QUANTITATIVE DETERMINATION OF THE EFFECTS OF OIL DEVELOPMENT IN THE BRISTOL BAY REGION ON THE COMMERCIAL FISHERIES IN THE BERING SEA

Edited by

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1. PURPOSE OF THE PROJECT

1.1 The Problem

The objective of this project is to quantitatively analyze the expected impact which might occur as a consequence of hypothetical spill scenarios for PU 3010 (see end of Chapter 1.2). This evaluation is the very first attempt to comprehensively estimate the possible adverse effects to the eastern Bering Sea environment and biota from spills of specified petroleum and volume at designated spill sites. Many data bases and studies on eastern Bering Sea environment and resources are available. Although much of this literature is relevant, since no information was specifically obtained to satisfy the subject, time, and area dimensions of the present study, we can anticipate that our analyses and results may not be as complete or as definitive as we would like. Regardless, the results of these studies may be the only basis for formulating some sensitive operational or socio-economic decisions regarding petroleum exploration and developoment. At the least, it will form a basis for further refinements and extensions of oil impact analyses. Consequently, these studies must be very carefully formulated and executed and apply current and relevant knowledge concerning the effects of oil on ecosystems from past oil spills, model and laboratory studies, and environmental studies of eastern Bering Sea. The findings must be presented in a form understandable to any interested party.

The very copious, marine oil spill literature records a number of instances of the esthetic damage and in some cases the catastrophic annihilation of virtually all intertidal organisms inundated by beached petroleum or fuel oil (e.g., Linden et al., 1983). The tainting of shellfish (e.g., oysters in Brittany from the Amoco Cadiz spill) as a consequence of oil spills is also well documented (Laubier, 1983). We have not, however, seen any documented evidence of the direct detrimental effects of oil on fish or shellfish production (excluding clams) in the marine environment, either from well blowouts or tanker accidents. Some Draconian forecasts of the possible impacts of oil developments on marine fisheries and ecosystems, however, have been presented. These views appear to have resulted from extrapolations of selective laboratory observations and experiments on the effects of hydrocarbons on the physiology, genetics, and mortality of fish (Payne, 1982). The results of past studies have failed to provide any empirical evidence to indicate that any oil spill was responsible for substantial direct mortality to juveniles and adults. Preliminary analyses in our study leads us also to conclude that the spill scenarios under study will have little if any impact on mature fish of eastern Bering Sea.

The preceding highlights one main difficulty in the study of oil spill impacts. As pointed out in the concluding words of the report on Petroleum in the Marine Environment by the National Academy of Science (1983), "The single most significant gap existing to date is our difficulty in transferring the information obtained from laboratory studies to predicting and/or evaluating potential impact of petroleum on living marine resources in the field, especially in the case of spill impact on such commercially important stocks as fish and shellfish."

The possible effects of oil on fishery resources will be evaluated here with numerical ecosystem simulations (models) that are based on validated quantitative laboratory observations as well as on the knowledge of fishery resources in the region. These simulations address four major areas of possible impacts (<u>oil in this report means petroleum hydrocarbons</u>):

1) Effect of oil (from accidents) on fish and shellfish eggs and larvae, and the projection of these effects on exploitable populations years later.

2) Possible effect of oil on adult fish, including effects on crabs and on migrating salmon.

3) Possible tainting of fish by direct exposure and by uptake of oil-contaminated food, and the possible need and extent of area closures in case of accidents.

4) Possible short- and long-term effects of oil on the bottom of the sea on the benthic ecosystem (including demersal fish).

All effects will be evaluated in the perspective of total fishery resources in the region of concern, taking into account the magnitude of errors in estimating the population sizes, the natural fluctuations and mortality of populations, and their seasonal migrations (by life history stages) .

Two important subjects will receive somewhat perfunctory consideration in our study, not because we think they are Unimportant but because the terms of the study exclude them.

The possible effects of oil on the beaches will be evaluated only in a semiquantitative manner. The emotion-laden problems of possible effects of oil on mammals and birds will be only qualitatively described. With the exclusion of these topics, the impact analysis will be incomplete.

1.2 Principles of evaluation of the possible effects of oil developments

A noticeable quantity of oil in water which might affect marine biota can originate from either a well blowout or from a tanker accident. First order calculations of the concentrations of oil in water originating from large accidents and its distribution in space and time indicate that in order to obtain the concentration of oil in the water or on the bottom which might affect the postlarval fish, and be of noticeable areal extent, the blowout and/or accident must be of considerable magnitude. (Note: The oil on the surface has very negligible effect on marine biota unless it is carried to very shallow water and to the beach.) Therefore, the computations in this project were done with Maximum Effect Conditions (MEC) which are defined as follows:

1) Accident scenarios include the largest plausible well blowout lasting 15 days (and longer) and a large tanker accident releasing most of the oil cargo within 24 hours.

2) The spreading of oil in the water occurs in such conditions of wind, tides, mixed layer depth, and temperature which produce largest possible area of highest possible concentration of water soluble fraction (WSF) of oil in the water (>1 ppm).

3) The blowout/accident occurs during the most unfavorable time with respect to the fishery resources (peak spawning time with maximum aggregation of fish per unit area, and/or peak migration time of anadromous fish) .

4) The prevailing conditions affecting the sedimentation of the oil to the bottom are such that highest possible quantity of oil accumulates on the bottom in the shortest possible time.

The effect of oil on the fishery resources (e.g., mortalities, diminished growth, etc.) must be evaluated against the size of the stocks of the fish in the region, taking into account:

a) magnitudes of the errors of the assessment of the stocks;

b) magnitudes of the natural fluctuations of the stocks;

c) size of the fishing and other "natural mortalities" of the stocks.

The degree of possible tainting of the exploitable part of the stock by external exposure and by uptake of oil contaminated food must be quantitatively determined and the area and duration of possible closure of fishing after the accident must be determined, taking into account:

a) the speed of oil deputation by the fish;

b) plausible distances of migration of tainted fish.

The weathered oil which accumulates on the bottom will affect the benthic ecosystem (including demersal fish and crab) in a variety of ways. These effects might be long lasting (up to a few years). The sedimentation of the oil to the bottom is quantitatively simulated (modelled), using the parameters known to affect this process (see Chapter 3). The effects of oil on the bottom will be evaluated with analogs to known and investigated effects, especially from Tsesis spill.

There are other possible effects of accidents which are excluded from this project, such as oil on the beaches and effects of oil on birds and mammals. These possible effects will be estimated, however, at least to the order of magnitude and compared to the oil effects on direct fishery resources.

The following accident scenario has been selected for the project:

1) Well blowout (in 3 locations), 20,000 bbl/day for 5 days. Prudhoe Bay crude oil.

2) Tanker accident (instantaneous spill at 3 locations), 240,000 bbl, automotive diesel (refined), released from the tanker at rate of 10,000 bbl/hr.

3) Three locations (Figure 1), 1) off Port Moller, 56°20'N, 161°20'W; 49 m depth; 2) off Port Heiden, S7″1O′N, 159°W; 43 m depth; 3) off Cape Newenham, 58°N, 164°W, 43 m depth.

4) Wind direction will be the most frequent for the location. Wind speed and tides will be such that they produce Maximum Effect Conditions (MEC).

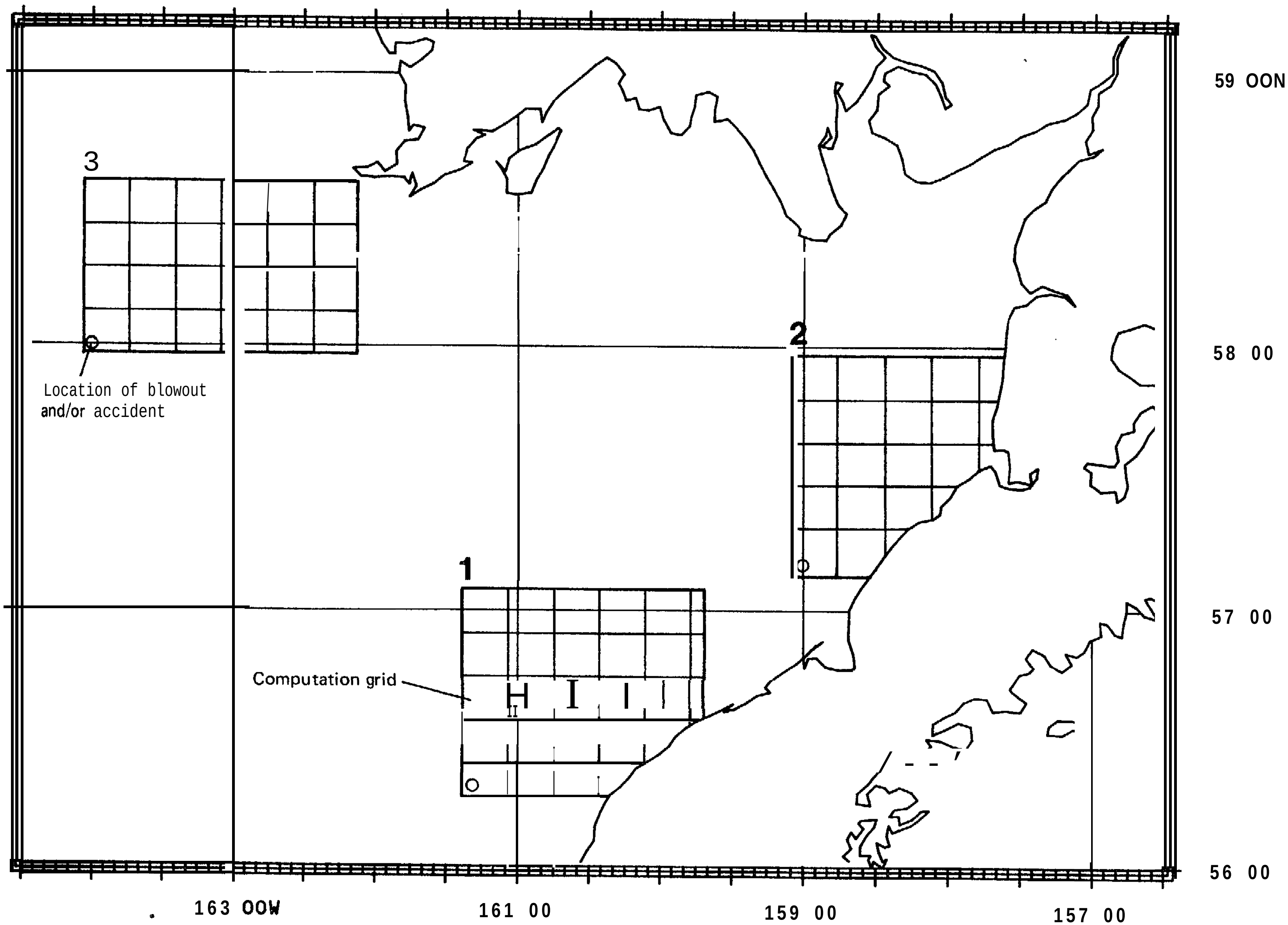

Figure 1.--Locations of hypothetical oil spills, and computational grids in Bristol Bay.

The computation of oil in the water (Water Soluble Fraction, WSF, which includes the oil in solution in molecular form, as well as oil dispersed in the water as very fine droplets) is being computed by Rand Corporation in cooperation with Science Applications Inc. (Liu, 1983).

Other details of the project scenario are given in next chapter under Numerical Methods.

2. METHODS OF THE STUDY AND SOURCES AND NATURE OF DATA

2.1 Numerical methods

Oil in water. The distribution of oil in water from the well blowout and tanker accidents are computed by Rand Corp. in cooperation with SAI.* Some examples of computed distributions are shown in Chapter 2.3. The methods of computations are reported elsewhere (Liu, 1983).

In the present project, we are not concerned with oil on the water surface, as it does not affect fish and/or fisheries to any noticeable degree. The effects of oil in the intertidal zone are estimated in this project only to the order of magnitude, because the Rand models have not as yet quantified the beaching of oil.

We are considering and operating with Water Soluble Fraction (WSF) (see definition above). This may constitute about 10% of the total crude oil present at the surface. In estimating the effects of WSF on marine biota (including fish and crabs), several peculiarities of the oil are taken into account, such as the knowledge that the more toxic volatile (aromatic) hydrocarbons reach their maximum concentration in water about 3 hours after release, but after about 12 hours only about half of their concentration is left (Payne, 1981).

The oil from the tanker accident scenario is considered to be "refined oil". According to Anderson et al. (1974), No. 2 fuel oil and Bunker C residual oil have the same effect on biota when their concentration is 3 to 5 times less than the concentration of WSF crude oil.

Oil on the bottom. About 20 to 50 percent of crude oil released in and/or on the water will ultimately reach the bottom of the sea as "weathered oil". This sedimentation of the oil is affected by the type of oil, temperature, turbidity, turbulence, depth of water, and other factors. The initial

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* Science Applications Inc., La Jolla, CA.

sedimentation (in about the first 15 days) is relatively rapid. However, the sedimentation of all the oil which will ultimately end up on the bottom takes considerable time; thus, it will meanwhile be distributed by currents over a large area, resulting in low concentrations on the bottom of the sea. Higher concentrations of oil on the bottom in shallower water (say <50 m depth) originate from the WSF within about 15 days of the oil addition to the water. Oil will first accumulate in a nepheloid layer near the bottom and will be slowly carried into the sediment, especially by the activity of infauna. This nepheloid layer is moved around with currents near the bottom, effecting the accumulation of it in deepenings (irregularities) in the bottom topography.

The numerical method for simulation of oil on the bottom is described in Chapter 3 of this report.

Oil on the bottom affects the behavior of mobile epifauna (e.g., emigration) and is taken up by sessile epifauna and infauna. The latter two are used as food by demersal fish and crabs. Weathered oil can last in the bottom for relatively long periods (a few years).

Contamination of eggs and larvae by oil. In the case of a well blowout, the eggs and larvae are passively carried into the oiled area by currents and become contaminated (Figure 2). The initial exposure is thus with high concentrations near the blowout. The same current speed and direction, which is used for computation of distribution of oil in the surface mixed layer, is also used for transport of eggs and larvae. Additional eggs and larvae are carried into the oiled area by eddy diffusion. This addition is computed from the area (lateral) extension of the oil concentrations.

The mechanisms effecting the spreading of oil from a tanker accident, complemented with eddy diffusion, are mainly active in exposing the eggs and

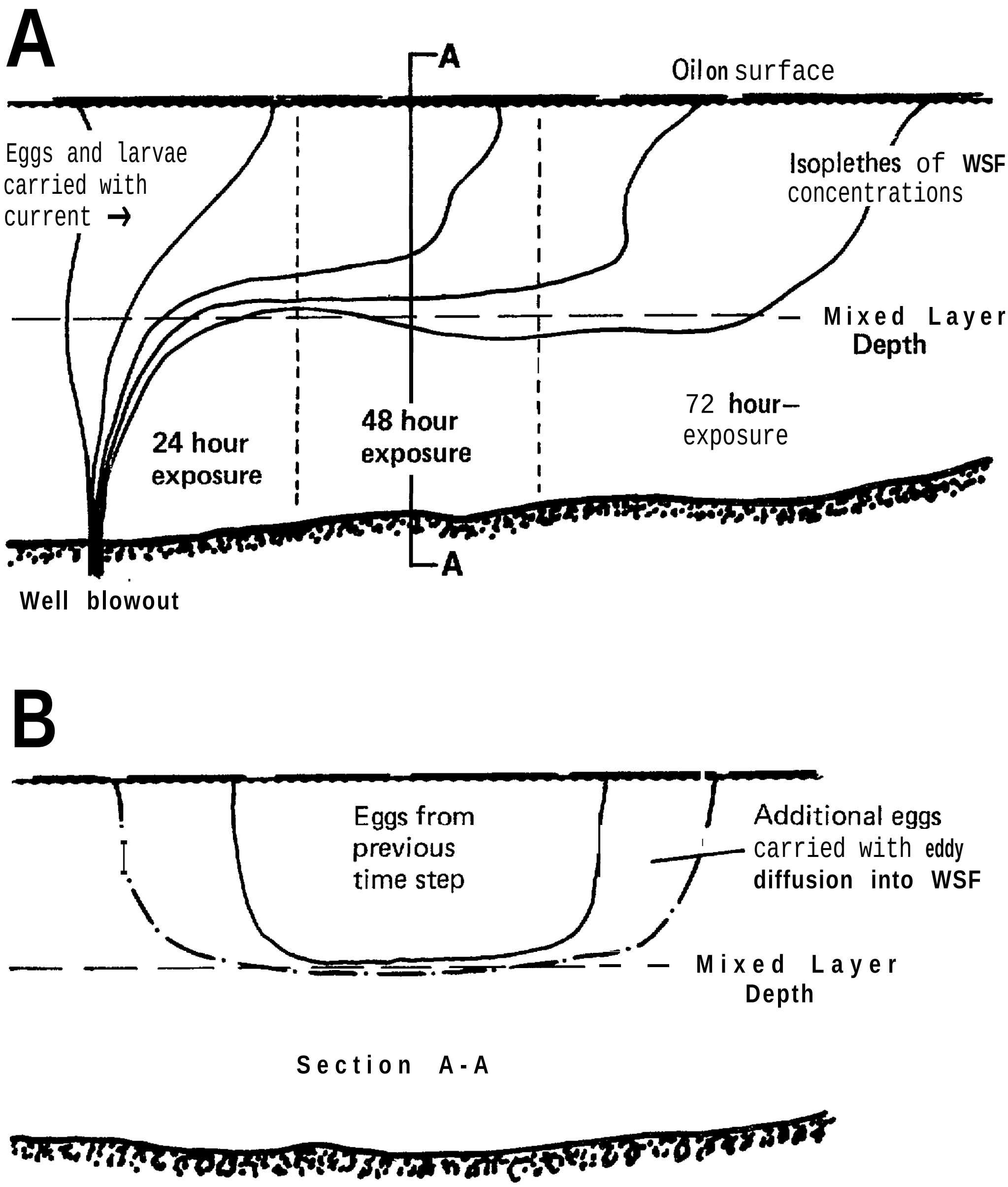

Figure 2.--Schematic presentation of contamination of eggs and larvae by oil. A-Section through an "oil plume". B-Cross-section through above plume (also indicative of contamination by eddy diffusion from an instantaneous source).

larvae to oil originating as instantaneous ("point") source from tanker accidents. These exposures are computed from the expansion of the oiled area with time (Figure 2B).

Empirical data on the spawning and distribution of eggs and larvae in space and time are very limited in the Bering Sea. The MEC conditions for eggs and larvae are computed with the following procedure (schematic presentation see Figure 3): The peak spawning season is estimated for each species. Estimates are also made of the distribution of spawning biomass during peak spawning. Using the data on fecundity of the species and the spawning concentration of biomass during peak spawning, the maximum concentrations of eggs and larvae resulting from 5 day spawning is estimated. These eggs and larvae are assumed to be found in the upper mixed layer. The above assumptions give MEC for the computation of egg and larvae mortality. Examples of the estimated amounts of eggs exposed to different concentrations of oil are given in Table 1.

Egg and larvae mortalities are estimated using data from effect studies (see Table 4 in Chapter 2.4).

The effect of possible egg and larvae mortality on the exploitable population years later is estimated with a linear assumption (see Figure 4), which gives MEC (i.e., the density dependent larval mortalities are neglected). No spawner-recruitment relations have been demonstrated for marine fish. The effects via possible, but uncertain spawner-recruitment relations on coming generations are, therefore, neglected.

Exposure of adult fish to oil. Fish can be affected by external exposure to oil (e.g., uptake of oil through gills). During exposure, fish either can be stationary in respect to general location, while oil moves into the area, or they can migrate through the oiled area (avoidance reaction of fish

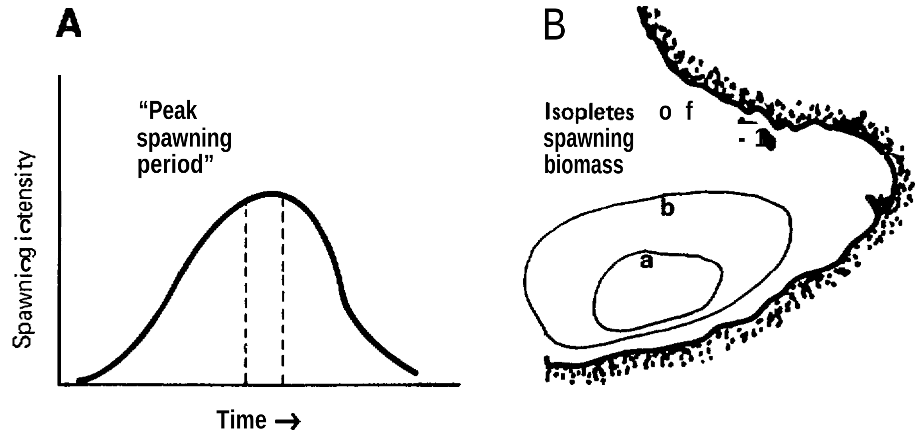

Figure 3.--A-Relative intensity of spawning with time;
B-Distribution of spawning biomass during peak spawning.

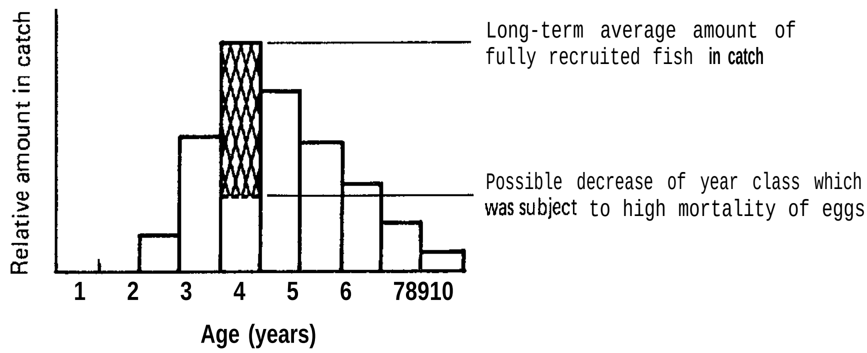

Figure 4.--Schematic presentation of the effect of egg mortality on the exploitable biomass 5 years later.

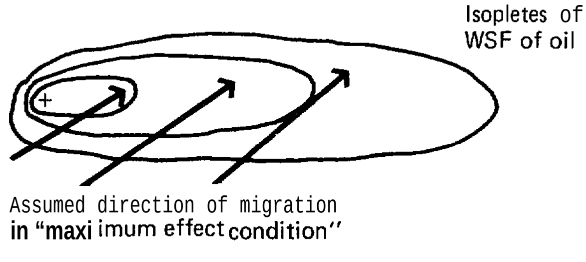

Figure 5.--Migration of fish through oiled area.

Table 1.--Example of computed quantities of eggs exposed to different concentrations of oil.

Area - Port Moller
Species No. 4 850 egg/larvae m^2
Continuous source (well blowout)
Time, days 7

	Number of eggs/larvae exposed (in billions)						
Oil concentration	Exposure time, days						
ppb	1	2	3		5	6	7
>100	6.2	-	-	-	-	-	-
50-100	9.6	12.1	11.7	10.6	9.1	6.3	5.2
10-50	3.3	6.0	8.2	7.2	5.5	3.8	2.8
1-1o	1.8	11.7	24.6	48.3	28.1	12.4	1.8

is neglected here to achieve MEC) . The direction of fish in relation to oil contamination and fish migration speed determine the time of exposure. The selected MEC migration direction is shown on Figure 5. Furthermore, all fish are assumed to migrate between the surface and the MLD .

Examples of the computed exposure of stationary and migrating fish is given in Table 2. Deputation of contaminated fish is a function of time and temperature. The migrating biomass is assumed to be the exploitable stock. The resulting contamination effects are computed by using data in Table 5 (Chapter 2.4).

Adult salmon, as well as smolt, are assumed to migrate through the oil although they may avoid it. The effects of oil on salmon are computed with a special model adapted for this purpose (see Appendix 5).

Uptake of oil with contaminated food. Fish, either "stationary" or moving through an oiled area, will take up pelagic and/or demersal food that may be contaminated with oil (feeding habits see Appendix 6). The magnitude of food uptake can be reduced, however, if the WSF is above a given level of concentration (see Table 6 in Chapter 2.4). For the purpose of MEC, food in the oiled area is assumed to have a bioaccumulation ratio of 50 times the concentration in the environment.

The uptake of oil is computed as mg of oil per kg of biomass. When the fish enter clean water (defined here as < 10 ppb of oil), a time and temperature dependent deputation is computed (see Table 7). Examples of the contamination of fish by food uptake is given in Table 3.

The quantities of fish affected by contaminated food (killed, tainted, etc.) are evaluated on the bases of data in Table 7. Since fish that move through the oiled area can be tainted through the uptake of contaminated food , it is important to know the distance and time that a fish travels before it has depurated below the tainting level. This information can

Table 2.--Example of computed exposure of stationary and migrating fish to different concentrations of oil.

Species 1 - 300 kg/km^2, migrating
Species 2 - 400 kg/km^2, stationary
Time, days 13

Total biomass (kg) exposed to WSF

Oil concentration ppb	Total biomass exposed (kg) Species 1	Species 2
>200	1200	1600
150-200	1200	1600
100-150	8400	11200
50-100	264oo	35200
10-50	25200	996800

Table 3.--Example of computed "contamination index" of fish (caused by uptake of contaminated food).

Location: Port Moller, Time Step: Day 15
Species No. 1 - Emigrating species (biomass 400 kg/km)
Species No. 2 - A non-migrating species (Biomass 300 kg/km)
(Contaminated biomass is summed over the grid and given in tonnes)

Concentrations in ppb (µg/kg)	Contaminated biomass in tonnes Migrating	Non-migrating
Cent. index greater than 100.000	0.000	0.000
Cent. index 50.000 to 100.000	0.000	0.000
Cent. index 10.000 to 50.000	0.000	0.323
Cent. index 1.000 to 10.000	0.562	2.684
Cont. index 0.100 to 1.000	1.034	11.434
Cent. index less than 0.100	2.678	16.162

be used for estimating the area of a closure to the fishery during an acute oil spill.

2.2 Evaluation of the fishery resources in the eastern Bering Sea and the Resource Thesaurus

The significance of an oil spill on commercial fishery resources cannot be evaluated simply from direct or indirect mortalities. Mortality from petroleum hydrocarbons is a population decrement which is superimposed upon ongoing natural and fishing mortality. Our analysis, therefore, requires not only isolating the component of total mortality which is attributable to petroleum hydrocarbon toxicity, but more importantly, evaluating whether mortality had any effect on population productivity. Such an evaluation requires considerable knowledge of the distribution, migration, life history, fisheries and population dynamics as well as the hydrocarbon toxicology of the affected species and stocks. We must know such things as the magnitude of the resources, their maximum and equilibrium yields, natural fluctuations and projected biomasses, the proportion of biomass distributed in the area of the oil spill.

In addition to the direct data on the magnitudes of the resources, a variety of other information and data are used in the models and in the evaluation of the results. Since the models, as well as results of this project, will be subject to scrutiny by several interested parties, it is imperative that the data used in the computations be available in readily usable form. Therefore, the data on the fishery resources and their environment will be summarized in a Resource Thesaurus. The outline of this thesaurus is given in Appendix 2.

Many data for the project were also derived from the large ecosystem simulations DYNUMES and PROBUB.

2.3 Distribution of oil from blowout and tanker accident.

The computed concentrations of the WSF from a blowout off Port Moller in Bristol Bay were provided by Rand Corporation. The distribution of these concentrations in the fifteenth day after blowout are given in Figure 6. These concentrations are low indeed; only in one grid point (grid size 2 km) the concentration is above 0.2 ppm and at additional seven grid points it is >0.1 ppm. Only 32 grids (128 km^2) have concentrations in excess of 50 ppb. The latter concentration is the lowest at which some mortalities of eggs and larvae have been observed (<50% mortality). No grid point has a concentration above 1 ppm--i.e., the lowest concentration causing any mortality of adult fish.

For the tanker accident, only a qualitative picture of the concentrations has been provided so far (Figure 7). Using this figure and the graphical data provided by Thorsteinson and Thorsteinson (1983), it can be estimated that the resulting initial concentrations of WSF would be 10 to 20 times higher from a tanker accident than from a blowout. It would also cover a more noticeable area, due mainly to the release of a greater quantity of oil in a shorter time period (ca 10 times higher release per unit time than blowout). Even in this case, however, the area of concentrations of 1 ppm and higher will be relatively small, and these concentrations will decay relatively fast.

The hydrocarbon concentrations in water resulting from substantial spills such as in hypothetical spill scenarios PU 3010 are several orders of magnitude less than the concentrations at which toxic effects were seen in laboratory experiments see next chapter). We would, therefore, expect that the direct effects to the adult fish populations would be small which is contrary to the prevailing popular conception of oil spill damage.

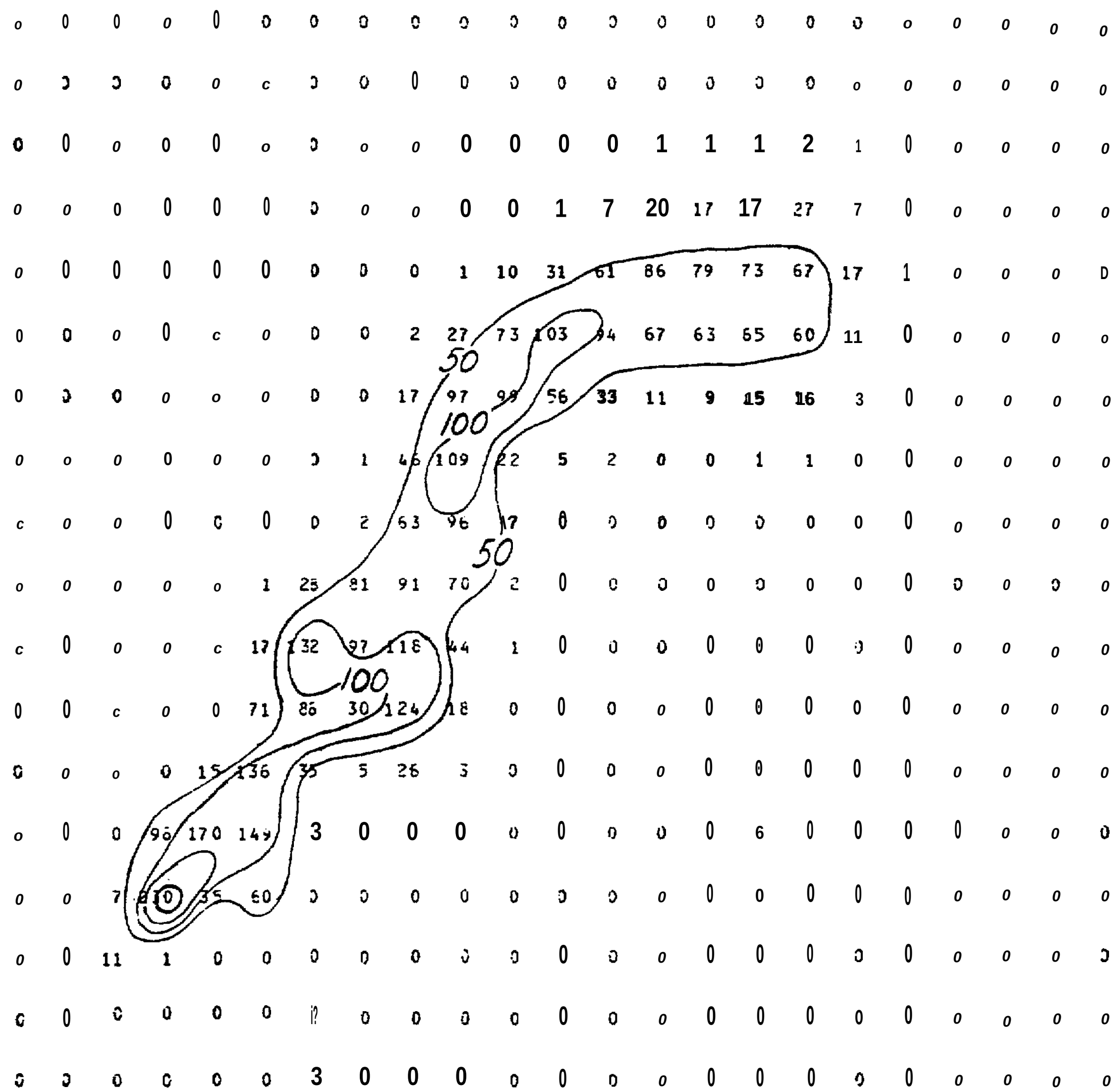

Figure 6.--Concentrations of WSF of crude oil in ppb in upper 15 m after 15 days from a well blowout. (Grid size 2 km.)

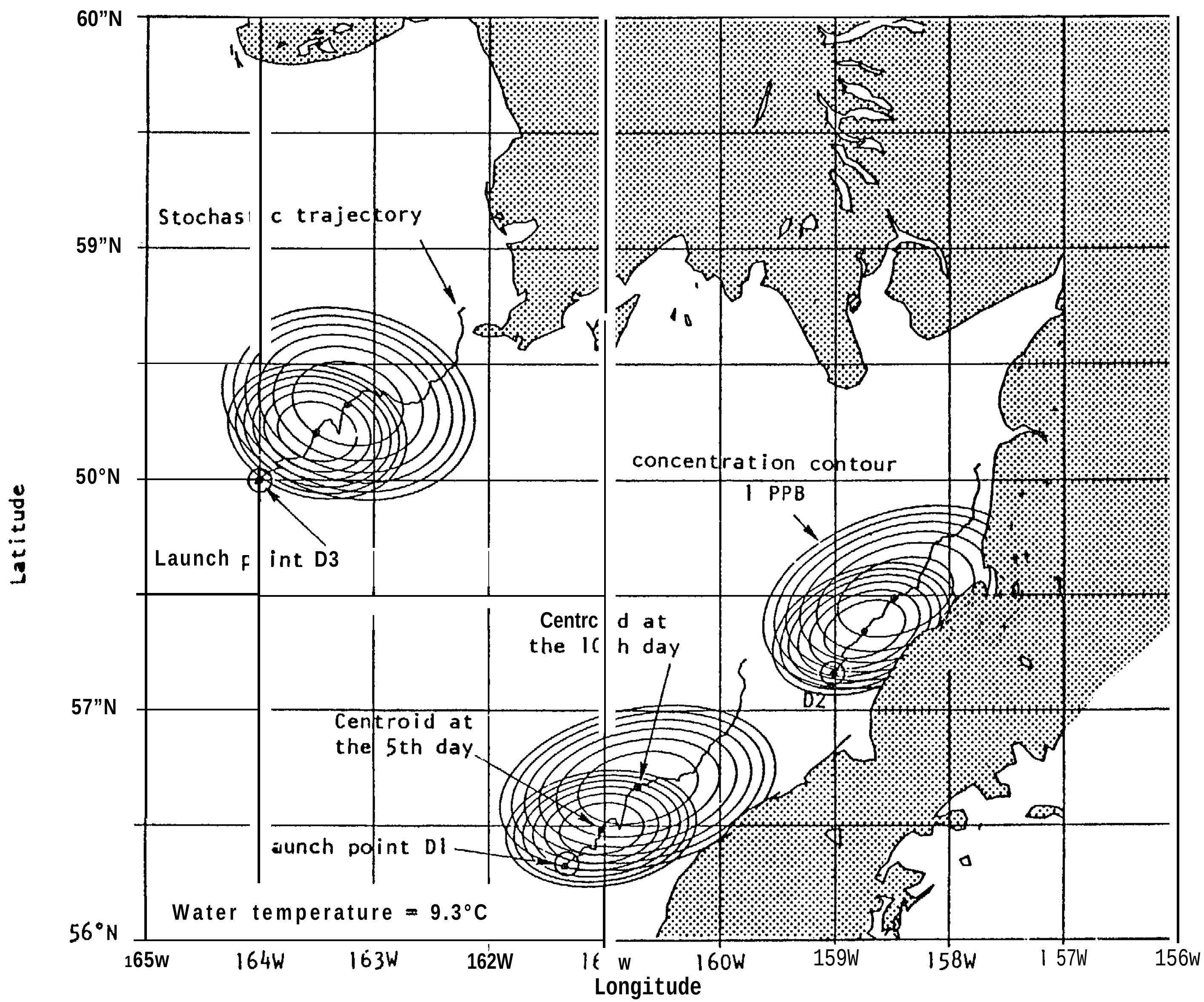

Fig. 7- Surface oil concentration for the 5th and the 10th day after the instantaneous release of 200000 bbls of Prudhoe Bay crude oil from three hypothetical spill sites. The movements and the shape of the dispersed oil is governed by the cumulated effects of local residual circulation, tidal excursion, vorticity, factors related to viscosity and surface tension (Liu 1983).

2.4 Review of the results of past effect studies.

A voluminous amount of literature are available on the laboratory studies of oil effects on fish and other aquatic biota. The corresponding reports on field studies are few, and their results often inconclusive.

The evaluation of the very variable results of the effect studies is difficult indeed; and their application to real field conditions even more difficult, as has been pointed out in the recent report from the National Academy of Science (see Chapter 1.1).

Main problems with the effect studies are:

1) Most of the studies have been carried out with WSF concentrations two to four orders of magnitude (100 to 10,000 times) higher than would occur with the greatest plausible accident. (Obviously lower concentrations showed little or no effects).

2) Different components of hydrocarbons have been used in these studies.

3) Very different methods of exposure have been used.

4) Treatment of species has been variable, and predominantly small and juvenile fish have been used.

5) Reporting of experimental conditions has often been incomplete.

6) Interpretations of results have often been qualitative.

After review of numerous effect studies, some quasi-quantitative criteria were developed for summarization of the results. The evaluated essentials of the oil exposure results pertaining to the present project are summarized in Tables 4 to 7. Some interpolation of these tables is necessary, and details will be provided in the final report when the results will be presented and evaluated.

Table 4 ---Percent of fish eggs and larvae affected by exposure to different concentrations of WSF of crude oil.

WSF concentration, ppm	0.01 to 0.1			0.1 to 1			1 to 10		
Exposure time, h	24	48	96 1/	24	48	96	24	48	96
Lethal		40	60	50	80	100	80	100	100
Hatching and development impaired, other sublethal effects 2/	20	60	80	80	100	100	100	100	100

1/ Effect after 96 hours remains unchanged (oil is becoming "weathered", etc.

2/ In computation of the effects these amounts are included in mortalities (there will be slower growth and higher vulnerability to predation). Reduced molting in crab larvae are included as sublethal effects.

3/ The effects of different concentrations of oil on zooplankton are comparable to the effects on eggs and larvae.

Table 5 ---Percent of population of marine fish and other fauna affected by exposure to different concentrations of WSF of crude oil. (Ohs. in estimating the effects using laboratory experiments it is assumed that "total aromatics" constitute 30% of WSF.)

WSF concentration, ppm 1/	0.1 to 1			1 to 10			10 to 100 4/		
Exposure time, h	24	48	96 5/	24 6/	48	96	24	48	96
Pelagic fish									
Lethal			10	20	40	70	60	80	100
Sublethal 2/		10	30	50	70	100	80	100	100
Demersal fish									
Lethal					20	40	30	60	100
Sublethal				30	50	80	50	80	100
Crustaceans, (epifauna) 3/									
Lethal						30	20	60	100
Sublethal					20	40	20	50	80
Infauna 3/									
Lethal							20	50	80
Sublethal						10	30	80	100

1/ Concentration on the bottom refers to concentration of "weathered oil" in the nepheloid layer near bottom.

2/ Sublethal effects include impairment of growth , fin rot, etc. (delayed effects). , (Sublethal effects start at ca 25% concentration of lethal concentrations.) (Sublethal effects do not result in mortal ity.)

3/ Pelagic crustaceans (incl. larval stages) are included in zooplankton. Epifauna includes some molluscs whereas burrowing molluscs are included in infauna.

4/ Most lethal effects are in this range of concentrations. The effects are often species specific. Values given in this column refer to ca25 ppm.

5/ Effects after 96 h can be considered as those at 96 h exposure.

6/ Concentration of ca 2 ppm can cause fish to avoid polluted areas (2-3 ppm inhibits salmon migrations).

Table 6---Effects of various concentrations of WSF of crude oil on the food uptake and tainting of marine fish and deputation times of these fish.

WSF concentration, ppm[1]	0.1 to 1			1 to 10			10 to 100		
Exposure time, h	24	48	96[6]	24	48	96	24	48	96
Pelagic fish									
Food uptake impaired[2]		10	30	20	40	80	100	100	100
Tainting[3]					20	40	60	80	100
Deputation; days[4]					2	4	8	10	15
Demersal fish[5]									
Food uptake impaired			10	10	30	70	40	70	100
Tainting				10	30	50	80	100	100
Deportation, days				2	4	7	12	15	20

1/ Concentrations on the bottom refer to "weathered oil" in the nepheloid layer.

2/ Values given are percentage of reduction of food uptake.

3/ Tainting refers both to degree and to percentage of population with unacceptable taste and odor.

4/ Deputation is dependent on temperature (longer time required at lower temperatures). Deputation refers to "detainting" of flesh. ,

5/ Demersal fish includes also clams and crabs.

6/ After 96 hours the effects are considered to remain the same as at 96 hours.

Table 7.--Effects of the uptake of contaminated food by fish (including crabs)

Contamination index[1/]	0.5 to 5	5 to 10	10 to 50	50 to 100	<100
Lethal			10	30	50
Sublethal[2/]	10	30	60	100	100
Tainting[3/]		10	30	60	100
Deputation, days[4/]		4	8	12	16

1/ Contamination index = food uptake (BWD) * concentration of oil in environment (ppm) * 50 (mean bioaccumulation factor) * 0.75 ("retention factor") = mg/kg. The contamination is accumulative. Deputation is computed linearily on contamination index.

2/ Sublethal effects include: slower growth, fin rot, tumors, etc.

3/ Tainting is dependent on accumulation of hydrocarbons in the body (50 ppm and higher).

4/ Deputation is dependent on temperature (slower in lower temperatures),

3. WEATHERED OIL ON THE BOTTOM

The task concerned with the effects of oil on the bottom has become one of the more important parts of this project. It has also demanded considerable effort for completion, since there exists a scarcity of both data and past investigations on this subject. The notes below present a tentative review of the progress in this subject.

3.1 Sedimentation of oil.

PONAS (paraffins, olefins, and napthas) constitute about 70% of crude oil; the rest (30%) are aromatics. Of the total oil, about 10% is WSF. It is estimated that more than half of the PONAs will ultimately end up as "weathered oil" on the bottom of the sea. The settling of oil is greatly affected by fine silt and clay in the water (suspended mineral matter). In addition, the settling of oiled phytoplankton (especially diatoms) and zoop?ankton fecal pellets also deposit oil on the sea bed. Although these pathways have been described, documentation of the principal processes of sedimentation and its quantification is generally lacking, particularly in subarctic waters.

Sediment loading in Bristol Bay can be about 40 g m^{-2} day^{-1}. According to Baker (1983), this sedimentation can bring down about 10 mg m^{-2} day^{-1} oil, if oil concentration is 1 ppb. (Maximum value in shallow water - 30 mg m^{-2} day^{-1}). Oil sedimentation rates of 3 mg m^{-2} day^{-1} have been observed elsewhere.

Besides the amount of mineral suspension in the water, sedimentation of the oil is also dependent on temperature, depth, presence or absence of thermocline, vertical circulation, and obviously on the concentration of oil in the water.

Only part of the oil sedimentizes within about the first 15 days after the accident. The remaining oil sedimentation takes place slowly and is thus distributed over large areas, resulting in low concentrations on the bottom.

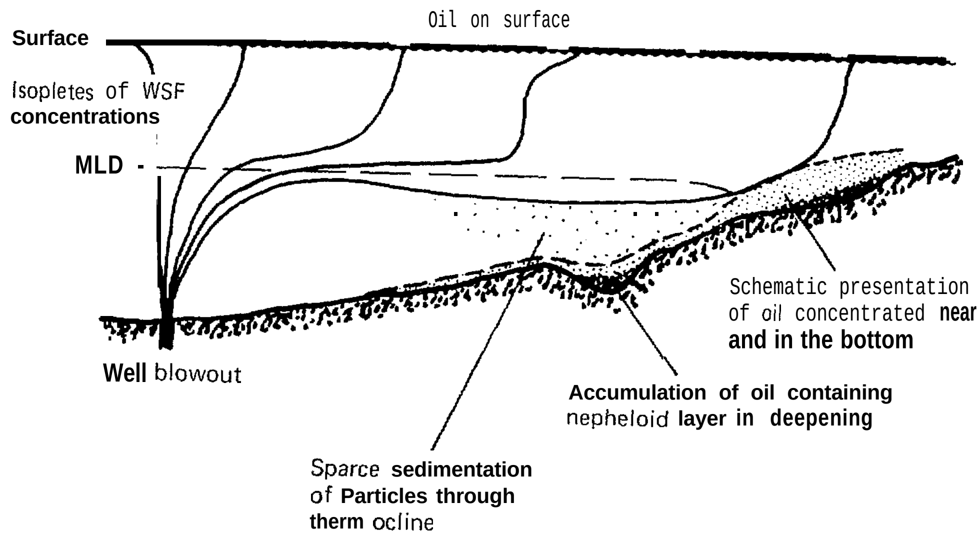

Figure 8.--Schematic presentation of sedimentation of oil.

The following tentative procedure and formulas have been empirically derived for computation of oil on the bottom:

The program simulates the distribution of oil on the sea bottom from the concentrations of WSF (emulsified and dissolved oil in the water) (S).

<u>Deposition and accumulation</u> of oil is made a function of turbulences (waves) which is approximated with wind speed (W, m/see), depth (D, m), time (presented with the count of 12-h time steps, K), and the presence or absence of the thermocline Potential Layer Depth (PLD) in any given grid point.

1. Instantaneous source ("tanker accident")

   a) PLD not present (shallow water, mixed from surface to bottom). No oil sedimentation to the bottom in first 12 hours. The amount of oil (AØ) on the bottom in time step t is:

   $$AØ = AØ_{t-1} + pS_t * F_s$$

   p is a tuning factor, dependent of the units of S

   $$F_s = (0.0013W + 0.062/D^{0.7}) * TK_s$$

   TK is time factor. K = 2 to 6 (incl.):

   $$TK_s = K/(6.5 - 0.7K)$$

   K = 6 and larger:

   $$TK_s = K/(3 + 0.2K)$$

   b) PLD (Thermocline) present at the grid point (no oil to the bottom in first 24 hours).

   $$AØ_t = AØ_{t-1} + pS_t * F_d$$

   p is a tuning factor, dependent of units of S

   $$F_d = (0.00065W + 0.038/D^{0.7}) * TK_d$$

   $$TK_d = K/(6 + K)$$

2. Continuous source ("blowout")

c) Depth is shallower than PLD (shallow water). (No oil to the bottom in first 12 h.)

Formula same as la, except distance from the source factor (DF) is added:

$$A\emptyset_t = A\emptyset_{t-1} + S_t * F_s * DF$$

DF = DIS(km)/15

d) Depth is greater than PLD (thermocline present). (No computation in first 24 hours.)

Formula same as lb, with the same distance factor as 2c added.

3. Oil on the bottom is assumed to form loose, floculous deposit. This deposit is moved 45° to the right of the mean current in the water, which has a speed 5% of that in the water.

4. The time step in the computation is 12 hours. The grid size is the same as used in the simulation of oil in the water (2 km).

5. The decay (degradation) of oil on the bottom from the previous time step is computed from the fourth 12 h time step on, before computing the sedimentation. The decay is a function of depth (D,m) and temperature (T,°C): (if K-3 ≥ O, bypass).

$$A\emptyset_{t(12)} = A\emptyset_{t-1}\, e^{-(t+d)}$$

$$t = T^{2.7} * (2 \times 10^{-5})$$

$$d = 0.015\sqrt{D}$$

$A\emptyset$ is computed in a 12-h time step. If a 24-h time step is used, the computation is repeated.

3.2 Fate of oil on the bottom.

Initially the weathered oil accumulates near the bottom in a nepheloid layer. It is nearly impossible to adequately characterize this layer in the ocean with conventional sampling tools. The nepheloid layer moves around with currents near the bottom and will accumulate in depressions. The burrowing animals carry the oil from the nepheloid layer into the sediment, where there is an accumulation of concentration of oil in the sediment. Some laboratory tests show a 1000 fold increase of concentration over that in water.

The weathered oil can persist in the sediment for a year or more. The loss of hydrocarbons from the sediment is a function of sediment type. Sand s found to lose ca 70% of oil during a month, whereas silt loses only ca 10% dur ng the same time period. Biodegration of the oil in sediment is dependent on m crobial fauna and temperature, with its rate known to more than double (ca 2.5 times) with a 10°C rise of temperature.

3.3 Effects of oil on the bottom on demersal fish and benthic ecosystem.

It is generally accepted that oil on bottom represents the most serious long term effects of oil spills. The main concern with oil on the bottom is its effects on demersal fish and the benthic ecosystem.

Linden et al. (1979) found that the effects of oil from the Tsesis spill were small and short lived on the pelagic ecosystem. However, the changes caused by oil in the benthic ecosystem were large; mobile macrofauna was drastically reduced, there was increased mortality in ostracods, and the biomass of bivalves (Macoma baltica) increased greatly. Amphipods, a very important fish food, were depressed and still are far below prespill levels (Elmgren, personal comm.). Flatfishes who fed on Macoma had 50 ppm concentration of hydrocarbons one year later.

Fletcher et al. (1981) have shown that heavily oiled sediment (2300 to 4500 ppm) remained toxic to winter flounder during the summer one year later, whereas during the winter there were no mortalities of the flounder (much reduced feeding during winter). Aged, oiled sediments had no effect on the feeding rate of the flounder.

oi1 on the bottom may not directly kill a given predator, but may indirectly reduce the growth and productivity of the population by selectively reducing an important prey population. Conversely, there has been some evidence of an increase in a clam population due perhaps to the oil imposed reduction of predators (Conan 1977, Amoco Cadiz). Ecosystem impact not involving prey-predator relationships have also been documented. For example, reproduction in Baltic herring was significantly reduced as an aftermath of the Tsesis spill. The mortalities were thought not to be attributable to the direct effects of oil on eggs. Rather, it was the consequence of a large mortality and decrease in amphipods which ordinarily graze on fungi growing on fish eggs, thus preventing fungal damage.

Summary of opinions on the effect of oil on the bottom by the world's foremost experts on this subject are found in Appendix 7 .

The effects of oil on the bottom will be quantified in the final report of this project.

4. PRELIMINARY QUALITATIVE RESULTS AND OTHER OBSERVATIONS

4.1 Contamination and tainting of migratory and sedentary adult fish.

1. The concentrations of WSF of the oil resulting from the largest possible accidents is several orders of magnitude lower than the concentrations used in laboratory effect studies. The possible effects of oil in the marine environment are, therefore, evaluated in terms of Maximum Effect Conditions (MEC) as defined in this report.

2. The effects of major accidents during the oil development on the Bering Sea continental shelf on adult fish appear to be small indeed, mainly because the concentrations of oil in the water would be low. The effect of a major tanker accident will be larger (but still below the error in a resource estimate), because higher concentrations might result and refined oil is more toxic than crude oil.

3. There may be some tainting of more sedentary fish under a part of the oil trajectory, but the area of possible closure seems to be relatively small and the closure time relatively short.

4. Of the salmon species chinook, pink, and chum salmon smelt may be affected to some degree if the accident occurs during the most unfavorable time.

5. The largest effect of accidental release of oil might be on the spawning and spawn of herring if the accident occurs near the major herring spawning beaches and during the short spawning time. Such a coincidence might be rare.

6. There may be some impact on the egg bearing females of king and Tanner crab since they carry eggs and remain in northern Aleutian shelf area almost all year round.

4.2 Effects of oil on eggs and larvae, and on the recruitment to exploitable stock .

1. The effects of oil on eggs and larvae will start at oil concentrations of 50 ppb and above. The max mum amount of annual egg production killed in MEC is, in general, less than 10% (and smaller) .

2. The effect of egg and arval mortality will show up as a possible reduction in the exploitable stock 3 to 8 years later when the affected year class is recruited to the fishery. The reduction of exploitable stock would then be only a few percent, as there are several year classes in the exploitable stock. Thus , this reduction is about an order of magnitude smaller than the plausible error in stock assessment.

3. in extremely rare circumstances the oil may affect a year class of herring eggs (see 4.3).

4. Some quantity of egg-carrying female crabs and instar stage of crab juveniles might be affected by the oil near or on the bottom.

4.3 Environmental and local conditions for maximum impacts.

1. More than 30% of the oil on and in the water will ultimately sedimentize to the bottom. In the area of the "oil plume" during the first 15 days, the sedimented oil will form concentrations high enough to affect the species composition of the benthos and may cause some tainting of more sedentary demersal fish and crabs.

2. The oil effect on the bottom can last longer than a year. The decay of the oil on the bottom is determined by the type of sediment and by temperature.

3. The largest effects of oil could be caused by beaching oil during the spawning of herring. It is possible that more than half of a year class can be killed and the annual harvesting of roe might fail. Such an event can be considered quite rare.

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APPENDIX 1

Personnel of the Project

Principal Investigators:

Marasco, Richard; NWAFC - Fisheries economics and management.

Laevastu, Taivo; NWAFC - Ecosystem simulation (modeling), sedimentation of oil.

Researchers and Other Personnel:

Bax, Nicholas; CS (contr.) - Salmon migrations, effects on smelt and adult salmon.

Fukuhara, Francis; U of W (contr.) - Fishery resources, effects of oil on fish and benthos.

Gallagher, Arthur; NWAFC - Simulation of feeding and uptake of oil as contaminant.

Goiney, Bernard; NWAFC - Laboratory technician.

Gregory, Marjorie; U of W (contr.) - Typist.

Hayes, Maureen; U of W (contr.) - Research assistant (computers, fisheries biology).

Ingraham, James; NWAFC - Environmental data; computations.

Kendall, Arthur; NWAFC - Fish eggs and larvae.

Kim, Suam; U of W (contr.) - Fish eggs, spawning.

Livingston, Patricia; NWAFC - Fish food and feeding habits.

Miyahara, Robert; NWAFC - Environmental and biological data.

Pola-Swan, Nancy; NWAFC - Simulation of migrations, contamination of fish; computation of egg/larvae mortalities.

Rabe, Kevin; CS (contr.) - Computer (production).

APPENDIX 2

THESAURUS OF THE ANALYZED AND DIGESTED DATA ON THE ENVIRONMENT AND BIOLOGICAL RESOURCES OF EASTERN BERING SEA PERTINENT TO HYPOTHETICAL OIL SPILL

F. Fukuhara

Evaluat ng the impacts of hypothetical oil spill scenarios for PU3010 requires the development and application of a series of predictive models. First, the direction, dimensions and fate of the simulated spills must be estimated. Hydrocarbon concentrations in the water column, their sedimentation and temporal persistence must be estimated. The communities of plants and animals inhabiting the polluted time-space must then be determined. Finally, the lethal and sublethal effects on the productivity and marketability of the commercially important species of fish and shellfish must be estimated.

The credibility of the assessment from th's complex sequence of estimation procedures (which are described only in broad and simplistic terms above), depends not only upon the rationality of the simulation models applied, but also on the quality of data bases for certain essential aspects of the environment and resources and on the applicability of experimental results on the physiological effects of hydrocarbons on the eastern Bering Sea biota. Current knowledge regarding the life history, productivity, and dynamics of the principal resources in the study area is also required because the significance of oil imposed mortality must be evaluated in the context of ongoing natural and fishing mortalities to these stocks.

In short, the impact evaluation of PU301O requires the synthesis of a considerable volume of environmental , biological, and fisheries information collected over the last two decades or more in the eastern Bering Sea. These data, and in most cases their analyses, are copiously documented in data files and in unpublished and published reports of several agencies and institutions concerned with Bering Sea fisheries management or environmental research. Also, although it is difficult to extract many general izations from past, large oil spill accidents, there are some analogies which have some interpretive value to the present study. Also, for lack of an alternative for directly estimating or assessing certain oil spill related phenomenon such as sedimentation and biological effects of hydrocarbons in the eastern Bering Sea setting, it is necessary to refer to certain empirical observations from past oil spill studies and laboratory studies for insights into formulation of predictive models and conclusions therefrom.

PURPOSE OF THE "RESOURCE THESAURUS": The purpose of this analyzed and digested report is to consolidate and summarize from these diverse sources, information specifically relevant to the following aspects of these oil impact studies:

1. the environmental factors which will determine the transportation, dimensions, dispersal, and persistence of oil spilled at Port Moller, Port Heiden, and off Cape Newenham;

2. the fisheries, species and stocks, life history, and quantity or biomass which might inhabit the spill area, and;

3. the lethal and sublethal impacts of oil on certain commercially important resources and important components of their food webs.

OUTLINE OF THESAURUS

1. Physical Factors Affecting the Transportation, Evaporation, Dissolution, Emulsification, Sedimentation, and Weathering of Crude Petroleum and Automotive Diesel Fuel Spilled off Port Heiden.
    - A. Characteristics of Prudhoe Bay crude oil and automotive diesel fuel and the climatological, geological, meteorological, and oceanographic features which affect the dispersal, persistence, and effect on the Bering Sea benthos.
        1. Characteristics of Prudhoe Bay crude
            - a. Chemical composition (hydrocarbons and polar compounds)

b. Physical characteristics (boiling point, viscosity, sp. gravity, etc.)

2. Characteristics of automotive diesel fuel (outline similar to above).

3. Transportation and weathering process of petroleum spill

a. Slick formation and transportation (oil viscosity, sea state, wind force and direction, surface and tidal currents).

b. Weathering Process

i. Evaporation

ii. Emulsification

iii. Dissolution

iv. Photo oxidation

v. Microbial degradation

vi. Residue

c. Sinking and sedimentation

i. Physical processes

a. entrainment of particles in vertical currents

b. adsorption of oil particles to suspended mineral matter (e.g., clay)

ii. Bio-physical processes

a. oiling and killing of plankton, sinking of carcasses

b. ingestion of oil and sinking in fecal pellets of zooplankton

4. Climatological, geological, meteorological, and oceanographic characteristics of E. Bering Sea which modify the dispersal, persistence, and biological effects of spilled petroleum.

a. Climate and weather

i. Subarctic seasonal characteristics

a. seasonal duration and variation of sunlight (relevant to photo-oxidation and phyto-plankton production)

b. monthly mean air temperatures (and range) and seasonal and annual variations

c. seasonal and annual variation in sea ice cover

d. monthly ranges and means of precipitation

e. monthly or seasonal wind duration and speed

b. Geology

i. Major embayments, lagoons, and shoreline characteristics of the north side of the Alaska Peninsula and Bristol Bay rim.

ii. Major drainage systems of southeastern Bering Sea (say, Kuskokwin R. and eastward-southward to False Pass).

III. Bathymetry and substrate type of eastern Bering Sea.

c. Oceanographic characteristics

i. Tidal currents (height and period), specifically in eastern Aleutians and Bristol Bay areas.

ii. Surface current patterns (monthly, seasonal, and annual variability).

iii. Monthly mean surface temperatures.

iv. Monthly mean salinities.

v. Vertical circulation and seasonal turnover or mixing of water column.

a. thermocline (stability and depth)

b. speed and depth of vertical currents

vi. Water chemistry

a. nutrient salts

b. suspended inorganic matter

c. naturally occurring, biogenic and petrogenic hydrocarbon concentrations on bottom and in water column.

II. Eastern Bering Sea Biota (commercially important species, prey, predators, and symbiotic organisms) most likely to be impacted by Spill Scenarios PU301O.

A. Food Web, Feeding Rates and Ecosystem Associations

1. Basic productivity of southeastern Bering Sea

2. Important herbivores (decapod larvae, copepods, amphipods, mysids, etc.)

3. Epifauna and infauna (amphipods, echinoderms, clams, worms, etc.)

B. Fish and shellfish of the southeastern Bering Sea benthos

1. Demersal fishes

a. General discussion

i. Commercially important species and the r distribut on

ii. Overall fisheries - production and value (products, fleets, processing facilities, work force)

b. Walleye pollock

i. Distribution and life history

a. life history groups

b. spawning season and migrations

c. feeding migrations

ii. The commercial fishery

a. catch

b. effort

c. biomass estimate (virtual pop. est.; fish. data)

d. annual and inst. fishing mortality

e. status of stock (MSY, EY, etc.)

iii. Biomass and population estimates from trawl surveys

a. number and proportion of total population in subareas 1 and 45 as estimated from 1975 and 1979 surveys and seasonal variations

iv. Recent and projected biomass estimates, status of steaks, and trends in productivity and abundance

v. Sensitivity of egg, larvae, juveniles, and adults of pollock to water soluble hydrocarbon fractions

a. deformities and debilitation

b. mortal ity

c. Yellowfin sole

(outline similar to that for pollock)

d. Pacific cod

(outline similar to that for pol lock)

e. Rock sole

(outline similar to that for pol lock)

f. Alaska plaice

(outline similar to that for pol lock)

9" Longhead dab

(outline similar to that for pollock)

h. Arrowtooth f'lounder

(outline similar to that for pollock)

i. Pacific halibut

(outline similar to that for pollock)

2. Anadromous and transient species (salmon and herring)

a. General discussion of salmon and herring

b. Salmon

i. Species, distribution, abundance of spawning stocks, and life history

a. smelt and juvenile distribution and ecology

b. route and timing of spawnings migration

c. food habits and predators

ii. Fisheries and natural mortality

a. targeted and incidental high seas catch

b. estimated growth and mortality

iii. Sensitivity to oil pollution

a. avoidance

b. debilitation and delay of migration

c. mortality to smelts and adults

c. Herring

i. Distribution and abundance of spawning stocks and life history

ii. Spawning, feeding, and juvenile migration routes and timing

iii. Fisheries and natural mortality

iv. Food habits and predation

v. Sensitivity to oil pollution

a. direct effects on herring

b. indirect effects on food items

c. pollution of spawning environment or mortality to symbiotic organisms

3. Crabs

a. General discussion

i. Species and their distribution

ii. Fisheries and their values

b. Red king crab

i. Distribution and life history

a. life history groups

b. spawning season and migrations

c. feeding migrations

ii. Numbers and proportion of total population in Subarea 1 as estimated from 1975 and 1979 surveys and seasonal variations

a. eggs and larvae (fecundity, development of pre-benthic stages)

b. pre-recruits

c. exploitable population

III. Recent and projected biomass estimates and trends in productivity

iv. Sensitivity to water soluble fractions of hydrocarbons

a. deformities and debilitation

b. mortal ity

c. Chionecoetes bairdi

i. Distribution and life history

a. life history groups

b. spawning season and migrations

c. feeding migrations

ii. Numbers and proportions of total population in Subareas 1 and 4 as estimated from 1975 and 1979 surveys and seasonal variations

a. eggs and larvae

b. pre-recruits

c. exploitable population

III. Extant and projected biomass estimates and trends in productivity

iv. Sensitivity to water soluble fractions of hydrocarbons

a. deformities and debilitation

b. mortality

4. Clams

a. General discussion of clams as latent resource

b. Species, distribution and abundance

c. Significance in food chain

d. Reaction to benthic poil pollution

i. Mortality

ii. Collectors, concentrators, and transmitters of benthic, hydrocarbon residue

5. Food Chain Organisms

a. Phytoplankton

b. Zooplankton (amphipods, copepods)

c. Hydro ds

d. Worms

e. Barna les

f. Non-commercial crabs and molluscs

g. Echinoderms

III. Summary Conclusions Re evant to S mulation Analyses for Estimat ng Impacts of Oil Spill Scenarios PU301O

A. Formulation of operational hypotheses regarding the transportation, dissolution, evaporation, weathering, and sedimentation of petroleum from spill scenarios PU301O.

1. lateral transport

2. chemical changes with time

3. sedimentation

4. seasonal variations

(above discussion based upon literature from Canyon, Cadiz, and Tsesis episodes as well as intuitive and simple "common sense" derivations of oil composition and environmental data in Section 1 - A through C.

B. Estimates of the exploitable biomass of species of commercial value which can be expected to occur in Subareas 1 and 4S based on past survey and commercial fishery data,

1. maximum and minimum biomass
2. seasonal variation
3* estimated rates of migration
4. spawning aggregations?

c. Estimates of the expected quantities of pre-adults to occur in Subareas 1 and 4S.

1. eggs
2. larvae
3. juveniles

D. Discussion of oil pollution induced perturbations to the food web.

E. Anticipated effects on various organisms of different concentrations of volatile hydrocarbons based upon past spill and experimental observations.

Iv. Effect of oil on coastal spawners.

v. Literature Cited.

VI. Literature Reviewed but not Cited.

APPENDIX 3

Special Computer Programmed and their Subroutines

1) PROBUB - Prognostic Bulk Biomass model

An extensive simulation model for the dynamics of the whole ecosystem in the Bering Sea and Gulf of Alaska. Model area is divided into 9 regions. The model contains numerous subroutines. It is used for a variety of purposes, such as computing the fishery resources (equilibrium biomasses), determination of the effects of fishing, natural fluctuation studies, etc.

2) DYNUMES - Dynamical Numerical Ecosystem simulation model for the Bering Sea

This model is similar to PROBUB (above), except it uses a computational grid (i.e., resolution in space). It allows, therefore, to compute, in addition to the computations with PROBUB, also migrations and any spatial effects of fishing pollution and other location specific phenomena.

3) DEMOIL - "Demersal Oil"

A programme for quantitative testing of the effects of accidents during oil developments.

Control programme sets input parameters, counts time steps, and calls all subroutines. The distribution of oil in the water can be read from tape or created with the subroutine CUROIL.

Subroutine CUROIL can create different currents fields (tidal and wind driven). It computes the distribution of the oil from either a continuous or a point source. The same subroutine is used to move and disperse oil near the bottom with prescribed currents.

Subroutine OILBOT computes the oil to the bottom in various conditions affecting the sedimentation. The oil is also allowed to decay with time, depending on the temperature.

Subroutine EGGLAR moves the eggs and larvae into the oil field (either with currents or with eddy diffusion) and computes the amounts of eggs exposed to different concentrations, as well as their exposure times.

Subroutine FIEXPO computes the quantities of either stationary or migratory fish exposed to different concentrations of oil.

Subroutine CONFOO computes the uptake of contaminated food by fish, and the deputation of contaminated fish.

Subroutine PRIMFS is for printing of various output fields in two dimensions.

4) WFL/OCSEAP - A programme for detailed computation of exposure of eggs, larvae, and fish to oil. Oil distribution in the water and on the bottom is read from the tape.

Subroutine FEDOIL is for detailed computation of uptake of oil hydrocarbons with contaminated pelagic and demersal food. Deputation (decay of hydrocarbons) of fish is also computed. Outputs give the "contamination index" which is the amount of hydrocarbons in the biomass (mg/kg).

Subroutine MIGR is for migrating the fish with different speed and direction through oiled areas and for computation of the exposure.

APPENDIX 4

Commercially Important Species Potentially Impacted at

Sites in Hypothetical Spill Scenarios

Port Heiden (57"1O'N 159°W)

Herring (eggs, juveniles and adults)
Sockeye (juveniles and adults)
Chinook (juveniles and adults)
Pinks and chum (juveniles and adults)
Yellowfin sole (juveniles and adults)
Pollock (eggs and larvae)
Halibut (juveniles)
Pacific cod (adults and larvae)
Pacific plaice
Greenland turbot
Flathead sole slight
Rock sole
King crab (P. camchatica)
Tanner- crab (C. bairdi)
Clams
- Surf clams (Spisula)
- Alaska tellin
- Cockles
- Razor clams

Cape Newenham (58°N164°W)

Herring (juveniles and adults)
Sockeye (juveniles and adults)
Chinook (juveniles and adults
Pinks and chum (juveniles and adults)
Yellowfin sole
Pollock (slight)
Halibut (juveniles)
Pacific cod (larvae, juveniles)
Pacific plaice
Greenland turbot (slight)
Flathead sole (slight)
C. opilio
C. bairdi
Korean hair crab
Surf clams

Appendix 4 (cent'd.)

port Moller (56°26'N 161°20'W)

Herring (eggs, juveniles, and adults)
Sockeye (juveniles and adults)
Chinook (juveniles and adults)
Pinks and chum (juvenile's and adults)
Yellowfin sole (juveniles and adults)
Pollock (eggs and larvae)
Halibut (juveniles)
Pacific cod (larvae and adults)
Pacific plaice
Greenland turbot
Flathead sole } slight
Rock sole
Arrowtooth flounder
King crab (*P. camchatica*)
Tanner crab (*C. bairdi*)
Clams
    Surf clams (Spisula)
    Alaska tellin
    Cock 1 es
    Razor clams

APPENDIX 5

Review of the model for estimation of the effects of oil developments on salmon

Nicholas Bax

This modelling exercise is limited to sockeye salmon (Oncorhynchus nerka), one of the four species of Pacific salmon utilizing the Bristol Bay area. The three remaining species (O. gorbuscha, O. keta, and O. tshawytscha) are strongly associated with nearshore habitats during early mar ne residence but this period could not be studied as the effects of the oil spil scenario on these habitats was not included in the oil trajectory model.

Rogers (1978) summar zes, and Eggers and Rogers (1978) present, the available data on the numbers (or indices) of sockeye salmon emigrations from the four principal river systems in Bristol Bay, and present the temporal distribution of these emigrations. Rogers (1978) lists the estimated adult returns to the coastal area by brood year to those four rivers, and Burgner (1980) illustrates its temporal variability. These data sets are the basis for this model ling exercise.

The model for the simulation of emigration of the smelts through Bristol Bay is complete, although the data sets require updating to include data not available to Rogers in 1978. The model is an adaptation of one proposed by Eggers and Rogers (1978), and simply moves the smelts through Bristol Bay at a rate dependent on their length. The inputs of smelts to this model are the stream counts or indices on the four major rivers, adjusted by river system to total 10 times the total adult coastal return from that brood year. The parameters and assumptions for this model were extrapolated from mark and recapture data presented by Straty (1974) and include the following:

1) Juvenile sockeye grow very little while migrating through the inner Bay (out to Port Heiden); growth begins when they leave the inner Bay.

2) Marked Ugashik sockeye salmon smelts doubled in size from a mean of 107 mm in 8 weeks (2 mm/d). Marked Wood River smelts increased by 50% from a mean of 85 mm in 4 weeks (1.5 mm/d). A value of 1.75 mm/d was used for the growth rate of smelts in outer Bristol Bay in this model.

3) Straty (1974) estimates the amount of time taken by smolts from each of the four river systems to move through the inner Bay. These estimates correspond to an average rate of travel of 0.7 body lengths/see. This value was used in the model.

The results for this model for the years 1967-1970 are presented as the numbers of smelts from each river system passing Port Heiden (.Figs. 1-4). The values presented include no allowance for daily mortality between the time the smelt count was taken and their arrival at Port Heiden, and thus are valid for their relative values only.

It is apparent that there are considerable variations in abundance at Port Heiden within and between years. The available data sets will be analyzed to estimate the maximum proportion of any smelt emigration that would be subject to the presented oil spill scenario at Port Heiden. With the assumptions in the model this will be an overestimate, because no allowance is made for temporal diffusion; a comparison of the temporal spread of the smelts as they leave the rivers (Rogers 1978) with that of the temporal spread of marked smelts in the Bay (Straty 1974) indicates a threefold increase in temporal spread over this period.

The model evaluating the effects of the presented oil spill scenario on the adult salmon will be formulated in the same manner as presented above, but using the annual time of arrival of the adults at the Bristol Bay fishing grounds as the principal data base and Straty's (1975) estimates of adult migration rates.

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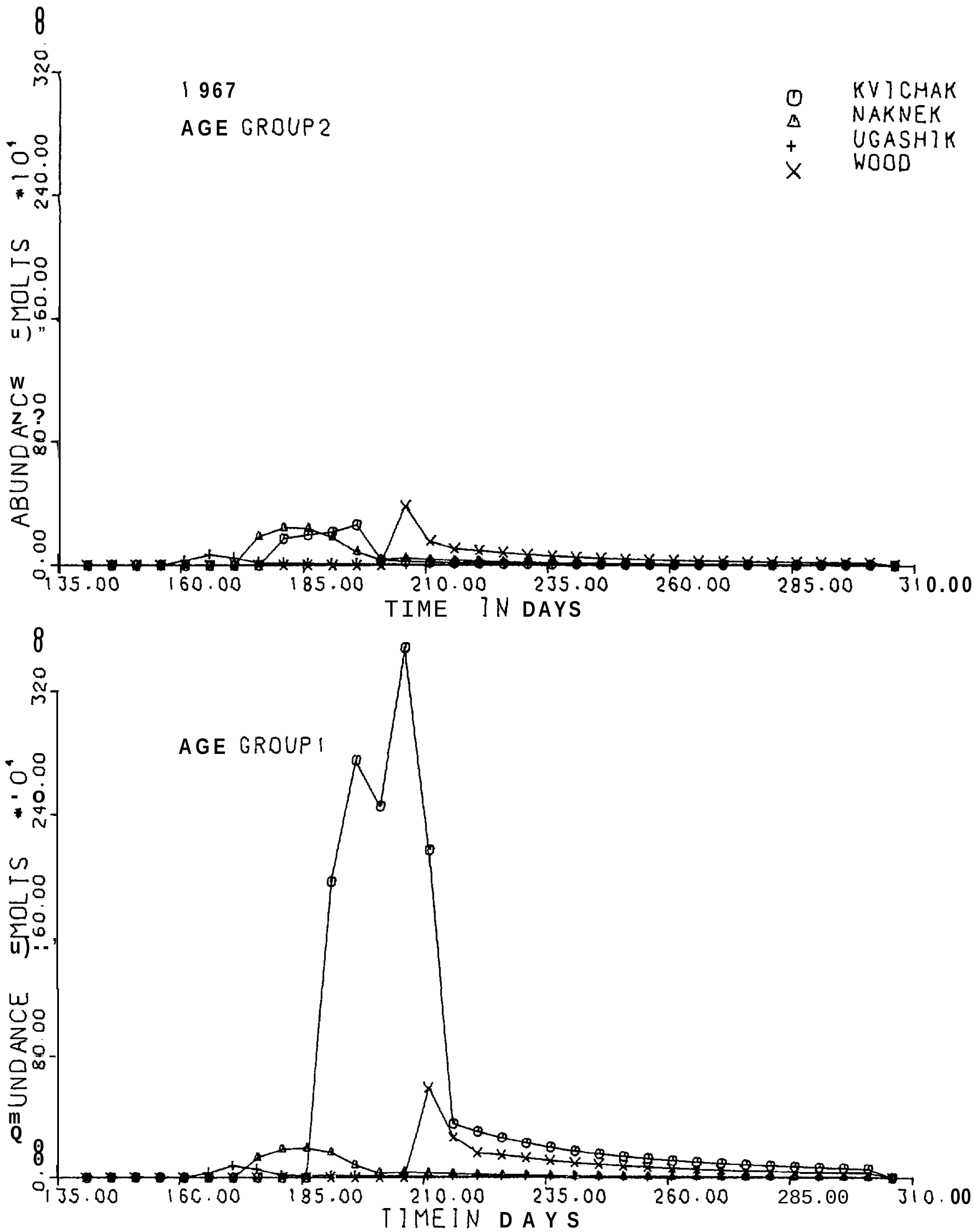

Figure 1.--Projected relative abundance of sockeye salmon smelts at Port Heiden in 1967.

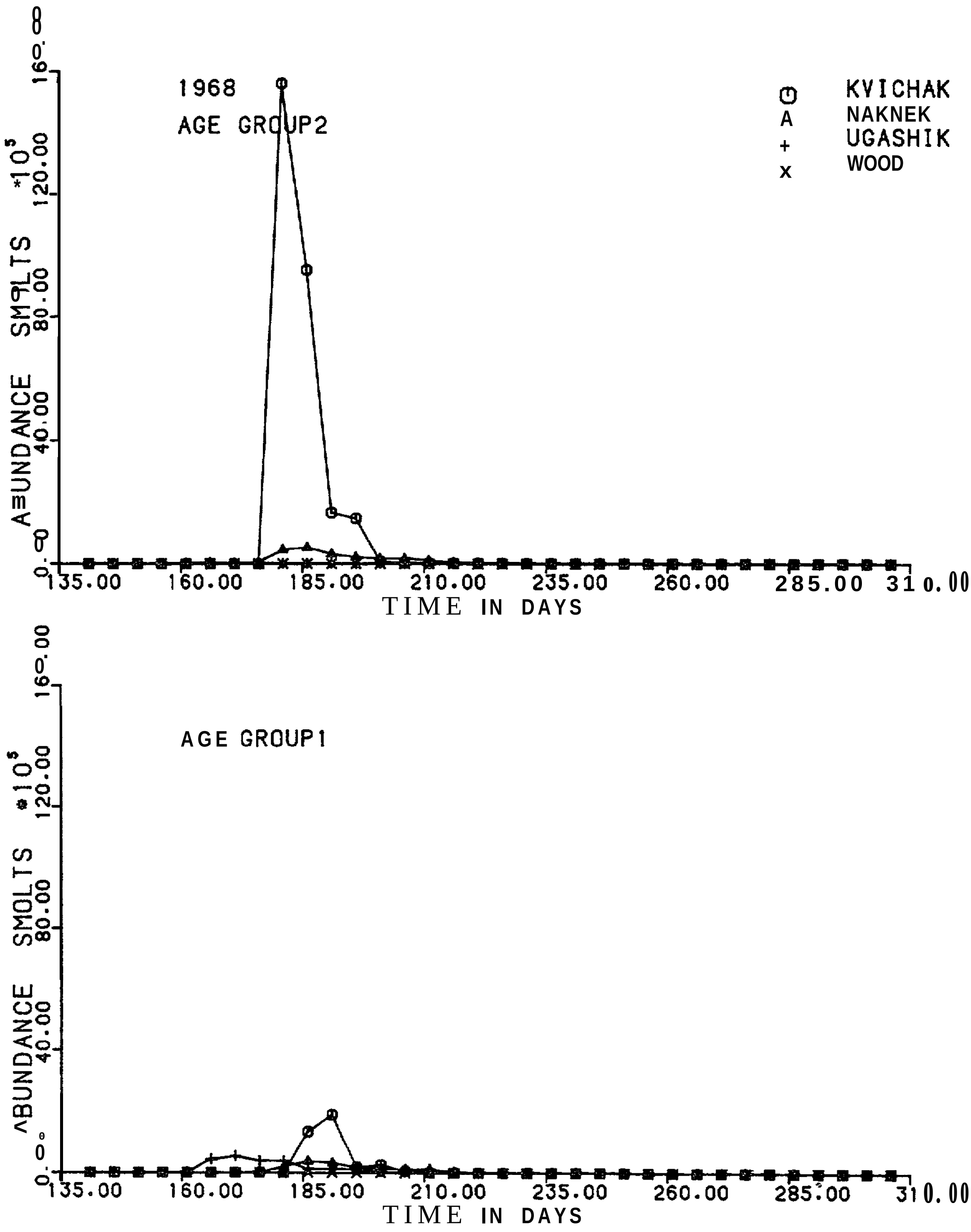

Figure 2.--Projected relative abundance of sockeye salmon smolts at Port Heiden in 1968.

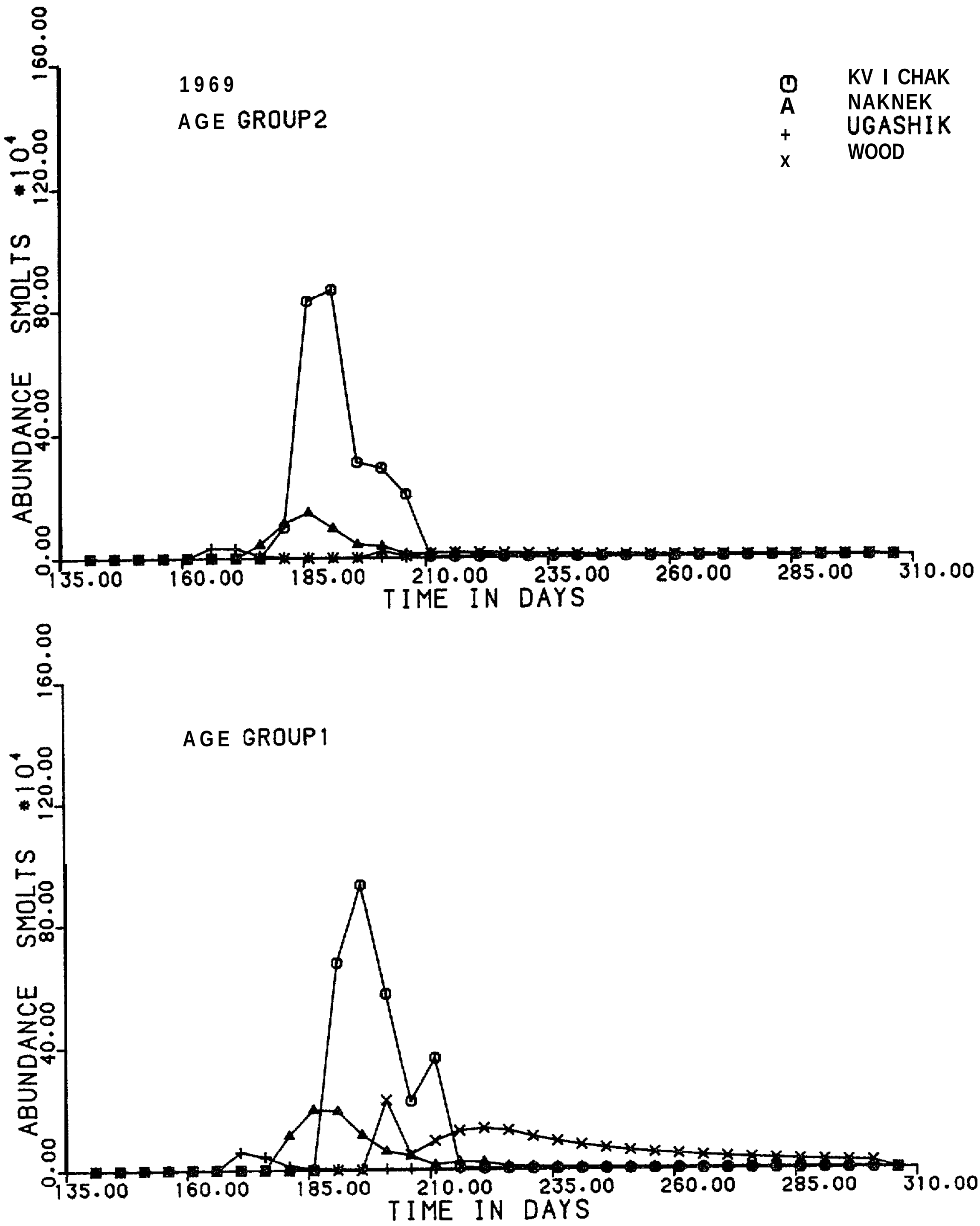

Figure 3.--Projected relative abundance of sockeye salmon smelts at Port Heiden in 1969.

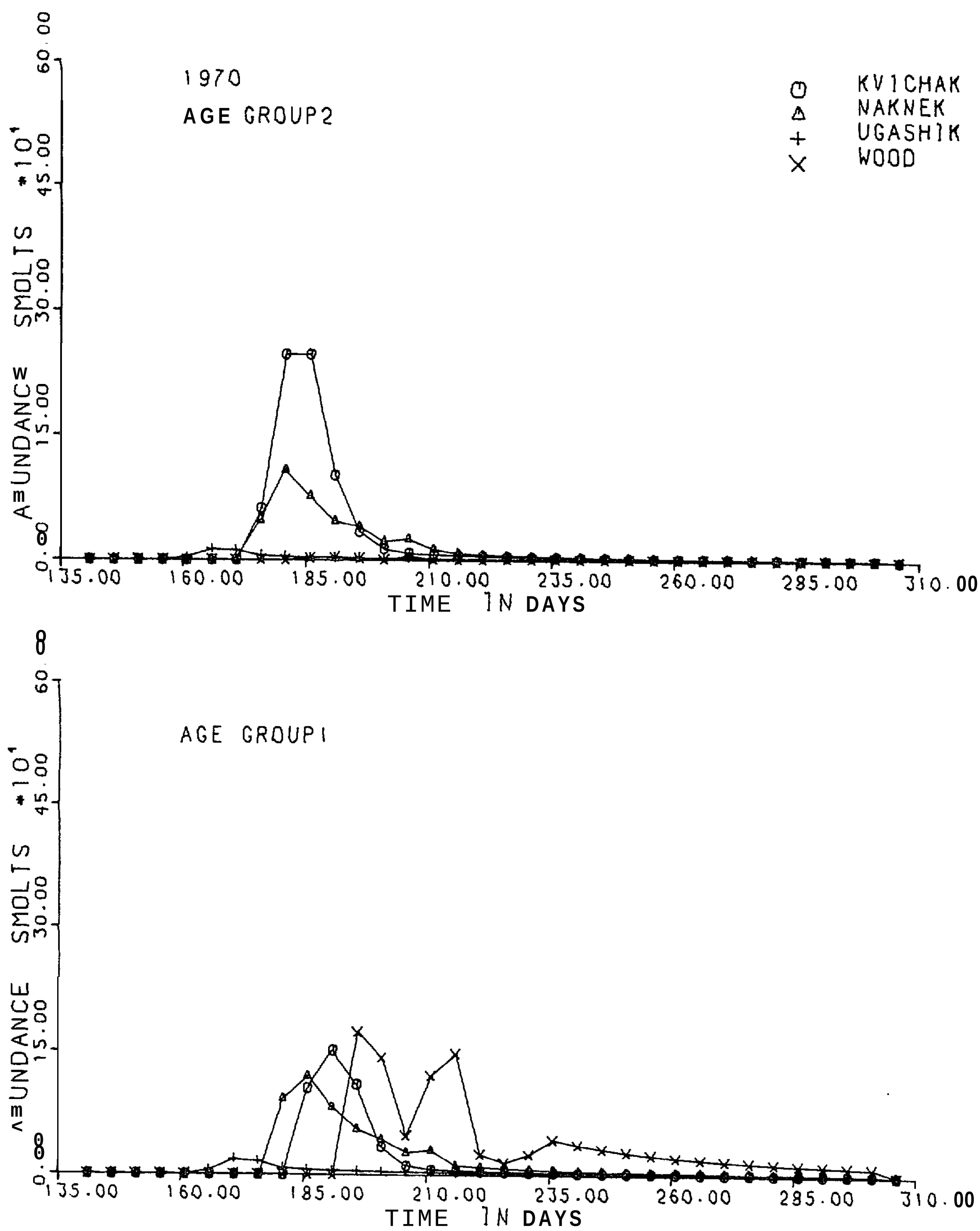

Figure 4.--Projected relative abundance of sockeye salmon smelts at Port Heiden in 1970.

APPENDIX 6

Selected food habits and life history information of four commercial fish and invertebrate stocks of the eastern Bering Sea

P. Livingston

In order to quantify the effects of oil spills on marine fauna in the Bristol Bay area of the Bering Sea, the population dynamics of four species of major commercial importance will be modelled. Some baseline information on the food habits and distribution of these species in the area needs to be established to assist in parametrizing the model. The following is a short summary overview of the food habits of sockeye salmon, *Oncorhynchus nerka*; yellowfin sole, *Limanda aspera*; Pacific herring, *Clupea pallasii*; and red king crab, *Paralithoides camtschatica*. For the most part, an attempt is made to outline only details directly pertinent to those species during that portion of their life history which they spend in Bristol Bay. However, some information is available only for other areas and hopefully should be representative of the species in Bristol Bay.

Sockeye Salmon, *Oncorhynchus nerka*

General Information

Adults begin arriving at river mouths in Bristol Bay in late June and early July. This spawning migration route from their western feeding grounds usually is along the southern portion of Bristol Bay in surface waters (Nishiyama 1974). Outmigrating smelts, which may be 57-122 mm long in British Columbia (Manzer 1969), are usually in the upper 2 m of water (Straty 1974) in Bristol Bay. This migration occurs between May 15-July 15. Smelts move westward alongshore past Port Heiden and Port Moller. They have sometimes been found as late as mid-August off Port Moller. Inshore and in the inner portion of Bristol Bay, most smelts have been found with empty stomachs.

Straty (1964) correlates this with extremely low zooplankton abundance in waters less than 20 fathoms deep. Smelts reaching Port Moller have been found with full stomachs, however.

Food habits

'Life history stage	Reference	Season	Area	Food items (% by weight)
Smelts	Manzer, 1969	Su	British Columbia	48% copepods, 24% fish, 14% larvaceans, 5% decapods, 4% insects, 3% amphipods.
Smelts	Straty, 1974	Su	Bristol Bay	Sandlance larvae, euphausiid larvae, copepods, cladocera, pteropods, decapod larvae, other fish larvae, invert. eggs, insects.
Adults	Kanno and Hamai, 1971	Su	E. Bering Sea shelf	43% euphausiids, 27.7% fish, 25.1% amphipods.
Adults	Nishiyama, 1974	Su	Bristol Bay	70% euphausiids, 20% fish larvae, 10% crab zoea, amphipods and pterapods.

Yellowfin sole, Limanda aspera

General Information

Spawning of yellowfin sole has been observed in the Bering Sea at depths of 15-75 m. Eggs have been found off Cape Newenham between June to September and larvae have been observed in the second half of July (Musienko 1968). Seasonal movements of yellowfin sole are not known in great detail but there does seem to be an inshore movement in spring and a movement towards the slope in fall. Some smaller fish (age 5-7) remain in Bristol Bay during winter (Fadeev 1972). It is not known when the pelagic larvae settle to the bottom but presumably they settle inshore. English sole larvae are pelagic for 6 to 10 weeks (Hart 1973) and possibly yellowfin sole larvae are pelagic for a similar length of time. Adults cease feeding in the winter although occasionally in some areas a few fish have been found with some food in their stomachs (Fadeev 1972). Fadeev (1972) also claims that the Cape Newenham area is poor in benthos, therefore yellowfin sole eat more pelagic prey in that area like euphausiids and nektobenthic prey like pandalid shrimp. Simenstad (1979) classified the yellowfin sole in Cook Inlet as a facultative piscivore because they were eating predominantly osmerids but supplementing their diet with other items which in this case were benthic and epibenthic items. In inshore areas of Bristol Bay, the yellowfin sole has been observed feeding on herring eggs attached to vegetation.

Food Habits

Life history stage	Reference	Season	Area	Food Items (% by weight
Larvae (2-10 mm) Limanda limanda	Last, 1980	Su	North Sea	90% copepodites, 10% decapod zoea.
Juveniles	Rogers et al. 1979	Sp, Su	Kodiak I.	22% fish (cottids), 20% poly chaetes, 18% crab, 14% clams.
Adults 100-200 mm	Wakabayashi, 1974	Su	Bering Sea	polychaetes, amphipods, echiuroids.
201-300 mm				polychaetes, bivalves, echiuroids, gadids, osmerids, amphipods.
301+ mm				Mostly bivalves and echiuroids.
Adults	Skalkin, 1963	Sp, Su	SW of Cape Newenham	mysids, euphausiids (30-50 m depth) polychaetes, molluscs (50-65 m depth).

Herring, *Clupea harengus pallasii*

General Information

Herring leave their wintering grounds in the southeast Bering Sea in March and April. These wintering herring rarely eat (except sometimes euphausiids) according to Dudnik and Usol'tsev (1968). Adults spawn in late April to May in Bristol Bay. Herring caught near Cape Newenham during a spawning survey were all >200 mm long. Adult herring stay inshore in summer for their main foraging period and may stay at least until August. Depths of spawning in British Columbia range between high tide and 11 m (Hart 1973). Eggs hatch in about 10 days and the larval yolk sac lasts at the longest for 2 weeks. After about 2 months the post-larvae begin forming schools which come to the surface in the evening as do the schools of adult herring.

Food habits

Life history stage	Reference	Season	Area	Food items (% by weight)
Larvae 9-20 mm	Wailes, 1963	Sp	British Columbia	40% invertebrate eggs, 40% diatoms, 20% copepods nauplii.
Larvae 9-20 mm	Barraclough, 1967	Sp, Su	British Columbia	90% copepod nauplii, 10% eggs and algae.
Juveniles 20-100 mm	Barraclough, 1967	Su	British Columbia	phytoplankton, copepod eggs, copepods, amphipods, larvaceans.
Adults 100+ mm	Wailes, 1963	Su, F, Sp	British Columbia	euphausiids, copepods.
Adults	Dudnik and Usol'tsev 1968	Su	Bering Sea	euphausiids, calanoid copepods, Sagitta.
Adults	Barraclough,	Sp, Su	British Columbia	90% copepods, 10% amphipods, euphausiids, brachyura larvae, and invert. eggs.

King Crab. Paralithodes camtschatica

General Information

During late winter and early spring adult males move inshore where females reside just off of Port Moller in the eastern Bering Sea for breeding purposes. Eggs carried by the females for the past year hatch about April 1 and are found all the way to Port Heiden. Females then molt and males mate with them just after the molt. A female must be inseminated within 5 days after the molt to produce viable eggs. Larvae pass through four pelagic zoeal stages. Each of these stages take about 2-3 weeks to complete. The larvae then spend a month as pelagic megalopae whereupon they metamorphose to first instars about mid-July to August and presumably settle on the bottom. These juveniles presumably stay very nearshore on the shelf north of the Aleutians until they are about 3 *yrs.* old (60 mm carapace length) (Armstrong et al. 1981).

Food habits

Life history stage	Reference	Season	Area	Food items (% by weight)
Pelagic larvae	Incze, pers. Comm .	Sp, Su	Bristol Bay	copepod nauplii, copepodites, cirripedia larvae.
Benthic juveniles	Takeuchi, 1968	Su		polychaetes, seaweed.
Adults	Cunningham, 1969	Su	Bristol Bay	49% echinoderms, 37% molluscs, 10% crustaceans, polychaetes.

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Appendix 7

Views of Dr's. Elmgren (University of Stockholm), Lehtinen and Linden (Swedish Environmental Research Institute) regarding oil in marine environment.

(Recorded by F. Fukuhara)

Dr. R. Elmgren, Zoological institute, University of Stockholm. Principal Investigator of Tsesis spill.

Elmgren had no specific comments regarding our general approach and agreed that sedimentation and the effects of oil on organisms *were* the most difficult to predict. He points out that the recognition that some of the oil in spills eventually reaches the bottom is relatively recent and since the Tsesis spill there has been a growing concern that the amount which gets to the bottom exceeds earlier estimates. We also discussed the difficulties of extrapolating laboratory results on the effects of hydrocarbons to actual field conditions. Elmgren recognizes this to be a prevalent problem in almost all toxicological evaluations but he feels that many biological organisms are far more sensitive to hydrocarbons that is normally, experimentally demonstrable.

Some of his views, although not particularly unique, seem useful to consider as general operational principles. One is that, like in the study of all natural phenomenon, there are no certainties in conclusions relating *to* oil spills and their effects on the ecosystem and organisms. He thought it useful to reiterate this thought to preclude the apiori discarding of speculations or hypotheses simply on the basis of inability to present rigorous proofs.

Like most European scientists in oil spill evaluations, Elmgren considers the impacts of oil on any species to be significant only if long term productivity is substantially reduced or the ecosystem proceeds to some long term secondary succession. Accordingly, he considers oil in the water column to be of interest mostly in terms of determining the quantity, direction, and ultimate deposition or disposition of the spilled oil. He does not consider the oiling of phytoplankton and zooplankton in the water to be anything but of very short term importance. This is partially because the life cycle of these organisms is short (therefore, quick regeneration time), but also because in the Tsesis, MERL, and other oil spill observations, phytoplankton and bacterioplankton increase in abundance and pelagic zooplankton seem not to be visibly impacted (although there is some thought that their feeding may become inhibited). The higher concentrations of sub-surface oil in the RAND analyses can be lethal or debilitating to eggs-and larvae(of invertebrates and fish) and may cause significant impact under certain circumstances. Sedimented oil will, of course, affect benthic zooplankton; however, the persistence of unfavorable concentrations will depend upon the hydrocarbon composition of the oil, the relative energy of the benthos and substrate type.

Also as a general consideration, in the real world of a Bering Sea spill he wondered if we should not give some thought and mention to the possible overriding political concern for the protection of birds and mammals. This would argue for the use of dispersants which would minimize the fouling of birds and mammals. This would, of course, increase the problem for fish and shellfish by assuring that the hydrocarbon concentrations in the water would increase from ppb to ppm.

Dr. Elmgren agrees that sedimentation of oil presents the most significant long term hazard of oil spills, but the persistence of oil in his view is dependent upon the hydro-carbon composition of the oil and the bottom sediment type. Oil on rock, gravel, and sand bottom is rather rapidly removed or weathered and the effects of spilled oil on these surfaces would be more immediate and short term. In the case of the Tsesis, the spill occurred in an archipelago of the Baltic Sea which has no measurable tide and very little flushing from the North Sea. Since it is totally surrounded by land, fetch is limited and agitation by wind is comparatively limited. The bottom is muddy or silty, providing the circumstances for long term persistence of oil. Also, the Baltic has little ecological and species diversity.

By contrast, the Amoco Cadiz spill occurred on the relatively high energy coast of Brittany with tides of 5 to 9 meters and very strong coastwise currents and winds generated over the fetch of the North Atlantic Ocean (at about 49*N. lat.). The exposed coast suffered relatively short impacts from the spill; however, some of the bays, inlets, mud flats, and salt marshes were still affected more than 2 years after the spill.

As a rule of thumb, Elmgren considered 2 gm/m^2 of bottom as a threshhold concentration for damage to the benthos. This concentration will cause total mortality to ostracods and amphipods, both of which seem relatively sensitive to petroleum hydrocarbons.

Concerning pathways of oil sedimentation, Elmgren had no real data. His feeling was that much more oil sinks to the bottom than intuition would lead one to believe. In the MERL experiments he now believes 50 - 60% of the introduced oil sank to the bottom. It is his view that most of the oil is transported to the bottom by vertical currents and adsorption of oil droplets to suspended particulate matter. Elmgren considers the oiling of phytoplankton carcasses and consolidation of oil droplets in zooplankton fecal pellets as not important pathways for oil sedimentation. The basis for his views are the MERL experiments in which 50 - 60% sedimentation occurred in tanks where very few zooplankton were present.

His offhand opinion of oil sedimentation in the northern Aleutian area: Given the present information on bottom sediment types, tidal, and boundary currents, and vertical circulation and suspended particulate matter, considerable oil may be sedimented. Because of the relatively active vertical transport of water and the coarse sandy nature of the substrate, he would expect the impacts to the benthos to be relatively short-lived in the P. Heiden and P. Moller spill sites. This would be more comparable to the Amoco Cadiz spill off the Brittany, France coast which has active surface turbulence, boundary and tidal currents so that oil was rapidly dissipated or weathered in the offshore benthos and intertidal areas, except in the heads of sheltered bays (Aber Wrath and Aber Benoil and certain areas of the Bays of Morlaix and Laurion).

In the MERL experiments the oil on the benthos was suspended about 1 cm from the bottom in a flocculence which drifted about and which was seen to escape bottom grabs or flow-through core sampling devices. Therefore, oil on the benthos is apt to impact more severely certain merofauna and infauna which are filter feeders rather than sediment feeders.

In the Tsesis investigations it was evident that oil on the bottom was patchy but according to Elmgren it was difficult to determine if the patchiness was associated with rather small scale variations in bottom topography. There was evidence that oil tended to collect in depressions.

In the MERL tank experiments, oil concentrations were always high in the depressions and fill of core sampling. Thought to occur as a consequence of the way in which sediments were replaced into the hole left by the corer.

As a general rule, Elmgren felt that the effects of an oil spill would last as long as the liftime of the longest-living species which was significantly impacted by oil hydrocarbon toxicity. In the Tsesis spill that happened to be the Macoma baltica which may live to be about 15 years old. The M. baltica, however, seemed not to be negatively impacted, their biomass increasing over pre-spill levels. Bering Sea has much more species diversity and a number of species which may live 15 years and considerably longer (e.g. flatfish).

Although he could offer no real hard evidence, Elmgren felt that oil concentrations of themselves may not be nearly as important in biological impacts as the hydrocarbon composition, in particular the aromatic content of the oil. He felt that the multimolecular aromatics such as the tri-methyl benzenes were particularly harmful.

Hydrocarbon in the Tsesis spill area has now returned to pre-spill background levels. These background levels are evidently increasing in the Baltic Sea and Gulf of Bothnia in general and in particular along the major transportation routes of tankers and other ship transportation.

Herring which were reduced in abundance and appeared to avoid certain areas in spawning the year after the spill, have now returned to pre-spill levels of abundance with no apparent aversion to feeding or spawning in areas affected by the Tsesis spill.

Macoma populations no longer carry large concentrations of Tsesis hydrocarbon and now exceed pre-spill abundance levels (roughly 10x pre-spill abundance). The amphipod Pontoporeia affinis, however, the abundance of which was directly related to the abundance of Macoma prior to the spill, remains severely depressed (1% of pre-spill abundance). The failure of Pontoporeia to recolonize the spill area is not easily explained. One thought is that the increasing population of Macoma in the absence of the Pontoporeia which normally prey upon Macoma spat, have so severely agitated the bottom in such a way that Pontoporeia cannot reestablish themselves. Another hypothesis is that unmeasured residues of Tsesis spill (perhaps polar compounds) remain in the sediments, effectively repelling or otherwise preventing the recolonization by P. affinis.

With regard to fish tainting, herring which normally occur in abundance in the Tsesis spill area,a month after the spill showed no particular aversion to oiled areas for feeding but showed no evidence of flesh taintedby petroleum hydrocarbons. Flatfish evidently had hydrocarbon concentration in the muscle of about 50 ppb. Although they were not tested for flavor, they were marketed without adverse consumer reactions. This did not surprise Elmgren since oysters taintedby Amoco Cadiz oil were marketed with tainting levels in the ppm. Although the marketability of oysters from the Bordeaux and Mediterranean, as well as the Brittany region, suffered from customer aversion after the Cadiz spill, levels of hydrocarbon in the tens of ppm were considered to be suitable for human consumption.

There is no evidence that hydrocarbons become progressively concentrated in the food chain. Although certain molluscs may be particularly resistant to high hydrocarbon concentration levels and may themselves be rather inefficient in hydrocarbon metabolization, and therefore, concentrate them, flatfish which eat Macoma may very efficiently dispose of petroleum hydrocarbons. More on this from Linden and Lehtinen.

Elmgren stated that experience with seabirds in the Baltic Sea indicated that most have the reproductive resilience and potential to recover rather rapidly from oil pollution. Animals such as birds which have very high metabolic rates can be expected to suffer more acute damage from the effects of oil spills. His conjecture was that in the Bering Sea, vertebrates such as birds and the sea otter (which lacks the conservative quality of lots of blubber) may be very sensitive to oil, whereas cetaceans and pinnipeds which have comparatively low metabolic rates may be able to better withstand the effects of oil.

In all cases, he suggests we consider such sublethal effects as reduced ability to find mates, capture prey, or elude predators.

Summary of Elmgren's Views

Regarding sedimentation, he agrees that oil on the bottom presents the more serious of oil spill problems. He could, however, present no further evidence relative to quantifying the pathways of oil to the benthos. He is, however, of the strong opinion that most of the sedimented oil results from circulation and adsorption of oil particles to suspended particulate matter. He has reiterated the generally prevalent view that the persistence of oil is related inversely with the rate of water circulation and replacement and in the relatively high energy circumstance of P. Moller and P. Heiden, sedimentation of oil is not expected to be a long term problem.

Concerning the biological impacts of oil, he reiterated what is in the literature relative to the Tsesis, Cadiz, etc. spills, although he brought us upto date on the Tsesis situation. He has added an interesting note regarding the tainting of fish on which Lehtinen and Linden have elaborated.

Elmgren asked that he be kept abreast of our progress and wanted copies of our reports.

References he suggested:

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Dr. Karl-Johan Lehtinen and Dr. Olaf Linden, Swedish Environmental Research Institute (IVL), Baltic Sea Laboratory, Utovagen, Karlskrona, Sweden.

Dr. Olaf Linden is the director of about 15 scientists studying the impacts of pulp mill effluents, oil, and other pollutants on the marine environment and organisms. They have ongoing studies on the weathering of certain oils on test beaches, they are testing the effectiveness and consequences of various dispersants on oiled beaches (test plots), and they retain a set of outdoor tanks with circulating sea water in which they are testing the effects of pulp mill effluents in various concentrations on the community and organisms of the area. They also have facilities and expertise for bioassays of various pollutants. My impression was that they are a very competent group which are only partially financed by the government but exist on private contracts and grants as a research foundation. Dr. Linden felt personally that he could probably help us most by focusing our reading to the better, more credible and relevant studies of oil spills and related studies. He felt that the oil spill literature was now so voluminous that with our limited involvement with the oil pollution problem it would be virtually impossible to weed out the "wheat from the chaff". He was convinced that a thorough canvasing of the extant oil pollution literature would be a many, many year task.

As with Elmgren, 1 reviewed very briefly the E. Bering Sea spill *scenarios,* data bases, background oceanography, biology, etc. and a sketch Of our strategy for solution of the simulation exercise.

Linden's view was that the higher concentrations in the Rand outputs *were* fairly high for actual spill conditions. High enough to impact seriously eggs and larvae and invertebrates and animals carrying exposed eggs.

Linden had nothing to add concerning sedimentation of oil beyond those reports associated with the Argo Merchant, Ixtoc 1, Cadiz, Tsesis, and Sefir spills. These reports give estimates of the amounts of oil sedimented but Linden could not elaborate further on the quantities sedimented through different pathways.

(To digress slightly, Dr. Linden is an acknowledged expert on oil spills. He is a member of a U.N. group which responds to world-wide spill problems. In this capacity he has been involved in the investigations of the Ixtoc I spill in which he recalculated the estimates of the amount of fate of the oil spilled (originally calculated by the Mexican government to show least impact on environment). He has also been at the site of at least 2 spills near the Arabian Peninsula. He has a number of publications on the effects of oil on marine organisms, including fish, but he has also published on the fate of oil in spills (Jernelöv and Linden, 1981)).

Linden thought it worthwhile to pay some special attention to the effects of oil washed ashore as it well may in any of the spill scenarios for south-eastern Bering Sea. Even if spills occur offshore, if oil washes onshore the effects on the littoral and intertidal fauna can be dramatic and disastrous: In the "Sefir" spill (similar to the "Florida" spill), Linden estimated that more than 90% mortal ity occurred to the shore and benthic fauna from the acute toxic effects of oil. In the Sefir spill, millions of animals were washed ashore and deposited in windrows on the beaches,

Linden shared Elmgren's view regarding the short term scale of impacts of oil spills on the pelagic community. He was not aware of any documented evidence of major and long term impacts of oil pollution on fish populations. Even in the Tsesis situation, he does not believe there is sufficient evidence to demonstrate that the oil had any direct impact on the behavior or productivity of herring or flatfish.

Also spoke with Dr. Karl-Johan Lehtinen (Carola's husband), a physiologist. On the matter of fish tainting, he believes experimental evidence indicates that oil taken through the food chain would first concentrate in the liver before appearance in circulatory system and flesh. Fish have enzyme systems which metabolize hydrocarbons. Both Lehtinen and Linden felt that high concentrations of hydrocarbon in the liver would probably manifest in debilitating effects before high enough concentrations could be built up in the muscles. For these reasons they felt that tainting of fish loins sufficient to affect human consumption might be a minor consideration. Lehtinen also felt that deposition of oil was more likely in lipids; therefore, might be concentrated in livers, gonads, gills, and perhaps in the flesh of very fatty fish.

Linden referred me to a very good summary report on the Cadiz spill consequences by Lucien Laubier. Laubier states, "oysters containing 20-30 ppm dry weight are considered to be slightly polluted by fossil fuels. On a practical basis, an average value of 60 ± 20 ppm, wet weight, was considered as the upper limit for human consumption".

Linden cautioned that much of the information on the Ixtoc I blowout (1979-80) is very unreliable.

Linden suggested the following as excellent references.

1. In the Wake of the Argo Merchant
Proc. of a Symp., Jan. -ii-13, 1978
Univ. of Rhode Island

(According to Linden this is one of the best scientific studies of an oil spill.)

2. K. J. Lehtinen, et al.
1982 - Physiological Effects of Fish Chronically Exposed to Low Levels of Hydrocarbons
Proc. 5th Arctic Marine Oil Spill Program Technical Seminar
June 15-17, 1982, Edmonton, Albert, pp 77-92.

3. Neff, Jerry M. and Jack W. Anderson
1981. Response of Marine Animals to Petroleum and Specific Hydrocarbons. Applied Science Publishers, Ltd., London, pp 177.

In Linden's view, Dr. Jerry Neff is an authority on the impact of the Amoco Cadiz spill on fish and oysters.

He also considers Boehm as the best oil chemist around (Cadiz expert, also).

Agrees that Van der Mueller of the Bedford Ocean. Inst. is a top-flight sedimentologist and authority on Cadiz oil sedimentation.

He also suggested reading reports related to the grounding of the "Florida" off Falmouth.

APPENDIX 8

Possible Effects of Oil Development in the Bering Sea on the Fishery Resources

(A quantitative numerical evaluation)

Summa ry

by

Northwest and Alaska Fisheries Center
Resource Ecology and Fisheries Management Division
Seattle, WA 98112

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1. Fishery resources in the eastern Bering Sea, their utilization, and their natural fluctuations.
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3. Migrations of fish in the eastern Bering Sea and effect of oil on migratory and stationary adult fish.
4. Food and feeding of fish in the eastern Bering Sea and uptake of contaminated food (including tainting of fish by oil).
5. Sedimentation of oil and effects of oil on the bottom on demersal fish and benthic ecosystem.