Pacific Marine Science Report 74-9

THE ALERT BAY OIL SPILL : A ONE- YEAR STUDY OF THE RECOVERY OF A CONTAMINATED BAY

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June, 1974

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INTRODUCTION

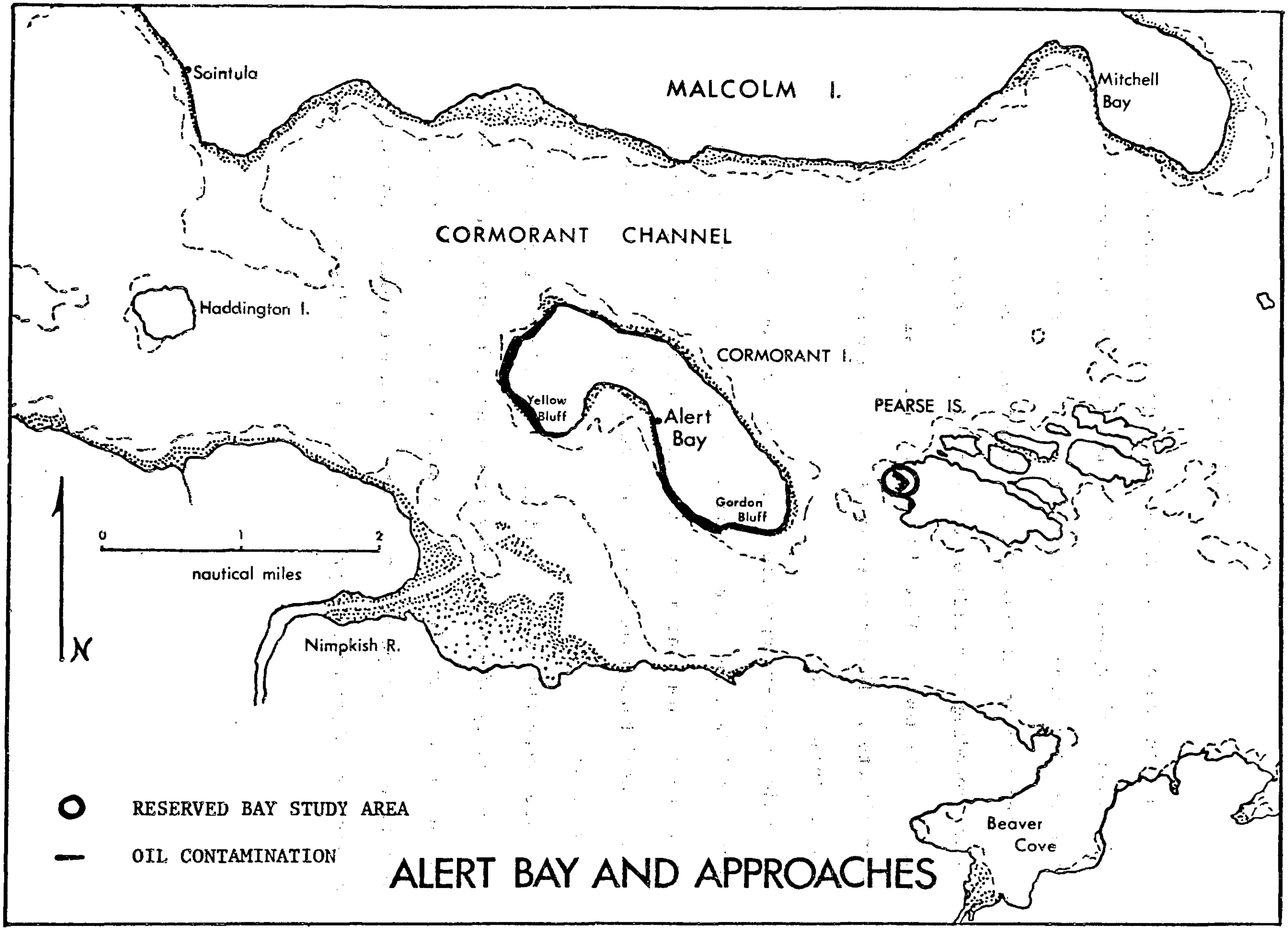
Late on January 24, 1973, the freighter Irish Stardust grounded on Haddington Reef rupturing two fuel tanks, and spilling roughly 200 tons of heavy '1000 second' fuel oil into Broughton Strait.

The majority of this oil was deposited along the shores to the east by the receding high tide on the morning of January 25 (high tide of 14.6'). The town of Alert Bay on Cormorant Island was the community most affected. The attached map shows the geography of the area and the most polluted beaches.

Major clean-up operations were conducted on the beaches of Cormorant Island and other islands further to the east. However, one of the more contaminated bays was sufficiently isolated that it could be left undisturbed for scientific study. This bay was code-named Reserved Bay.

The Ocean Chemistry Division, Marine Sciences Directorate, pursued a study of Reserved Bay to gather information on the natural degradation of heavy fuel oil. A series of five visits to the bay was made over the period of a year to obtain chemical samples, observe the physical fate of the oil, and follow its ecological effects.

FIGURE 1.



Sointula
MALCOLM I.
Mitchell Bay
CORMORANT CHANNEL
Haddington I.
CORMORANT I.
Yellow Bluff
Alert Bay
PEARSE IS.
Gordon Bluff
0
1
2
nautical miles
N
Nimpkish R.
Beaver Cove
RESERVED BAY STUDY AREA
OIL CONTAMINATION
ALERT BAY AND APPROACHES

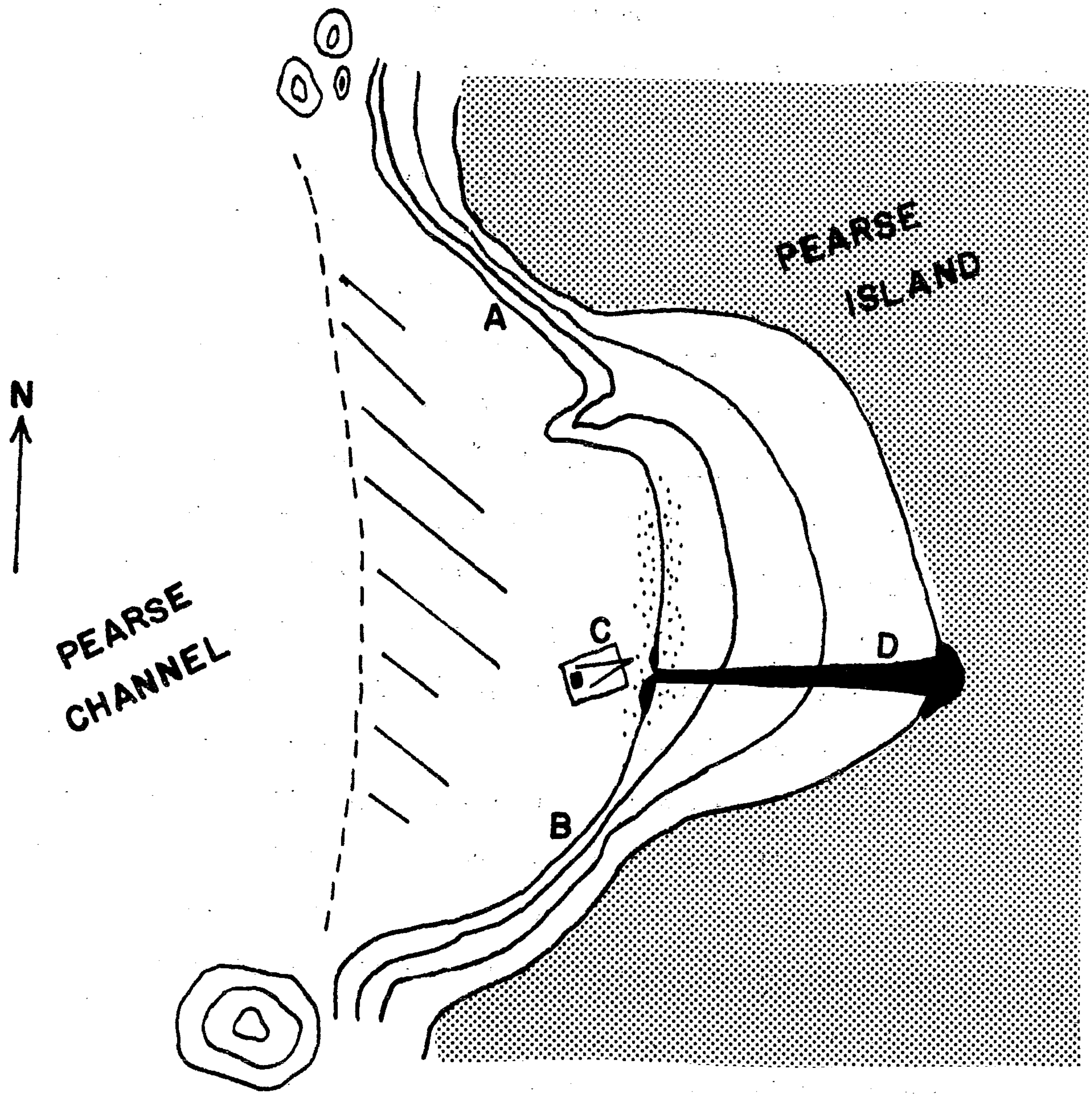
DESCRIPTION OF THE STUDY AREA

Reserved Bay is a semi-exposed bay situated on the west side of the largest island of the Pearse group (see Fig. 2). The north and south sides of the bay are bounded by vertical rock faces five to ten feet in height. Its head is bordered by a lowland of meadow and marsh grasses. A small stream flows onto the south end of the beach. The low-tide zone consists of a clay-based mudflat; the mid-tide zone of stone, sand, and pebble areas; and the high-tide zone of rock faces and patches of sand, stone, and pebbles. The area surrounding the stream is mostly a sand-clay mixture.

Rockweed (*Fucus distichus*) extends from high to mid-tidal areas. The low-tide mudflat harbours eelgrass beds (*Zostera marina*). Brown algae (*Alaria marginata* and *Laminaira sp.*) grow on logs which are partially embedded in the mud. Mud holes suggest the presence of clams, polychaete worms, and/or shrimp. Barnacles (*Balanus glandulus*), shore crabs (*Hemigrapsus nudus* and *H. oregonensis*), amphipods (*Orchestia sp.*), periwinkles (*Littorina sitkana* and *L. scutulata*), and turban snails (*Calliostoma sp.*) frequent mid-tidal areas; while the latter three and the limpets (*Acmaea spp.*) are the prominent fauna in the higher tidal zones. A peculiar characteristic of the bay is the absence of the typical scattering of barnacles at the higher tidal levels.

In general, this species composition is typical of intertidal life in a British Columbia semi-exposed habitat. Also, the physical characteristics of the bay are common to thousands of inlets and bays along the complex coastline of British Columbia and Alaska. Reserved Bay, then, provides a good 'case study' of the environment which would be affected by an oil spill on the west coast.

Figure 2. Reserved Bay Study Area



LEGEND

A: northern rock face
B: southern rock face
C: abandoned logging winch
D: stream

marsh grass
mudflats
low tide mark
island

contour lines are at two foot intervals

FIELD METHODS

Reserved Bay was visited five times over a one-year period as follows:

January 24, 1973	Grounding of Irish Stardust
January 25	Oil contamination of Reserved Bay
January 30	First visit, five days after spill
March 9	Second visit, six weeks after the spill
June 5	Third visit, four and a half months after the spill
August 28	Fourth visit, approximately eight months after the spill
January 26, 1974	Fifth visit, one year after the spill

On each visit the same general procedure of observation and sampling was followed. The ensuing paragraphs detail this procedure.

Observation of the Oil:

The physical appearance of the beach and the extent of oil contamination were described. To complement the written description and objectively record the appearance of the beach, a series of colour photographs was taken.

Chemical Sampling:

Samples were taken down the beach from the heavily contaminated upper tidal area to the apparently clean lower area, and further samples were taken of the various contaminated substrates (sand, gravel, rockweed and rock face) and of oil floating as a slick. They were stored in tightly-capped brown bottles and frozen upon arrival at the laboratory.

Biological Observations and Sampling:

On the first visit, there was no biologist present, so unfortunately no assessment was made of the effect of the oil on the intertidal life.

For the remaining visits, the biological program included:

a) a general description of the biological state of affairs

b) a transect down the beach

c) core sampling for meiofauna (benthic animals less than one mm largest dimension).

The following section gives the general observations recorded for each visit.

OBSERVATIONS

FIRST VISIT

January 30, 1973
1000-1400
Tides: High of 14.3 ft. at 1005
Low of 4.4 ft. at 1740
Five days after spill

Visual Observations:

There was an oily sheen on the surface waters of the cove. Oil-soaked material and thick black patches of oil were observed near the beach.

The receding tide revealed the following oil pollution in the cove above the mid-tide mark:

Northern rock face to logging winch:A band of oil covered a vertical height of approximately five feet downwards from the high tide mark. Coverage was continuous over rocks, rock faces, logs and sea weed, with a coating 1 to 5 mm thick. The sand was oily but not coated. A thick bed of detached, heavily-oiled rockweed (*Fucus distichus*) covered the high-tidal area at the head of the beach. The sand beneath was not oiled.

Logging winch to south rock face: Trace amounts of oil only.

South rock face: Oil coating was present but not continuous (approximately 25% coverage in the five foot contamination band).

Below mid-tide, the beach and rock faces appeared to be totally oil-free.

SECOND VISIT

March 9, 1973
1030-1500
Tides: Low of 3.4 ft. at 1030
High of 12.9 ft. at 1635
Six weeks after the spill

Visual Observation:

The areas of beach and rock affected by the oil were unchanged from the first visit. No migration of oil down the beach or to adjacent unoiled areas had taken place.

The oil was perhaps less glossy and less sticky than on the first visit, but not markedly so. The coating of oil on the rockweed appeared to be thinner and more evenly spread. However, in general appearance, the oil looked very much as it had two months before.

Biological Observations:

Marsh grasses on the eastern head of the beach were heavily oiled, although surrounding sands were clean. The northern head of the beach was thickly covered with oiled, unattached rockweed (Fucus sp.). Removal of the algae revealed clean sands harbouring many active amphipods (Orchestia sp.). Attached, unoiled plants further down toward the mid-tidal zone were healthy in appearance.

At the foot of the northern rock face, oil was very thick among the rocks. Among the rocks, many oil-covered amphipods were found. Most were alive (slow, restrained movements) while smaller numbers exhibited no movement at all.

Many empty, unweathered limpet shells (Acmaea spp.) were found lying at the base of oiled rock faces, suggesting a heavy kill of these animals by oil contamination. For example, forty-two recently dead limpets were found at the base of a heavily oiled rock face one square metre in area. The northern rock face, which was well oiled, was almost devoid of limpets ($\sim 2/m^2$) while southern rocks, with only patchy oil coverage, harboured much greater populations ($\sim 50/m^2$).

Most periwinkles (Littorina spp.) found under oiled rocks in the upper tidal zones were lying free on the ground with their opercula tightly in position.

The faunal and floral populations of the unoiled mid- and low-tidal area appeared to be unaffected.

Comment:

Biological damage appeared to be limited to those flora and fauna smothered by the oil. Populations of animals and plants living near, but not directly contaminated by the oil appeared to be healthy and normal.

The action of waves and tides had not altered the pattern of contamination of the cove in any way.

The natural degradation processes appeared to be very slow. The oil had much the same visual appearance and properties as on the first visit six weeks earlier.

THIRD VISIT

June 5, 1973
0930-1230
Tides: Low of 1.4 ft. at 1040
High of 13.6 ft. at 1710
Four and one half months after the spill

Visual Observations:

The oil occupied the same areas of the intertidal zone as before. It was less sticky and glossy-looking, with a dull, black, asphalt-like appearance.

Closer examination showed that the oil still stuck to hands and feet, still leached a film of oil into the water, and still appeared fresh and glossy in crannies or under rocks.

Biological Observations:

Unattached oiled beds of rockweed still lay at the eastern head of the beach. The oil covering had weathered somewhat, and the plants were in a desiccated condition. More rockweed beds (unoiled) had recently been cast up approximately one metre below the oiled beds. The moist sand substrate beneath the rockweed harboured numerous healthy amphipods.

Nearly all limpets had died and fallen off heavily oiled rock faces. The few remaining appeared to be successfully grazing on the oiled rock.

FOURTH VISIT

August 28, 1973
1130-0100 (+7)
Tides: Low of 1.7 ft. at 0715 (+8)
High of 15.2 ft. at 1330 (+8)
∿ Eight months after the spill

Visual Observations:

Oil was still very evident along the rock faces and on the rock and gravel portions of the affected beach. It was not present in the sand.

The oil had lost most of its sticky, contaminating properties and was very asphalt-like in appearance. However, fresher-looking oil could still be found under rocks. Oil still leached a surface slick on to the advancing tide wherever the beach had been disturbed and the fresher oil revealed.

Biological Observations:

Oil coverage of marsh grasses on the extreme eastern head of the beach was more weathered and plants were no longer stuck together in clumps. The grasses appeared to have been scoured free of some of the oil (perhaps sand scour). Surrounding sands were clean.

About half of the bed of oiled rockweed had disappeared. All plants were well weathered and dried.

A very high density amphipod population existed under the rockweed wherever dampness persisted, (∿ 1000 or more amphipods per square meter). Under-rock areas near quadrat 1 harboured many large amphipods (a few small amphipods as well) in spite of a sticky, oiled substrate.

The oiled rock faces did not have any significant recolonization of limpets or littorinids. Southern rock faces described as relatively unoiled at the time of the spill, still had approximately the same species composition and abundance as described in Visit 2.

FIFTH VISIT

January 26, 1974
0930-1130
Tides: Low of 6.7 ft. at 0900
High of 14.9 ft. at 1440
One year after the spill

Visual Observations:

A superficial examination indicated the oil had disappeared. It was no longer evident on the small stones of the beach; and on the rock walls the dark stains of the oil were nearly gone. No oil was evident in the sand; and the oiled rockweed at the high tide line had completely disappeared and been replaced by fresh rockweed debris.

Closer examination clearly revealed coagulated oil immobilizing the gravel on the most heavily affected portion of the beach. However, there were no pockets of fresh oil still hidden among the rocks, and the oil present had almost completely lost its sticky contaminating nature. Rocks and gravel could be handled without the need for plastic gloves.

Visually, then, the cove appeared much cleaner, but oil was still present in the gravel and an unobtrusive thin black coating was present on rocks in some places.

Biological observations:

Biological conditions had undergone noticeable change with respect to previous visits. Oiled marsh grass stands on the north head of the beach, previously observed to be 15-25 cm high, were now about three to five cm high. Similar marsh grass stands on the southern beach head, which were not contaminated by oil, were growing in lenghts of 15-30 cm. Apparently the marsh grass had been affected by the oil.

The beds of unattached, oiled rockweed had disappeared and new beds had been washed up. Few amphipods were found in these new rockweed beds. However, the base of the northern rockwall harboured very high numbers of small to large-sized amphipods. Limpets had not yet begun to recolonize the northern rock face but were beginning to recolonize smaller rock faces a few metres away. Periwinkles were found under rocks in areas previously devoid of them.

BIOLOGICAL EFFECTS

In addition to the general biological observations already described, more quantitative data were obtained from transects and by analyzing sand cores for meiofauna (benthic animals less than one mm in length). The methods and results are discussed below.

METHODS OF ANALYSIS AND RESULTS

Meiofauna Sampling:

At each station, a glass tube (four cm in diameter) was inserted 1.5 cm into the substrate and removed with a core inside. The core was then preserved with four percent formalin in sea water.

Animals were separated from the sand by electration. Faunal divisions classified and enumerated were:

1. Nematodes - (Phylum Aschelminthes)
2. Annelids - (Phylum Annelida)
3. Copepods - (Phylum Arthropoda)
4. Amphipods - (Phylum Arthropoda)
5. Ostracods - (Phylum Arthropoda)

Other organisms found in the samples were generally too few in number to be of significance, or too small to be identified (eg. foraminifera).

Sampling areas were dictated by the availability of suitable sand substrates. Coring stations fell in a line down the shore, beginning below the northern rock face.

The results of the sampling are presented as a table on the next page.

ERRATUM

Page 14, line 10: 'electration' should read 'elutriation'.

TABLE I

MEIOFAUNA SAMPLING--RESULTS

Visit/Date	Core Station	Substrate Grain Size	No.'s of Organisms per Core Sample Nematodes	Annelids	Copepods	Amphipods*	Ostracods
2-9/3/73	1	Fine	620	80	118	-	160
	2	Coarse	-	38	10	-	62
4-28/873	1	Fine	165	262	4	-	174
	2	Fine	1282	220	14	-	34
	3	Fine	615	112	160	-	100
5-26/1/74	1	Fine	227	72	66	13	31
	2	Medium Fine	163	11	40	18	90
	3	Fine	780	160	25	50	41

*Anisogammarus Sp.

Transect Method

During visits 3, 4, and 5, a transect was run on a perpendicular from the rock wall below benchmark B toward the lower tidal area. Quadrats were placed at one metre intervals along the transect, quadrat 1 situated at the base of the wall. Quadrat size was 30 square cm. Recorded for each quadrat were: organisms present, numbers of organisms, percent composition of substrate, and visual presence or absence of oil. The data from these transects are given in the following tables.

THIRD VISIT

QUADRAT NUMBER	OIL PRESENCE	% COMPOSITION OF SUBSTRATE Rock	Pebble	Sand	FLORAL COVERAGE	LIMPETS (Acmaea Spp.) Living	Moribund or Dead	LITTORINIDS Living	Moribund or Dead	AMPHIPODS Living	Moribund or Dead	OTHER
1	Oil at base of rocks, weathered oil on rocks	90	-	10	-	-	1	2	3	-	-	1 crab (Hemigrapsus oregonesis)
2	Weathered on rocks	75	20	5	-	-	8	7	20	-	-	
3	No visible oil	55	25	20	5 (Gigartina)	-	-	26	2	-	-	
4	No visible oil	30	20	50	2 (Fucus) 4 (Gigartina)	2	1	11	3	-	-	
5	No visible oil	5	-	95	3 (Fucus)	-	-	17	-	-	-	
6	No visible oil	40	15	45	4 (Fucus)	8	-	21	5	-	-	
7	No visible oil	55	45	-	-	7	-	36	-	-	-	
8	No visible oil	-	5	95	4 (Gigartina)	-	-	3	-	-	-	

FOURTH VISIT

QUADRAT NUMBER	OIL PRESENCE	% COMPOSITION OF SUBSTRATE Rock	Pebble	Sand	FLORAL COVERAGE	LIMPETS (Acmaea Spp.) Living	Moribund or Dead	LITTORINIDS Living	Moribund or Dead	AMPHIPODS Living	Moribund or Dead	OTHER
1	Weathered on rocks - sticky tar on sands	80	-	20	-	-	2	2	1	1	-	
2	Weathered on rocks - sticky tar(slight) on sand	70	15	15	-	1	6	14	12	-	-	
3	Weathered on rocks - not visible in surface sands	30	55	15	-	2	1	1	2	-	-	
4	Small amount weathered on rocks	-	30	70	2 Gigartina sp. plants Very Desiccated	-	-	4	3	-	-	1 Hemigrapsus nudus living
5	No visible oil	85	10	5	1 Gigartina sp. plant	4	-	5	2	-	-	
6	No visible oil	10	10	80	1 Large Fucus sp. plant	-	2	25	-	-	-	
7	No visible oil	10	20	70	80% coverage of Fucus sp. 1 young Gigartina sp.	-	-	28	2	-	-	
8	No visible oil	70	15	15	1 young Gigartina sp.	7	-	4	2	-	-	

FIFTH VISIT

QUADRAT NUMBER	OIL PRESENCE	% COMPOSITION OF SUBSTRATE Rock	Pebble	Sand	FLORAL COVERAGE	LIMPETS (_Acmaea Spp._) Living	Moribund or Dead	LITTORINIDS Living	Moribund or Dead	AMPHIPODS Living	Moribund or Dead	OTHER
1	Tarry residue in sand around rocks. Weathered oil on rock	60	40	–	1 _Fucus_	–	2	20	7	~100	–	
2	Weathered oil on rock	50	50	–	–	1	2	75	20	~100	–	2 barnacles
3	No visible oil	40	60	–	1 _Gigartina_	1	–			–	–	encrusting brown algae (0.05%coverage)
4	No visible oil	–	10	90	–	–	–	1	1	2	–	
5	No visible oil	75	25	–	1 _Gigartina_	13	–	60	10	30	–	
6	No visible oil	–	5	95	–	–	–	5	–	10	–	6 barnacle
7	No visible oil	20	80	–	1 _Fucus_	5	2	20	–	–	–	8 barnacle
8	No visible oil	–	5	95	–	–	–	–	–	5	–	–

Transect Results

Of the organisms identified during this study, the most numerous were:

Aigae:	_Fucus distichus_ (rockweed)
	Gigartina sp.
Molluscs:	_Acinara spp._ (limpets)
	Littorina scutulata } (periwinkles)
	L. sitkana } (periwinkles)
	Calliostoma sp.
Crustacea:	_Orchestia sp._ (amphipods)

The population numbers of these species remained fairly stable throughout the study with the exception of the amphipods. Table 5 summarizes the change in amphipod numbers over time.

TABLE 5

TRANSECT STUDY: AMPHIPOD NUMBERS/TIME

Quadrat No.	Visit Number		
	3	4	5
1	-	1	∿100
2	-	-	∿100
3	-	-	-
4	-	-	2
5	-	-	30
6	-	-	10
7	-	-	-
8	-	-	5

DISCUSSION OF BIOLOGICAL EFFECTS

Introduction:

This is not a before and after study. There are no data or observations of the conditions of the biota before the spill. Therefore, comment can only be made as to how the after-spill conditions in Reserved Bay differed from other similar but uncontaminated areas, and how populations have changed over time since the spill occurred. A further limitation is that only lethal and obvious physical damage to the biota have been studied. Long-term sub-lethal effects have not been assessed.

General Observations:

The area physically covered by the spill was the upper tidal zone, and consequently populations in this area were the most affected.

Marsh grasses at the upper limits of the spill experienced physical damage. Parts of the plant which were covered with oil (upper stems) were lost. It is not uncommon, however, for winter storms to similarly reduce marsh grasses to near-ground level, with extensive spring and summer growth restoring the aerial parts of the plant. Therefore, rejuvenation can be expected, and in fact the damage to the grasses may have been natural.

It is a common occurrence for large amounts of rockweed to be tossed into the higher tidal reaches. The bed of detached rockweed observed at the top of the beach was almost certainly there before the spill, and then was oiled; almost rather then being oiled in the living state, detaching and washing ashore. However, some rockweed damage did occur due to the spill. The few attached plants in the oiled area of the beach became desiccated and moribund, presumably because oil coverage prevented light absorption and gas exchange.[1]

Heavy densities of amphipods were observed in the detached bed of oiled rockweed. This is a common occurrence in a bed of decaying algae, and probably not a manifestation of the oil covering.

The group of animals most obviously affected by the oil coverage were the grazers: limpets and periwinkles. Many dead and moribund periwinkles were found in oiled areas on the second visit and they did not reappear there until visit 5. The northern and southern rock faces provided a clear comparison for limpets: the northern was well oiled, the southern relatively unoiled. Southern rock faces sustained high densities of limpets (∿ 50/m^2) throughout the study, while the oiled northern rock face was nearly devoid of them (∿ 2/m^2). It is apparent that the oil coverage sharply reduced the limpet numbers. This statement is supported by the fact that large numbers of recently dead limpets were found at the base of the northern rock face and at the base of other oiled rocks.

Meiofauna in Sand Cores:

The core samples contained meiofauna which are characteristic of a marine sandy environment (Bawden et al, 1973). There were relatively stable numbers of all members of the meiofauna except the amphipods(Table 5).

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[1]These beds of rockweed retain the oil, keeping it from the sand surfaces beneath. This contradicts observations made on a Bunker C oil spill by Thomas (1973). Thomas indicated that species of rockweed were protected from oil coverage by a mucilaginous surface layer. The rock weed found in Reserved Bay (<u>Fucus distichus</u>) appeared to retain rather than repel oil coverage.

Virtually no amphipods existed in the cores from Visits 2 and 4, with a sudden appearance of substantial numbers in cores from Visit 5. This could reflect a recovery of the population from the effects of oil (perhaps recolonization from other tidal levels). On the other hand, it could also reflect a seasonal habitat preference of various stages in the life cycle of this particular organism (Orchestia sp.). Whatever the explanation the meiofauna appear to be a healthy and diverse community that were not devastated by the effects of the oil.

Transects:

Transect studies also reveal fluctations in amphipod densities while the densities of other organisms are relatively stable. Visits 3 and 4 record very few amphipod numbers, while Visit 5 demonstrates a significant rise in numbers, particularly in the higher tidal levels. The fact that this recolonization consisted of both large and small amphipods indicates that this is not a recently hatched brood which has taken over since the spill, but rather a group of animals which has moved in from unaffected areas and taken up residence in the oiled habitat.

Conclusion:

Of the biotic community in Reserved Bay, only the organisms actually covered with oil appear to have been significantly reduced in numbers. However, many of these animals have vertical zonal distributions which extend into uncontaminated areas and, therefore, have the chance for fairly rapid recolonization. Once the oil has weathered sufficiently, adult animals may move directly into the affected areas, or young larval stages may settle out of the plankton. Natural recovery of the damaged areas should not be difficult. Considering the limited size of the spill, and the natural resiliency of marine biological communities, there should be no permanent damage to the biota of the bay.

CHEMICAL STUDY

Method of Analysis

Oil samples from each visit to Alert Bay were analyzed by gas chromatography to determine the chemical changes that occurred to the oil due to the effects of weathering.

Roughly one gram of material was weighed out from each sample into a centrifuge tube. Five ml of carbon disulfide were added and vigorously shaken to dissolve the oil. The tube was then centrifuged to remove particles of sand and other foreign material, and the CS_2 solution was decanted into a glass septum vial (teflon septum). These vials were kept refrigerated when not in use.

The samples were analyzed by gas chromatography using two different kinds of columns. First the sample was run on a Dexsil column. Dexsil 300 is a non-polar, high-temperature packing which can be programmed up to $400^{o}C$ with very little bleed. This gave a full chromatogram of the oil sample on a stable baseline.

Secondly, a partial chromatogram of the sample was obtained running the sample on a FFAP column. FFAP is a polar packing, and it was used to separate the isoprenoid peaks (pristane and phytane) from the corresponding paraffin peaks (C_{17} and C_{18}).

The significance of these peaks will be made clear shortly.

Results

The results of the gas chromatographic analysis are given on the following pages in two sections, the first presenting the full chromatograms, the second presenting the isoprenoid/paraffin ratios. In both, the traces proceed chronologically from the original spilled oil through to the samples from the final visit.

The spectrum of peaks in the full chromatograms reflects the concentration of paraffinic compounds, the main components of oil. The numbering indicates the number of carbon atoms in the compound creating the peak. Thus the area under the peak labeled '15' corresponds to the amount of pentadecane in the sample.

Technical Data - Gas Chromatography Procedure

Full (high-temperature) chromatograms:

A Varian Aerograph 1400 gas chromatograph was used for this portion of the work. The working parameters were as follows:

Sample size: 5 to 40 μl Carrier gas: N_2
Column: length 10' by 1/8" diameter
3% Dexsil 300 on 100/120 mesh Chromosorb W (acid-washed)
ml/min: Carrier 20 H_2 50 Air 350
Inj. port: $300^{o}C$ Detector: $400^{o}C$
Column Conditions: Programmed
Initial temp: $70^{o}C$, for two minutes
Final temp: $400^{o}C$, hold
Program rate: 6^{o}/min Chart speed: 0.5 IPM
Detector: FID
Sensitivity: variable, usually 32×10^{-10}

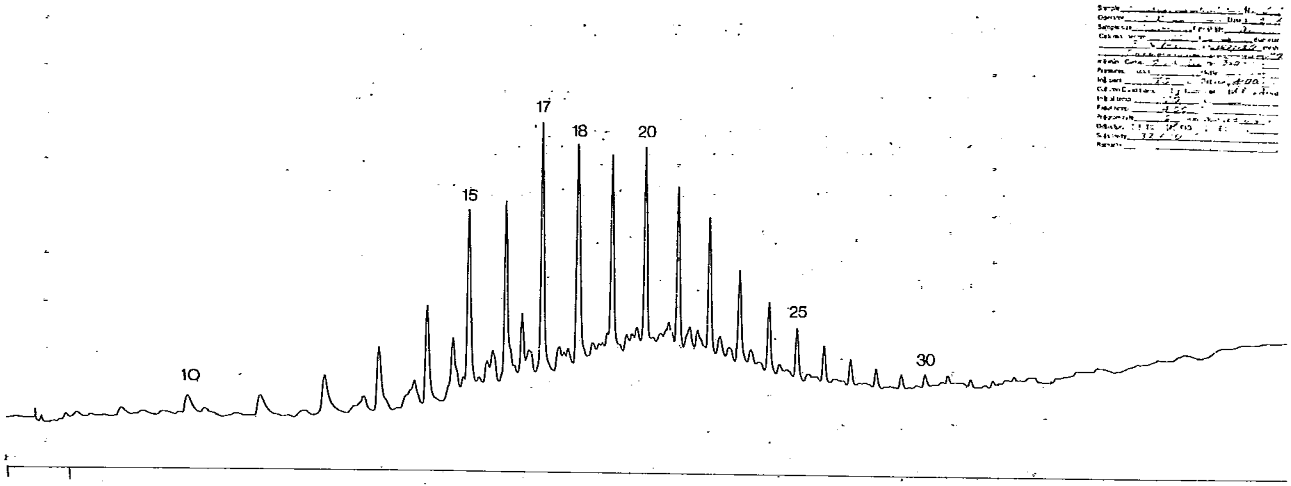
Chromatograms for isoprenoid/paraffin ratios

A Hewlett-Packard Model 5710A gas chromatograph was used. The parameters were as follows:

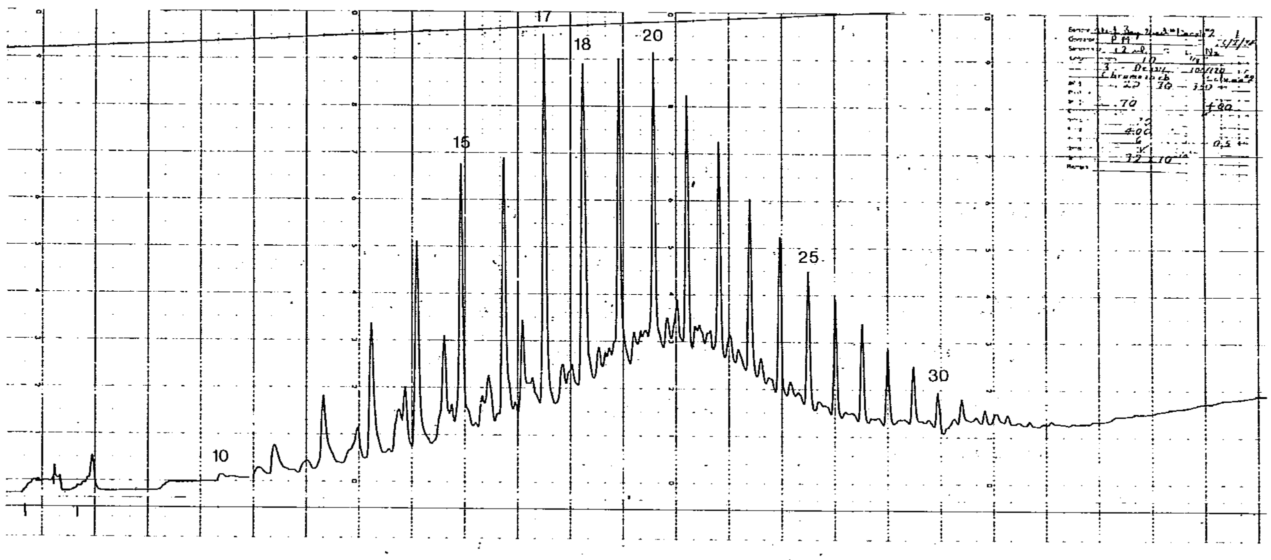
Sample size: 5 to 40 μl Carrier gas: He
Column: length 10' x 1/8" diameter
12.5% FFAP on 80/100 mesh Chromosorb G (acid-washed, DMCS treated)
ml/min: Carrier 30 H_2 34 Air 260 Make-up Carrier 26
Inj. port: $200^{o}C$ Detector port: $300^{o}C$
Column conditions: programmed
Initial temp.: $100^{o}C$ for 2 min.
Final temp.: $260^{o}C$ for 4 min.
Program rate: 8^{o}/min. Chart speed: 0.5 IPM
Detector: FID
Sensitivity: 8 x 100

CHROMATOGRAMS

Sample of oil spilled at Alert Bay
(taken directly from the fuel tanks of the Irish Stardust)



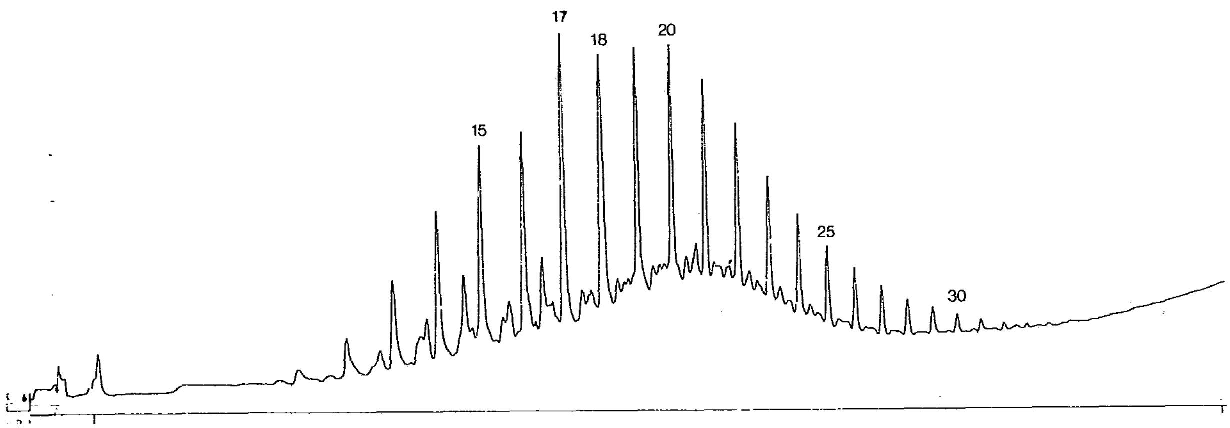
Reserved Bay, first visit, five days after the spill
(thick floating slick near the beach)



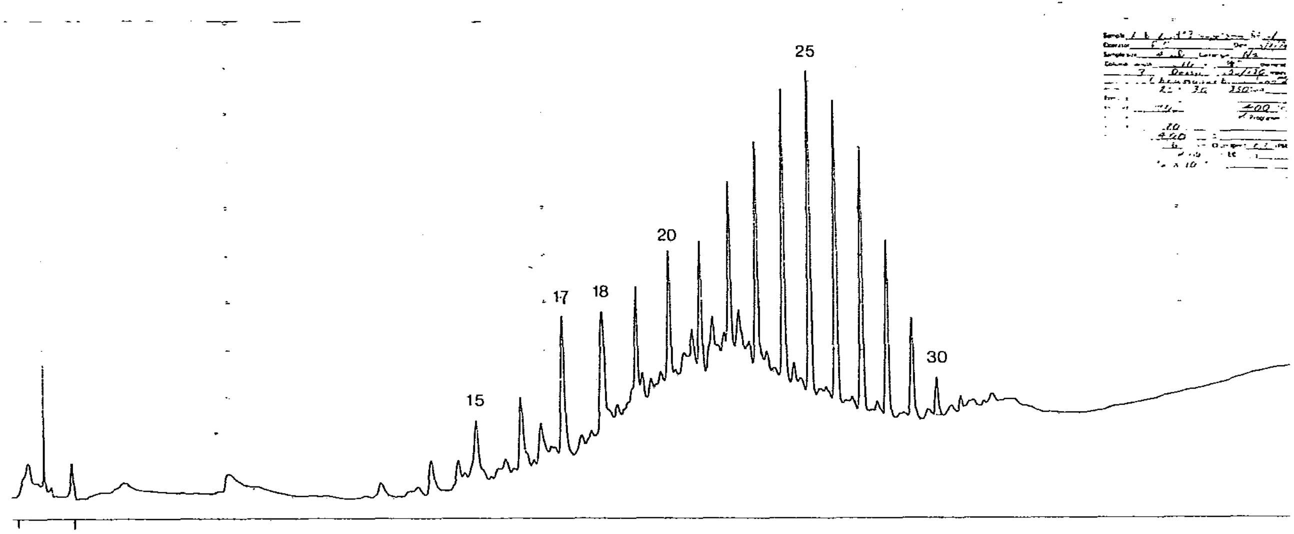
Comment: Note the very great similarity of the two chromatograms, with the relative heights of all peaks approximately the same. The only apparent weathering is a very small loss of C_9 and C_{10} compounds.

If the source of the polluting oil had been uncertain these chromatograms would have provided convincing evidence that the oil came from the Irish Stardust.

Second visit, six weeks after spill
(thick oil from between the rocks)

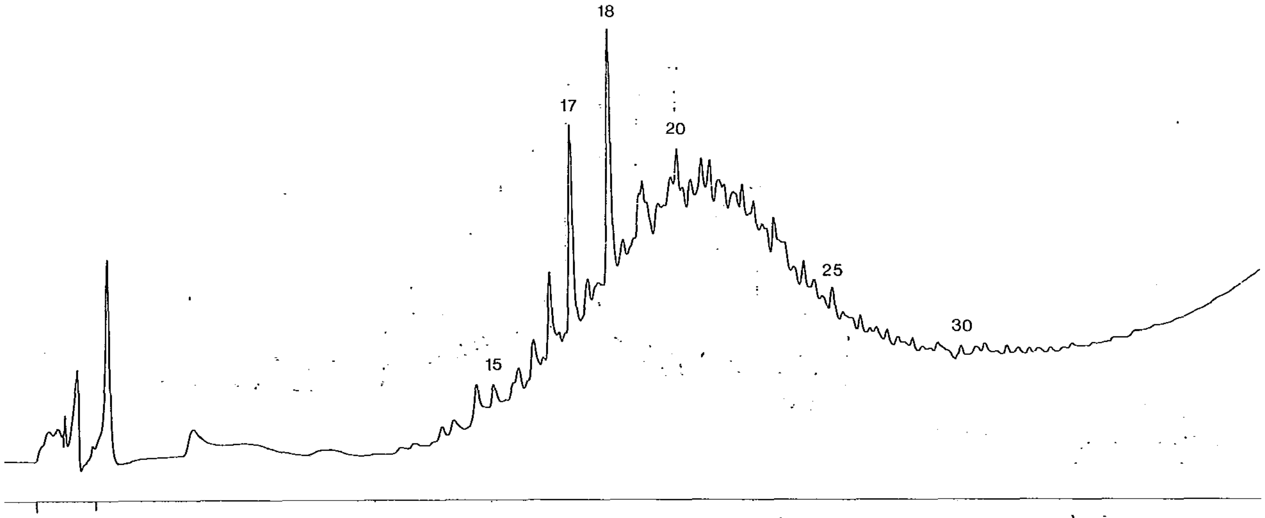


Third visit, four and a half months after spill
(oiled sand)

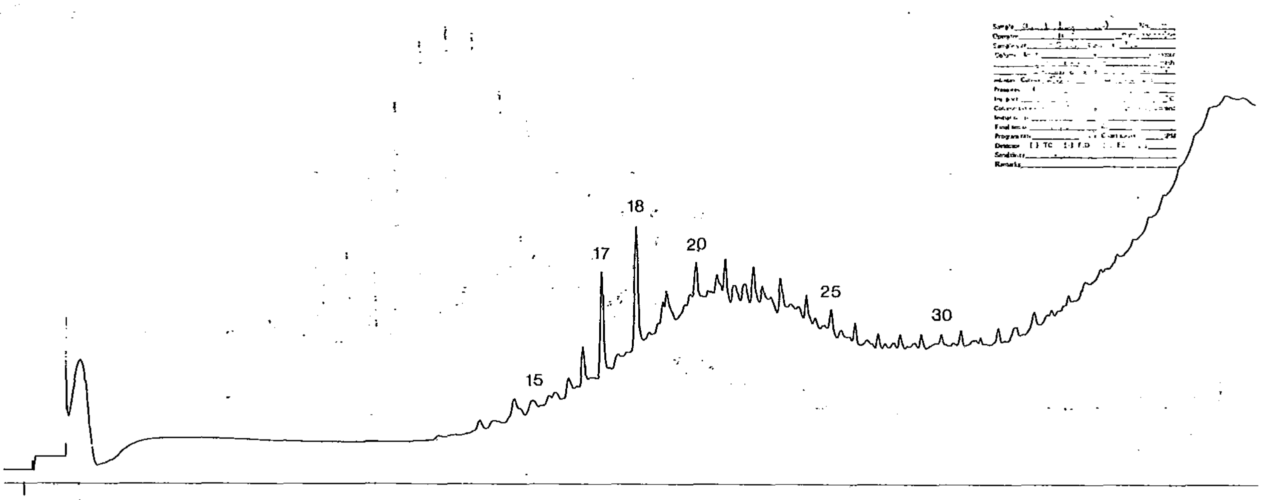


Comment: Very little change had occurred by the second visit, possibly because this sample was protected from some of the effects of weathering by being trapped between rocks. However, by the third visit a definite loss of compounds lighter than C_{25} had occurred relative to the heavier compounds.

Fourth visit, eight months after spill
(oiled surface gravel)



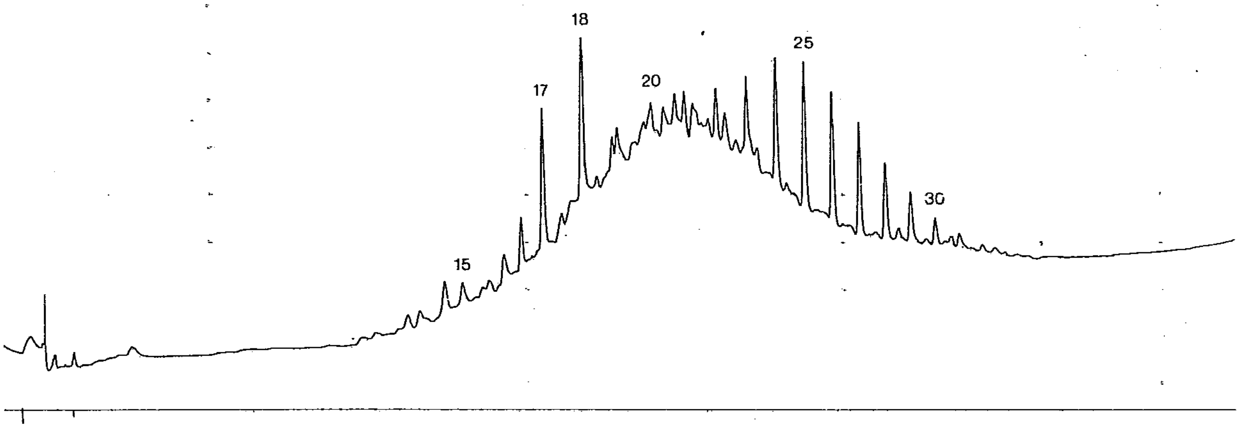
Fifth visit, one year after spill
(oiled surface gravel)



Comment: By the fourth visit all the paraffin compounds had been degraded. The peaks at 17 and 18 are the isoprenoids: pristane and phytane. These two compounds elute at the same time as the paraffins C_{17} and C_{18} respectively, but are not degraded as quickly by bacteria. The partial chromatograms in the next section separate the isoprenoid and paraffin peaks to show the relative amounts of each.

By the fifth visit, the 17 and 18 peaks appear to be diminishing, indicating the degradation of the isoprenoids.

Fifth visit
second sample of oiled gravel



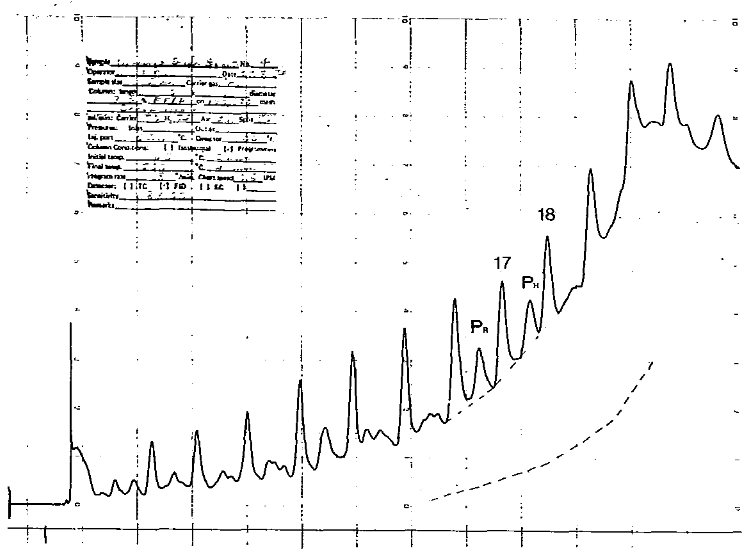
Comment: This sample was taken a few metres from the previous fifth visit sample. The chromatogram indicates that the oil in this sample is not as severely degraded as even the fourth visit sample, since the paraffins from C_{25} to C_{30} are obviously still present.

There is, then, a significant variation in the rate of degradation of the sample depending on its locale.

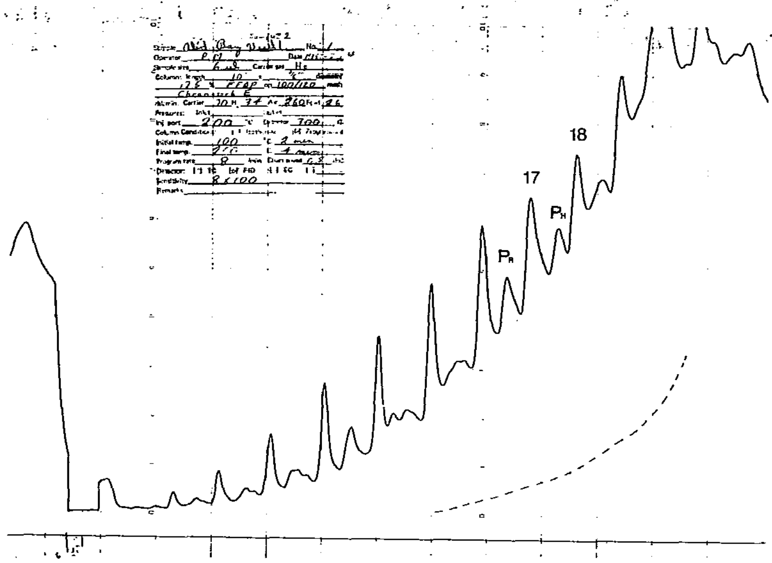
Isoprenoid/Paraffin Ratios

The ratio of paraffins to isoprenoids gives a numerical means of indicating the rate of degradation of oil. The following chromatograms separate the paraffins from the more slowly degraded isoprenoids, and the ratios are given in a table following the chromatograms. (The same samples have been used as for the previous chromatograms.)

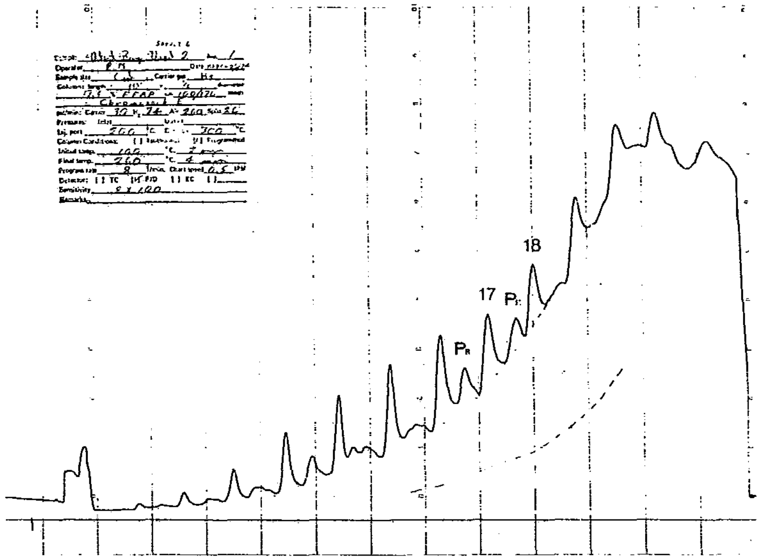
Original oil
from Irish Stardust



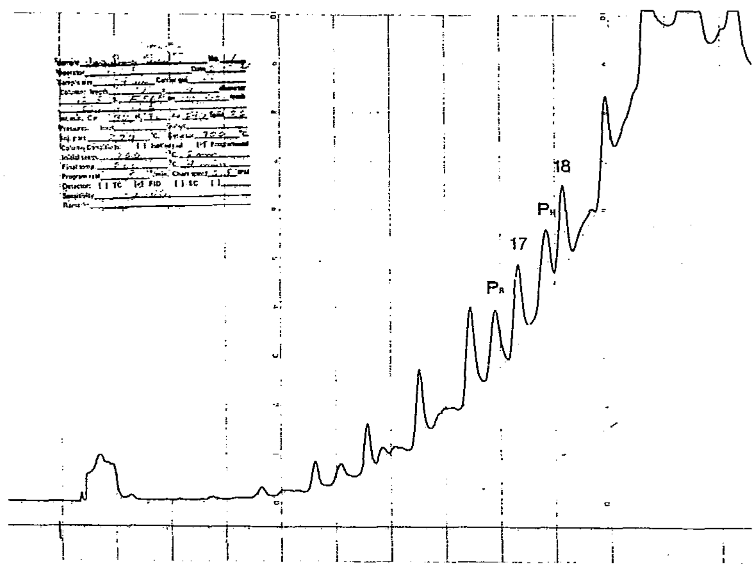
First visit
five days after spill
thick surface slick



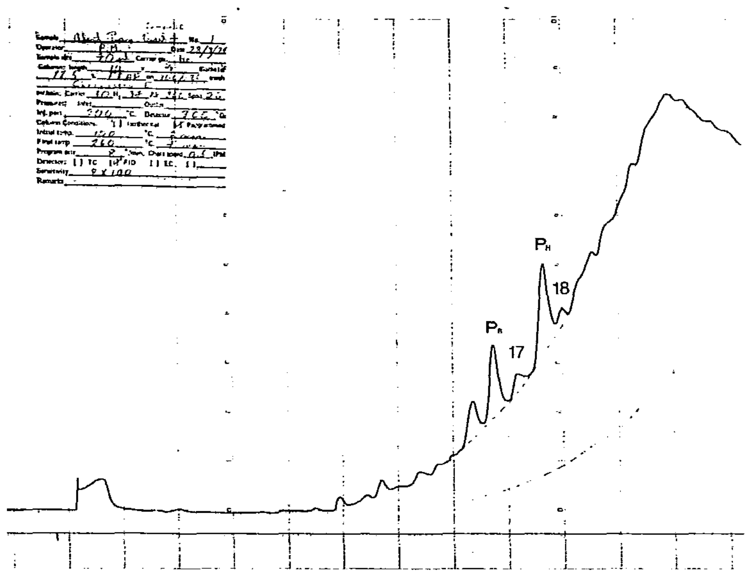
Second visit
6 weeks after spill
thick oil between rocks

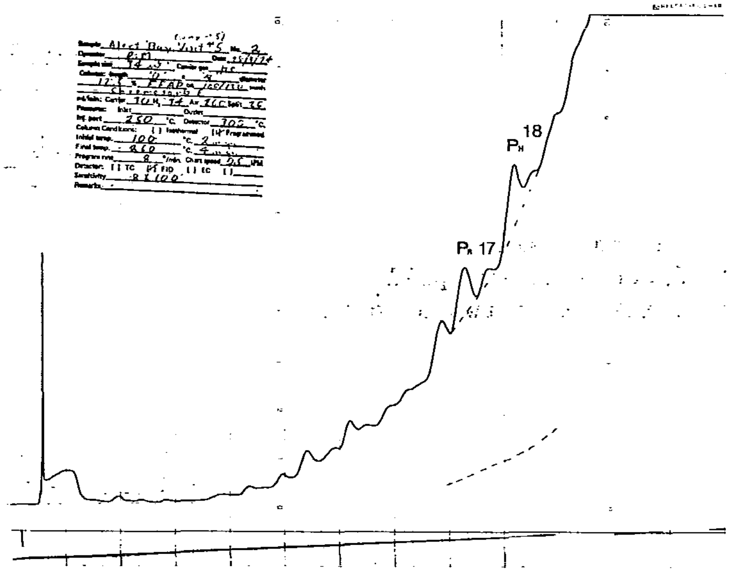


Third visit
4 1/2 months after spill
oiled sand

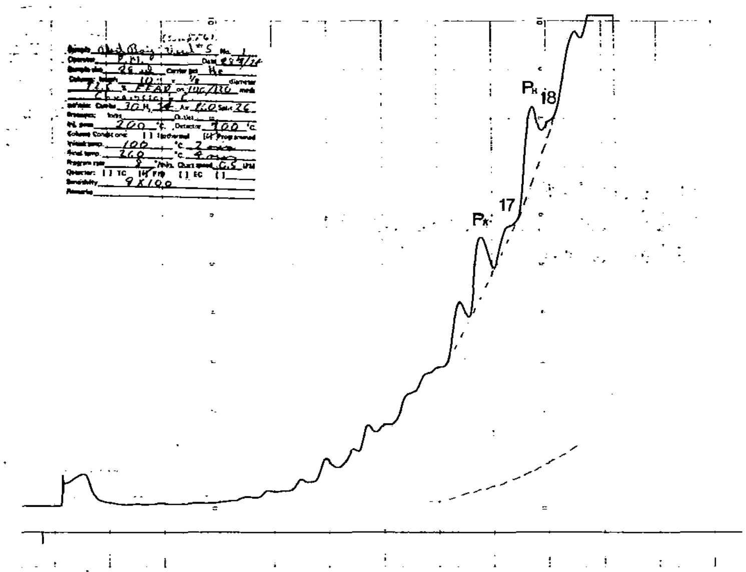


Fourth visit
8 months after spill
oiled gravel





Fifth visit
one year after spill
oiled gravel



Fifth visit
second sample of oiled
gravel

TABLE 6

Paraffin/Isoprenoid Ratios

Sample	C_{17}/Pr*	C_{18}/Ph*
Original fuel	1.9	2.2
Visit 1	1.9	2.2
Visit 2	1.7	1.8
Visit 3	1.2	1.2
Visit 4	.3	.2
Visit 5 sample 1	.3	.2
Visit 5 sample 2	.2	.3

*Uncertainty: 15% rising to 30% for final samples

Comment: The ratios clearly show the more rapid loss of the paraffins (heptadecane and octadecane) relative to the isoprenoids (pristane and phytane). This is characteristic of biological degradation of oil. Other natural degradative processes, such as photo-oxidation, normally oxidize the isoprenoids more quickly than the paraffins.

Discussion

It should be clearly understood that the chemical analysis of the spilt oil does not deal with the removal of the oil by physical processes. The action of wind, waves, and tide can physically carry away the oil without chemically altering it. We term this 'physical weathering'. Some physical weathering of the oil occurred at Reserved Bay, and this was described in the visual observations made during each visit.

'Chemical weathering' refers to the chemical alteration of the oil by the environment. It is this form of weathering that is revealed by the chromatograms.

Four processes are known to cause chemical weathering:

dissolution
evaporation
abiological oxidation and polymerization(mostly photo-oxidation)
biodegradation.

Dissolution and evaporation, the most rapid processes, affect only the lighter compounds since these are the most soluble and volatile. The heavy fuel oil spilt by the Irish Stardust included only a small portion of these lighter components and so dissolution/evaporation have only a minimal effect on the weathering of the oil. It is not surprising that there is very little change in the chemical composition of the oil over the first five days of exposure as shown by the first two chromatograms.

Photo-oxidation and biodegradation are slower-acting processes. The effects of each are not easily separated. However, the more rapid removal of the paraffins relative to the isoprenoids,(as shown by the second set of chromatograms) is characteristic of biodegradation, indicating that this is the dominant process.

The full chromatograms show the steady advance of biodegradation until, after approximately a year, the paraffins have been completely degraded. By comparison, in the laboratory where conditions are ideal, bacterial cultures can completely remove the paraffins from oil within 24 hours (Mechalas et al, 1973).

Bacterial degradation, then, appears to be the main mechanism for altering the chemistry of the oil on the beach. Under the conditions in the bay, and with the type of oil spilt, it takes on the order of one year for the bacteria to complete the degradation of the paraffins, leaving an asphalt-like residue on the stones of the beach.

CONCLUSIONS

The conclusions that can be drawn from this study have some general application in any oil spill situation, but their generality is limited by several factors.

First, this oil spill was small; the coating was not continuous along the coastline, did not cover the entire vertical range of the intertidal zone, and was not particularly thick (1-5mm). A more complete coverage of the intertidal zone could have more drastic biological effects, since recolonization from unpolluted areas would be much more difficult. A thicker covering may take exponentially longer to weather since it may immobilize the beach, paving it like a road, so preventing physical weathering and also bacterial degradation of the middle layers.

Secondly, the conclusions apply directly only to the type of oil spilt: heavy fuel oil. Oils with light components, for example diesel fuel, could be expected to disappear more quickly due to the effects of evaporation and dissolution but to have more severe biological effects. In the case of crude oil, the heavy fraction could be expected to behave like fuel oil, while the light fraction would, like diesel fuel, disappear rapidly and yet cause more biological damage.

Thirdly, the conclusions are relevant mainly to shorelines that are semi-exposed. Exposed locations would undergo more physical weathering and the oil covering could be expected to disappear more rapidly. Very protected areas would be slower to recover.

Biological Effects

Only those species that were in direct contact with oil seem to have been harmfully affected, particularly limpets and periwinkles, and perhaps isopods, rockweed and marsh grass.

No species has been completely eliminated, and there are indications that recolonization is occurring.

Within the limitations of the study, it appears that there will not be any permanent effects on the biological community at Reserved Bay.

Physical Weathering

The physical action of the wind, waves, and tide did not appear to have much effect on the oil-covering in this semi-exposed location. The pattern of contamination remained identical throughout the year-long study, with the exception of the oiled rockweed and sand, which were gradually removed.

Chemical Weathering:

The major mechanism for altering the chemistry of the oil in the bay was the action of bacteria. The bacteria took on the order of one year to degrade the paraffin portion of the oil, leaving a thin, unobtrusive, asphalt-like covering on the rock and gravel of the beach. This thin coating appeared to be more susceptible to physical weathering than the original oil, and was gradually disappearing.

In conclusion, the beach at Reserved Bay was still polluted by oil one year after the spillage occurred. However, approximately 90-95 percent of the volume of the oil had been removed by various natural processes, and the area was beginning to recover from the relatively small amount of biological damage that had occurred.

ACKNOWLEGEMENTS

We would particularly like to thank R. Schek and D. Parker, Fisheries Officers at Alert Bay, for their generous co-operation in providing transportation to Pearse Island and vicinity on each of our field trips to Reserved Bay.

Furthermore, we are indebted to P. Montgomery for his assistance in running the gas chromatographic analyses; to C. Hatfield of the Environmental Protection Service and A. Ages of the Marine Sciences Directorate for locating the study area; and to Dr. T. Parsons for his advice and help with administrative arrangements.

APPENDIX 1

SPECIFICATIONS OF FUEL OIL SPILT AT ALERT BAY:

Specific Gravity at 15°C	0.9412
A.P.I.	--
Vis. R.W. No. 1	465
Carbon	9.0%
Flash Point	91°C
Pour Point	-10°C
Sulfur	2.41%
Ash	Trace
Water	Trace

From fuelling report - Osaka, Japan

This fuel is termed '1000 second fuel oil'. It is a less viscous mix than Bunker C.

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