Government of South Australia
Department of the Premier and Cabinet

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DPC16/1299

13 October 2016

Mr Dan Monceaux
3/15 Myall Avenue
KENSINGTON GARDENS SA 5068

Sent by email: foi+request-2280-113b094c@righttoknow.org.au

Dear Mr Monceaux

I refer to your application for internal review of a determination made under the *Freedom of Information Act 1991* (the Act) by the Department of the Premier and Cabinet (DPC), received on 4 March 2016. The purpose of this letter is to advise you of the outcome of my review.

Your initial application

Your initial application to DPC sought access under DPC Circular PC031, 'Freedom of Information Release of Cabinet Documents under the Ten Year Rule', to:

Date	Docket Number	Cabinet Submission Title	Minister
21/06/1993	DEP218/92	First Report on Effects of the "Era" Oil Spill	Mr Kym Mayes

Determination under review

DPC did not make a determination on your initial application within the 30-day time period required by the Act. Accordingly, DPC was deemed to have refused access in full to all documents relevant to your application.

Outcome of internal review

One document was identified as answering the terms of your application. I have determined to release this document in full

If you have any questions in relation to this matter, please contact Fiona Braendler, Manager, Freedom of Information, on telephone (08) 8226 2768 or via email fiona.braendler@sa.gov.au.

External review

If you remain dissatisfied with this determination, you have the right to apply to the Ombudsman for external review under section 39 of the Act. You have 30 days from the date on which you receive this letter to apply for an external review. If you have any questions about an application to the Ombudsman, please contact his office on (08) 8226 8699.

Yours sincerely

Kym Winter-Dewhirst
PRINCIPAL FOI OFFICER

6.1

Approved 21/6/93

MINUTES forming ENCLOSURE to DL 218/92.

TO THE PREMIER : FOR CABINET

RE: FIRST REPORT ON EFFECTS OF THE ERA OIL SPILL

1. PROPOSAL

To approve release of the reports from the Environmental Protection Council (reports attached).

2. BACKGROUND

2.1 The National Plan to Combat Pollution of the Sea by Oil does not provide for monitoring of the effects of an oil spill after emergency clean-up procedures have been completed.

2.2 When it became apparent that this spill could have substantial impact on the mangroves south of Port Pirie, the Marine Environment Protection committee (MEPC) recommended that these effects be monitored.

2.3 MEPC set up a Reference Group, convened by Dr Alan Butler of Adelaide University (Chair of EPC and MEPC), to coordinate studies.

2.4 The program which the Reference Group prepared was tightly costed, but still totalled $120 000. With no ready source of funds from Government for the cash component, I approached private sector shipping and petroleum interests for contributions. Those interests contributed $35 000, which, with contributions 'in kind' by Government agencies, and a cash contribution of $10 000 from Department of Mines and Energy, meant that we could start the program.

3. DISCUSSION

3.1 This first report finds that there has been some damage from the oil, but relatively little direct economic effect so far. These observations have been useful in guiding response under the National Plan.

3.2 The sites will be monitored for several years, to gauge recovery of mangroves, fish and bird stocks.

../2.

3.3 EPC has recommended particular functions and reserve funding to be provided for the proposed EPA to carry out similar monitoring after any future spills.

3.4 I have also referred the issue of post-spill monitoring to the Australian and New Zealand Environment and Conservation Council.

3.5 There is substantial mass media interest in these reports.

3.6 **Financial Implications**
The rest of this program will be covered in Departmental operational allocations, and by the funds contributed from industry and DME. This leaves little capacity to respond to another spill until the Commonwealth can arrange funding for post-spill monitoring under the National Plan.

3.7 **Consultation**
The Reference Group includes representatives of public and private sector bodies involved in petroleum processing and shipping. Its reports are made through MEPC and EPC, which have wide representation from commerce, conservation interests, local government and the community.

4. RECOMMENDATIONS

It is recommended that Cabinet:

4.1 approve release of the "First Report on Monitoring the Effects of the Era Oil Spill"

4.2 approve release of the report "The Distribution and Persistence of Petroleum Hydrocarbons in Mangrove Swamps Impacted by the Era Oil Spill (September 1992)".

KYM MAYES MP
MINISTER OF ENVIRONMENT AND LAND MANAGEMENT

Date: 5/6/93.

ENVIRONMENTAL PROTECTION COUNCIL
Marine Environment Protection Committee

Outline of

First Report to Minister of Environment and Land Management on Monitoring the Effects of the *Era* Oil Spill

The report was prepared by a Reference Group established under the Marine Environment Protection Committee, a subcommittee of the Environmental Protection Council.

To determine the effects of an accident such as this on the environment, after the event, is an almost impossible scientific problem because of the natural variation of environmental quantities, the lack of data taken before the event, and the lack of identical, non-impacted "reference areas" or "control areas". There is always the risk of confusing effects of the oil spill with effects of some other event (known or unknown) that occurred at the same time, such as, in this case, the flooding of the River Broughton.

The studies were therefore focused on:

1 organisms obvously impacted, such as birds, mangrove and samphire plants
2 organisms which, even though technically very difficult to assess, are economically important, such as juvenile fish and prawns
3 the fate of the oil itself, after it had beached in the tidal swamps SW of Port Pirie.

Funding for the study came partly from Government sources (DELM, DPI, SARDI, DME[cash contribution of $10,000]) and partly from the following generous contributions by private agencies involved:

BP Australia	$10,000
Howard Smith Industries	$10,000
SANTOS	$10,000 + additional monitoring work / logistic support
Adelaide Steamship Co	$5,000

The study is necessarily long-term. This report gives only the first results, based on field trips up to early March 1993.

The results indicate that, whilst there has been an impact of the spill on certain components of the marine ecosystem it is small-scale, not a disaster. The monitoring provides an opportunity for learning about a number of aspects of the impact, but especially about two things:

i the behaviour and fate of the oil itself, which might enable us to better manage a large spill should one occur
ii how to manage the monitoring of any future environmental accident,
and the report makes recommendations about ii.

The report covers nine components of the monitoring program, most of which are ongoing and planned to continue for two or three years; results to date are summarized below.

i. Fate of hydrocarbons. Oiling occurred over a 15 km front, impacting mangroves and sediments approximately 50 m from the Gulf fringe.

Approximately 75-100 hectares of mangrove swamp were oiled, of which less than 5 hectares still exhibited heavy oiling by November. Mangroves in the region cover approx. 20 km^2 (2000 hectares).

In some areas oiling was associated with deep depositions of seagrass debris, and this oil appears to be weathering unusually slowly and is a source of some concern lest it be remobilized.

Defoliation of mangroves is occurring in heavily oiled areas (approximately 23 hectares). Moderately oiled areas (approximately 5.5 hectares) exhibit some leaf damage. Lightly oiled areas are expected to show limited effect, probably loss of oiled leaves. Generally, the mangrove woodland is expected to recover in all areas except those characterised by heavy oiling of sediment or extensive deposition of oily seagrass wrack. Death of individual trees or saplings is likely to occur in all areas but should be significant only in the heavily oiled areas.

It is planned to continue monitoring the fate of the oil and recovery of the mangroves.

ii. Birds. Pied Cormorants, one colony of which was heavily impacted by the oil, are nesting to the north and south of the spill area but breeding colonies within the impacted area have been abandoned. Bird breeding will continue to be monitored.

iii. Juvenile fish and prawns in shallow areas near mangroves. It is too early to draw any conclusions as to the effects of the oil spill on the fish community and on juvenile prawns and the program is continuing.

iv. Mangrove monitoring. On the visits reported so far (up to December), large-scale leaf loss had not been observed, but there was leaf curling, chlorosis and blackening; it is too soon to interpret the data on mangroves in detail.

v. Gross changes in samphires and mangroves. Fixed photo-points have shown substantial re-shooting of the samphires and a variety of responses in mangroves, but it is too soon to draw final conclusions about the fate of these oiled plants.

vi. Bottom samples were trawled in the Gulf during the first days after the spill; none of the samples analysed to date contained detectable hydrocarbons characteristic of the *Era*'s bunker fuel.

vii. Taint testing of prawns. An experienced tasting panel failed to detect any tainting by hydrocarbons in prawns caught in the spill area.

viii. Seagrasses and associated fauna. This study is hampered by possible confounding with other events; there are areas of blackening and foliage loss of seagrass but it is not clear that this is associated with the oil. The study is continuing and samples still being analysed.

ix. Aerial photography. An initial survey provided an immediate baseline of the impact of the oil ten days after the spill. The extent of the oil was small relative to the area of vegetation surveyed. The first survey was used by monitoring teams to locate areas of impact for more detailed work on the ground. The survey was repeated in February 1993 and will be continued, using infra-red photos as well as normal colour to detect unhealthy vegetation.

x. Other matters not commissioned by the MEPC but of which it is being advised included studies of *Mangrove physiology, Fish enzymes,* both seeking evidence of signs of stress, *Hydrocarbon analyses of crab samples*, which showed no traces of hydrocarbons, and a report on the *Dispersants used,* namely COREXIT 9527, COREXIT 7664 and ARDROX which (unlike dispersants used in some early oil spills overseas) are of low toxicity.

Recommendations

The report recommends that the costs of monitoring the effect of an oil spill on the marine ecosystems should be provided for under the National Plan to Combat Pollution of the Sea by Oil. It makes some comments about effective initiation of a monitoring program in any future case.

For environmental accidents generally (not only oil spills) it recommends that there should be a fund set aside to enable monitoring to begin without delay. It also recommends that the proposed Environmental Protection Authority have the authority and responsibility to *both initiate and coordinate* studies of the environmental impacts of such accidents.

Dr Alan Butler
Chair

April 1993

ENVIRONMENTAL PROTECTION COUNCIL

Marine Environment Protection Committee

First Report to the

Minister of Environment and Land Management

Monitoring the effects of the *Era* Oil Spill

April 1993

Report prepared by Dr Alan J Butler
Senior Lecturer, Zoology Department, Adelaide University
Chair EPC and MEPC

Published by the Environmental Protection Council of South Australia

Secretariat:

Department of Environment & Land Management
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Contents

1. Role of MEPC in South Australia

The Environmental Protection Council is a Statutory Body (Act of 1972) charged with advising the Minister on very broadly defined matters concerning protection of the environment.

The Marine Environment Protection Committee was established as a subcommittee of EPC under the Marine Environment Protection Act 1990, with duties to advise the Minister on his/her functions under that Act, namely (and informally expressed):

> *Objects*: protect marine environment; see that polluters monitor and pay; waste minimisation
> *Functions of Minister:* review condition of marine environment; research, public education; concern with terrestrial surface waters that impact on sea; promote public awareness & commitment to protection of marine environment; integrate and coordinate Government policies that affect marine environment...consult with other relevant Ministers, etc.

The MEPC has membership representing conservation interests (including a nominee of the Conservation Council), industry (including the fishing industry), local government and expertise in marine environmental research. Its agenda papers and minutes are available to the public.

Most of the Committee's work prior to the date of the spill had concerned statutory instruments for licensing of point sources under the Act.

The government intends that the MEP Act will be repealed by a new Environment Protection Act establishing an Environment Protection Authority, and its functions taken into the new Act. I comment below on possible functions of the EPA in regard to events such as this oil spill.

In the present case, the MEPC became involved because of its duties to advise the Minister on reviewing the condition of the marine environment and on integrating and coordinating Government policies that affect marine environment, consulting with other relevant Ministers, etc.

2. No comment on cause of spill

Although MEPC was briefed on the events that led to the spill it did not concern itself formally with those events nor with the procedures followed. Nor does it wish to comment on the cleanup procedures, though it certainly followed them closely. It took an active interest, however, in the ecological effects of the spill.

3. MEPC was informed of the event

The MEPC has no executive function in events such as this, but I was notified, for information, on the day after the spill occurred, and told what immediate action was being taken both in the response procedures and by Government officers of the then DEP to inspect the area.

It was clear that DEP (Marine Unit and NPWS) and the Fisheries Department were involved, actively in the field, in assessing the ecological impact of the spill and in the cleanup and bird rescue; these are agencies long identified with a responsibility for the health of the marine environment (*inter alia*) and MEPC maintained a watching brief initially.

4. A coordinating role: formation of the Reference Group

The suggestion came from SANTOS, supported, I believe, by all the agencies mentioned above, that there was a need for (a) coordination of the studies already being commissioned to examine the effects of the spill and (b) some independent assessment of whether those studies were adequate. It was suggested that because of its role in advising the Minister on the coordinating and integrating functions under the Act, MEPC could take that coordinating role.

The MEPC, at its 15 September meeting, agreed with this suggestion. The matter was seen as being very urgent, because there was public concern at the effects of the spill and because monitoring should be initiated immediately. MEPC authorised me to chair a Reference Group which would have the status of a subcommittee of MEPC; MEPC has subsequently been provided with minutes of the Reference Group and has endorsed its decisions.

5. Composition of the Reference Group

The Reference Group included representatives of those agencies already involved in ecological monitoring of the effects of the spill (as they were then, SADF, DEP (Marine Unit), DEP (NPWS)) and those who had expressed concern that monitoring should be coordinated urgently (SANTOS Ltd and DME, both of whom had offered to contribute funds for the monitoring; SANTOS had already commissioned some monitoring at its expense); after the first, urgent meeting Mr Lou Zollo, Secretary to the MEPC, served as secretary and at a later date Capt. J. Page (DMH) was informed of the Reference Group and invited to attend meetings. Membership of the Reference Group is:

Dr Alan Butler	(MEPC; Chair)
Mr Lindsay Best	(DELM - NPWS)
Ms Iris Dobrzinski	(DME)
Mr John Johnson	(DPI - Fisheries)
Mr Oleg Morozow	(SANTOS Ltd)
Mr Brian Wagstaff	(DELM - Marine Unit)
Captain John Page	(DMH)
Mr Lou Zollo	(MEPC; Secretary)

The Reference Group met on 17 September and on six subsequent occasions. At its first meeting it set itself the following terms of reference:

1. to determine the impacts of the oil spill
2. to establish and coordinate the monitoring program
3. to identify sources of funding for the study
4. to receive and coordinate the reports on findings, collate the results and report them to the MEPC, which will report to EPC and thence to the Minister for Environment and Land Management.

6. Nature of the monitoring task in marine waters

Since there is some public concern as to whether enough has been done to determine the effects of the spill, it is important to comment on this as a scientific problem.

Any monitoring, including that of the effects of such an accident, looks for changes in biological variables, such as numbers of certain kinds of organisms, or measures of their physiological states or functioning. It must be recognised that (1) these quantities are highly variable, naturally, and (2) their natural values and ranges of variation not often well documented. The problem of detecting an effect from a possible perturbation (e.g., an oil spill) is thus very difficult.

This general problem has been extensively addressed in the scientific literature and in a number of recent specialist meetings and some rigorous advice can be assembled. The gist of that advice is that it is essential to have both "before" and "after" information, and to monitor, as well as the site of the event, a number of "control" sites not impacted by the event, and that the intensity of sampling and the frequency and the time-period over which it is done need to be appropriate.

It is important to understand that, because of the natural variability in the system, the interpretation of the data will always be in the nature of gambling - making decisions in the face of uncertainty. The costs of drawing the wrong conclusion *in either direction* (concluding there is an effect when there really is not, *or* concluding that there is no effect when in fact there has been one) could be high. To reduce the risks of these two kinds of errors to acceptably low levels is likely to require intensive and therefore expensive sampling - and in some cases actually to raise the question whether the sampling itself is doing more damage than it is worth.

7. Approved Monitoring Program

The Reference Group, considering the problem of assessing the effect of the spill, was aware of the considerations mentioned under 6. There were no "before" data except what existed as a result of studies done, for other reasons, in the area (but not at the exact site). The logical difficulty in assessing the effect of the spill was highlighted by the exceptional flow of freshwater from the land, especially down the flooded Broughton River, shortly after the spill; thus, without a very sophisticated "before-after-control-and-impact" study, the effects of the spill would not be distinguishable from the effects of the floods except regarding certain organisms obviously impacted. The Reference Group therefore focussed on such organisms, plus some that were of particular political or economic concern.

The Reference Group agreed upon a program of monitoring, some components of which were commenced very soon after the spill before the formation of the Reference Group, and the last of which were commenced in November. The components and the agencies conducting them are:

i. Fate-of-hydrocarbons study - the rate at which and manner in which oil breaks down and disperses in the mangrove and samphire areas was seen as the highest priority item because of its utility in future and because it is more validly achievable than some other possible programs. This was done by a consultant to DELM, Mr John Wardrop of AGC Woodward-Clyde. This component was not commissioned until it became clear that the cost could be met. It began in November.

ii. Birds - recovery of cormorant colonies over two or more years. DELM-NPWS (Mr Lindsay Best) is doing this work.

iii. Juvenile prawns & fish in shallow areas near mangroves - although the technical difficulties mentioned under 6. are serious here, these organisms were nevertheless included in the program because of their commercial importance and the concern expressed about effects of the spill on their feeding and nursery areas. Sampling is being done by SARDI-Fisheries staff (Ms M. Kangas, prawns & Dr K. Jones, scalefish).

iv. Mangrove monitoring - mangroves and saltmarsh (samphire) communities are considered important in the ecosystem of the gulf and some plants had clearly been oiled; thus, again despite technical problems in interpretation, the Reference Group considered it necessary to monitor the health and recovery of mangrove and samphire plants. Mangroves are being monitored by SARDI-Fisheries staff (Dr K. Edyvane), with some additional observations from the AGC Woodward-Clyde team.

v. Gross changes in samphires and mangroves (photopoints) - soon after the oil came ashore, SANTOS commissioned Mr D. Wiltshire to set up six permanent photopoints to record visually the fate of samphire and mangrove plants. The first photos were taken on 17th September.

vi. Benthic samples were trawled on the bottom in deep water in the Gulf during the first days after the spill, by SADF in collaboration with Prawn Fishers. Samples of sediment, flounder and prawns were taken on a series of transects away from the path of the spill and frozen to be analysed for hydrocarbons.

vii. Taint testing of prawns. Samples were taken by Fisheries Research Vessel *Ngerin* in late October from two areas along the path of the slick, one near Point Lowly and the other close to where the oil came ashore, 8-10 km north-west of Sixth Creek. They were tested for taint by an experienced panel convened by SEA, who had developed a blind-tasting procedure in earlier studies of possible effects of the operations at Port Bonython. Prawns from Spencer Gulf were compared with prawns from Western Australia (panellists not knowing which was which).

viii. Seagrasses and associated fauna - Mr R. Connolly (Adelaide University, Zoology Department) was engaged as consultant to examine the effects on seagrass just offshore from the impacted mangrove areas, and on animals associated with seagrass. This component, like the AGC Woodward-Clyde work, was not commenced until funding was assured.

ix. Aerial photography - Immediately after the spill, in September 1992, the then S.A. Department of Lands were contacted by the State Committee of the National Plan to take colour and infra-red photography of the mangrove area to the south west of Port Pirie. This survey was repeated in February 1993. The first survey was used by monitoring teams to locate areas of impact for more detailed work.

x. Other matters. The Reference Group has been informed of other measurements which were not commissioned or discussed by it, so it has no information about the mode of collection, handling of samples, etc., but it is nevertheless glad to have been informed of the results.

Samples of damaged crabs and fish were brought in by various people and handed to SARDI-Fisheries for testing for hydrocarbons. The Reference Group has been informed of the analytical results.

Certain physiological and biochemical aspects of mangroves are being examined by Dr S. Tyerman (Flinders University, Biological Sciences) and biochemical indicators in fish by Dr J. Wiskich and Ms K. Bellette (Adelaide University, Botany Department) and their progress reported to the Reference Group by Dr Edyvane.

8. Funding

The total cost of the program was estimated as $120,000. Most components of the program began with support in cash or personnel time from SANTOS, Department of Mines and Energy, DPI (Fisheries - then SADF), the Marine Unit and NPWS of DELM (then DEP) and we approached the then Minister of Environment and Planning (and through her, if she saw fit, other relevant Ministers) as well as the insurers of the vessel, for additional contributions to the cost of the full program. The change in the Ministry intervened but on 12 November I met with the new Minister of Environment and Land Management who stated that the program should go ahead without delay and indicated that his staff would arrange approaches to other governmental and private-sector agencies for contributions towards the costs. These approaches eventually resulted in the contributions listed below, and then the final components of the program could begin. I would like formally to record the gratitude of all concerned, already publicly expressed by the Minister, for these contributions.

	$
BP Australia	10,000
Howard Smith Industries	10,000
SANTOS	10,000
DME	10,000
Adelaide Steamship Co	5,000

SANTOS also commissioned a photopoint survey, at a cost outside the abovementioned funds.

The funds from non-governmental contributors will be used only for the cost of outside consultancies. Other costs are being absorbed by Government Departments, viz. DPI and DELM.

9. Results to date

The study is necessarily long-term. For example, the effect on seabird rookeries needs to be assessed by estimating breeding numbers in several breeding seasons (one per year, the first of them only occurring about now); oiled, and apparently dead, mangroves have been known to recover many months later, and the opposite has also been recorded, so mangrove monitoring needs to be long-term. Therefore, the Reference Group has only received interim results to date.

The Reference Group received status reports from seven of the component studies at or just after its 7th meeting on 11th March, 1993. These are held by the Secretary of MEPC and summarised below. For future reference, they are numbered here, and listed below.

i. Fate of hydrocarbons. As well as simply studying the extent and severity of oiling, Mr Wardrop recorded any gross damage to mangroves; his report is thus complementary to that of Dr Edyvane, iv. below. Because the study could not commence until late November, his report, Paper 1, describes the distribution and nature of *residual* oil after almost 12 weeks and attempts to infer the original degree of oiling. It also deals with the degree of weathering of residual oil. Likely long term effects are postulated and recommendations made regarding future monitoring, cleanup and response.

Oiling occurred over a 15 km front with oil passing through sparse fringing mangroves and impacting mangroves and sediments approximately 50 m from the Gulf fringe. This resulted in oil being deposited in mallee-form mangroves in front of the dense, tall inner mangroves.

Approximately 75-100 hectares of mangrove swamp were oiled, of which less than 5 hectares still exhibit heavy oiling. Mangroves in the region cover approx. 20 km^2 (2000 hectares).

In some areas oiling is associated with deep depositions of seagrass debris. It is postulated that this oil is relatively mobile and is the source of brown oil films and sheen which continues to pass through the lower elevation of the swamp channels and creeks. Some sediment samples showed the presence of light hydrocarbon fractions, characteristic of diesel oil. The source of these is thought to be this seagrass debris.

Oil residues on sediments form continuous tarmats in some areas. These are weathered and unlikely to be the source of chronic oiling of adjacent areas. The consolidated tarmats may prevent successful recolonisation of defoliated areas. Defoliation is occurring in heavily oiled areas and numerous trees appear "dead", i.e., all leaves are brown. Such areas cover approximately 23 hectares. Recovery of totally defoliated trees has been observed in other spill studies, although such recovery may take years. The consultant recommends that apparently-dead trees or areas should continue to be monitored.

Moderately oiled areas (approximately 5.5 hectares) exhibit some leaf damage in mangroves but recovery is expected.

Lightly oiled areas are expected to show limited effect, probably loss of oiled leaves. This may result in the loss of a significant proportion of canopy in smaller trees and tree death may occur over time in these lightly oiled areas. Overall, effects are expected to be small and recovery rapid.

Generally, community recovery is expected to occur in all areas except those characterised by heavy oiling of sediment or extensive deposition of oily seagrass wrack. Death of individual trees or saplings is likely to occur in all areas but should be significant only in the heavily oiled areas.

It is recommended that recovery of the community should be monitored and documented.

It is particularly recommended that the weathering behaviour and distribution of residual oils should be monitored, particularly the oil associated with seagrass wrack. This oil could, potentially, be remobilised and constitute a source of pollution to adjacent swamps and waters.

ii. Birds. The DELM, Biological Conservation Branch, is monitoring the breeding success of Pied Cormorants, the most commonly oiled species of bird during this spill (Paper 2). There are historical data on sites and numbers of this species breeding to the north and south of the spill area. DELM staff have established that colonies can be surveyed and nesting numbers estimated from the air. Pied Cormorants are nesting to the north and south of the spill area. Breeding colonies within the impacted area have been abandoned, but a new breeding colony has been established close by to the south of Fisherman's Creek. How these changes have affected the annual production of the species in Spencer Gulf has not yet been determined.

iii. Juvenile prawns & fish in shallow areas near mangroves. Paper 3 concerns mainly juvenile fish. It details methods used and the layout of the sampling. Eleven sites were sampled inside creeks and 12 at entrances to creeks, ranging from Fisherman's Creek in the south to Second Creek in the north. Thus, some sites are considered "control" sites (i.e., relatively far from the oiled areas) and others "affected" (near to or in oiled creeks). Sampling was done in September, November and February. Species caught are listed and data on numbers caught are presented. Although there appear to be some small differences between "control" and "affected" areas, the data are still being statistically analysed and it is too early to draw any conclusions as to the effects of the oil spill on the fish community.

iv. Mangrove monitoring. SARDI-Fisheries staff are examining effects on mortality, recruitment, phenology, leaf loss, and pneumatophore density (Paper 4). In addition to a random survey of oiled and non-oiled mangroves on 50-m belt transects, seedlings, saplings and mature trees have been tagged in oiled and non-oiled areas. The report covers visits in October, November and December. On the visits reported, large-scale leaf loss was not observed, but it was too soon to expect it; it has been observed on other, later survey visits (e.g., fish, fate of hydrocarbons) and will presumably be found in the March scheduled survey. Leaf curling, chlorosis and blackening has also been observed by this and other teams, and not always on obviously-oiled plants. However, it is too soon to interpret the data on mangroves in detail.

v. Gross changes in samphires and mangroves (photopoints). The Reference Group has received three sets of photos, taken 17 September, 27 October and 27 January (Papers 5,6,7). The initial photos showed heavily oiled samphire patches (area *ca.* 4 - 100 m^2), small mangroves completely oiled, and larger ones oiled up to 1.5 m above ground. Later surveys have shown a substantial re-shooting of the samphires, some juvenile mangroves having shed oiled leaves and produced new shoots, but other juveniles apparently having died; some larger trees have shed oiled leaves and are shooting new ones, but others still show little change. As noted above, it is too soon to draw final conclusions about the fate of these oiled plants.

vi. Benthic samples trawled in Gulf during the first days after the spill are mostly stored frozen. The Reference Group has received a report from State Chemistry (Paper 11) on analysis of sediment samples. None of the samples contained any hydrocarbons characteristic of bunker fuel (ex *Era*) at a concentration exceeding 0.5 Êg/g.

vii. Taint testing of prawns. The report from SEA is Paper 8. Only one prawn in the entire set of 128 tasted was scored "unsure but possibly tainted" by one panellist. All others were scored "not tainted" and in a statistically highly significant majority of cases the Western Australian prawn was considered inferior to the Spencer Gulf one. This panel has been trained and "calibrated" in the past, and would have detected faint traces of hydrocarbon taint, if present. Ideally, prawns from Spencer Gulf (but far from the spill area) would have been preferable over the WA prawns as controls, but the clear result is that no tainting by hydrocarbons was detected. It is unlikely that prawns in the region have become tainted in a way that would affect their acceptability in the market.

viii. Seagrasses and associated fauna. Mr Connolly has submitted two interim reports, Papers 9 & 10. Patches of blackened eelgrass were noted on the first visit, and sampling was designed to compare eelgrass, and fauna associated with it, in blackened vs. non-blackened patches, and also in areas adjacent to vs. far from locations where oil had been deposited ashore. Blackened patches were more common near heavily oiled areas of the shore, but did also occur outside what had been considered the oil-impacted area. Discoloured patches had lower above-ground biomass than green patches. Fauna collected from the seagrass are still being counted, measured and identified. Whilst the results suggest that the blackening (and foliage loss) of seagrass is associated with heavily oiled areas, there is doubt about how far the influence of the oil may have extended, and so the next sampling (in March) was done on a greatly expanded scale.

ix. Aerial photography. The first survey (No. 4560) provided an immediate baseline of the impact of the oil ten days after the spill. It proved difficult to detect the impact site at the photo scale of 1:25000, not because oiling cannot be detected in photographs, but because the extent of the oil was small relative to the area of vegetation surveyed. At this scale, each photo shows about 6 km of coast and there is between 25 and 30 km of mangrove coast. The spill shows as a narrow, intermittent black band, with a maximum length of 600 m at two sites. The total length of coast affected is about 6 km.

The first survey was used by monitoring teams to locate areas of impact for more detailed work on the ground.

The survey was repeated in February 1993 (No. 4635); this showed no significant changes. The infra-red photos can be used to detect unhealthy vegetation (e.g. trees with dying leaves), and this can be confirmed by ground teams. The extent of damaged vegetation shown in the photographs in this case, like the extent of the oil itself, is small compared with the area of the mangroves. The interpretation of the aerial photographic results to date is that no drastic or widespread impact has been detected. It is proposed to fly another survey in September 1993, particularly to monitor the condition of the vegetation.

x. Other matters not discussed by the Reference Group.

Mangrove physiology. Dr Edyvane's report outlines work done by the Flinders University team on photosynthesis and ion balance of oiled and non-oiled mangrove trees but results have not yet been analysed and field work continued on the March visit.

Fish enzymes. Dr Edyvane's report outlines work being done by the Adelaide University Botany Department group on mixed-function oxidases in fish from oiled and non-oiled areas; this work is continuing and results are not yet available.

Hydrocarbon analyses of crab samples. Blue crabs had been collected by a local crab fisher near Pt Lowly, showing "holes" or deterioration of the carapace. Various body parts of these crabs were analysed by the State Chemistry Laboratories at the request of DPI-Fisheries, and Paper 12 states that hydrocarbons in the range C11 to C20 were not detected in any of the samples at a detection limit of 0.5 Êg/g (and in later samples 0.25 Êg/g). A small number of fish were also included, with the same result.

Dispersants used. MEPC received on January 20, 1993 a briefing paper (Paper 13) on this topic. COREXIT 9527 and COREXIT 7664 were used on August 30 and ARDROX on August 31. Paper 13 notes the composition of these mixtures. Ardrox and various formulations of Corexit have been tested for toxicity overseas and in Australia (in the Victorian Marine Science Laboratories and at James Cook University). The available data indicate that the toxicity of these substances is acceptably low. In discussion in MEPC it was made clear that the widespread belief that dispersants are more harmful than oil is based on the kinds of dispersants used long ago (e.g. in the *Torrey Canyon* spill).

Recent observations. At its March meeting, MEPC noted reports that fishers have not seen recovery of stocks of pelagic fish, particularly garfish, in the spill area.

10. Likely timings of further results

Some components of the study should run for at least several years, albeit at a low intensity after the initial period. Results will be reported to the Reference Group as they come to hand.

11. Recommendations for the future

i. Funding

Whilst it is established that those responsible for a spill of this sort are responsible for costs of the cleanup and identifiable economic losses resulting from the spill, the costs of monitoring the effect on the marine ecosystems are not currently provided for under the National Plan.

The MEPC thinks that they should be. One reason for this is the stated intention under the National Plan to keep the technology under review and to use the best, and least environmentally damaging, technology for managing oil spills (Capt. J. Page, personal communication). Clearly, technologies cannot be evaluated unless there is monitoring of the effects of a spill and its cleanup on the ecosystem.

The MELM has already received the MEPC's advice that representations should be made in relevant forums (notably ANZECC) for the National Plan to be amended to include monitoring, perhaps by a small increase in the levy on shipping which has not been raised for some years.

More generally, MEPC considers that the new EPA should maintain a fund for the purposes of such emergency monitoring; we have said this in commenting on the draft EPA Bill and to the Minister.

ii. Speed of response and effective coordination

There are currently several agencies with responsibilities for the "health" of marine ecosystems, notably DPI-Fisheries and DELM (Marine Unit and Biological Conservation Branch), and the MELM has functions under the MEP Act which it was intended would lead to monitoring programs (funded by the Marine Environment Protection Fund) of a "State of the marine Environment" nature, but not necessarily an "event-monitoring" nature. Whilst these agencies acted promptly in this case, there was little coordination of their activities, because there was no single agency charged with ensuring that the relevant monitoring was done nor, for that matter, with taking the potentially difficult decisions that certain things, perhaps of concern to pressure groups, need *not* be done.

In short, there is, for environmental monitoring, nothing like the system devised for the initial response and cleanup. There is no contingency plan and no chain of command.

MEPC was called in to take a coordinating role, which it attempted to do, but (a) this was after a number of components had already been commenced, and (b) MEPC is an advisory Committee to the MELM and has no powers directly to commission work and commit resources, nor any powers to instruct agencies; all it could do was to attempt to facilitate agreement between the resource departments to ensure that the required work was done. In doing this it was in effect, because of the urgency, carrying out part of its Minister's function under the Act in "integrating, consulting...". Thus the present system simply cannot respond quickly.

MEPC believes that the EPA, when established, will be an appropriate body to respond quickly and to *both initiate and coordinate* studies of environmental impacts of environmental accidents. The Committee believes EPA should be given the duty, and the necessary powers, to do so, and (as noted above) that it should hold a reserve fund to enable it to act without waiting to determine responsibility for the costs.

III. Specific recommendations for future oil spills

Recommendations for monitoring of future spills (should they come ashore in a mangrove area as in this case) are included in the report of AGC Woodward-Clyde (Paper 1). In outline, they are to use aerial photography early, to determine the location and extent of the oiling, to get people experienced in the behaviour of oil itself on site as early as possible, and have them advise on the location of other components of the monitoring. In the present case, those doing mangrove-tagging, seagrass sampling etc., had some difficulty deciding on the best sampling layout (and made somewhat different decisions from one another, some of those decisions being amended in light of experience on the first field visits).

List of reports received by Reference Group to March 1993

1. John A Wardrop, Brian Wagstaff, Rod Connolly, & John Leeder. *The distribution and persistence of petroleum hydrocarbons in mangrove swamps impacted by the "Era" oil spill (September, 1992).* AGC Woodward-Clyde, Report 5182 to Environmental Protection Council.

2. Memo to Lou Zollo from Lindsay Best dated March 8, 1993, Subject: *Monitoring of Impacts of Oil Spill* concerns monitoring of breeding colonies of Pied Cormorants.

3. G.K Jones (SARDI-Fisheries) and R. Connolly (Dept. of Zoology, University of Adelaide) *Port Pirie Oil Spill Survey - The effect of the oil spill on the fish community and recruitment and growth of economically important 0 gp fish in the mangrove creek ecosystem.*

4. K.S. Edyvane (Fisheries (SARDI)) *Progress report on the biological monitoring of the Port Pirie mangrove ecosystem following the Spencer Gulf oil spill.*

5. SANTOS Ltd. *Port Bonython Oil Spill Photo-point Monitoring.* Prepared by Social and Ecological Assessment Pty Ltd. September 1992.

6. SANTOS Ltd. *Port Bonython Oil Spill Photo-point Monitoring (Survey 2).* Prepared by Social and Ecological Assessment Pty Ltd. October 1992.

7. SANTOS Ltd. *Port Bonython Oil Spill Photo-point Monitoring (Survey 3).* Prepared by Social and Ecological Assessment Pty Ltd. February 1993.

8. DEPARTMENT OF PRIMARY INDUSTRY (FISHERIES). *Port Bonython Oil Spill Prawn Taint Assessment.* Social and Ecological Assessment Pty Ltd. November 1992.

9. Connolly, R. (University of Adelaide, Department of Zoology) *Effect of Oil on Seagrass - Port Pirie.* January 1993.

10. Connolly, R. (University of Adelaide, Department of Zoology) *Effect of Oil on Seagrass - ERA Spill. Preliminary Report on Sampling in Dec 1992.* March 1993.

11. Fax from Acting Director, State Chemistry Laboratories to Mr M Clark, Dept of Fisheries, Sept. 30 1992. Re: *Analysis of sediment samples.*

12. Letters from Director of Fisheries to Dr A. Butler dated 22 December 1992 and 4 January 1993 enclosing Minutes from Acting Director, State Chemistry Laboratories to CEO, DPI (Attention Dr K Edyvane, Fisheries Branch), November 24, December 14 and December 22, 1992; Subject, *Analysis of hydrocarbon residues in crabs and fish.*

13. Environmental Protection Council, Marine Environment Protection Committee. Briefing paper by Ian Kirkegaard, Executive Officer, agenda item 4.4, meeting 23, January 20 1993. *Dispersants used in "Era" oil spill (Port Bonython 1992).*

Abbreviations used in the Report

ANZECC	Australian and New Zealand Environment and Conservation Council
DELM	South Australian Department of Environment and Land Management
DEP	South Australian Department of Environment and Planning
DME	South Australian Department of Mines and Energy
DMH	South Australian Department of Marine and Harbors
DPI - Fisheries	South Australian Department of Primary Industry - Fisheries Division
EPA	Environment Protection Authority
EPC	Environmental Protection Council
MELM	Minister of Environment and Land Management
MEP Act	Marine Environment Protection Act 1990
MEPC	Marine Environment Protection Committee
National Plan	National Plan to Combat Pollution of the Sea by Oil
NPWS	National Parks and Wildlife Service
Reference Group	The Oil Spill Reference Group established under MEPC to coordinate monitoring of the effects of the *Era* oil spill
SADF	South Australian Department of Fisheries
SARDI - Fisheries	South Australian Research and Development Institute - Fisheries Division
SEA	Social and Ecological Assessment Pty Ltd

THE DISTRIBUTION AND PERSISTENCE OF PETROLEUM HYDROCARBONS IN MANGROVE SWAMPS IMPACTED BY THE "ERA" OIL SPILL (SEPTEMBER, 1992)

ENVIRONMENTAL
PROTECTION
COUNCIL

John A Wardrop
Brian Wagstaff
Rod Connolly
John Leeder

ENVIRONMENTAL PROTECTION COUNCIL

THE DISTRIBUTION AND PERSISTENCE OF PETROLEUM HYDROCARBONS IN MANGROVE SWAMPS IMPACTED BY THE "ERA" OIL SPILL (SEPTEMBER, 1992)

Prepared by

Woodward-Clyde

Report 5182

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SUMMARY

This report details the findings of a field survey, in November 1992, of mangroves impacted by oil spilled from the "ERA" at Port Bonython. The oiled mangroves lie southwest of Port Pirie and most oil beached between Sixth Creek and Fourth Creek.

The objectives of the study were to determine the extent and degree of residual oil and to ascertain the original degree of oiling. The degree of weathering of residual oil was also determined. Any gross damage caused by the oil was recorded and baseline data was recorded. This data is not intended to constitute a detailed assessment of biological effects but rather to relate the degree of oiling to gross effects on mangrove trees and their distribution. Likely long term effects are postulated and recommendations made with regards future monitoring, cleanup and response.

Oiling occurred over a 15 km front with oil passing through sparse fringing mangroves and impacting mangroves and sediments approximately 50m from the gulf fringe. This resulted in oil being deposited in mallee-form mangroves in front of the dense, tall inner mangroves.

Approximately 75-100 hectares of mangrove swamp were oiled of which less than 5 hectares still exhibit heavy oiling. Mangroves in the region cover approximately 20km^2 (2000 hectares).

In some areas oiling is associated with deep deposits of seagrass debris. It is postulated that this oil is relatively mobile and is the source of brown oil films and sheen which continue to pass through the lower elevations of the swamp, channels and creeks. Some sediment samples showed the presence of light hydrocarbon fractions, characteristic of diesel oil. The source of these is thought to be this seagrass debris.

Oil residues on sediments form continuous tarmats in some areas. These residues are weathered and consolidated and unlikely to be the source of chronic oiling of adjacent areas. The consolidated tarmats may prevent successful recolonisation of defoliated areas by seedlings. Defoliation is occurring in heavily oiled areas (approx 4 hectares) and numerous trees appear 'dead' ie. all leaves are brown or black. Such 'dead' areas cover approximately 23 hectares. Recovery of totally

defoliated trees has been observed in other spill studies, although such recovery may take years. Apparently dead trees or areas should continue to be monitored.

Moderately oiled areas (approx 5.5 hectares) exhibit some leaf damage in mangroves but recovery is expected.

Lightly oiled areas are expected to show limited effect, probably loss of oiled leaves. This may result in the loss of a significant proportion of canopy in smaller trees and some sapling death may occur over in these lightly oiled areas. Overall, effects are expected to be small and recovery rapid.

Generally, community recovery is expected to occur in all areas except those characterised by heavy oiling of sediment or extensive deposition of oily seagrass wrack. Death of individual trees or saplings is likely to occur in all areas but should be significant only in those heavily oiled.

Recovery of the community should be monitored and documented.

The weathering behaviour and distribution of residual oils should be monitored, particularly the oil associated with seagrass wrack. This oil can, potentially, be remobilised and constitute a source of pollution to adjacent swamps and waters.

1.0
INTRODUCTION

1.1 THE "ERA" OIL SPILL

On Sunday August 30th, 1992 the oil tanker "Era" was involved in a collision with the tug "Turmoil". The accident occurred at the head of the Port Bonython jetty (Figure 1) during the final stages of berthing (Report DMH 1594/92).

As a result of the collision an estimated 296 tonnes of oil was released into gulf waters. The oil was a blend of diesel oil (diesoleum), and heavy residual oil.

Reportedly, most of this spilt oil was carried around Lowly Point into Upper Spencer Gulf although it was later drawn south, under tidal influence, into Germain Bay. No coastal impact on Upper Spencer Gulf coastlines was reported (B. Wagstaff).

Chemical dispersants (Corexit 9527 & Corexit 7664) were applied to the slick within two to three hours, from vessels, and Ardrox dispersant was applied the following day using fixed-wing aircraft. A total of approximately eight tonnes of dispersant were used.

Oil remained in Germain Bay and attempts were made, by the relevant authorities over the next two days, to collect it. These efforts were hampered by deteriorating weather conditions and, eventually, some oil did impact the shoreline.

Coastal impact was largely restricted to a landfall between Fourth Creek and Sixth Creek, southwest of Port Pirie (Figure 1). This coastline is characterised by extensive intertidal sandy mudflats up to 1 km wide, merging with sparse to dense mangrove shrublands (*Avicennia marina*). The intertidal flats and associated shallows are characterised by patches of seagrass (*Zostera marina - Heterozostera tasmanica*). Numerous creeks extend inland, the larger to supratidal samphire swamps (*Sarcornia spp - Halosarcia spp*). Creeks and channels are also characterised by seagrass although the distribution of these is variable.

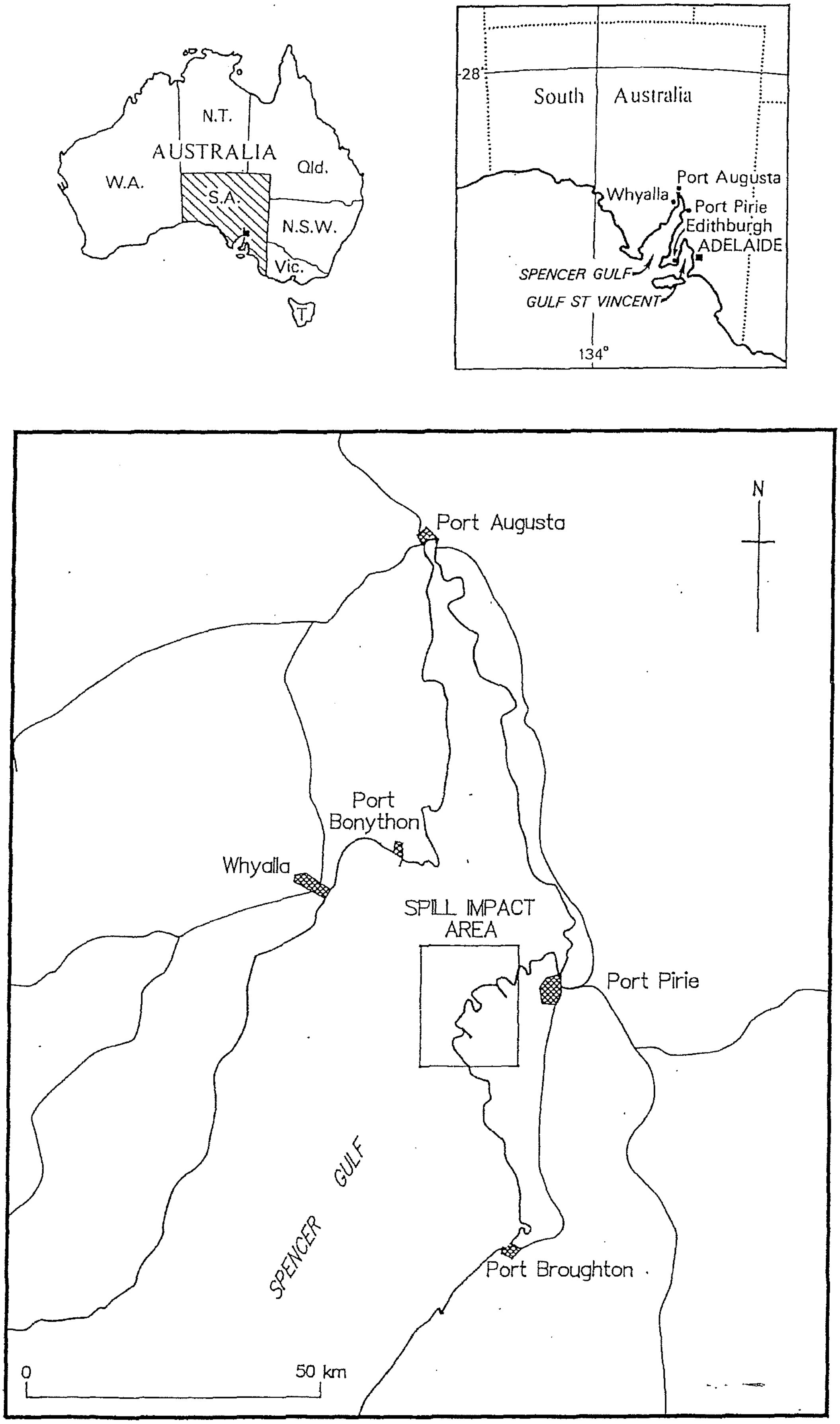

FIGURE 1 MID-SPENCER GULF SHOWING PORT BONYTHON, PORT PIRIE AND OIL IMPACTED COASTLINE

The length of oiled coastline was initially estimated at between twelve and fifteen kilometres (B. Wagstaff). In addition, the mangroves and samphires along Fifth and Sixth Creeks were oiled, with a lesser impact along Fourth Creek. A number of minor creeks were also oiled.

The precise time of the impact is not known, but occurred overnight between Tuesday, September 1, and Wednesday September 2; two to three days after the initial spillage.

No impact of oil on seagrass areas was reported.

The circumstances of the spill have been the subject of two enquiries. One, into the causes of the collision, was undertaken by the Crown Solicitor's Office. The second was undertaken by the South Australian State Committee of the 'National Plan', and investigated the spill response. Other aspects of spill planning and response are the subject of an enquiry by the Parliamentary Environment, Resources and Development Committee. These matters will not be addressed in this report.

1.2 STUDY OBJECTIVES

The principal objective of this study was to determine the extent and severity of the oiling of the mangrove swamp which resulted from the "Era" spill. It was intended that this investigation be undertaken within days, or at most weeks, of the spill.

However, the survey was undertaken between 24th and 27th November, 1992, almost twelve weeks after the spill. Consequently, the objective actually pursued was to determine the distribution and nature of any residual oil.

Post spill studies have shown that oiled leaves will continue to show staining from dark oils for several months and that stains on branches and trunks may continue to indicate the passage of oil for some years. Oil on sediment surfaces may, however, be rapidly removed and so the absence of residual oil on surface sediments is no guarantee that oil did not impact these (Wardrop and Wagstaff, in press).

Consequently, the initial distribution of oil has been postulated on the basis of this (November, 1992) survey and also on aerial surveys (visual and photographic), undertaken in early September by spill response personnel. However, such remote surveying techniques cannot detect oil on sediments below a closed canopy. This, together with tidal flushing effects make these initial estimates conservative.

In addition to these objectives, the survey aimed to determine the chemical and physical character of residual oil. This information was used to determine the degree and extent of oil weathering that had occurred; both physical and biological. Probable future persistence or mobility of the oil was also be estimated.

This, in turn, is used to assess any possible future effects of the oil and the probability of community recovery.

TABLE 1 SUMMARY OF STUDY OBJECTIVES

- **To determine the distribution, and degree, of residual oil in impacted mangroves.**
- **To determine the probable distribution, and degree, of initial oiling of mangrove swamps.**
- **To determine the chemical and physical character of residual oil, ie :**
  - **degree of weathering (physical)**
  - **extent of biodegradation**
- **To assess the potential for residual oil to affect the mangrove swamp or other, associated habitats.**
- **To assess the possible influence of residual oil on the recovery, or non recovery, of individual mangroves or sections of the community.**

Initially, it was not intended that biological effects data would be obtained by this study since this was to be the subject of a separate programme undertaken by the South Australian Department of Fisheries (SADF). However, in view of the limited information available from SADF, and the apparent study design adopted, it was decided that some biological data would be required. This decision was made, on site, after the preliminary ground survey and an inspection of SADF study sites. The biological effects data collected is intended to relate specifically to those mangrove plants within the sediment sampling sites. As such it will enable a direct and valid comparison between data on oil retention and character with that relating to effects on mangroves and tree and community recovery.

Study methods are described in Section 2.

2.0
STUDY METHODS AND RATIONALE

The study programme was designed so as to provide precise, reliable data relating to the distribution and character of oil remaining within the swamp, and to allow prediction of the future potential for oil mobility or effect on the area.

The study was limited by budget and time. The level of chemical analysis undertaken was particularly constrained by budget considerations.

Selection of suitable "control" sites is difficult in post-spill studies. In principle, the comparability of 'test' and 'control' sites should be established before an event (in this case, the spill) occurs. This is rarely, if ever, possible for oil spills. Consequently, it is necessary to locate areas which are 'impacted' to a variety of degrees, and to find comparable unimpacted 'control' sites. However, much of the data needed to establish comparability between impacted and control sites has been affected by the oil. For example, leaf fitness data such as degree of insect or fungal damage etc.

Each of the creeks and swamp sectors in the region have particular features which differentiate them from the others. Second Creek, for example, receives effluent from the Port Pirie common effluent (sewage) plant and First Creek receives industrial effluent from BHAS (lead, zinc plant). Differences in sediment type, catchment, and exposure to tidal flows are also evident. Port Davis Creek, the largest creek of the complex, is the main outlet for the Broughton River which, at the time of the spill, was in an almost unprecedented flood.

Such variability makes the selection of 'control' sites difficult, even in the absence of oiling. This variability is, as noted in Section 1.2, one reason for the collection of biological data linked closely with sediment sampling sites.

Control site selection is further complicated by the fact that the absence of visible oil on trees or sediment does not necessarily indicate an absence of initial impact, or later impact, by sheen or remobilised oil.

In view of these difficulties and the time, and other constraints, it was decided that no strict controls could be sought. Rather, the approach adopted was to select 'representative' sites within the general impact zone and to monitor changes at each of these over time. These changes will then be correlated to the degree of oiling and persistence of oil in sediments or on trees. Since broader biological data was to be the subject of the SADF study programme and the prime focus of this study was on the oil, such an approach was considered valid and efficient.

The sites selected represented a range of degrees of oiling, which can be correlated with the biological data obtained by this study.

The study approach adopted consisted of four components :

- Reconnaissance Survey
- Study Site Establishment and Sediment Sampling
- Chemical Analysis and Oil Characterisation
- Biological Effects Studies

These are detailed in the following sections.

2.1 RECONNAISSANCE SURVEY

These surveys were undertaken in order to ascertain the extent of any oil impact and to assess the range in degree of oil impact in the swamps. Surveys were undertaken in four phases:

1. Pre-Field assessment
2. Initial ground survey (Fifth Creek-Sixth Creek)
3. Boat survey (Third Creek to Seventh Creek)
4. Second ground survey (Third Creek to Fifth Creek)

These are discussed below.

2.1.1 Pre-Field Assessment

A number of photographs of coastal impact were taken at the time of the oil spill by the Scientific Support Coordinator during helicopter reconnaissance flights together with sketch maps and notes. These were examined and approximate locations of the photos were assigned. The allocation of photographic position was greatly facilitated by aerial photography taken shortly after the coastal impact, by Lands SA. One of these photographs is reproduced in Plate 1.

In addition, a number of fixed photopoints were established, shortly after the spill, by SANTOS. Photographs from these were also examined.

Areas of likely heavy, moderate or light oiling, together with possible 'clean' areas, were identified. These were targeted for investigation by ground survey.

2.1.2 Initial Ground Survey (Fifth Creek to Sixth Creek)

The first ground survey was undertaken on November 24th, 1992 and encompassed the area immediately south of Sixth Creek, and northeast of Sixth Creek towards Fifth Creek.

The survey was undertaken during low tide so that intertidal flats, mangrove sediments, pneumatophores and foliage were fully exposed. This also avoided the risk of inadvertent bias towards the more elevated sections of the swamp that may have occurred had surveys been undertaken at higher, or neap, tides.

Since all creeks are inaccessible at low tide, this necessitated the entry of Sixth Creek, by vessel, at high tide. The time during which the tide was receding was occupied mapping the extent of oiling along the fringes of Sixth Creek, and assessing impacted supratidal (samphire) areas.

Care was taken during the survey of the mangrove swamp to cover all areas identified as (potentially) heavily, moderately or lightly oiled, or unoiled. In addition, a number of 'transects' were walked from the seaward mangrove fringe through to the denser, inner mangrove areas.

Since the denser 'inner fringe' areas possess a closed canopy, any oiling of sediment or foliage was considered unlikely to be shown by the aerial photographs available. The identification of the innermost limit of oiling is important since it is in these areas that, often, most oily debris is deposited. In the case of the "Era" spill this is an important consideration since oil impact occurred during a high 'king' tide.

The study areas of the SADF and photopoints established by SANTOS were also visited.

A number of parameters were noted, or assessed, during this survey (Table 2). These were used to determine areas that were roughly equivalent in the degree and extent of oiling and the nature of the mangrove community (trees and sediment). This would be used later to determine areas considered as both 'typical' of the swamp and 'representative' of the degree and type of oiling (see Section 2.3).

2.1.3 Boat Survey (Third Creek to Seventh Creek)

The coastline from Third Creek to Seventh Creek was surveyed, by boat, during a receding tide. This was undertaken on November 26th. This part of the reconnaissance survey was designed to better define the limits of the coastal impact and to verify that the extent indicated on the Lands SA aerial photograph had not changed due to any remobilisation of oil.

The coastline was traversed and the position of oiled, or unoiled, mangrove fringes were fixed using a portable Geographic Positioning System (GPS) and a running electronic log. The coastline and all creeks were surveyed in this manner. In addition to oiled fringes, the position of areas of defoliation or leaf browning, which were evident in the inner fringes, were logged.

TABLE 2 **PARAMETERS NOTED DURING INITIAL GROUND SURVEYS OF THE SWAMP**

General Mangrove Character Tree height Canopy height Canopy cover (open/closed) Sediment character (colour, shell or other debris, firm, soft etc) Leaf damage (% in unoiled sections of foliage) **Extent of Oiling** Oil on sediment (presence/absence;% cover;colour) Oil on trees (trunk/branches/leaves/pneumatophores; maximum and minimum heights on trunks or leaves etc.) **Nature of Oil** Colour Oil weathering (dry/tacky/wet) Oily debris (presence/absence/character) **Possible Effects** Leaves above oiled zone (dead/brown/yellowing etc) Defoliation Animal Remains (presence/absence;type)

Fourth, Fifth, Sixth and Seventh Creek were similarly surveyed as were two smaller creeks which possessed cormorant rookeries.

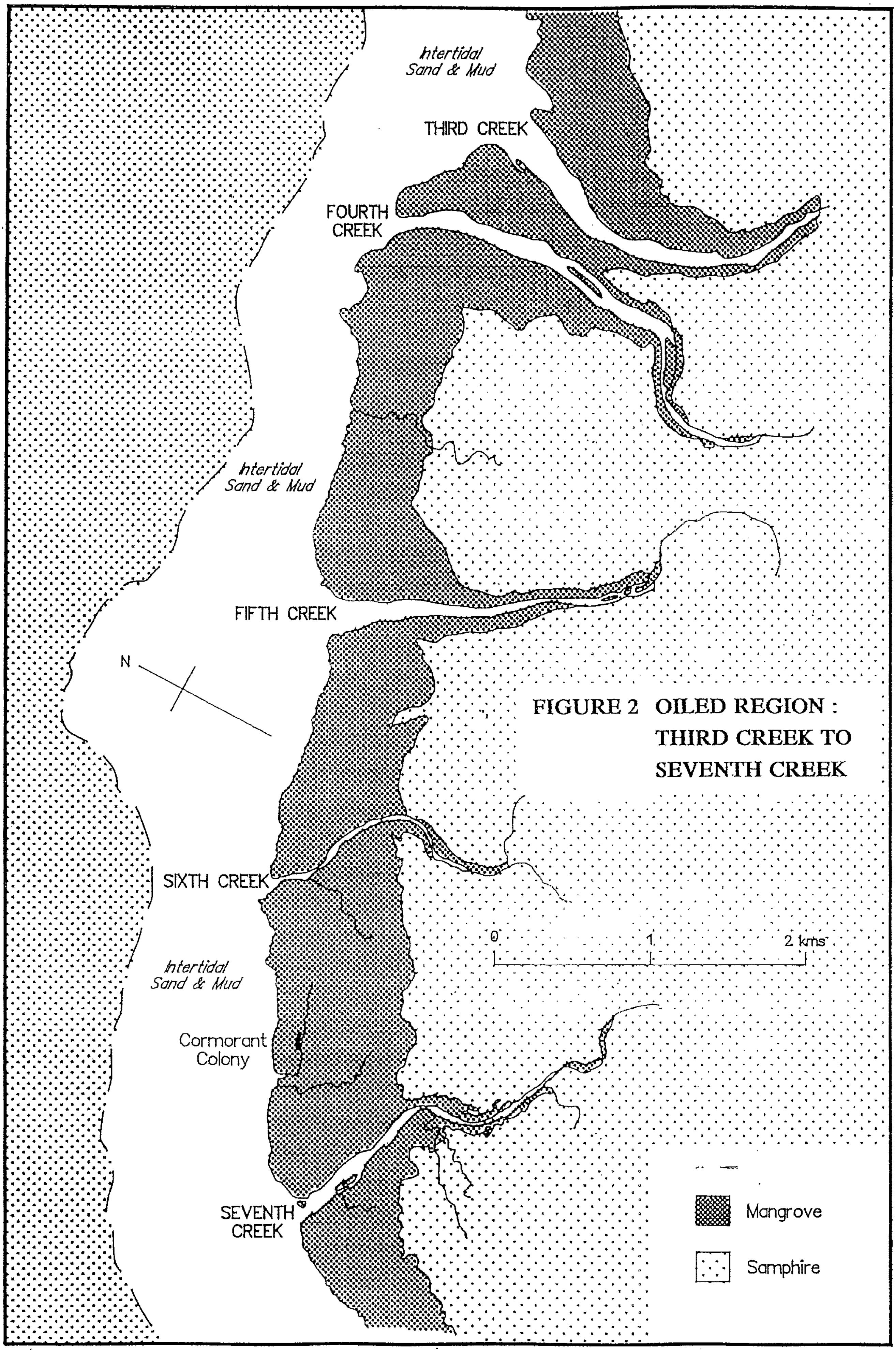

FIGURE 2 OILED REGION : THIRD CREEK TO SEVENTH CREEK

2.1.4 Second Ground Survey (Fourth Creek to Fifth Creek)

This section of swamp was surveyed on November 27th and used methods similar to those employed during the first ground survey (Section 2.2.2).

2.2 SITE ESTABLISHMENT AND SEDIMENT SAMPLING

A number of sites were selected for detailed study (Figure 2). These sites were chosen such that they represented areas of either 'heavy', 'moderate' or 'light' oiling. These terms are discussed and defined in Appendix C.

Each site was assessed with regard to the degree of oiling of mangroves, sediment and overall. A number of parameters were noted to facilitate quantification of oiling, general mangrove fitness, or swamp character. Field checklists are given in Appendix A.

Each site was marked with a white position marker-post and a GPS position was taken. Each post was marked with a site number. Numbers reflected the creek used for access, bank 'north' or 'south' and numerical order in which the sites were established.

Three mangrove plants were marked for biological study at each site (see Section 2.4.1).

Reference photographs were taken at all sites.

Samples were taken, as appropriate, and included leaves, seagrass debris, sediment and free oil residue. Sediment samples included both cores and 'scrapes' of surface or surface residue. These were taken using clean wooden, disposable, spatulas. Such scrapes represented surface oil or residue to a depth of 2-5 mm.

Cores were taken at a number of sites and samples taken at surface (see above), 1-2 cm, 5 cm and 10 cm depths. The method used to extract cores was similar to that developed by Wardrop and Wagstaff (in press), and effectively eliminates the possibility of contaminating non-surface samples with surface residue. Other methods of coring risk pushing surface oil into the underlying strata during the sampling procedure.

The method used consisted of making three, deep (20 cm) 'spade cuts' into the sediment in a squared 'U' configuration. A wedge of sediment is then removed adjacent to the central (base) cut. A spade is then used to slice through the bottom layer of sediment and lever the core out of position. The fourth side of the core is thus torn from its place. Loose sediment from this fourth face is removed and horizontal samples are sliced from this 'clean' face.

Unused sediment was returned to the hole in the same order as it was taken thus minimising sediment disturbance.

Seagrass debris, mangrove leaves or other samples were also taken using sterile, disposable wooden spatulas.

All samples were placed in 50 ml glass jars with bakelite screw caps. Aluminium foil was used to separate caps from samples.

Wherever possible, jars were completely filled with the samples. This was not possible with samples of leaves or free oil residues, and much air was still present in these jars and those containing seagrass debris.

Jars were labelled on-site with date, location, depth and sample description. All jars were numbered prior to use in the field and sample details were both logged in field data sheets and on a separate sample log.

Samples were chilled and stored in refrigerators until transported to Adelaide. Transport was undertaken with samples stacked in insulated containers with ice and 'refrigerator blocks'. Refrigerator blocks were sealed in plastic bags, as were samples.

In Adelaide, samples were stored in a refrigerator (Temperature $<5^{\circ}C$) and then transported to Melbourne using dry ice as a refrigerant. Samples were transported from Adelaide to Melbourne (AES Laboratories) via air express in sealed containers.

2.3 CHEMICAL ANALYSIS AND OIL CHARACTERISATION

Chemical analysis was undertaken by Applied Environmental Services (AES). AES is situated in the Bundoora Campus of the Royal Melbourne Institute of Technology (RMIT) and provides analytical services to industry and government. If necessary, they are able to draw on the resources of the RMIT and from their parent company Consil Associates Pty Ltd. AES are accredited by the National Association of Testing Authority (NATA) for a wide range of chemical analysis. A stringent and effective quality assurance/quality control (QA/QC) programme operating within AES ensures that the accuracy and precision of analytical data generated is sufficient for its intended end-use.

AGC Woodward-Clyde have audited AES Laboratories as part of an Australia-wide programme to identify facilities best able to undertake work for the company.

AES is regularly used by AGC Woodward-Clyde for analyses of hydrocarbons in sediments and other media.

2.3.1 Total Petroleum Hydrocarbons

Petroleum derived contamination is commonly seen in capillary gas chromatography as a distribution of n-alkanes showing little or no predominance of either odd or even chain lengths and as an unresolved complex mixture (UCM). The severity of oil pollution in a region can be measured from the amount of petroleum hydrocarbons found in surface sediments.

The method employed for analysis of the sediments and vegetation is based on the US ASTM Gas Chromatography/Flame Ionisation Detector (GC/FID) method for analysis of oil spill samples. Sediments, seagrass and leaves were all solvent extracted. The solvent extracts were dried with anhydrous sodium sulfate, then loaded into vials and analysed by GC/FID.

Gas Chromatography is a physical method for separating components of a volatile mixture. It is based on the partitioning of molecular species between the inert carrier gas and the stationary liquid phase in the capillary column. The separated components are detected as they elute from the column. The relative detected amounts of the components are recorded as a function of the components retention time and concentration to produce a Gas Chromatogram. This chromatogram is a chemical "fingerprint" of the sample. The GC/FID system employed was a Hewlett Packard 5890 Series II with a 7673 auto-injector. The analytical column employed was a 25 m SGE BP-1 fused silica capillary with high purity Helium used as the carrier gas. Results for the Total Petroleum Hydrocarbons are reported on a dry weight basis for sediment only. Seagrass and samples of leaves are reported on an as received basis. The homologous series of straight chain alkanes from nC12 to nC32 (molecules with between 12 and 32 carbon atoms) and two isoprenoid hydrocarbons, Pristane and Phytane are reported individually in mg/kg (ppm). Pristane and Phytane are found at slightly higher boiling points than nC17 and nC18 respectively. These two isoprenoids, present in varying amounts in most oils, are relatively resistant to weathering factors including biodegradation.

The unresolved complex mixture (UCM) seen on the chromatogram as a broad hump was also integrated and is reported in mg/Kg. The shape of this UCM is indicative of the type of oil, and is also an indication of petroleum contamination. The chromatograms are attached to this report in Appendix B.

A second portion of this solvent extract was analysed by Infra Red Spectroscopy (IR). This method measures the absorption of the carbon hydrogen stretch of the extract IR. It is useful in determining the Total Oil and Grease fraction that is solvent extractable and will include, lipids, fatty acids, mineral hydrocarbons and everything else that is solvent extractable and has a Carbon-Hydrogen stretch.

The results are expressed as Total Oil and Grease extractables, and are reported on a dry weight basis in mg/Kg (ppm) for sediment, and on an "as received" basis for seagrass and leaves.

2.3.2 Characterisation of Oil

Three samples of the ship's bunker oil and one sample of oil contaminated sediment were fully characterised. One bunker sample was taken from the "Era" at the time of the spill and the other two were taken from the sea surface some time after the spill. The oil was solvent extracted out of the contaminated sediments. Portions of the three weathered oils and the fresh bunker were then deposited onto basic alumina after spiking with surrogates. They were then separated into aromatic hydrocarbons and saturated hydrocarbon fractions by open column chromatography. The fractions were then concentrated down with Kudurna Danish glassware and finally spiked with a deuterated internal standard mix.

The prepared extracts were then loaded into vials and analysed by HRCGC/MS. The Hewlett Packard High Resolution Capillary Gas Chromatography-Mass Spectometry (HRCGC-MS) system comprises a 5890 Series II chromatograph equipped with 7673 auto-injector, purged spitless injector, 30 m J&W DB-5 fused silica capillary column, and direct interface to the 5971 mass selective detector. Spectra were obtained by Electron Impact (EI) at a nominal voltage of 70eV with PFTBA autotune conditions, from 100-320 amu for the aromatic fraction and 60-450 amu for the saturated hydrocarbon fraction. Instrument control, data acquisition, and manipulation were carried out with Hewlett Packard Chemstation software. Peak identification was based on a combination of operator interpretation, retention time comparison to standards and PBM searching of the Wiley mass spectral database (130,000 spectra).

The polycyclic aromatic hydrocarbon fraction was quantified by HRGS/MS and the saturated hydrocarbon fraction by GC/FID.

2.3.3 Total Organic Carbon

The total organic carbon was determined by the gravimetric procedure. Sediment samples were firstly dried in an air oven at 105°C for twenty four hours. The sediments were then accurately weighed out into crucibles and muffled for eight hours at 400°C.

The total organic carbon was then calculated.

2.4 BIOLOGICAL STUDIES

As noted in Section 1 there was, originally, no intention of obtaining data concerning the effect of oil on mangroves in this study, nor of monitoring long term effects or recovery. This task was to be undertaken by the South Australian Department of Fisheries (SADF).

However, few details could be obtained from the SADF with regards to parameters to be measured, or sites to be eventually monitored. The sites which had been established at the time of this study were in lightly oiled areas fringing the creeks. These tended to have an elevated canopy and be well drained with sediments cut by numerous deep drainage channels. As such they were not considered to be typical of the non creek fringing mangroves or of the oil-impacted community.

The SADF survey was undertaken during neap tide conditions when sediments were not likely to be exposed. Consequently sediment oiling could not have been quantified. Heavily oiled areas were not sampled and consequently the sites were not considered to represent the full range of degrees of oil impact.

This highlights the need for an assessment of the distribution and character of stranded oil immediately after a spill and prior to any other survey. This is essential if study sites are to be located appropriately. As it transpired, oil was found to be in the areas nominated as most likely from reconnaissance work during the spill. Post-spill monitoring must be coordinated with information from the spill.

Given this, and the variability of the extent of oiling of trees and sediments that occurred within each of the SADF sites, it was decided that tree descriptions would be obtained. This included data which related specifically to trees within the sediment-oil monitoring sites. In this way oil characteristics (distribution, weathering etc) could be correlated directly to both observed effects and to longer term mangrove responses.

Little information was available with regards SADF monitoring methods, it was not clear whether the site-specific data would be comparable with any data from a broader SADF programme. Therefore data relating to general swamp effects were also needed. A limited programme was initiated to facilitate the extrapolation of site specific data to the general swamp. This decision was made in the field after inspection of SADF monitoring sites.

The methods chosen for this study were designed to provide data rapidly and reliably and to avoid problems associated with the dieback, or partial dieback, of mangroves. For example, tags or tagged branches were not used since past work has shown that both tags and oiled branches tend to be lost over time. This loss renders comparisons of results from different sampling times difficult. Similarly, while the die-back of tagged oiled branches may be permanent, the whole plant may 'recover' by producing new foliage and stems. The use of tag-dependent data consequently may fail to reflect the true fitness of trees. For this reason whole-plant datum is emphasised here.

The two study components are outlined below.

2.4.1 Site-Specific Monitoring Programme

Three trees in the immediate vicinity of each sediment sample site location marker (see Section 2.2) were chosen at random. The 'immediate vicinity' was taken to be within a ten metre radius of the marker post. Any tree, shrub, sapling or seedling was chosen provided that no other plant (mangrove) lay in a direct line between it and the central marker post, provided that it could be unambiguously identified (ie. it was a distinct tree). In most instances this resulted in mangroves within three to four metres of the pegs being chosen.

A yellow marker peg was placed adjacent to each tree and hammered into the sediment. These were numbered by notching the peg ie.'tree 1' had no notches, 'tree 2' had one notch and 'tree 3' had two notches. Each tree was assessed against a series of parameters.

Key parameters quantified were :

(i) Tree height (in m)

(ii) Height of canopy from sediment (m)

(iii) Height of oiling (maximum and minimum, in m)

(iv) Estimated % of leaf oil coverage in oiled zone

(v) Extent of oiling (trunk, branches, leaves, pneumatophores)

(vi) Foliage (dense/moderate/sparse)

(vii) Leaf damage (percentage in both oiled and unoiled sections)

(viii) Pneumatophore numbers and density

(ix) Pneumatophores density in open sediment areas

(x) Colour of oil stain on sediment

(xi) Percentage oil coverage of sediment surface

Other parameters are listed in the field data sheets given in Appendix A.

Parameters (i) to (iv) together allow a quantification of the degree of oiling suffered by each plant. Parameters (i), (ii) and (vi) also enables tree growth or long term changes in tree morphology to be monitored.

The extent of oiling (vi) indicates the possible mechanisms by which a tress could be affected by oil.

Pneumatophore density may be a good indicator of the level of oxygen in sediments and the relative sensitivity of the trees to oil-induced pneumatophore damage. This is considered by some authors to be a valuable indicator of swamp sensitivities (Dicks, 1986) but at present is supported by little data.

Parameters (x) and (xi) allow a preliminary or field estimation of the degree of sediment oiling (see Appendix C).

Data from individual threes were supported by general observations and photographs of the trees and sediments of each study location. This data allows for a rapid assessment of tree fitness and degree of oiling (see Appendices A and C).

2.4.2 General Swamp Monitoring

Three transects were established through the section of swamp between Sixth Creek and Fifth Creek. Transects were oriented so as to run approximately perpendicular to the coastline and were long enough to encompass the shoreline fringe and the dense, inner fringe mangroves. This included the entire zone of oiling and also the full range of degrees of oiling. Each transect was approximately 200m long.

Two transects were associated with heavy tree oiling the other with predominantly lightly oiled areas. Within these areas transects were chosen at random.

Trees and shrubs with stems or trunks within 50 cm of the transect were marked for measurement. The location of trees and extent of oiling is indicated in Figure 1.

Trees were identified by a white wooden stake notched to indicate number and placed within 1 to 2 metres of the tree on its seaward side (except where this was obstructed, in which case its location was noted).

Trees and associated sediment were assessed against the parameters noted in Section 2.5.1 (Table 3).

Transect A was 90m WSW of SN3 (ie. towards Sixth Creek).

Transect B was 100m ENE of SN3 (ie. towards Fifth Creek).

Transect C was 100m WSW of the small creek between Fifth and Sixth Creeks (ie. on its Sixth Creek side).

3.0
RESULTS

3.1 RECONNAISSANCE SURVEY : DISTRIBUTION OF RESIDUAL OIL

The area of oiled swamp was divided into three sectors :

- South of Sixth Creek
- Sixth Creek to Fifth Creek
- Fifth Creek to Fourth Creek

Each of these were surveyed in turn.

The degree of oiling in these and other sites are summarised in Table 3.

3.1.1 Southwest of Sixth Creek

The area southwest of Sixth Creek is characterised by areas of light oiling with small expanses of moderate oiling.

Areas immediately adjacent to Sixth Creek are well drained and networked by deep drainage channels. The tree canopy is high and closed. Oil is largely limited,in these areas, to sparsely distributed small patches ($<1m^2$) of dark residual oil and a thin (10-20 cm) stain on trunks. Foliage is generally clean, although branches or small shrubs overhanging the creek were lightly oiled.

Fringing swamps at the mouth of Sixth Creek exhibit light to moderate oiling of canopy with either no oiling, or light oiling, of sediments.

Defoliation, and leaf browning and curling, was evident in some low-lying 'wet' areas and was complete for some trees. Little or no residual oil was noted in the sediments or seagrass debris associated with these areas but oil was evident on leaves and shrub trunks. However, some areas of this wet swamp were not accessible and so the presence or absence of residual oil in sediments could not be ascertained. Consequently, defoliation could not be definitely associated with the presence of oil or degree of oiling.

Three sites were established in this sector; SS1, SS2 and SS3.

Two creeks containing cormorant rookeries were briefly surveyed. Mangroves along the fringes of these creeks were either lightly oiled or apparently unoiled. Trees at both rookeries were partly defoliated particularly in the upper canopy. This had been noted immediately after the oil spill and is attributed to the presence of the rookeries rather than to any oiling or oil-related factor. It was noted during the survey, three months after the spill, that new leaves were sprouting in these denuded areas. Little or no oil was present at the rookery sites.

No birds were observed at either rookery during the survey.

3.1.2 Sixth Creek To Fifth Creek

The sediments of the northeastern fringes of Sixth Creek are moderately oiled, although foliage oiling is light to non existent.

TABLE 3 THE DEGREE OF MANGROVE AND SEDIMENT OILING IN THE PORT PIRIE STUDY AREA

LOCATION	DEGREE OF OILING		
	SEDIMENT	MANGROVES	OVERALL
Sixth Creek to Fifth Creek			
SN1	Heavy	Heavy	Heavy
SN2	Moderate	Moderate	Moderate
SN3	Clean	Light	Light
SN4	Light	Moderate	Light
SN5	Clean	Light	Light
SN6	Moderate	Light	Light
FS1	Moderate	Moderate	Moderate
FS2	Light	Light	Light
FS3	Heavy	Moderate	Heavy
Southwest of Sixth Creek			
SS1	Clean	Moderate	Light
SS2	Light	Moderate	Light
SS3	Light	Light	Light
Fifth Creek to Fourth Creek			
FN1	Heavy	Light	Moderate
FN2	Moderate	Moderate	Moderate
FN3	Moderate	Light	Light
FN4	Light	Moderate	Light
FN5	light	Moderate	Light
FN6	Light	Moderate	Light
FN7	Heavy	Heavy	Heavy
FN8	Heavy	Moderate	Heavy
FN9	Moderate	Light	Light
Samphire Area			
SE	Light	N/A	Light

Residual oil on the sediment is more uniform than on the southwestern creek fringes. The absence of foliage oiling reflects the higher canopy around the creek margins.

The swamp fringe areas immediately adjoining the gulf proper are characterised by low mallee-form shrubs and sandy sediment. Oiling here is largely restricted to foliage and the extent of this is variable. Sediments generally appear free of oil although sheen and brown oil films can be found around drainage channels and other areas. These appeared to be flowing from deeper within the swamp. The degree of oiling is greater towards the inner fringes with extensive areas of moderate oiling (foliage and sediment). Some defoliation has occurred in these areas.

Heavily oiled areas are also present. These are characterised by a uniform dry, weathered, 'tarmat' of oil on the sediment up to 5mm thick, and extensive oiling of foliage, trunks and branches. Within these areas defoliation is extensive and leaf mortality has reached 100% in numerous trees. This leaf loss and damage extends to unoiled sections of the canopy as well as oiled lower sections (see Plate 2).

Defoliated areas extend in a 20-30 m wide band of about 400m in length. The current position and distribution of these is shown in Figure 3.

Oil sheen (silver and rainbow colour) are common, and in fact are always present on water bodies within this swamp sector. Also common are thin sheets of brown oil film.

Oiled seagrass debris is present in many moderately and heavily oiled areas. In places oiled seagrass forms extensive mats, often piled against the foliage of the mangrove trees. The oily surface of these seagrass mats is tarry and often forms a consolidated mass. In places this mat is underlain by seagrass coated in less viscous, apparently fresh, oil.

These areas of extensive oily seagrass deposition occur throughout this sector and lie to the immediate shoreward of the taller, inner swamp mangroves. They are particularly extensive towards Fifth Creek and Sixth Creek.

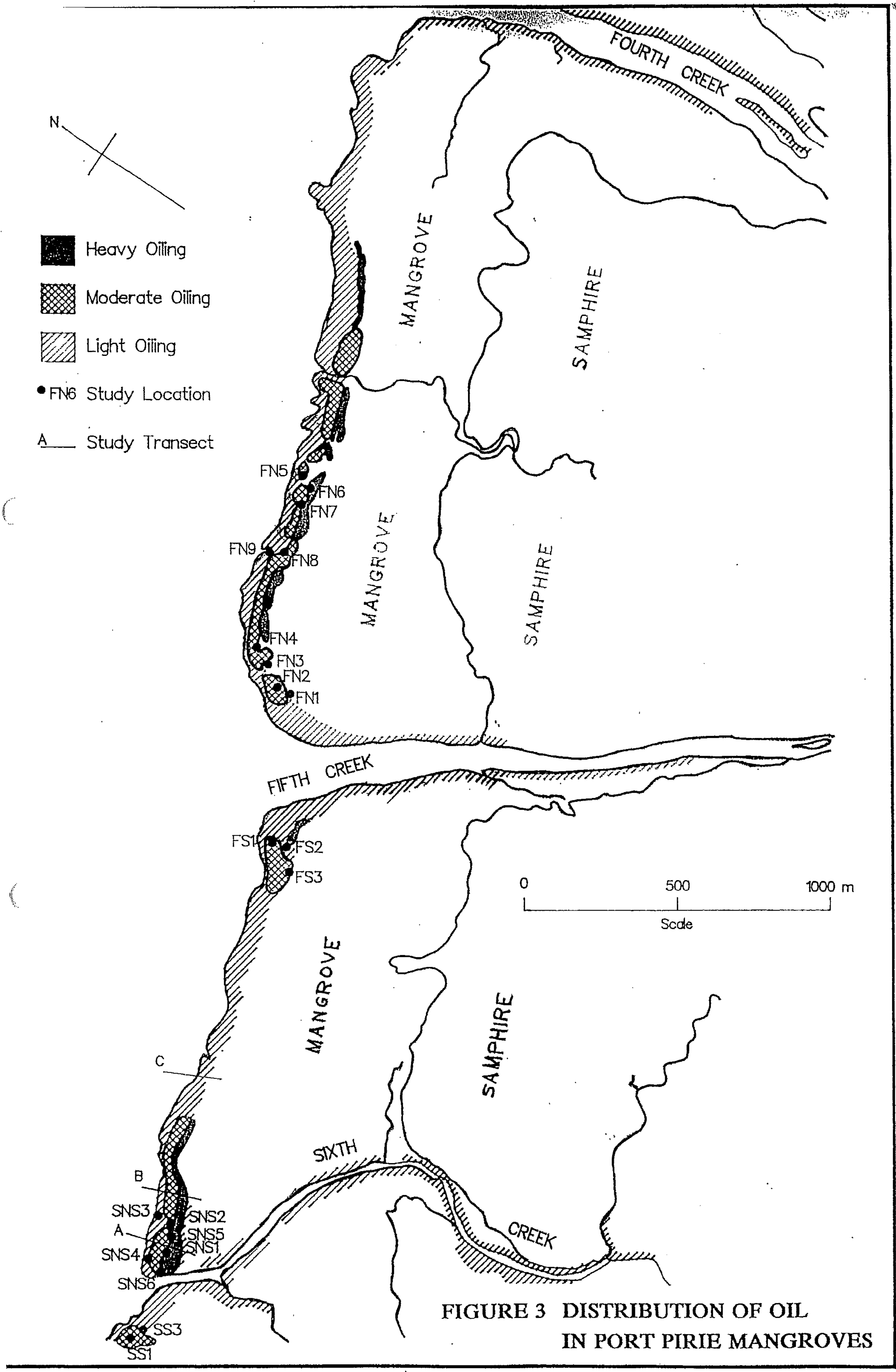

FIGURE 3 DISTRIBUTION OF OIL IN PORT PIRIE MANGROVES

Nine study locations were established in this sector. Six (SN1 to SN6) are accessed via Sixth Creek, and three (FS1 to FS3) are reached via Fifth Creek.

3.1.3 Fifth Creek to Fourth Creek

The distribution of oil, and the range in degrees of oiling in this sector was very similar to that observed between Fifth and Sixth Creeks. This includes heavy, moderate and lightly oiled areas.

As with the Fifth Creek-Sixth Creek sector heavy oiling with extensive defoliation, has occurred in a band towards the higher, denser inner swamp mangroves. The position of these areas is shown in Figure 3.

Nine locations were established in this sector (FN1 to FN9). These were similar to areas between Fifth and Sixth Creeks and so it was decided to concentrate sampling in the latter sector and leave the Fifth Creek to Fourth Creek sector essentially undisturbed.

3.1.4 Samphire Areas

Samphires were known to have been oiled near the head of Sixth Creek and these sites were visited. Oil had penetrated tidal channels and extensive staining and tarry residues were evident on the samphire areas above these.

Oil on exposed sediments appeared dry or tarry. However, fresher oil was found on sediments below the foliage of oiled samphire. Fresh oil was also found in some burrows of mudcrabs (*Helograpsus haswellianus*) and all mudcrab burrows inspected in impacted areas showed a dark staining. This indicated that oil had penetrated the burrows (Plate 5).

Regeneration of oil impacted samphire (*Sarcocornia sp*) was already evident, with fresh green shoots being present on even heavily oiled plants. This green foliage occurred at varied elevations within patches of thoroughly oiled vegetation and so was not likely to constitute unimpacted branches.

Five photopoints were established in this sector and three of these were sampled for chemical analysis of sediment.

3.2 CHEMICAL ANALYSIS

3.2.1 Total Petroleum Hydrocarbons

Sediments

Total petroleum hydrocarbons (TPH) for sediment samples are given in Table 4.

These results indicate that most oil residues have remained on the sediment surface with no detectable oil present in any sample taken from depth greater than 2 cm.

Surface hydrocarbon concentrations, from scrapes, generally reflect the 'heavy', 'moderate', 'light' oiling and 'clean' sediment descriptions allocated in the field (see Appendix C). However, site SN4 was initially classified as having 'clean' sediment but was found to be lightly oiled with a TPH of 608 ppm on the surface. This may reflect an inability to visually detect residual oils at this level or the fact that oil was present below the surface. This is discussed in Section 4. Location SN5 was deemed to be lightly oiled on the basis of the field inspection but showed no detectable TPH by GCFID analysis. Total oil and grease levels in the surface sediment sample from this site were, however, higher in this than those from other 'clean' sediments. This suggests that the surface staining observed could be due to heavier oil fractions (nC35+). This is discussed further in Section 4.

No analysis was carried out on the polar fraction of the oil. This is generally more mobile in sediments and more toxic. Compounds in the polar fraction include benzene, toluene, ethylbenzene, xylenes, C2 alkylated benzenes (eg. monoaromatic hydrocarbons) and phenolics.

Organic Debris

The oily residue on seagrass wrack, from seagrass debris in mangrove foliage, was quantified. These are given in Table 5.

TABLE 4

SEDIMENT HYDROCARBON ANALYSIS
(All figures in mg/kg dry weight)

LOCATION	DEPTH	SAMPLE NO:	TOTAL PETROLEUM HYDRO-CARBON	TOTAL OIL & GREASE
SS1	0 cm	5	*	*
SS1	2 cm	7	*	*
SS1	5 - 10	6	*	*
SS2/3	0 cm	1	17	400
SS2/3	1 - 2	2	*	*
SS2/3	2 - 5	3	*	*
SN1	0	10	105,000	110,000
SN1	2	11	40,000	32,000
SN1	5	13	*	300
SN1	10	12	*	200
SN2(A)	0	16	56,000	57,000
SN2(A)	2	17	2,000	17,000
SN2(A)	5	18	*	*
SN2(A)	10	19	*	*
SN2(B)	0	20	77,000	67,000
SN2(B)	2	21	2,000	1,000
SN2(B)	5	22	*	*
SN2(B)	10	23	*	*
SN3	0	24	*	200
SN3	2	25	*	*
SN3	5	26	*	*
SN4	0	27	609	800
SN4	2	28	*	*
SN4	5	29	*	100
SN5	0	30	54	600
SN6	0	31	85,000	99,000
SN6	2	32	*	100
SN6	5	33	*	200
SN6	10	34	*	*
FS1	0	42	84,000	100,000
FS1	2	43	13,000	130,000
FS1	5	44	*	*
FS2	0	40	9,000	8,000
FS2	0 - 1	36	6,000	2,000
FS2	2	41	2,000	900
FS2	5	37	*	100
FS3	0	38	5,000	5,000
FS4	0	35	*	200

TABLE 4 Continued

SEDIMENT HYDROCARBON ANALYSIS
(All figures in mg/kg dry weight)

LOCATION	DEPTH	SAMPLE NO:	TOTAL PETROLEUM HYDRO-CARBON	TOTAL OIL & GREASE
FN1	0	49	43,000	42,000
FN2	0	48	*	200
FN5	0	50	*	200
FN5-FN6	0	53	*	*
FN5-FN6	0	54	*	600
FN5-FN6	0	55	125,000	140,000
SE(A)	0	56	7,000	7,000
SE(A)	2	57	200	1,000
SE(A)	5	58	*	*
SE/(B)	0	59	22,000	21,000
SE(SAM)	0	60	81,000	87,000
SE(C)	0	61	61,000	48,000
Control PD	0	62	*	*
Control PD	1-2	63	*	*
Control PA/A	0	64	*	200
Control PA/A	2	65	*	*
Control PA/B	5	67	*	*

*Below detection limits.

TABLE 5 TOTAL PETROLEUM HYDROCARBON (TPH) AND TOTAL OILS AND GREASE (TOG) FOR SEAGRASS SAMPLES (Units in mg/kg as sampled)

LOCATION	SAMPLE NO:	TPH	TOG	SOURCE
SS1	8	75,000	150,000	Wet Sediment
SS1	9	3,000	3,000	Channel (Sed)
SN1	15	161,000	220,000	Mangrove Foliage
FS3	39	150,000	180,000	Sediment Mats
FS1	46	150,000	180,000	Mangrove Foliage
FS1	47	3,000	1,000	Channels (Sed)
FN5/6	51	182,000	210,000	Foliage/Mat

With the exception of seagrass debris taken from the bottom sediments of wet swamp areas and channels, all seagrass debris shows a very high component of oil. For those taken from the seagrass rack on sediment or in foliage this constitutes an oil content of over 15%.

3.2.2 Oil Weathering in Sediments

Isoprenoid ratios (nC17/Pristane, and nC18/Phytane) were calculated for all samples and these are given in Tables 6, 7 and 8.

Values for oil samples were also obtained and these are given in section 3.2.3.

TABLE 6 ISOPRENOID RATIOS IN OILED SEDIMENT SAMPLES

LOCATION	DEPTH (cm)	SAMPLE NO.	nC17/ PRISTANE	nC18/ PHYTANE	PRISTANE/ PHYTANE
SS2/3	0	1	0.89	3.40	3.80
SN1	0	10	0.91	3.12	3.72
SN1	2	11	0.95	5.56	6.03
SN2(A)	0	16	0.77	4.51	6.24
SN2(A)	2	17	0.83	4.69	6.07
SN2(B)	0	20	0.92	2.83	2.65
SN2(B)	2	21	0.71	6.35	8.45
SN4	0	27	1.44	6.33	4.82
SN5	0	30	0.74	1.41	3.00
SN6	0	31	0.64	2.82	5.26
FS3 3	0	38	0.30	1.61	4.19
FS2	0	40	1.00	4.98	5.81
FS2	1	36	1.33	6.10	5.18
FS2	2	41	1.62	8.13	5.20
FS1	0	42	0.54	2.31	5.53
FS1	2	43	0.95	4.82	5.12
FN1	0	49	1.00	5.17	5.72
FN5/6	0	55	1.52	7.65	6.04
SE(A)*	0	56	0.35	1.25	8.50
SE(B)*	0	59	0.31	0.92	2.32
SE(C)*	0	61	0.44	1.40	3.57
Average Surface Samples (Mangroves)			0.82	3.74	
Average 2cm Depth Samples (Mangroves)			1.09	5.80	
Average Samphire Areas			0.66	2.81	

* Locations in Samphire Areas

TABLE 7 **ISOPRENOID RATIOS IN OILED SEAGRASS SAMPLES**

LOCATION	SOURCE	SAMPLE NO.	nC17/ PRISTANE	nC18/ PHYTANE	PRISTANE/ PHYTANE
SS1		8	1.15	5.71	4.57
SS1		9	0.85	4.00	4.33
SN1		15	1.61	9.40	2.00
FS3		39	1.36	6.53	3.08
FS1		46	1.45	7.69	2.24
FS1		47	0.58	2.77	4.40
FN5/6		51	1.50	7.82	2.48
Average			1.20	6.27	3.30

TABLE 8 **ISOPRENOID RATIOS IN OIL FROM MANGROVE AND SAMPHIRE (*) LEAF SAMPLES**

LOCATION	SAMPLE NO.	nC17/ PRISTANE	nC18/ PHYTANE	PRISTANE/ PHYTANE
SN1	14	1.59	10.80	1.69
FS1	45	1.70	8.93	1.34
SE*	60	0.91	4.49	3.58
Average (Mangroves only)		1.65	9.86	1.52

3.2.3 Oil Characterisation

Three oil samples, taken from Gulf water, and one oil sediment sample were characterised (see Section 2.2).

Polycyclic Aromatic Hydrocarbons and Saturated Fractions

After oil samples were 'cleaned up' on alumina columns, the aromatic compounds were analysed by HRCGC/MS. The polycyclic aromatic hydrocarbon (PAH) content in listed in Table 9.

Other aromatic compounds were detected in the oil samples. These include:

- Tetrahydronaphthalenes
- C5 alkyl benzenes
- Tetrahydromethyl naphthalenes
- Tetrahydrodimethyl naphthalenes
- Methyl Biphenyls
- Dimethyl Biphenyls
- C4 Alkyl naphthalenes
- Methyl Fluorenes
- Dimethyl Fluorenes
- Trimethyl Biphenyls
- Tetramethyl Biphenyls
- Methyl Anthracenes
- Trimethyl Phenanthrenes
- Methyl Chrysenes

The following sulfur containing polycyclic aromatic hydrocarbons were also detected:

- Dibenzothiophene
- Methyl Dibenzothiophenes
- Dimethyl Dibenzothiophenes
- Trimethyl Dibenzothiophenes.

Saturated fractions are given in Table 10.

TABLE 9 **AROMATIC HYDROCARBON OF OIL "ERA" BUNKER OIL SAMPLES**

SOURCE	SPILL SITE (WATERS)	SPENCER GULF (WATERS)	SPENCER GULF (WATERS)	OILED SEDIMENT PORT PIRIE
Sample No.	72	70	71	16
Date Sampled	31/8/92	9/9/92	27/10/92	25/11/92
Parameter	ug/g	ug/g	ug/g	ug/g
Naphthalene	480	< 6	< 6	< 6
Methyl Naphthalenes	3600	10	< 6	< 6
Biphenyl	190	4	< 4	< 4
Dimethyl Naphthalenes	6400	380	37	130
Trimethyl Naphthalenes	5300	1500	390	470
Phenanthrene	390	310	190	160
Methyl Phenanthrenes	1500	1300	1000	910
Dimethyl Phenanthrenes	2100	1900	1800	1500
Fluoranthene	10	11	11	10
Pyrene	38	35	33	29
Benz(a)anthracene	13	14	10	10
Chrysene	56	61	60	55
Benzo(e)pyrene	22	25	23	20
Acenaphthylene	< 30	< 6	< 6	< 6
Acenaphthene	< 30	< 6	< 6	< 6
Fluorene	<100	< 40	< 40	< 40
Sum Benzo(bjk) fluoranthene*	< 30	< 30	< 30	< 30
Benzo(a)pyrene	< 20	< 20	< 20	< 20
Perylene	< 20	< 20	< 20	< 20
Indeno(123-cd)pyrene	< 20	< 20	< 20	< 20
Dibenz(ah)anthracene	< 20	< 20	< 20	< 20
Benzo(ghi)perylene	< 20	< 20	< 20	< 20
Sum PAHs	20100	5500	3550	3300
Surrogate recovery %	102	100	94	89

Note: * The sum of Benzo(b), Benzo(j), and Benzo(k)fluoranthene are reported.
Results are reported in ug/g (ppm) on the extracted oil.

TABLE 10 SATURATED FRACTIONS OF "ERA" BUNKER OIL SAMPLES

SOURCE	SPILL SITE (WATERS)	SPENCER GULF WATERS	SPENCER GULF WATERS	OILED SEDIMENT PORT PIRIE
Sample No.	72	70	71	16
Date Sampled	31/8/92	9/9/92	27/10/92	25/11/92
Parameter				
nC10	370	< 1	< 1	< 1
nC11	1300	< 1	< 1	< 1
nC12	2200	< 1	< 1	< 1
nC13	4700	< 1	< 1	< 1
nC14	7500	350	20	42
nC15	9200	2200	320	280
nC16	8300	4800	1300	790
Norpristane	1700	1200	710	480
nC17	7200	6300	2500	1300
Pristane	4200	6300	2350	1800
nC18	5900	6100	2800	1600
Phytane	680	860	550	550
nC19	5000	5400	2800	1600
nC20	4000	4600	2300	1300
nC21	3000	3400	1900	995
nC22	2050	2400	1200	580
nC23	1200	1400	730	250
nC24	720	800	410	66
nC25	480	550	290	80
nC26	350	390	210	< 10
nC27	300	310	180	< 10
nC28	230	230	140	< 10
nC29	190	200	130	< 10
nC30	144	150	110	< 10
nC31	340	370	330	< 10
nC32	160	190	160	< 10
nC33	< 10	< 10	< 10	< 10
nC34	< 10	< 10	< 10	< 10
UCM	90000	58000	55000	41000

Note: Results are reported in ug/g (ppm) on the extracted oil.

Weathering of Oil

Table 10 indicates that the more volatile and water soluble PAHs were rapidly lost from the spilt oil. Isoprenoid ratios were calculated from the four oil samples and these are given in Table 11. Table 11 also contains the isoprenoid ratios for 'sample 4'; a dark oil bitumen taken from site SS1 (refer to Figure 2).

TABLE 11 ISOPRENOID RATIOS FOR OIL SAMPLES

SAMPLE DESCRIPT.	SAMPLE NO.	SAMPLING DATE	nC17/ PRISTANE	nC18/ PHYTANE	PRISTANE/ PHYTANE
Bunker Oil	72	31/8/92	1.73	8.71	6.14
Oil Residue From Gulf Waters	70	9/9/92	1.00	7.09	7.32
Oily Residue from Gulf Waters	71	27/10/92	1.06	5.09	4.27
Oily Residue from Sediment Surface Port Pirie	16	25/11/92	0.72	2.91	3.27
Bituminous Residue from Site SS1	4	25/11/92	1.13	5.71	4.57

Both nC17/Pristane and nC18/Phytane ratios are decreasing with time. This shows that the alkanes are being biodegraded through beta-oxidation.

Biomarker Profiles

Several biomarkers were examined in the four oils. The hopane (m/z191) profiles were examined by HRCGC/MS and are reported. Very little sterane biomarkers (m/z 217) were detected in the oil samples. Three hopane correlation ratios were calculated and are listed below in Table 12.

TABLE 12 HOPANE RATIOS IN OIL SAMPLES

SAMPLE NO.	72	70	71	16
DATE SAMPLED	31/8/92	9/9/92	27/10/92	25/11/92
RATIO				
A	1.16	1.23	1.20	1.14
B	0.92	0.90	0.91	0.96
C	1.29	1.23	1.32	1.33

The ratios calculated are as follows:
A - 17a(H),21b(H)-30-Norhopane $C_{29}H_{50}$ / 17a(h)2lb(H)-Hopane $C_{30}H_{52}$
B - 17a(H),22,29,30-Trisnorhopane $C_{27}H_{46}$ / 18a(H),22,29,30-Trisnorneohopane $C_{27}H_{46}$.
C - 17a(H),21b(H)-Homohopane(22R)$C_{31}H_{54}$ / 17a(H),21b(H)-Homohopane(22S) $C_{31}H_{54}$.

The hopane profile has remained unchanged after three months of weathering. Hopanes are very resistant to weathering and biodegradation and make an excellent parameter for identification of the oil source. The hopane profiles and ratios listed above can be used to fingerprint this oil in the mangrove swamps.

3.2.4 Total Organic Carbon in Sediment

Six randomly chosen sediment samples from the oiled study sites were analysed for total organic carbon. Six samples were also taken, and analysed, from Port Davis and Port Adelaide (Table 13).

TABLE 13 TOTAL ORGANIC CARBON IN MANGROVE SEDIMENTS

	LOCATION NO.	SURFACE	2CM DEPTH
Impact Site	SN1	15.0	-
	SN3	5.9	4.9
	SN4	-	5.5
	SN6	-	8.2
	FN1	13.0	-
Control Sites	Port Davis	20.0	16.0
	Port Adelaide	18.0	6.0
	Port Adelaide	9.0	4.0

Port Pirie sediments are comparable with those of 'control' areas.

3.3 BIOLOGICAL (MANGROVE) MONITORING

3.3.1 Site Specific Monitoring

Trees were classified as having 'Heavy', 'Moderate' or 'Light' oiling on the basis of the proportion of canopy oiled and the degree of oil cover within the oiled zone. The proportion of canopy oiled was calculated using the height (or vertical width) of the oiled band relative to the tree height and this was also compared with estimates made in the field. Degree of oiling was determined as per Appendix C.

The classifications are consistent with the observation of defoliation with all but one of the heavily oiled trees showing leaf loss (X^2_2 for independence = 6.265; $P \leq 0.05$). The classifications are not correlated with the degree of general leaf damage in the unoiled canopy sections due to the high level of variability in leaf damage present in the trees. The inability to definitely differentiate between damage caused by oil and that due to insects or other factors means that this data should be assessed in the longer term and with reference to other parameters such as canopy density, and the photographic record.

TABLE 14 SUMMARY OF TREE PARAMETERS AT STUDY LOCATIONS AND DEGREE OF MANGROVE OILING

Location	Tree No.	Tree Height (m)	Height of Oiled Zone max.(m)	Height of Oiled Zone min.(m)	% Oil Cover in Oiled Sector	Degree of Oiling(1)	% Leaf Damage In Unoiled Zone General (blackened)	Defoliation
SN1	1	2.1	1.2	0	100	Moderate	100(2)(100)	Y
	2	0.5	0.5	0	100	Heavy	N/A	N
	3	1.5	1.2	0	100	Heavy	100(2)(100)	Y
SN2	1	2.5	1.5	0	100	Moderate	100(2)(100)	Y
	2	1.5	1.5	0	100	Heavy	N/A	Y
	3	2.0	1.5	0	100	Heavy	100(2)(100)	Y
SN3	1	2.5	0.7	0.4	<25	Light	30(3)(0)	N
	2	3.0	0.7	0.4	<25	Light	80(3)(0)	N
	3	3.0	0.8	0.4	<25	Light	80(3)(0)	N
SN4	1	1.2	1.2	0	100	Heavy	N/A	N
	2	2.0	1.2	0	50	Moderate	50 (0)	N
	3	2.5	1.5	0.05	100	Moderate	60 (0)	N
SN6	1	3.5	0.5	0	100	Light	90 (5)	N
	2	3.5	0.9	0	100	Light	65 (0)	N
FS1	1	1.0	1.0	0	100	Heavy	N/A	Y
	2	2.2	1.5	0	100	Moderate	100 (20)	N
	3	2.5	1.6	0	100	Moderate	100 (2)(10)	N
FS2	1	2.5	1.6	0.3	40	Light	80 (5)	N
FS3	1	3.5	1.2	0	100	Moderate	50 (30)	Y
	2	1.5	1.5	0	100	Heavy	N/A	Y
	3	2.2	1.5	0	100	Moderate	60 (50)	Y

(1) Refer to Appendix C

(2) All leaves black or brown. Curling is also common.

(3) Fungal damage

The mean leaf damage in unoiled canopy does appear to correspond with the degree of oiling (Table 14) but differences between trees from the different oiling classifications are not, at present, statistically significant. No clear correlation between the broader range (percentage) of oiling and level of leaf damage in unoiled canopy is demonstrable (Table 15). Care is needed in interpreting this data since the degree of oiling is dependent, in part, on the position of trees within the swamp. This position may also influence the level of insect or fungal attack on leaves. Consequently, a cause and effect relationship should not be assumed even where correlations do exist. This is illustrated in the data from the General Swamp Monitoring study (Table 17) which indicates that the moderately oiled sites appear to have a lower average level of general leaf damage in the unoiled canopy compared to lightly oiled trees.

Extensive or total damage of individual leaves is often noted after oil has impacted on mangroves and such damage consists of blackening, or browning, and curling of leaves. This form of damage is found in unoiled swamps but occurs at a much lower level than general leaf damage. Leaves affected in this way can be considered to be dead and will, ultimately, be lost. This damage occurs in both oiled and unoiled sections of the canopy and in the latter case are indicative of the overall initial effect of oiling on mangrove trees.

The loss of these leaves can take several weeks to occur, although damage (blackening and curling) can occur rapidly. Consequently the level of these leaves in the unoiled canopy may provide a better indication of initial damage, and longer term effect than defoliation. The fact that it occurs at relatively low levels in unimpacted swamps suggests that, initially, the level of this type of damage will be a better indicator than general leaf damage data.

The levels of 'blackened, curled leaf' damage for each tree is given in Table 14 and 15.

The level of this type of damage correlates well with the classification of the degree of oiling and also with the observation of defoliation.

Oiling of pneumatophores has been suggested, in the scientific literature, as being a possible cause of mangrove damage and, as noted earlier (Section 2.4.1), the density of these may provide an indicator of mangrove sensitivity to oiling.

Pneumatophore densities are given in Table 16 for the trees in the Sixth Creek to Fifth Creek sector. At present these cannot be correlated with any observed oil induced effect.

It is anticipated that the additional parameters noted in Section 2.4 and Appendix A can be used in the future to determine gross changes in the fitness or character of the trees and that these can be used to determine the extent of oil induced damage.

TABLE 15 COMPARISON BETWEEN DEGREE OF MANGROVE OILING AND EXTENT OF DAMAGE IN UNOILED CANOPY (SITE SPECIFIC MONITORING)

ESTIMATED DEGREE OF TREE OILING (%)	% ESTIMATED LEAF DAMAGE IN UNOILED CANOPY[1]		LOCATION - TREE NUMBER
	General	Blackened/ Curled	
EAVY			
80	100	100	SN1 - 3
75	100	100	SN2 - 3
Average	**100**	**100**	
MODERATE			
68	100	20	FS1 - 2
68	60	50	FS3 - 3
64	100	10	FS1 - 3
60	100	100	SN2 - 1
60	60	0	SN4 - 3
57	100	100	SN1 - 1
34	50	30	FS3 - 1
30	50	0	SN4 - 2
Average	**77.5**	**35**	
LIGHT			
25	65	0	SN6 - 2
25	80	5	FS2 - 1
15	90	5	SN6 - 1
<10	30	0	SN3 - 1
<10	80	0	SN3 - 2
<10	80	0	SN3 - 3
Average	**70.8**	**1.7**	

1 The following trees were oiled over their entire canopy and therefore do not appear in the table : SN1-2, SN2-2, SN4-1, FS1-1 and FS3-2.

TABLE 16 PNEUMATOPHORE DENSITIES FOR SITES IN STUDY AREAS (SIXTH CREEK TO FIFTH CREEK)

LOCATION	TREE NO	PNEUMATOPHORE DENSITY	DEFOLIATION
SN1	1	90	Y
	2	90	N
	3	90	Y
SN2	1	20	Y
	2	35	Y
	3	25	Y
SN3	1	35	N
	2	220	N
	3	220	N
SN4	1	110	N
	2	120	N
	3	120	N
SN6	1	20	N
	2	20	N
FS1	1	60	Y
	2	80	N
	3	60	N
FS2	1	250	N
FS3	1	<5	Y
	2	<2	Y
	3	-	Y

3.3.2 General Swamp Monitoring

A total of 54 plants were assessed in the three transects established for the general monitoring programme. Each was assessed in a manner consistent with the site-specific study and classified according to degree of oiling (see Plates 2, 3 and 4). The distribution, height of tree, and degree of oiling are represented in Figure 4.

As with the site-specific data the degree of oiling corresponds well with the average leaf damage in unoiled canopy (Table 17), and the occurrence of defoliation but these are not significant if we compare the three tree groups, or attempt to correlate the extent of canopy damage to calculated percentage oiling. Defoliation was commonly observed in heavily oiled trees and the sediment below these were often littered with oil covered leaves.

TABLE 17 COMPARISON OF DEGREE OF MANGROVE OILING AND EXTENT OF DAMAGE IN UNOILED CANOPY (GENERAL SWAMP MONITORING)

Degree of Oiling	Average Estimated General Leaf Damage (and Blackened Curled Leaves) in Unoiled Canopy(1)			
	Transect C	Transect B	Transect B	Average Over All Trees
Heavy	-	100 (100)	100 (100)	100 (100)
Moderate	20 (0)	26.3 (0)	20.5 (0)	23.6 (0)
Light	37.5(0)	21.0 (0)	33.8 (0)	31.6 (0)

(1) Averages do not include data from completely oiled trees.

Pneumatophore numbers were recorded as in the site-specific study but again these are not correlated to the extent of leaf damage in similarly oiled mangrove groups.

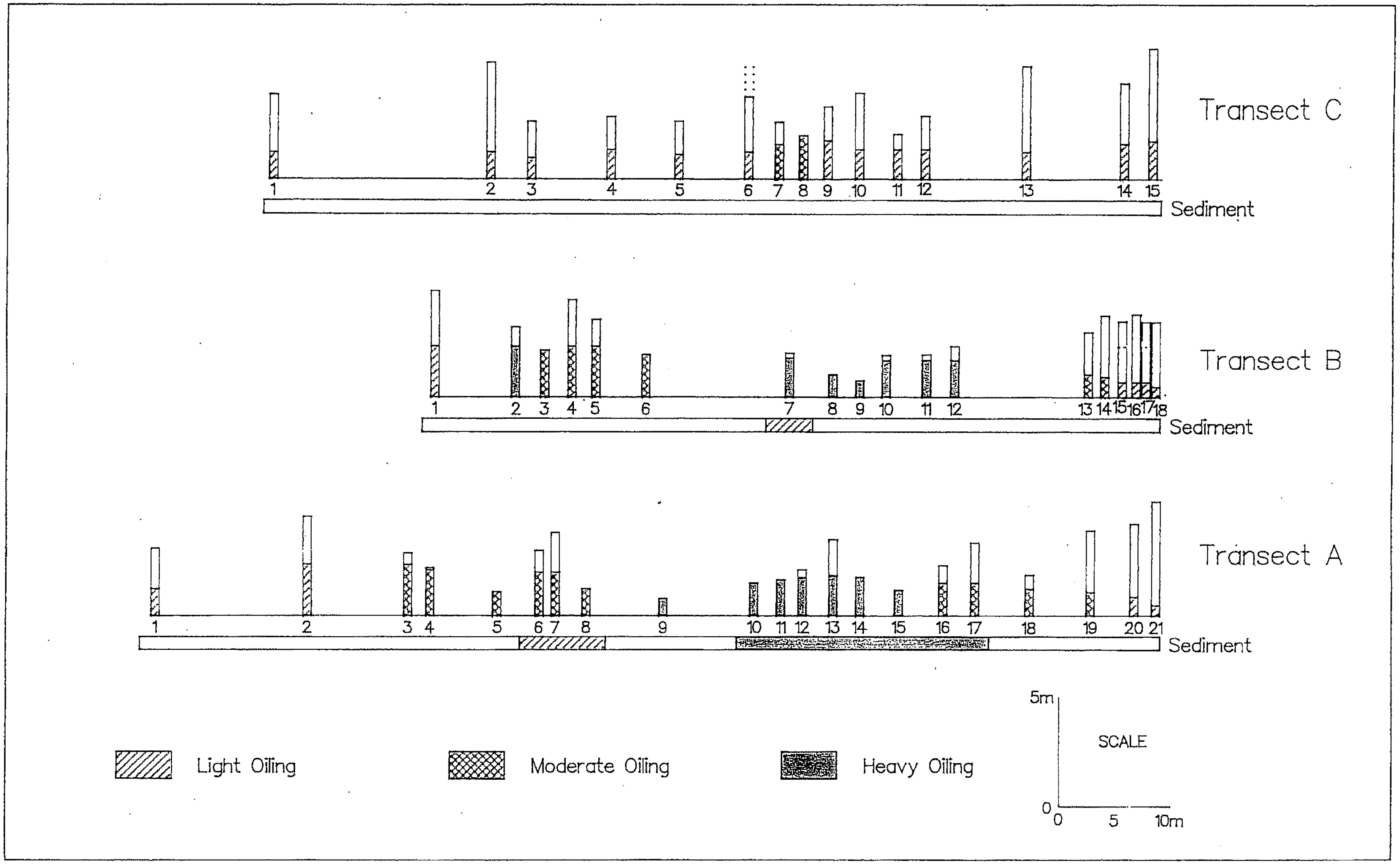

FIGURE 4 GENERAL SWAMP MONITORING. MANGROVE HEIGHT, POSITION AND DEGREE OF OILING

4.0
DISCUSSION

4.1 DISTRIBUTION AND CHARACTER OF RESIDUAL OIL

4.1.1 Oil Distribution and Area

Oil has impacted both sediment and mangroves along a 12 km stretch of the coastline. In the outer mangrove fringes this oiling is largely limited to mangrove trunks and foliage but has heavily impacted the inner fringe areas, some 50 metres from the coastline. These heavily oiled areas form a relatively thin band of oil, some 20 to 30 m in depth, running parallel to the shoreline.

These heavily oiled areas are characterised by black bituminous surface residues on the sediment surface and these form continuous mats in some areas. A fine layer of sand masks the extent of the presence of this residue in some areas although it is unclear whether this is formed by the removal of residue from (i.e. cleaning of) surfaces or by the deposition of clean sediment. The latter is suspected on the basis of the integrity of the tarmat and the probability that sediment would adhere to the residue, particularly when fresher.

The extent of sediment coverage within these areas was variable, but generally was considered 'heavy' if more than 50% of the surface showed oil. It has been estimated that the total area covered by this heavy oiling is as follows:

Southwest of Sixth Creek	none
Sixth Creek to Fifth Creek	1.6 ha (16,000m^2)
Fifth Creek to Fourth Creek	2.3 ha (22,500m^2)
Northeast of Fourth Creek	none

The residual oil content of sediments within the heavily oiled areas has been roughly estimated to average in the region of 30,000 ppm in the surface 5 cm with surface concentrations of up to 105,000 ppm. This estimate is very approximate since budgeting constraints precluded the taking of random sediment core samples from within each area. However, assuming a sediment dry weight of 2 gms per cm^2, this represents approximately 3 kg of oil residue per m^2.

Heavily oiled areas are also characterised by a heavy oiling of mangrove canopy and extensive mats of oiled seagrass may also be present. The volume of oil residue still held on mangrove leafs cannot be calculated and volumes held in the seagrass mats (wrack) is likewise difficult to estimate.

Moderately oiled areas cover an estimated 5.5 ha of swamp (see Figure 3). In these areas sediment oiling is generally lighter and more variable. Surface hydrocarbon concentrates of between 66,000 and 85,000 ppm have been reported and surface oil coverage ranges between 25 and 50 percent in the studied locations. This represents an oil residue of about 0.6 kg per square metre for moderately oiled sediments.

The extent of moderate oiling is illustrated in Figure 4 and is approximately:

Southwest of Sixth Creek	0.8 ha (8,000m^2)
Sixth Creek to Fifth Creek	1.8 ha (18,000m^2)
Fifth Creek to Fourth Creek	2.9 ha (29,000m^2)
Northeast of Fourth Creek	none observed

Lightly oiled areas cover about 70 hectares and are characterised by clean sediments and light to moderate oiling of mangroves. Residual hydrocarbons in these areas are considered to be relatively minor.

Estimated areas by swamp sector are:

Southwest of Sixth Creek	more than 10 ha
Sixth Creek to Fifth Creek	15 ha
Fifth Creek to Fourth Creek	3 ha
Northeast of Fourth Creek	over 10 ha

It is difficult to estimate the quantity of oil residue now present within the swamp or to calculate the volumes that impacted the area in September 1992.

One difficulty encountered in the field is illustrated by study location FS2. Initially this site was thought to be lightly oiled and with lightly or unimpacted sediment. Sediment was apparently clean and no evidence of dark oil films was evident, although sheen was present in nearby channels.

In the process of taking a surface scrape, however, oil "bleeds" appeared on the surface. This comprised brown oil which was drawn from small polychaete burrows by the action of the scraper (see Plate 6). This observation resulted in the sediment of the site being reclassified, in the field as "moderately" oiled, a rating confirmed by the chemical analysis.

Such apparently clean areas had been noted elsewhere, in close association with areas covered by bituminous residues (see earlier, this section). They had not been noted in generally clean sediment areas, with moderate mangrove oiling as characterised site FS2.

This site illustrates the difficulties in mapping the original oil distribution or quantifying impacts, so long after the impact of the spill has occurred. This difficulty is increased by the fact that the bunker residues concerned have little or no odour.

An unusual feature of this spill is the amount of oil which is associated with seagrass debris. As noted in Section 3, these may form thick depositions and be underlain by relatively non-viscous (i.e. fresh) oil. It is not possible to quantify the amount of oil which was initially incorporated into this rack, or the amount of residue which remains within them, or underlying them. It is likely though that they constitute the main reservoir of residual oil within the swamp.

4.1.2 Distribution of Oil in Sediment Cores

Oil is largely restricted to the surface of sediments and very little has penetrated below 2 cm depth. Penetration below the depth did not even occur at FS2 where vertical movement would appear to have been aided by polychaete burrows. The failure to penetrate the sediment is a marked contrast to other studies such as that following the Port Adelaide oil spill in 1985 (Bunker C oil; Wardrop and Wagstaff, in press) or in overseas spills (see Baker et al 1981; Rutzler & Serrer, 1970). This probably reflects the high viscosity of the fuel oil, further enhanced by three days weathering at sea, but also the character of the sediment, in particular, its grain size.

It is also interesting to note that the burrowing crab *Helograpsus haswellianus* is absent from much of the swamp and so the facilitation of sediment penetration through the mechanism was not operating. *Helograpsus* is present in the lower lying samphire areas and it is worth noting that oil black residues were noted in these burrows in location SE1, (the samphire at the top of Sixth Creek).

4.1.3 Nature of the Residual Oil

The bunker oil from the "Era" (Sample No. 72) was characterised by HRCGC/MS and found to be a blend of approximately 30% diesel fuel and 70% heavy fuel oil. Total asphaltenes content was about 25% with a boiling point in the range of nC17 to nC35. This was a surprising result since the oil was reportedly 60% diesel and 40% heavy residue. While some margin or analytical latitude is allowable, given that the precise nature of the heavy oil component is not known, it is unlikely that such a large discrepancy can be explained in this way.

Further analysis of the bunker oil is required to verify that the sample supplied by SANTOS via the Department of Environment and Land Management (DELM ex.DEP) has retained its chemical integrity.

Analysis of the other samples showed the bunker oil had, as expected, lost most of its lighter; volatile components fairly rapidly. These include the nC10 to nC14 saturated hydrocarbons and the volatile polycyclic aromatic hydrocarbons (PAH) and other aromatics. This loss was due to evaporation.

However, a large proportion of the sediment samples still contained nC16 (hexadecane) and below. After three months of weathering (Sept, Oct, Nov.) it would be expected that the nC16 and lighter fractions would have been lost due to weathering (evaporation). It is possible that the asphaltenes are forming a protective film on the surface of the oil thus reducing the losses of the lighter ends through evaporation. Such viscous films have been observed and, in fact, are common throughout the swamp.

The persistence of oil to date, and the likelihood of future persistence is discussed in Section 4.2.

It is worth noting here, though, that some samples chromatographic profiles characteristic of diesel but without the UCM 'hump' associated with the heavy fuel oil component of the mixture. This suggests that the diesel oil may have separated from the heavy fuel oil. However, the samples in which this was found encompass a variety of sites, depths and sample types and so no definite explanation for this can be offered (Table 18).

TABLE 18 SAMPLES SHOWING DIESEL CHARACTER IN ABSENCE OF HEAVY FUEL OIL

LOCATION	SAMPLE NO.	SAMPLE TYPE	DEPTH OR OTHER DESCRIPTION
SS3	1	Sediment	Surface (0 cm).
SS1	9	Seagrass	
SN1	12	Sediment	10 cm depth.
SN2	21	Sediment	2 cm depth (Core B).
SN4	27	Sediment	Surface (0 cm).
FS2	41	Sediment	2 cm depth.
Fifth Creek	54	Oily Residue	Stained sediment and oily residue on creek bank.
SE	57	Sediment	2 cm depth in samphire area.

It is possible though that diesel is continuing to be leached from fuel oil in associated heavily or moderately oiled sediments and that these findings represent recent, perhaps temporary oiling of these otherwise clean sediments. This explanation fits well with the presence of diesel in the oil film taken from the edge of Fifth Creek at low tide (Sample 54). The hypothesis is also supported by the presence of sheen (silver to rainbow) on most of the water bodies and drainage channel, particularly between Fifth and Sixth Creek.

However, there are a number of possible sources of this sheen. These include chronic releases of sediment oils, release of oil from seagrass rack or underneath this rack, sheen from remobilised floating seagrass debris or fallen mangrove leaves.

All of these may be contributing to any chronic release of oil, although sheen associated with fallen mangrove leaves was not observed. Sheen, colour, brown film and globules were all noted in wet areas associated with oiled seagrass debris and this is considered to be the most likely source of remobilised diesel, or oil generally.

This is discussed in the next section.

4.2 LIKELY PERSISTENCE OF RESIDUAL OIL

4.2.1 Oil Degradation

As we have seen the oil had lost a significant portion of light fractions but that the extent of this loss in sediment-bound oils is less than would be expected in oils exposed to weathering for 3 months. This is all the more surprising since oil residues are close to, or on the sediment surface. The persistence of diesel oil in surface sediments is similarly unexpected (Table 18).

The possibility that these lighter oils are being redeposited in surface sediments from associated heavily oiled areas, such as the seagrass debris, is considered the most likely explanation for this observation. The 'skinning' effect of the heavy fuel oil is not inconsistent with this suggestion and indeed, as previously stated, such films were commonly observed passing down drainage channels from the heavily oiled inner fringe areas, and deposited upon otherwise clean looking sediments. These films were particularly prevalent in channels draining from those areas with heavy seagrass depositions.

Generally sediments do show reduced nC17/Pristane and nC18/Phytane ratios suggesting that biodegradation is taking place, albeit at a slower pace than would be anticipated in surface deposits.

Surface samples have lower nC17/Pristane ratios than underlying sediments in all cases but in core SN2(B) and nC18/Phytane ratios are lower in all surface samples relative to 2 cm depths. This is not reflected in the overall distribution of values, for all samples, but the small sample numbers make the establishment of statistically significant data difficult.

Nevertheless it would appear reasonable that biodegradation in surface sediments should proceed at a faster rate than in underlying sediments, particularly where these are not bioturbated.

The rate of biodegradation in the samphire areas appears to be relatively rapid though. The isoprenoid ratios in these areas are significantly lower than surface sediments in the mangrove swamp. This is true for both nC17/Pristane ($P < .05$, Willcox Rank Sum Test) and nC18/Phytane ratios ($P < .01$). In two samples (56 and 59) a high degree of biodegradation has occurred with the alkane component being almost entirely removed.

Weathering of oil on mangrove leaves and seagrass has been by evaporation rather than biodegradation and this is indicated by the isoprenoid ratios which are very similar to the fresh bunker oil.

The slow biodegradation in sediments, particularly surface sediments, is unexpected. In some areas the lack of biodegradation may be due to sediments lying in areas that are covered with water for some period of time. In this case, sediments would be exposed to an anaerobic then aerobic environment, thus making the environment very unfavourable to potential oil degrading microbes. The relative rapidity of the degradation process in the less frequently inundated samphire area would, in any case, suggest that swamp rather than oil characteristics are the reason.

It is also possible that the presence of relatively light hydrocarbons in sheens depresses bacterial activity, or that the heavy oil film is both resistant to degradation and acts to suppress the degradation of underlying oils perhaps through depleted oxygen, or elevated temperatures. It is worth noting here that the viscous oil films so characteristic of the mangrove swamp areas were absent in the samphire areas.

4.2.2 Remobilisation and Physical Removal of Oil

Oiled mangrove leaves can be expected to be lost within six months and the process of defoliation generally begins within a few weeks for heavily oiled leaves.

Indeed, defoliation was already well underway in some areas of the swamp at the time of the survey. In some areas, such as location SS2-3 much of these leaves will be trapped in sediments associated with the poorly flushed bodies of water that characterise the area. Much of the oil associated with these leaves will be well weathered and consequently of little biological concern. In other areas, such as the open fringes between Sixth and Fifth Creek, mangrove leaves will tend to be swept out into the Gulf, possibly to be incorporated into adjacent seagrass habitats. Again, this is of little biological concern given the extreme weathering that has occurred, and will occur, and the wide distribution (and hence dilution) of this debris.

Heavily oiled sediments appear to be consolidated into tarmat and little or no sheen or colour was observed rising from this areas.

Overall the mobility of sediment bound oil is likely to be low. Unfortunately, biodegradation also appears to be slow and this will require further monitoring. The behaviour of the oil in the Port Pirie mangrove sediments is unusual, in both its vertical distribution and immobility, to those reported elsewhere in the scientific literature.

Oil in association with seagrass wrack is probably the most significant component of residual oil, both in terms of quantity and potential for remobilisation. This oil is deposited high within the fringing swamps, particularly towards Fifth Creek and is largely inaccessible (Plate 7). As stated earlier non-viscous oils were found below the seagrass and brown films and globules were common in associated and underlying waters. It is highly likely that this is the source of much of the mobile oil within swamp and creeks.

Oil impact occurred during high tide conditions and with high on shore winds. Under these conditions it is possible that both oil and seagrass debris were deposited higher within the swamp than is usually the case. If this is the case then large scale remobilisation of the oily debris is unlikely unless similarly extreme conditions occur or unless they are disturbed by other agents. The inner fringe mangroves against which much of the debris is deposited, have effectively baffled the movement of both oil and debris and so it is possible that less extreme weather and tidal conditions could result in remobilisation of both oils and seagrass debris. Indeed, such movement was observed during the field survey programme. The degree or intensity with which this may occur cannot be quantified.

Manual removal of debris is not recommended, and probably not feasible. To attempt to remove such large volumes would be very demanding of labour and would result in much physical disturbance to both mangroves and sediment. It is also likely to result in much mobilisation of oil and debris and consequently in reoiling of adjacent areas and of free oil finding its way to open water. This happened for some weeks after the spill.

4.3 EFFECT OF OIL ON MANGROVES

The most obvious effect of oil impact to date has been leaf staining, discolouration (chlorosis), leaf death (black and curled) and, in some areas, defoliation. This damage may extend to both unoiled and oiled sections of the canopy. The extent and nature of damage in oiled sections of the canopy is difficult to assess because the oily stain is generally uniform, thick and dark. Leaf damage in the unoiled canopy provides a better indicator of tree fitness or stress.

Although, no clear association between the extent of general leaf damage in the unoiled canopy, and percentage level of oiling is evident at present. Extensive leaf damage, in both oiled and unoiled canopy, in the heavily oiled trees was dramatic and clearly related to the oil impact (Plate 2). Defoliation was observed in moderately and heavily impacted sites, but was more pronounced in the heavily oiled locations. The loss of oiled leaves was expected and has been generally observed in a number of spills and field trials (Wardrop and Wagstaff, in press; Wardrop et al 1987). Damage to, and particularly loss of, unoiled leaves is a more significant observation in early post-spill monitoring programmes and provides a better indicator of the damage caused to the mangrove tree or shrub. Consequently, it is also a better indicator of likely longer term damage or recovery. It is important, therefore, that damage to oiled and unoiled canopy is recorded separately.

The changing level of damage (including staining) in the oiled canopy will provide a good indication of leaf renewal, particularly where heavy oils ensure that an oiled leaf remains stained. ie. As tree recovery occurs the percentage leaf damage should drop to levels comparable to the initially observed levels of the unoiled foliage. However, such data will be interpreted against the photographic record.

Past studies using fresh crude oils have suggested that defoliation should reach a maximum about 4-12 weeks post spill. It was evident in the present study that defoliation had in fact only started. This may reflect the relatively 'heavy' nature of the oil ie. the relatively low concentrations of the lighter oil fractions which tend o be most toxic. It is likely that much of the leaf loss is due to the physical effects of the oil rather than a chemical toxicity resulting from the absorption of the light oil fractions. Consequently the rate of leaf loss is expected to be slower than that achieved in the earlier studies.

Deleterious effects on fauna associated with the mangrove swamps was not specifically studied in the programme although the cormorant colonies in the region were visited during the reconnaissance survey. Remains of animals were noted on the field data sheets wherever observed but observations were limited to one skeletal remains of a cormorant at location SS1. Indeed, very little evidence of fauna was found during core sampling in the mangrove swamps. As noted earlier, polychaete burrows were found at one site (FS2), filled with oil. No polychaetes were observed.

An interesting observation made in the field was the absence of mosquitoes in the oil impacted sectors. This was not noted until unimpacted sites at Port Davis and Port Adelaide were visited. The difference in mosquito abundance was not qualified but was clearly evident. The significance of this observation is unclear. It is quite possible that mosquito numbers in the Port Pirie mangroves are naturally low compared to the control sites or that the heavy rains, and resultant freshwater outflow from creeks had depressed numbers.

It is also possible that the apparently low numbers are due to the oil, either through the oil impact, or the presence of oily sheen or films on sediments and bodies of water within the swamp. A simple mosquito survey should be considered as part of any future monitoring programme.

The sampling regime, including the experimental design, the measure of damage, and the number of plans, seems adequate to assess gross effects on mangroves of heavy oiling. Measurements at 9 and 15 months will provide the information necessary to determine effects of oiling over time. However, the confidence about conclusions from this study can be significantly bolstered, with a comparatively small amount of extra effort, by immediately marking several more plants. This would permit both a more rigorous analysis of oiling effects, and the addition of a sampling date at 24 months after the spill, aimed at assessing recovery of heavily oiled mangroves.

4.4 AN ASSESSMENT OF POTENTIAL LONG TERM EFFECTS

Long term damage, to both mangrove swamps and individual trees, resulting from single oil spills have been reported from post spill studies although relatively few such studies have monitored impacted sites over a number of years.

Several reports have reviewed the available data and it is not intended to do so here. The reviews by Getter et al (1981), Lewis (1983) and Wardrop (1987) are deferred to.

Table 19 summarises the long term effects that have been reported from single spills but, again, it must be stressed that this is based on very few studies. These have dealt with a variety of oil types, mangrove species and swamp types and consequently must be viewed as very broad generalisation. They nevertheless give an indication of the time scale and nature of effects that should be anticipated.

Long term effects have been ascribed to :

- Persistence of oils in sediments. It is known from both laboratory studies and field observation that seedlings may not be able to become established in oiled sediments or else do not thrive. Similarly, deleterious effects on both trees and infauna may be due to the uptake of these persistent oils.

- Decreased sediment stability, due to either the death of surface algaes or loss of mangrove root mass.

- Slow weathering of persistent oils. Mangrove sediments are generally anaerobic below the surface 0-2 cm. Oil penetrating deeply into sediments are therefore unlikely to be biodegraded.

TABLE 19 GENERAL RESPONSES OF MANGROVE FORESTS TO OIL SPILLS (Adapted from Lewis, 1983)

Stage		Observed Impact
Acute	0-15 days	Death of birds and other fauna exposed to oil.
	15-30 days	Defoliation and death of small mangroves (<m). Loss of associated root communities.
Chronic	30 days- 1 year	Defoliation and death of medium mangroves (<3m). Tissues damage to aerial roots (pneumatophores)
	1-5 years	Death of larger mangroves (>3m). Loss of aerial roots and regrowth of new roots (possibly deformed).
	1-10 years	Recolonisation of oil impacted areas by new seedlings. Reduced production and leaf litter fall. Reduced seedling survival. Death or reduced growth of young colonising tress and saplings. Possible increased insect damage.
	10-50 years	Complete recovery.

The likelihood of those factors influencing long term effects, and the degree to which they may occur is dependent on a number of factors including swamp morphology, sediment type, and the distribution of oil within the swamp and sediments.

Various swamp types, and oil impacts have been classified according to their susceptibility to oil spills, the likely persistence of the oil, and their potential for biological damage. These are given in Table 20 (Getter et al, 1981). The swamps of South Australia do not readily compare in structure or morphology to those of North America which were used to develop this index. Even though the impact of the spill at Port Pirie extended from an outer fringe to a near inner fringe impact, the sparsity of the mangrove fringe is likely to reduce the overall susceptibility of the swamp.

TABLE 20 PREDICTED RELATIVE EFFECTS ON VARIOUS MANGROVE FOREST TYPES RANKED BY SUSCEPTIBILITY, PERSISTENCE AND SENSITIVITY (Derived from Getter et al, 1981)

Oil Spill Vulnerability	Susceptibility to Oil Impact	Potential Duration of Impact	Observed Sensitivity of Forest Type
Forest Type			
Low Potential For Biological Damage			
Riverine Forest	-	0	-
Overwash Forest	+	-	-
Moderate Potential For Biological Damage			
Dwarf Forest	-	+	0
Outer Fringe Forest	+	-	0
High Potential For Biological Damage			
Inner Fringe Forest	0	+	+
Basin Forest	0	+	+

+ High Vulnerability
0 Moderate Vulnerability
- Low Vulnerability

The degree of flushing in the innermost spill impact zones in the Port Pirie swamps is likely to be far greater then those in the 'inner fringe swamp' impact in Getters' index and general levels of exposure will be far greater. Indeed, the Port Pirie impact distribution is likely to be closer to an overwash/dwarf forest impact in those mangroves close to the shoreline, and an outer fringe impact in the innermost impacted swamps. This is consistent with observations made of the height (maximum and minimum) of oiling, and degree of sediment oiling.

The lightly oiled and moderately oiled areas of the swamp would appear to be well flushed and drained and so the likely persistence of oil or oily debris is likely to be low. Consequently little long term damage is expected to occur in these areas. The influence that the continued input of sheen, from heavily oiled areas, will have on this prognosis is however difficult to quantify. It is not unlikely that the levels of this contamination are high enough to cause gross damage to lightly oiled mangroves or to significantly retard recovery. This should be monitored though.

Heavily oiled areas are already showing signs of defoliation and oil is clearly persistent. This tarmat is likely to constitute a physical barrier to colonisation by seedlings, even if the toxic components of the oil residue are not present. Coverage of the sediment surface is variable and even in heavily oiled areas exposed oil-free sediment is present. Generally these oil free patches are in the open areas and so seedling establishment is expected to occur. Seedling numbers within the swamp are low and so recolonisation is expected to be slow.

The tarmat is not considered to be a likely source of chronic oil pollution. The large deposits of oiled seagrass wrack are likely to be the source of chronic oil release and this may include light oil fractions originating from the diesel component of the fuel oil. Again, the significance of these levels of chronic oil pollution to the rate of recovery of trees, or recolonisation of oiled areas by seedlings, is unclear.

The fact that the vast majority of the residual oil is in the surface of the sediment suggests that this oil persistence will not be a significant factor in long term effects or inhibition of recovery.

The most likely source of such longer term effects is the oil associated with the seagrass wrack deposited along the inner fringes of the swamp. This material would constitute a significant potential source of damage if remobilised on a large scale. Possible effects would be more likely to be associated with smothering of pneumatophores rather than toxic effects of lighter oil components. This is because the weather and tide conditions that would release the debris quickly, would also lead to rapidly disperse free floating oil.

It is important that the character of oil associated with this debris be monitored and that any effects on adjacent mangroves be assessed.

One potential influence of this seagrass debris is the effect on underlying sediment temperatures and oxygen levels. Temperatures are likely to be elevated due to the dark colour of the wrack and oxygen levels are likely to be depressed due to reduced flushing or biodegradation. Indeed, this lack of oxygen may be a factor limiting the degradation of oils beneath these areas. elevated temperatures are also likely beneath the weathered tarmat in the heavily oiled areas. The consequence of these, should they occur, are not known but sediment temperature should be added to the list of parameters measured in future monitoring programmes.

Overall, the probability of long term damage is considered to be low. Open well flushed swamps such as these are not as sensitive as denser mangrove areas due to the reduced potential for the retention of unweathered oils and the lower reliance of trees on pneumatophores (see Dicks, 1986). This renders them less susceptible to smothering effects. Since the oil which impacted this region is a heavy weathered fuel oil, smothering is likely to be a prime cause of biological damage.

The potential problems associated with the oily seagrass wrack is nevertheless a source of some concern, not only for the associated mangrove areas but also for subtidal areas and associated surface waters. Refloated oily wrack is unlikely to be a concern in terms of toxicity but may have nuisance value for recreational or professional fishermen.

However, the scale of the problem should not be overstated. Only a relatively small area of swamp was impacted by oil and the heavily impacted areas cover a very small area compared to the extent of mangroves in the region.

5.0 RECOMMENDATIONS

5.1 CLEANUP

Cleanup of residual oil is not feasible at present. Oil on sediments is weathered and oil associated with seagrass debris constitutes too great a volume to be handled by manual methods. Generally oil was deposited, and remains, on sediments approximately 30m from the coastal edge and consequently manual cleanup methods would be hampered by logistical difficulties. Substantial damage to mangrove swamps may result from cleanup attempts.

5.2 MONITORING

It is recommended that monitoring of the swamp be continued. Monitoring should emphasise the :

- Distribution and mobility of residual oil (TPH and total oil and grease analysis by GCFID) on surface 0-5cm of sediment and at all stations established between Sixth Creek and Fifth Creek.

- Visual monitoring of oil distribution between Fifth Creek and Fourth Creek, and southwest of Sixth Creek.

- Assessment of degradation of the oil (nC17/Pristane and nC18/Phytane ratios, obtained by GCFID).

- Gross changes in mangroves within the swamp generally, and at established monitoring sites between Sixth Creek and Fifth Creek.

Detailed monitoring of mangroves is not recommended. Variability within the swamp makes the identification of control sites difficult and subtle changes cannot be ascribed to oiling or degree of oiling.

This broad monitoring programme should be supported by aerial photography. This is important in qualifying the area of any defoliation and, if necessary, monitoring any change in oil distribution. Aerial photography may also provide data relating to any gross changes in inshore seagrass communities.

The monitoring programme should be extended to include an approximate measurement of mosquito numbers, or numbers relative to other areas of swamp.

Sediment temperatures below dark oily mats (tarmats) should also be measured.

5.3 SPILL PLANNING

It is recommended that a post spill survey, to determine the distribution, volume and potential mobility of beached oil, should be incorporated into all oil spill contingency plans. This is essential for coastlines where 'no cleanup' of beached oil is likely to be recommended. This information must be accurately recorded.

Such an assessment is justified as a support for oil spill response and, if planned, could be funded as part of the spill response.

An immediate assessment of oil distribution and character is also necessary if other monitoring programmes, or cleanup effects are to be well directed and efficiently undertaken.

6.0
PLATES

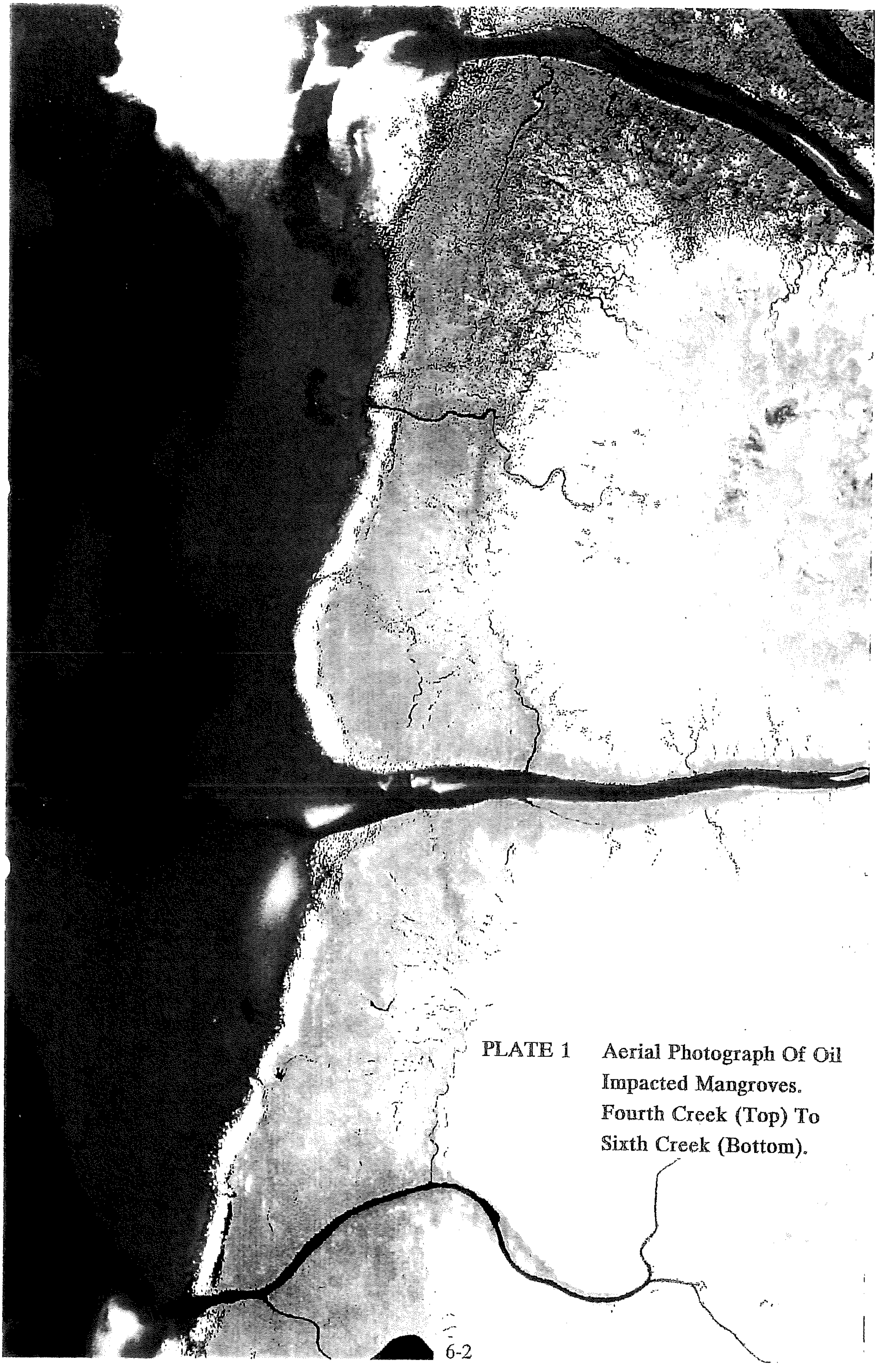

PLATE 1 Aerial Photograph Of Oil Impacted Mangroves. Fourth Creek (Top) To Sixth Creek (Bottom).

PLATE 2 Heavily Oiled Mangroves. Note The Level Of Leaf Damage Occurring Above The Oiled Zone (Location SN1 and SN5)

PLATE 3 Moderately Oiled Mangroves (Location FS1)

PLATE 4 Lightly Oiled Mangroves. (Location SN6)

PLATE 5 Oil In Mudcrab Burrows (Location SE1)

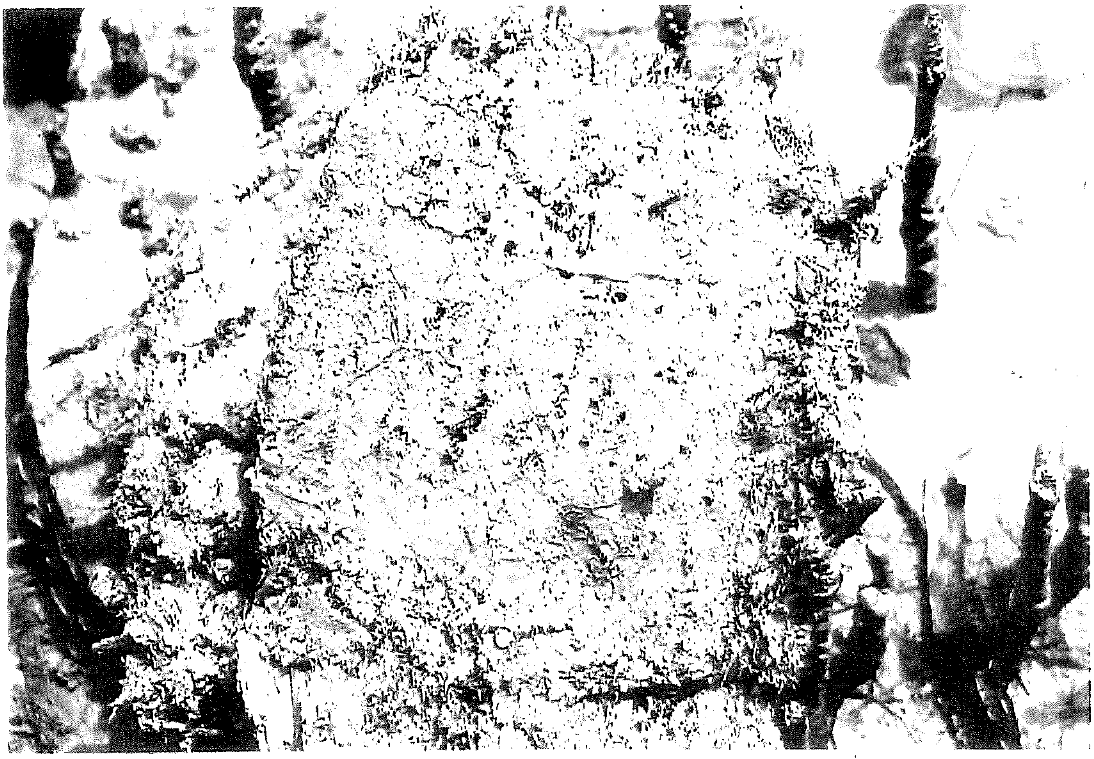

PLATE 6 Oil In Sediment. Oil Retained In Polychaete Burrows (Location FS2)

PLATE 7 Oiled Seagrass Debris (Location FS3)

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APPENDIX A

FIELD DATA SHEETS

MANGROVE FITNESS AND OILING
DATA SHEET

SITE OR TRANSECT NO:____________________ **Page 1**
OPERATOR ________________________________ **DATE** __________

	TREE NUMBER									
TREE DATA										
Height (m)										
Form (Tree/Mallee/Shrub -Bush/Sapling/Seedling)(1)										
Height Of Canopy from Sediment										
Oil/Stain Present (Y/N)										
Oil Wet(W)/Tacky(T)/Dry(D)										
Height of Oiling (m) - Max										
Min										
Extent of Oiling (Y/N) Trunk										
Branches										
Leaves										
Pneumatophores										
Est % of Leaf Oiling (% of oily zone)										
Foliage (Dense/Mod/Sparse) Oiled Section										
In Unoiled Section										
General Leaf Damage (% based on 20 random leaves) In Oiled Section										
In Unoiled Section										
Blackened Curled Leaves (In Unoiled Section)										
Source of Damage (Oil/Insect/Fungi/Not Det.)										
Pneumatophore Around Tree[3] Est/0.1m^2										
(Dense/Mod/Sparse/None)										

MANGROVE FITNESS AND OILING
DATA SHEET

SITE OR TRANSECT NO:____________________ **Page 2**
OPERATOR ________________________________ **DATE** ____________

	TREE NUMBER									
SEDIMENT DATA										
Colour										
Pneumatophores (Est No/M^2) (Open Sediment)										
Sediment Oil Stain (Y/N)(2)										
Colour of Oil (Black/Dark Brown/Brown/Other)										
Oil Wet(W), Tacky(T), Dry(D)										
% Oil Cover (% est.)										
Sample(s) Taken Tree										
Sediment										
Other										

(1) Tree, Mallee, Bush, Sapling, Seedling.

(2) Hexane Test positive H+ negative H-
Dichloromethane positive D+ negative D-
Personal Assessment + or -

(3) Calculated at ⅓ distance between the trunk and outer limit of canopy

POST SPILL SHORELINE ASSESSMENT
FIELD DATA SHEET No______

SITE DESCRIPTION :	SURVEY DETAILS
Type : Mangrove/Swamp	Survey/Study Name :'Era' Spill, Port Pirie
Energy/Exposure	Date
Vegetation/Fauna	Time
Sediment	Location No
Map Ref	GPS: Lat
Other	Lon
	Team/Author (circle) JW BW RC

A. MANGROVES - General Description

Height : (Ave est)______ m (Max est)______ m
Form : Tree/ Mallee form/ Shrub-bush/ Saplings only/ Seedlings only
Canopy Cover : Open/ Medium/ Dense (Closed)/ est % ______
Tree Canopy/Cover : Dense/ Mod/ Sparse/ Partly defoliated
Pneumatophores : Open sediment ______per m^2 (est)
Around stems : Few/ Moderate/ Dense Clusters
Leaf Fitness : (Based on random 10 branches & last 4-5 rachides per site) ______% damaged
Other Notes : ______

A.2. Individual Tree Descriptions (If Required)

Tree Marker No					
Height (m est)					
Leaf Damage %					
Defoliation ? (Y?N)					
Extent of Defoliation : % lost est : Height Above Sedt					
Any Other Signs Of Damage ? (Y/N)*					
Samples Taken ? (Enter Sample No)					

* Other Notes ______

B. RESIDUAL OIL DISTRIBUTION AND ASSESSMENT

B.1 Mangroves

Is Stain Present On : Leaves/ Branches/ Trunk/ Seedlings (Circle any/all)
Is Cover Uniform On All Trees At Site ? Yes/No
Height At Which Staining Is Evident : ______m above sedt (lowest)
______m above sedt (highest)
Extent Of Oiling At Site (% Within Oiled Profile est)______%

Character of Residue	1				
Colour (BL,DB,B,LB)[2]					
Odour (Y/N)					
Residue Still Wet (W) or Dry(D)					
Hexane Test (+/-/N.D.)					
DichloroMethane Test (+/-/N.D.)					

Samples Taken : Yes/No
Sample Nos : ______;______;______;______;______;
______;______;______;______;______

Other Notes/Conclusions :______________________________

B.2. Sediment

Is Stain Present On Surface (Visual) Yes/No
Is The Stain : Uniform/ Patchy-Mottled/ Occasional Patches/ Few Patches
Estimate % Area Covered : ______%
Hexane Test : Positive/ Negative/ Not Done
DichloroMethane Test : Positive/ Negative/ Not Done
Core Samples Taken : Yes/No

Character of Residue					
Depth					
Odour					
Colour[2]					
Hexane (+/-/N.D.)					
DichloroMethane (+/-/N.D.)					
Sample Taken (Enter No)					

Sediment Samples Taken For Analysis : Yes/No
Sample Nos : ______;______;______;______;______;
______;______;______;______;______

Other Notes/Conclusions :______________________________

N.B. 1. Enter type of sample (leaf/Pneumatophore etc) or sample or tree no.
2. Bl + Black; DB = Dark Brown; B = Brown; LB = Light Brown (enter other)

C. GENERAL SITE NOTES/PROMPTS

Is There An Obvious Source Of Leaf Damage : Yes/No
If Yes : Scale Insect/ Other Insect/ Fungi/ Oil/ Other
If No, Comment : ______________________________
____
____

Is There Any Evidence Of Seawater Pooling Or Other Poor Drainage : Yes/No

Sediment Colour/Texture (Describe) : ______________________________
____
____

Depth Of Sediment Water Table ______cm (est/measured)
Evidence Of Oil-Like Sheen On Water (Sedt) Yes/No
In Seeps Yes/No
In Channels Yes/No
Is The Sediment At This Site Generally Typical Of The Area Yes/No
If No, Comment :______________________________
____
____

Are There Any Dead Specimens Or Remains Of Fauna Present Yes/No
If Yes : Mudcrabs/ Polychaetes/ Barnacles/ Molluscs/ Birds/ Fish
Further Details :______________________________
____
____

Does Sediment Have Obvious Cover Of Algae : Yes/No
If Yes ______% (Cover Est)
Is There Ulva Or Other Algal Debris Present : Yes/No
If Yes______% (Distribution/Levels)
Is There Other Debris Present : Yes/No
If Yes, Comment :______________________________
____
____

Other Notes/Comments : ______________________________
____
____
____
____
____
____
____

D. SAMPLE RECORD

Sample No	Analysis Required				Sealed (Date)	Despd (Date)	Recd (AES)
	TPH	Oil Charact	Sedt. Size	Organic			

GENERAL NOTES :

APPENDIX B

ADDITIONAL CHEMICAL DATA AND CHROMATOGRAPHS

SAMPLE NUMBERS

Sample No	Location	Depth (cm)/Character
1	SS3	Surface (0)
2	SS2	1 - 2
3	SS2	2 - 5
4	SS1	Oily Residue (Surface)
5	SS1	Surface
6	SS1	5 - 10
7	SS1	2
8	SS1	Seagrass Debris
9	SS1	Seagrass Debris
10	SN1	0
11	SN1	2
12	SN1	10
13	SN1	5
14	SN1	Mangrove Leaves
15	SN1	Seagrass Debris
16	SN2 Core A	0
17	SN2 Core A	2
18	SN2 Core A	5
19	SN2 Core A	10
20	SN2 Core B	0
21	SN2 Core B	2
22	SN2 Core B	5
23	SN2 Core B	10
24	SN3	0
25	SN3	2
26	SN3	5
27	SN4	0
28	SN4	2
29	SN4	5
30	SN5	0
31	SN6	0
32	SN6	2

SAMPLE NUMBERS (cont)

Sample No	Location	Depth (cm)/Character
33	SN6	5
34	SN6	10
35	FS4	0
36	FS2	1
37	FS2	5
38	FS3	0
39	FS3	Seagrass Debris
40	FS2	0
41	FS2	2
42	FS1	0
43	FS1	2
44	FS1	5
45	FS1	Mangrove Leaves
46	FS1	Seagrass Debris
47	FS1	Seagrass Debris
48	FN2	0
49	FN1	0
50	FN5	0
51	FN5 - 6	Oily Residue
52	FN5 - 6	Oily Residue
53	FN5 - 6	0
54	FN5 - 6	0
55	FN5 - 6	0
56	SE1	0
57	SE1	2
58	SE1	5
59	SE1 Sample B	0
60	SE1	Samphire
61	SE2	Samphire
62	Port Davis	0
63	Port Davis	1 - 2
64	Port Adelaide A	0

SAMPLE NUMBERS (cont)

Sample No	Location	Depth (cm)/Character
65	Port Adelaide A	2
66	Port Adelaide	5
67	Port Adelaide	0
68	Port Adelaide	2
69	Port Adelaide	5
70	Spencer Gulf	Oil Sample (Sept, 1992)
71	Spencer Gulf	Oil Sample (Oct, 1992)
72	"ERA"	Reference Oil Sample (Aug, 1992)

RESULTS

Oil Chracterisation (Aromatic Fraction)

After the alumina column clean-up of the four oils, the fraction containing the aromatic compounds was analysed by HRCGC/MS. The following PAHs were detected and are reported.

	AGC Sample No:			
	72	70	71	16
Date Sampled	31/8/92	9/9/92	27/10/92	25/11/92
Parameter	ug/g	ug/g	ug/g	ug/g
Naphthalene	480	<6	<6	<6
Methyl Naphthalenes	3600	10	<6	<6
Biphenyl	190	4	<4	<4
Dimethyl Naphthalenes	6400	380	37	130
Trimethyl Naphthalenes	5300	1500	390	470
Phenanthrene	390	310	190	160
Methyl Phenanthrenes	1500	1300	1000	910
Dimethyl Phenanthrenes	2100	1900	1800	1500
Fluoranthene	10	11	11	10
Pyrene	38	35	33	29
Benz(a)anthracene	13	14	10	10
Chrysene	56	61	60	55
Benzo(e)pyrene	22	25	23	20
Acenaphthylene	<30	<6	<6	<6
Acenaphthene	<30	<6	<6	<6
Fluorene	<100	<40	<40	<40
Sum Benzo(bjk)fluoranthene *	<30	<30	<30	<30
Benzo(a)pyrene	<20	<20	<20	<20
Perylene	<20	<20	<20	<20
Indeno(123-cd)pyrene	<20	<20	<20	<20
Dibenz(ah)anthracene	<20	<20	<20	<20
Benzo(ghi)perylene	<20	<20	<20	<20
Sum PAHs	20100	5500	3550	3300
Surrogate recovery %	102	100	94	89

Note: * The sum of Benzo(b), Benzo(j), and Benzo(k)fluoranthene are reported. Results are reported in ug/g (ppm) on the extracted oil.

Other aromatic compounds were detected in the oil samples. These include:

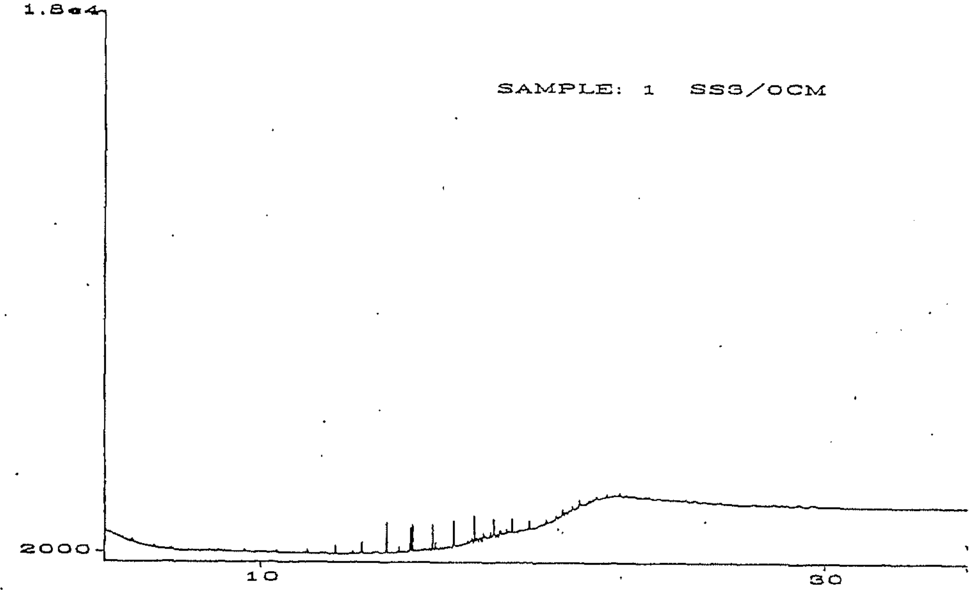
Tetrahydronaphthalenes, C5 alkyl benzenes, Tetrahydromethyl naphthalenes, Tetrahydrodimethyl naphthalenes, Methyl Biphenyls, Dimethyl Biphenyls, C4 Alkyl Naphthalenes, Methyl Fluorenes, Dimethyl Fluorenes, Trimethyl Biphenyls, Tetramethyl Biphenyls, Methyl Anthracenes, Trimethyl Phenanthrenes, and Methyl Chrysenes.

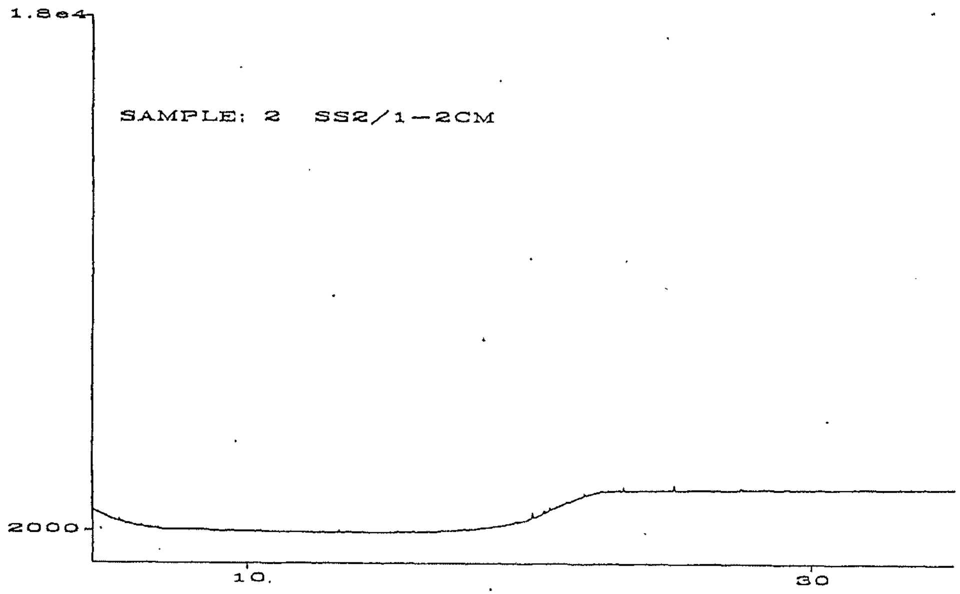
The following sulfur containing polycyclic aromatic hydrocarbons were also detected. Dibenzothiophene, Methyl Dibenzothiophenes, Dimethyl Dibenzothiophenes, and Trimethyl Dibenzothiophenes.

Oil Chracterisation (Saturated Fraction)

	AGC Sample No:			
	72	70	71	16
Date Sampled	31/8/92	9/9/92	27/10/92	25/11/92
Parameter	ug/g	ug/g	ug/g	ug/g
nC10	370	<1	<1	<1
nC11	1300	<1	<1	<1
nC12	2200	<1	<1	<1
nC13	4700	<1	<1	<1
nC14	7500	350	20	42
nC15	9200	2200	320	280
nC16	8300	4800	1300	790
Norpristane	1700	1200	710	480
nC17	7200	6300	2500	1300
Pristane	4200	6300	2350	1800
nC18	5900	6100	2800	1600
Phytane	680	860	550	550
nC19	5000	5400	2800	1600
nC20	4000	4600	2300	1300
nC21	3000	3400	1900	995
nC22	2050	2400	1200	580
nC23	1200	1400	730	250
nC24	720	800	410	66
nC25	480	550	290	80
nC26	350	390	210	<10
nC27	300	310	180	<10
nC28	230	230	140	<10
nC29	190	200	130	<10
nC30	144	150	110	<10
nC31	340	370	330	<10
nC32	160	190	160	<10
nC33	<10	<10	<10	<10
nC34	<10	<10	<10	<10
UCM	90000	58000	55000	41000

Note: Results are reported in ug/g (ppm) on the extracted oil.


SAMPLE: 1 SS3/0CM
1.8e4
2000
10
30


SAMPLE: 2 SS2/1-2CM
1.8e4
2000
10
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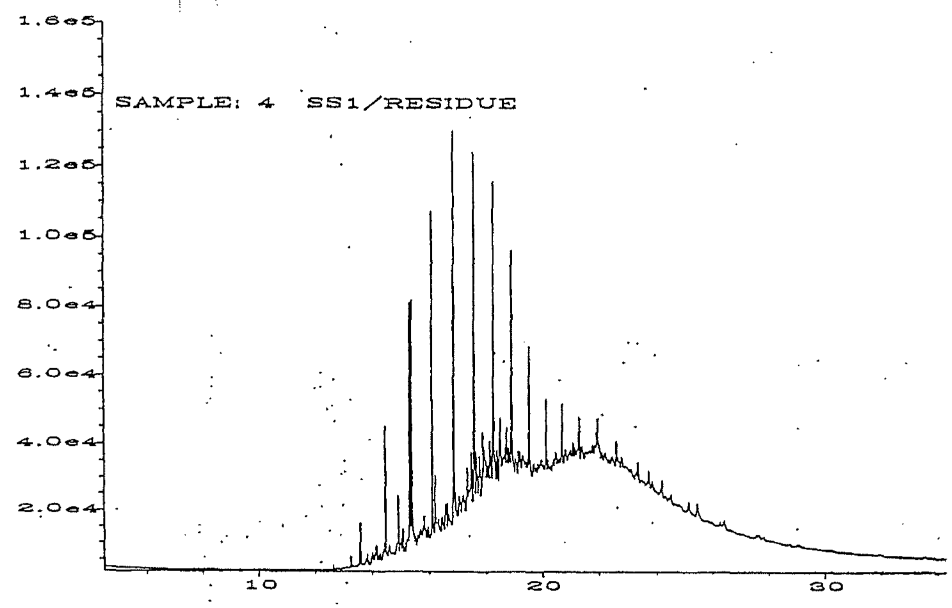
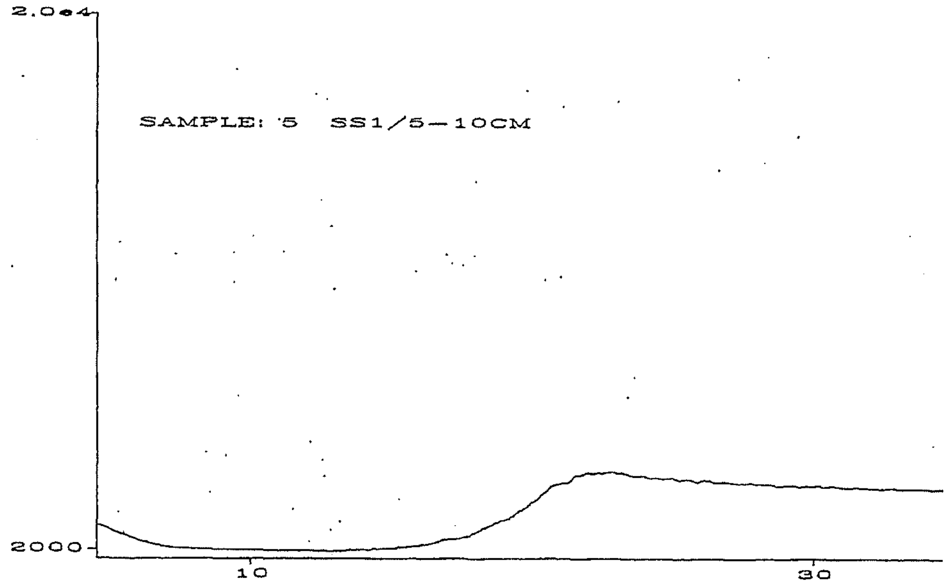
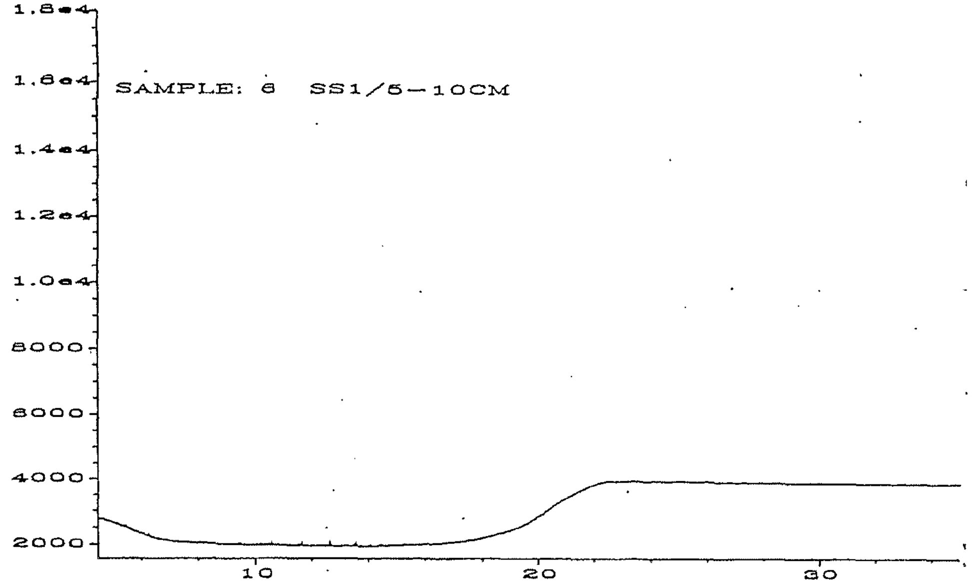
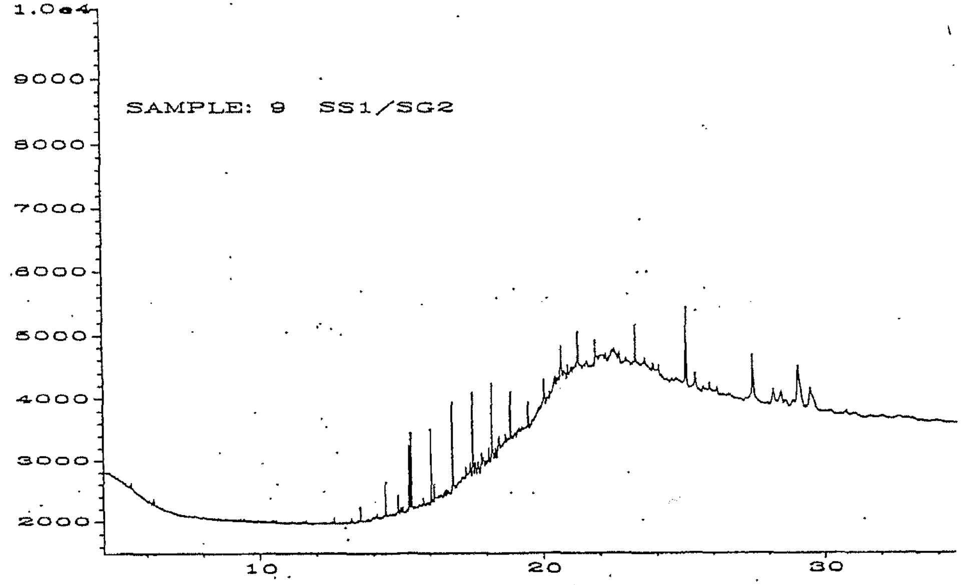
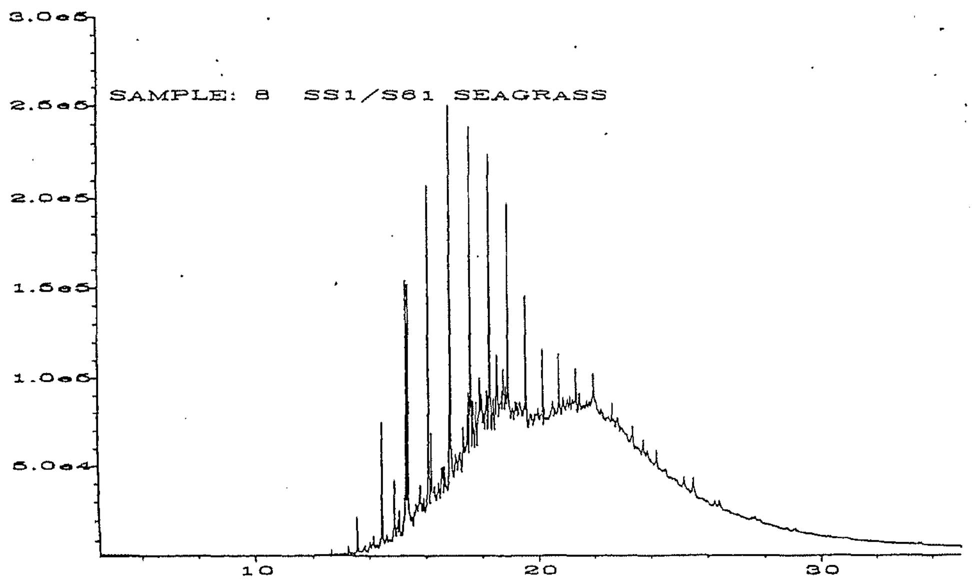
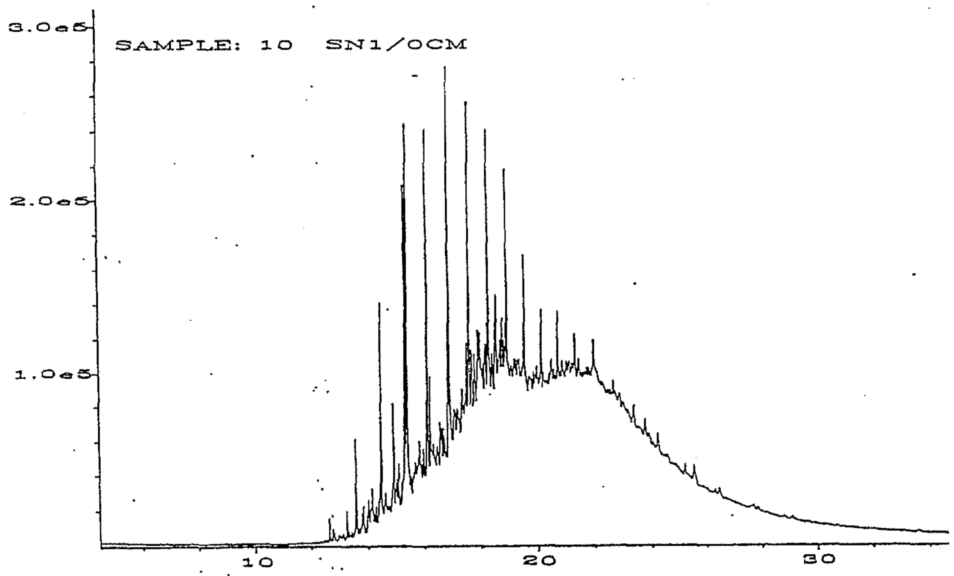

SAMPLE: 4 SS1/RESIDUE
1.6e5
1.4e5
1.2e5
1.0e5
8.0e4
6.0e4
4.0e4
2.0e4
10
20
30

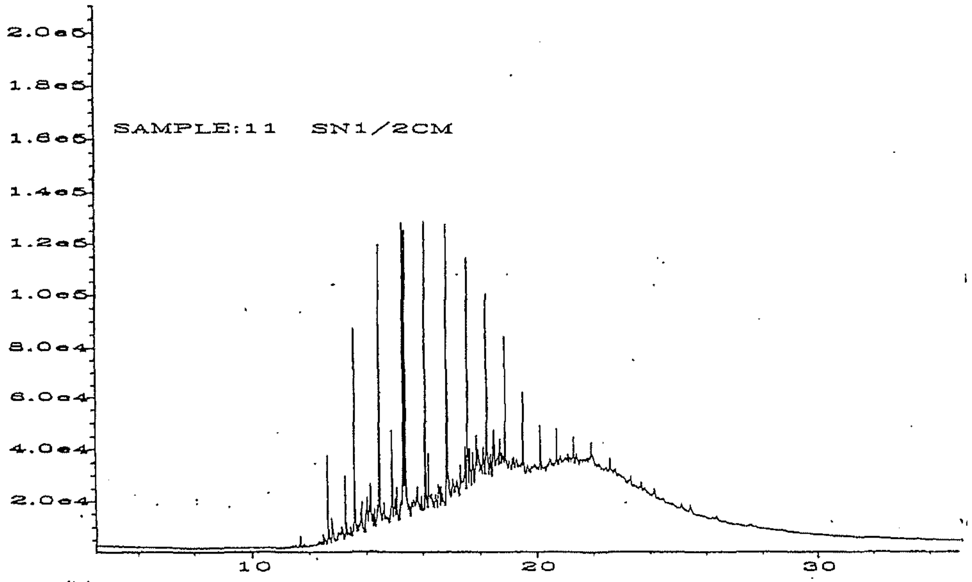

SAMPLE: 5 SS1/5-10CM
2.0e4
2000
10
30

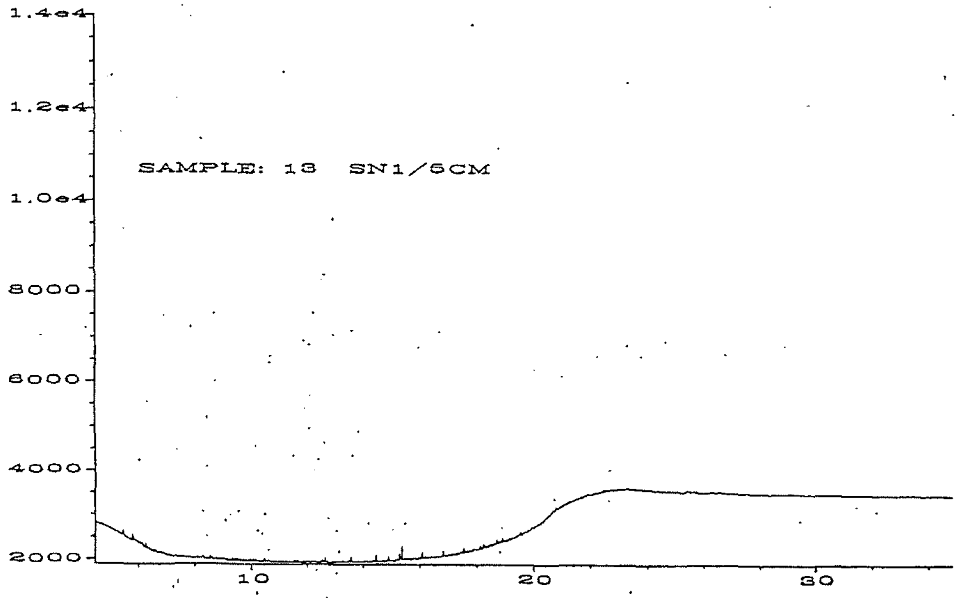

SAMPLE: 6 SS1/5—10CM
1.8e4
1.6e4
1.4e4
1.2e4
1.0e4
8000
6000
4000
2000
10
20
30

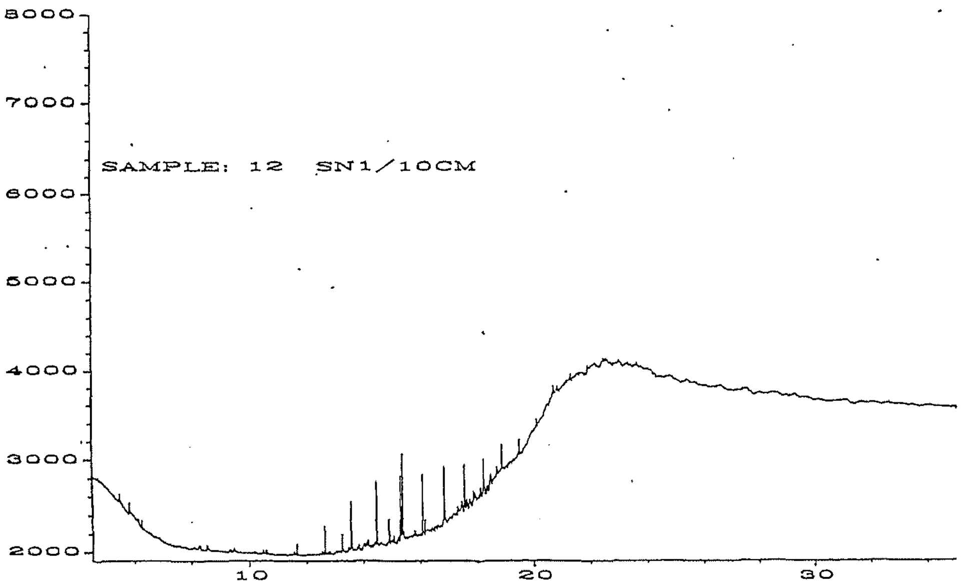

SAMPLE: 9 SS1/SG2
1.0e4
9000
8000
7000
6000
5000
4000
3000
2000
10
20
30

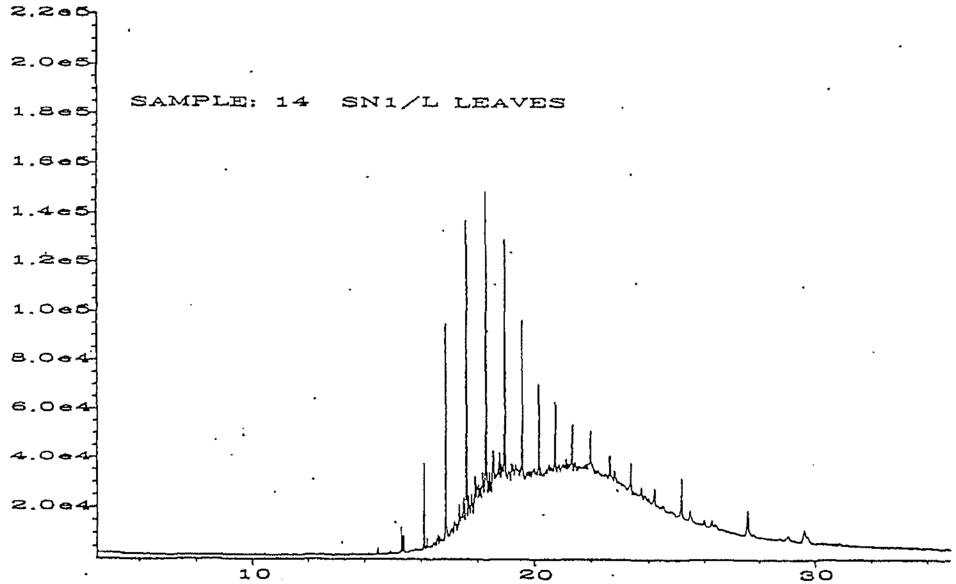

SAMPLE: 8 SS1/S61 SEAGRASS
3.0e5
2.5e5
2.0e5
1.5e5
1.0e5
5.0e4
10
20
30

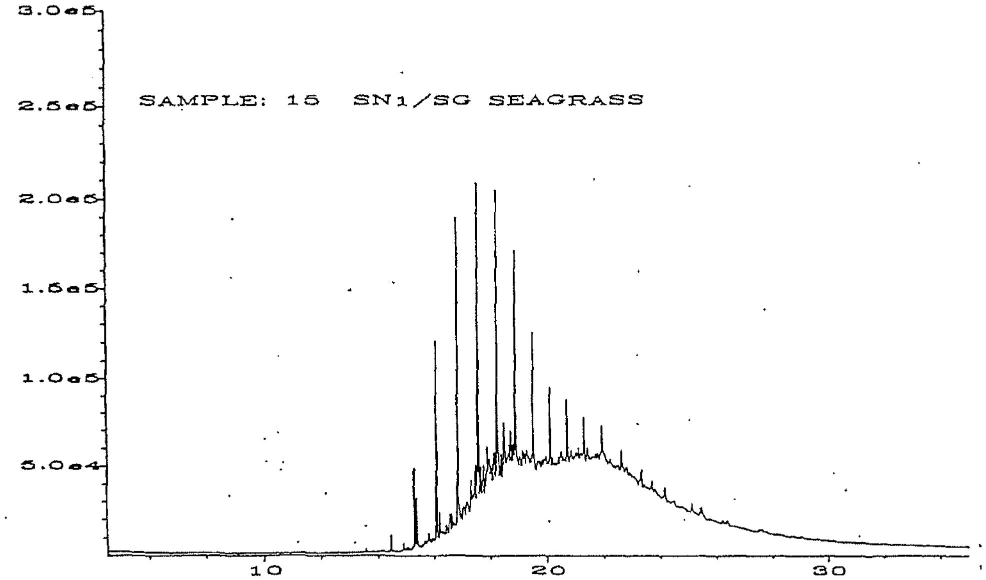

SAMPLE: 10 SN1/0CM
3.0e5
2.0e5
1.0e5
10
20
30

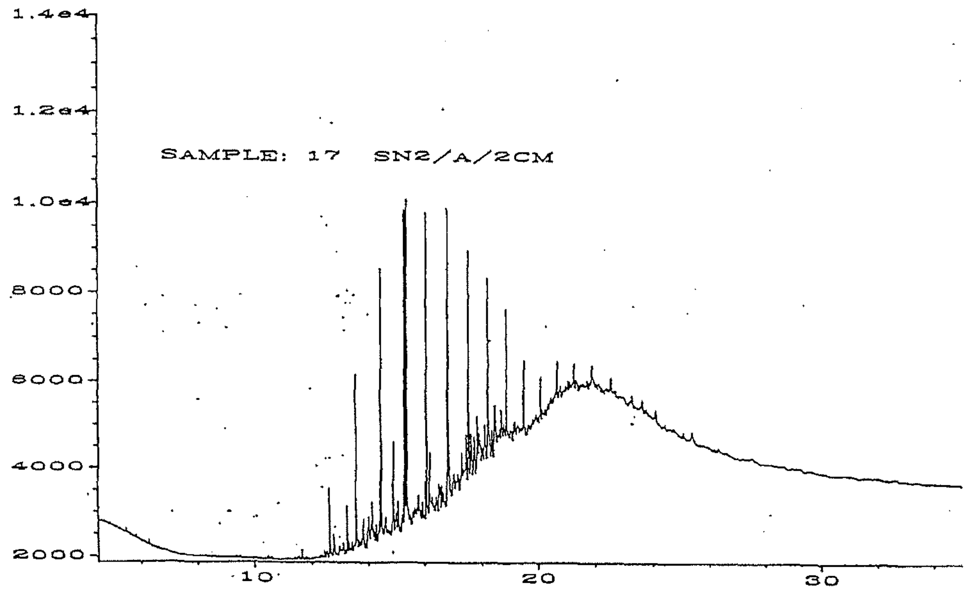

SAMPLE:11 SN1/2CM
2.0e5
1.8e5
1.6e5
1.4e5
1.2e5
1.0e5
8.0e4
6.0e4
4.0e4
2.0e4
10
20
30

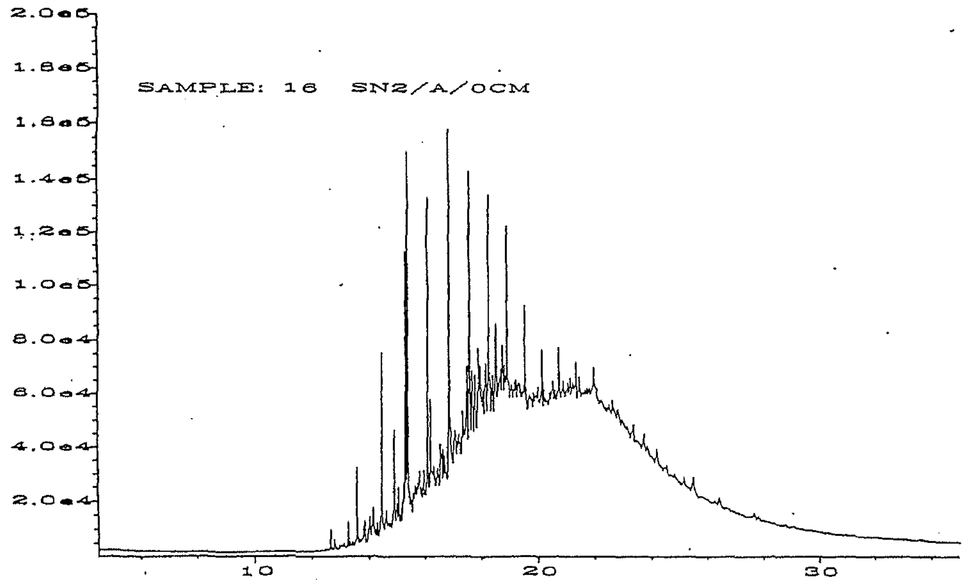

SAMPLE: 13 SN1/5CM
1.4e4
1.2e4
1.0e4
8000
6000
4000
2000
10
20
30

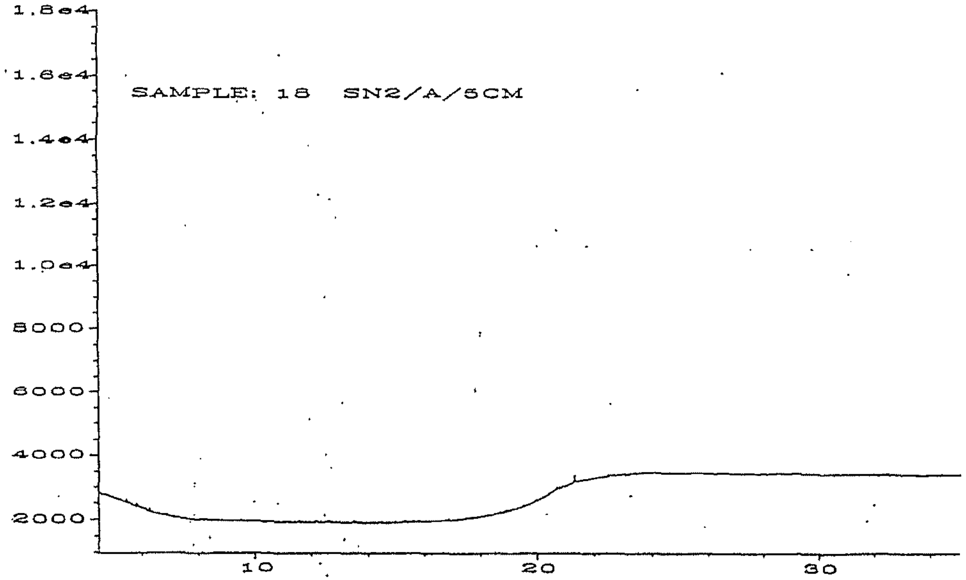

SAMPLE: 12 SN1/10CM
8000
7000
6000
5000
4000
3000
2000
10
20
30

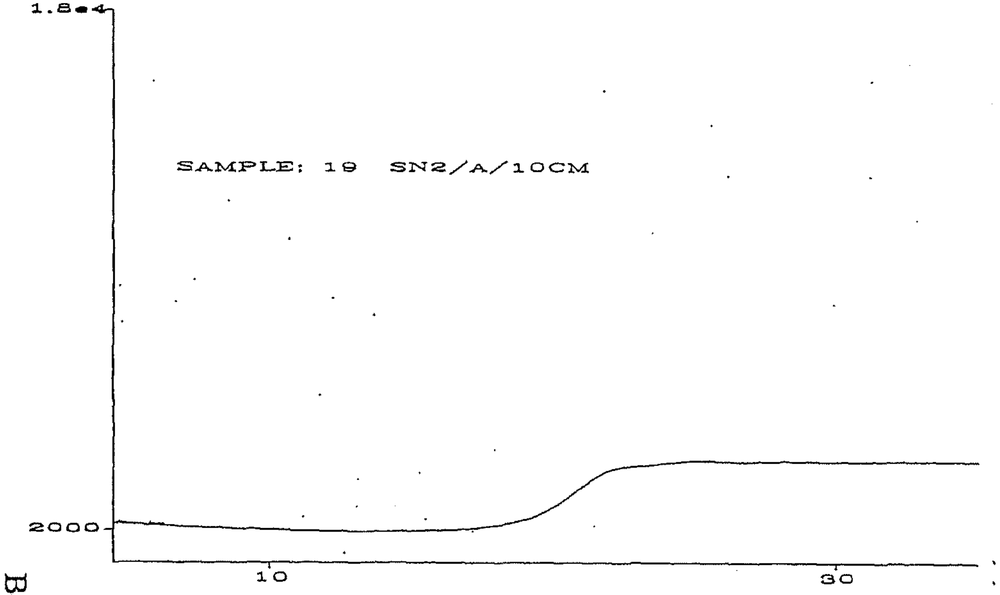

SAMPLE: 14 SN1/L LEAVES
2.2e5
2.0e5
1.8e5
1.6e5
1.4e5
1.2e5
1.0e5
8.0e4
6.0e4
4.0e4
2.0e4
10
20
30

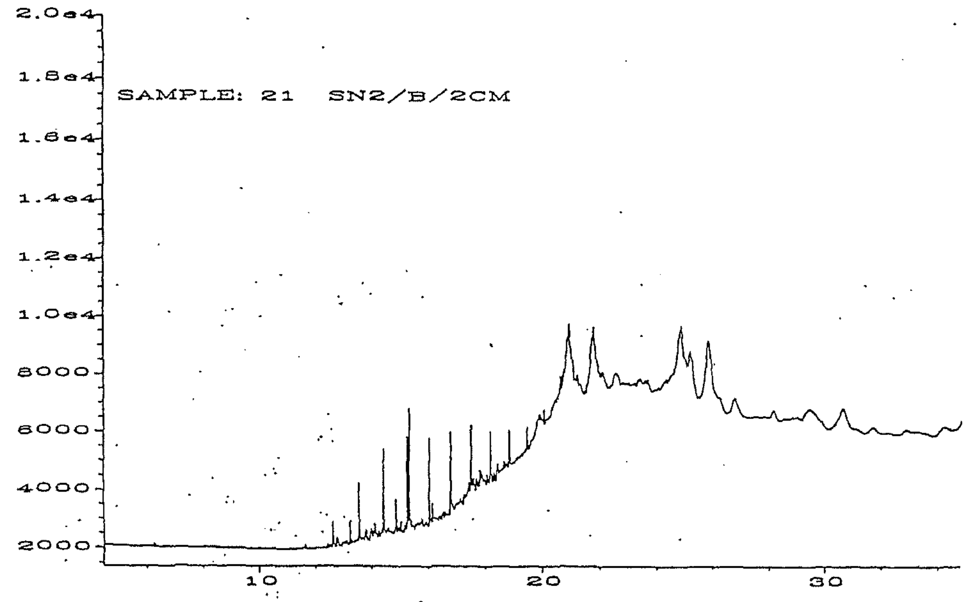

SAMPLE: 15 SN1/SG SEAGRASS
3.0e5
2.5e5
2.0e5
1.5e5
1.0e5
5.0e4
10
20
30

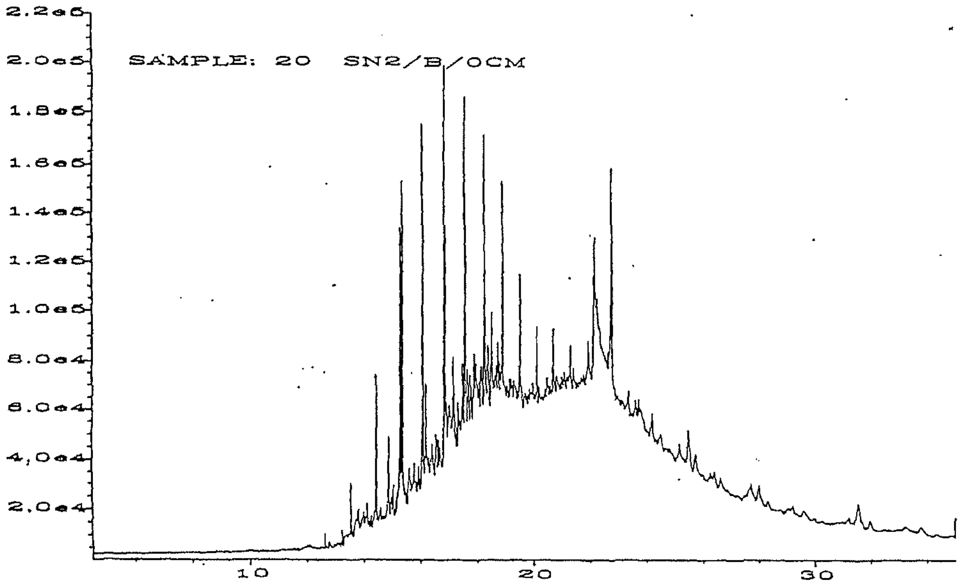

SAMPLE: 17 SN2/A/2CM
1.4e4
1.2e4
1.0e4
8000
6000
4000
2000
10
20
30

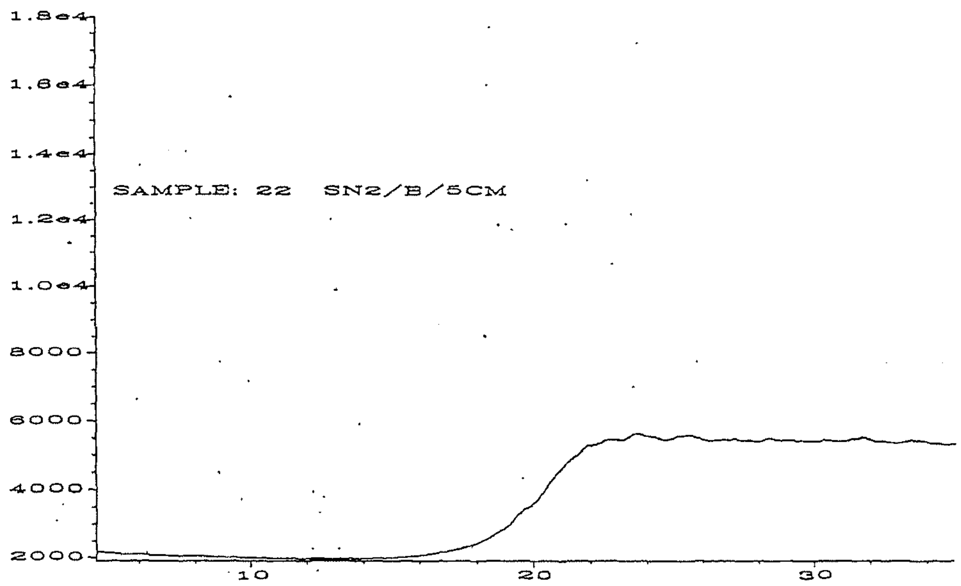

SAMPLE: 16 SN2/A/0CM
2.0e5
1.4e5
1.2e5
1.0e5
8.0e4
6.0e4
4.0e4
2.0e4
10
20
30

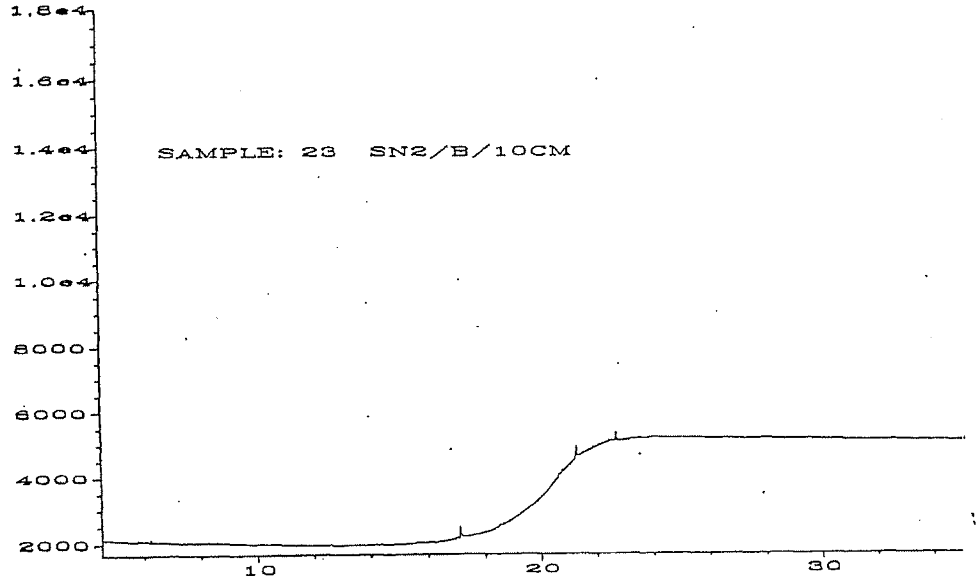

SAMPLE: 18 SN2/A/5CM
1.8e4
1.6e4
1.4e4
1.2e4
1.0e4
8000
6000
4000
2000
10
20
30

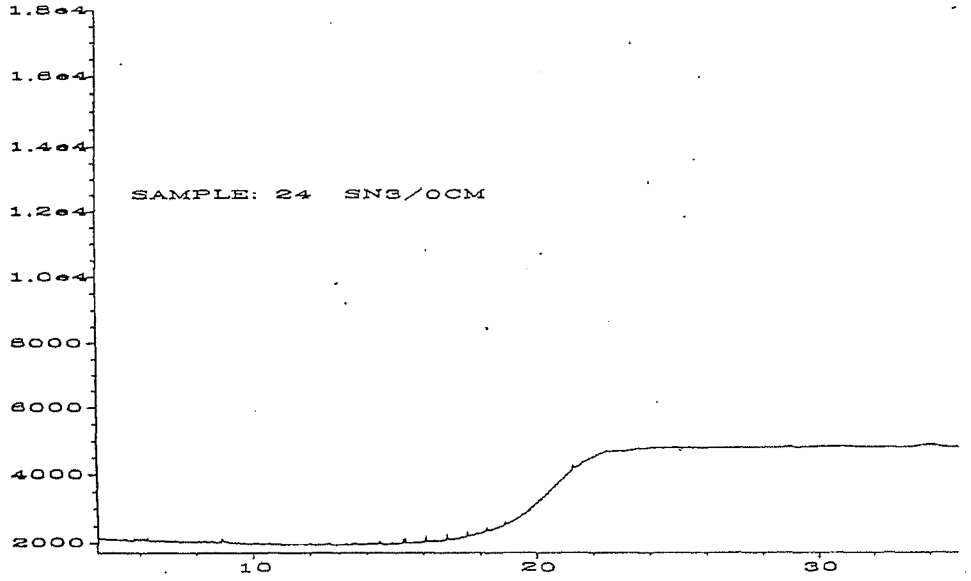

SAMPLE: 19 SN2/A/10CM
1.8e4
2000
10
30

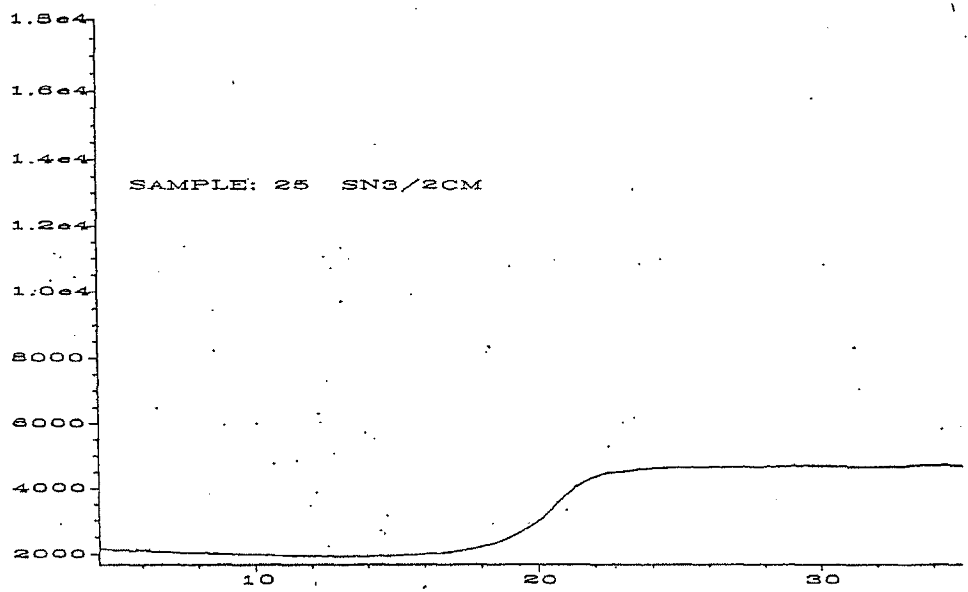

SAMPLE: 21 SN2/B/2CM
2.0e4
1.8e4
1.6e4
1.4e4
1.2e4
1.0e4
8000
6000
4000
2000
10
20
30

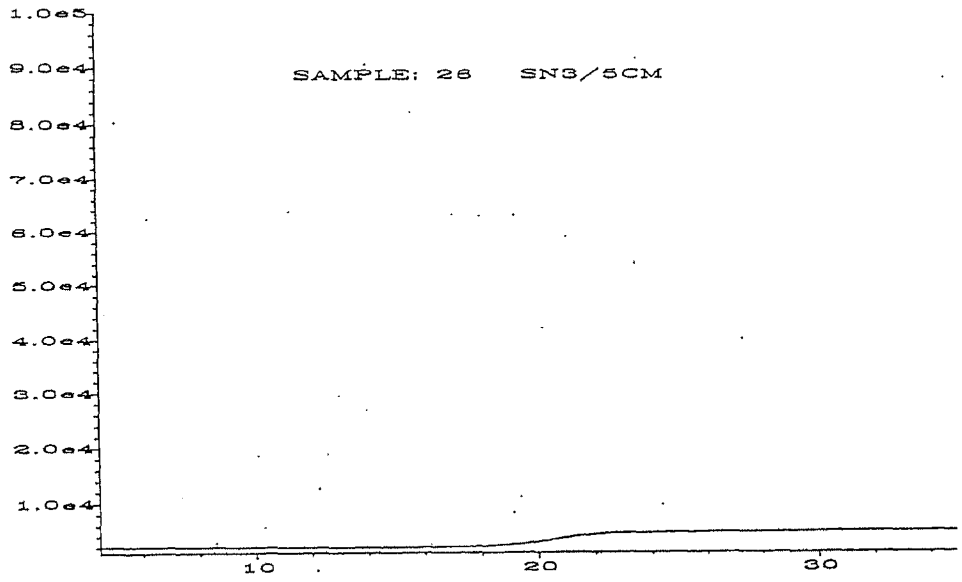

SAMPLE: 20 SN2/B/0CM
2.2e5
2.0e5
1.8e5
1.6e5
1.4e5
1.2e5
1.0e5
8.0e4
6.0e4
4.0e4
2.0e4
10
20
30

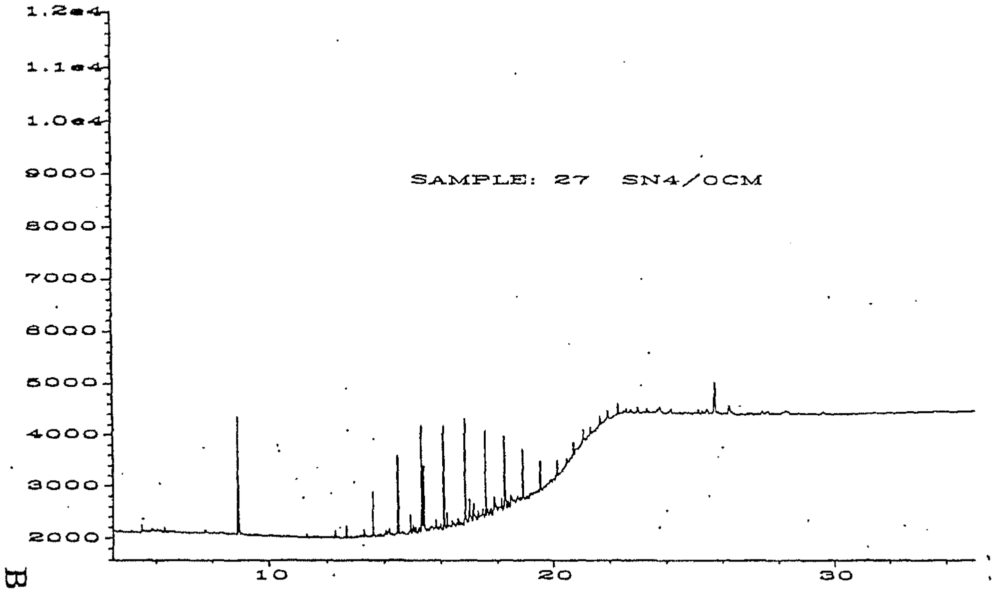

SAMPLE: 22 SN2/B/5CM
1.8e4
1.6e4
1.4e4
1.2e4
1.0e4
8000
6000
4000
2000
10
20
30

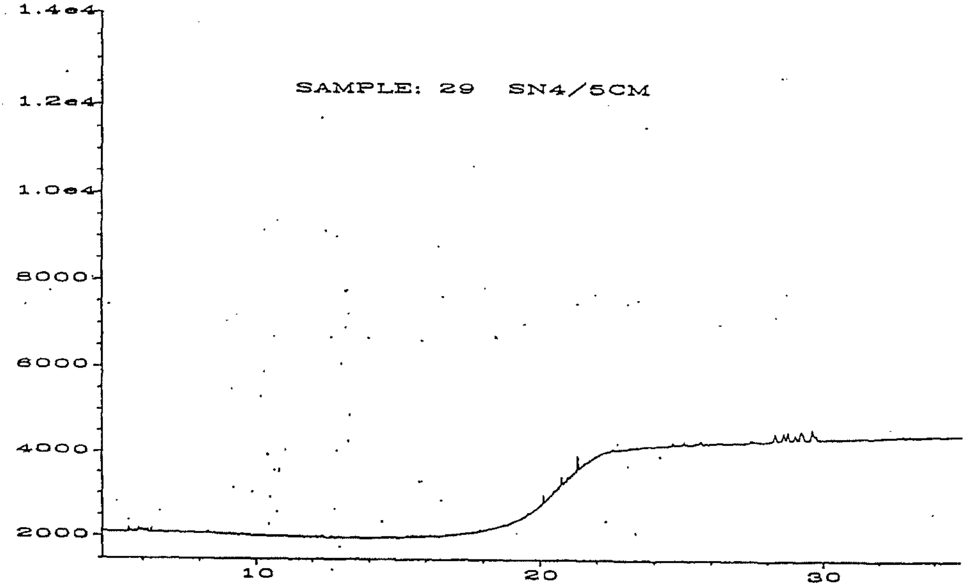

SAMPLE: 23 SN2/B/10CM
1.8e4
1.6e4
1.4e4
1.2e4
1.0e4
8000
6000
4000
2000
10
20
30

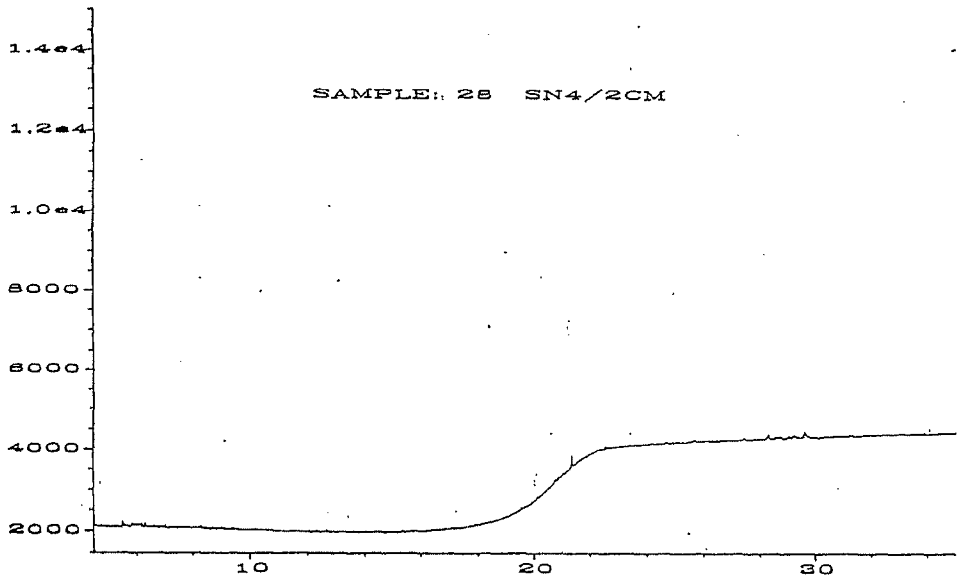

SAMPLE: 24 SN3/OCM
1.8e4
1.6e4
1.4e4
1.2e4
1.0e4
8000
6000
4000
2000
10
20
30

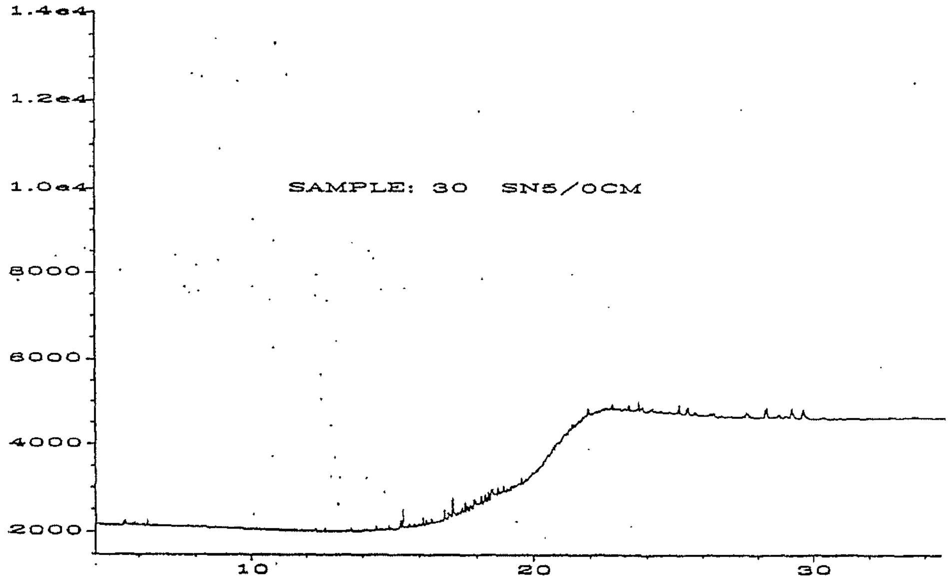

SAMPLE: 25 SN3/2CM
1.8e4
1.6e4
1.4e4
1.2e4
1.0e4
8000
6000
4000
2000
10
20
30

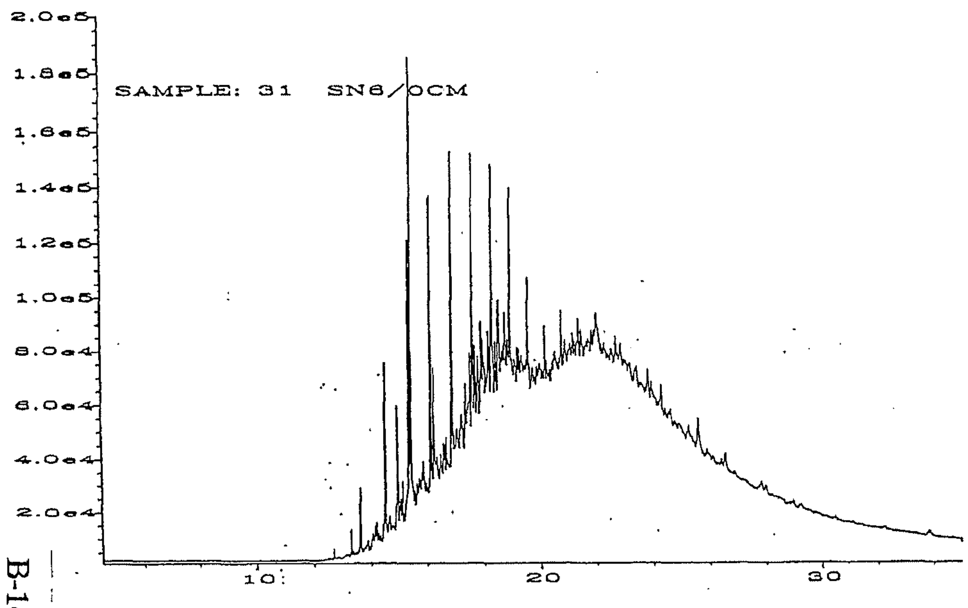

SAMPLE: 26 SN3/5CM
1.0e5
9.0e4
8.0e4
7.0e4
6.0e4
5.0e4
4.0e4
3.0e4
2.0e4
1.0e4
10
20
30


SAMPLE: 27 SN4/0CM
1.2e4
1.1e4
1.0e4
9000
8000
7000
6000
5000
4000
3000
2000
10
20
30

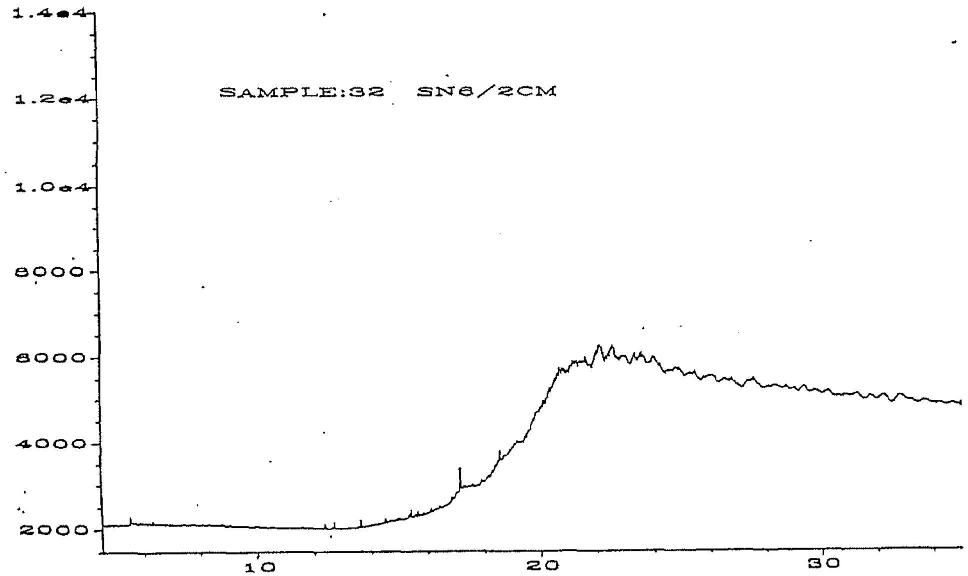

SAMPLE: 29 SN4/5CM
1.4e4
1.2e4
1.0e4
8000
6000
4000
2000
10
20
30


SAMPLE: 28 SN4/2CM
1.4e4
1.2e4
1.0e4
8000
6000
4000
2000
10
20
30

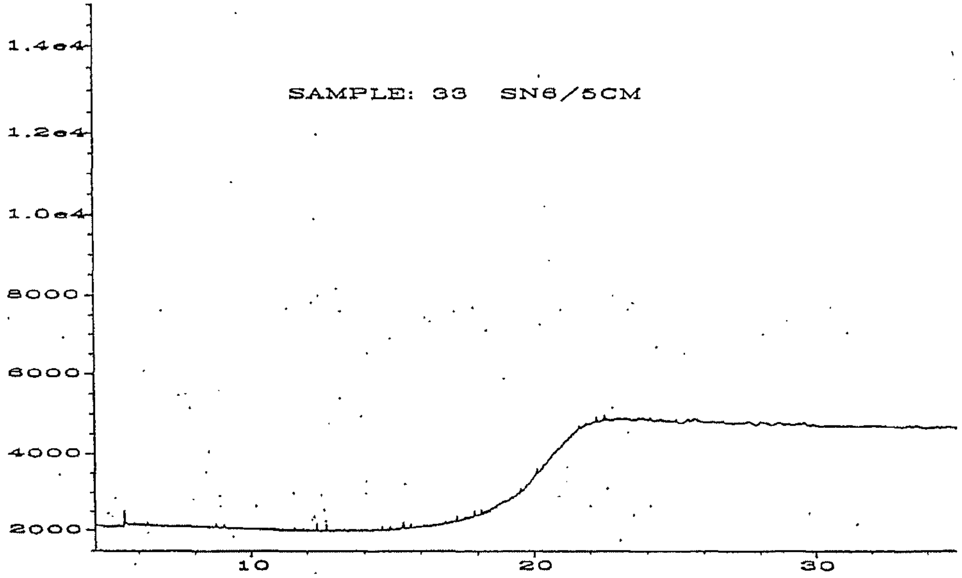

SAMPLE: 30 SN5/0CM
1.4e4
1.2e4
1.0e4
8000
6000
4000
2000
10
20
30



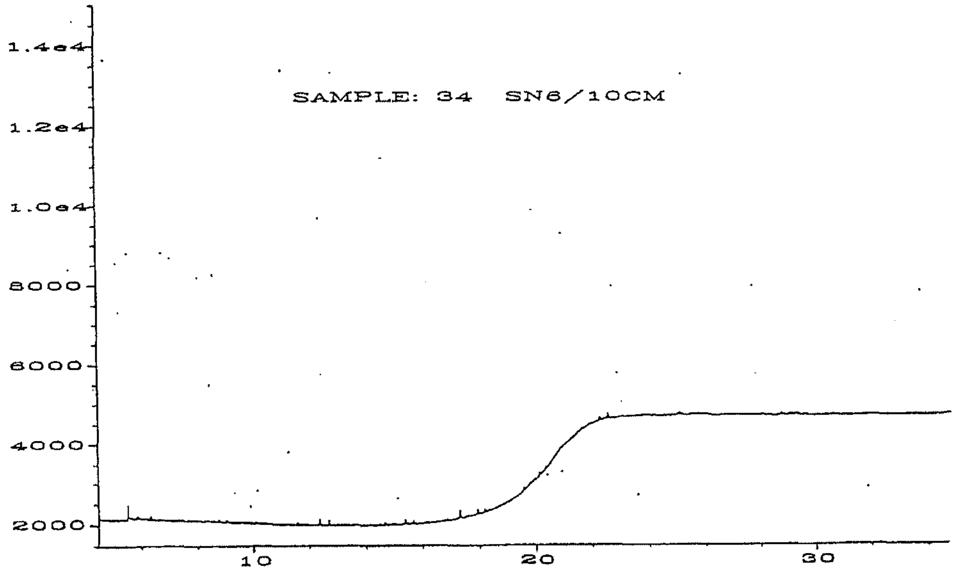
SAMPLE: 31 SN6/0CM
2.0e5
1.8e5
1.6e5
1.4e5
1.2e5
1.0e5
8.0e4
6.0e4
4.0e4
2.0e4
10
20
30



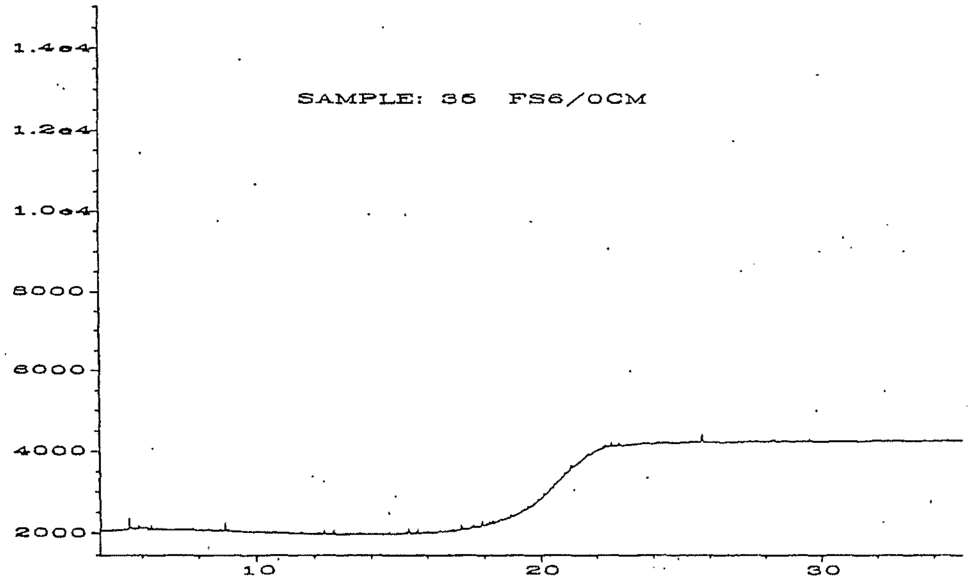
SAMPLE:32 SN6/2CM
1.4e4
1.2e4
1.0e4
8000
6000
4000
2000
10
20
30

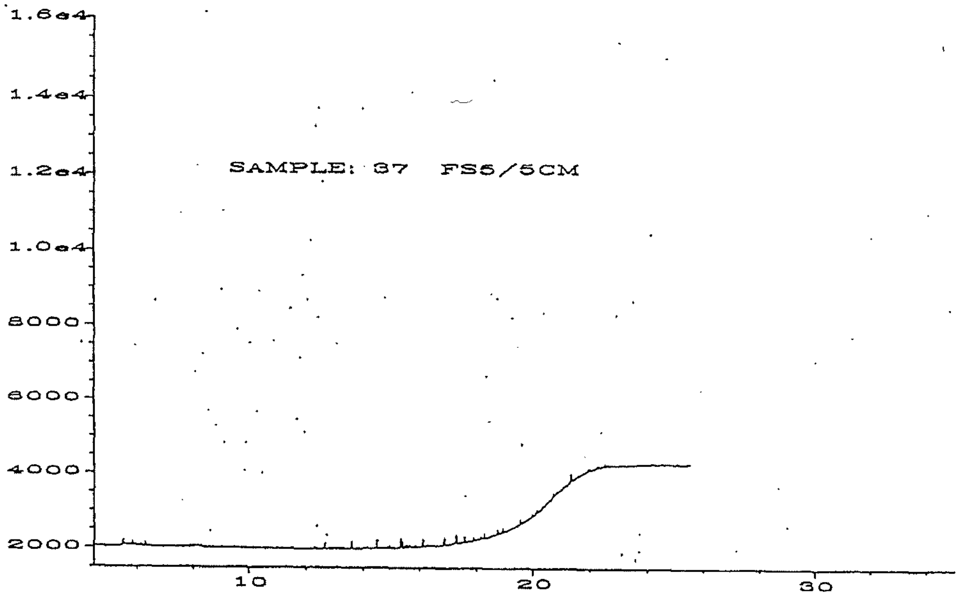


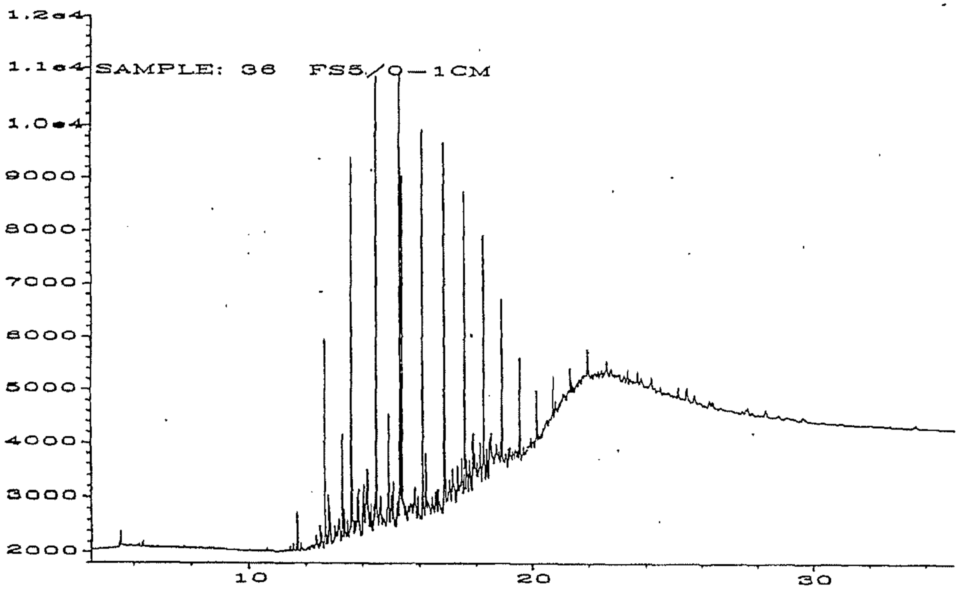
SAMPLE: 33 SN6/5CM
1.4e4
1.2e4
1.0e4
8000
6000
4000
2000
10
20
30

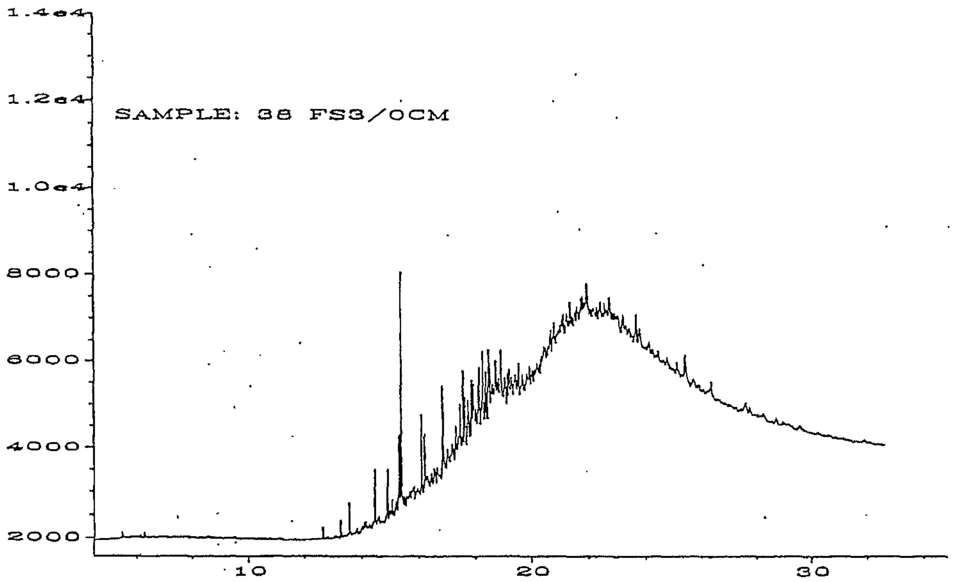


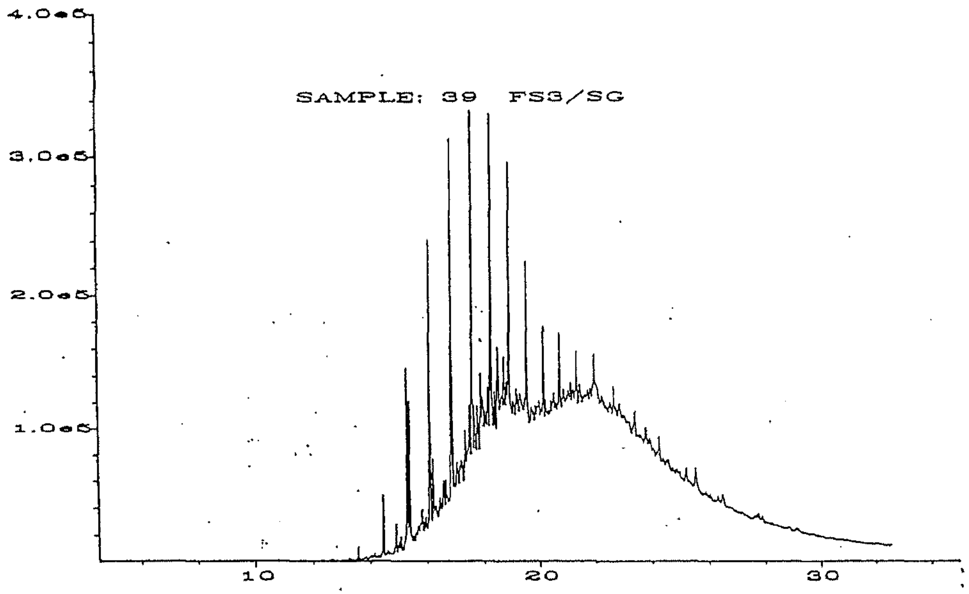
SAMPLE: 34 SN6/10CM
1.4e4
1.2e4
1.0e4
8000
6000
4000
2000
10
20
30

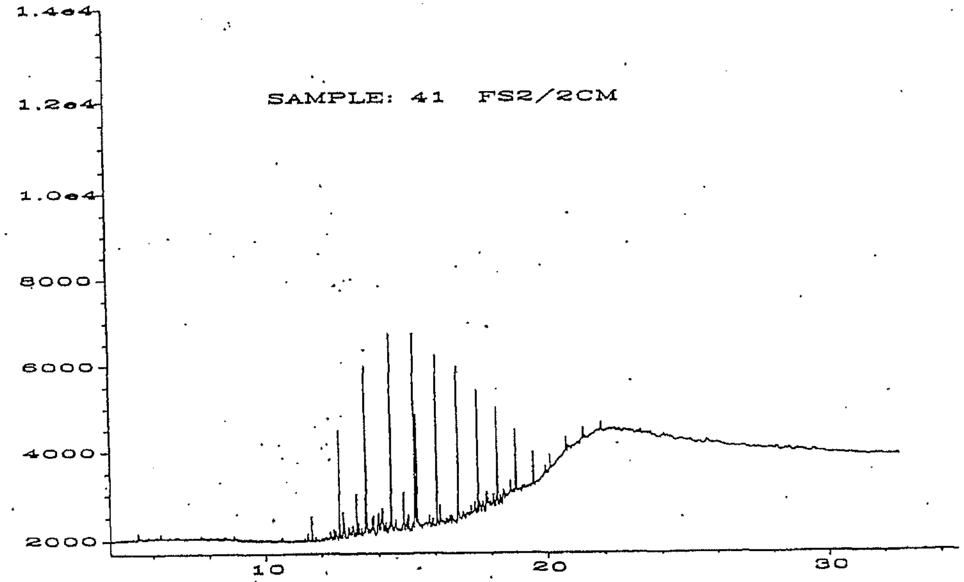

SAMPLE: 35 FS6/0CM
1.4e4
1.2e4
1.0e4
8000
6000
4000
2000
10
20
30

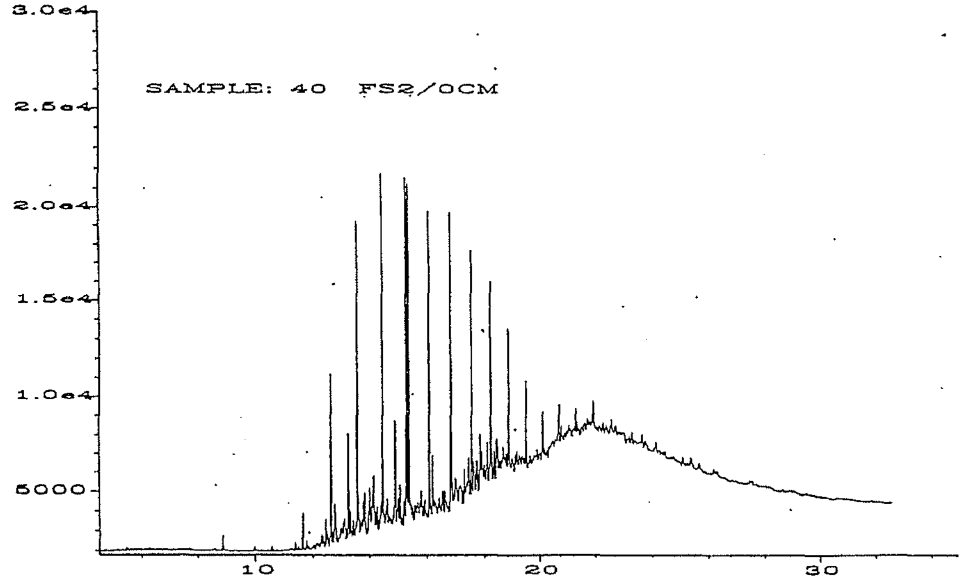

SAMPLE: 37 FS5/5CM
1.6e4
1.4e4
1.2e4
1.0e4
8000
6000
4000
2000
10
20
30

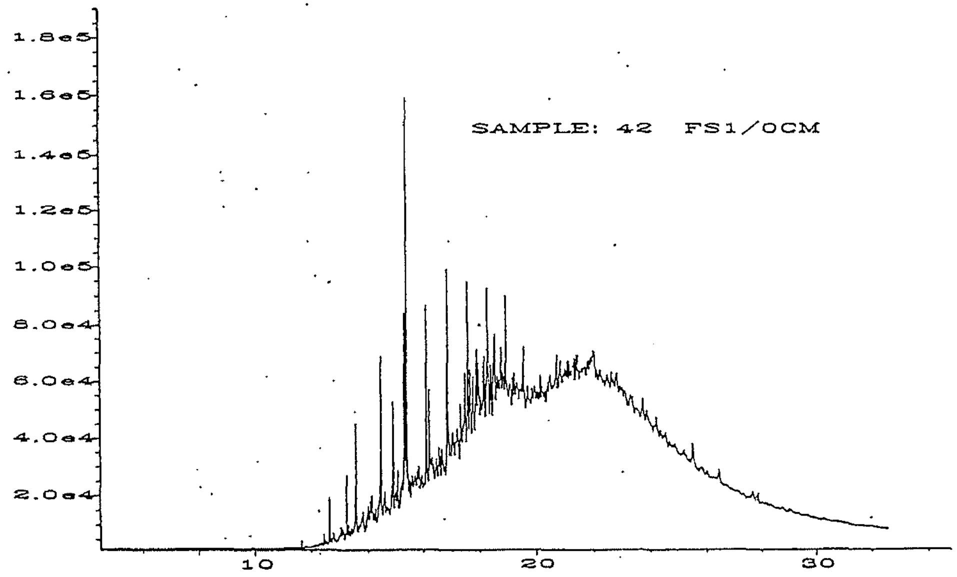

SAMPLE: 36 FS5/0-1CM
1.2e4
1.1e4
1.0e4
9000
8000
7000
6000
5000
4000
3000
2000
10
20
30

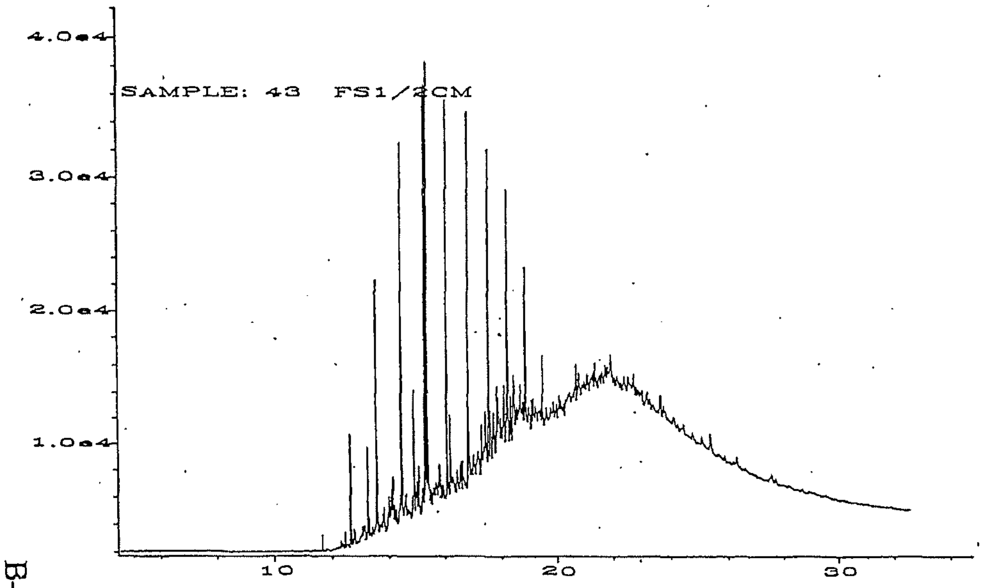

SAMPLE: 38 FS3/0CM
1.4e4
1.2e4
1.0e4
8000
6000
4000
2000
10
20
30

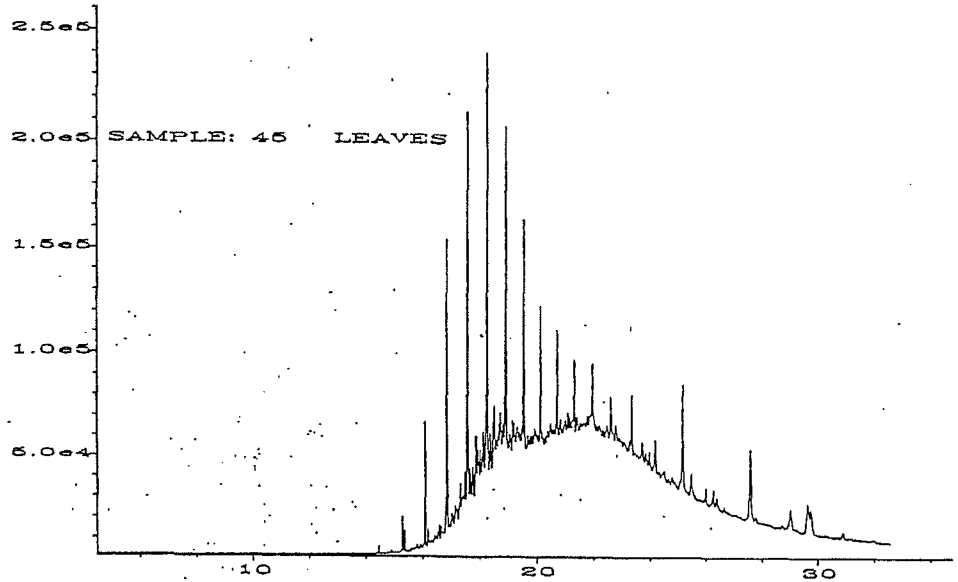

SAMPLE: 39 FS3/SG
4.0e5
3.0e5
2.0e5
1.0e5
10
20
30

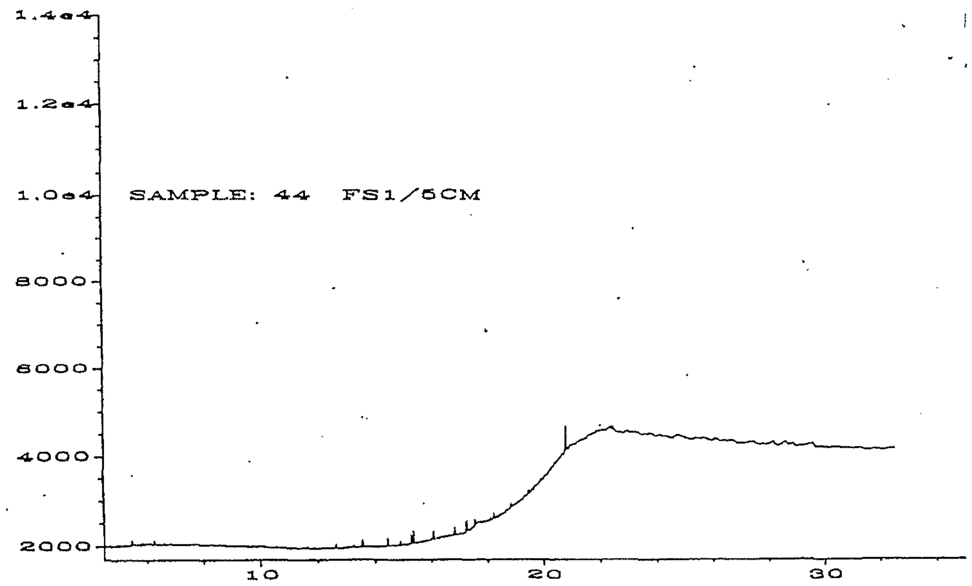

SAMPLE: 41 FS2/2CM
1.4e4
1.2e4
1.0e4
8000
6000
4000
2000
10
20
30

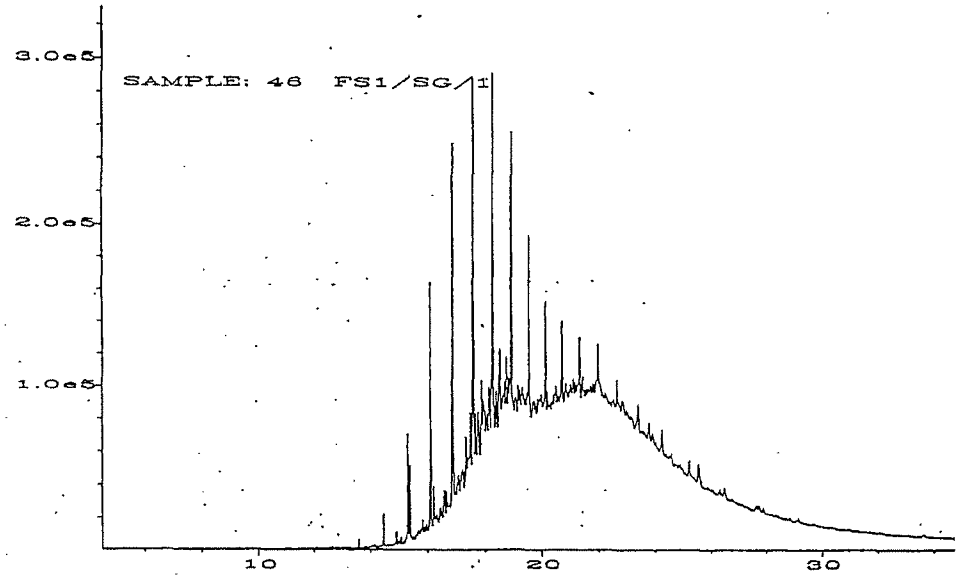

SAMPLE: 40 FS2/0CM
3.0e4
2.5e4
2.0e4
1.5e4
1.0e4
5000
10
20
30

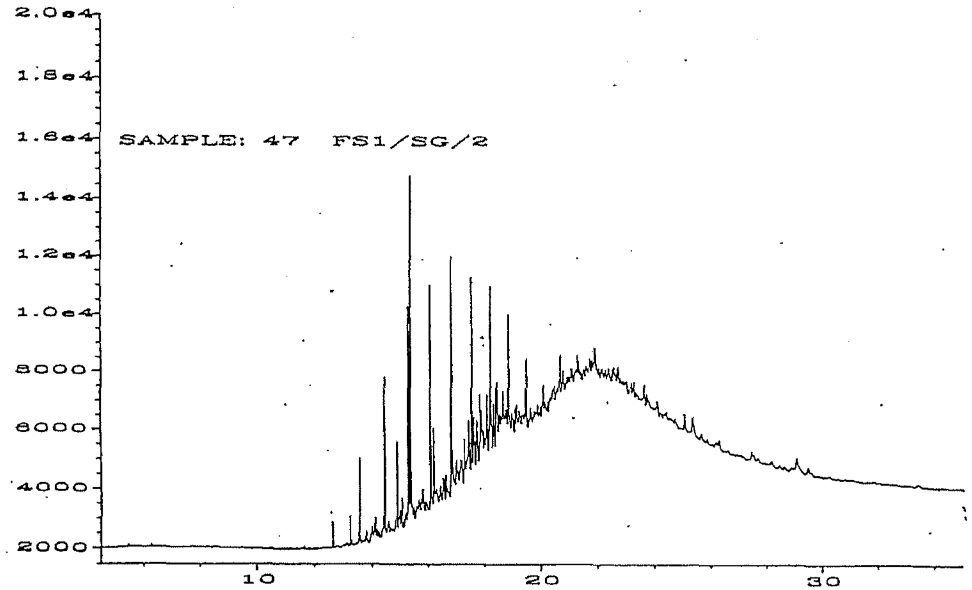

SAMPLE: 42 FS1/0CM
1.8e5
1.6e5
1.4e5
1.2e5
1.0e5
8.0e4
6.0e4
4.0e4
2.0e4
10
20
30

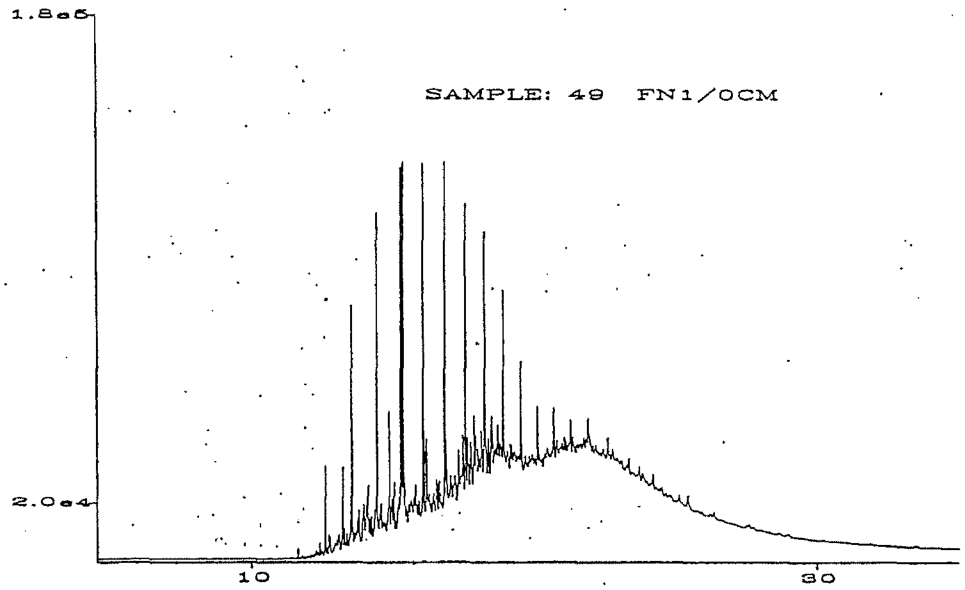

SAMPLE: 43 FS1/2CM
4.0e4
3.0e4
2.0e4
1.0e4
10
20
30

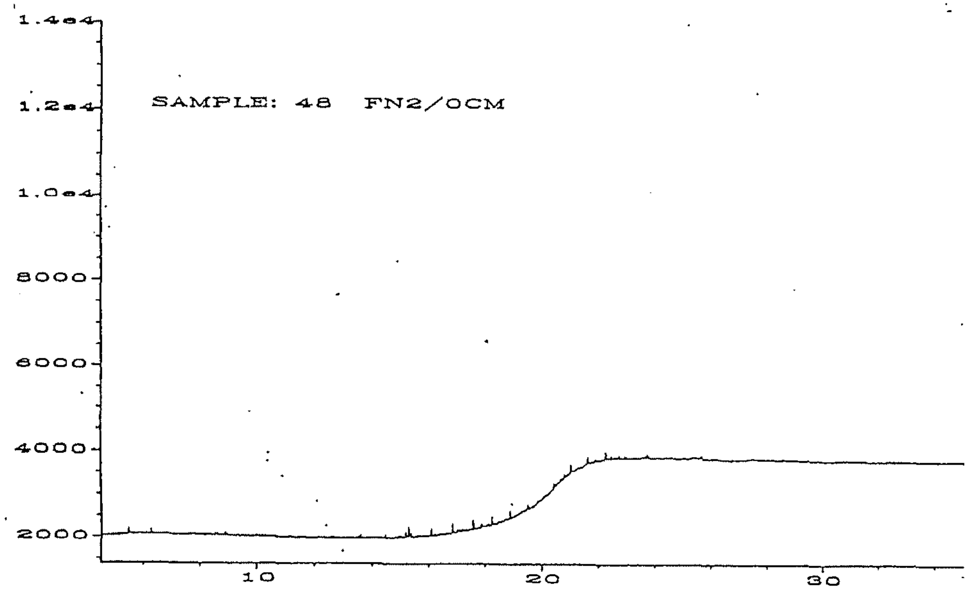

SAMPLE: 45 LEAVES
2.5e5
2.0e5
1.5e5
1.0e5
5.0e4
10
20
30

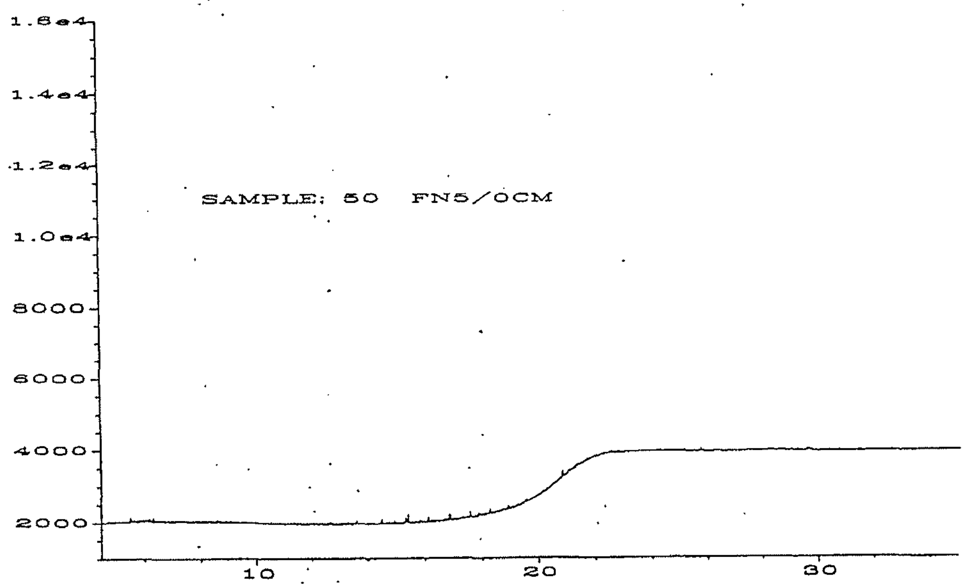

SAMPLE: 44 FS1/5CM
1.4e4
1.2e4
1.0e4
8000
6000
4000
2000
10
20
30

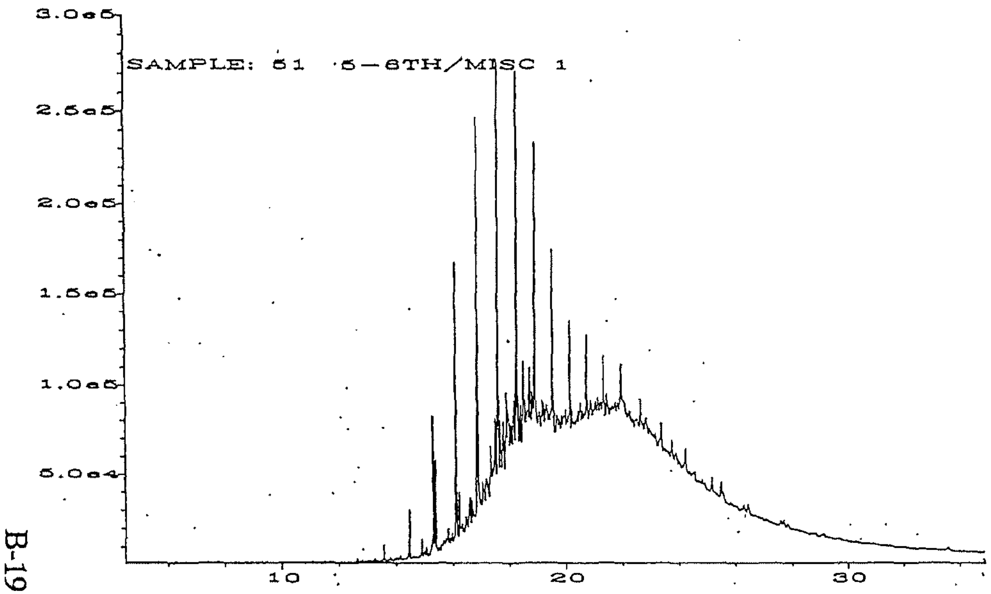

SAMPLE: 46 FS1/SG/1
3.0e5
2.0e5
1.0e5
10
20
30

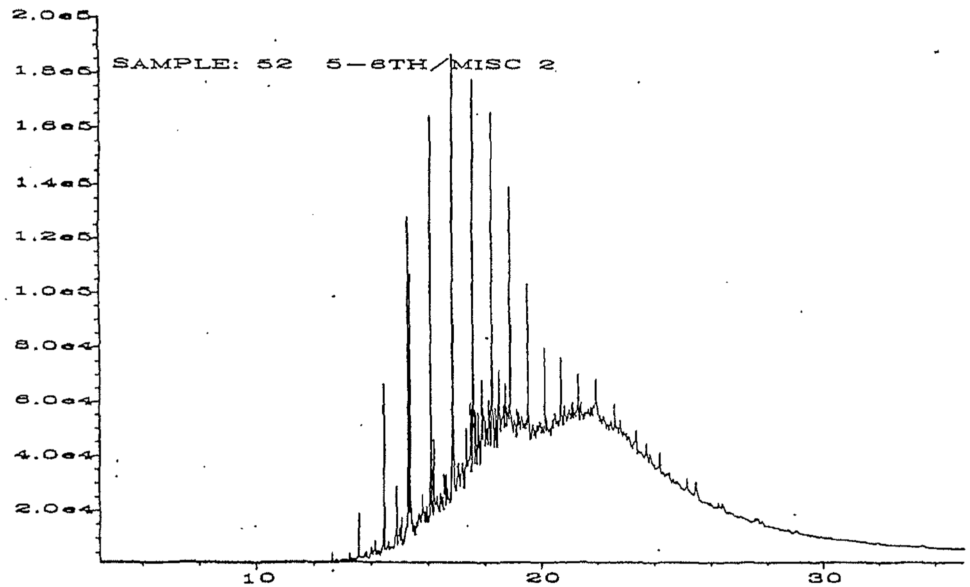

SAMPLE: 47 FS1/SG/2
2.0e4
1.8e4
1.6e4
1.4e4
1.2e4
1.0e4
8000
6000
4000
2000
10
20
30


SAMPLE: 49 FN1/0CM
1.8e5
2.0e4
10
30


SAMPLE: 48 FN2/0CM
1.4e4
1.2e4
1.0e4
8000
6000
4000
2000
10
20
30


SAMPLE: 50 FN5/0CM
1.6e4
1.4e4
1.2e4
1.0e4
8000
6000
4000
2000
10
20
30


SAMPLE: 51 5-6TH/MISC 1
3.0e5
2.5e5
2.0e5
1.5e5
1.0e5
5.0e4
10
20
30


SAMPLE: 52 5-6TH/MISC 2
2.0e5
1.8e5
1.6e5
1.4e5
1.2e5
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4.0e4
2.0e4
10
20
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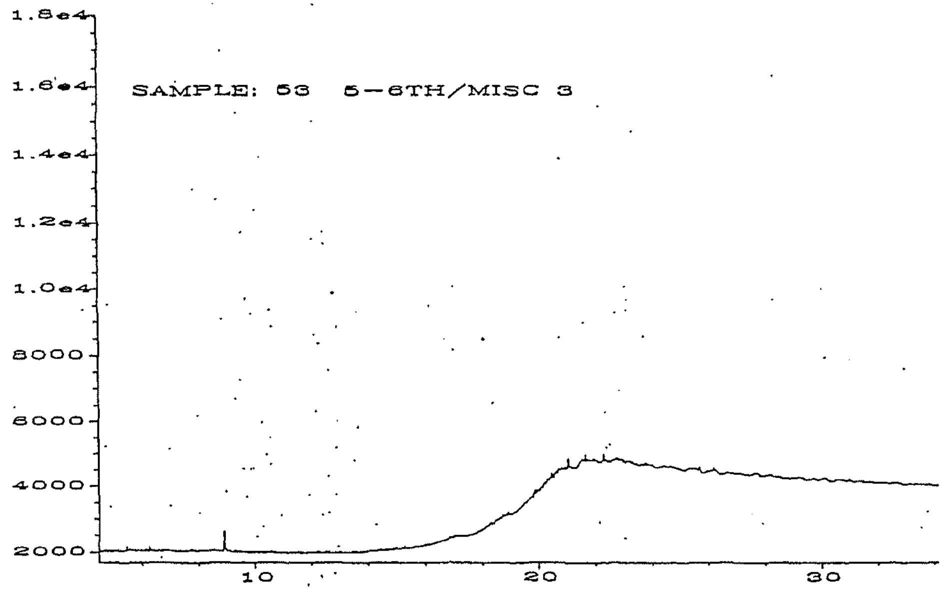
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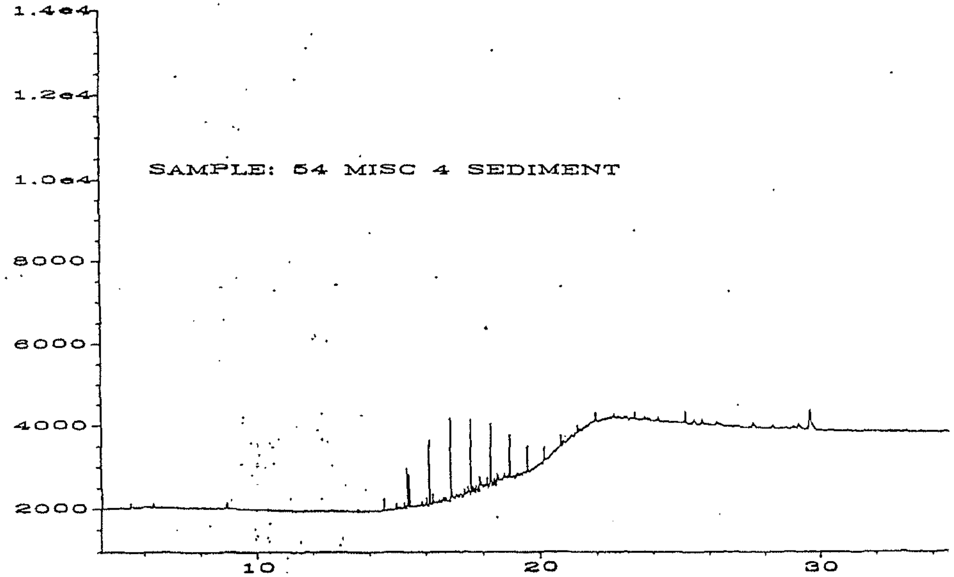
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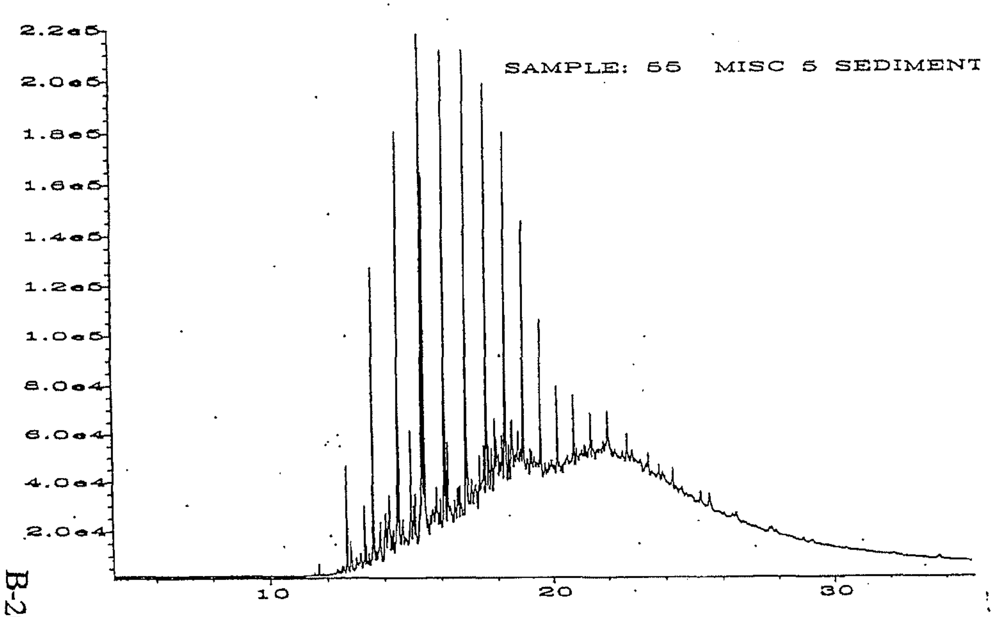
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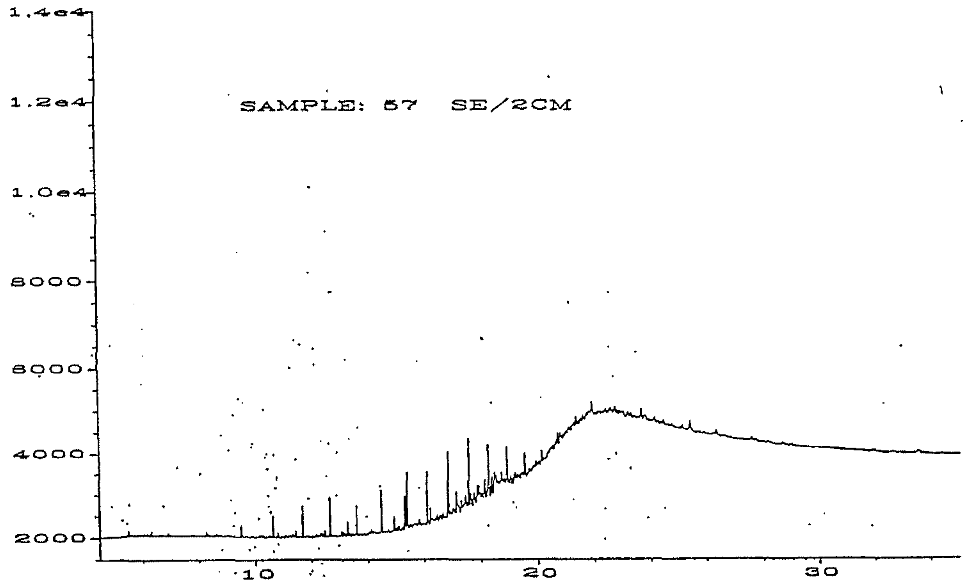
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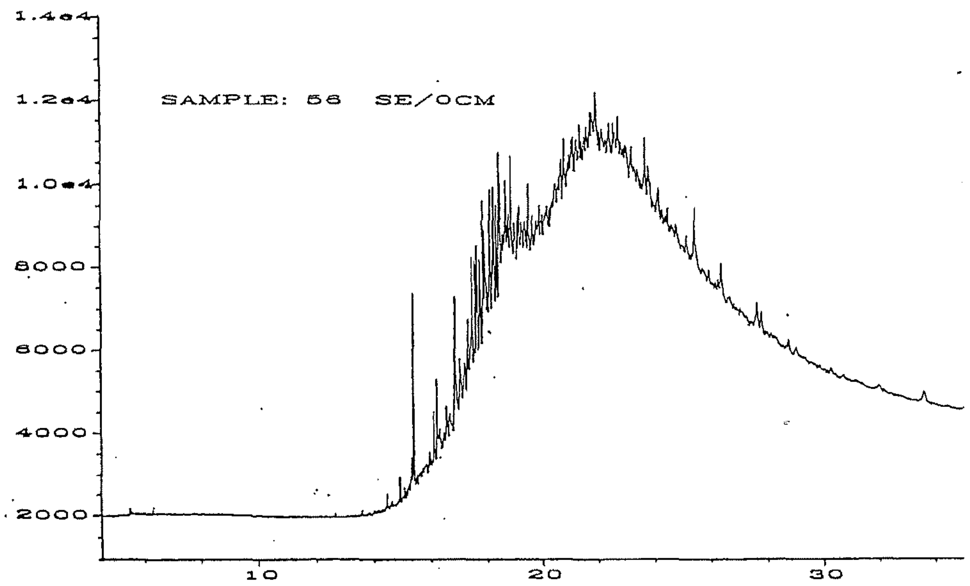
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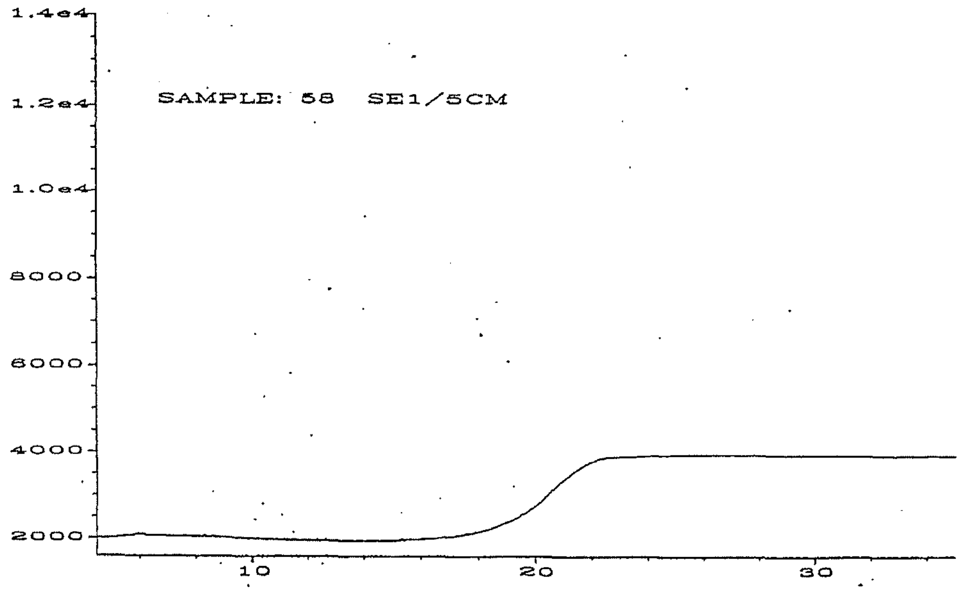
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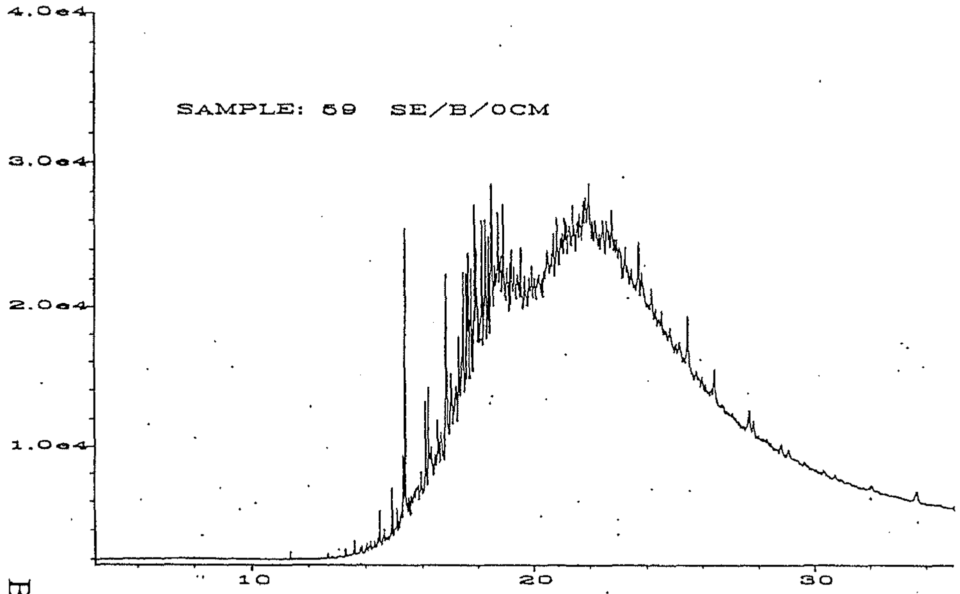
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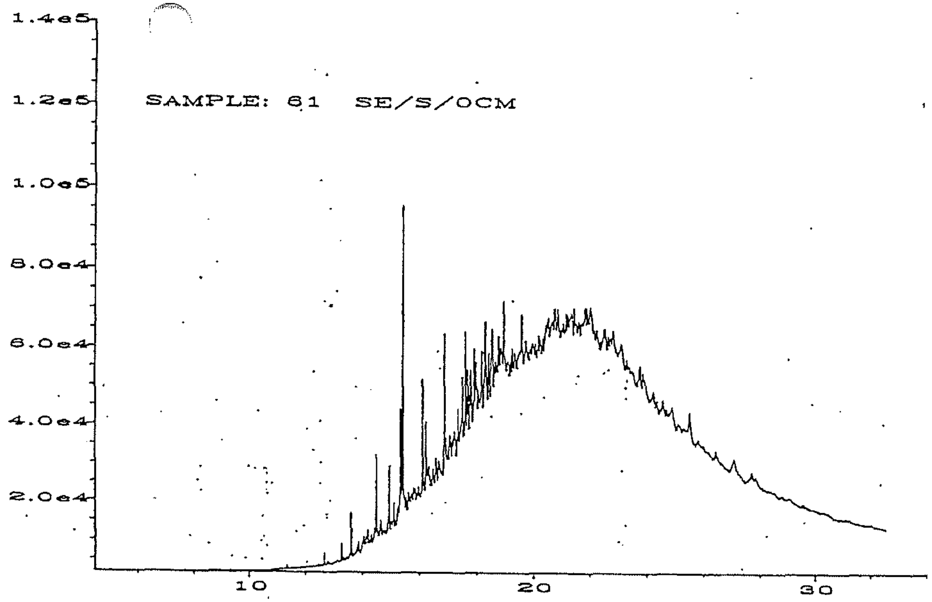
20
30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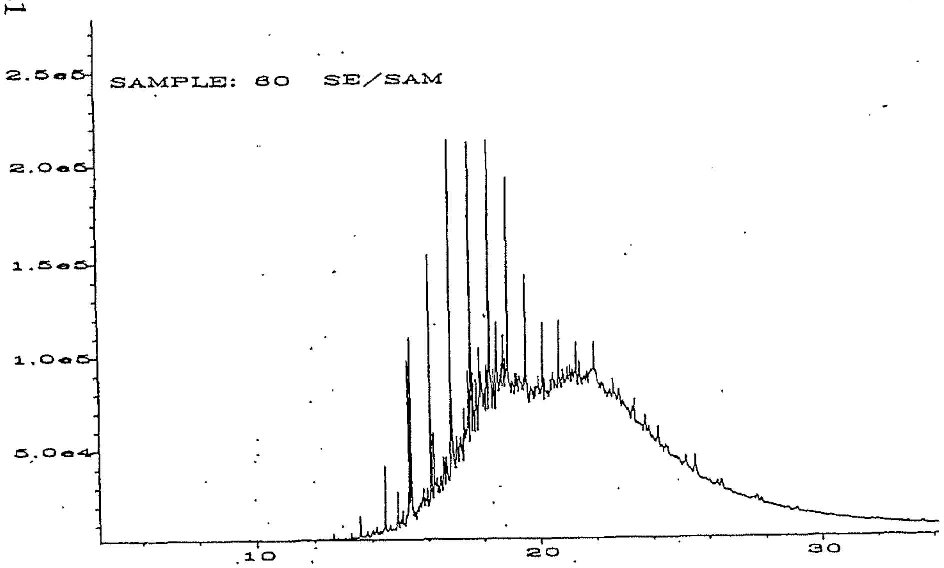
10
20
30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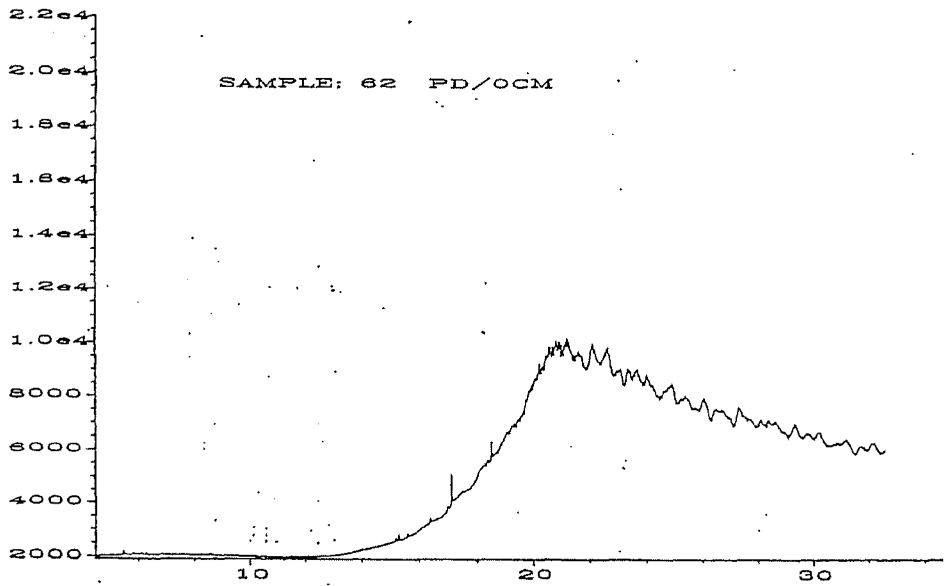
5.0e4
10
20
30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2000
10
20
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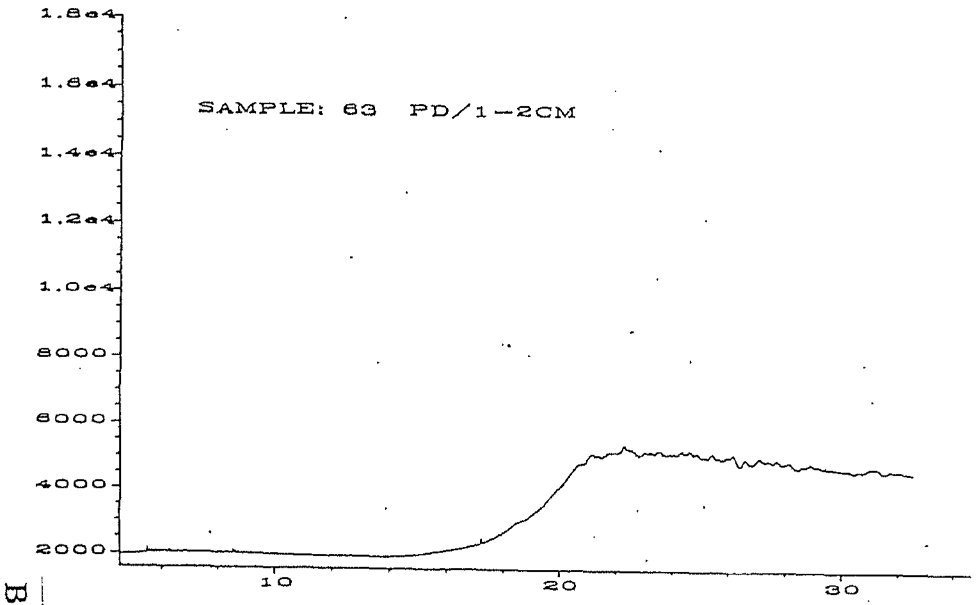
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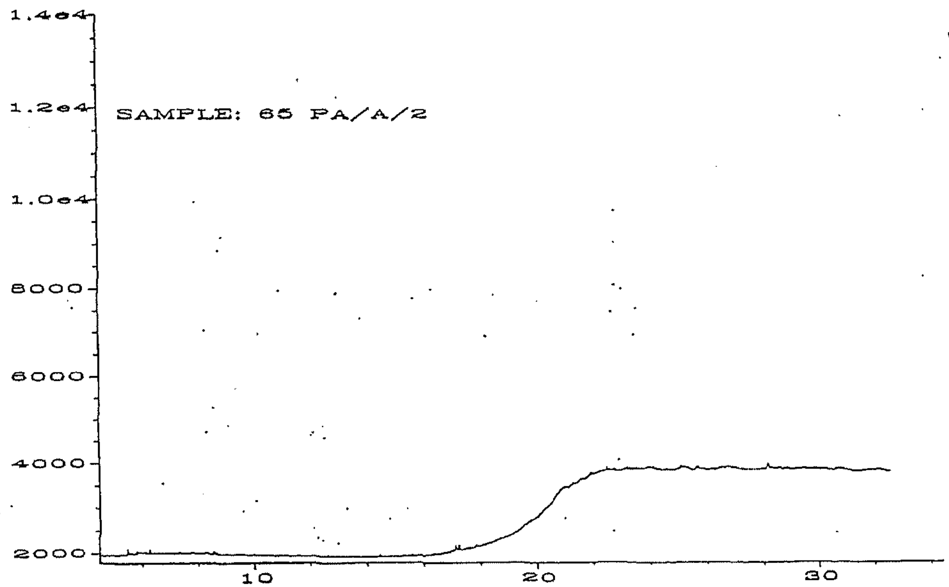
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20
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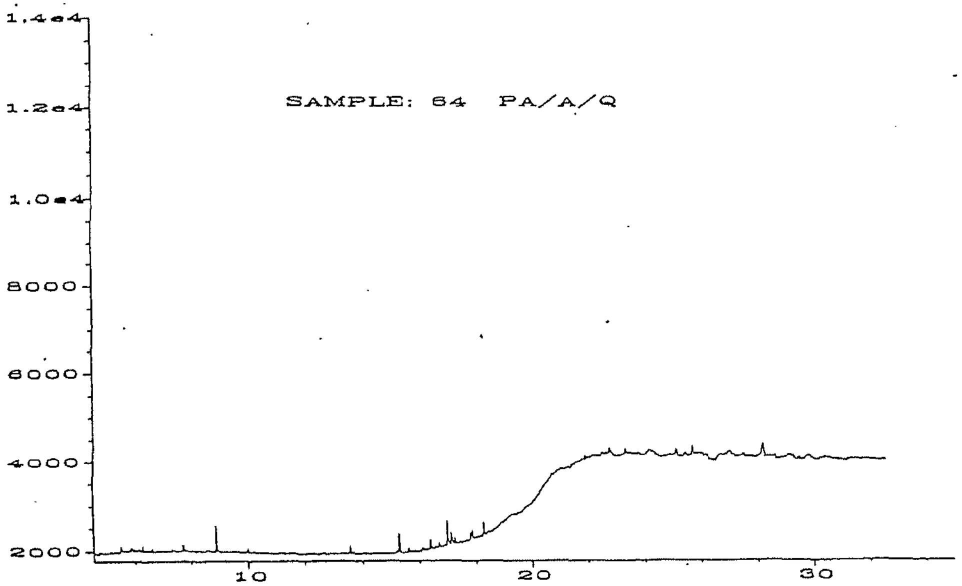
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6000
4000
2000
10
20
30

APPENDIX C

DEFINITION AND DISCUSSION OF

DEGREE OF OILING

C.1 INTRODUCTION

In order to discuss the various levels of impact within the mangrove community and to relate this to any observed effect it is necessary to either quantify the amount of oil that is, or has been, present in an area or to use general terms such as 'heavy', 'moderate' or 'light' oiling. The latter is the only practical course but we must then define these terms, as best we can, and ensure that they are applied uniformly.

This is difficult to do in the field since our impressions are often influenced not by the degree of oiling but by the condition of the community, particularly the mangroves themselves. Areas characterised by trees which are defoliated, or with black shrivelled leaves will tend to be classed as 'heavily oiled' regardless of the amount of oil actually observed. Similarly plants with fresh green leaves and shoots may, at best, be classed as 'moderately' oiled despite obvious and extensive oiling.

Our impressions are influenced too by the character of the oil. Darker, heavy oils are more obvious than light crudes and products and so areas impacted by these tend to classed as 'heavily' oiled.

We must also bear in mind that the degree of oiling of the swamp reflects both the oiling of the trees and the oiling of sediments.

Both the extent and degree of sediment oiling and tree oiling are important in considering the likely effect of oil on various components of the biological community, the community generally, and the likelihood of recovery or recolonisation.

The relative sensitivities of swamps or species to each of these is variable and, furthermore, this variability is difficult to predict.

It is important therefore, that three oiling values are assigned:

- Mangrove Oiling
- Sediment Oiling
- Overall (Site) Oiling

The determination of each of these is outlined below.

C.2 MANGROVE OILING

No generally accepted terms or definitions have been developed for describing the degree of oiling of individual mangroves. The term 'heavy', 'moderate' or 'light' are often used in the scientific literature but are rarely, if ever, defined.

Oiling may be present on roots (pneumatophores), trunks, branches and leaves but it is probable that pneumatophores and leaf impact are the most likely sources of damage. Again the relative contribution of these two factors to tree stress will be variable. Early investigations of oil spills tended to emphasise pneumatophore impact ie the "smothering" of breathing pores (lenticels). Later research has drawn attention to the often lethal effects of leaf oiling, particularly where the oil is light.

An "Adult tree oiling index" has been developed by Getter et al (1980a) and this is calculated by estimating the 'extent' of oil on mangrove trunks and prop roots and consigning points as follows :

- Heavy (81 - 100% cover); 0.9 points
- Moderate (21 - 80% cover); 0.5 points
- Light (1 - 20% cover); 0.1 points
- Clean (0%); 0.0 points

Each score is then multiplied by the height of oiling of each sector totalled for each tree. This sum is the 'Adult tree oiling index'. While such a method can be adapted for *Avicennia* it is difficult to see how the calculations can be adjusted to include foliage. Clearly, a 1m wide band of oil on foliage constitutes a higher degree of oiling for a tree or shrub than a 1m band on a bare trunk. The index may, however, be a good indicator of exposure to oil (ie. volume and time).

At Port Pirie the oiling of leaves dominates, partly because of the low canopy of the shrubs, but also because sediment and pneumatophore oiling is variable and visibly absent from many areas.

The 'moderate' classification is also considered to be too broad (21 - 80%), and the basis for this breadth is not clear. Indeed, the basis for three divisions is not explained and it is not clear whether they reflect any spill (oil), biological or response related factors.

It is likely that the divisions are arbitrary, and in the absence of clear data relating response (or potential response) to degrees of oiling this is inevitable. The divisions used in this report are similarly arbitrary; we do not know, for example, whether we can expect any difference in response between trees with a 90% oiling (heavy) and a 60% oiling (moderate).

However, trees were assessed against a number of parameters and these are used to calculate the degree of oiling. These were then used to classify trees as 'heavy', 'moderate' or 'light' oiling. It is anticipated that these classifications can be reassessed in view of the short term responses and recovery of the trees. Ideally, the terms should reflect both of these (Table C.1).

TABLE C.1 DESIRABLE MEANING AND IMPLICATIONS OF OILING CLASSIFICATIONS

Degree of Oiling	Immediate Effect	Recovery
Heavy	Major effects	Slow or No Recovery
Moderate	Major Effect	Recovery
	Moderate Effect	Slow Recovery
Light	Moderate Effect	Rapid Recovery
	Little or No Effect	N/A

The method used to classify individual Port Pirie mangroves is outlined below. This method was also used to classify the degree of mangrove oiling within study locations. In this case average data was used.

The following parameters were estimated for each tree, or averaged for trees within each location.

- Tree height, in metres (H)
- Maximum height of oiling (Omax)
- Minimum height of oiling (Omin)
- Percentage of oil cover within oiled zone (P)

Individual trees and location were then photographed. The percentage of tree canopy oiled (T) was calculated using the formula :

$$T = \frac{Omax - Omin}{H} \times P$$

Degree of oiling was assigned on the basis of :

- Heavy 71-100
- Moderate 31-70
- Light 0-30

Oiled pneumatophores, if noted, resulted in the upgrading of degree of oiling provided :

- Sediment oiling was moderate or heavy, and either
- The 'T' score was within 20% of the upper division, or
- Pneumatophore density ≥150 per m^2

This method will require refining as results from detailed post spill surveys are obtained. Pneumatophore density, for example, probably reflects the degree of reliance of trees or shrubs on this form of respiration. The figure of 150 is based on the findings of Dicks (1986). Although related to a quite different swamp (albeit *A. marina* this figure represents the only one relating pneumatophore density to sediment character and sensitivity to oil.

Classifications were checked against the photographic record and the following 'rapid assessment' would appear to be appropriate for the swamp between Sixth and Fourth Creek :

- **LIGHT** : Scattered leaves covered with spots of oil; trunk and branches with band of oil; demarcation between oiled/ not-oiled section indistinct; little or no oil on sediment.
- **MODERATE** : Thick enough oiling on leaves and branches to make oiled/not-oiled demarcation easily observed at 3m but less obvious up close; no oil, or light oil on sediment.
- **HEAVY** : Trunk, branches and most leaves in oiled section completely covered with oil; tacky oil present; demarcation between oil/ not-oil obvious at 3m and up close (providing no leaf death). Sediment (usually) oiled.

Modification for pneumatophore oiling or (later) damage is still required.

Table C.2 gives classifications for all sites established during the programme.

TABLE C.2 DEGREE OF MANGROVE OILING

Location	Tree Height (Ave)	Oiling		% Cover in Oiled Sector	Degree of Oiling
		Max	Min		
SN1	2.0	1.5	0	100	Heavy
SN2	1.5	1.0	0	100	Moderate
SN3	3.0	1.0	0.2	75	Light
SN4	1.2	1.0	0.5	100	Moderate
SN5	2.5	0.6	0	100	Light
SN6	4.0	0.8	0	100	Light
FS1	2.5	1.6	0	100	Moderate
FS2	3.0	1.2	0.3	75	Light
FS3	2.5	1.5	0	100	Moderate
SS1	2.5	1.5	0	100	Moderate
SS2	2.5	1.5	0	100	Moderate
SS3	4.0	1.2	0	100	Light
FN1	4.0	1.0	0	100	Light
FN2	1.5	1.0	0	100	Moderate
FN3	3.0	1.1	0.3	100	Light
FN4	3.5	1.5	0	100	Moderate
FN5	3.5	1.5	0.3	100	Moderate
FN6	4.0	1.8	0	80	Moderate
FN7	2.5	1.9	0	100	Heavy
FN8	4.0	1.5	0.1	100	Moderate
FN9	3.0	1.2	0.2	100	Light

C.3 SEDIMENT OILING

The degree of sediment oiling was assigned, in the field, primarily on the basis of the percentage cover of dark asphaltine residues, ie :

Percentage Cover	0 - 20	21 - 50	>50
Degree	Light	Moderate	Heavy

The presence of brown film or sheen on sediments resulted in a 'light' oil classification. The absence of odour precluded this as a method of allocating 'light' oiling status in the absence of visible evidence of oil.

Chemical analyses was used to confirm or modify the classifications. Total petroleum hydrocarbons were calculated for surface, 2cm and 5cm depths and total hydrocarbon loads (L) estimated for each core in each location. These were expressed in $\mu g/g$ x Q per $5cm^3$ column where Q is the mass (in grams) of one cm^3 of the sediment.

Total underlying (5cm depth) hydrocarbons were used rather than surface levels since surface oils may be removed progressively.

To estimate the average 'load' of the site this number (L) was multiplied by the % coverage of oil.

TABLE C.3 CLASSIFICATION OF DEGREE OF SEDIMENT OILING

Site	% Surface Oiled	Field Classification	TPH (Surface)	L (x Q)	L x % Cover	Adjusted Classification
SN1	75	Heavy	105,000	205,000	154,000	Heavy
SN2	25	Moderate	66,000	71,000	18,000	Moderate
SN3	0	Clean	*	*	-	Clean
SN4	0	Clean	600	600	-	Light•
SN5	Trace (0)	Light	*	*	-	Clean•
SN6	40	Moderate	85,000	85,000	34,000	Moderate
FS1	35	Moderate	84,000	129,000	45,000	Moderate
FS2	Trace (0)	Light	9,000	15,000	-	Light
FS3	100	Heavy	5,000	5,000		Heavy**
SS1	0	Clean	*	-	-	Clean
SS2/3	100	Light	17	17	17	Light
FN1	75	Heavy	43,000	-	32,500	Heavy++
FN2	40	Moderate	*	*		Moderate
FN3	30	Moderate	-	-		Moderate++
FN4	0	Light	-	-	-	Light++
FN5	10	Light	*	*	-	Light++
FN6	20	Light	-	-	-	Light++
FN7	60	Heavy	-	-	-	Heavy
FN8	100	Heavy	-	-	-	Heavy++
FN9	50	Moderate	-	-	-	Moderate++

Footnotes :
- * Below detection limit
- \+ Surface only analysed
- • Field classification amended on basis of analysis
- \- Not done
- ** Assigned on the basis of overlying total cover of oiled seagrass debris
- ++ No adjustment made since only limited analysis, or no sample analysed

At present it is not proposed, or possible, to define the degree of oiling on the estimated oil load of sediment. In order to do this several replicate cores would be required to ensure that figures are accurate and representative of the location. The value of the revision, at present, is as a check on 'clean' areas.

C.4 LOCATION (SITE) OILING

Overall degree of oiling ratings were assigned as per Table C.4.

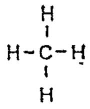
TABLE C.4 CLASSIFICATION OF STUDY LOCATIONS (SIXTH CREEK TO FIFTH CREEK) ACCORDING TO DEGREE OF MANGROVE, SEDIMENT AND OVERALL (SITE) OILING

Mangrove / Sediment	Light	Moderate	Heavy
Light (or clean)	SN3 SN5 FS2 SS3 (Light)	SN4 SS1 SS2 FN4 FN5 FN6 (Light)	(Moderate)
Moderate	SN6 FN3 FN9 (Light)	SN2 FS1 FN2 (Moderate)	(Heavy)
Heavy	FN1 (Moderate)	FS3 FN8 (Heavy)	SN1 FN7 (Heavy)

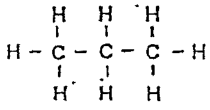
APPENDIX D

GLOSSARY OF TERMS

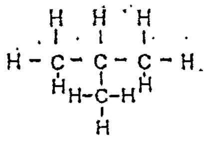
Alkane : Simple saturated oliphatic (straight chain) hydrocarbons. Also called 'paraffins'. Examples are:



METHANE

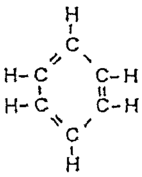


PROPANE

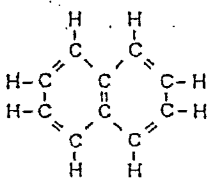


ISOBUTANE

Aromatic Hydrocarbon : Hydrocarbons consisting of, or containing ringed structures (eg. benzene rings). Examples are :



BENZENE



NAPHTHALENE

Effect : Changes to trees (mangroves), fauna or sediment due to their exposure to oil. Effects may range from subtle sublethal effects to death (lethal effect).

Impact : The physical contact between oil and the coastline, mangroves or sediment.

Location : See SITE.

Oiling : Impact. The degree of oiling is classified as either 'Heavy', 'Moderate' or ' Light'. These are defined in Appendix C.

Pneumatophore : Breathing roots of mangroves protruding vertically through sediment. Pneumatophores possess breathing pores or 'lenticels'.

Polycyclic Aromatic Hydrocarbon (PAH) :
Complex hydrocarbons consisting of a many-ringed stucture.

Region : The coastline from Port Pirie to Fisherman's Creek.

Sector : Defined sections of coastlines between creeks eg. Fifth Creek to Sixth Creek, Fourth Creek to Fifth Creek.

Site : Location. A small area chosen for quantitative study in the programme, or by another.