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RESEARCH ACTIVITIES RELATED TO OIL POLLUTION INCIDENTS

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ABSTRACT

This report is based on the proceedings of an ad hoc Working Group of ICES, which was set up to consider what scientific studies can and should be initiated in relation to spills of oil at sea. The output of the Working Group was discussed by the Marine Environmental Quality Committee (MEQC) and by the Advisory Committee on Marine Pollution (ACMP), and, in producing this report, comments of these Committees as well as comments from appropriate experts in member countries have been taken into account.

While the central matters discussed are those concerned with the sort of scientific program designed to provide information on the effects of spills, the report also ranges over both pre- and post-spill situations.

The need for and value of maps of environmental characteristics and resources is emphasised, and the problems discussed.

In the area of physical data, the spreading of oil on the sea and its subsequent weathering are considered and the use of models of physical parameters referred to. The contribution from geological expertise is also considered.

The various techniques and the available equipment for collecting samples of water, sediments and organisms for study in relation to an oil spill are presented and evaluated.

In the field of chemistry, analytical methods are reviewed, problems of interpretation examined, and the need for adequate intercalibration emphasised.

Biological effects of oil on all the main components of the ecosystem are separately dealt with, and proposals made for the optimum study program. In view of the importance of microbiological processes, a separate section is devoted to sampling methods in the field.

1. BACKGROUND OF THE REPORT

At the 65th Statutory Meeting of ICES held in Reykjavik in 1977, a number of papers were presented to the Fisheries Improvement Committee (now Marine Environmental Quality Committee) on the scientific studies which were conducted in relation to the Ekofisk blow-out and the sinking of the "Argo Merchant". It was clear that much of the work represented an ad hoc response and was not part of any previously designed plan. Discussion focused on the type of observation which should be made to determine the short- and long-term effects of an oil spill and the Committee concluded that ICES should stimulate the planning of relevant programmes. Subsequently, a Council resolution (C.Res.1977/2:11) initiated an ad hoc group on oil pollution incidents whose terms of reference were inter alia: "To determine the scientific studies relevant to marine environmental problems which should be conducted in response to a significant oil spill or blow-out, including identification of the types of observations, equipment and expertise required. Such plans should include studies necessary for both a minimum level response as well as a complete study of resultant effects".

The group (see Appendix A for membership details) met in Brest in June 1978 and again in Charlottenlund in March 1979 and produced a report (C.M.1979/E:10) which was presented to the Marine Environmental Quality Committee at the 67th Statutory Meeting in Warsaw in October 1979. In the interim, with the stimulus of major incidents such as the "Amoco Cadiz" spill and the Gulf of Mexico IXTOC I blow-out, three new oil response plans (C.M.1978/E:38, C.M.1979/E:64 and E:70) were available at the 67th Statutory Meeting and others were ready or being developed by countries which foresaw the possibility of major spills affecting their coasts. At the same time a number of major international symposia were convened on related topics such as the fate and effects of drilling fluids and cuttings (Symposium, 1980) and detailed reports were distributed on regional oil spills (Hann et al., 1979) and responses to them.

The Marine Environmental Quality Committee felt that the ad hoc group's report could be improved by taking account of these recent plans and information, and a small sub-group (see Appendix A) convened during the Statutory Meeting under the chairmanship of Dr John Pearce to consider revision of the document. It was then proposed (C.Res.1979/1:6) that Dr Pearce should work by correspondence with appropriate scientists to consolidate the revision in the light of further comments from member countries and that subject to approval by ACMP the document should be published in the Cooperative Research Reports series.

2. INTRODUCTION

Given the background outlined above, it will be clear that the following report is a result of consultation between experts from various ICES member countries, syntheses of elements from existing national and regional oil response plans, and information gleaned from the growing literature on oil spill incidents. It is aimed at the scientist who must design and conduct laboratory experiments and field observations and also at administrators who must prepare for and react to oil incidents.

The basic framework of this report is contained in a lengthy tabulation (Table 1) which outlines tasks and research items that were deemed important in the scientific investigation of spilled oil in the marine environment. The participants recognise that all oil spills are not the same and many of the tasks outlined in this table may be unnecessary or unwarranted because of prevailing conditions at the time of the spill. However, they felt it best to provide a complete outline of the optimal tasks and research items that may be implemented under various circumstances. The table is organised vertically into three sections:

1. pre-event considerations and research
2. operational considerations, research and monitoring
3. basic or applied research items available to support research during or following a spill.

MATRIX OF TASKS AND OPPORTUNITIES RELATED TO NEARSHORE AND OFFSHORE OIL SPILLS

	Pre-event Tasks	Operational Tasks: Applicable to cleanup	Operational Tasks: Applicable to socio-economic impacts	Research Opportunities During and Following Event
Mapping	Map resources:-	Aerial reconnaissance		Mapping affected areas - location of control sites
	Map fish and fishing distribution and seasonal variations	Commercial fish distribution	Estimation of vulnerability and impact	Effect on fishing effort and success - recovery of spoiled grounds
	Seasonal distribution - fish eggs and larvae			See
	Distribution of benthos	Benthos distribution in path of slick	Prediction of effects	below:
	Distribution of plankton - seasonal variations	Plankton distribution in path of slick	Prediction of effects	Effects
	Known spawning areas	Species spawning and distribution	Prediction of effects	on
	Zones of primary and secondary productivity	Productive zones in path of slick	Assessment of vulnerability	Biological Systems
	Baseline distribution of hydrocarbons	Hydrocarbons in water and sediments		Distribution of hydrocarbons in water and sediments
	General distribution of sediment types	Sediment types in path of slick		
	General summary of risk areas		Predictions of risk in vulnerable areas	Verification of risk predictions
	General summary of currents, water masses	Current measurements and water masses		
	Selection of baseline study areas	Selection of reference sites		
Physics	Maps of general climatic conditions and seasonal changes	Meteorological observations		Atmospheric dispersion and fate of volatiles
	General studies of ocean processes			Use of oil "tags" for current plotting
	Predictive modelling - effect of winds on currents	Prediction of slick trajectories	Identification of sensitive targets	Testing slick trajectory predictions
	Physical properties of oils - general studies	Physical properties of source samples		Weathering rates and routes
		Oil distribution and state		Long-term stability of oil reservoirs
	General studies on dispersion -includes mousse formation	Evaluate dispersion - longshore transport		Effect of small or large bulk releases on dispersion
		Mixing of oil in water column		Vertical dispersion of oil in water column
		Sedimentation - incorporation into bottom		Sedimentation processes and fate of sedimented oil
		Slick thickness, distribution, viscosity, etc.		Dispersion rates and routes at water surface
	Oil/ice interactions and dispersants	Fate of oil on beaches	Strategy for cleanup	Weathering and dispersion of oil from beaches
		Ice studies as appropriate	Strategy for cleanup	Interactions of oil and ice
Geomorphology	Baseline studies on sediment distribution	Sediment distribution in threatened area		Recovery of contaminated sediments
	Studies of degree of exposure relevant to self-cleaning of beaches	Assessment of erosional/depositional beaches	Affects cleanup strategy	Geomorphological stability of contaminated beaches, sediments
		Fate of oil on beaches	Affects cleanup strategy	Effects of cleanup on beach structure
Chemistry & Biochemistry	General studies - oil/ice interactions dispersants			
	Reference manual of chemical properties of oils	Reference samples of source - properties		
	Weathering properties of oils dispersants	Weathering rates, dispersion routes		Chemical aspects of weathering
	Development of analytical techniques	Selection of analytical techniques		
	Intercalibration - between participating laboratories	Intercalibration of labs		
	Development of rapid analytical methods for field use	Selection of field techniques		
	Tests of dispersants against representative organisms	Selection of suitable dispersants		Field testing of dispersants, cleanup techniques
	Baseline studies of hydrocarbon concentrations - water and sediments	Contamination in water and sediments		Relationship between hydrocarbon concentrations in water, sediments and biota
	Baseline studies of hydrocarbon concentrations in biota	Measurement of hydrocarbons in biota		
	Studies of tainting and depuration - incorporation of PAH	Assessment of tainting	Implication for fisheries closures	Permanence of tainting, recovery, depuration
	Seasonal distribution of nutrients - relevant to microbial biodegradation			
Biology	Baseline studies on ecosystems	Effects of oil dispersants on communities		Effect of oil on structure and diversity and recovery of communities
	Distributon of areas of productivity	Effects on productivity		Long-term effects on primary and secondary productivity
	Baseline productivity indices			
	Baseline studies on mortality in natural populations			Additional effects of oil on natural mortality in plankton populations
	Variations in fish egg and larval abundance	Effects on fish eggs and larvae	Short-term predictions	Effects of oil on different species of fish eggs and larvae
	Annual variations in egg and larval mortality	Mortality, teratogenic effects		Long-term studies on future year-class strength following oil spills
	Laboratory studies on benthos	Effects on benthos		Long-term studies on benthos and recovery following oil contamination
	Laboratory studies on selected pelagic species	Effects on standard organisms		Effects on standard or pre-selected species
	Laboratory studies on behaviour - especially fish			Effects on behaviour, migration, etc.
				Differential effects at trophic levels or ecological niches
	Laboratory studies on reproductive processes			Effects on reproductive processes, physiological and behavioural
	Laboratory studies on genetic effects			Genetic effects, mutagenic effects
				Histopathology of affected organisms
		Mircobiology		Microbiology - "switching on" microbial degradation response
				Effect on plankton on biodegradation processes
	Distribution and vulnerability of marine mammals	Marine mammals distribution and vulnerability	Affects cleanup strategy	Marine mammals - basic research into affects of oil
	Distribution and vulnerability of marine birds	Marine birds distribution and vulnerability	Affects cleanup strategy	Marine birds - opportunity for shared resources - ships of opportunity
Technical	Development of techniques for sampling water, sediments, organisms	Selection of techniques, methods		Development of sampling techniques
	Development of storage techniques and availability	Storage techniques		Development of storage techniques
	Creation of tissue banks for future reference	Sampling of contaminated tissues		Long-term accumulation of oil - PAH in tissues
		Effects of oil on fishing gear, vessels	Costs of cleaning or loss of effort	Development of alternate fishing techniques or strategies
General	Preparation of national action plan and lists of experts			
	Dissemination of information			Dissemination of information
	Exercises to test national plans, controlled spills			
	Logistics - includes cooperation at international level	Logistics - + international cooperation	Costs of compensation	International cooperation, exchange, coordination
	Public relations - identify responsible agencies	Public relationships	Legal implications	
	Funding - identify and secure sources for baseline and emergency programs			Funding - long-term sources

Analysis of scientific involvement in previous oil spill incidents has shown that the scientific input to the clean-up strategy and the analysis of impact on biological resources would be greatly aided by "pre-event" preparation and analysis (Pollack & Stotzenbach, 1977). One valuable set of information the scientist would like to have at the time of a spill is a series of maps providing the information on temporal and spatial variations of biotic resources at the spill site. Maps that show the distribution of variables such as eggs and larvae, fisheries and fishing effort, and benthic communities allow the scientist to give better advice on protection of sensitive areas during clean-up. Such information is also invaluable in providing baseline information which allows more precise assessment of change or damage. Maps of prevailing currents, tides and winds will also aid in predictions of oil movement with time. Other pre-event tasks such as agreed analytical methods, intercalibration protocols, and sampling methods will add to the scientific validity of the information obtained during a spill study. The working group recognised the need to provide contingency funds in advance of incidents, so that required research during a spill can proceed, rather than be held in abeyance until funds are allocated, resulting in the loss of critical information and advice.

During an oil spill incident, the marine science community has an important role to play in the operational aspects of the spill response. Aerial photography and other remote sensing imagery (Klemas et al., 1977), analysis of wind and current patterns (Bishop, 1980), and computer modelling (Noll, Cornillon and Spaulding, 1977) can aid in the predictions of oil movement in the sea. Knowledge of local biotic resources and their sensitivity to oil can aid in decisions for usage of dispersants and booming of specific sensitive coastal areas. Scientific information is required to determine damage to communities and impact on commercial fisheries. The general public and government officials will ask and expect answers to questions involving damage to living resources and rates of recovery of these resources.

An oil spill occurrence or practice responses to a simulated spill offer opportunities to investigate and learn how to handle better the next actual incident. Information can be gleaned on the behaviour of surface oil, recovery rates of biological communities, impact of oil on particular species, and the residual times of oil in various habitats and resource organisms.

The following report briefly discusses the various research disciplines appropriate in the scientific investigations of oil spills in coastal and open sea waters. It is not intended as a complete manual on how to carry out the tasks suggested, but it provides the background and rationale for the suggestions made. The report is directed towards the ways in which spills can be exploited to provide the maximum scientific information. Although it is not primarily concerned with clean-up operations, there are opportunities for scientific input at all stages in a major spill, and an attempt has been made to cover the full spectrum. Literature cited and suggested readings indicate methodologies, techniques and results of previous oil spill investigations. Further, it is recognised that if provisions are not made for clean-up, in addition to scientific research and monitoring responses, scientists will spend a considerable portion of their efforts in clean-up activities.

3. SEABED AND RESOURCES MAPPING

3.1 Pre-Event Considerations

Several recent papers have been concerned with the protocols to be followed in responding to spills of oil and other hazardous substances. Hershner et al. (1978) have outlined the procedures for study of accidental discharges of petroleum in estuarine, coastal and oceanic ecosystems. Their general approach to biological damage assessment entails analysing the distribution and abundance of organisms in an area affected by oil. They note that "one of the major difficulties with most post-spill studies is a lack of any data documenting pre-spill conditions in impacted areas".

Other Working Groups and authors concerned with responding to spills of petroleum have emphasized the frequent lack of baseline data against which to compare the effects of sudden release of oil (Sherman and Pearce, 1979; Pearce, 1978). Investigators (Lewis, 1978) have also suggested that there is a need for widespread baseline/surveillance schemes, particularly for the benthos.

Some years ago the International Council for the Exploration of the Sea (ICES) passed a resolution (C.Res.1976/4:14) that charts and maps should be prepared which indicate the distribution and abundance of living resources in relation to areas likely to be the sites for extraction (mining) of marine aggregates (sands and gravels). The results were presented in the report of the appropriate Working Group (C.M.1977/E:68), and the Council requested (C.Res.1977/4:12) that member countries should carry this activity forward.

The oil working group endorsed the value of such charts. They could show the distribution and abundance of principal commercially important finfish and shellfish. Also, charts could be prepared which indicate these variables for certain important planktonic (phyto- and zooplankton) and benthic species which are parts of food chains or recognized indicator organisms of pollution effects. Other charts could illustrate the temporal abundance and distribution of fish eggs and larvae and the boundaries of principal nursery grounds, and for benthic organisms could indicate diversity of benthic communities and information such as biomass, community structure and distribution. The distribution and temporal variation in fishing effort, where well documented, could also be shown. Levels of productivity, including primary production, have already been mapped for limited areas in Europe and North America. Seasonal distribution of nutrients, which might be affected by petroleum and other pollutants, should also be shown on charts. Physical data, including information on major and local current systems, are available as charts for several parts of the world. Recently, Bishop (1980) has developed a compendium of maps showing monthly wind and current conditions in the Middle Atlantic Bight off North America. This information is summarized so that it can be used to compare surface oil movements in relation to vulnerable living resources.

Data on the distribution of sediment types and the association of petroleum-derived hydrocarbons with sediments are available for limited areas and have been mapped in a few instances. The same is true for hydrocarbons in the water column but since there is considerable variability, little effort has been made to chart such data. Programs such as "Mussel Watch" (Goldberg, 1978), and "Ocean Pulse/Northeast Monitoring Program" (Pearce, 1979) offer the possibility of mapping the distributions of petroleum hydrocarbons in tissues of selected indicator species. Since it is known that certain organisms, including the filter feeding bivalve molluscs, are capable of rapid uptake of hydrocarbons (Lee et al., 1978) such maps will provide substantial baselines in the event of oil spill incidents.

All charts must be periodically reviewed and updated. In many instances, ongoing fisheries assessments required for management purposes will provide data for the adult populations as well as information on the distribution and abundance of key benthic species in heavily polluted areas such as the New York Bight, as well as on principal fishing grounds such as the Dogger and Georges Banks. In the case of the New York and Middle Atlantic Bights, annual surveys allow regular upgrading and revision of charts on benthic distributions. To be most useful, charts should be developed to standard scales.

3.2 Operational Considerations

When a spill of oil or other hazardous material occurs, charts such as described above may be used in the context of damage assessment and mitigation. They will help to locate resource species and habitats which should receive special protection by "booming", barriers and similar techniques, and to which dispersants and other oil control chemicals should not be applied. Charts might also be used to locate areas for disposal of collected oil.

The maps of resource species and physical data such as currents (Bishop, 1980) can also be used to predict possible impacts on important fisheries, marine ecosystems and coastal amenities, such as swimming beaches. Such predictions can then be used to allocate equipment, personnel and supplies to reduce impacts, protect resources and mitigate damage. The charts and maps will permit an early assessment of the long-term implications of a particular spill.

Charts which show the distribution and abundance of petroleum hydrocarbons and other contaminants will serve as baselines against which increases in petroleum in the physical environment (sediments) can be compared and the persistence of a specific oil spill can be evaluated.

3.3 Required Research Considerations: Mapping

At the present time, data exist for many resource species in Europe and North America to permit charts to be prepared which could serve as baselines for their distribution and abundance. For many important species and geographic areas, however, there is insufficient information for mapping purposes. Such areas and species should be identified on a national basis and efforts made to collect data which would permit the development of charts.

Following spills, affected areas should be mapped or re-mapped; control or reference sites should be identified. Effects on fishing efforts and recovery of contaminated fishing grounds or habitats should be considered and depicted on maps.

In mapping living resources, great importance should be given to using standard methods of collection, analyses and data presentation for biological, physical and chemical studies. Stefan and Grant (1978) outline standard methods to be used in sampling phytoplankton and O'Reilly and Thomas (1979) provide a manual for measurement of primary production using the ^{14}C technique. Jacobs and Grant (1978) provide guidelines for zooplankton sampling in baseline and monitoring programs. Mearns and Allen (1978) and Swartz (1978) have developed standard methods for coastal fishery assessments using small trawls for sampling and for analysing the benthos respectively. Gonor and Kemp (1978) and Gray et al. (1978) give procedures for quantitative ecological assessments in intertidal environments; their standard techniques may be used in making measurements which would be used in mapping intertidal and sub-littoral environments.

Hershner et al. (1978), Linden et al. (1979) and Whittle et al. (1978) have provided guidance which can be used in responding scientifically to accidental oil spills; these, again, might provide standard methods or guidelines for developing data to be used in mapping. Finally, Maienthal and Becker (1979) have reviewed the literature on sampling, sample handling and long-term storage for environmental materials. Again, proper sampling and handling of samples are extremely important in research designed to provide monitoring and baseline data for mapping and other purposes.

4. PHYSICAL MEASUREMENTS AND MODELLING OF PHYSICAL PARAMETERS

A number of numerical models are available for prediction of the movement and mixing of oil under varying wind, sea state and current regimes (see Stolzenbach et al., 1977; Grose and Mattson, 1977; Ahlstrom and Wise, 1976). Most models solve the mass balance or distribution of variables equation (Sverdrup et al., 1942) using marked particles and a basically Lagrangian approach, representing diffusive effects stochastically or with Monte-Carlo techniques. A second characteristic of existing models is that they typically do not include more than a few of the most obvious processes. There is usually an estimate of the residual ocean current which advects oil particles. Wave/oil/wind processes are simulated by a displacement that is proportional to the wind, usually 1 to 3 per cent of the wind velocity, and this is vectorially added to the ocean current displacement. However, the wind drift depends on the wind shear, which may be significantly different for an air-oil-water interface than for an air-water interface. This is supported by laboratory experiments suggesting the important role of oil viscosity in the mechanisms of oil displacement and spreading. Oil viscosity varies according to weathering as a function of time, which in turn seems to be important for the spreading of oil. Models intended for smaller scale spills may include explicit spreading algorithms and an attempt to represent weathering (Stolzenbach et al., 1977). In at least one case, a simple parameterization is introduced to simulate beaching processes (Ahlstrom and Wise, 1976). Current conceptual approaches are largely empirical, and observational data from actual spills, particularly in the early stages, are generally lacking.

Thus, present-day modelling efforts, particularly for large-scale spills, are conceptually simplistic. Most have concentrated on adequately representing the background oceanographic environment of currents and winds. Results have been a qualified success in that even with modest amounts of current data and regional wind statistics, the dominant direction of the trajectory can be determined and initial estimates of scatter are available.

Several recent oil spills have resulted in increased interest in developing drift prediction models. Noll et al. (1977) have developed a preliminary report on such a model. Trajectories calculated in historical wind data followed the actual "Argo Merchant" slick during a 25-day period when the slick became influenced by currents.

It is clear that improvement on the state-of-the-art in spill modelling will depend on advancements along both the theoretical and the observational fronts. The discussion below highlights certain areas which require expansion. The value of prompt communication of findings between workers from different countries should be noted. Organisations such as ICES can play a useful role in the consolidation and exchange of data obtained in controlled experiments and during spill studies.

4.1 Pre-Event Considerations

Several research groups are currently working to improve our understanding of the processes controlling oil distribution and develop more realistic modelling algorithms. Much current research is directed toward the processes of oil spreading, wave/oil momentum transfer, and weathering. Mackay et al. (1979) provide insight into oil spill processes and models, including dispersion and emulsion formation from oil slicks.

4.1.1 Oil spreading

The extent and form of oil spreading is a complex function of the fluid properties of both the oil and water. A number of studies have been carried out to describe the process (see Stolzenbach et al., 1977). Models of the process are highly idealized and typically require constraints derived from observational data. Considerable variation is noted between data sets, which is not surprising considering the limited physics included in the parameterization and the general difficulty in obtaining quantitative spill data. It is reasonable to say that all spreading models adequately represent the initial increase in slick surface area, however, in all cases the quality of the representation breaks down as the processes involved become more complex - thick and thin regions, pancakes, stringers, or wind rows. Considerable further research will be required before suitable descriptions of oil spreading are possible.

4.1.2 Wave/oil momentum transfer

Despite a long observational history, the dynamics of the wave/oil slick interaction are poorly understood, yet the details of these processes are of particular significance to oil transport and environmental impact problems. It is observed that short gravity waves and capillary waves are quickly dampended when entering an oil slick. Wave momentum is transferred to the oil slick or a boundary layer. The consequences of this process are at least twofold. First, the momentum exchange acts to propel the oil slick over the water, thus making it move faster than the surface drift in the direction of the dominant waves (downwind). In addition, since the shorter gravity waves and capillary waves have some components coming from all directions there will be an additional momentum transfer acting as a compressional force on the oil slick. This effect acts to counter the natural spreading of the slick and tends to reinforce surface tension effects. It can be seen that two major components needed in trajectory predictions appear to be closely tied to this wave/oil/momentum transfer process: 1) differential oil/water movement and 2) final expected spreading, pancake formation, etc. Experimental data appear to give ambiguous parameterizations of these processes (Stolzenbach et al., 1977). It is likely then that the relevant physical or chemical characteristics of the oil have yet to be identified. Recent work by Steward (1976) indicates that surface active molecules play a major role in these processes.To the extent that these interface characteristics introduce new, or distinctly different, dynamic effects from those attributed to either the bulk form of oil or water, it will be necessary to develop alternate parameterization schemes. We are faced with the possibility that the actual controlling dynamics will depend on some small molecular fraction of the oil. In addition, weathering effects will preferentially modify this surface active fraction so that the required algorithms will depend on oil type, environmental conditions and complex time histories.

Regardless of what algorithms are ultimately chosen to represent oil/wave momentum transfer and the associated drift, compressional forces and secondary circulations, it is clear that an appropriate dynamic theory has yet to be developed. In the pursuit of an acceptable theory, more carefully collected data are needed in conjunction with expanded conceptualizations of actual processes.

4.1.3 Weathering

Hydrocarbons once released into the marine environment cannot be treated as conservative quantities. As time goes on they are both modified in form and removed from the surface by a number of processes including evaporation, emulsification, sediment interactions and biological degradation (Afghan and Mackay, 1980).

Some hydrocarbons will evaporate from a surface slick, resulting in significant losses of mass to the atmosphere. This process is not at all uniform and depends on a number of characteristics of the oil. Obviously, the lighter molecular fractions tend to evaporate more rapidly than the heavier ones. This process modifies the bulk properties of the slick in such a way that certain feedback mechanisms become important. The heavy residuals left at the surface of the slick can form a crust or skin that inhibits further evaporation until mechanical processes, such as wave action, break or perturb the surface. Another important secondary effect associated with evaporation is the fractionation of the oil, which leaves the heavier component behind. In some cases the heavier fractions may be dense enough to sink. There have been examples where patches have sunk in relatively large chunks, and recent studies (Mattson, 1978) suggest that small flakes (which were presumably originally in suspension in the lighter oil fraction during the USNS "Potomac" spill) can sink as residuals after evaporation. This phenomenon was verified in the paper by Grose et al. (1979). Linden et al. (1979) also report that oil reached the benthos during the "Thesis" oil spill in the Baltic.

Observational data show very large variations in the loss of mass of oil due to evaporation from spill to spill. Although the accuracy of the observations can certainly be questioned, the range of losses appeared to be from practically nil in the "Argo Merchant" spill (No.6 oil) to over 50% in the "Ekofisk" spill (light crude oil). It should be noted that the mechanisms and final results of the weathering may to some extent depend on the amount of oil, the nature of the incident, and the size of the slick. Thus the evaporation from small slicks may be determined by different mechanisms than from large ones. There seems to be no universally applicable theory for evaporation losses - they seem to vary from case to case.

A second weathering process is associated with emulsification. It occurs in two ways, leading to quite different results. Oil-in-water emulsification can form where small oil droplets go into suspension in water. In such a case the oil no longer behaves as a surface slick, but moves with the water, mixing throughout the upper layer somewhat like plankton. Sustained weathering effects in this form are not known, but oil-in-water emulsions appear to remove the oil from the surface so emulsification agents are often considered part of a clean-up strategy. A second type of emulsification (water-in-oil) is one in which the mixture contains up to 80% water. Such a water-in-oil emulsification, often called mousse, appears to resist certain types of continued weathering and takes on physical properties quite different from those of surface oil. The development of algorithms to predict mousse formation is of major importance for predicting overall oil impacts. Similarly, algorithms should be developed for the rate of formation and size distribution of subsurface oil particles.

A third type of weathering process affecting oil slicks is related to oil interacting with suspended sediments in the water column. In at least some cases, oil droplets appear to adhere to particles. This is not a universal effect, and probably depends on complex geochemical interactions as well as oil characteristics. For example, in the Santa Barbara blowout, sediment from the Ventura River bound up quantities of oil whereas large amounts of oil from the "Argo Merchant" spill did not appear to end up in the sediments. In other cases ("Arrow", West Falmouth, and "Metula") mechanical mixing was responsible for oil being driven into the sediment where the weathering processes and residence times were entirely different from those of oil in the water column and at the surface.

A fourth weathering process is related to biological utilization of the hydrocarbons as an energy source (see Section 8). This tends to be a slower process than the ones mentioned above and consequently is of secondary importance, at least during the initial stages of a spill. For the long-term fate of spilled hydrocarbons, biological breakdown is still likely to be significant, but this is typically beyond the period when trajectory tracking techniques can contribute to a meaningful estimate of the hydrocarbon mass balance.

4.1.4 Other problems

Research on the effect of an oil film on the gas exchange through the air/water interface has produced some discrepancies between experimental results (Liss, 1977). The problem may be theoretically rather complicated, but according to recent theories the capillary waves and wind shear have an important role in gas exchange. If there is any reduction in gas exchange, this could be important in shallow, sheltered areas, particularly those which have undergone eutrophication.

In northern latitudes, special problems are raised by the presence of ice, and research is required on the conditions for a surface oil layer to find its way under ice cover, and on the processes involved; on the physics of oil entrainment in or under ice and the subsequent effects on movement, weathering, and dissipation.

4.2 Operational Considerations

An oil spill offers opportunities to validate existing hypotheses and to collect field data required for models and predictions.

During the spill incident, mechanisms must exist to obtain rapidly information on the initial distribution and composition of the oil, as well as data on current and predicted meteorological and oceanic conditions. Estimations of various model coefficients are also required. Much of this information will result from initial mapping activities discussed in earlier sections. Time is of the essence in this activity and rapid means of data communication to and from the spill site are essential.

Experience indicates that frequent updating of the actual distribution of the spill is necessary to "re-initialize" the model as well as detect possible errors in dispersion and other coefficients used in model calculations. Continued mapping activity, measurement of surface currents and winds, calculation of oil/water differential motion, and measurement of subsurface oil concentrations is necessary throughout the spill incident in order to refine subsequent trajectory predictions.

4.3 After the Event

Given that sufficient mapping data are available, it is especially useful, after the event, to "hindcast" physical spill parameters using actual winds, currents, and other relevant data obtained during the incident. This process very clearly reveals errors in model assumptions and provides further insights regarding underlying physical processes not otherwise obtainable. The exchange of such "hindcast" results from a number of incidents (involving several oil types and environmental settings) will aid substantially the development of improved physical models. Again, an attempt should be made through an international organisation such as ICES to foster the exchange of information following spills.

5. GEOLOGY

5.1 Pre-Event Considerations

Recently, Hayes and Gundlach (1979) have developed a scheme for measuring the vulnerability of beaches to oil spills (Table 2). Their information has been used at the "Amoco Cadiz" and other spills and is important in 1) assessing the possible impacts of oil spills on recreational beaches and intertidal and sub-littoral fish habitats and 2) establishing the vulnerability of geological and biological resources. These authors emphasize that the morphology of a coastline provides the basic framework to which other relevant factors, such as biological habitat and physical processes, are tied. Therefore, a general knowledge of the coastal morphology of a spill site is of primary importance in planning the response to a spill. For example, a young mountain range coast, backed by cliffs in bedrock, with beaches of coarse gravel presents an entirely different set of problems from that of a low-lying coastal plain shoreline with abundant mud flats and salt marshes. The morphology of coastlines is determined by five primary controlling factors: 1) global tectonic crustal movements; 2) hydrographic regime; 3) sediment supply and sources; 4) climate; and 5) geological history. They further state that a knowledge of beach morphology, sediments and processes is important for planning for oil spills in coastal areas. A few of the more important considerations noted are:

5.1.1 Beach morphology varies from place to place depending primarily on variations in exposure to wave action and sediment size. A typical beach profile with superimposed beach terminology is presented in Figure 1. Slopes of beach faces are governed by the interactions of sediment grain size and wave action.

Table 2. Summary of proposed environmental classification in order of increasing vulnerability to oil spill damage (Gundlach and Hayes, 1978).

VULNERABILITY INDEX	SHORELINE TYPE	COMMENTS
1	Exposed rock headlands	Wave reflection keeps most of the oil off shore. No clean-up is necessary.
2	Eroding wave-cut platforms	Wave swept. Most oil removed by natural processes within weeks.
3	Fine-grained sand beaches	Oil doesn't penetrate into the sediment, facilitating mechanical removal if necessary. Otherwise, oil may persist several months.
4	Coarse-grained sand beaches	Oil may sink and/or be buried rapidly making clean-up difficult. Under moderate to high energy conditions, oil will be removed naturally within months from most of the beachface.
5	Exposed, compacted tidal flats	Most oil will not adhere to, nor penetrate into, the compacted tidal flat. Clean-up is usually unnecessary.
6	Mixed sand and gravel beaches	Oil may undergo rapid penetration and burial. Under moderate to low energy conditions, oil may persist for years.
7	Gravel beaches	Same as above. Clean-up should concentrate on the high-tide swash area. A solid asphalt pavement may form under heavy oil accumulations.
8	Sheltered rocky coasts	Areas of reduced wave action. Oil may persist for many years. Clean-up is not recommended unless oil concentration is very heavy.
9	Sheltered tidal flats	Areas of great biologic activity and low wave energy. Oil may persist for years. Clean-up is not recommended unless oil accumulation is very heavy. These areas should receive priority protection by using booms or oil sorbent materials.
10	Salt marshes and mangroves	Most productive of aquatic environments. Oil may persist for years. Cleaning of salt marshes by burning or cutting should be undertaken only if heavily oiled. Mangroves should not be altered. Protection of these environments by booms or sorbent material should receive first priority.

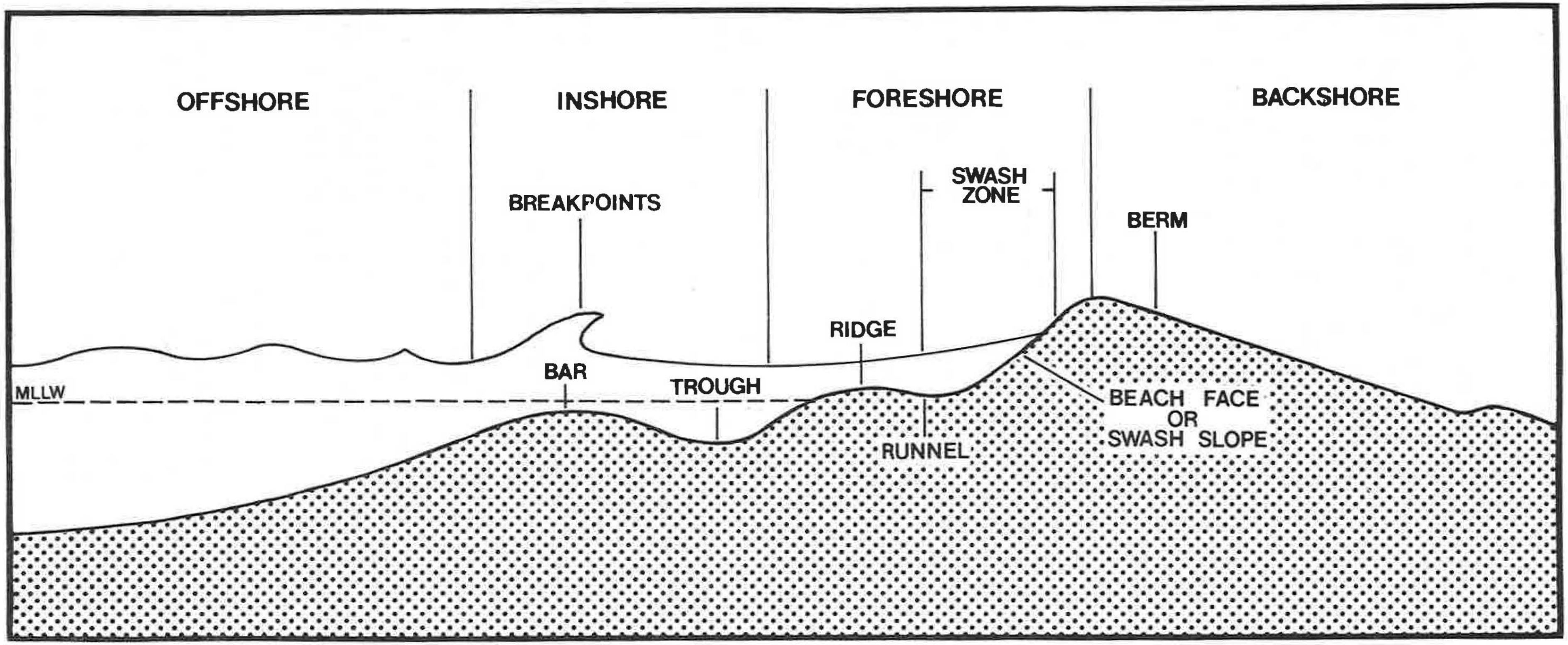

Figure 1. Beach morphology and terms. (From Davies, 1973.)

5.1.2 The cycle of erosion and deposition on beaches differs markedly from place to place and is dependent upon such variables as: 1) direction of prevailing winds relating to shoreline alignment, 2) nature of storm activity, 3) sediment grain size, 4) wave climate, and 5) nature of offshore topography. Several authors have observed a striking contrast between beach cycles on the North American east coast and those of the west coast. Development of winter profiles on beaches of, for instance, the Atlantic coast north of Delaware Bay, and on beaches of the California coast, differ in a way that appears to depend on mean wave climates and seasonal changes in wave climates of the two regions. Such differences may result in completely different impacts of oil pollution on the geology and biota of coastal areas affected by either coastal or offshore spills. The significant geological features should be mapped in a way so that seasonal aspects can be phased into an understanding of how a spill will affect the biota and other coastal resources.

Hayes et al. (1973) developed a standard procedure for systematic sampling to rapidly classify large sections of coastline. The procedure, called the zonal method, is effective to assess rapidly the extent and persistence of spilled oil on a coastline and establish the vulnerability of beaches and biota. It is discussed further in Section 5.2. In addition to required geomorphological studies Gonor and Kemp (1978) and Gray et al. (1978) have set forth procedures for quantitative ecological assessments in intertidal environments; their standard techniques may be used in making measurements which would be used in mapping intertidal and sublittoral environments.

5.2 Operational Tasks

Hayes and Gundlach (1979) have applied zonal techniques (see below) to describing geomorphology and coastal processes as they interact with spilled oil and provide rapid assessments of the effects of oil spills. Their approach has been applied to numerous coastlines in several areas of the world. The main advantage of the zonal approach is that valuable in-depth information is provided on the amounts and effects of spilled oil over large areas and in a short period of time. This, in turn, allows oil spill response teams to determine on an ecosystem basis the vulnerability of coastal areas within the frameworks of the geophysical environment and contained ecosystems. Incorporation of rapid biological assessment with the geomorphological zonal approach allows for assessment of the biological components and results in a combined biological and geological vulnerability prediction. This essentially means one can then better predict how long oil will remain within an area or habitat and what biological organisms and community types will be affected.

A descriptive biological approach requires that one or two biologists accompany the intertidal or coastal processes team (one or two geologists) to each survey (census, photographic, or sampling) area. Biological team members assist the geologists in detailed geological mapping, while biological observations on species present and affected are gathered and incorporated into geological profile maps. After the beach or marsh profiling is finished, more detailed biological observations are made and important representative species collected and preserved for subsequent detailed observations and analyses. Biological observations emphasize the following: 1) vegetation, ecologically important species; 2) epifaunal and infaunal organisms, ecologically important species; 3) economically important species; 4) rare/endangered species; 5) birds and mammals; 6) socio-economic importance; 7) trophic structure of community; 8) physical parameters, temperature and salinity; 9) oil affected species, how affected; 10) potential indicator species and their niches; and 11) chemical analyses for body burdens of petroleum hydrocarbons, dissolved oxygen, etc. (see Section 7 for greater detail).

The modified zonal method of Hayes and Gundlach (1979) is as follows:

5.2.1 Collection and study of available literature, aerial photographs, maps and charts must occur as soon as possible following a spill. Maps on a scale of 1:20 000 are available from many national sources and should be retained at all of the response facilities. These are most useful for delineating oil distribution, as well as for determining coastal geomorphology.

5.2.2 An aerial reconnaissance (200 m) of the entire area affected by the spill should be conducted during low tide to observe maximum exposure of the inter-tidal area; this allows an extremely rapid assessment of the spill site and is especially useful in determining the relationship between regional geomorphology, ecosystems and oil distribution. In-flight observations can be recorded on tape and photographically with a hand-held camera. Either helicopters or fixed-wing aircraft may be used.

5.2.3 Based on the aerial survey, local maps, and oil distribution, representative areas are selected for detailed study. The sampling interval depends on the variety of coastal types as well as logistical and financial considerations. Areas should be selected that are representative of the local geomorphology, ecosystems and oil distribution.

5.2.4 Two types of stations are set up, visual inspection and zonal stations. Visual inspection stations are areas surveyed rapidly to determine coastal type, extent of oil coverage, and the thickness and depth of buried oil layers as observed in small trenches dug across the beachface. Photographs are taken to document oil distribution, biological impact and coastal morphology. Notes taken should be recorded in a field notebook or on tape. Observations of biological impact are made simultaneously with notes and samples on geological structure. Each site is given a station designation. The distribution of oil, sediment type, and geomorphology at zonal stations are studied in greater detail. The following tasks are performed at each station:

1) A topographic profile is run from the back beach to seaward of the low water line. The profile is run within 2 hours of low tide in micro (0-2 m) or meso-tidal (2-6 m) areas. In macro-tidal areas (> 4 m), the beachface is exposed for a greater amount of time and profiles can be run within 3 hours of low tide. It is necessary to record the change in vertical distance, the percent oil coverage (estimated along that section of beach), and the oil thickness as read off the profile

rod for each horizontal distance (3 m maximum). Comments should include sediment type, geomorphic variations (berm, ridge-and-runnel, etc.), oil appearance and biological information (species and abundance). Samples should also be taken for chemical analyses. The high-tide swash line and water level should be appropriately marked. Stake heights are necessary to determine erosion or deposition between repetitive profiles. A check list can be included in the profile sheet.

2) Sediment samples are taken at three equidistant sites along the profile (Figure 2). Sampling sites are paced off and marked before running of the profile, so that they can be appropriately marked on the profile sheet. If possible, an unoiled sample is taken for textural analysis; otherwise, the oil will have to be removed by tedious chemical processes. Surface oil should be scraped away. The sample should consist of 100-200 g of sediment taken to a depth of 10-15 cm. If the sediment grain size is too large to allow sampling, a photograph (with scale) is taken of the site. Sediment size is measured from the projected image after development. If time and expenditure are important, one sample taken at the mid-beachface will suffice. The remaining sampling sites should be described in detail as to sediment size and sorting.

3) Visible effects of the oil in biological communities are observed and recorded. The location and distribution of oiled grasses, algae and epibenthic animals are photographed and described to determine temporal changes in biota. In each case, a 15 cm or 30 cm scale is placed in the picture to determine surface area (eg 0.8 m^2) photographed for mortality counts.

4) A trench is dug along the profile line to discern the distribution of buried oil. The thickness, depth of burial and general consistency of the oil are described. Photographs are taken of the entire trench as well as of several detailed areas. Data concerning the extent of buried oil are necessary to determine accurately the quantity of oil incorporated within shoreline environments. If desired, samples may be taken of the oiled layers within the trench to determine oil quantity and composition.

5) A hand-drawn sketch is made to force inspection of all aspects of the site. The following should be noted in the sketch: 1) beach morphology, etc.; 2) profile line; 3) sediment sample location; 4) oil distribution; 5) trench location; 6) depth of buried oil; 7) relevant biology; 8) clean-up operation; 9) all samples taken, and 10) all photographs taken.

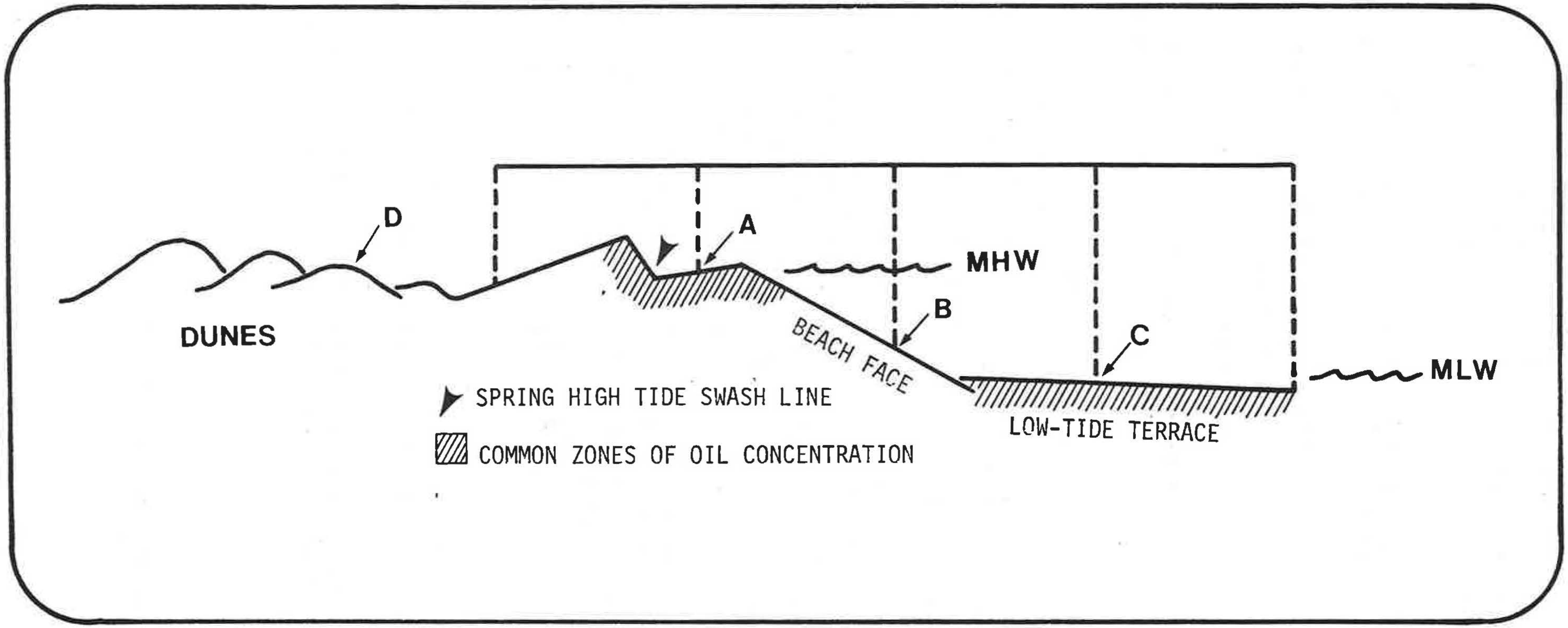

Figure 2. Three equally spaced sediment samples are taken at each zonal station as indicated in this figure from Metula report (Hayes and Gundlach, 1975).

5.2.5 Sediment samples are analysed for size characteristics by accepted standard sieving techniques or by a rapid sediment analyzer. If these instruments are not readily available or time is critical, grain size can be estimated using a "phi size finder" which contains sediment divided into pre-measured size classes for direct comparison to the sample.

5.2.6 The coast is geomorphologically categorised, and oil distribution is superimposed on base maps. Oil distribution may be divided as follows:

light	-	< 25% coverage of the intertidal zone
moderate	-	25-65% coverage
heavy	-	> 65% coverage

5.2.7 Follow-up surveys and overflights are necessary to determine longer-term oil retention, clean-up effectiveness, and geomorphic changes.

5.2.8 During the spill, communication with the SSC*) is maintained. Small scale maps and field sketches are an efficient way to transmit information. After the spill, if a damage assessment program is warranted, base maps, photographs, and field notes are compiled and analysed to determine accurately original oil distribution, its persistence, and overall impact.

5.2.9 The morphology of the coast and the distribution and retention of oil along the shoreline are integrally tied to the physical processes which affect the coast. In the field, measurements must be taken of the following: 1) wave type, 2) wave height, 3) wave period, 4) wave direction, 5) breaker depth, 6) direction of longshore transport, 7) velocity of longshore current, 8) wind direction, 9) wind velocity and 10) general weather conditions.

5.2.10 After the foregoing observations are taken, a rough profile is drawn and the biological species found within each area of the profile and the impacts on them are listed under their appropriate section and compared with baseline maps and charts. In addition, photographic documentation is made of the various items observed; these are catalogued, evaluated and incorporated into field notes.

5.3 Post-Event Tasks

Temporal collections should document the rate at which oils are cleansed from sediments and the biota recolonise areas from which they were eliminated.

It is also important that geologists study the effects of oil on beach morphology; do sediments erode or deposit at greater rates? Do beaches become unstable?

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* Scientific Support Coordinator, see Section 10.

6. CHEMISTRY

A requirement to analyse various marine samples for oil often follows from marine accidents involving spillage of crude or refined petroleum products. Such analysis may be designed to satisfy a variety of needs:

1) to estimate the quantity of oil released from individual sources;
2) to identify oil for legal purposes;
3) to determine the lateral and vertical dispersion of oil and any associated interactions with, or effects on, marine biota;
4) to provide information to public health and commercial sea product inspection authorities on the incidence of oil in organisms or their environment which might cause tainting or pose health hazards;
5) to assess the weathering rate of oil and the changes in composition resulting from weathering processes;
6) to describe the distribution of spilled oil in a sufficiently detailed manner so that correlations with unforeseen phenomena and the incidence of oil can be detected;
7) to assess the efficacy of oil clean-up procedures;
8) to assess the recovery of contaminated areas.

The following sections describe the criteria and methods by which these tasks can be achieved in an expedient and effective manner, and suggest where additional science is required.

6.1 Pre-Event Considerations

The necessary advance work comprises all aspects of contingency planning both administrative and technical. It should be stressed that, aside from technical considerations, contingency plans must include detailed specification of the management and organisational framework for the emergency response (see Sections 9 and 10). On the technical side the most important aspects of pre-event requirements involve sampling and analytical technology. Methodologies exist to satisfy the objectives stated above, but they must be chosen and adequately tested well in advance of any emergency application. A most effective way in which experience with the chosen techniques to tackle oil spill situations can be gained is through surveys of the background levels of petroleum hydrocarbons in the marine environment, especially in areas of intense tanker traffic, refining and petroleum development. Such an approach not only permits an assessment of the procedures and familiarity with their use but also results in the collection of essential baseline information against which any increase due to accidents can be determined. One aspect of analytical performance that remains to be addressed adequately is the intercomparability of oil survey data, and ICES has recently completed its first intercalibration exercise on the chemical analyses of oil (see Section 6.2).

6.1.1 Methods of analysis

A variety of analytical methods for hydrocarbon detection and determination are applicable to marine oil spill situations. These include:

1) gravimetry;
2) colorimetry;
3) UV and IR absorption spectrophotometry;
4) UV fluorescence spectrophotometry;
5) liquid chromatography;
6) gas chromatography; and
7) gas chromatography-mass spectrometry (GC/MS).

While these methods cover a range of differing applications and analytical complexity, the procedure to be used in any particular situation depends on the nature of the questions to be answered. The degree to which the chemical composition of the oil must be determined will, in large part, define the analytical refinement required. In the majority of oil spill situations what is needed is a sensitive, fast and reliable method of analysis for oil in sea water that can be employed on board ship or that can be incorporated into an analytical protocol recognising the several problems of sample storage or preliminary work-up and extraction at sea. For determining the concentrations of large weathered oil particles in the sea surface gravimetry is a viable procedure. In the case of dissolved or dispersed hydrocarbons in the water column which result from chronic or acute oil releases to the ocean, a suitable analytical procedure is UV fluorescence spectrophotometry. This method is usable over large concentration ranges and has a very good (100 ng/l) detection limit for 1 litre samples. Since the emission spectrum depends upon the relative concentrations of the fluorescing substances, a more sophisticated analysis and interpretation can provide some qualitative information on the nature of the oil. It does not, of course, offer high specificity, and while it can be recommended in terms of the ease and speed needed for the large number of analyses required after an oil spill, the more detailed and accurate methods such as gas chromatography and GC/MS must be used to improve information on the composition of both environmental and source oils. A major difficulty with the fluorescence technique is that although the detection limit may be 100 ng/l the background values in the sea may be ten times this. Great care is required in interpretation. High petroleum concentrations certainly give high fluorescence but high fluorescence does not necessarily signify high petroleum content. The group discussed at some length the need for development of rapid field analytical techniques which can be used as a guide by biologists and others working at sea and on the beaches.

Finally, the possibility of remote methods should be considered. When large numbers of rapid measurements, perhaps over wide areas, are required, laser scanning for surface oil and towed drogues for continuous fluorescence measurement are relevant.

6.1.2 Sampling methods

The procedures used for collecting samples which are to be analysed for petroleum hydrocarbons depend upon the media being sampled. Examples of methods which have been found suitable for particular purposes are given below. These examples are certainly not exclusive of other methods and it must be remembered that contamination of the sample can arise either from the sampling platforms and sampling equipment or during analysis. All sources of contamination must be eliminated or reduced to the lowest possible levels. Such efforts will range from positioning the vessels to reduce stack (exhaust gases) wastes impinging upon samples, to exhaustive pretreatment of glass or metal sample bottles and foil wrappings with pesticide grade solvents to eliminate sources of hydrocarbon contamination.

6.1.2.1 Surface films can be sampled using a 200 mesh stainless steel screen (Garrett, 1965) or a Teflon disc (Miget *et al.*, 1974). Such sampling can be done only when sea conditions are relatively calm.

6.1.2.2 Water column samples are usually taken at 1 m below the surface and at additional selected intervals between surface and bottom, depending on depth. Samples of 2.5 or 5 litres may be collected from the upper few metres using the system described for the IGOSS Marine Pollution Monitoring Pilot Project (IOC/WMO, 1976) or remote bottle filling (Keizer *et al.*, 1977). These are only applicable to depths of 10-20 m. Samples from greater depths can be collected with 1) PVG Niskin samplers, provided reasonable care is taken to avoid contamination and pretreat (clean) the devices (Levy, 1979), 2) the Blumer contamination-free sampler (Clark *et al.*, 1967), 3) a modified Menzel-Dazzler bottle (Mackie *et al.*, 1978), or 4) the Teflon-coated General Oceanics type 1080 sampling bottle.

When sampling under continuous slicks it is difficult to prevent contamination by entrainment from the surface layer, but sampling devices may be put under the surface outside the slick area and towed submerged to the sampling site. Alternately, a sampler developed by General Oceanics[1)] ("sterile bag samples"), which can sample through slicks, should be considered. It has been reported that oil may adhere to the inner surface of the bag within 3 minutes; this must be considered during its development and use. A special sampler has been constructed at the Institute of Analytical Chemistry, University of Göteborg. It consists of a 1 litre glass bottle, closed with Teflon and secured to a special frame. It is opened by messenger once the proper depth is attained and operates well to depths of 35 m. By using it on special nylon line it is possible to avoid contamination by oil hydrographic wire. Whenever possible, samples should be chemically extracted on board ship. In the ideal situation, where a spectrofluorimeter is available, samples should be quantified for total hydrocarbons. Further analyses can then be conducted in the onshore analytical facilities.

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1) General Oceanics Co., Inc.
1219 New 163rd Street,
Miami, Florida, 33169 USA.

6.1.2.3 Isolated or dispersed floating tarballs can be sampled by neuston net (Sameoto and Jarozynski, 1969) and a tow of 1 nautical mile would normally be used as standard. The procedures used by the IGOSS Pilot Project may be adopted (IOC/WMO, 1976).

6.1.2.4 For bottom sediments in water depths of less than about 20 m, the most satisfactory collecting method is the use of hand-manipulated corers by divers. In deeper waters, or when no divers are available, corers, box-corers or grabs can be used. The shockwave which travels ahead of the instrument may disturb the surface and light flocculent material will be lost. Grab samplers must be kept as free as possible of oil-based lubricants; samples of any lubricant used should be taken for subsequent analysis if contamination is suspected. Frequently, it is desirable to take samples for chemical analyses from the same grab sample used to collect benthic organisms. Analyses of the biota and sediment can then be referenced to one another.

Reports developed during the "Thesis" experience suggest that the use of sediment traps will yield information not obtainable from cores and other devices.

6.1.2.5 Plankton sampling will include the use of a variety of plankton nets, oblique, horizontal or vertical tows being used as required. A 250 µ mesh net with a bucket-type codend can be used when live organisms are required. Underway collections, using plankton pumps, are possible and these may be useful in reducing contamination, although through-the-hull fittings and water intakes should be avoided. In all cases davits, booms and other gears for over-the-side collections should be rigged to avoid contamination from the vessel's hull and other running gear.

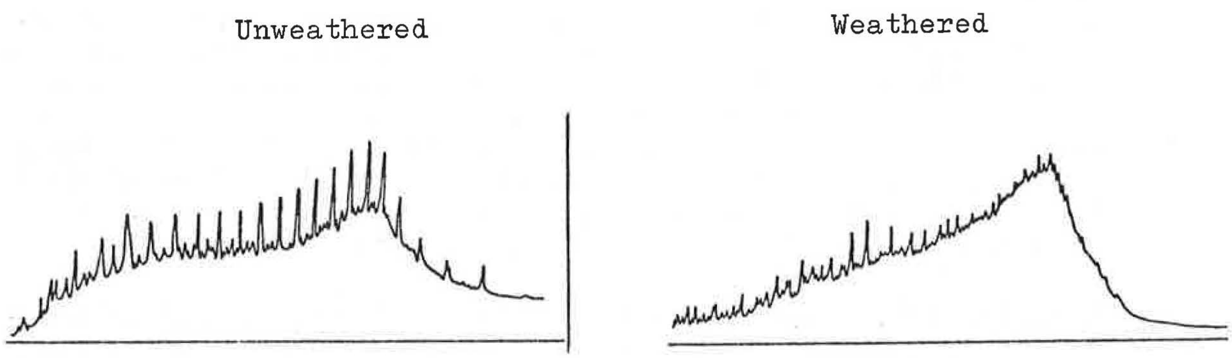
6.1.2.6 Benthos for chemical analyses is best sampled by divers, where possible (see Section 7), but otherwise dredges or grab samplers can be used, with precautions to minimise contamination. Standard methods are noted in Sections 3, 7 and 9. Because benthic or intertidal organisms such as mussels concentrate a variety of contaminants, the use of these organisms to concentrate petroleum components should be considered. When such an approach is adopted the experimental animals used must be 1) collected from oil-free, uncontaminated areas, 2) maintained in uncontaminated water in a healthy state, possible on board ship, until they may be 3) suspended in cages at the oil spill at appropriate water depths, or placed near the bottom, and 4) subsequently analysed chemically and compared with individuals from the clean, oil-free reference area. At least 10 mussels should be analysed to establish that supposedly "clean" animals are free of petroleum hydrocarbons. Recent measurements of mussels from supposedly "clean" habitats in coastal waters of New Jersey, USA, indicated petroleum hydrocarbon levels of 90 µg/g. Obviously a source of uncontaminated mussels or other species should be identified as part of a prespill protocol or operations.

6.1.2.7 Fish collections for pelagic and demersal species should involve standard, quantitative fish collecting methods using trawls and nets where available. Dangers of contamination during hauling and on-deck handling after catching must be recognised and avoided. This applies equally to sieving of benthic samples.

6.1.3 Rapid methods have been developed for immediate detection of oil in the field. These are distinct from the quantitative, laboratory-based methods outlined above. One method (Brown et al., 1978) involves extraction, paper chromatography and UV detection, and can be executed in a short period; it yields a qualitative indication of the presence of aromatic compounds in waters and sediments.

6.1.4 Samples will consist of whole oils, or oils in water, sediments or tissues. Whole oils or solutions or suspensions in water can be prepared for analysis by extraction into a suitable solvent. Pesticide-grade carbon tetrachloride is available from the purely analytical point of view but substances of this type are considered to be mutagenic, and the health risk must be carefully considered before the solvent is selected. Pentane is perhaps most acceptable in this context but cannot be used for IR work. Sediments can be extracted by shaking with mixtures of water and suitable solvents; the solvent should be less dense than water and as polar as possible, if measurements based on PAH are contemplated, so that PAH are desorbed from sediment particles.

6.1.5 The mechanisms of petroleum weathering must also be investigated, i.e. 1) evaporation only, 2) evaporation plus solution, 3) evaporation plus solution plus photooxidation, etc. Changes in the ratios of alkanes (GC) to PAH (fluorescence) are often used as an index of weathering as shown below.



6.1.6 The classes of compounds involved in tainting have yet to be adequately identified and specific methods for their analysis in all matrices (especially tissues) developed. The nature of the substances involved probably limit these investigations to laboratories equipped with GC/MS. In addition, as noted in Section 7, access to a properly trained taste panel is necessary.

6.1.7 Recent observations strongly suggest that although carcinogenic hydrocarbons can be detected in many oils, mutagenic activity with the Ames test cannot be detected. This may be due to 1) low concentration comparable to those observable in non-oil-polluted matrices or 2) competition of non-mutagenic compounds for the activation sites in exposed organisms. The fact that tumours have been detected in fish near spill sites strongly suggests that this question urgently requires further research.

6.2 Intercalibration

When a number of laboratories are involved in complementary or overlapping surveys for identical chemical substances, it is obviously desirable to assess the intercomparability of their data. While in many cases these intercomparisons can be handled on a national or regional basis it is often more effective to carry out international intercalibration exercises. ICES has conducted extensive intercalibration for metals in sea water and marine biota and for organochlorines in biota and is examining the problem of sediment intercalibration.

The need for intercalibration of petroleum hydrocarbon analyses has also been recognized and, under the auspices of the Marine Chemistry Working Group, an intercomparison exercise has been organized by ICES. This exercise was undertaken in 1980 and more than 30 laboratories were provided with sample material. The object of the first exercise is to establish the range of comparability between laboratories analysing the same samples by a variety of different methods. Since some of the laboratories will be using similar techniques, some measure of the comparability in results between laboratories using the same method of analysis should also be obtained. For this exercise no particular method of analysis is stipulated, each laboratory being free to analyse the samples by the method of their own choice. It is expected that a more sophisticated exercise will follow this first round with analysis by stipulated and probably advanced techniques.

There are major problems in the comparison of analysis of oil conducted by different laboratories in that the standard used is usually different from laboratory to laboratory. Attention is being paid within ICES to the desirability and feasibility of using a single reference oil or compound for oil analysis. This will present major practical and technical difficulties. However, there is a strong case for all the laboratories involved in a spill study situation adopting the same standard for their studies of that incident; ideally this should be the oil in question or at least a compound known to be an important component of that oil.

6.3 Research and Monitoring Tasks During and Following the Event

Since the result of chemical analysis will be required primarily in conjunction with other disciplines, most of the activity by chemists will be in servicing the needs of other physical scientists and biologists for information on the concentrations and composition of oil in the various compartments in the marine environment. The purpose of much purely chemical post-spill research is the refinement of analytical and sampling techniques developed in the pre-event research phase.

Examples of projects which will require chemical input in the course of post-spill investigations conducted by other disciplines are: 1) identification of toxic (acute and chronic) carcinogenic/teratogenic/mutagenic/pherome substances detected by biological studies and 2) the identification of changes in composition of the spilled oil and its ultimate fate. It is increasingly obvious that responses to and understanding of oil spills will require interdisciplinary research. Nowhere is this more needed than in understanding the physical/chemical fates and pathways of petroleum hydrocarbons and their accumulation and toxic effects in marine ecosystems. Many of the important questions have recently been reviewed in Afghan and Mackay (1980).

7. BIOLOGY

In the study of oil spills, a variety of biological approaches are available and several of these are included in some existing national response plans (C.M.1978/E:42, C.M.1979/E:64 and E:70). Table 1 summarizes those procedures which have been considered important in the understanding of effects of oil on particular components of ecosystems. Additional discussion is provided in the following paragraphs, but it is worth commenting that observations and experiments done in the field before, during and following an oil spill will rely heavily on existing data and the previous experience of investigators. Investigators in Norway have recently developed a bibliography on biological effects of oil pollution in the marine environment (Filion-Myklebust and Johannessen, 1980); this important document should be consulted prior to implementation of biological effects programs. Finally, workers in Europe and North America will be interested in a selected bibliography prepared by Canadian workers (Samson et al., 1980) and concerned with fate and effects of oil pollution.

A variety of biological responses can be expected to result from any oil spill, and the magnitude of the effects will depend upon 1) the size of the body of water receiving oil - if the oil is spilled in enclosed nearshore habitats or turbulent waters, the impact can be expected to be many times worse than if the oil is spilled in offshore areas; 2) the type of oil spill (is it a refined product or a crude oil? where does the oil originate from); 3) the geographic extent of the spill; 4) the prevailing sea state and weather conditions; 5) the total amount of oil released, e.g. from a sinking, pipeline rupture or oilwell blowout; and 6) the type of habitat which is immediately and eventually affected.

Since the original drafting of this document, a number of spills have occurred which have resulted in significant findings. Moreover, several authors have reviewed the efficacy of previous oil spill responses in relation to the effects of oil on biota.

In investigations with experimental ecosystems exposed to low levels of No.2 fuel oil in enclosed microcosms, Grassle et al. (1978) found that simulated chronic oil pollution resulted in what was regarded as a significant decline in the number of macrofaunal and meiofaunal organisms in the experimental tank when compared with control systems. Not only were numbers of individuals reduced, but the number of species was also reduced. Such controlled experiments verify field operations in which significant portions of the benthic fauna were immediately killed by the presence of oil (Sanders et al., 1980). The latter investigator found that the effects of oil spilled on a marsh at West Falmouth, Massachusetts, were seen for over a decade. At sheltered sites affected by the "Torrey Canyon" it has been reported that effects were immediate and recovery took up to 10 years (Southward and Southward, 1978), but the dispersants used were thought to have made a significant contribution to the toxicity.

Oil spill response plans emanating from several countries suggest that contingency plans should be developed for both offshore and inshore or coastal/estuarine spills (Gray et al., 1978; Hayes and Gundlach, 1979, and Pearce, 1979).

Recent documents which review the consequences of oil spills and responses to them indicate that there is a general lack of baseline data and understanding of the biological effects of chronic and acute oil pollution (Pollack and Stolzenbach, 1977). Moreover, many investigators now note the need for simultaneous, complementary studies by biologists, chemists and geologists. Hayes and Gundlach (1979) emphasized the importance of understanding the geological situations in areas likely to be impacted by petroleum oil spills and other sources. Finally, as indicated in Section 4, biologists interested in predicting the effects of an oil spill must work in concert with physical oceanographers in order to determine the trajectory of oil spills and coastal areas that will become vulnerable.

7.1 Prespill Activities

As in the case of responses by chemists and physical oceanographers in advance of an oil spill, it is important that biologists within particular regions have available to them maps showing crucial areas for living resources and habitats that are particularly vulnerable to oil spills. Moreover, as suggested by Gray et al. (1978), during the initial phases of an oil spill biologists must be prepared to sample reference or control areas which have not yet been impacted by spilled oil, but which may be considered to have populations and community structures similar to the areas initially affected. Gray et al. (1980), Whittle et al. (1978), and Pearce (1979) have provided information on the methodologies to be followed during the early phases of an oil spill. In many cases photography offers an excellent opportunity for documenting the ecological situation in rocky and sandy intertidal environments prior to the arrival of spilled oil. Similarly, underwater photographic techniques can be used by divers to document conditions in sublittoral habitats, prior to the impact of sunken oils.

Along with photographic documentation, previously developed maps can be elaborated upon by the use of collections made at sites along transects established perpendicular to beaches. Gray et al. (1978), Pearce (1978) and Hayes and Gundlach (1979) gave specific techniques for such intertidal and sublittoral surveys.

In addition to surveys of attached (epibenthic) and infaunal benthic organisms, it is important to document standing stocks and diversity of planktonic organisms and shallow water finfishes and shellfish in those areas that will serve as reference or control sites.

In habitats of marine mammals and endangered species, including birds, efforts should be made to assess the populations of such organisms, as well as superficial appearances prior to the arrival of spilled oil.

7.2 Operational Aspects

Once an oil spill has occurred and areas have been affected by 1) oil at the air-water interface, 2) sunken oil at the sediment/water interface and 3) extensive distribution of oil over intertidal flats, rocky outcroppings and the operational zone, investigations should emphasize the documentation of impacts on endangered organisms. As suggested by Gray et al. (1978), photographic documentation should be done in a standard manner with close-up photographs being taken with standard tripods or suspensive devices. Collections should be made, as in the case of the reference or control areas, in a standard manner which will allow comparisons in regard to decreases in numbers of individuals, changes in species diversity and for preparation of sediment, water and tissue samples for chemical analyses.

Aerial photography offers excellent opportunities to depict the extent of oil spills, and particular emphasis should be placed upon documenting conditions that might prevail in shoal areas or rocky outcroppings located some distance from coastlines immediately affected by spilled oils.

Aerial photographs using telephoto lens, as well as closed circuit television techniques from aircraft, can allow a rapid assessment of the populations of sea birds prior to and during an oil spill event. Photographs and magnetic tapes provide extremely valuable sources of information during the later phases of an oil spill assessment.

7.3 Impacts on Components of Ecosystems

Techniques available for assessing the interrelationships between spilled oil and oil degrading microorganisms are discussed in Section 8. The present section is concerned principally with phytoplankton, zooplankton, fish eggs and larvae, benthic organisms, fish and shellfish, and birds and marine mammals.

7.3.1 Phytoplankton

As was previously mentioned, Linden *et al.* (1979) noted that following the sinking of "Tsesis" there were significant effects on phytoplankton organisms. Their studies indicate that there were possible increases in phytoplankton biomass and primary production in areas affected by the spilled oil. It was not shown whether this was the result of increased nutrients that developed at the sites of the oil spill or whether it was the result of decreased zooplankton grazing, but there was little apparent change in phytoplankton species composition. It is deemed important, however, that one of the first measurements to be accomplished during the initial phase of response to an offshore or inshore oil spill is the assessment of phytoplankton standing stocks and diversity as well as measurements of primary productivity following standard methods such as those provided in O'Reilly and Thomas (1979). Corner (1978) has reviewed the effects of petroleum hydrocarbons on plankton generally.

Where collections must be made from water covered by floating oil the sampling devices should be towed into oiled areas at depths well below the water/oil-air interface. Samples of water should be collected for chemical analyses, as well as for the determination of phytoplankton population characteristics and laboratory studies of living organisms. References to methods for collection of phytoplankton samples are provided in Sections 3 and 9.

7.3.2 Zooplankton

A number of recent reports have indicated that zooplankton can be affected by oil spills. Grose *et al.* (1979) found that zooplankton species were contaminated by oil during the Melville Bay spill, but noted that only a small proportion of the total zooplankton population was believed to be affected. Linden *et al.* (1979) observed that approximately 50% of some zooplankton specimens were visibly contaminated by oil droplets either internally or externally. Moreover, they noted that after three weeks following the spill, some 20% of the specimens were still contaminated with oil. Similar observations were made following the sinking of the "Argo Merchant" (Polak *et al.*, 1978). Elmgren *et al.* (1980) have observed that the densities of zooplankton were markedly lower in experimental microcosms to which oil was added, and Davies *et al.* (1979) noted an adverse effect on copepod reproduction and survival in CEPEX bags.

The foregoing suggests that zooplankton populations should be examined during the assessment of oil spills. Again, there are several accepted protocols and standard methods which can be used to collect samples of zooplankton populations in offshore and coastal environments prior to and during the expansion of spilled oil. As noted in Section 7.3.1 it is possible to obtain samples for analyses of zooplankton population characteristics by towing collection devices into areas with spilled oil. In addition to studies concerned with the abundance and diversity of zooplankton populations, it is possible to conduct behavioral and feeding studies to determine the effects of oil on normal patterns. Also, physiological studies should be performed, where conditions allow, in regard to metabolism, oxygen uptake and other physiological variables.

7.3.3 Ichthyoplankton (eggs and larvae)

The meroplanktonic stages, eggs and larvae, of many commercially important benthic invertebrates and fish are particularly vulnerable to oil pollution. In recent years standard methods for surveying the ichthyoplankton have been developed by a number of ICES member nations (Smith and Richardson, 1977), which allow the quantitative collection of these important components of the marine ecosystem. Assessments can be made of the ichthyoplankton prior to and following oil spills. Fish eggs and larvae should also be observed to determine if surface oils have adhered to them. Observations made during the "Argo Merchant" oil spill indicated that a significant number of fish eggs carried what appeared to be oil particulates (Grose and Mattson, 1977). Subsequent to this particular oil spill event, fish eggs are being examined to determine the possible mutagenic effects of oil on fish eggs.

Standard assessments of fish eggs and larvae affected by oil spills may indicate possible effects of the oil on future year class strengths. As was mentioned in the case of phytoplankton and zooplankton, assessment collections should be made of an advancing oil spill, as well as from water underlying the surface oils. Again, unless special gear is available, collections will have to be made by towing open/closing nets into the area of an oil spill starting outside the spill. In such cases, however, factors important to quantifying data should be considered, i.e. duration of tow, etc.

As discussed in the sections on zooplankton and benthos, fish eggs and larvae known to have been exposed to spilled oil or components of spilled oil should be collected for on-vessel or shore-side laboratory experiments concerned with behaviour, physiology and biochemistry, growth rates and other variables that can be measured by standard bioassay techniques. These techniques were discussed at a recent ICES Workshop on Biological Effects of Pollutants (McIntyre and Pearce, 1980).

7.3.4 Benthos

It is now generally recognized that when spills occur in deep water (greater than 100 m), the benthos is unlikely to be affected immediately by oil. However, certain types of petroleum products (asphalts, extremely heavy crude oils, etc.) have the potential to be carried to deeper benthic environments within a short period following a spill. It is, therefore, essential to understand the nature of the spilled oil so that studies of the benthos can be initiated when required.

Also, as oil drilling and production begin to occur in progressively deeper coastal waters, there is the potential for oil blowouts resulting in the spread of petroleum over the sea bed. Further, breaks in pipes used to carry crude oil to terrestrial transportation systems may result in the release of oils which will affect benthic habitats.

Even lighter moieties of oil may be carried by down-welling, adherence to denser particulates, and other forms of transport to deeper benthic environments. The foregoing indicates that the initial assessment of oil spills in deeper waters should consider the nature of the oil, as well as hydrographic conditions in the immediate area of the spill, and those phenomena which might result in oils being moved to deeper environments some distance from spills.

It is now recognized by many investigators that oil spills in shallow shelf and coastal waters may almost immediately impact on demersal fisheries and benthic populations.

Sanders *et al.* (1980) and Southward and Southward (1978) have noted that petroleum impact upon coastal habitats and shallow benthic communities may have effects which last for decades. Obviously, there is an important need to assess immediately benthic community structures and the demersal fisheries following massive oil spills. The initial surveys should be followed by frequent surveys or censuses of the benthic community for a period of several months following an oil spill, after which the surveys could be done less frequently. After the first year following a spill, at least semi-annual surveys would determine the final total extent of the effects of a spill on benthic community structure, as well as the progress of recolonisation. Recolonisation studies must consider the explosive increases in opportunistic species. Assessments of these species will determine if they represent adequate forage for important finfish and shellfish. Where spills have occurred and have affected extensive areas, there is good indication that the total food chain within an area will probably be affected. Benthic studies should include the collection of sediments and biota for chemical analyses. The investigations of Sanders *et al.* (1980) suggest that sediments may not lose entrapped oil at a significant rate over a period of at least 10 years. Sheltered areas such as the fjords and enclosed embayments or salt marshes are likely to be affected over periods of decades when oil pollution has been particularly heavy or extensive.

At the present time most national oil spill contingency plans indicate that oil spill response plans should take into consideration that different methods will be required for damage assessment in the open sea, in coastal waters and in estuaries or intertidal areas likely to be affected by specific spills. The Norwegian oil spill response plan (Gray *et al.*, 1978), as well as the plan developed in Great Britain (Whittle *et al.*, 1978) and the United States (Pearce, 1979) all recognize that different approaches are required in response to offshore and onshore spills.

Finally, the research by Grassle *et al.* (1978) provides good information on the rapidity of changes in benthic community structure in relation to oil contamination. Numerous studies of oil spills in coastal waters or in embayments and estuaries all indicate that alterations to benthic populations and community structure and diversity occur very rapidly following contamination by petroleum products. Again, as in the case of phytoplankton and zooplankton assessments, the immediate response of biologists during spills should include assessments of estuarine or coastal benthic populations that are initially unaffected by the spill. Obviously, benthic assessments must be done in those areas initially affected by an oil spill. Once the hydrographers and physical oceanographers have determined the possible dynamics of surface oil movements, attempts should be made to census the benthic populations likely to be contaminated within a matter of hours. It is essential that accurate locations of populations be made so that biologists can return to these sites. Navigation systems such as Decca, as well as Loran C and Raydist may be used.

7.3.4.1 The methods used in benthic surveys, while in general quite similar, have varied somewhat from one investigation to another. In recent years there has been an attempt to standardise benthic sampling or at least to require that certain variables be considered. Holme and McIntyre (1971) and McIntyre (1971) set forth methodologies that could be used for sampling the infauna, macrofauna and meiofauna. More recently investigators in North America have set forth certain "standard methods" to be followed. Swartz (1978) described methods recommended by the U.S. Environmental Protection Agency for benthic sampling and Gonor and Kemp (1978) describe procedures for littoral benthic assessments. Gray _et al._ (1978) discuss the general procedures to be used in assessing changes in intertidal populations due to oil spills.

The use of divers in benthic oil spill assessments has many advantages. The size of samples taken by diving biologists has not been standardized and because of various equipment and gear available to diving biologists, and special needs of various nations and agencies, it is unlikely that there will be standardization in the near future. In any case, samples should be collected by SCUBA divers in such a way that the resulting data on distribution and abundance of the dominant infauna as well as the larger macrofauna can be related to some standard area, probably 1 m^2. As previously noted, underwater photography is excellent for recording standing stocks of surface dwelling or epibenthic organisms but, again, it must be conducted so that a scale of reference can be established.

In terms of methodologies and their use in temporal responses, investigators should be aware of reports which indicate the rates at which benthic populations are affected and these should be considered in planning responses to oil spills (e.g. Grassle _et al._, 1978). It cannot be emphasized too strongly that responses should be conducted so that proper reference or control sites are studied prior to the effects of oiling.

Finally, as was noted in the sections on phytoplankton and zooplankton, it is important to consider baseline physiological and biochemical measurements. Again, the equipment for such measurements is often sophisticated and expensive, but many national programs have developed biological effects monitoring techniques which allow baselines to be established in regard to physiological and biochemical variables. Since several nations are developing biological effects monitoring programs, in many instances the equipment and expertise for performing such measurements before and during oil spills are available. The various techniques involved in such measurements are given in several sections of the proceedings of an ICES Workshop on Effects Monitoring (McIntyre and Pearce, 1980).

7.3.5 Fish and shellfish

Invariably the principal questions in regard to the effects of oil spills on living marine and estuarine resources have to do with impacts on commercially important species. In the case of benthic shellfish, including clams, mussels, oysters, shrimps and lobsters, assessments are often easily made. Such species tend to have small rates of mobility or are sedentary and hence the effects of oils can be relatively easily ascertained. In many instances, however, marine finfish may be highly migratory or will show rapid avoidance response to oil. In such cases fish may be exposed only temporarily to the effects of oil and may migrate miles from the oil spill site before proper measurements and assessments can be made. On the other hand, some reports indicate that certain important species are attracted to oil and may thus become particularly vulnerable to spills.

In any event, an attempt should be made to determine standing stocks on finfish and shellfish in areas which are exposed to spilled oils. This can best be done through trawling activities and some ICES member nations have adopted standard protocols for the assessment of demersal and pelagic fisheries (Ricker, 1975).

Scientists concerned with the effects of oil spills on fishery resources have noted several areas especially worth of study. These include: 1) the behaviour of different fish species in response to oil and oil plus dispersant mixtures, especially factors important in the avoidance of contaminated waters by finfish and the ability of shellfish to survive exposures to contaminated waters; 2) the uptake of petroleum hydrocarbon moieties derived from spilled oil and dispersants by different finfish species from food and water contaminated by oils (particular emphasis should be given to the range of organisms and tissues affected by different components of petroleum); 3) the rate of discharge of contaminants and tars due to excretion and biodegradation of petroleum products; 4) the threat to human health from consumption of contaminated fish, especially possible carcinogenic effects; 5) long-term effects on fish and shellfish such as the incidence of tumours, fin rot and mutagenic effects; 6) short-term effects such as unnatural mortality, effects on fertility and reproduction, and growth rates; and 7) effects of sunken oil on burrowing species such as *Nephrops.*

Again, the degree to which member nations can respond to the aforementioned areas of investigation will depend upon the equipment and personnel available to each nation or responding agency.

In many instances it will be possible to census species of finfish and shellfish that are known to have small dispersion rates and do not undergo extensive migration. Fish and shellfish can be periodically assessed visually to determine if there are increased incidences of externally visible tumours, gill clogging and other gill anomalies, or fin rot syndromes. Institutions, agencies, or nations that have laboratories dedicated to fish disease can perform autopsies and histological examinations to determine both the short-term and long-term effects on the relative health of fish. Techniques such as the Ames test (Ames *et al.*, 1975) can be used to ascertain possible carcinogenic effects of petroleum in fish and shellfish.

Changes in the behaviour of fish and shellfish may be observed using techniques provided in the behaviour section of McIntyre and Pearce (1980). Recent studies of decapod crustaceans suggest that feeding activities and the ability to find forage species may be changed by the presence of oil.

There is a variety of techniques that can be used for analysing fish for the presence of oil and metabolites derived from fish and shellfish tissues (see Section 6). Fish collected from estuarine or coastal sites and from areas that are exposed to spilled oil can be analysed immediately following the spill and at predetermined intervals afterwards to determine the residence times of oil in fish tissues. Finally, as noted in Grassle et al. (1978), observations can be made of benthic organisms in experimental systems and in field situations to determine the effects of oil on infaunal species. Sediment reworking by infaunal species is an excellent indicator of the possible effects of oil.

While biologists are particularly concerned with the effects of petroleum per se on living resources, consideration should be given to the possible effects of chemical dispersants used for the control of oil spills. In a recent review volume, McCarthy et al. (1978) presented considerable information on the effects of dispersants on a wide range of biota. This volume contains numerous references to studies on the effects of dispersants.

In regard to tainting of shellfish by petroleum and its metabolites, Stansby (1978) notes that there has been very little research done in relation to flavours that are picked up from petroleum. This review article discusses the general problems of tainting and indicates some of the techniques that have been used to quantify odours and tastes in fish contaminated with petroleum products. The reviewer notes that "information on the level of petroleum-derived components in fish which barely are sufficiently high to cause detectable flavour are still too incomplete to give any indication of what levels might be tolerable". Howgate et al. (1976) discuss petroleum tainting in demersal fish which live near sediments which contain oil. What is generally recognised by fishery biologists is that in many parts of the world, especially industrialized harbours and estuaries, fish have detectable tastes due to petroleum tainting. Stansby (1978) does not believe that fish in the open ocean will generally have levels of petroleum that will be detectable to most consumers. He does, however, suggest that massive oil spills such as the "Torrey Canyon" or "Argo Merchant" could result in tainted fish. Therefore, individuals conducting assessments on the effects of oil spills on living resources should be concerned with tainting and the obvious problems in relation to marketing tainted sea foods. Trained test panels (Stansby, 1978) can be used to assess the quality of contaminated seafood products from the consumer point of view. As was suggested in the review article by Stansby, long-term basic research is required to determine the threshold for tainting by various kinds of petroleum and petroleum metabolites in order to manage effectively living resources that are affected by chronic and acute oil spills.

7.3.6 Birds

Environmentalists and ornithologists are highly conscious of the threat of oil to seabirds. Some of the first concerns in relation to spilled oil were voiced by researchers who were troubled by oiling of birds and other wildlife. Many ICES member nations have identified national plans or conservation activities which express concern in regard to the effects of oil spills on wildlife. Protocols have been etablished by a variety of organisations involved with the survival of seabirds that have been affected by oil spills (International Bird Rescue Research Center, 1978). Several oil response workshops have been concerned principally with the effects of oil on aquatic birds (Fore, 1977). There is little doubt that there will be continuing, if not increased, interest in evaluating the effects of oil spills on seabirds. Fishery biologists and marine scientists who are generally involved with major oil spills should give full concentration to obtaining the cooperation of ornithologists and bird observers during cruises and shoreline studies to assess the effects of oil spills. In most instances the observations of bird specialists will not interfere with other studies ongoing. Particular attention should be paid to the interactions between oiled birds and their normal fish and shellfish food species, i.e., oysters, mussels, clams and small fish, so that the effects of oil on marine food chains culminating in seabirds can be ascertained. It has been suggested that where birds are severely affected, and consequently bird predation reduced, significant buildup in certain aquatic populations may occur. If the effects of oil on such trophic relationships are not thoroughly documented, conclusions may be reached that oil has resulted in the increase of certain populations and thus was beneficial.

7.3.7 Marine mammals

Where possible, information should be obtained on the biology and behaviour of marine mammals as observed in or near slicks resulting from oil spills. In a recent report, Geraci and St. Aubin (1979) reviews the possible effects of oil spills and petroleum development situations on marine mammals. This report was prepared for the use by the International Whaling Commission and contains considerable information that will be of importance in assessing the effects of oil spills on marine mammals. Since some marine mammals are regarded by several nations as endangered species and since they may be affected by oil spills, it is extremely important that all observations be reported. Observations of marine mammals are, because of their habitats and wide-ranging activities, of necessity quite rare. Reports on the effects of petroleum, while becoming more numerous, are still scarce and this, again, emphasizes the need to document the effects of oil on marine mammals wherever possible.

7.3.8 Summary

The recent review of possible effects of petroleum hydrocarbons and related compounds on marine plankton (Corner, 1978) is important in that it indicates that the matter of assessing the effects of oil pollution is not simple. Oils of several types and sources have been shown to have a wide range of effects on a diversity of marine organisms. The review does, however, suggest that relatively small amounts of petroleum products can have significant effects on individuals, populations and communities. It is, therefore, important that all personnel involved in oil spill assessments be particularly aware of the published literature and its significance. Under many conditions, in which oil spills occur, i.e., heavy sea state, bad weather and hazardous coastal conditions, it is difficult at best to make adequate biological assessments. The only way such assessments can be made with some degree of confidence is to have thoroughly developed oil spill response plans which are appropriate for the habitats characteristic of ICES member nations. Plans developed for the rocky coastal areas of Norway, while helpful in developing other plans, may not be the best plans to follow during a major oil spill in the offings of Chesapeake Bay, the United States.

Many agencies and institutions have recently become involved with developing models which attempt to predict the effects of oil spills on a fishery or a component of a fishery. For instance, Reed (1980) has recently developed a model system designed to estimate the impacts of offshore oil spills on commercially fished stocks emphasizing the cod (Gadus morhua). As oil spill plans are developed and as assessments are made of major and minor oil spills it will become possible to refine such models so that persons responsible for evaluating the eventual total impacts on oil spills can have before them thoroughly useful documents.

8. MICROBIOLOGY

Biodegradation by organisms is one of the principal processes by which oil is ultimately reduced to simpler constituents. Together with evaporation, dispersion/advection, and dilution of dispersed oil, biodegradation is responsible for waters and beaches becoming free of spilled oil. Oil degrading microorganisms are the principal organisms for which oil serves as a nutrient. Gunkel (1973), Atlas and Bartha (1973) and other authors have discussed the distribution and abundance of oil degrading microorganisms and their roles in marine ecosystems.

The eventual rates of oil degradation are not necessarily dependent on the size of microbial populations present at the beginning of an oil spill; it is only necessary that oil degrading species be present in the environment at the time of the spill. This is often the case in coastal areas and the continental shelf regions. The actual degradation rates are dependent on:

1) the kind of oil (characterised by chemistry, solubility, and surface-to-volume ratio), and

2) the environmental conditions which prevail at the time of exposure to oil, e.g., available inorganic nitrogen and phosphorus and other nutrients, temperature, oxygen and interfering substances. Also, organisms which feed on microorganisms can limit their growth, population size, and metabolic activities.

Recently a number of studies of oil spills in the field and controlled spills in microcosms have indicated limited oil degradation by microorganisms. For instance, Grose et al. (1979) found that during the "Potomac" oil spill in Melville Bay, Greenland, there was apparently little biodegradation of spilled oil. These authors report that the total number of microorganisms in affected waters was small and oil degrading microorganisms constituted less than 1% of the total count. They found no increase in the total number of oil degrading organisms in samples collected 16 days following the spill, as compared with samples collected eight days after the spill. The authors felt that the microbiological studies indicated that in situ biodegradation would have been very slow. The addition of nutrients to the oil and water samples affected increased degradation strongly.

In laboratory experiments involving marine microcosms to which a No.2 fuel oil was added, it was found that biodegradation did not occur during the first 11 days of exposure in the month of March or in the first 4 days of exposure in September (MERL, 1980). The researchers found that biodegradation began immediately in an oil acclimated tank during the month of July. In unacclimated tanks the aliphatic hydrocarbons had already decreased by 70% before biodegradation occurred. This led the investigators to conclude that biodegradation was not a very important removal process within the marine microcosm system, at least in temperate waters of Rhode Island.

The foregoing indicates that while microbiological investigations will have great significance in responses to oil spills, close cooperation with chemical investigations of oil spills is essential.

8.1 Sampling Methods

Microbiological sampling should be conducted at the same locations and water depths as for benthos, plankton and chemistry research. Special attention should be paid to the surface layers of water and to the sediment-water interface. In all cases, floating oil should be included in the sampling activities and subsequent analyses. The surface film should be sampled by use of Teflon discs (Miget *et al.*, 1974) and 200 mesh stainless steel screens (Mackie *et al.*, 1977) or with Millipore filters applied to the surface of the water. The uppermost layers of the surface waters (within centimeters) should be sampled through the use of a suction funnel and subsurface pick up (Oppenheimer *et al.*,1977). At least one water sample should be taken from layers at least 10 m in depth.

As previously mentioned, the uppermost layers of sediment should also be sampled. Standard methods for such sampling have been published in Dudley *et al.* (1977).

Dilution series of the oil/water samples can be made after emulsifying the oil in sterile seawaters to which a relatively nontoxic, nondegradable emulsifier and a defoaming agent have been added. A high speed mixer can be used in this process (Gunkel *et al.*, 1967).

Standard microbiological techniques for counting saprophytes and hydrocarbon degrading bacteria on appropriate media should be used (Gunkel, 1973). In addition, total counts of bacteria using epifluorescence techniques should be used (Zimmermann *et al.*, 1974). Such data can reveal changes in the ratio of hydrocarbon degraders to total saprophytes and total numbers, and serve as an indicator of oil degrading microorganisms. Such techniques may not, however, provide data on the total activity of oil degrading microorganisms.

The establishment of rates of relative activity of oil degrading microorganisms will require use of complementary technique, for example: 1) direct measurements, using ^{14}C labeled substrates resulting from mineralization of selected important hydrocarbons, which will indicate the rates at which particular groups of compounds were mineralized (Massie, 1978) and 2) determination of oxygen consumption using control water and water to which oil and individual hydrocarbon moieties have been added, with different times of incubation. Neither method is entirely satisfactory, but when used in combination they will give some indication of microbial responses to petroleum hydrocarbons.

Emphasis should be placed on utilising available methods in determining the activity of oil degrading organisms (Reinheimer, 1978) and their effects, especially during the initial stages of oxidation, that is during the formation of metabolites.

9. TECHNICAL ASPECTS

Until recently there have been relatively few detailed plans that set forth the technical requirements for implementing responses to oil spills and releases of other toxic substances. In recent years, however, three papers (C.M.1978/E:38, C.M.1979/E:64 and E:70) have been presented to ICES which provide relatively detailed information in regard to oil spill responses. Other protocols have been established as a result of workshops and meetings and in almost every instance the proceedings of these have emphasized it is essential that advanced planning be done in regard to the types of observations, experiments and measurements that should be conducted at the time of an oil spill. Perhaps even more important, it has been emphasized that the appropriate collection and analytical apparatus should be available before a spill. Most preliminary oil spill response plans that are available give some indication of the kinds of equipment and apparatus that should be available for immediate use at the time of an oil spill response. Also, laboratory and storage space should be available for the storage and use of the various equipment.

In regard to the actual format of field and laboratory experiments and measurements, a number of nations have recently developed extensive handbooks. For instance, the Netherlands Organisation for Applied Scientific Research (TNO), now known as "The Division of Technology for Society" has recently published an extensive volume entitled "Degradability, ecotoxicity and bioaccumulation; the determination of the possible effects of chemicals and wastes on the aquatic environment". This document is perhaps the most detailed handbook ever prepared in regard to techniques that might be used during responses to spills of various toxic substances, including oil.

It is recommended that other nations give consideration to the preparation of similar documents which are appropriate for particular habitats and species that will be affected by spilled or released wastes in estuarine and marine ecosystems under the jurisdiction of specific nations. The aforementioned document is published by the Netherlands Government Publishing Office, the Hague, and may be consulted as a model for the development of similar handbooks by other nations.

Since there is evolving a series of protocols and handbooks which are concerned with the technical aspects of evaluating the impacts of spilled oils and other wastes, it would not, at the present time, be appropriate to provide extensive details in this paper. It is, again, emphasized that various nations likely to experience oil spills consult these documents as they become available and draft appropriate contingency plans and develop standard methods that will allow for intercalibration and intercomparison of techniques in the event of major oil spills.

10. OTHER SCIENTIFIC AND ADMINISTRATIVE ACTIVITIES

In addition to the tasks mentioned in the previous sections, there are several other more general areas where it is important or useful that work be carried out. The tasks in this section have been divided according to whether they pertain to scientific or administrative matters. Due to their more general nature, most of the tasks discussed here are part of the pre-event and organizational aspects for preparations for an eventual oil incident.

10.1 Pre-event Preparations on Scientific Issues

Sampling methods and analytical techniques for the determination of oil in sediments, water and biota are discussed in Section 6 and extensive references are provided in Section 11. While recognizing that considerable research has already been done on this subject, it is considered necessary that further intercalibration exercises or, where necessary, standardization of sampling and analytical techniques be done on an international basis to promote comparability of results obtained by different national laboratories.

In regard to sample storage it is suggested that storage at -90°C be considered appropriate and recommended because deep-freezing at normal temperatures is inadequate for proper preservation of samples, especially biological materials collected for petroleum hydrocarbon analyses. In regard to tissue or specimen banks, it is considered useful to establish specimen banks for retention of tissue and sediment samples.

The matter of collecting, handling and storage of samples to be used in pollution studies was the subject of a meeting held in Berlin, October 1978. This meeting was concerned principally with long-term storage of samples from terrestrial, fresh water and marine environments. A formal report from the Berlin workshop to the environmental protection agencies of the Federal Republic of Germany and the United States recommends (Luepke, 1980) precise techniques for:

1) collection and analyses of biota, water, sediments, and air for immediate and future analyses of the presently more important toxic substances and contaminants, as well as for

2) the storage of samples for eventual analyses of these materials as well as for as yet unrecognized pollutants.

The United States National Bureau of Standards also has recently produced a document entitled "A survey of current literature on sampling, sample handling, and long-term storage for environmental materials" (Maienthal and Becker, 1979) which is the result of an extensive literature survey to establish optimum sampling techniques, sample handling and long-term storage methods for a wide variety of environmental samples so as to retain sample integrity. The components of interest in these samples are trace elements, organics, pesticides, radionuclides and microbiologicals and pathogens. This survey was done both manually and by use of various bibliographical retrieval services; the advice and opinions of workers in various aspects of the field were obtained.

In regard to improving oil spill responses, controlled oil spills have been considered practical to test the entire or appropriate components of scientific research programs in actual oil spill situations. Several member nations have been involved in such programs.

While it was the consensus of most participants in the three Working Group meetings that this document should not include extensive details on spilled oil removal or clean-up, the Warsaw meeting indicated that at least some mention be made of the current status of oil spill clean-up techniques. While there are several papers and reports on the subject it is only recently that attempts have been made to summarize the various documents. The University of Rhode Island has recently prepared an extensive report on oil spreading, retention and clean-up. This document contains discussions of the current status of physical and chemical means for removal of spilled oils, as well as extensive and useful series of bibliographies. Finally, the use of chemical dispersants for the control of oil spills was thoroughly discussed in a proceedings volume edited by McCarthy et al. (1978). Again, this volume contains numerous up-to-date references which will be useful in developing the clean-up aspects of oil spill response plans.

Even more important than in the planning process, the matter of oil spill containment and clean-up must be considered by researchers involved with damage assessments and scientific investigations of oil spills.

10.2 Pre-event Administrative Preparations

The plans developed by several member nations in regard to oil spill responses have generally included sections on the organization or administration of such programs. In the Norwegian Ecological Action Plan (NEAP) (Gray et al., 1980) the coast is divided into five regions or districts with a team leader for each one. The leader is an experienced ecologist and heads a team including a zoologist and an algologist and four additional persons from local research institutes. The teams are involved in annual training and coordinating sessions.

In addition to the action teams a Chief Administrative Coordinator provides the link between the teams and the Action Command of the Ministry of the Environment and State Pollution Control Authority. Logistic support including food and lodging, communications and aerial photography is provided, in part, by the military.

The current response plan for the United States also emphasizes a regional approach. Each of the four regions (Northeast, Southeast and Gulf, West Coast, and Alaska) has a Regional Response Team (RRT) which is usually chaired by a United States Coast Guard (USCG) person and includes representatives from the United States Environmental Protection Agency (EPA) and the National Oceanic and Atmospheric Administration (NOAA). The RRTs are responsive to a Federal On-Scene Coordinator (OSC) who is responsible for initially determining 1) the nature and extent of the spill or potential spill, 2) the feasibility and means of removal and 3) the timing and type of assistance required from the RRT.

Generally, the OSC will be assisted by a NOAA Scientific Support Coordinator (SSC) who coordinates the scientific and technical activities of all federal, state and academic participants in the spill response and serves as the primary contact point between the OSC and responding experts.

Regional response plans include telephone networks between Regional Response Centers (RRC) and key personnel or institutions. The plan also specifies quarters, communications beyond the telephone network, information and data storage, and other requirements for coordinating the response to spills.

As part of the development of national plans it is proposed that each country be encouraged to prepare lists of project coordinators and experts in each relevant scientific field for internal use within the country. For international assistance, it is proposed that one responsible authority be designated in each member nation who could identify appropriate experts who would be able to assist in geographical areas and scientific disciplines where expertise is requested. Authorities in each country should be encouraged to consider how international assistance and coordination can best be carried out.

It is also proposed that each country prepare an inventory of planned and on-going studies related to oil pollution and its effects on the marine environment. This inventory could be updated every two years and be collated and presented to the Marine Environmental Quality Committee during the even-year Statutory Meetings.

10.2.1 Dissemination of information

It is recognized that concerned scientists and authorities have a general responsibility to disseminate within their country information relevant to oil pollution response research. Such information is not only scientifically important but is extremely useful to inform the general public so that the citizenry can understand the broad scope of scientific resources needed in response to oil spill situations.

10.2.2 Funding

The Working Groups were of the consensus that adequate funding for scientific research in relation to responses to oil pollution incidents is an important, but internal, responsibility of each country. While it was recognized that different mechanisms exist for such funding in different countries, it was repeatedly suggested that ICES work to foster communications and cooperation in regard to oil spill incidents and, further, that member nations cooperate where possible in national and international spills.

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Appendix A

Names of participants in the three ad hoc working group meetings to develop the report on oil spill incidents. * indicates the chairman of the three meetings and ** indicates the editors drafters of this penultimate version.

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Indication of spine colours

Reports of the Advisory Committee on Fishery Management	Red
Reports of the Advisory Committee on Marine Pollution	Yellow
Fish Assessment Reports	Grey
Pollution Studies	Green
Others	Black

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