EVALUATION OF THE EFFECTS OF OIL DEVELOPMENT ON THE COMMERCIAL FISHERIES IN THE EASTERN BERING SEA

by

T. Laevastu and R. Marasco
Project Leaders,
and
N. Bax and T. Honkalehto
Compass Systems, Inc.,

R. Fredin and F. Fukuhara
University of Washington and
Natural Resource Consultants,
and
A. Gallagher, J. Ingraham, P. Livingston,
R. Miyahara, and N. Pola

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PREFACE

Statements made in this report must be considered in light of the assumptions and caveats associated with the study. Any attempt to develop generalizations from the results of this study must be approached with caution.

This report summarizes findings presented in a series of reports that describe the results of a research project that was undertaken to provide OCSEAP estimates of the impact of two specific oil spill accidents at three sites on red king crab, yellowfin sole, Pacific cod, and sockeye salmon (Table 1). The study addressed three major areas of possible impacts of oil on fisheries: 1) effects of oil on fish and shellfish eggs and larvae and the projection of these effects over subsequent years, 2) effects of oil on adult fish and the possible uptake of hydrocarbons by fish, and 3) effects on the benthic ecosystem of weathered oil on the bottom of the ocean. Evidence based upon the best environmental and biological data available suggests that spills of the magnitude and at the locations indicated would not seriously impact the productivity of these stocks. Tainting was considered to be a potential problem. The impact on the fishery of the loss of fishing area and/or the fouling of vessels or gear were considered to the extent allowed by the data. The impact of oil accidents under various ice conditions, the effects of oil on the beach and inshore areas, and the effects of oil on marine mammals and birds were not considered. It is important to recognize that study findings must be evaluated within the context of the validity of assumptions made. Further, any change in the scenario, location of spills, or changes in the distribution of animals relative to the spill can be expected to produce a different impact. Such an evaluation would require a new study, as would the assessment of the impact of the original scenarios on other species of plants or animals and the impact if, in the simulation, significant quantities of oil were permitted to invade the beaches and estuaries of Bristol Bay.

This report is from a series of processed reports and program documentation produced by the Northwest and Alaska Fisheries Center, National Marine Fisheries Service, NOAA, in Seattle, Washington, and is individually available as Processed Report 85-19 from that source.

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NWAFC PROCESSED REPORT 85-19

'This report does not constitute a publication and is for information only.
All data contained herein are to be considered provisional.

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1. THE POSING OF THE PROBLEMS OF OIL DEVELOPMENTS AND FISHERIES INTERACTIONS

1.1 The posing of the problems pertaining to the effects of oil developments on the fisheries.

Some past oil spills from grounded tankers have caused extensive damage to beaches and have damaged local inter- and subtidal marine ecosystems. These coastal spills have received considerable attention in the news media and from the scientific community. However, no evidence has been found documenting notceable detrimental effects of past oil developments on fishery resources (excluding minor local impacts), despite many Draconian forecasts of the possible impacts of oil developments on marine fisheries and ecosystems. Many of these sinister forecasts appear to have resulted from incorrect extrapolations of selective laboratory observations on the effects of hydrocarbons on the physiology, genetics, and mortality of fish (Payne 1982). As a result of misconceptions of possible effects of oil developments on marine ecosystems, an antagonistic attitude between oil development and fisheries (mainly presented by "environmentalists") prevails in the United States, whereas in Europe and in eastern Canada a cooperative attitude exists which is based on multiple use concepts of natural resources.

To clarify the possible effects of offshore oil development on fisheries, it is necessary to investigate this complex of problems quantitatively (numerically) using all available pertinent knowledge. A contract to this effect was given from Mineral Management Service via National Ocean Service to the Northwest and Alaska Fisheries Center. The present report presents the summary of the studies of the possible effects of oil developments on the fishery resources in the eastern Bering Sea, mainly in Bristol Bay.

1.2 Hypotheses on the probable effects of oil development on fisheries and fishery resources.

A main detrimental effect of local oil development on a fishery and its resources might be caused by an oil spill from a well blow-out or from a pipeline rupture. On the other hand, an oil spill from a tanker accident may occur anywhere in the world where oil is transported.

Oil spills at sea spread at the surface, from where the greatest part of it evaporates, and the remainder dissipates through the water column by dissolution and emulsification. Weathered oil settles to the bottom, and if the accident happens near the coast some of the oil might be blown to the shore. (This latter aspect is not considered in this study.)

If considerable concentrations of oil were to be found in the water column (dissolved and/or emulsified) , it might have some lethal and sublethal effects on organisms (e.g. fish), before the natural purification restores the environment to pre-spill conditions (a matter of weeks). Sedimentized weathered oil on the bottom will, however, persist longer than in the water column, and may have some effect on benthic animals (including demersal fish) for a longer period.

It has been assumed in the past that some direct (and immediate) effects of an oil spill on fishing might be:

1) Loss of fishing area, due to presumption by the spill or cleanup activity (see Section 4.3).

2) Possibility of fouling of vessels or gear (a discounted possibility of extreme rarity).

3) Inability to sell catch due to tainting (see Sections 4.2 and 4.3). (Possible consumer avoidance, often intensified by journalistic sensationalism.)

4) Possible loss of catch, due to toxic mortality of exploitable stock, or of eggs and larvae affecting future exploitable stock (see Sections 4.1, 4.2, and 4.4).

5) Acute but latent mortality to eggs, larvae, juveniles, and adults (see Sections 4.1, 4.2, and 4.4).

6) Effects on habitat and alteration of prey population and food chain (see Section 4.2).

Although possible genetic mutations are mentioned in some literature, no serious scientific evidence can be found to elaborate on this very remote hypothesis.

Many other factors besides possible oil spill effects operate on fishery resources, such as year to year differences in availability of fish in given locations, natural fluctuations of stocks, effects of fishing on stocks, and market conditions. The effects of all factors affecting fish stocks can be evaluated on a comparative basis (i.e. comparing the oil spill effects to natural fluctuations and to the local effects of resource changes on the fishery as a whole).

1.3 Objectives of present study.

The potential impacts of oil development on fisher es are assessable with the present state of knowledge of complex dynamic, bio ogical processes of stock production arid ecosystem interactions, which can be attacked with complex marine fish ecosystem simulations.

The present study addressed three major areas of possible impacts of oil on fisheries:

1) Effects of oil (from accidents) on fish and shellfish eggs and larvae, and the projection of these effects over subsequent years.

2) Possible effects of oil on adult fish (including crabs and migrating salmon), and the possible uptake of hydrocarbons by fish (re. tainting and possible area closure in case of accidents).

3) Possible effects of weathered oil on the bottom on the benthic ecosystem (including demersal fish).

Two subjects received perfunctory consideration because the terms of the contract excluded them: the possible effects of oil on the beaches, and the emotion-laden problems of possible effects of oil on marine mammals and birds.

The numerical study was carried out with hypothetical well blowouts and tanker accidents (Table 1) with the objective of achieving Maximum Effect Conditions (MEC), which was defined as follows (see also Table 1):

1) Either the largest plausible well blowouts in one of 3 locations (see Fig. 1), releasing 20,000 bbl/day of Prudhoe Bay crude oil for 15 days, or a tanker accident releasing 240,000 bbl automotive diesel (refined) at a rate of 10,000 bbl/hr in one of the same three locations: (1) off Port Moller, 45 m depth; 2) off Port Heiden, 43 m depth; and 3) off Cape Newenham, 43 m depth) .

2) The spreading of oil in the water occurred in conditions of winds, tides, mixed layer depth, and temperature which produced the largest possible area of highest possible concentration (>1 ppm) of water soluble fraction (WSF) of oil in the water. The wind direction chosen was the most frequent for the location.

3) The blowout/accident occurred during the most unfavorable time with respect to the fishery resources (peak spawning time with maximum aggregation

Table I.--Hypothetical oil-spill scenarios.

Scenario	Oil type	Volume	Duration	Computation grid size (mesh 2 km)
Blowout	Prudhoe Bay crude	20,000 bbl/day	15 days	50 x 50
Accident	Automotive diesel (refined)	240,000 bbl (10,000 bbl/hr)	10 days	32 X 34

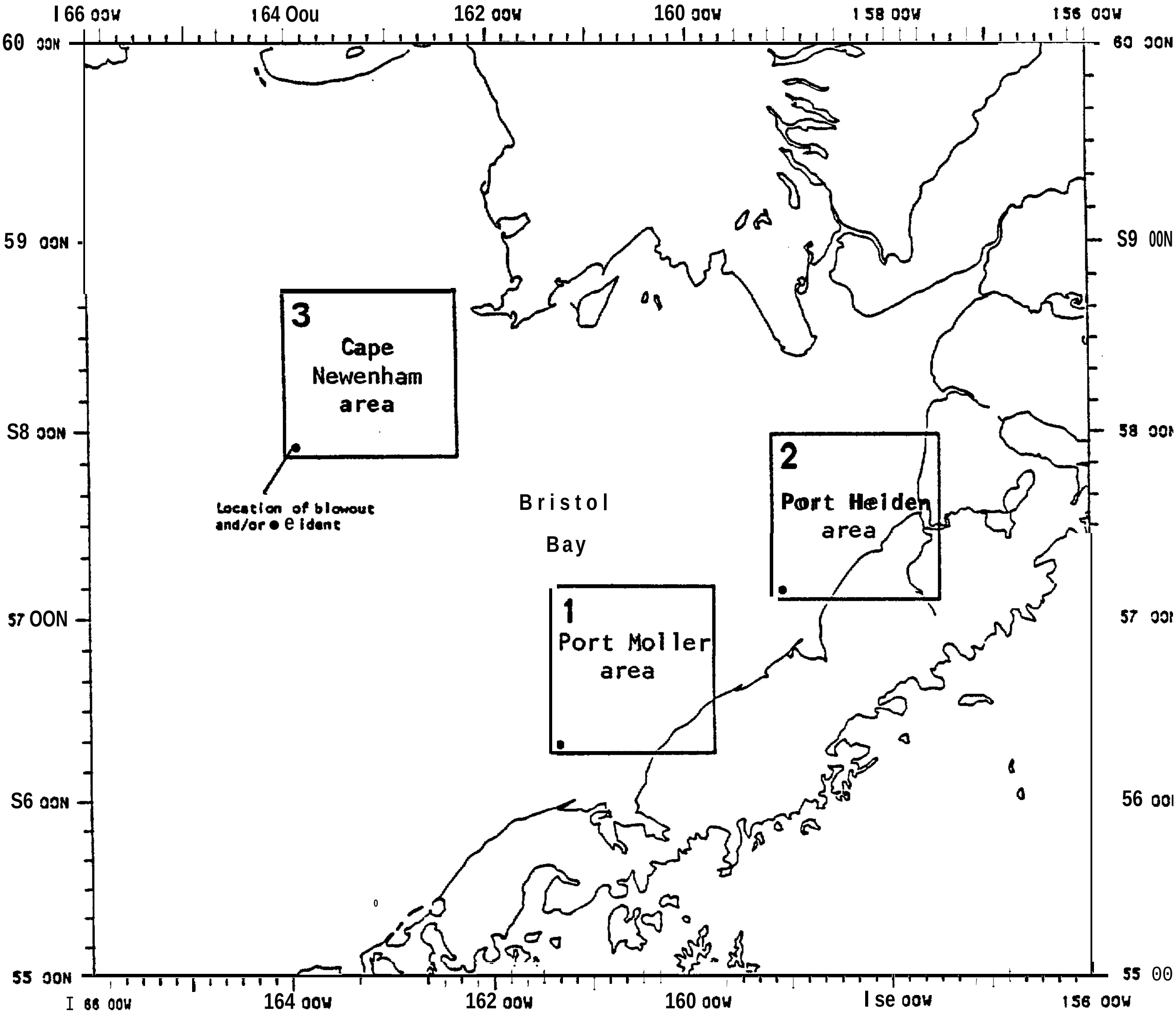

Figure 1---Locations of hypothetical oil spill scenarios.

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 were such that highest possible quantity of oil accumulated on the bottom in the shortest possible time.

Detailed results of the study are found in fifteen technical reports (see Section 5); this report presents the summary of the essential results.

2. REVIEW OF PAST RESEARCH AND ITS APPLICABILITY.

2.1 Interpretation of laboratory research.

A voluminous amount of literature is available on the laboratory stud es of oil effects on fish and other aquatic biota. The corresponding report: on field studies are few, and are mostly qualitative, inconclusive descriptions of past accidents. Some summary works on the subject are also available (e.g. Connell and Miller 1980, and U S. National Academy of Science (numerous authors) 1984). Objective quantitative evaluation of the laboratory studies and their applicability to the "real wor d" is difficult indeed, and one has to agree with the conclusion of the National Academy of Science report (1984):

"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,"

Principal problems with the evaluation of the past effect studies are:

1) Most of the laboratory studies have been carried out with WSF concentrations two to four orders of magnitudes (100 to 10,000 times) higher than would occur in the ocean with the greatest plausible accident.

2) Numerous different components of hydrocarbons have been used in these studies, with very different methods of exposure of fish and other marine organisms.

Only rarely does some report state honestly the applicability of their results, as has been done by Duval and Fink 1981:

'Hydrocarbon levels in water following oil spills would rarely persist at the concentrations required to cause many of the physiological and behavioral effects observed during this investigation."

Studies of sublethal effects of petroleum hydrocarbons have also been summarized by Connell and Miller, op. cit., Nat. Acad. Sci. (op. cit.) and by Malins et al. 1982.

The essential applicable conclusion from the numerous past studies is that WSF concentrations in excess of 100 ppb are lethal to fish eggs and larvae within a few days, and that adult fish tolerate concentrations in excess of 1 ppm. The latter concentration can be taken as lowest limit of WSF concentrations which cause mortalities in fish within a few days.

The same concentrations (1 ppm) can be taken as the lower limit which causes sublethal effects in adult fish. The latter are often ill-defined; pathological changes in the liver of flatfish, for example, occur both in oil-exposed and non-exposed fish (Malins et al. 1982).

Most marine animals (including fish) are capable of metabolizing hydrocarbons. Metabolic products are usually retained longer in the bodies than parent hydrocarbons. Most of the hydrocarbons are taken up with food (especially benthos). It was concluded from the literature review that fish can be considered tainted if the concentrations of hydrocarbons in the body is >5 ppm. Hydrocarbons can be present in fish even when no tainting is detected (Grahl-Nielsen, Neppelberg, Palmork, Westrheim, and Wilhelmsen 1976).

2.2 Past experiences with oil spills as pertaining to fisheries.

Frequent remarks on possible effects of oil spills on fish and fisheries can be found in existing "oil spill literature". These unquantified remarks are, however, unsubstantiated in the majority of cases. Only five reports (summarized below) attempt to evaluate quantitatively the possible effects of oil developments and oil spills on fisheries. In addition, there exists a few good local studies on the subject which cover (and emphasize) the socio-economic aspects of oil developments on local fishing communities (e.g. Canadian studies from Newfoundland and Nova Scotia).

An ear" ier study by Johnston (1977) concludes that losses reckoned as fish production or its approximate cash equivalent are very small even for a catastrophe c oil spill. Another study by Norwegian sc' entists (Norges Offentlige Utredninger NOU 1980:25) points out that the main effects of an oil spill on fish resources is via the effects of oil on fish eggs and larvae. These effects would be delayed several years and entirely masked by natural fluctuations of recruitment, and compensated by the presence of severa' year classes of fish in exploitable parts of the stocks.

Davenport (' 982) reported that field studies have revealed no last ng damage to the planktonic ecosystem (one of the food sources for fish) caused by oil. Conan (1982) described that in case of catastrophic oil spills reaching estuaries (Amoco Cadiz spill), the estuarine benthos was affected by oil (see further details in Laevastu and Fukuhara 1985, ref. 7 in Section 5), whereas the resident fishes (flatfishes and mullets) were affected to a minor degree (possible reduced growth and fecundity, and some fin rot).

A thorough examination of the oil pollution and fisheries by McIntyre (1982) concludes that no long-term adverse effects on fish stocks can be attributed to oil. There might be, however, some local impacts, such as in estuaries as reported by Conan (op. cit.).

The results reported in this summary are the very first attempts to comprehensively estimate the possible adverse effects to the eastern Bering Sea environment and biota caused by spills of petroleum of specified composition and volume at designated spill sites. The list of the reports resulting from this study is presented in Section 5 .

3. METHODS AND DATA USED IN PRESENT STUDY

3.1 Numerical methods.

3.1.1 Oil in the water.

The computations of the distribution of oil from the three sites of hypothetical well blowouts and tanker accidents (see Section 1.2 and Fig. 1) were carried out by Rand Corporation (Liu and Pelton 1984MS, Mannen and Pelto 1984). The dissolution and dispersion of oil in the water was based on studies by Payne, Kirsten, McNabb, Lambach, de 01 ivera, Jordan, and Horn 1983; and Payne and Kirsten 1985MS.

The presence and distribution of oil on the surface in offshore areas has no consequences to fish or fisheries. Any area closure for fishing will be determined by the area where contaminated fish can be found, which is considerably larger than the oil distribution area on the surface (see

Section 4.3). Obviously in some conditions oil on the surface could be beached, where it will be of local concern. Although some marine birds and mammals could be affected (and killed) by surface oil, these kills are relatively small in offshore waters (most birds and mammals have avoidance reactions), compared to the great amounts of birds and mammals present in the Bering Sea. Some fisheries interests consider it beneficial for fisheries if the birds and mammals get decimated.

The maximum concentrations of oil in water (WSF, including soluble and emulsified oil) was <0.34 ppm from the blowout scenarios. These low concentrations correspond well to observed concentrations from IXTOC blowout. Grahl-Nielsen et al. (1976) also observed low concentrations of oil under the oil slick (0.450 ppm 1 m under oil slick after 8 to 9 hours; 0.01 ppm after 24 hours). An example of distribution of oil from a blowout scenario is shown in Figure 2.

The maximum concentrations from the "tanker accident" were higher (ca 9 ppm), mainly because refined diesel oil was considered to be involved. The areas covered by different concentrations are reported by Pola, Miyahara, and Gallagher 1985 (see ref. 10, Section 5).

3.1.2 Oil on the bottom.

After "weathering" in the water much of the residual oil precipitates to the bottom. Gearing and Gearing (1983) found that about 50% of aromatics with three or more rings and saturates with 10 or more carbon atoms were rapidly transported to the sediments where their half lives ranged from 33 to 80 days. In shallow water the concentration of oil in muddy bottoms might reach 100 ppm (Marchand, Capris 1982).

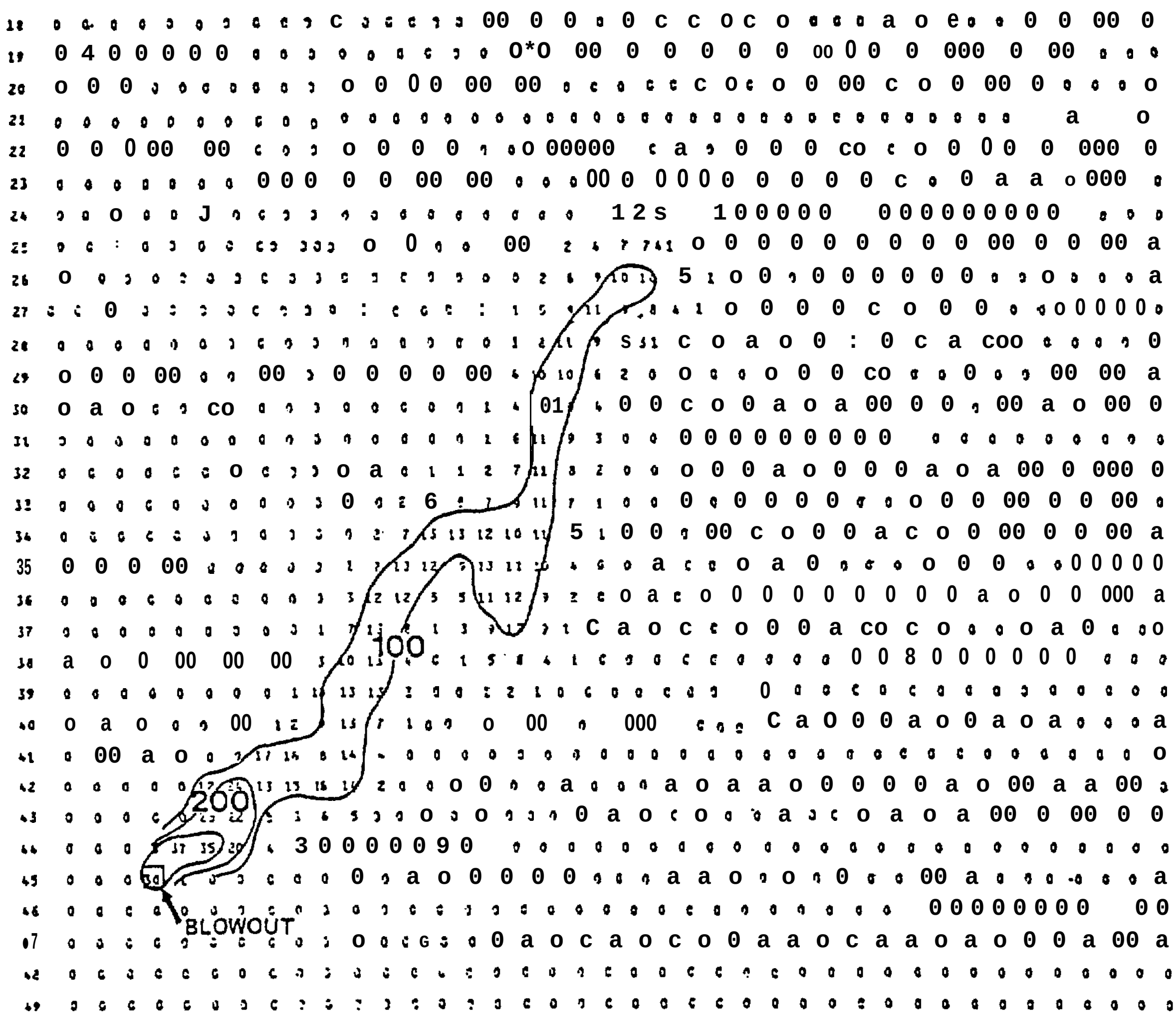

Figure 2.--Distribution of oil from a blow-out (20,000 bbl/day) after 10 days (concentrations in ppb in water - from surface to 15 m; grid mesh size 2 km).

The available literature on the sedimentation of oil and the effects of oil on the bottom on the benthos and demersal fish was reviewed and a numerical model for sedimentation of oil was designed (Laevastu and Fukuhara 1985). This model accounts quantitatively for all factors affecting the oil sedimentation (see example in Figure 3).

Initially the weathered sedimentized oil accumulates in the near-bottom nepheloid layer. The existence and thickness of this layer is dependent on several environmental factors, such as water depth, nature of the bottom, and water movement over the bottom.

Weathered oil is no longer directly poisonous to organisms and is taken up by benthos and via benthic food also by fish, causing tainting in fish. These tainting effects by sedimentized oil are considerably larger than the tainting from WSF of oil. Tainting is a temporary condition, as most petroleum hydrocarbons are disseminated from the body by various means (see Gallagher and Pola 1984, ref. 5, Section 5). The main effects of tainting would be a necessary area closure for fisheries (see Section 4.3).

3.1.3 Uptake and dissemination of petroleum hydrocarbons by fish.

After an extensive review of literature on uptake and dissemination of petroleum hydrocarbons a numerical model was designed which accounts for uptake, bioaccumulation, and dissemination of petroleum hydrocarbons (Gallagher and Pola 1984, Pola 1984, and Gallagher 1984 refs. 5, 3, 4 in Section 5). This model accounts for species differences due to e.g. feeding habits by assigning different uptake and deputation rate constants to different species. The model was tested via sensitivity analyses with the best available empirical data.

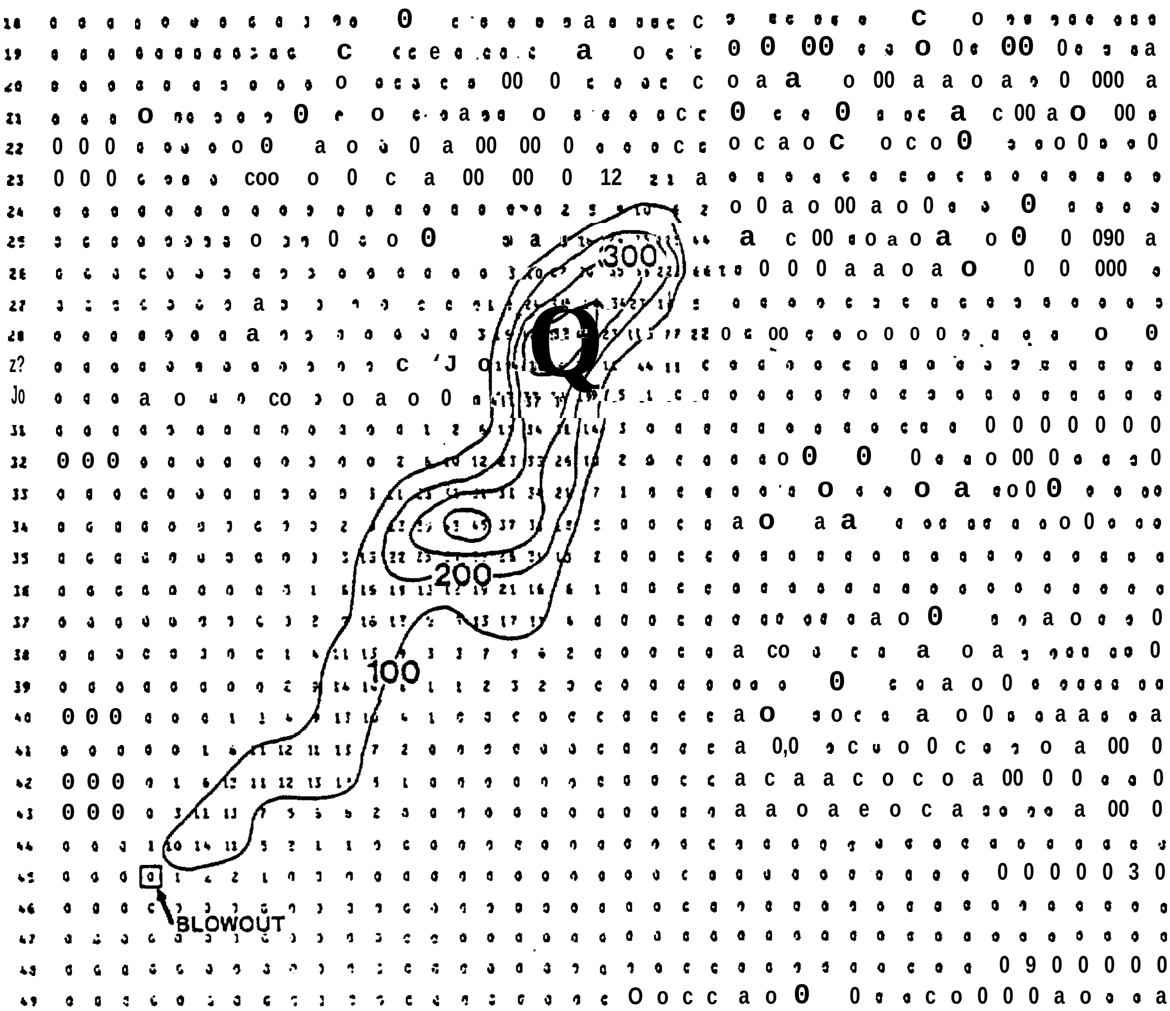

Figure 3--Distribution of oil in the bottom nepheloid layer (10 cm) in ppb 10 days after a well blowout (see Figure 2); grid size 2 km).

Another companion model moves the fish through the oil-contaminated area in various directions and with selected plausible fish migration speeds. During the migrations the uptake and dissemination model computes the contamination of fish by hydrocarbons. Thus the areas and times of possible fishery closure resulting from a given accident can be assessed (see Section 4.3).

As the anadromous fish (salmon) pose somewhat d' fferent problems, a special model was devised for computing possible oi contamination effects on migrating salmon (smelts and adults) (Bax 1985, ref. 8 in Section 5) (results see Section 4.4).

3.2 Data.

3.2.1 Environmental data pertaining to oil development - fisheries interactions.

Few environmental data are required for the evaluation of the effects of oil development on fisheries. The distribution of oil in the water and on the bottom was computed with wind and tide conditions which gave maximum concentrations of oil in the water and on the bottom. For computation of oil on the bottom optimum suspended matter load, bottom type, and mixed layer depth was assumed which would give MEC conditions. Some other environmental data is location and season dependent. The essential environmental data were summarized by Miyahara and Ingraham 1984 (ref. 6 in Section 5).

3.2.2 Fishery resources, their fluctuations, and fish species which might be affected by an oil spill.

The fishery resources in the eastern Bering Sea are mobile, with extensive seasonal and life cycle migrations. Thus the total Bering Sea resources and their seasonal distributions must be considered while investigating the effects of oil development. Furthermore, the natural fluctuations of the stocks must be taken into consideration, together with many species specific behaviors.

The resource estimates, using presently existing survey methods, are rather inaccurate, usually gross underestimates, but also overestimates in case of some flatfishes (i.e. "herding" effects of trawls]. Resource evaluation with ecosystem simulation models, which account for a number of resource determinants, produces considerably more accurate results and has been used in the present study.

A list of species and their densities (kg/km^2) used in the three oil spill scenario areas (Figure 1) is given in Table 2. Table 3 gives the species present in the three computation areas as percentage of total Bering Sea biomasses of corresponding species. The feeding habits of the species under consideration have been described by Livingston 1985 (ref. 12, Section 5). In addition the biology and ecology of the most important commercial species in the area have been summarized by Fredin 1985, Fukuhara 1985a and 1985b (refs. 9, 13, and 15, Section 5). Pertinent biology, ecology, and resource fluctuations data on sockeye salmon have been summarized by Bax 1985 (ref. 8, Section 5).

Of some pertinence to the evaluation of the oil development impacts might be the following generalized data. The Bristol Bay area (where oil development

Table 2--List of species and input biomass data (by location) used in BIOS[1/] model.

No.	Species Name	Input Biomass Data (kg/km^2)[2/] Port Moller	Port Heiden	Cape Newenham
1	Herring juveniles	1409	521	1551
2	Herring adults	1121	414	1234
3	Pollock juveniles	3708	2322	3261
4	Pollock adults	11007	6893	9679
5	Pacific cod juveniles	424	279	307
6	Halibut juveniles	730	330	240
7	Yellowfin sole juveniles	722	482	711
8	Other flatfish juveniles	2004	472	1650
9	Yellowfin sole adults	800	534	789
10	Other flatfish adults	2004	472	1650
11	Pacific cod adults	861	461	681
12	King and Bairdi crab juveniles	664	222	432
13	King and Bairdi crab adults	1654	553	1078
14	Mobile epifauna	5970	4995	6075
15	Sessile epifauna	13930	11655	14175
16	Infauna	19150	13750	19250

1/ The DYNUMES model (Laevastu and Larkins, 1981) was used to get initial estimates of input biomass data for the three model locations of the BIOS model.

2/ The following assumptions were used to convert the data obtained from the DYNUMES model to biomass fields for use in the BIOS model.

a) Unless noted differently below, the breakdown of species biomass data into juvenile and adult fractions was based on Niggol (1982).

b) DYNUMES species group 5 (halibut) was assumed to be 100% juvenile (i.e., in these shallow waters during this season).

c) Yellowfin sole data were assumed to comprise 75% of DYNUMES species group 7 (yellowfin and rock sole).

d) DYNUMES species group 13 (Pacific and saffron cod) was assumed to be 100% Pacific cod.

e) DYNUMES species groups 7 (rock sole-25%), 6 (flathead sole, flounder), and 8 (other flatfish) were combined to make up the other flatfish group (species 8 and 9) for the BIOS model. These groups were assumed to be equally divided between juveniles and adults.

f) DYNUMES species groups 19 (king crab) and 20 (Tanner crab) were combined, and using available survey data, assumed to be comprised of 71.4% adults and 28.6% juveniles.

g) DYNUMES species group 24 (epifauna) was assumed to be 30% mobile and 70% sessile.

Table 3.--Percent of Bering Sea biomass (from DYNUMES model) in blowout and accident scenario study areas.

Species (group)		Location		
		Pt. Moller	Pt. Heiden	C. Newenham
1	Herring, juveniles	0.505	0.187	0.556
2	Herring, adults	0.505	0.187	0.556
3	Pollock, juveniles	0.471	0.295	0.414
4	Pollock, adults	0.471	0.295	0.414
5	Pacific cod, juveniles	0.577	0.379	0.418
6	Halibut, juveniles	1.220	0.551	0.401
7	Yellowfin sole, juveniles	0.902	0.602	0.888
8	Other flatfish, juveniles	1.141	0.838	0.939
9	Yellowfin sole, adults	0.900	0.601	0.888
10	Other flatfish, adults	1.141	0.838	0.939
11	Pacific cod, adults	0.577	0.309	0.456
12	King and Bairdi crab, juveniles	0.806	0.269	0.524
13	King and Bairdi crab, adults	0.804	0.268	0.524
14	Mobile epifauna	0.416	0.348	0.424
15	Sessile epifauna	0.416	0.348	0.424
16	Infauna	0.604	0.433	0.607

might occur) is ca 250,000 km and the rest of the fishery area in the Bering Sea is about 400,000 km^2. However, at some definer! seasons Bristol Bay might contain about 80% of crab resources, 70% of herring, 70% of yellowfin and halibut, 60% of cod, and 50% of other fish resources of the Bering Sea. These high percentages do not, however, occur at the same time.

4. RESULTS OF QUANTITATIVE EVALUATION OF FISHERIES - OIL DEVELOPMENT INTERACTIONS.

4.1 Possible effects on eggs and larvae.

Eggs and larvae of marine animals are most sensitive to dissolved and emulsified oil(WSF) in the water. The mortalities and serious sublethal effects start at concentration of ca 100 ppb.

The areas covered with WSF >100 ppb are relatively small in case of a substantial b" owout lasting 15 days (<150 km^2, Table 4). Even in case of such an unl kely event as 200,000 t tanker accident with diesel fuel (released almost nstantaneously) , the area covered by this concentration is <1200 km^2 (Table 4) .

Most marine fish spawn over relatively large areas, and the pelagic eggs and larvae are distributed with currents and turbulence over very large areas. Furthermore, the spawning of most marine fish lasts three to six months, with peak spawning lasting also in excess of three weeks.

Of the species studied, the spawning of yellowfin sole and its eggs and larvae were found most affected by the simulated blowout and tanker accidents in Bristol Bay. (Coastal spawning of herring and capelin was not considered

Table 4.--Maximum spatial coverage (km*) and maximum duration (days) of various levels of oil in water (WSF) and in bottom nepheloid layer (TARS) at different concentrations at Port Heiden.

Oil cone. (ppm)	Accident				B 10WOU t			
	WSF		TARS		WSF		TARS	
	area	duration	area	duration	area	duration	area	duration
>1.0	380	13	752	33	0	0	0	0
>0.1	1160	21	1548	>50	132	12	248	24
>0.01	1844	28	2140	>50	444	20	460	43
>0.001	248o	36	2560	>50	616	27	652	> 5 0

in this study and salmon is described in Section 4.4). If all yellowfin sole would spawn within two weeks and this spawning would coincide with the very unlikely tanker accident, only 1.2 percent of yellowfin eggs and larvae would be killed (Table 5). However, the yellowfin sole spawning period is about five times longer than that used for the simulated accident--thus less than 0.3 percent of yellowfin eggs and larvae would be affected. The fraction of eggs and larvae of other fish species that would be killed is less than this fraction.

The natural mortality of fish eggs and larvae is very large (the reduction in numbers from eggs to spawning adults is in general from between 2,000,000 to 2, to 50,000 to 2). Furthermore, if considerable mortality would occur due to an extensive oil spill, this would not affect the fishery resources, as the exploitable stocks are "buffered" by the presence of several yearclasses (Honkalehto 1985, ref. 11, Section 5). Consequently the possible oil developments in Bristol Bay would have no effects on fishery resources in this area via effects on eggs and larvae. Similar conclusion was reached by Järvela, Thorsteinson, and Pe?to (1984) in respect to Navarin Basin. Further detailed considerations on this subject are given in reports by Fredin (1985) and Fukuhara (1985a, b, ref. 9, 13 and 15 in Section 5).

4.2 Exposure and contamination of fish by hydrocarbons.

The lethal effects of WSF of oi' on fish commence in the 1 to 10 ppm range. In present studies we have used the lower value (1 ppm) to achieve MEC (Maximum Effect Condition). The maximum areas covered with different ranges of concentrations (blowout and the unrealistically large tanker accident) are

Table 5--- Estimated percentage of mortality from acute toxicity in yellowfin sole in the accident scenarios at Port Moller, Port Heiden and Cape Newenham by life history group and quarter.

	A. Percentage Mortality at Port Moller or Port Heiden Spill Sites							
QUARTERS	1		2		3		4	
STAGE	WSF	TARS	WSF	TARS	WSF	TARS	WSF	TARS
EGGS & LARVAE	o	0	0	0	0	0	0	0
JUVENILES	.03	.15	.03	,15	.03	.15	.03	.15
ADULTS	0	0	.03	.15	.03	.15	0	0
	B. Percentage Mortality at Cape Newenham Spill Site							
EGGS & LARVAE	o	0	0	0	1.2	0	0	0
JUVENILES	.03	.15	.03	.15	.03	.15	.03	.15
ADULTS	o	0	.03	.15	.03	.15	0	0

given in Table 4. in evaluating the effects (lethal and serious sublethal) we have also assumed that concentrations of weathered oil on the bottom (tars) in excess of 5 ppm affect the juvenile adult fish. This assumption is somewhat excessive accord' ng to ava' lable literature, but would give an absolute MEC.

Detailed computations were made with the models and results given in technical reports (see Section 5). For summary considerations we can use a simplified approach by considering data in Table 4 and Figure 4 with the data in Table 2 which gives the amounts of species present in the three computation areas (Figure 1) and the fraction of this biomass of the total species biomass in the eastern Bering Sea (Table 3) (most species have only one stock in this sea) .

Of the species considered in this study, yellowfin sole and king crab were found to be most affected by the hypothetical oil spill (salmon see Section 4.4). A summary of the possible lethal effects of the spills on yellowfin sole are given in Table 5.

The extensive well blowout would kill and/or seriously affect only 0.03 percent of yellowfin (and crab) population in the eastern Bering Sea, which is nearly three orders of magnitude less than the accuracy of resource estimates. Thus an extensive blowout would have no quantifiable effect on offshore fishery resources in the eastern Bering Sea.

An unnaturally large tanker accident as used in our scenarios might kill or otherwise seriously affect 0.15 percent of the adult yellowfin population. This amount is about two orders of magnitude less than the accuracy of resource estimate, and at present less than 2 percent of the catch--i.e. about an

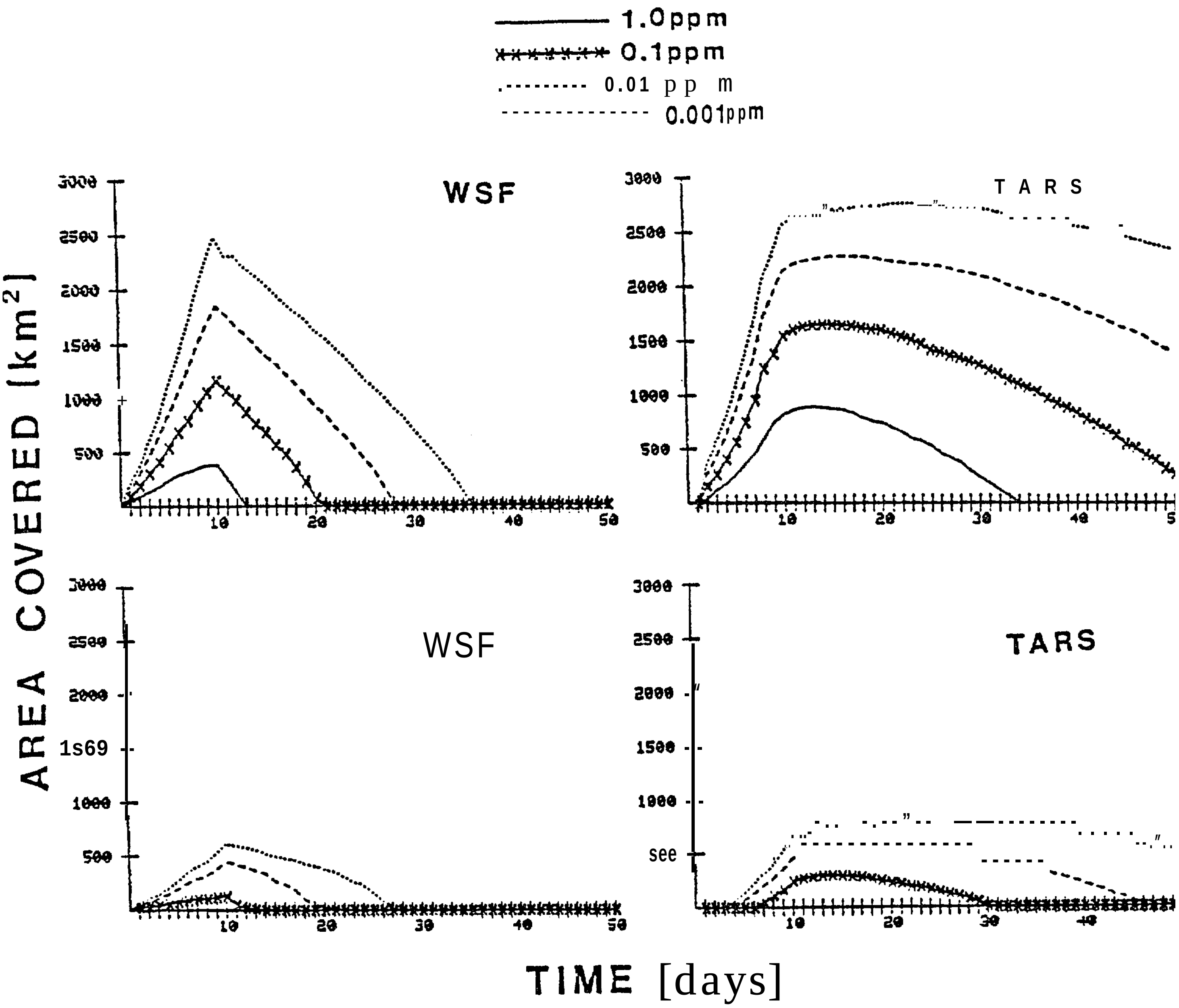

Figure 4.--Time series of total area covered (km*) by WSF and by TARS at concentrations greater than 1.0 ppm, 0. 1 ppm, 0.01 ppm, and 0.001 ppm for the accident (upper) and blowout (lower) scenarios.

order of magnitude less than the error in the estimation of catch. However, a 0.15 percent fluctuation of resource would have no effect. on catch whatsoever. Thus even a large, unnatural tanker accident would have no quantifiable effect on' the offshore fishery resources in the eastern Bering Sea.

Fish can, however, be temporarily tainted with petroleum hydrocarbons by direct exposure as well as by food uptake of contaminated food, mainly benthos. The uptake of petroleum hydrocarbons and their dissemination with time was computed in detail with numerical models (Gallagher and Pola 1985; Pola, Miyahara, and Gallagher 1985; refs. 5 and 10 in Section 5). The percentage of some biomasses in the computation area with internal contamination of >5 ppm (lower level of tainting) is given in Figure 5. These values have meaning to fisheries in terms of areas covered, which are given in Table 6. These areas are significant n the case of the blowout and/or accident when they should be temporarily c'osed for fishing to prevent tainted fish from being caught and marketed.

4.3 Effects of possible precautionary measures in offshore areas during an accident.

The possibilities of contaminating fishing gear with oil is often mentioned when listing the possible effects of oil developments on fisheries. We cannot see this ever happening in Bristol Bay. There is very little set gear (e.g. traps, longlines) used in this area. If some gear would be in the vicin ty of the accident, there would be ample time to remove it. Mobile fishing gear (e.g. trawls) cannot be contaminated with oil, unless it is done willful y.

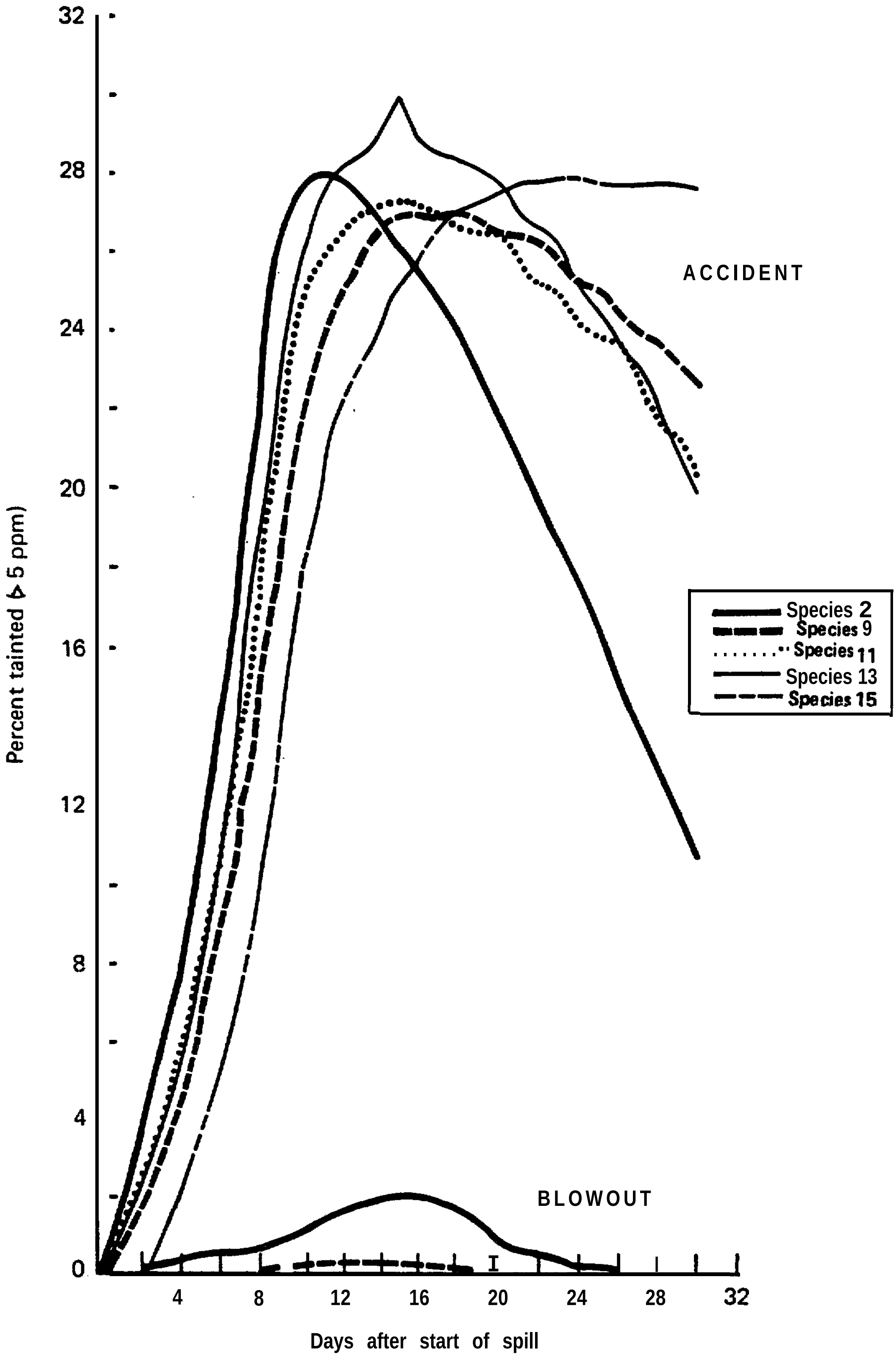

Figure 5.--Percent of biomass of selected species within the BIOS model grid tainted in the" accident and blowout scenarios,

Table 6.--Areas covered with herring juveniles (Species 1) and adult King and Bairdi crabs (Species 13) contaminated with petroleum hydrocarbons at various levels. (Time sequence in days; area covered in km².) No migrations. Port Heiden accident scenario,

Day	Species 1 Contamination (ppm) >5	>10	>50	>100	Species 13 Contamination (ppm) >5	>10	>50	>100
1	72	56	24	4	24	8	0	0
2	144	120	60	32	80	52	0	0
3	240	208	?6	48	144	96	0	0
4	356	292	140	80	228	160	8	0
5	468	392	192	96	320	232	40	0
6	616	512	248	116	424	324	68	0
7	764	632	304	144	564	428	?2	0
8	968	792	360	148	736	544	124	0
9	1080	900	412	152	904	684	156	4
10	1212	988	452	168	1020	788	216	20
11	1224	1020	472	152	1108	868	268	24
12	1232	1036	452	136	1144	920	292	32
13	1216	1012	424	104	1192	960	328	32
14	1188	976	376	56	1228	976	356	32
15	1152	936	328	20	1236	1000	364	28
16	1100	880	268	0	1240	1008	368	20
17	1068	856	192	0	1240	1004	352	16
18	1036	792	116	0	1244	996	336	12
19	?72	744	52	0	1240	976	320	8
20	?24	684	4	0	1220	960	292	4
21	868	604	0	0	1188	952	272	0
22	820	552	0	0	1168	932	220	0
23	744	476	0	0	1152	916	196	0
24	688	400	0	0	1148	884	156	0
25	604	340	0	0	1128	860	112	0
26	540	248	0	0	1104'	832	80	0
27	472	152	0	0	1068	784	24	0
28	388	76	0	0	1040	760	0	0
29	324	8	0	0	1016	732	0	0
30	224	0	0	0	968	696	0	0
31	128	0	0	0	940	640	0	0
32	48	0	0	0	904	592	0	0
33	0	0	O	0	864	568	0	0
34	0	0	o	0	824	516	0	0
35	0	0	O	0	780	448	0	0
36	0	O	0	0	748	412	0	0
37	0	0	0	0	6?2	372	0	0
38	0	0	0	0	648	304	0	0
39	G	0	0	0	58S	248	0	0
40	o	0	0	0	548	180	0	0
41	0	0	0	0	488	116	0	0
42	0	0	0	0	440	64	0	0
43	0	0	0	0	384	16	0	0
44	0	0	0	0	324	0	0	0
45	0	0	0	0	268	0	0	0
46	0	0	0	0	192	0	0	0
47	0	0	0	0	136	0	0	0
48	0	0	0	0	92	0	0	0
49	0	0	0	0	28	0	0	0
50	0	0	0	0	0	0	0	0

If an accident should happen (i.e. oil spilled in the water in considerable quantities), fishing in the affected area must stop for awhile in order to prevent the capture and marketing of fish tainted with oil. The tainting of fish and the area covered, and time period of tainting, was computed with our simulations (Pola, Miyahara, and Gallagher 1985, ref. 10 in Section 5). The maximum areas covered in the cases of well blowout and tanker accident are given in Table 6 for two typical species (juvenile herring and adult crabs). Figure 6 shows the development of these areas with time and the subsequent deputation. Both Table 6 and Figure 6 refer to the tanker accident which produces the largest effect.

The maximum area covered with tainted crabs is <1300 km^2. After 30 days the area has decreased to <1000 km^2 and after 50 days all fish and crab would be depurated below detectable level. The tainting from a well blowout was considerably less, covering less than a quarter of the abovementioned areas.

In case of a very unlikely tanker accident (which might happen anywhere in the world), an area of about 2000 km^2 should be closed for fishing for about 45 days. Whether and how much such a closure can affect fisheries is meaningless to evaluate quantitatively. First, the event is extremely rare. Secondly, it might happen in an area which is not a traditional fishing ground. Thirally, the fishing areas (grounds) are of considerable extent (species and season dependent) and fishing might continue in other nearby areas with same profitability as it would have done in closed area. (It could be noted that 2000 km^2 is less than 1% of the area of Bristol Bay, and equally less than 1% of the "prime" fishing grounds in the Bering Sea.)

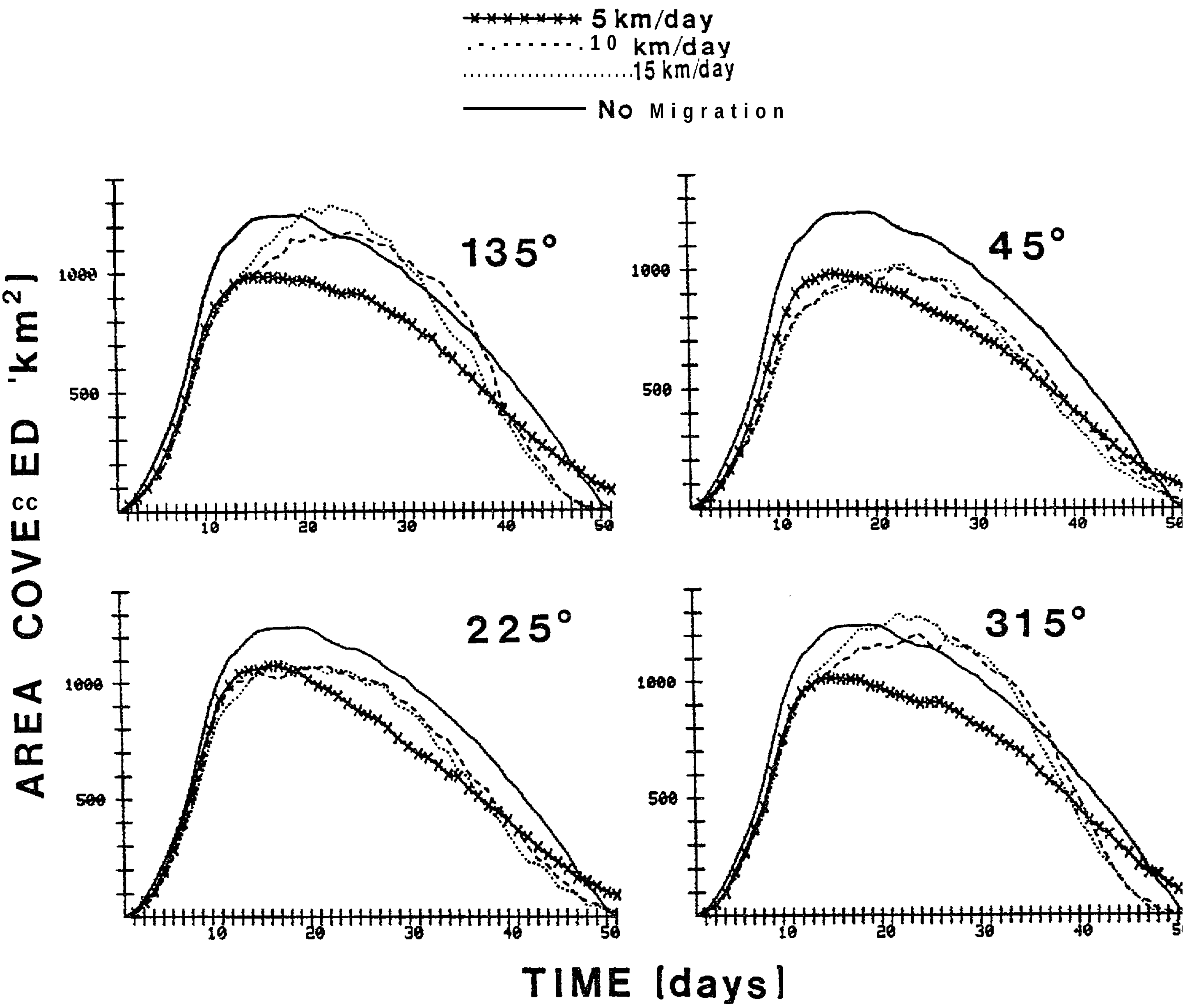

Figure 6.--Area covered by tainting (contamination >5 ppm) of a pelagic fish species from a model run with no migrations (solid line) and with migrations of 5, 10, and 15 km/day. Migration directions are shown.

4.4 Special considerations with anadromous fish

Special, careful consideration of the possible effects of oil development on salmon is required due to its importance in Alaskan fisheries and especially because of the possibility of the presence (and/or passage) of a great portion of outmigrating juveniles (smelt) and returning adults in possible oil spill sites. A thorough numerical study of possible effects of oil on sockeye salmon (the main species in Bristol Bay) was conducted within the three blowout and accident sites (Bax 1985, ref. 8, Section 5). The assumptions of oil effects in this study were more conservative than with marine fish to achieve MEC (100% mortality at 450 ppb of fuel oil in 24 h; 100% mortality at 2.5 ppm of crude oil in 24 h; tainting level in salmon flesh 600 ppb).

The computations of migrations of smelt (juveniles) and adults was carried out with no-avoidance and with avoidance reaction. The results of the effects of blowout and tanker accident happening during the most unfavorable periods in Port Heiden and Port Meller areas are summarized in Tables 7 and 8 (considering only that portion of the populations passing through these areas at the accident time). The mortalities and tainting extrapolated to whole Bristol Bay sockeye population for the tanker accident is given in Table 9.

A maximum of 13% mortality of outmigrating smelt could be caused by unlikely tanker accident. This does not mean that the returning year class would be affected by the same amount, as the natural mortality of smelt is variable from year to year (on average 90%). It is unrealistic to quantify the minor effect on smolt in terms of future (2 or 3 years later) fishing on returning adults.

Table 7--- Simulated percent mortalities of sockeye salmon migrating through the oil spill grids either directly or with avoidance of the spill.

Spill scenario	Run time (hrs)	Percent mortalities	
		Direct migration	Migration with avoidance
Juveniles			
Port Heiden			
Tanker spill/fuel oil	240	35.5	15.4
Blowout/crude oil	480	0.4	0.5
Port Moller			
Tanker spill/fuel oil	240	14.2	7.0
Blowout/crude oil	480	1.2	0.5
Adults			
Port Heiden			
Tanker spill/fuel oil	240	17.6	3.2
Blowout/crude oil	480	0.2	0.1
Port Moller			
Tanker spill/fuel oil	240	11.6	2.1
Blowout/crude oil	480	0.2	0.1

Table 8--- Simulated percent taintings of sockeye salmon migrating through the oil spill grids either directly or with avoidance of the spill.

Spill scenario	Run time (hrs)	Percent tainted above 0.6 ppm	
		Direct migration	Migration with avoidance
Juveniles			
Port Heiden			
Tanker spill/fuel oil	240	17.7	10.6
Blowout/crude oil	480	0.0	0.0
Port Moller			
Tanker spill/fuel oil	240	5.2	3.1
Blowout/crude oil	480	0.1	0.0
Adults			
Port Heiden			
Tanker spill/fuel oil	240	7.1	3.1
Blowout/crude oil	480	0.0	0.O
Port Moller			
Tanker spill/fuel oil	240	5.0	2.6
Blowout/crude oil	480	0.0	0.0

Table 9--- Percent mortalities and tainting from tanker spill scenarios extrapolated to whole population.

Age group	Location of spill	Reduction factor xx	Percent mortalities Direct	Percent mortalities Avoid	Percent tainted Direct	Percent tainted Avoid
Juveniles 1.[x] (combined rivers)	Pt. Heiden	0.36	12.8	5.5	6.4	3.8
	Pt. Moller	0.47	6.7	3.3	2.4	1.5
Juveniles 2.[x] (combined rivers)	Pt. Heiden	0.28	9.9	4.3	5.0	3.0
	Pt. Moller	0.36	5.1	2.5	1.9	1.1
Adults	Pt. Heiden	0.27	4.8	0.9	1.9	0.8
	Pt. Moller	0.41	4.8	0.9	2.1	1.1

x Juveniles which spend 1 resp. 2 years in fresh water.
xx Fraction of the population passing through the three oil spill scenario areas.

The adults of total Bristol Bay sockeye salmon population might sustain a 5% mortality and an additional 2% tainting. Local disruption of salmon fishery might occur if a tanker accident of the unreal magnitude would occur during the peak salmon run (within about a month), especially if this occurred close to the fishing grounds.

5. LIST OF TECHNICAL REPORTS RESULTING FROM THE STUDY

(listed in chronological order of reproduction)

1. Kim, S. and A.W. Kendall.

   1983 (December). The numbers and distribution of walleye pollock eggs and larvae in the southeastern Bering Sea. NWAFC Proc. Rpt. 83-22, 35 pp.

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3. Pola-Swan, N.

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4. Gallagher, A.F.

   1984 (May). Documentation of the biological impact of an oil spill model (BIOS). Part 2: Fish feeding and contamination through consumption - Subroutine FEDOIL. NWAFC/REEST Prog. Dec. 22, 21 pp.

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