gharrett, N. I. Calvin, T. R. Merrell, Jr. 1978. Baseline/ reconnaissance characterization littoral biota, Gulf of Alaska and Bering Sea. In Environmental Assessment of the Alaskan Continental Shelf. Annual Reports of Principal Investigators for the Year Ending March 1978. Volume 4, Receptors--Fish, Littoral, Benthos, p. 256-415. U.S. Dep. Commer., NOAA. Available Arctic Environmental Assessment Center, 222 W. 8th Ave., No. 56, Anchorage, AK 99513.

Distribution and relative abundance patterns of littoral plants and invertebrates at representative sites in the eastern Gulf of Alaska are described. Eighteen sites were chosen for study. In addition we examined, insofar as the data permit, those factors which are likely to play important roles in structuring intertidal communities.

Understanding how communities are organized is important for predicting the effects of oil and gas development on community composition.

Within the limitations of our data we examine the role of an important interaction in intertidal communities, competition for space, especially competition among dominant competitors and accompanying effects on subdominant. Our data indicates that total species richness tends to be greater in patches of intertidal area dominated by Mytilus edulis than in patches dominated by Fucus distichus, and that the difference is accounted for by increased species richness of small subdominant in Mytilus dominated areas. Mytilus does not appear to have a greater adverse effect on competitively inferior large subdominant than does Fucus.

43 O'Clair, C. E., and S. D. Rice. 1985. Depression of feeding and growth rates of the seastar ***Evasterias troschelii*** during long-term exposure to the water-soluble fraction of crude oil. Mar. Biol. 84:331-340.

To test the effect of petroleum hydrocarbons on predation by the seastar Evasterias troschelii (Stimpson, 1862) on the mussel Mytilus edulis (L.), we exposed the predator with the prey to six concentrations of the water-soluble fraction (WSF) of Cook Inlet crude oil. During a 28 d exposure in a flow-through system, seastars were more sensitive to the WSF than mussels: the LC_{50} for the seastars was 0.82 ppm at Day 19 and, although no mussels were exposed to WSF for more than 12 d, none died. Daily feeding rates and growth of seastars were significantly reduced at all concentrations above 0.12 ppm. At 0.20, 0.28 and 0.72 ppm WSF, daily feeding rates were, respectively, 53, 37, and 5% of the control rate; at higher concentrations, the seastars did not feed. These laboratory results show that E. troschelii is more sensitive to chronic low levels of the WSF of crude oil than the prey. Oil pollution could reduce predation on mussels and increase their dominance in the intertidal zones.

44 Pelto, M. J., R. W. Williamson, and J. Knull. 1978. Dispersion of drogues: an estimation of pollutant dispersal in Port Valdez, Alaska. Northwest and Alaska Fisheries Center Processed Report, 10 p. Northwest and Alaska Fish. Cent., Natl. Mar. Fish. Serv., NOAA, 2725 Montlake Blvd. E., Seattle, WA 98112.

Assemblages of drogues in Port Valdez dispersed at rates which increase with time. The rates of dispersal were found by computing the variance (D^2) of the distances transited by the drogues and fitting the results to $D^2 - at^b$. A mean value of 1.8 was determined for b with a range between 0.1 and 2.5.

Rates of change of the variance of drogue distances found imply that effective diffusivity in the direction of flow was between 3.2×10^3 and 14.2×10^3 cm^2/sec. Diffusivity in the transverse direction was between 0.6×10^3 and 6.8×10^3 cm^2/sec. These values are an order of magnitude less than found by another type of drogue method in Lake Michigan and establish lower limits to rates of diffusion in Port Valdez.

45 Rice, S. D. 1985. Effects of oil on fish. In F. R. Engelhardt (editor), Petroleum Effects in the Arctic Environment, p. 157-182. Elsevier Applied Science Publishers, New York.

Literature related to the effects of oil on fish is reviewed with particular emphasis on implications for spilled oil in the Arctic. Although toxicity of oil and its components to individual fish is well documented in laboratory studies, the effects of oil spills on fish are less understood. In the laboratory, concentrations of <1 ppm aromatic hydrocarbons have been found to affect growth in fish. Outside the laboratory, fish are more likely to be affected by chronic sources of oil pollution than by a one-time spill with short-term, high concentrations. Eggs and larvae are the most sensitive life stages of fish: concentrations of <1 ppm aromatic hydrocarbons probably affect their development in many species. Although fish at all life stages are apparently vulnerable to damage from oil spills, devastation to fishery stocks as a result of spills is not documented. Local populations have, however, been eliminated from industrialized bays and estuaries where oil may be a contributing pollutant.

Little is known about spilled oil in the Arctic, but Arctic populations may be relatively vulnerable because aromatic hydrocarbons may persist longer in shallow, cold waters like those found on the northern continental shelf.[1]

46 Rice, S. D. 1985. Fisheries and oil: facts and figures. Alaska Fish and Game 18[17](6):35-37.

For ten years, biologists at the Auke Bay Laboratory, National Marine Fisheries Service, have studied the effects of oil on selected marine animals. They have found that the lethal concentration of Alaskan crude oil is about 1-2 ppm aromatic compounds for salmon, 1-3 ppm for king crab and shrimp, and over 10 ppm for intertidal animals such as prickleback eels and mussels after 96-h exposures. For shrimp and crab larvae concentrations as low as 0.2 ppm are lethal, and salmon smolts in seawater were found to be twice as sensitive to oil as smolts in freshwater.

Researchers noted that aquatic animals, especially fish, can rid themselves of petroleum hydrocarbons when placed in fresh water. Marine eggs and larvae, and sedentary animals such as clams, may not be able to avoid contaminated areas. Laboratory studies indicate that crabs living in subtidal areas with fine sediment substrates may accumulate hydrocarbons in tissues and egg-bearing success may be affected. Animals like crabs and salmon may detect oil through their sense of smell and, in the laboratory, avoid oil after detection.

Researchers concluded that wetlands are probably the habitat most vulnerable to adverse impacts from oil pollution because they are shallow, highly productive nursery areas for many oil-sensitive species and because decontaminating bottom sediments would be difficult. Rocky shores are less productive and could be cleansed of oil by wave action, but seasonal concentrations of birds and marine mammals along these shores could be vulnerable to oil-spill effects.[1]

47 Rice, S. D. 1977. A review of oil toxicity studies conducted at the Auke Bay Laboratory. In B. Melteff (editor), Oil and Aquatic Ecosystems, Tanker Safety and Oil Pollution Liability. Proceedings of the Cordova Fisheries Institute, April 1-3, 1977, Cordova, Alaska, p. 111-113. Univ. Alaska, Fairbanks, Alaska Sea Grant Rep. 77-8.

Although each of our publications has specific conclusions, the two most significant general conclusions are:

1. We have generally found crustacean larvae to be the most sensitive life stage, especially when molting.

2. Alaskan species may be more vulnerable to oil than species from warmer waters, since lower temperatures cause toxic aromatic hydrocarbons to persist longer. Temperature effects on oil toxicity and animal sensitivity are complex and warrant further study.

48 Rice, S. D. 1974. Toxicity and avoidance tests with Prudhoe Bay oil and pink salmon fry. In 1973 Proceedings of the Joint Conference on Prevention and Control of Oil Spills, March 13-15, 1973, Washington, DC, p. 667-670. American Petroleum Institute, Washington, DC.

With the potential of oil pollution harming Alaska's marine resources, experiments were conducted at the National Marine Fisheries Service, Auke Bay Fisheries Laboratory to determine the concentrations of Prudhoe Bay crude oil that are acutely toxic to pink salmon fry in fresh water and seawater and also the concentrations of this oil that fish avoid. Observed 96-h TLm values were 88 mg of oil/liter of water in fresh water and 213 mg/liter in seawater in June and 100 mg/liter in seawater in August. Among fry held in seawater, older fry were more susceptible to oil toxicity than younger fry and older fry were also more sensitive in their detection and avoidance of oil; older fry in seawater avoided oil concentrations as low as 1.6 mg of oil/liter of water. The avoidance of oil by salmon fry was quite apparent and suggests that there is potential for oil pollution to change their migration behavior.

49 Rice, S. D., and M. M. Babcock. 1989. Effects of habitat and environmental variables on red king crabs, and settling of glaucothoe. In L. E. Jarvela and L. K. Thorsteinson (editors), Proceedings of the Gulf of Alaska, Cook Inlet, and North Aleutian Basin Information Update Meeting, February 7-8, 1989, Anchorage, Alaska, p. 49-53. Available National Marine Fisheries Service, Auke Bay Laboratory.

Bering Sea red king crab (Paralithodes camtschatica) populations crashed in the early 1980's. There is considerable speculation on the causes of the population decline. Understanding of the population dynamics of king crabs is limited by the lack of biological knowledge, particularly for the larval and juvenile life stages. The impacts of environmental and habitat variables on the early life stages remain largely unknown.

The objectives of this research were to determine the role of environmental and habitat variables on red king crab eggs, larvae, and juveniles. Many of these variables influence year-class strength. Adults were not the focus of the study, except for ovigerous females that were incubating eggs. Both laboratory and field studies were conducted at Auke Bay, Southeast Alaska.

A comprehensive report detailing the results of our research on red king crabs is scheduled to be finished in spring 1990.

50 Rice, S. D., M. M. Babcock, C. C. Brodersen, M. G. Carls, J. A. Gharrett, S. Korn, A. Moles, and J. W. Short. 1987. Lethal and sublethal effects of the water-soluble fraction of Cook Inlet crude oil on Pacific herring (Clupea harengus pallasi) reproduction. U.S. Dep. Commer., NOAA Tech. Memo. NMFS F/NWC-111, 63 p.

Pacific herring (Clupea harengus pallasi) are a valuable commercial fishery in the northwestern Pacific Ocean, where they are harvested primarily just before spawning when the edible ovaries are at maximum ripeness. Our studies examined the effects of oil on important stages of the herring reproductive process. Using the water-soluble fraction (WSF) of Cook Inlet crude oil, we studied effects of lethal and sublethal exposures on prespawn adult Pacific herring, eggs, yolk sac larvae, and feeding larvae. We also studied the effects of feeding oil-contaminated prey to herring larvae. The results of our study are summarized:

1. Prespawn adult herring exposed to WSF had a 2- and 12-day LC_{50} (the median concentration that killed 50% of the herring) of 2.3 parts per million (ppm) aromatic hydrocarbons.

2. Adults exposed 12 days to 1.6 ppm produced eggs that had normal hatching success.

3. Eggs exposed 2 days to 5.3 ppm had normal hatching success; eggs exposed 12, days had LC_{50} of 1.5 ppm.

4. Yolk-sac larvae exposed ???h to 6.1 ppm survived; yolk-sac larvae exposed from 16 h to 6 days had LC_{50}'s of 2.8 to 2.3 ppm.

5. Feeding larvae exposed 7 days had a LC_{50} of 1.8 ppm; exposed 21 days, 0.36 ppm.

6. Uptake of hydrocarbons in adult herring was rapid in muscle, liver, testes, and mature and immature ovaries, but equilibrium was not reached in 10 days of exposure.

7. Muscle tissue generally accumulated the highest levels of hydrocarbons; immature ovarian tissue accumulated almost two times the levels found in mature ovarian tissue.

8. In adults, initial depuration was rapid but slowed after 24 h, and 10% of the hydrocarbons were still present after 7 days in clean water. After 14 days, hydrocarbon levels were not significantly higher in the control levels.

9. Uptake in larvae was more rapid than in adults and reached equilibrium within 4 h. Retention was lower in larvae than adults, and after 24 h, only 2% of the ^{14}C-labeled naphthalene remained in larval tissues.

10. Larval growth was significantly reduced after 7 days of exposure to 0.3 ppm, and growth reductions were greater after longer exposures and higher concentrations.

11. Growth of larvae was not significantly reduced by a diet of oil contaminated prey.

Feeding larvae of Pacific herring are killed by shorter exposures and lower concentrations than are the eggs or the adults. This is therefore the life stage most likely to be impaired by oil. Even if oil is present at levels too low to threaten the survival of herring, fisheries could be impacted if the rapid bioaccumulation and persistent retention of oil hydrocarbons in the edible ovarian tissues made the herring unmarketable.

51 Rice, S. D., M. M. Babcock, C. C. Brodersen, J. A. Gharrett, and S. Korn. 1987. Uptake and depuration of aromatic hydrocarbons by reproductively ripe Pacific herring and the subsequent effect of residues on egg hatching and survival. In W. B. Vernberg, A. Calabrese, F. P. Thurberg, and F. J. Vernberg (editors), Pollution Physiology of Estuarine Organisms, p. 139-154. Univ. South Carolina Press, Columbia, SC.

Adult Pacific herring (Clupea harengus pallasi) were exposed to the water-soluble fraction (WSF) of Cook Inlet crude oil to determine uptake and depuration of aromatic hydrocarbons in tissues (including ovaries) and survival of ova and spawn. Adults accumulated high concentrations of aromatic hydrocarbons in tissues (including ovaries), but tissue concentrations did not reach equilibrium during the 10-d sampling. Depuration occurred rapidly during the first 24 h, but then took 14 d before tissue concentrations were not significantly different from controls. Exposure to WSF did not affect the survival of ova and spawn. If the adults survived, their spawn hatched. In a companion test, artificially spawned and fertilized eggs from unexposed adults were exposed to several concentrations of WSF. Herring eggs were tolerant to short-term (2-d), direct exposures to high concentrations of WSF but had a lower (1.5 ppm) LC_{50} (median lethal concentration) than did adults (2.2 ppm) for 12-d exposure. The reproductive process of herring just prior to spawning did not appear to be as sensitive to oil as did eggs.

52 Rice, S. D. and J. F. Karinen. 1976. Acute and chronic toxicity, uptake and depuration, and sublethal metabolic response of Alaska marine organisms to petroleum hydrocarbons. In Environmental Assessment of the Alaskan Continental Shelf. Annual Reports of Principal Investigators for the Year Ending March 1976, Vol. 8, Effects of contaminants, p. 25-118. U.S. Dep. Commer., NOAA. Available Arctic Environmental Assessment Center, 222 W. 8th Ave., No. 56, Anchorage, AK 99513.

This study was designed to determine the acute and chronic toxicity of crude oil and its component fractions on physiological and behavioral mechanisms of selected Arctic and subarctic organisms and to determine recovery rates of selected organisms in laboratory and field studies.

Conclusions to date: Bioassays with invertebrates require modification of standard bioassay procedures because they do not complete their response in 96-h. Temperature has little effect on toxicity, so that data generated at 12°C can be extrapolated to colder climates. Oil exposures stimulate metabolism in fish, rather than depress metabolism, as in crabs.

53 Rice, S. D., J. F. Karinen, and C. C. Brodersen. 1985. Effects of oiled sediment on juvenile king crab. In Outer Continental Shelf Assessment Program, Final Reports of Principal Investigators, Vol. 29, p. 287-310. U.S. Dep. Commer., NOAA. Available Arctic Environmental Assessment Center, 222 W. 8th Ave., No. 56, Anchorage, AK 99513.

This l-year project to determine effects of oiled sediment on juvenile king crab began in April 1982. Juvenile king crab (Paralithodes camtschatica) were exposed to the water-soluble fraction of Cook Inlet crude oil (flow-through, stable concentrations for 30 days) or to oiled sediments for 3 months. The higher exposure concentrations of the water-soluble fraction were toxic and affected survival, growth, feeding rate, and scope for growth. Adverse effects were visible in just a few days. In contrast, the oiled sediments did not cause any measurable adverse effects on survival, feeding rate, growth, molting success, or scope for growth during the 3-month exposure, including those crabs exposed to the highest concentrations--2%. Aromatic hydrocarbons were detected in some tissues of the crabs, including the crabs exposed to oiled sediment. Most experimental evidence suggests that exposures to oiled sediment will have minimal impact directly on survival and growth of juvenile king crab. However, the fact that hydrocarbons were detected in the tissues means that there is some contact with the hydrocarbons, and adverse effects are possible, although exposures longer than 3 months would be required.

54 Rice, S. D., J. F. Karinen, and S. Korn. 1978. Acute and chronic toxicity, uptake and depuration, and sublethal response of Alaska marine organisms to petroleum hydrocarbons. In D. A. Wolfe (editor), Marine Biological Effects of OCS Petroleum Development, p. 11-24. U.S. Dep. Commer., NOAA Tech. Memo. ERL-OCSEAP-1.

Oil effects studies at the Auke Bay Laboratory are reviewed. The studies can be broken down into two basic themes: (1) Toxicity challenge experiments, where an attempt is made to identify sensitive species, life stages, factors that affect toxicity, or components that are most responsible for toxicity; and (2) sublethal physiological response, where an attempt is made to identify, measure, and characterize physiological responses that are indicative of oil stress. Results from the series of sublethal effects studies may have application to monitoring effects of oil and defining the mode of action of toxicants.

55 Rice, S. D., S. Korn, C. C. Brodersen, S. A. Lindsay, and S. A. Andrews. 1981. Toxicity of ballast-water treatment effluent to marine organisms at Port Valdez, Alaska. In Proceedings 1981 Oil Spill Conference, Atlanta, Georgia, March 2-5, p. 55-61. American Petroleum Institute, Washington, DC.

Approximately 12 million gallons of oily ballast water is taken ashore and treated daily at the Alyeska treatment plant, where tankers take on crude oil at the terminus of the Trans Alaska pipeline near Valdez, Alaska. Most oil is removed, but light aromatic hydrocarbons (1 to 16 parts per million) remain in the large volume of discharged effluent. Between May and July, the concentration of aromatic hydrocarbons in the treated effluent (measured by gas chromatography) generally declined as seasonal temperatures increased. We measured the toxicity of the effluent on site at Valdez. For the larvae of crustaceans the median lethal concentration LC_{50} was between 10 and 20 percent of treated effluent in 96-h static tests. For salmon fry and shrimp in repeated acute flow-through assays, the (LC_{50}) was quite consistent, between 20 and 40 percent of treated effluent. Because the concentrations of aromatic hydrocarbons was much lower in the later tests but the toxicity of the effluent was not lower, toxicants other than aromatic hydrocarbons must contribute significantly to the toxicity of the effluent from the ballast-water treatment plant.

56 Rice, S. D., S. Korn, and J. F. Karinen. 1981. Lethal and sublethal effects on selected Alaskan marine species after acute and long-term exposure to oil and oil components. In Environmental Assessment of the Alaskan Continental Shelf. Annual Reports of Principal Investigators for the Year Ending March 1981, Vol. 4, Effects of Contaminants, p. 61-78. U.S. Dep. Commer., NOAA. Available Arctic

Environmental Assessment Center, 222 W. 8th Ave., No. 56, Anchorage, AK 99513.

This report consists of an Annual Report that summarizes status and programs for FY 80 studies, followed by Quarterly Report summarizing status of FY 81 studies. All of our studies are applied laboratory studies, where we expose a variety of marine species and life stages, to determine survival and effects of short and long-term exposures to water-soluble fractions of oil. We had two major objectives in FY 80: (1) to determine the vulnerability of pink salmon alevins exposed to oil in a simulated intertidal spawning environment. (2) to synthesize and publish results to previous OCSEAP research.

57 Rice S. D., S. Korn, and J. F. Karinen. 1980. Lethal and sublethal effects on selected Alaskan marine species after acute and long-term exposure to oil and oil components. In Environmental Assessment of the Alaskan Continental Shelf. Annual Reports of Principal Investigators for the Year Ending March 1980, Vol. 3, Effects, Contaminant Baselines, p. 1-12. U.S. Dep. Commer., NOAA. Available Arctic Environmental Assessment Center, 222 W. 8th Ave., No. 56, Anchorage, AK 99513.

Fish were more sensitive than the Arctic invertebrates tested and were comparable to pink salmon (subarctic species). Arctic animals were highly adaptable to temperature changes, although there were no effects of temperature on sensitivity of Arctic animals to oil. Results indicate little difference in sensitivity of Arctic and subarctic animals to oil. Lower environmental temperatures in the Arctic could result in oil persisting longer after a spill due to lower volatility and biodegradation of oil components and because oil would become trapped or immobilized in ice. There are fewer species in the Arctic and food chains are very short. If a species is affected, there would be few replacement species. The Arctic habitat is more vulnerable, and once changed, less able to adjust, even though individual species are generally very hearty and tolerant of natural environmental extremes and limited amounts of pollution.

58 Rice, S. D., S. Korn, and J. F. Karinen. 1978. Lethal and sublethal effects on selected Alaskan marine species after acute and long-term exposure to oil and oil components. In Environmental Assessment of the Alaskan Continental Shelf. Final Reports of Principal Investigators, Vol. 1, Biological Studies, p. 1-32. U.S. Dep. Commer., NOAA. Available Arctic Environmental Assessment Center, 222 W. 8th Ave., No. 56, Anchorage, AK 99513.

Annual Report: The research involves physiological and bioassay tests of applied research on species indigenous to the Gulf of Alaska, Bering Sea, and Beaufort Sea. The major emphasis has shifted from strictly descriptive acute toxicity determinations to mechanistic studies and sublethal tests that will eventually allow prediction of oil impact on the biota. The studies have two basic themes. Toxicity challenge experiments, where sensitive species, life stages, factors that affect toxicity, or components that are most responsible for toxicity are identified; and sublethal physiological response, where physiological responses that are indicative of oil stress are identified, measured, and characterized.

59 Rice, S. D., S. Korn, and J. F. Karinen. 1977. Lethal and sublethal effects on selected Alaskan marine species after acute and long-term exposure to oil and oil components. In Environmental Assessment of the Alaskan Continental Shelf. Annual Reports of Principal Investigators for the Year Ending March 1977, Vol. 12, Effects, p. 23-124. U.S. Dep. Commer., NOAA. Available Arctic Environmental Assessment Center, 222 W. 8th Ave., No. 56, Anchorage, AK 99513.

Laboratory and field studies were conducted to determine recovery rates of selected organisms and ecosystems from perturbations resulting from either contamination or other disturbances associated with petroleum development. The research involved physiological and bioassay tests of applied research on species indigenous to the Gulf of Alaska, Bering Sea, and Beaufort Sea. The major emphasis of research has shifted from strictly descriptive acute toxicity determinations to mechanistic studies and sublethal tests that will eventually allow prediction of oil impact on the biota. Studies to determine the acute toxicity of the water-soluble fraction (WSF) of crude oil continue with experiments with species not tested previously. Experiments also continue with larvae of species not tested previously. Emphasis is on intertidal species, such as mussels, barnacles, snails, and sea urchins.

60 Rice, S. D., and D. A. Moles. 1991. Humpies and hydrocarbons: Relating laboratory effects studies to potential effects from the *Exxon Valdez* oil spill. Unpublished manuscript. National Marine Fisheries Service, Auke Bay Laboratory.

The potential effects from the *Exxon Valdez* oil spill on the pink salmon, *Oncorhynchus gorbuscha,* are examined in light of controlled laboratory studies. Eggs and alevins are tolerant of short term water-borne oil exposures, but are especially vulnerable in Prince William Sound where whole oil could contaminate the intertidal redds. Out migrant fry in seawater are about twice as sensitive as fry in freshwater, but exposure to high levels of hydrocarbons in seawater from a spill is unlikely. If spilled oil affects out migrant fry, laboratory studies suggest that decreased growth will be the most likely effect. Returning adults have declining abilities to metabolize hydrocarbons, but their exposures are likely to be minimal.

61 Rice, S. D., D. A. Moles, J. F. Karinen, S. Korn, M. G. Carls, C. C. Brodersen, J. A. Gharrett, and M. M. Babcock. 1984. 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. Dep. Commer., NOAA Tech. Memo. NMFS F/NWC-67, 128 p.

This report reviews and summarizes all oil-effects research by the Auke Bay Laboratory from the beginning of these studies in 1970 through 1981. Both published and unpublished results from 62 studies are included, regardless of funding source. Research is reviewed according to subject (e.g. toxicity, sublethal effects, studies at Port Valdez). A bibliography and abstracts are also included.

62 Rice, S. D., A. Moles, and J. W. Short. 1975. The effect of Prudhoe Bay crude oil on survival and growth of eggs, alevins, and fry of pink salmon, Oncorhynchus gorbuscha. In Proceedings of 1975 Conference on Prevention and Control of Oil Pollution, p. 503-507. American Petroleum Institute, Washington, DC.

Standard 96-h bioassays with "total" oil solutions in fresh water and seawater determined differences in sensitivity of the developing life stages of pink salmon (Oncorhynchus gorbuscha). Eggs were the most resistant and emergent fry (yolk sac absorbed) the most sensitive to acute 4-day exposures. In fresh water, the 96-h median tolerance limit (TLm) of fry was 12 ppm as measured in subsurface water by infrared spectrophotometry. In seawater, it was 6 ppm.

Three life stages of alevins were exposed to IO-day sublethal exposures of the water-soluble fraction to determine what doses might affect growth. Growth was affected most severely in alevins exposed during later developmental stages. Decreased growth was observed in fry after 10-day exposures at about 10% of the 96-h TLm limit for that life stage.

63 Rice, S. D., D. A. Moles, T. T. Taylor, and J. F. Karinen. 1979. Sensitivity of 39 Alaskan marine species to Cook Inlet crude oil and No. 2 fuel oil. In Proceedings of 1979 Oil Spill Conference (Prevention, Behavior, Control, Cleanup), p. 549-554. American Petroleum Institute, Washington, DC.

The sensitivities of 39 subarctic Alaska species of marine fish and invertebrates to water-soluble fractions of Cook Inlet crude oil and No. 2 fuel oil were determined.

Sensitivity was correlated to habitat. Pelagic fish and shrimp were the most sensitive animals to Cook Inlet crude oil with 96-h median tolerance limits (TLm's) from 1-3 mg/l total aromatic hydrocarbons. Benthic animals, including fish, crabs, and scallops were moderately tolerant (TLm's to Cook Inlet crude oil of 3-8 mg/l total aromatic hydrocarbons). Intertidal animals, including fish, crabs, starfish, and many molluscs, were the most tolerant forms to water-soluble fraction of petroleum (TLm's greater than 8-12 mg/l of total aromatic hydrocarbons). Most of the intertidal animals were not killed by static oil exposures. No. 2 fuel oil was more toxic to most species than Cook Inlet crude oil.

Sensitive pelagic animals are not necessarily more vulnerable to oil spills than tolerant intertidal forms--oil may damage intertidal environments more easily and adverse effects may persist longer than in damaged pelagic environments.

64 Rice, S. D., J. W. Short, C. C. Brodersen, T. A. Mecklenburg, D. A. Moles, C. J. Misch, D. L. Cheatham, and J. F. Karinen. 1976. Acute toxicity and uptake-depuration studies with Cook Inlet crude oil, Prudhoe Bay crude oil, No. 2 fuel oil and several subarctic marine organisms. Northwest Fisheries Center Processed Report, 90 p. Northwest and Alaska Fish. Cent., Natl. Mar. Fish. Serv., NOAA, 2725 Montlake Blvd. E., Seattle, WA 98112.

Several life stages of Alaskan fish, shrimp, scallops, and crab were subjected to laboratory experiments to determine levels of acute toxicity of Cook Inlet and Prudhoe Bay crude oils and fuel oil and to determine the rate and degree of depuration of hydrocarbons from sublethal concentrations of water-soluble fractions of Cook Inlet crude oil.

Acute toxicity of crude oil was determined by standard bioassays using both oil-water dispersions and water-soluble fractions.

Results of the study are reported as median tolerance limits in ppm oil and are given by species at specified temperature ranges. Both larval and adult forms were tested. Larvae were most sensitive, and median tolerance limits of all non-larval stages of the eight species tested were similar.

Rate and amount of hydrocarbon uptake and depuration were determined by exposing test organisms to seawater containing less than 20% of the WSF concentration that would be expected to kill 50% of the animals in 96 h. Exposure and depuration periods each lasted for 96 h. Gas chromatography was used to determine hydrocarbon concentrations in samples of tissues taken periodically during the test periods. All species tested accumulated significant amounts of aromatic hydrocarbons; depuration rates varied with species.

Behavioral observations of larvae near surface oil slicks and physiological studies of the effect of dissolved oil fractions on crab respiration were also made.[1]

65 Rice, S. D., J. W. Short, and J. F. Karinen. 1977. Comparative oil toxicity and comparative animal sensitivity. In D. A. Wolfe (editor), Fate and Effects of Petroleum Hydrocarbons in Marine Ecosystems and Organisms, p. 78-94. Pergamon Press, New York.

A review is presented of studies concerning: (1) the behavior of oil in water, (2) the methodology problems associated with bioassays, (3) the comparative toxicity of oils, oil-water mixes, and oil components, (4) the comparative sensitivity of different life stages and species. Conclusions relating to these subjects are presented in list form, incorporating recommendations and guidelines for future work. Improvements in methodology are advocated, in order that sensitivity tests may be applied to new species and to previously investigated species with greater accuracy.

66 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, p. 395-406. American Institute of Biological Sciences, Washington, DC.

We used 96-h static bioassay to determine the TLm's (median tolerance levels) of 27 different invertebrate and vertebrate Alaskan marine species exposed to WSF's (water-soluble fractions) of Cook Inlet crude oil and No. 2 fuel oil. Concentrations of oil in the exposure doses of the WSF's were determined by infrared spectrophotometry.

No. 2 fuel oil was somewhat more toxic than the Cook Inlet crude oil to some of the species. Fish were consistently among the more sensitive species with 96-h TLm's from 0.81 to 2.94 ppm. Some invertebrates were as sensitive as fish, while others were quite resistant. Intertidal invertebrates were consistently among the most resistant species.

It appears that Alaskan marine species may be slightly more sensitive than similar species residing in more temperate regions. However, the differences in observed sensitivity may be due to the greater toxicity of oil at lower temperatures (because of greater persistence of hydrocarbons) rather than to actual increases in the sensitivity of the animals.

67 Rice, S. D., and R. E. Thomas. 1989. Effect of pre-treatment exposures of toluene or naphthalene on the tolerance of pink salmon ***(Oncorhynchus gorbuscha)*** and kelp shrimp ***(Eualis*** [sic] ***suckleyi).*** Comp. Biochem. Physiol. C Comp. Pharmacol. 94:289-293.

1. Toluene pre-treatment exposures did not affect survival of kelp shrimp or pink salmon fry in subsequent bioassays.

2. Naphthalene pre-treatment exposures to kelp shrimp caused increased sensitivity in subsequent bioassays.

3. Naphthalene pre-treatment exposures to pink salmon caused increase in tolerance in subsequent bioassays. Tolerance increase was proportional to concentration and duration of pre-treatment exposures, and decreased with periods of depuration.

68 Rice, S. D., R. E. Thomas, and J. W. Short. 1977. Effect of petroleum hydrocarbons on breathing and coughing rates and hydrocarbon uptake-depuration in pink salmon fry. In F. J. Vernberg, A. Calabrese, F. P. Thurberg, and W. B. Vernberg (editors), Physiological Responses of Marine Biota to Pollutants, p. 259-277. Academic Press, New York.

We report the changes in breathing rates during the extended exposure of pink salmon, Oncorhynchus gorbuscha, fry to oil, and examine the return to near normal rates during extended exposure. Cook Inlet and Prudhoe Bay crude oil and No. 2 fuel oil were used in the experiments. The 3 oils caused similar increases in breathing and coughing rates in the fry, and these rates increased in proportion to the oil concentrations, as measured by UV but not by IR (suggesting that naphthalenes rather than paraffins are responsible for this effect). Breathing and coughing rates of the fry remained above normal during exposure to a constant dose of oil for 72 h. High breathing rates during the first 24 h of exposure, elimination of most aromatics by 20 h, and the continued high breathing rates during the constant dose exposure for 72 h indicate that salmon fry can cope with a sublethal exposure to hydrocarbons, but at the cost of an increased metabolic rate. Increased metabolic rates may be detrimental to survival if the stress persists for long periods of time.

69 Schwartz, J. P. 1985. Effect of oil-contaminated prey on the feeding and growth rate of pink salmon fry (Oncorhynchus gorbuscha). In F. J. Vernberg, A. Calabrese, and W. Vernberg (editors), Marine Pollution and Physiology: Recent Advances, p. 459-476. Univ. South Carolina Press, Columbia, SC.

Pink salmon fry fed 0.6, 3.2 and 6.5 ppm oil-contaminated prey (OCP) for 10 d ate less than fry fed uncontaminated prey. Fry fed 0.6 ppm OCP ate more than fry fed 6.5 ppm OCP. Fry feeding rates at each OCP dose level did not improve when the fish were fed uncontaminated prey for 5 d after exposure.

The growth rate of pink salmon fry exposed to OCP for 50 d decreased with increased dose levels of OCP. The wet weight of fry fed 0.6 ppm was significantly greater than fry fed 3.2 and 6.5 ppm OCP after 50 d. Decreases in fry feeding and growth rates were not proportional to OCP hydrocarbon concentrations, but reductions in fry feeding rate correlated with reduction in growth rate. Reductions in the growth of fry exposed to the 96-h LC_{50} (0.7 ppm) of the water soluble fraction (WSF) of Cook Inlet crude oil were greater than the reduction in growth of fry fed OCP.

Pink salmon fry accumulated bicyclic aromatic hydrocarbons from OCP during the first 12 h of exposure, but concentrations returned to levels below detection after 10-d exposure to OCP. Fry exposed to WSF rapidly accumulated both mono- and bicyclic hydrocarbons within 24 h.

OCP were not acutely toxic to pink salmon fry. Fry were able to feed and grow at OCP hydrocarbon concentrations that were 5-10 times the 96-h LC_{50} for the WSF of Cook Inlet crude oil in sea water. However, reductions in the feeding rate of pink salmon fry both during and after exposure to OCP, and reductions in fry growth rate from exposure to OCP, have the potential for reducing fry survival during early sea life.

70 Schwartz, J. P. 1984. The effects of oil-contaminated prey on the feeding, growth, and related energetics of pink salmon, *Oncorhynchus gorbuscha* Walbaum, fry. Ph.D. Thesis, Univ. Alaska, Fairbanks, 99 p.

Pink salmon, Oncorhynchus gorbuscha Walbaum, fry were exposed to oil-contaminated prey (OCP) in a series of experiments to determine the effects of oil exposure via the diet on the ability of pink fry to survive. Brine shrimp, Artemia salina, nauplii were contaminated with petroleum hydrocarbons by exposure to the water-soluble fraction (WSF) of Cook Inlet crude oil and fed to the fish. Feeding rates were measured for 10 days using OCP and for 5 days using uncontaminated prey (post-exposure period). In a separate experiment, fry growth was measured over a 50 day period. In another experiment, fry oxygen consumption, food absorption and utilization, and ammonia excretion was measured to determine the effects of OCP on fry metabolic activity.

Fry feeding rates were reduced by exposure to OCP, and remained suppressed during the post-exposure period. Chronic exposure to OCP for 50 days reduced fry growth. OCP were not lethal to the fry. There was no change in fry oxygen consumption or ammonia excretion from exposure to OCP, but the fish exposed to OCP absorbed less food than controls and continued to absorb less food for 7 days after exposure. Results indicate that exposure to OCP can reduce fry growth primarily by reducing food intake, but additional nutrition is lost from the non-absorption of ingested food. Reductions in growth could decrease fry survival, and thereby reduce the number of returning adult pink salmon.

71 Short, J. W., S. D. Rice, and D. L. Cheatham. 1976. Comparison of two methods for oil and grease determination. In D. W. Hood and D. C. Burrell (editors), Assessment of the Arctic Marine Environment: Selected Topics, p. 451-465. Univ. Alaska, Fairbanks.

A gravimetric method is used by government regulatory agencies for determining levels of oil pollutants in discharge waters. This method involves extraction with an organic solvent, evaporation at elevated temperatures, and gravimetric determination of the residue. The authors compared oil content determined by the gravimetric method with oil content determined by infrared spectrophotometry for toxic water-soluble fractions of Prudhoe Bay and Cook Inlet crude oils and a No. 2 fuel oil.

The gravimetric method is adequate for grease but not for the oils. Recovery of a synthetic grease standard was 98 percent, whereas the recovery of the three pure oils ranged from 52 to 65 percent by the gravimetric method. Recovery of all the oils and the grease standard was essentially 100 percent by the infrared method. The differences between the two methods are ascribed to significant losses of volatile compounds from the oils during the evaporation step of the gravimetric method.

Gravimetric estimates of oil in toxic concentrations of water-soluble fractions ranged from 0 to 36 percent of those determined by the infrared method. Oil content of the No. 2 fuel oil water-soluble fractions was below detectable limits of the gravimetric method (1.5 mg/liter). Four-day median tolerance limits of shrimp *(Eualus fabricii)* and scallops *(Chlamys rubida),* as evaluated by the infrared water-soluble fractions of the three oils, were between 0.25 mg/liter (No. 2 fuel oil) and 3.82 mg/liter (crude oils).

It is concluded that the gravimetric method is sensitive to heavier compounds, but these have only a casual relationship to acute toxicity. Concentrations of oil in water known to have adverse effects are much lower than can be detected by the standard gravimetric method. When oil concentrations in water are to be measured and correlated with chemical toxicity, the gravimetric procedure should be supplemented with a method specific for the more soluble and volatile components.

72 Stickle, W. B., M. A. Kapper, T. C. Shirley, M. G. Carls, and S. D. Rice. 1987. Bioenergetics and tolerance of the pink shrimp *(Pandalus borealis)* during long-term exposure to the water-soluble fraction and oiled sediment from Cook Inlet crude oil. In W. B. Vernberg, A. Calabrese, F. P. Thurberg, and F. J. Vernberg (editors), Pollution Physiology of Estuarine Organisms, p. 87-106. Univ. South Carolina Press, Columbia, SC.

Adult Pandalus borealis were exposed to the water-soluble fraction (WSF) of and sediments oiled with Cook Inlet crude oil. Fifteen times more total aromatic hydrocarbons were bioaccumulated into the soft tissues of the shrimp cephalothorax during 10-d exposure to 550 ppb WSF aromatic hydrocarbons than to 84-d exposure to 2% oiled sediment. Little bioaccumulation of aromatic hydrocarbons into abdominal muscle of either group occurred. The tolerance of shrimp to the WSF fraction declined linearly with duration of exposure, to a 28-d LC_{50} value of 28 ppb total aromatic hydrocarbons. Scope for growth, or the energy budget, of shrimp remained positive at all sublethal WSF concentrations but declined significantly below control values, as a result of a decreased rate of food consumption, in shrimp exposed to concentration which were eventually lethal. Insufficient mortality occurred in shrimp exposed to oiled sediment to calculate an LC_{50} value; in fact, shrimp exposed to the highest concentrations exhibited increased scope for growth compared with control shrimp as a result of increase food consumption. Shrimp exposed to the WSF were far more vulnerable to oil effects on their survival and bioenergetics than shrimp exposed to oiled sediment.

73 Stickle, W. B., S. D. Rice, and A. Moles. 1984. Bioenergetics and survival of the marine snail *Thais lima* during long-term oil exposure. Mar. Biol. 80:281-289.

The carnivorous snail Thais lima was fed *Mytilus edulis* during a 28-d exposure to the water soluble fraction (WSF) of Cook Inlet crude oil. The LC_{50} of T. lima declined from >3,000 ppb aromatic hydrocarbons on Day 7 to 818 + 118 ppb on Day 28. The LC_{50} of M. edulis declined from > 3,000 ppb aromatic hydrocarbons on Day 7 to 1,686 + 42 ppb on Day 28. Predation rate declined linearly with increasing aromatic hydrocarbon concentration up to 302 ppb; little predation occurred at 538 ppb and none at 1,160 or 1,761 ppb. Snail absorption efficiency averaged 93.5% and did not vary as a function of WSF dose. Total energy expenditure (R+U) increased at 44 ppb aromatics and declined at lethal WSF exposures. At sublethal WSF exposures, percentages of total energy expenditure were: respiration (87%), ammonia excretion (9%) and primary amine loss (4%). These percentages did not vary as a function of WSF dose or time. 0xygen:nitrogen ratios were not affected by WSF concentration or time and indicated that T. lima derived most of its energy from protein catabolism. The uptake of aromatic hydrocarbons into the soft tissues of snails and mussels was directly related to the WSF concentration. Naphthalenes accounted for 67 to 78% of the aromatic hydrocarbons in T. lima and 56 to 71% in M. edulis. The scope for growth was negative above 150 ppb WSF aromatic hydrocarbons and above 1,204 ppb soft-body aromatic hydrocarbons. These snails were physiologically stressed at an aromatic hydrocarbon concentration which was 19% of the 28-d WSF LC_{50} (818 + 118 ppb) and/or 48% of the 28-d LC_{50} of soft tissue aromatics (2,502 ppb).

74 Stickle, W. B., Jr., S. D. Rice, C. Villars, and W. Metcalf. 1985. Bioenergetics and survival of the marine mussel, *Mytilus edulis* L., during long-term exposure to the water-soluble fraction of Cook Inlet crude oil. In F. J. Vernberg, F. P. Thurberg, A. Calabrese, and W. B. Vernberg (editors), Marine Pollution and Physiology: Recent Advances, p. 427-446. Univ. South Carolina Press, Columbia, SC.

The sensitivity of Mytilus edulis on exposure to the WSF of Cook Inlet crude oil increased with duration of exposure. Scope for growth declined in an inverse manner with WSF concentration to zero at 1163 ppb aromatic hydrocarbons, this value represents 82% of the 28-d LC_{50}. Therefore, M. edulis is not a particularly sensitive species to utilize for the study of sublethal stress during WSF exposures over long-term (one month) exposure periods. The primary determinant of a decline in scope with increased concentration of WSF was a decline in algal consumption. Scope for growth regressed in an inverse manner-against total tissue aromatic hydrocarbons at WSF concentrations up to 1083 ppb over 28-d exposure, but no relationship existed between scope for growth and total tissue concentration of aliphatic hydrocarbons. At a higher WSF aromatic hydrocarbon concentration (1083 ppb), uptake of aromatic hydrocarbons was probably reduced because of a reduced algal clearance (= feeding) rate. Oxygen:nitrogen ratios were low indicating protein catabolism, and did not decline with increased WSF exposure; however, mussels were in the postspawning phase of their reproductive cycle.

75 Stickle, W. B., T. D. Sabourin, and S. D. Rice. 1982. Bensitivity and osmoregulation of coho salmon, *Oncorhynchus kisutch,* exposed to toluene and naphthalene at different salinities. In W. B. Vernberg, A. Calabrese, F. P. Thurberg, and F. J. Vernberg (editors), Physiological Mechanisms of Marine Pollutant Toxicity, p. 331-348. Academic Press,. New York.

Coho salmon smolts were more sensitive to toluene and naphthalene in seawater than in freshwater. Tolerance dropped linearly from 0 through 10, 20, and 30%. Smolt tolerance at 30% were 54% and 63% of the 48-h TLm in freshwater for toluene and naphthalene, respectively. Smolt tolerances to toluene and naphthalene were the same after 12, 22, and 42 d of acclimation to seawater as they were after only 1 d of acclimation. The increase in sensitivity was not transient nor did it appear related to acclimation stress because the smolts gained 30% in weight in 42 d.

Toluene and naphthalene affected serum osmolality and ions but only at lethal concentrations of 100 and 130% of the 48-h TLm. At those exposure concentrations, osmolality, Na^+, and Cl^- moved down the diffusion gradients between the serum of the smolts and ambient water: decreased in freshwater smolts and increased in seawater smolts. At the same concentration, K^+ concentrations in the serum increased, even in freshwater smolts, indicating cellular damage. Exposures of 70% of the 48-h TLm had no effect on serum osmolality or ions. Consequently, we conclude that the increase in sensitivity of smolts in seawater is not related to a failure in ion-regulation ability, but rather the loss of ion-regulating ability at lethal exposures is symptomatic of other toxic actions. Increased sensitivity of smolts in seawater is not transient and the cause remains unknown.

76 Taylor, T. L., and J. F. Karinen. 1977. Response of the clam, Macoma balthica (Linnaeus), exposed to Prudhoe Bay crude oil as unmixed oil, water-soluble fraction, and oil-contaminated sediment in the laboratory. In D. A. Wolfe (editor), Fate and Effects of Petroleum Hydrocarbons in the Marine Ecosystems and Organisms, p. 229-237. Pergamon Press, New York.

The small clam, *Macoma balthica* (Linnaeus 1758), will likely be subjected to oil slicks layered on the mud and to water-soluble fractions (WSF) of crude oil or oil-contaminated sediment. Groups of adult clams in or on their natural sediment were exposed in flow-through aquaria at 7°-12°C to various concentrations of Prudhoe Bay crude oil layered on the mud surface, the water-soluble fraction of the crude oil, and oil-treated sediment (OTS).

Gentle settling of crude oil over clam beds had negligible effects on clams observed for 2 months. Water-soluble and oil-treated sediment fractions of Prudhoe Bay crude oil inhibited burrowing and caused clams to move to the sediment surface. Responses were directly proportional to concentrations of the WSF or amount of OTS. The l-h and 72-h effective median concentrations of the WSF for the responses of burrowing by unburied clams and surfacing by buried clams were 0.234 and 0.367 ppm naphthalene equivalents respectively. The interpolated amount of OTS needed for a 50% surfacing response within 24 h was 0.67 g OTS cm^{-2}.

Although short-term exposures of clams to the WSF of crude oil and OTS caused few deaths, behavioral responses of clams to oil may be of great importance to their survival in the natural environment. In these laboratory tests, many of the clams recovered, but in nature clams that come to the sediment surface may be eaten by predators or die from exposure.

77 Thomas, R. E., and S. D. Rice. 1987. Effect of water-soluble fraction of Cook Inlet crude oil on swimming performance and plasma cortisol in juvenile coho salmon ***(Oncorhynchus kisutch).*** Comp. Biochem. Physiol. C Comp. Pharmacol. Toxicol. 87:177-180.

1. Swimming performance of juvenile coho salmon decreased and plasma cortisol increased following 48-h exposure to the water-soluble fraction (WSF) of Cook Inlet crude oil at 75% of the LC_{50}.

2. Exposure of 25 and 50% of the LC_{50} did not significantly reduce swimming performance.

3. Plasma cortisol concentrations were highest in fish exposed to both the combined stress of WSF exposure and of forced swimming in a stamina tunnel.

78 Thomas, R. E., and S. D. Rice. 1986. The effects of salinity on uptake and metabolism of toluene and naphthalene by Dolly Varden, ***Salvelinus malma.*** Mar. Environ. Res. 18:203-214.

Dolly Varden ***(Salvelinus malma)*** were force-fed ^{14}C-toluene or ^{14}C-naphthalene and held for 12, 24 and 48 h in freshwater or seawater (30%) in order to determine the effect of salinity on uptake and metabolism of aromatic hydrocarbons. Fish held in seawater had slightly more ^{14}C removed from the gut than did fish held in freshwater. Whether held in freshwater or seawater, toluene was more readily metabolized by fish than was naphthalene; after 48 h, 2-3 times more ^{14}C from toluene was in the metabolite fraction of liver and central nervous system tissues. Fish held in seawater metabolized significantly less toluene and naphthalene than those in freshwater. The increased toxicity of toluene and naphthalene to Dolly Varden held in seawater appears to be the result of the decreased metabolism of these compounds by the fish.

79 Thomas, R. E., and S. D. Rice. 1986. Effect of temperature on uptake and metabolism of toluene and naphthalene by Dolly Varden char, *Salvelinus malma.* Comp. Biochem. Physiol. C Comp. Pharmacol. Toxicol. 84:83-86.

1. Tissue concentrations and metabolism of ^{14}C toluene and ^{14}C naphthalene were measured in Dolly Varden char at exposure temperatures of 4 and 12°C after oral administration of the hydrocarbons.

2. Tissue concentrations of toluene and toluene metabolites were slightly less at 12 than 4°C.

3. Metabolism of toluene was significantly greater at 12 than 4°C.

4. Tissue concentrations of naphthalene and naphthalene metabolites were less at 12 than 4°C after 48 h exposure.

5. Naphthalene metabolism was not consistently different between fish exposed at 4 and 12°C.

6. Failure to adequately metabolize toluene at reduced temperatures appears to contribute to the increased sensitivity of fish to toluene when exposed at low temperatures.

7. Lack of temperature effect on naphthalene metabolism correlates with lack of temperature-induced changes in the toxicity of naphthalene to fish.

80 Thomas, R. E., and S. D. Rice. 1985. Effect of pretreatment exposure to toluene and naphthalene on the subsequent metabolism of dietary toluene and naphthalene by Dolly Varden, *Salvelinus* malma. In F. J. Vernberg, F. J., F. P. Thurberg, A. Calabrese and W. A. Vernberg (editors), Marine Pollution and Physiology: Recent Advances, p. 505-520. Univ. South Carolina Press, Columbia, SC.

Pretreatment exposure of Dolly Varden to naphthalene in sea water resulted in increased metabolism of orally-administered ^{14}C-naphthalene, but pretreatment exposure to toluene did not alter the rate of metabolism of orally-administered ^{14}C-toluene. Naphthalene is less polar than toluene and thus requires significant bioconversion before it is excreted by fish. Toluene is more polar and is readily excreted by fish, therefore inducement of increased bioconversion of toluene in the fish is not needed.

Several pretreatment factors influenced the rate of naphthalene bioconversion, including; 1) length of pretreatment exposure, 2) concentration of pretreatment exposure, and 3) duration of depuration after pretreatment exposure.

Pretreatment exposure of fish to naphthalene (75% of the 96-h LC^{50}) for 48 h doubled or tripled the percentage of naphthalene metabolites in brain, liver, and muscle tissue, and decreased the amount of carbon-14 recovered in those tissues. Pretreatment exposure for only 24 h caused some increases in tissue metabolites, but no significant differences in percent metabolites of tissue burden were measured between the pretreatment fish and controls which were not pretreated.

The concentration of the pretreatment is directly related to the increase in bioconversion rate of naphthalene. Exposure to 25 and 50% of the 96-h LC_{50} did not result in increased metabolism of naphthalene or in lower tissue burdens of the hydrocarbons. Exposure at 75% of the LC_{50} resulted in significant increases in tissue metabolites and decreases in total tissue hydrocarbon burden.

Periods of depuration following pretreatment exposure resulted in a decrease in the induced rate of metabolism of naphthalene. Depuration for as little as 24 h resulted in the return of the naphthalene bioconversion rate to that of control fish.

Pretreatment exposure of fish can induce increased metabolism of aromatic hydrocarbons, such as naphthalene, and may increase the survival of fish in subsequent exposures. Dinuclear and polynuclear aromatic hydrocarbons are quite lipophilic and must be metabolized before they can be excreted. Inducement of increased metabolism of these compounds, resulting from a previous exposure, increases excretion and therefore reduces hydrocarbon accumulation in the tissues of fish.

81 Thomas, R. E., and S. D. Rice. 1982. Metabolism and clearance of phenolic and mono-, di-, and polynuclear aromatic hydrocarbons by Dolly Varden Char. In W. B. Vernberg, A. Calabrese, F. P. Thurberg, and F. J. Vernberg (editors), Physiological Mechanisms of Marine Pollutant Toxicity, p. 161-176. Academic Press, New York.

Once hydrocarbons were absorbed from capsules placed in the gut of Dolly Varden char, size and polarity of the hydrocarbons influenced the elimination, metabolism, and tissue distribution. Size of the hydrocarbon appeared to be the most critical factor in excretion of hydrocarbons by the gills. The gills of fish can easily excrete phenolic and mononuclear aromatic compounds. Some naphthalene was excreted by the gills, but virtually none of the polynuclear aromatic hydrocarbons were excreted through the gills. Even though the partition coefficients (log of octanol/water partition) of phenol and cresol are about 1/10 of toluene, these similar-sized hydrocarbons were excreted from the gills in approximately equal amounts.

Polar phenolic compounds were excreted into the cloacal chamber but not toluene or the larger polynuclear aromatic hydrocarbons. Partition coefficient is apparently a more important factor than size in excretion of hydrocarbons into the cloacal chamber because the excretion of phenol and cresol into the cloacal chamber was more than 10 times that of similar-sized toluene.

The excretion of the largest hydrocarbons tested, anthracene and benzo[a]pyrene, was minimal in 24 h (3.2% and l.2%, respectively). These compounds were slowly absorbed from the gut probably because they are relatively nonpolar and have a high partition coefficient (octanol/water), therefore are more difficult to remove from a lipid matrix (membrane). The mobility of these compounds between tissues is limited, and they probably have to be metabolized before excretion. Consequently, metabolism in the liver and secretion into the bile is probably the most important pathway for excretion of large molecular weight hydrocarbons; however, this is a relatively slow proces that takes much longer than 24 h.

82 Thomas, R. E., and S. D. Rice. 1981. Excretion of aromatic hydrocarbons and their metabolites by freshwater and seawater Dolly Varden char. In F. J. Vernberg, A. Calabrese, F. P. Thurberg, and W. B. Vernberg (editors), Biological Monitoring of Marine Pollutants, p. 425-448. Academic Press, New York.

The gills were the most important pathway for excretion of carbon-14 from ^{14}C naphthalene. Most of the carbon-14 excreted by the gills was still attached to the parent compound. About 10% of the excreted carbon-14 appeared in the cloacal chamber, mostly as metabolites. Less than 1% of the total carbon-14 was excreted in the urine, predominantly as metabolites.

Tissues retained a significant amount of carbon-14 at 24 h. Although muscle contained large amounts of carbon-14 because of its mass, the gall bladder had the highest specific activity. The brain also retained significant quantities of carbon-14. Although more ^{14}C toluene was excreted and metabolized than ^{14}C naphthalene, more ^{14}C naphthalene was retained in the tissue. A lower percentage of the carbon-14 was recovered in ^{14}C naphthalene metabolites than in ^{14}C toluene metabolites. Seawater and freshwater Dolly Varden char excreted similar amounts of carbon-14; however, the percentage of metabolites in the excretions and tissues of seawater fish was lower than the percentage of metabolites in excretions and tissues of freshwater fish. For example, we recovered greater amounts of carbon-14 with a lower percentage of metabolites from the brain-spinal cord of seawater fish than from the brain-spinal cord of freshwater fish--possibly explaining why seawater Dolly Varden are more sensitive to aromatic hydrocarbons and the water-soluble fraction of oil than freshwater Dolly Varden.

83 Thomas, R. E., and S. D. Rice. 1979. The effect of exposure temperature on oxygen consumption and opercular breathing rates of pink salmon fry exposed to toluene, naphthalene, and water-soluble fractions of Cook Inlet crude oil and No. 2 fuel oil. In W. B. Vernberg, A. Calabrese, F. P. Thurberg, and F. J. Vernberg (editors), Marine

Pollution: Functional Responses, p. 39-52. Academic Press, New York.

Breathing rates were measured in pink salmon fry exposed to equivalent concentrations of water soluble concentrations of Cook Inlet crude oil (containing mononuclear and dinuclear aromatics) and No. 2 fuel oil (containing dinuclear aromatics) at 4° and l2°C to determine whether responses differ with temperature.

Opercular breathing and oxygen consumption in fry exposed to toluene (mononuclear) and naphthalene (dinuclear) were measured and indicated that increased breathing rates reflect increased energy demands as toxicants are metabolized. Exposure of the fry to 107%, 70%, and 45% of the 24-h median tolerance limits of naphthalene resulted in increased breathing rates; exposure to toluene concentrations of 94% and 69% produced increased breathing rates, but breathing rates at exposures of 45% and 30% remained unchanged. For both toluene and naphthalene, increases in breathing rates with increased exposure were linear.

Results of exposure to the four toxicants at 4° and 12°C were not uniform. At 4°C, 17 of 24 fry exposed to toluene had died 15 h after initial exposure; no deaths occurred among fry exposed to toluene at 12°C or fry exposed to other substances at either temperature. Greatest increase in breathing rates occurred with exposures to naphthalene and No. 2 fuel oil at 4°C, with breathing rates among fry nearly doubled. Results of the study indicate that lower temperatures may influence the effect of hydrocarbons on coldwater fish and that oils with relatively high concentrations of mononuclear aromatic hydrocarbons may be particularly damaging.[1]

84 Thomas, R. E., and S. D. Rice. 1975. Increased opercular rates of pink salmon ***(Oncorhynchus gorbuscha)*** fry after exposure to the water-soluble fraction of Prudhoe Bay crude oil. J. Fish. Res. Board Can. 32:2221-2224.

The opercular rates of pink salmon ***(Oncorhynchus gorbuscha)*** fry were measured during 24-h exposure to sublethal concentrations of the water-soluble fraction of Prudhoe Bay crude oil. Opercular rates increased significantly for as long as 9 and 12 h after exposure to water-soluble fractions prepared from oil-water solution of 2.83 and 3.46 ppm. The increases in rates were proportional to increases in dose. Recording changes in opercular rates appears to be a suitable method for detecting sublethal physiological effects of stress, because the observed changes occurred at approximately 20% of the 96-h LC_{50}.

85 Thomas, R. E., S. D. Rice, M. M. Babcock, and A. Moles. 1989. Differences in hydrocarbon uptake and mixed function oxidase activity between juvenile and spawning adult coho salmon ***(Oncorhynchus kisutch)*** exposed to Cook Inlet crude oil. Comp. Biochem. Physiol. C Comp. Pharmacol. 93:155-159.

1. Coho salmon smolts accumulated up to 30 times more hydrocarbon in selected tissues than did coho salmon jacks when exposed to water-soluble fraction of Cook Inlet crude oil.

2. Aryl hydrocarbon hydroxylase (AHH) activity continued to increase during 12 days of exposure in coho smolts, in contrast to jacks in which AHH activity peaked at 2 days and remained elevated during 20 days of exposure.

3. Cytochrome P-450 concentrations peaked in 48 h and returned to control levels in exposed smolts. In exposed and control jacks, cytochrome P-450 decreased during the 20 day experimental period. Concentrations of P-450 were significantly greater, however, in exposed jacks than in control jacks.

4. Aryl hydrocarbon hydroxylase (AHH) activity and cytochrome P-450 concentrations were greater in non-exposed coho smolts and jacks than in non-exposed pre-spawning adults.

5. Coho jacks were not as responsive as coho smolts in terms of P-450 induction; however, they were more responsive than anticipated for a fish in a terminal life stage.

86 Thomas, R. E., S. D. Rice, M. M. Babcock, and A. Moles. 1988. Differences in hydrocarbon uptake and mixed function oxidase activity between juvenile and spawning adult coho salmon exposed to Cook Inlet crude oil. Am. Zool. 28(4):104A. (Abstract only).

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87 Thomas, R. E., S. D. Rice, and S. Korn. 1987. Reduced swimming performance of juvenile coho salmon ***(Oncorphynchus*** [sic] ***kisutch)*** exposed to the water-soluble fraction of Cook Inlet crude oil. In W. B. Vernberg, A. Calabrese, F. P. Thurberg, and F. J. Vernberg (editors), Pollution Physiology of Estuarine Organisms, p. 127-137. Univ. South Carolina Press, Columbia, SC.

The magnitude of the effect exposure to the water-soluble fraction (WSF) of Cook Inlet crude oil on swimming performance of juvenile coho salmon ***(Oncorhynchus kisutch)*** was found to be dependent on both the concentration of the WSF and the length of the time that fish were exposed. Swimming activity was reduced to a greater extent at higher concentrations than at lower concentrations. Some of the lower concentrations, which did not significantly reduce swimming performance when fish were exposed for only 48 h, had a greater effect when fish were exposed for 5 or 13 d. When fish were transferred to clean water for a period of depuration prior to determining swimming performance, control levels of swimming activity were restored within 8 h of transfer.

It is suggested that exposure of salmon to the WSF of crude oil induces an increased metabolism which reduces the energy available for swimming. When fish are no longer exposed to the WSF, this energy is no longer required and swimming performance is restored to normal.

Prince William Sound and Related Papers/Reports

88 Barr, L. 1970. Alaska's fishery resources: The shrimps. U.S. Fish Wildl. Serv. Fish. Leafl. 631, 10 p.

Shrimp fishing began in Alaska over 50 years ago. Recently the annual domestic catch has been as high as 40 million pounds. Japanese and Soviet Union fishermen operating in Alaska waters have caught as much as 70 million pounds annually in recent years.

The five commercially important shrimp of Alaska belong to the family Pandalidae; the most important is the pink shrimp, *Pandalus borealis.*

The complicated life histories of these shrimp are all similar. The shrimp develop first as males and after several years transform to females, which they remain for the rest of their lives.

United States fishermen use otter trawls, beam trawls, and pots, and deliver their catch to ports in Alaska; foreign fishermen use larger otter trawls and process the catch at sea.

The Alaska Department of Fish and Game and the Bureau of Commercial Fisheries are studying shrimp. They are sampling the commercial catch, trying to improve the product, and conducting exploratory fishing and biological research.

89 Barr, L. 1970. Diel vertical migration of *Pandalus borealis* in Kachemak Bay, Alaska. J. Fish. Res. Board Can. 27:669-676.

Catches of *Pandalus borealis* by surface-to-bottom pot fishing in Kachemak Bay, Alaska, showed that this species was distributed in large numbers throughout the water column at night and suggested a diel vertical migration. The shrimp apparently left the vicinity of the bottom about dusk and returned about dawn; the apparent length of time they were off bottom was directly related to the length of the night. Bottom trawling clearly showed lower availability of *P. borealis* on bottom at night than during the day. Catches of shrimp by pot fishing and trawling indicated that small *P. borealis* have a greater tendency to migrate vertically than the larger individuals.

90 Calvin, N. I., and R. J. Ellis. 1978. Quantitative and qualitative observations of ***Laminaria dentigera*** and other subtidal kelps of southern Kodiak Island, Alaska. Mar. Biol. 47:331-336.

Observations were made and quantitative samples of non-canopy kelps were collected, using SCUBA, at 9 subtidal sites off southern Kodiak Island in May, 1976. At a 10th site, only observations were made. The most abundant species in the quadrants were *Laminaria dentigera, L. yezoensis, Pleurophycus gardneri, Agarum cribrosum,* and *Alaria marginata.* We found fertile plants of all these species. *L. dentigera* dominated at all sampled sites except one within a bed of *Nereocystis luetkeana,* where *P. gardneri* was dominant. *L. yezoensis* was dominant at the site which was visited but not sampled. The average wet weight of non-canopy kelps in the 55 samples was 12 kg m^{-2}, and the quadrant range was 2 to 35 kg m^{-2}. The reported ranges of *P. gardneri* and *Alaria marginata* are extended westward from Montague Island (147°22'W) to Bumble Bay, Kodiak Island (154°43'W), where A. *marginata* was found at a depth of 8.5 m.

91 Calvin, N. I., and S. C. Lindstrom. 1980. Intertidal algae of Port Valdez, Alaska: species and distribution with annotations. Bot. Mar. 23:791-797.

We found 18 species of Chlorophyta, 20 species of Phaeophyta, and 42 species of Rhodophyta at 7 intertidal sites in Port Valdez, Alaska. Of these species, *Kornmannia zostericola, Antithamnionella pacifica, Cryptonemia borealis, Halosaccion firmum, Neodilsea integra,* and *Ceramium gardneri* were found beyond their previously reported range. *Dumontia simplex,* known from Japan and previously reported in Alaska only at Amchitka Island in the Aleutian Islands, was found at one site. *Fucus distichus* was the most abundant and ubiquitous algal species in the intertidal zone, and species of *Alaria* were notably absent from the shore.

92 Dahlberg, M. L. 1979. History of fishery and summary statistics of the sockeye salmon, Oncorhynchus nerka, runs to the Chignik Lakes, Alaska, 1888-1966. NOAA (Natl. Oceanic Atmos. Adm.) Tech. Rep. NMFS (Natl. Mar. Fish. Serv.) SSRF (Spec. Sci. Rep. Fish.) 735, 16 p.

Annual runs of sockeye salmon to the Chignik Lakes, Alaska, decreased from an average of 1.9 million during the period 1922-39 to an average of 0.9 million during the period 1949-66. In order to study the dynamics of the runs' historic catch, escapement and age structure data were compiled by spawning stock and brood year. This history of fishing and management of the runs from inception of the fishery until 1966 is described. The high seas and coastal distributions of Chignik sockeye salmon indicated significant interception by the fishery in only one area other than the Chignik Bay and Chignik Lagoon; the fishery at Cape Igvak started in the mid-1960's. Results of the study were used to construct parent-progeny relationships that formed the basis for a management strategy to restore the runs to former level of abundance.

93 Dahlberg, M. L. 1973. Stock-and-recruitment relationships and optimum escapements of sockeye salmon stocks of the Chignik Lakes, Alaska. Rapp. P.-V. Reun. Cons. Penn. Int. Explor. Mer 164:98-105.

The Chignik River system of western Alaska offers opportunity to formulate a model management strategy for enhancement of sockeye salmon runs based on precise harvest regulation. This is possible because the system is segregated from other similar systems and accurate statistics on catch and escapement are available for a 38 year period.

By statistically studying spawner-return relationships, a model of spawner-returns was derived for Chignik Lake and Black Lake stocks, the two contributors to the Chignik River system, and for the combined stocks. Alternative models were examined. Optimum escapements were estimated for each stock and for combined stocks. Results indicate that higher yields can be realized by fishing each stock at its optimum rate of exploitation rather than harvesting a mixture of stocks at a common rate of exploitation.[1]

94 Dahlberg, M. L. 1968. Analysis of the dynamics of sockeye salmon returns to the Chignik Lakes, Alaska. Ph.D. Thesis, Univ. Washington, Seattle, 337 p.

Records of the abundance and age structure of sockeye salmon *(Oncorhynchus nerka* (Walbaum)) returns to the Chignik Lakes, Alaska, were studied to determine factors responsible for the marked decrease of the populations over the past 50 years. The average abundance of the stocks has dwindled in recent years to less than one-half the average abundance during the period from 1922 to 1939. Based on the tacit assumption that a potential for increase still exists in the populations, a plan for improved management of the stocks is proposed; prerequisites for the plan are adopted as specific objectives of the study.

The prerequisites of the plan for rebuilding the stocks required (1) compilation of the historic records of catch, escapement and age composition of the runs since 1888, (2) determination of the relationship between the abundance of mature progeny and size of parental spawning stocks and (3) determination of the most accurate methods of forecasting the magnitude and time of return of the yearly runs of sockeye to Chignik.

Density-dependent and density-independent factors possibly related to the decrease in abundance are presented and discussed. A differential decrease in the abundance of the two stocks is attributed tentatively to increase density dependent mortality in one stock, probably a result of ecological changes in the nursery lake brought about by consistent underescapement. The proposed management strategy for increased production of Chignik sockeye requires increased escapement levels, precisely regulated, to the two nursery lakes. This should result in ecological changes which should enhance the production of sockeye salmon.

95 Frame, G. W. 1976. Alaska's fishing black bear. Pac. Discovery 29(3):19-25.

The author spent one summer observing black bear behavior at Olsen Creek which flows into Olsen Bay in Prince William Sound, Alaska. Specifically, he observed behavior of 18 individually identified black bears fishing and eating chum and pink salmon. Although both species were available in roughly equal numbers, the preferred target was chum salmon (possibly because they are slower and larger). Three types of fishing and eating behavior were identified (in order of frequency of occurrence)--(l) active fishing for chums and preference for females with eggs; (2) feeding on dead salmon caught by other bears; and, (3) feeding on salmon that had spawned out and died from natural causes. The eggs were the preferred part of the fish, with the head and nape areas of the fish following in preference. The author estimated that black bears killed 8% of the salmon before they had an opportunity to spawn; therefore, they did not pose a serious threat to population maintenance.[1]

96 Frame, G. W. 1974. Black bear predation on salmon at Olsen Creek, Alaska. Z. Tierpsychol. 35:23-38.

Activities of black bears *(Ursus americanus)* were observed on a stream used for spawning by chum salmon *(Oncorhynchus keta)* and pink salmon (0. *gorbuscha)* at Olsen Bay, Prince William Sound, Alaska, during the summer of 1967. Black bears were most active for 2 hours beginning at dawn and for several hours before and after dusk. The most common activity was eating salmon killed and abandoned by other black bears. An average of seven attempts was made for each salmon captured and retained. Black bears preferred eggs over the rest of the carcass and were able to recognize live unspawned female salmon. Although equal numbers of male and female salmon were captured, twice as many females were retained; 65% of these females were relatively unspawned when captured. Black bears captured about 8% of the female salmon population before they spawned. There was no evidence of fishing territories.

97 Harry, G. Y. 1964. The shrimp fishery of Alaska. Proc. Gulf Caribb. Fish. Inst. 16:64-71.

Until 1958, the shrimp fishery of Alaska was confined to southeastern Alaska where from 1 to 2 million pounds of hand-picked shrimp were packed annually for more than 30 years. In 1958 the shrimp fishery expanded westward, with new plants in Seldovia, Kodiak, and Seward. Alaska has the potential for a much larger shrimp fishery than exists at present. Four species of shrimp are of commercial importance; *Pandalus borealis, P. platyceros, P. hypsinotus,* and *Pandalopsis dispar,* with pink shrimp *(P. borealis)* being of greatest importance.

Shrimp fishing by foreign powers in water off Alaska has been primarily in the Bering Sea. The initial Japanese effort in 1961 took about 19 million pounds of shrimp, and in 1962, 40 million pounds were taken. In 1963, the U.S. Bureau of Commercial Fisheries received reliable reports of Soviet shrimp fishing in the Bering Sea.

98 Haynes, E. 1983. Distribution and abundance of larvae of king crab, ***Paralithodes camtschatica,*** and Pandalid shrimp in the Kachemak Bay area, Alaska, 1972 and 1976. NOAA (Natl. Oceanic Atmos. Adm.) Tech. Rep. NMFS (Natl. Mar. Fish. Serv.) SSRF (Spec. Sci. Rep. Fish.) 765, 64,p.

Distribution and abundance of larvae of king crab, *Paralithodes camtschatica*, northern shrimp, *Pandalus borealis,* humpy shrimp, *P. goniurus,* coonstripe shrimp, *P. hypsinotus,* and sidestripe shrimp, *Pandalopsis dispar,* were studied in the Kachemak Bay area, Alaska, in 1972 and 1976. In both 1972 and 1976, larvae of king crab, northern shrimp, and humpy shrimp first appeared in outer Kachemak Bay; their abundance was greatest in the central portion of the outer bay. Two additional species were studied in 1972, coonstripe shrimp and sidestripe shrimp. In 1972, the center of abundance of sidestripe shrimp larvae was similar to that of larvae of king crab, northern shrimp, and humpy shrimp. Coonstripe shrimp larvae were most abundant in the inner bay and along the northern shore of the outer bay.

The direction in which larvae were transported out of outer Kachemak Bay was only in partial agreement with suspected water-current patterns and may have been influenced by behavior of the larvae. Continued abundance of larvae in outer Kachemak Bay may be caused by entrainment of the larvae in gyres.

Depending on species and area, pandalid shrimp larvae are released at different times and over different periods. For example, larvae of northern shrimp appeared in plankton catches earlier than larvae of humpy shrimp. Coonstripe shrimp had the longest release period of all the shrimp studied.

From the percentage of glaucothoe in the samples, king crab larvae probably settled in the Bluff Point area in outer Kachemak Bay. Larvae of pandalid shrimp probably settle in outer Kachemak Bay and possibly lower Cook Inlet, but exact locations cannot be determined only by observing changes in morphology of the larvae.

Vertical depth distributions of larvae of king crab and pandalid shrimp were generally similar. Early-stage larvae of king crab, northern shrimp, and humpy shrimp migrated vertically in a diel cycle. A thermocline did not prevent migration to surface waters.

99 Haynes, E. 1981. Description of stage II zoeae of snow crab, Chionoecetes bairdi, (Oxyrhyncha, Majidae) from plankton of lower Cook Inlet, Alaska. Fish. Bull., U.S. 79:177-182.

Chionoecetes bairdi Rathbun 1924 (subfamily Oregoniinae) is the only species of snow crab (genus Chionoecetes) that occurs in Cook Inlet, Alaska, and contributes about 20% of the total value of the commercial fisheries harvest of the area. The larval stages of C. *bairdi* consist of one prezoeal, two zoeal, and one megalopal stage. The zoeae are readily distinguished from known zoeae of other genera of the subfamily Oregoniinae *(Hyas* and *Oregonia)* by size (the zoeae of *C. bairdi* are nearly twice as large as zoeae of *Hyas* and *Oregonia)* and by slight differences in morphology, especially setation of the antennule and length of the posterior lateral spines. The prezoeae, Stage I zoeae, and megalopa of *C. bairdi* have been described from known parentage. In this report, I describe the Stage II zoeae from plankton and compare them with other known Oregoniinae zoeae from the North Pacific Ocean.

100 Haynes, E. 1980. Stage I zoeae of a crangonid shrimp, ***Crangon franciscorum angustimana,*** hatched from ovigerous females collected in Kachemak Bay, Alaska. Fish. Bull., U.S. 77:991-995.

Information on the larval stages of crangonid shrimp of the North Pacific Ocean is meager. Needler (1941) described the first zoeal stage of *Crangon septemspinosa* (as *Crago septemspinosus* Say) hatched in the laboratory from ovigerous females and the remaining four zoeal stages from plankton collected near Prince Edward Island, Canada. Kurata (1964) described the larval stages of c. *affinis* de Haan and various larval stages of six, unidentified *Crangon* spp. from Japanese waters. He obtained the first zoeal stage of C. *affinis* from known parentage, but the remaining stages were collected from plankton. Markarov (1967) briefly described larvae of C. *dalli* Rathbun and C. *septemspinosa* (Say) which were collected from plankton along the western Kamchatka shelf. He suggested that C. *dalli* was an analog of *C. allmani* Kinahan and *C. septemspinosa* was an analog of *C. crangon* (Linnaeus). *Crangon allmani* and *C. crangon* are eastern Atlantic species. He assumed that the C. *affinis* larvae described by Kurata (1964) was actually larvae of *C. septemspinosa.* Loveland (1968) described larvae of *C. alaskensis* Rathbun reared in the laboratory from females collected near Anacortes, Washington.

Morphology of Stage I larvae is closely related to Caridean development and can be used to estimate the number of larval stages, classify species, categorize larvae for identification purposes, and identify subsequent larval stages (Needler 1938; Pike and Williamson 1961, 1964; Kurata 1964; Ivanov 1971; and others). In this report I describe and illustrate the first zoeal stage of *C. franciscorum angustimana* Rathbun from ovigerous females and compare these zoeae with Stage I zoeae of crangonids described by other authors. Also, I show that the criterion of the absence of exopodites on the second pair of pereopods for distinguishing larvae of *Crangon* from other genera of the Crangonidae is invalid for Crangonidae of the North Pacific Ocean.

101 Haynes, E. 1979. Description of larvae of the northern shrimp, Pandalus borealis, reared in situ in Kachemak Bay, Alaska. Fish. Bull., U.S. 77:157-173.

Northern shrimp, *Pandalus* borealis, were reared in situ in Kachemak Bay, Alaska, from Stage I (first zoeal) through Stage VIII (second juvenile). Each of the six larval stages and first juvenile stage is described and illustrated, and a brief description is given for the second juvenile stage. Apparently larvae of *P. borealis* in Alaska waters have at least one less stage than larvae of *P. borealis* in either British Columbia, Greenland, or Japan waters. Of the known larvae of the North Pacific Ocean, larvae of *P. borealis* are most similar morphologically to larvae of *P. goniurus* but are separable from them by being slightly larger in size and, in zoeal Stages I-III, by bearing more setae on certain appendages, particularly the antennal scale and certain mouth parts. From Stage IV to megalopa, the rostrum of ***P. borealis*** has more dorsal teeth, the second pereopods are more developed, and the pleopods are fringed with more setae than for larvae of P. goniurus. The criterion of the lack of an outer seta on the maxillule for distinguishing zoeae of Pandalus from certain other Caridea is shown to be invalid.

102 Haynes, E. 1970. Age and growth of giant Pacific sea scallops in the Gulf of Alaska. Proc. Natl. Shellfish. Assoc. 60:14. (Abstract only).

Giant Pacific sea scallops, ***Patinopecten*** caurinus, in the Gulf of Alaska have a typically sigmoid-shaped growth curve with an inflection point at about 3 years of age or 55 mm shell height. Increase in shell height decreases thereafter, tending toward an upper asymptote that varies with geographical area. Sea scallops grow fastest off Kodiak Island and slowest off southeastern Alaska; between these areas their growth rate is intermediate. Within-age variability in shell height is greatest in scallops 2-4 years old and is much reduced and nearly constant thereafter, suggesting the presence of a compensating growth mechanism which limits variability in growth as scallops get older. Causes for the differences in scallop growth among the different areas have not been established but may be related to certain environmental conditions.

103 Haynes, E. B., and J. C. McMullen. 1970. Relation between meat weight and shell height of the giant Pacific sea scallop, ***Patinopcten caurinus,*** from the Gulf of Alaska. Proc. Natl. Shellfish. Assoc. 60:50-53.

Meat weight-shell height relations were obtained for giant Pacific sea scallops, ***Patinopecten caurinus,*** collected from two areas in the Gulf of Alaska. W is meat weight in g and L is shell height in mm.

Ocean Cape $\hat{W} = 3.833 \times 10^{-6} L^{3.121}$

Kodiak Island $\hat{W} = 2.006 \times 10^{-5} L^{2.844}$

Over the range of shell height; examined, the mean weight of scallop meats differed significantly (1% level) between the areas.

104 Heard, W. R., R. L. Wallace, and W. L. Hartman. 1969. Distributions of fishes in fresh water of Katmai National Monument, Alaska, and their zoogeographical implications. U. S. Fish Wildl. Serv. Spec. Sci. Rep. Fish. 590, 20 p.

Katmai National Monument covers 10,916 km on the base of the Alaska Peninsula and is divided by the Aleutian Mountain Range into two principal drainage areas. Streams north of the Aleutian Range flow into Bristol Bay of the Bering Sea, and those south of the mountains flow into Shelikof Strait of the North Pacific Ocean. The large multilake Naknek River system is the dominant drainage area on the Bristol Bay side of the monument, whereas small single lakes and short streams and rivers constitute many separate drainages on the Shelikof Strait side. Twenty-four species of fish occur in the Bristol Bay drainages of the monument, but only eight species were collected in streams and lakes draining into Shelikof Strait. Evidently the Aleutian Range has been a barrier to the southward movement of freshwater fishes in the monument. All eight species in Shelikof Strait drainages are capable of dispersal through salt water, whereas several forms in Bristol Bay drainages require fresh water for dispersal. Variable numbers of species occur in the interconnecting lakes of the Naknek River system. Naknek Lake, the downstream terminus of the lake system, contains 24 known species and each upstream lake contains fewer species than the one into which it drains. The present distribution of fishes in this system is discussed in terms of the sequential timing of species invasion and the postglacial development of barriers.

105 Helle, J. H. 1989. Relation between size-at-maturity and survival of progeny in chum salmon, ***Oncorhynchus keta*** (Walbaum). J. Fish Biol. 35(A):99-107.

Data on age- and size-at-maturity, growth, and abundance of chum salmon were collected from 1959 to 1977 at Olsen Creek in Prince William Sound, Alaska. Age composition of spawners (3 to 6-year-olds) varied from year to year: 4-year-old fish were the dominant age group in most (16 out of 19) years and 6-year-old fish usually represented less than 1% of the returns. Mean size of older spawners was significantly larger than that of younger spawners. Size-at-maturity was similar among fish from different broods maturing at different ages in the same year. Size-at-maturity and survival of progeny were significantly related. The larger the mean size of spawners, the higher the survival rate to adulthood of their progeny. Possible reasons for this relationship are discussed.

106 Helle, J. H. 1984. Age and size at maturity of some populations of chum salmon in North America. *In* P. A. Moiseev (editor), Proceedings of the Pacific Salmon Biology Conference, Yuzhno-Sakhalinsk, USSR, 3-13 October 1978, p. 126-143. Pacific Scientific Institute of Fisheries and Oceanography (TINRO), 4 Shevchenko Alley 690600, Vladivostok, USSR.

In North America, chum salmon, *Oncorhynchus keta,* spawn in watersheds from the Mackenzie River in northern Canada southward to northern California, U.S.A. (Bakkala 1970). However, only small spawning populations exist north of Kotzebue Sound, Alaska, U.S.A., or south of the central Oregon coast in the United States.

Published records of size and age of chum salmon at maturity in North America have been sporadic (see Marr 1943; Henry 1954; Thorsteinson, Noerenberg, and Smith 1963; Bakkala 1970). Further, most of the reported observations described size and age at maturity for commercial catches of mixed stocks. Comprehensive records of size and age of individual spawning populations of chum salmon are very limited.

In 1959, I began sampling the spawning population of chum salmon at Olsen Creek, a small coastal stream in Port Gravina, Prince William Sound, Alaska, for size and age throughout the spawning season. The objectives of this study were to (1) describe the variation in size and age composition of chum salmon during a spawning season (intraseasonal), and (2) describe the variation in size and age of spawning chum salmon in different years (interseasonal).

In 1971-78, I sampled several other spawning populations of chum salmon in different geographical areas--Noatak River, near Kotzebue, Alaska; Chilkat River, in northern southeastern Alaska near Haines; Disappearance Creek, in Cholmondeley Sound on Prince of Wales Island near Ketchikan, Alaska; Fish Creek, at the head of Portland Canal near Hyder, Alaska; Quilcene Hatchery, at Walcott Slough on Hood Canal near Brinnon, Washington; and Whiskey Creek, in Netarts Bay, Oregon. The chum salmon run at Walcott Slough is maintained by artificial propagation by the U.S. Fish and Wildlife Service, Quilcene National Fish Hatchery. The run at Whiskey Creek is maintained by natural spawning and an experimental hatchery operated by Oregon State University. The objectives of these additional observations were to compare size and age at time of spawning of chum salmon that were geographically and ecologically diverse.

107 Helle, J. H. 1982. Some effects of the marine environment on age at maturity and growth of chum salmon in Prince William Sound, Alaska. In B. R. Melteff and R. A. Neve (editors), Proceedings of the North Pacific Aquaculture Symposium, p. 91. (Abstract only.) Univ. Alaska, Fairbanks, Sea Grant Rep. 82-2.

Influence of the marine environment on age and size at maturity, early marine growth, and abundance of chum salmon, *Oncorhynchus keta*, from Olsen Creek in Prince William Sound, Alaska, was studied during the years 1959 to 1978 (Helle, 1979).

Age composition of the spawners returning to Olsen Creek varied from year to year, but they were predominately 3-, 4-, and 5-year fish. Some 6-year fish returned between 1968 and 1975, but this age group usually did not represent more than 1 percent of the returns. Mean age composition for the brood years 1956 to 1972 for males was 15, 66, and 19 percent for 3-, 4-, and 5-year fish, respectively. Mean age composition for females of the same broods showed higher percentages of older fish: 9, 67, and 23 percent for 3-, 4-, and 5-year fish, respectively.

Interseasonally, mean age at maturity increased as number of fish in a brood increased. Intraseasonally, age of new chum salmon spawners at Olsen Creek decreased as the season progressed. Mean size of older spawners was significantly larger than the mean size of younger spawners, but the ranges in size of the three age groups overlap each other so size is not a good criterion for estimating age of chum salmon.

Numbers of circuli and distances-between annuli on adult scales were used to estimate growth of chum salmon during their first two years at sea. Growth during the first year at sea was related to sea-surface temperatures and marine weather parameters in Prince William Sound and in the northern Gulf of Alaska.

Growth during the first year at sea was not significantly related to age at maturity; however, growth during the second year at sea was negatively related to age at maturity.

Size at maturity was related to sea-surface temperatures and marine weather parameters in the northern Gulf of Alaska and Prince William Sound during the year of return. Fluctuations in size at maturity were more similar between fish from different broods returning during the same year than between fish from the same broods maturing at different ages. A highly significant relationship was found between survival of progeny and mean size of parents.

108 Helle, J. H. 1981. Significance of the stock concept in artificial propagation of salmonids in Alaska. Can. J. Fish. Aquat. Sci. 38:1665-1671.

Hatcheries could make a significant contribution to the enhancement of salmonid fisheries if application of this technology is based on principles of the stock concept. Evidence for the stock concept is reviewed and discussed in relation to transplantation of stocks, mating procedures, maintenance of genetic diversity, different methods of artificial propagation, and location of artificial propagation facilities. A strategy is developed for management of both wild and artificially propagated stocks.

109 Helle, J. H. 1979. Influence of marine environment on age and size at maturity, growth, and abundance of chum salmon, ***Oncorhynchus keta*** (Walbaum), from Olsen Creek, Prince William Sound, Alaska. Ph.D. Thesis, Oregon State Univ., Corvallis, 118 p.

Effects of the marine environment on age and size at maturity, early marine growth, and abundance of chum salmon, *Oncorhynchus keta,* were studied at Olsen Creek during 1959-77.

Chum salmon return to Olsen Creek as predominately 3-, 4-, and 5-year fish; however, age composition varied from year to year. The mean age composition for the brood years 1956-72 for males was 15%, 66%, and 19% for 3-, 4-, and 5-year fish, respectively. Mean age composition for females of the same broods showed slightly higher percentages of older fish: 9%, 67%, and 23% for 3-, 4-, and 5-year fish, respectively. Some 6-year chum salmon returned to Olsen Creek between 1968 and 1975; but, only in 1973 did the number of 6-year fish (3%) represent more than 1% of the returns. Population sizes tended to be larger during these years, and mean age increased as the number of fish in a brood increased. Intraseasonally, age of new chum salmon spawners at Olsen Creek decreased as the season progressed. Mean size of older spawners was greater than the mean size of younger spawners; but, the ranges in size of the three age groups overlap each other so size is not a good criterion for estimating age of chum salmon.

Measurement of circuli and distances on adult scales were used to estimate growth of chum salmon during their first two years of marine life. Both number of circuli and distances on scales of juvenile chum salmon after their first summer in Prince William Sound were shown to be related to length of the fish. Growth during the first season at sea was not related to age at maturity; however, amount of growth acquired during the second marine season was negatively related to age at maturity. Growth during the first summer at sea was related to sea surface temperatures and marine weather parameters in Prince William Sound in the northern Gulf of Alaska. Location of chum salmon from Olsen Creek during their second year at sea is unknown.

Fluctuations in size (length) at maturity were more similar between fish from different broods returning during the same year than they were for fish that matured at different ages from the same broods. Length at maturity was related to marine weather factors during their last summer at sea in the northern Gulf of Alaska and Prince William Sound and also mean summer sea surface temperature in Prince William Sound during the year of return.

Total survival of each brood was estimated from the ratio of number of progeny (returns) to number of parents (spawners). No direct relationships were found between survival and growth during the first or second season in the sea, sea surface temperatures, or upwelling indices along the coast. However, a highly significant relationship was found between the survival of progeny and mean length of the parents.

110 Helle, J. H. 1970. Biological characteristics of intertidal and fresh-water spawning pink salmon at Olsen Creek, Prince William Sound, Alaska, 1962-63. U.S. Fish Wildl. Serv. Spec. Sci. Rep. Fish. 602, 19 p.

Prince William Sound is unique among major pink salmon-producing areas in that a significant portion of the spawning takes place in the intertidal zones of streams. Olsen Creek is one of the major spawning streams in the Sound.

The percentage of fines (solids passing through an 0.833 mm sieve) in spawning-bed materials increased progressively from higher to lower intertidal levels, i.e., higher intertidal levels contained coarser spawning gravel than lower levels.

Although less than one-third of the spawning area available in the Olsen Creek drainage is subject to tidal influence, 70 percent of the total pink salmon spawners occupied this area in 1962 and 30 percent in 1963. Late-run fish of the even-year line spawned only in the intertidal area; fish of both the early and late runs of the odd-year line spawned in both the intertidal and fresh-water areas. The size of the spawning populations was estimated by a repetitive stream survey technique, which is described and compared with the three methods used in 1960 and 1961.

The length of pink salmon was compared between sexes, between spawning areas, and between times of spawning. Fish in the even-year line that spawned in the small intertidal creeks tended to be smaller than those that used the main stream, but in the odd-year line this difference was confined to females. The mean lengths of females were about the same in 1962 and 1963, but females from the odd-year line were more fecund. In both years a significant positive correlation was shown between lengths of females and numbers of eggs.

111 Helle, J. H. 1966. Behavior of displaced adult pink salmon. Trans. Am. Fish. Soc. 95:188-195.

Studies to show whether pink salmon ***Oncorhynchus gorbuscha*** (Walbaum) will repeat their original choice of spawning area when captured and transported to another location were done in Olsen Creek, Prince William Sound, Alaska in 1961, 1962, and 1963. Fish to be displaced were anesthetized with MS-222 (except in 1961 when no anesthesia was used) and marked with Petersen disk tags. Equal numbers of control fish were treated in an identical manner and left at the donor site.

In 1961, 100 pink salmon were displaced from Olsen Creek beyond the entrance of the bay, a distance of more than 3 miles from the creek mouth. Of the 54 fish accounted for, 91% returned to Olsen Creek.

In 1962 and 1963, the displacements were confined to Olsen Bay. Fish displaced "on-route" achieved a higher rate of return than fish displaced "off-route". Further, under conditions of extremely low stream flow, displaced fish did not return to their original choice of spawning area. When stream flows were normal or high, they showed a strong tendency to return to areas of their original choice.

112 Helle, J. H. 1960. Characteristics and structure of early and late spawning runs of chum salmon, Oncorhpchus keta (Walbaum), in streams of Prince William Sound, Alaska. M.S. Thesis, Univ. Idaho, Moscow, ID, 53 p.

Due to a poor escapement of pink salmon in 1957 the commercial fishery for pink and chum salmon was closed in 1959. This closure provided an opportunity to observe on the spawning grounds the total return of chum salmon to Prince William Sound in 1959. This study describes the abundance, distribution, age, size, and fecundity of chum salmon that spawned in some of the major streams along the eastern shore of Prince William Sound between Valdez Arm and Orca Inlet.

113 Helle, J. H., R. S. Williamson, and J. E. Bailey. 1964. Intertidal ecology and life history of pink salmon at Olsen Creek, Prince William Bound, Alaska. U.S. Fish Wildl. Serv. Spec. Sci. Rep. Fish. 483, 26 p.

Intertidal spawning of pink salmon is of major importance in Prince William Sound. Studies were initiated at Olsen Bay in 1960 to ascertain how much these intertidal spawners contributed to the total production of pink salmon.

Olsen Creek is inundated with tidewater about 80 percent of the time at the 3-foot tide level and about 7 percent of the time at the 11-foot level. Saline water was shown to penetrate the gravel at redd depth during high tides. The highest concentration at the 11-foot tide level was 9.3‰ during a 14.5-foot tide. Temperature changes of up to 10°F, would occur within 1 hour at evaluations up to the 8-foot level on floodtide.

The occurrence of spawners in 1960 and 1961 was bimodal; however, in 1960 the late run utilized only the intertidal spawning area, while in 1961 the late run utilized both the intertidal and fresh-water areas. During the 2 years the early run spawned in both environments. In 1960, 98,574 pink salmon spawned in Olsen Creek and 1961, 135,905 spawned. During both years 74 percent of the total run spawned in the intertidal portion of the stream.

Temporal and spatial distribution of spawners, size differences, and seasonal changes in sex ratios provide evidence for the existence of discrete spawning groups or races.

Live egg densities and survival over winter to the preemergent fry stage were progressively greater from the lower to the higher levels in the intertidal area. Overwinter survival between egg and fry stages below the 4-foot level was 0. Survival at the 7- to 9-foot level and the 10- to 11-foot level was 20 and 54 percent respectively.

114 Hubbard, J. D. 1971. Distribution and abundance of intertidal invertebrates at Olsen Bay in Prince William Bound, Alaska, one year after the 1964 earthquake. In The Great Alaska Earthquake of 1964: Biology, p. 137-157. National Academy of Sciences, Washington, DC.

In the summer of 1965, the Bureau of Commercial Fisheries began a study of intertidal invertebrates in the Olsen Bay area of Prince William Sound; this included an evaluation of the effect on intertidal organisms of uplift caused by the 1964 Alaska earthquake. Intensive sampling of four areas representative of the three most common types of habitat in this protected bay revealed a vertical distribution and abundance of invertebrates species strongly influenced by substrate composition and tidal exposure. Mean tide level (+6.2 ft) exhibited particular importance as the upper limit of numerous organisms. It was found that the uplift produced measurable changes. in the distributions of certain intertidal organisms. The amount of uplift, approximately 3.0 to 3.5 ft in Olsen Bay, could be estimated by comparing the positions of some of these organisms before and after the earthquake. The most obvious and reliable quantitative index of the uplift was provided by pre- and postearthquake limits of barnacle populations, whereas supportive evidence was obtained from examination of certain bivalve mollusk distributions. Differential mortality, noted especially between different species of mollusks and between different age-classes of certain species, was apparently attributable to earthquake-related processes. While reproductive success of some species appeared unaffected by the earthquake, other species have apparently experienced little reproduction since the earthquake.

115 Kirkwood, J. B. 1962. Inshore-marine and freshwater life history phases of the pink salmon, Oncorhynchus gorbuscha (Walbaum) and the chum salmon 0. keta (Walbaum) in Prince William Bound, Alaska. Ph.D. Thesis, Univ. Louisville, Louisville, KY, 300 p.

The salmon resources are of great economic importance to the people of Alaska. Pink and chum salmon are most abundant along the coast of central and southeastern Alaska. Numbers of pink and chum salmon returning to Prince William Sound each year has generally declined since 1943. The current study was designed to determine the causes of this decline. Since it seemed likely that the major limiting factors probably occurred while the salmon were in fresh water, emphasis was placed on studying this phase of the life histories of both species.

The 194 streams listed as spawning streams were stratified according to the annual abundance of pink salmon spawners and time of spawning during the 10 years prior to 1957. Aerial surveys were used to determine the sizes of spawning populations so that these populations could be correlated with fry production and subsequent adult returns. Surveys were conducted at 12 streams during 1957 and 40 streams during 1958 and 1959.

During 1958, 6,273 adult chum salmon were sampled to study the age, length and sex composition of the spawning populations in Prince William Sound. Larval development and mortality were studied during the fall and winter of 1958-1959 to determine the time and causes of mortality of the salmon while they were in the gravel. Fry-migration studies consisted in capturing a portion of the migrating fry in each study stream and intertidal area as they moved from the gravel to the sea.

Larger populations of pink salmon spawned in study streams during 1958 than in either 1957 or 1959, and a greater percentage of the spawners utilized the intertidal zones during 1958.

The survival of eggs and larvae in intertidal and stream zones is discussed and the survival is correlated with air and water temperatures in one stream. Other possible mortality factors are explored.

Population estimates of fry migrations in stream zones of study streams, categories of streams, and Prince William Sound are presented. The survival of fry during migration to sea is greatly affected by predators, particularly birds and other fish.

A discussion is given of the recruitment of fry correlated with parent spawners. Points included in this discussion include the success of fry production resulting from even- and odd-year spawning populations and the success of reproduction in intertidal and stream zones.

116 Kirkwood, J. B., and R. M. Yancey. 1965. Effects of the March 27 earthquake upon the shellfish resources of Alaska. Proc. Alaska Sci. Conf. 15:162.

Between June 8 and June 24, 1964, a general survey was conducted to learn the effects of the March 27, 1964, earthquake upon shellfish populations and their habitats. Fishermen, packers, state management personnel, and others were visited in Cordova, Anchorage, Seldovia, Homer, Kasitsna Bay, Kodiak, Olga Bay, Sand Point, and Squaw Harbor. Razor clam beaches also were visited at Cordova, Ninilchik, Poly Creek, and Swickshak. The area affected by the earthquake has been estimated at more than 30,000 square miles. More than 22,000 square miles located east of the tectonic hinge-zone subsided and at least 12,000 square miles located west of this zone uplifted. The major effect on shellfishes occurred near Cordova. Razor clam beaches rose about six feet in the Copper River area; butter clams *(Saxidomus nuttallii)* and cockles *(Clinocardium nuttallii)* were found dead on exposed beaches in Orca Inlet after the quake; and submarine landslides may have caused mortality to shellfishes in western Prince William Sound where several square miles of dead rockfish *(Sebastodes* sp. and *Sebastolobus* sp.) and cod *(Gadus* sp.) were observed on March 28, 1964. Other razor clam beaches were probably not affected since these areas were not uplifted or lowered greatly by the earthquake. Subsidence of the area which includes Kasitsna Bay will reduce the availability of butter clams there by about 80%. There was no evidence of mortality of king crab, shrimp, and Dungeness crab or major changes in their habitats except possibly in the Prince William Sound area.

117 Leatherwood, S., A. E. Bowles, E. Krygier, J. D. Hall, and S. Ignell. 1984. Killer whales *(Orcinus orca)* in southeast Alaska, Prince William Sound, and Shelikof Strait; A review of available information. Rep. Int. Whaling Comm. 34:521-530.

Information on killer whales is summarized from a formal sightings network, 1976-1981 (Southeast Alaska), aerial surveys, 1976-1978 and small boat surveys, 1976-1982 (Prince William Sound), aerial surveys, 1982-1983 (Shelikof Strait), and interviews with marine scientists, fishermen and other knowledgeable mariners (all areas). Although present year-round, killer whales in each area increase in numbers and concentrate in specific areas in late summer through early fall, apparently in response to concentrations of salmon. In Prince William Sound, one group apparently remains within a limited home-range (less than 25 km radius) in Knight Island Passage each summer. Minimum counts from portions of the three areas are 93, 80 and 66 whales, respectively. Data indicate concurrent presence of killer whales in other unstudied portions of all three areas; so, 'populations' in each area certainly number in excess of 100 animals. Herds include an average of 4-6 animals (n=890) in Southeast Alaska. Of the three areas surveyed, Prince William Sound and Southeast Alaska appear most suitable as areas for long-term observational studies of killer whales of the sort pioneered in inland waters of Washington and British Columbia.

118 Lindstrom, S. C., and N. I. Calvin. 1975. New records of marine red algae from the Gulf of Alaska. Syesis 8:405-406.

The documented ranges of eight species of red marine algae are extended into the northeast Gulf of Alaska as a result of intertidal sampling done in 1974 as part of baseline surveys of area continental shelf baseline studies conducted in anticipation of oil development. The extensions are as follows: *Erythrocladia subintegra*--found at Anchor Cove, not previously reported in Alaska; *Erythrotrichia carnea*--found at Zaikof Bay, not previously reported from Alaska; *Farlowia mollis*--Macleod Harbor, previously reported northern limit as Dixon Entrance; *Gigartina exasperata*--found near Ocean Cape, previously reported northern limit as northern California; *Nemalion elminthoides*--MacLeod Harbor, previous northernmost collection from Khaz Bay, Chichagof Island; *Botryoglossum farlowianum, Callophyllis violacea,* and *Serraticardia macmillani*--found in the drift zone at Middleton Island; none had previously been reported north of Khaz Bay.[1]

119 Meehan, W. R. 1966. Growth and survival of sockeye salmon introduced into Ruth Lake after removal of resident fish populations. U.S. Fish Wildl. Serv. Spec. Sci. Rep. Fish. 532, 18 p.

Sockeye salmon *(Oncorhynchus nerka)* in three lakes on Afognak Island, Alaska, were studied. Ruth Lake was treated with rotenone to remove resident fish. Midarm Lake, which has no salmon, and Little Kitoi Lake, which has a small run of sockeye, were used as controls to compare survival and growth of introduced fry and natural fry with survival and growth of introduced fry in Ruth Lake. Other factors that might influence sockeye production, such as plankton and bottom fauna, were also considered.

In general, growth and survival of fry and biological production were greater in the treated lake. Growth and survival decreased as fry densities increased.

120 Meyer, R. M. 1968. The Dungeness crab fishery around Kodiak, Alaska. Comm. Fish. Rev. 30(8-9):44-47.

Alaska seiners and power barges form the bulk of the fleet that fishes for Dungeness crabs in Kodiak waters from May to October. Crews normally number three men who may set, pull, and reset over ten 30-pot strings a day in shallow, near-shore waters. The pots are baited with herring, clams, or squid. As each pot is pulled, the catch is placed in tanks filled with circulating sea water to insure live delivery to the processing plants. The crabs are usually butchered, cooked, and frozen at the plant and are shipped south for further processing.

121 Moyle, Peter. 1966. Feeding behavior of the Glaucous-winged Gull on an Alaska salmon stream. Wilson Bull. 78:175-190.

The feeding behavior of the Glaucous-winged Gull was studied on Olsen Creek, a salmon stream flowing into Prince William Sound, Alaska. It was found that feeding took place in two distinct situations: (1) on the banks of the stream on salmon carcasses pulled up by gulls or bears and (2) in the stream itself, on salmon eggs drifting with the current. The behavior patterns centering around the defense of salmon carcasses appeared to be very similar to the territorial displays of the breeding season with these exceptions; actual territories did not exist, the carcasses were defended only by hungry birds, and the attacking gull won more often than the defender in disputes over a carcass. Upright Displays, Oblique-cum-Long-Call Displays, and Mew Call Displays were all observed frequently during carcass defense. The effectiveness of such behavior, however, tended to break down in the presence of bears feeding on freshly caught salmon, particularly when the salmon were females. The gulls also seemed to exhibit preference for female over male carcasses of spawned out salmon. Birds in immature plumage usually could not defend a salmon carcass against adult gulls, although first year juveniles had a certain immunity to attack by their unresponsiveness to adult threat displays. Apparently, even adults cannot defend themselves against other adult gulls while diving for drift eggs in the stream. At the approach of a low-flying attacker, the swimming gull must either fly up or be bowled over. If drift egg feeding occurs in a riffle, however, the riffle can be defended like a salmon carcass. Paddling, probably to stir up salmon eggs caught in the surface gravel also occurred in the riffles.

122 O'Clair, C. E., and S. T. Zimmerman. 1987. Biogeography and ecology of intertidal and shallow subtidal communities. In D.W. Hood and S. T. Zimmerman, (editors), The Gulf of Alaska: Physical Environment and Biological Resources, p. 305-343. NOAA, U.S. Dep. Commer. Available Superintendent of Documents, U.S. Gov. Print. Office, Washington, DC 20402.

Recent studies of the natural shore communities of the Gulf of Alaska provide a descriptive foundation for future work on the primary factors that determine both geographical and local distribution and abundance patterns for algal and invertebrates populations. However, there is still a lack of experimental evaluation to determine the role that physical disturbances, gradients in physical regimes, and biological interactions play in determining these patterns.

Our analysis of both the biotic composition and the zoogeographic affinities of those invertebrates of the major phyla revealed no major biogeographical discontinuities between Yakutat and the eastern Aleutian Islands. However, we found that the intertidal flora and fauna of the western Aleutians (Amchitka and Shermya Islands) differed markedly from the flora and fauna of the eastern Gulf. The distribution of species among trophic levels was similar between these two regions, but the western Aleutians had more Asiatic and fewer North American species, and had a greater proportion of endemic species of Mollusca, Crustacea, and Echinodermata than were found in the eastern Gulf.

Physical disturbances were only of overriding importance in controlling community structure at three of the 29 study sites. Gradients in the regimes for salinity, turbidity, and exposure altered both the community composition and the relative abundances of intertidal species, such as *Semibalanus balanoides* and *Balanus glandula,* which have a tolerance for a broad range of values for these factors. *Pisaster ochraceus* and *Evasterias troschelli* do not appear to play key roles in the organization of intertidal communities in Alaska because *Mytilus californianus* is rare there and *M. edulis* is vulnerable to the activities of other predators and perhaps to physical disturbance as well.

When most intertidal species are lifted even slightly above their upper vertical limits by land-level changes, they either die or emigrate. This supports the contentions that the upper limits of most intertidal organisms are physiologically determined. The exceptions are *Balanus glandula, Semibalanus cariosus,* and *Chthamalus dalli* which can survive uplift of nearly 1 m above their upper limits. It normally takes at least three years for communities to redevelop to their former condition after an uplift.

123 Olsen, J. C. 1973. Pandalid shrimp life history research at Kachemak Bay, Alaska. Mar. Fish. Rev. 35(3-4):62-64.

Kachemak Bay, an arm of lower Cook Inlet, is the site of NMFS field studies of *Pandalus borealis,* the most important commercial shrimp species in Alaska. Research activities focus on shrimp life histories, behavior, and population dynamics; effects of fishing on shrimp stocks; annual fluctuations in shrimp stock abundance; characteristics and ecology of shrimp habitat; and the role of pandalid shrimp in the organic production system of the North Pacific. Weekly sampling of the commercial shrimp catches, begun in 1970, provides information on growth, recruitment, and mortality of *P. borealis* and *P. goniurus.* Larval studies of shrimp, begun in 1971, have focused on understanding time and place of hatching, diurnal vertical distribution patterns, survival estimates, and annual larval production. Identification and description of larval stages will be accomplished through laboratory cultures and field collections.[1]

124 Orsi, J. A., R. K. Gish, and B. L. Wing. 1991. Northern range extensions of four nearshore marine fishes in Alaska. Can. Field-Nat. 105:82-86.

Northern range extensions of *Oxylebius pictus* (Hexagrammidae), *Syngnathus leptorhynchus* (Syngnathidae), *Synchirus gilli* (Cottidae), and *Citharichthys stigmaeus* (Bothidae) are reported. All four species were collected north of 60 N in Prince William Sound in the Gulf of Alaska from April through June 1989. This is the first published account of a verified specimen of *O. pictus* in Alaska.

125 Phinney, D. E. 1970. Spawning ground catalog of the Chignik River system, Alaska. U.S. Fish Wildl. Serv. Data Rep. 41, 147 p.

All known information about the sockeye salmon runs and the spawning grounds of the Chignik River system, Alaska, is cataloged in this report. The system, which is composed of two lakes, Chignik and Black, supports the largest run of sockeye salmon on the south side of the Alaska Peninsula. The catalog lists for each spawning stream or beach the name, location, physical description, description of the sockeye salmon runs, and a chronological listing of the spawning ground surveys.

126 Quast, J. C., and E. L. Hall. 1972. List of fishes of Alaska and adjacent waters with a guide to some of their literature. NOAA (Natl. Oceanic Atmos. Admin.) Tech. Rep. NMFS (Natl. Mar. Fish. Serv.) SSRF (Spec. Sci. Rep. Fish.) 658, 47 p.

The authors list 432 species known to occur in Alaska water, supplemented by 137 species that have been recorded from neighboring waters and, in the authors' opinion, should be considered when new collections are identified. Species entries are annotated to include common names, recorded range, useful references, localities represented by specimens in the collection of the Auke Bay Fisheries Laboratory, and comments on taxonomy. Recorded geographic ranges are extended for 26 species: Ophidiidae--*Spectrunculus radcliffei;* Scorpaenidae--Sebastes *emphaeus, S. nigrocinctus, S. wilsoni;* Cottidae--Eurymen *gyrinus, Gymnocanthus detrisus, G. pistilliger, Hemilepidotus zapus, Icelus spatula, I. uncinalis, Myoxocephalus jaok, Nautichthys pribilovius, Triglops scepticus;* Agonidae--Agonopsis *emmelane, Aspidophoroides bartoni, Ocella verrucosa;* Cyclopteridae--*Careproctus melanurus, C. rastrinus, Cyclopteropsis phrynoides, Liparis bristolense, L. ochotensis, Paraliparis caudatus, P. deani, Temnocora candida;* Scombridae--Thunnus *thynnus;* Pleuronectidae--Limanda *proboscidea.*

127 Reid, G. M. 1971. Age composition, weight, length, and sex of herring, *Clupea pallasii,* used for reduction in Alaska, 1929-66. NOAA (Natl. Oceanic Atmos. Admin.) Tech. Rep. NMFS (Natl. Mar. Fish. Serv.) SSRF (Spec. Sci. Rep. Fish.) 634, 25 p.

Sampling data from the reduction fisheries for herring, *Clupea pallasii,* in southeastern Alaska (1929-66), Prince William Sound (1937-58), Kodiak (1936-59) are summarized. The data include the weight of the catches, the weight allowed by quota, and age composition, average weight, average length, and sex ratios.

128 Sears, H. S., and S. T. Zimmerman. 1977. Alaska intertidal survey atlas, 402 p. National Marine Fisheries Service, Auke Bay Laboratory.

This atlas describes the intertidal habitat types from Yakutat to Shumagin Pass to Cape Prince of Wales on the Bering Strait. All surveys were made from low flying aircraft, with some ground truthing. This work was an extension of a more detailed study at specific sites along the Alaska coast. The flights were started in summer 1975, but were interrupted by the crash and sinking of the survey aircraft, and were completed in 1976. Data for all beaches described in the atlas, except for Yakataga to Copper River, were collected during the 1976 period.

129 Skud, B. E., H. M. Sakuda, and G. M. Reid. 1960. Statistics of the Alaska herring fishery 1878-1956. U.S. Fish Wildl. Serv. Bur. Comm. Fish. Stat. Dig. 48, 21 p.

Statistics of the herring fishery in Alaska are summarized in this report for the years 1878 to 1956 insofar as detailed data were available.

Catches are recorded by statistical areas in Southeastern Alaska, Prince William Sound, and Kodiak and represent a revision of previously published figures obtained by converting meal production to pounds of fish. Products of the fishery and the statistics of operation are summarized for all Alaska.

130 Tait, H. D., and J. B. Kirkwood. 1962. Estimating abundance of pink and chum salmon fry in Prince William Sound, 1957. U.S. Fish Wildl. Serv. Spec. Sci. Rep. Fish. 429, 21 p.

Salmon fry enumeration studies conducted on eight streams in the Prince William Sound area of Alaska provided estimates of the numbers of pink and chum salmon fry produced in streams of that area in 1957. The studies were conducted to provide a basis for predicting returns of adult salmon. Methods of deriving estimates of fry production from trapping experiments and excavations of pre-emergent fry in intertidal gravel were developed. Timing and duration of migration of chum and pink salmon fry were recorded, and recommendations were made for future fry sampling programs.

131 Thorsteinson, F. V. 1965. Effects of the Alaska earthquake on pink and chum salmon runs in Prince William Sound. Proc. Alaska Sci. Conf. 15:267-280.

The earthquake that struck Alaska March 27, 1964, centered in northwestern Prince William Sound and produced drastic environmental changes in the spawning habitat of pink (Oncorhynchus gorbuscha) and chum (0. keta) salmon runs homing to streams of that area. Its total impact cannot be measured until spring, 1965 when the survival of salmon eggs deposited in uplifted or downwarped stream areas in 1964 can be determined. In this report, some results of pre-earthquake ecological studies on a Prince William Sound stream are presented, and their implications regarding future abundance of pink salmon in view of the earthquake-produced changes in spawning habitat are discussed.

132 Thorsteinson, F. V. 1965. Aftermaths of the Alaska earthquake in Prince William Bound. Pac. Fisherman 63(6):10-11.

Prince William Sound pink salmon spawning streams were adversely affected by the March 27, 1964, earthquake. Elevations of 226 streams used by 75 percent of the total population were changed. Thirty seven percent of the fish in odd year runs and 56 percent of fish in even year runs were potentially affected. In streams affected by subsidence, previously used intertidal spawning areas were drowned, forcing fish to move upstream to productive tide levels. In streams located in areas of uplift, low intertidal streambeds were raised to levels that might be useful for spawning but siltation led to low egg survival. Some streams in uplifted areas proved unstable as they degraded or moved laterally to form new flow patterns, and, as a result, deposited eggs were sometimes lost. Eggs and developing embryos in all streams may have been affected by compaction of spawning beds. In general, egg and fry mortalities among pink salmon were expected to be higher than average until streams stabilized and digging activity of spawning salmon removed fine materials from newly exposed spawning beds.[1]

133 Thorsteinson, F. V., J. H. Helle, and D. G. Birkholz. 1971. Salmon survival in intertidal zones of Prince William Sound in uplifted and subsided areas. In The Great Alaska Earthquake of 1964: Biology, p. 194-219. National Academy of Sciences, Washington, DC.

Large numbers of pink and chum salmon, spawned each year in intertidal portions of streams in the Prince William Sound, were affected by the Alaska earthquake of March 27, 1964. Detailed studies of the effects of changes in land level were made at Olsen Creek (uplifted about 4 ft), a stream for which a large amount of pre-earthquake data existed. General studies were made at three other streams--two in areas that were uplifted 10 ft and one in an area that subsided 6 ft. Despite relocation of intertidal spawning beds in relation to tidal levels, the areas occupied and the distribution by the runs of returning pink and chum salmon were at approximately the same levels and in the same proportions as before the earthquake. The first spawners occupied upper intertidal areas, and those that came later spawned at lower levels; very few fish spawned below the 6 ft tide level. Survival of eggs was high in upper areas and lower in downstream areas. Stream slope adjustment caused by changes in elevation created unstable streambed conditions. Scour, fill, and channel shifts caused mortalities to eggs and alevins. We estimate that these secondary effects of the earthquake caused the disappearance of 7.27 million pink salmon eggs and 1.1 million chum salmon eggs from Olsen Creek intertidal streambeds during the summer and fall of 1965 and 0.54 million pink salmon alevins and 0.43 million chum salmon alevins during the 1965-1966 winter.

134 Thorsteinson, F. V., W. H. Noerenberg, and H. D. Smith. 1963. The length, age, and sex ratio of chum salmon in the Alaska Peninsula, Kodiak Island, and Prince William Sound area of Alaska. U.S. Fish Wildl. Serv. Spec. Sci. Rep. Fish. 430, 84 p.

Data on length, age, and sex ratio of chum salmon from the Alaska Peninsula area from 1951 through 1957, the Kodiak Island area from 1948 through 1951 and 1955 through 1957, and the Prince William Sound area from 1952 through 1958 show that age and length composition in these areas varied in a similar manner. Lengths of fish in the 3-, 4-, and 5-year age classes overlapped to such an extent that length was not a useful guide to age. The average age composition for the combined samples was about 10 percent 3-year-olds, 75 percent 4-year-olds, and 15 percent 5-year-olds. Mean age decreased as the season advanced. The percentage of males decreased slightly as the runs progressed.

135 Zimmerman, S. T., J. L. Hanson, J. T. Fujioka, N. I. Calvin, J. A. Gharrett, and J. S. MacKinnon. 1978. Intertidal biota and subtidal kelp communities of the Kodiak Island area. *In* Environmental Assessment of the Alaskan Continental Shelf. Final Reports of Principal Investigators, Vol. 4, Biological Studies, p. 316-508. U.S. Dep. Commer., NOAA. Available Arctic Environmental Assessment Center, 222 W. 8th Ave., No. 56, Anchorage, AK 99513.

The distributions and abundances of principal intertidal plants and invertebrates are described at about 40 sites in the Kodiak Island region.

Comparison of species composition and biomass on adjacent transects at two sites indicated that spatial variability within sites was high, obscuring seasonal patterns and confounding between-site comparisons. Nevertheless, when sites were classed according to exposure, topography, and substrate, exposed flat bedrock beaches appeared to have lower species number and biomass than other stable bedrock beaches. *Mytilus edulis* appeared to reach highest densities in protected or partly protected areas and were uncommon at exposed locations.

Densities of biota were lower at sites affected by frequent physical disturbance such as scouring by sand or gravel and unstable substrates (cobble and boulders) at exposed sites. Benthic kelps were widely distributed and high in biomass in the region of Kodiak Island. Very large individuals of *Nereocystis* luetkeana and Laminaria *dentigera* were recorded. The total biomass of *Fucus* spp. on rocky beaches in the Kodiak Island region was estimated to be $3x10^7$ to $1x10^8$ kg. Diversity indices did not reveal any clear patterns in species diversity of plants or animals within or between sites.

1992 Addendum

These two manuscripts represent research conducted before the Exxon Valdez oil spill; both manuscripts are currently in draft form and nearing completion.

136 Karinen, J. F., M. M. Babcock, D. W. Brown, W. D. MacLeod, Jr., L. S. Ramos, and J. W. Short. In Preparation. Hydrocarbons in intertidal sediments and mussels from Prince William Bound, Alaska, 1977-1980: Characterization and probable sources. National Marine Fisheries Service, Auke Bay Laboratory.

We collected and analyzed samples of sediments and mussels (Mytilus trossulus) for alkane and aromatic hydrocarbons from eight sampling stations adjacent to the oil tanker vessel transportation corridor through Prince William Sound, Alaska, during the period 1977 to 1980, to determine baseline concentrations of these analytes prior to any pollution that might result from oil tanker traffic through the sound.

Results indicate chronic, low-level hydrocarbon contamination that probably originates from small fuel spills, ballast water discharges, and fuel-combustion exhaust emissions of occasional vessel activity adjacent to three stations: Constantine Harbor, Rocky Bay, and Mineral Flats. The other five stations show no indication of petroleum hydrocarbon contamination; detected aromatic hydrocarbons are present only sporadically and at concentrations that are generally near detection limits. Exceptions are perylene, which is found at concentrations well above detection limits at all sampling station outside Port Valdez, and which probably has natural sources; and phenanthrene, which is found sporadically at all sampling stations and which also may come from natural sources.

Concentrations of individual n-alkanes vary substantially in sediments and in mussels. The most abundant n-alkanes in sediments include odd carbon-numbered alkanes of molecular weight greater than tetradecane (C-14). Concentrations of these n-alkanes are generally in the range of 10 to 100 ng/g dry sediment weight, but exceed 1000 ng/g at Constantine Harbor. The most abundant n-alkanes in mussels include decane (C-10) through heptadecane (C-17), and pristane, at concentrations generally ranging from 10 to several hundred ng/g dry tissue weight.

Sources of alkanes in sediments include terrigenous plant waxes, marine plankton, and possibly marine macrophytic algae at all the sampling stations, and petroleum-derived alkanes in addition at Constantine Harbor.

Except in areas affected by local vessel traffic, intertidal sediments and mussels in Prince William Sound are remarkably free of petroleum-contaminant hydrocarbons during the period of this study. The hydrocarbons found in sediments and mussels unaffected by vessel traffic can be adequately explained by known, natural sources. As a result, sediments and mussels contaminated by crude oil from the Exxon Valdez oil spill should be particularly apparent, due to the general absence of confounding sources of petroleum hydrocarbons.

137 Myren, R. T., G. Perkins, and T. R. Merrell. In Preparation. Reduced abundance of ***Macoma balthica*** near an oil tanker terminal in Port Valdez, Alaska, 1971-1984. National Marine Fisheries Service, Auke Bay Laboratory.

Populations of *Macoma balthica,* a small intertidal clam in mudflats, were monitored for 14 years (1971-1984) at Port Valdez, to determine whether treated ballast water effluent would cause a decrease in the populations. The Alyeska terminal began treating oily ballast water from tankers in August 1977, averaging 2 million gallons of low-level oil in water per day. Populations of large *Macoma* clams were stable for the 7 years before treated ballast water discharge began, but declined to levels of less than 20% by 1982-84. The population decline coincides with the massive continuous discharge of effluent contaminated with low levels of hydrocarbons and other unmeasured toxic compounds, but cause and effect is not proven.

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