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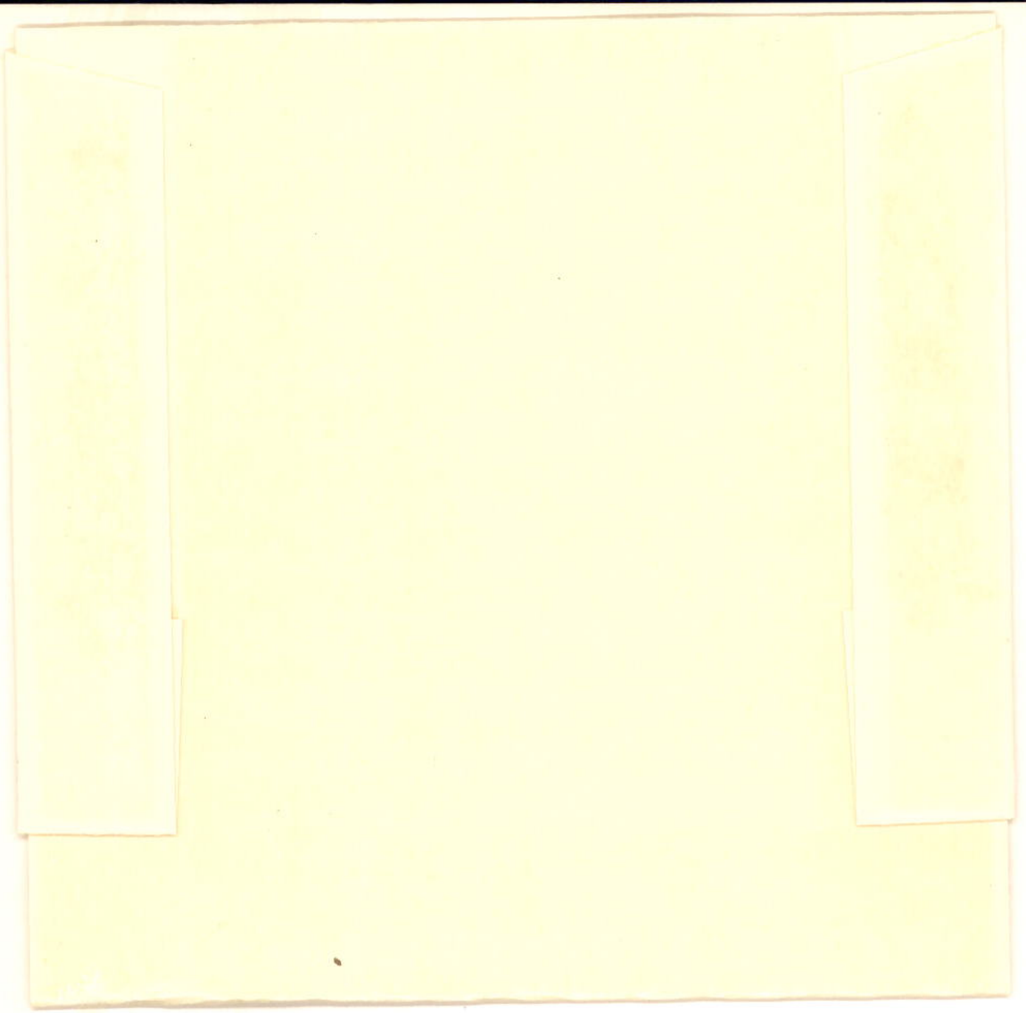
The TSESIS Oil Spill



March 1980

Prepared for:

U.S. Department of Commerce
National Oceanic and Atmospheric Administration
Outer Continental Shelf Environmental Assessment Program



Cover Photo

Species is a copepodid of *Temora longicornis*.
A indicates oil droplets in the gut.
B indicates an oil drop on feeding appendage.
Courtesy of Sif Johansson, Askö Laboratory.

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THE THESIS OIL SPILL

Report of the first year scientific study
(October 26, 1977 to December 1978)

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ASKÖ LABORATORY, UNIVERSITY OF STOCKHOLM, SWEDEN

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U.S. DEPARTMENT OF COMMERCE
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BOULDER, COLORADO, U.S.A.

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TABLE OF CONTENTS

		Page
	Editors' Note	vii
	Abstract	ix
Chapter 1	Executive Summary	3
1.1	Development, early history and cleanup of the spill (Olle Lindén and John Kineman)	3
1.2	The scientific study and participating institutions	12
1.3	Scientific personnel participating in the study	15
1.4	Acknowledgements	16
1.5	Funding	19
1.6	Lessons learned for the management of oil spill investigations (Olle Lindén, Ragnar Elmgren, Lars Westin and John Kineman)	20
1.7	References	26
Chapter 2	Perspective	29
2.1	Baltic perspective (Ragnar Elmgren, Lars Westin and Olle Lindén)	29
2.2	Alaskan perspective (Ragnar Elmgren and John Kineman)	33
2.3	References	38
Chapter 3	Scientific Summary and General Discussion (Olle Lindén, Ragnar Elmgren, Lars Westin and John Kineman)	43
3.1	Background	43
3.2	Discussion of results and major conclusions	44
3.3	Recommendations for spill research contingency plans	50
3.4	References	56
Chapter 4	Impact of Oil on the Pelagic Ecosystem (Sif Johansson)	61
4.1	Introduction	61
4.2	Material and methods	62
4.2.1	Sampling stations	62
4.2.2	Methods	62
4.2.2.1	Phytoplankton	62
4.2.2.2	Primary production	64
4.2.2.3	Bacteria	64
4.2.2.4	Zooplankton	64
4.2.2.5	Sedimentation	65
4.3	Results	65
4.3.1	Phytoplankton	65
4.3.1.1	Phytoplankton biomass	65
4.3.1.2	Phytoplankton species composition	65

4.3.2 Primary production 67
4.3.3 Bacteria 67
4.3.4 Zooplankton 70
4.3.5 Sedimentation 70
4.4 Discussion 74
4.5 Conclusions 77
4.6 Acknowledgements 77
4.7 References 79

Chapter 5 NOAA Acute Phase Experiments on Pelagic and Surface Oil . . 83
(John Kineman, 5.1, 5.3-5.5; Robert C. Clark, Jr., 5.2)

5.1 Experiment design 83
5.2 Hydrocarbon analysis associated with the Tsesis oil spill . 84
5.3 Water samples with a sterile bag sampler 87
5.4 Water column data from two scuba-obtained glass jar samples . 90
5.4.1 Results of analysis 90
5.4.2 Discussion 90
5.4.3 Conclusion 92
5.5 Aerial mapping of visible floating oil 93
5.6 References 93

Chapter 6 Impact of Oil on Deep Soft Bottoms 97
(Ragnar Elmgren, Sture Hansson, Ulf Larsson and Brita Sundelin)

6.1 Introduction 97
6.1.1 Background 97
6.1.2 The spill area 98
6.2 Methods 98
6.2.1 Sediment sampling 98
6.2.2 Macrofauna 100
6.2.2.1 Macrofauna sampling 100
6.2.2.2 Reproduction of Pontoporeia affinis . . 100
6.2.3 Meiofauna 101
6.3 Results 101
6.3.1 Sediment samples 101
6.3.2 Macrofauna 102
6.3.2.1 Macrofauna community response . . . 102
6.3.2.2 Pontoporeia affinis reproduction . . . 110
6.3.3 Meiofauna 110
6.4 Discussion 117
6.4.1 Sediment samples 117
6.4.2 Macrofauna 118
6.4.2.1 Macrofauna community response . . . 118
6.4.2.2 Pontoporeia affinis reproduction . . . 120
6.4.3 Meiofauna 121
6.5 Summary and conclusions 122
6.6 Suggested further studies 123
6.7 Acknowledgement 123
6.8 References 124

Chapter 7 Impact of Oil on the Littoral Ecosystem 129

7.1 Introduction 129
(Mats Notini)
7.2 Effects on Fucus macrofauna 130
(Mats Notini)
7.2.1 Introduction 130
7.2.2 Materials and methods 131
7.2.3 Preliminary results 131
7.2.4 Discussion 139
7.2.5 References 144
7.3 Effects on the phytal ecosystem 146
(Hans Kautsky)
7.3.1 Materials and methods 146
7.3.2 Results 146
7.3.2.1 Field observations 146
7.3.2.2 Calculations from collected data . . . 148
7.3.2.3 Comparison with data from oil analysis of Mytilus edulis 156
7.3.3 Discussion 156
7.3.4 References 160
7.4 In situ respiration of three littoral communities near the Tsesis oil spill 161
(Björn Guterstöm)
7.4.1 Introduction 161
7.4.2 Methods 162
7.4.3 Results and discussion 162
7.4.4 References 165

Chapter 8 Impact of Oil on the Supralittoral Zone 169

8.1 Damage on shore vegetation 169
(Anders Lindhe)
8.1.1 Introduction 169
8.1.2 Methods 169
8.1.3 Results: Acute effects on vegetation 170
8.1.4 Some comments on the clean-up methods 170
8.1.5 Concluding remarks 172

8.2 Effects on the supralittoral fauna 173
(Maria Foberg)
8.2.1 Introduction 173
8.2.2 Materials and methods 173
8.2.3 Description of the stations 178
8.2.4 Results 178
8.2.4.1 Pitfall traps 178
8.2.4.2 Quantitative samples 181
8.2.5 Discussion 185
8.2.6 Conclusions 188
8.2.7 Acknowledgements 188
8.2.8 References 188

Chapter 9 Impact of Oil on the Local Fish Fauna 193
(Sture Nellbring, Sture Hansson, Gunnar Aneer and Lars Westin)

9.1 Introduction 193
9.2 Material and methods 193
9.3 Results 195
9.4 Discussion 200
9.5 References 201

Chapter 10 Laboratory Studies Carried Out in Connection with the Spill . 205

10.1 Introduction 205
(Olle Lindén)

10.2 Respiration measurements on the mussel Mytilus edulis . . 205
(Sture Hansson)
10.2.1 Materials and methods 205
10.2.2 Results 206
10.2.3 Conclusions and discussion 209
10.2.4 References 209
10.3 Measurements of byssus formation by the mussel Mytilus edulis 210
(Olle Lindén and Maria Foberg)
10.4 Burrowing behavior in the clam Macoma balthica 213
(Olle Lindén)

Chapter 11 The Analytical Chemistry of Mytilus edulis, Macoma balthica, Sediment Trap and Surface Sediment Samples 219
(Paul D. Boehm, Judith Barak, David Fiest and Adria Elskus)

11.1 Introduction 219
11.2 Methods 221
11.2.1 Sampling 221
11.2.2 Sample analysis 221
11.3 Results 225
11.3.1 Mytilus edulis 225
11.3.1.1 Aliphatic hydrocarbons 225
11.3.1.2 Aromatic hydrocarbons 233
11.3.2 Sediment traps 239
11.3.3 Surface sediments 251
11.3.4 Macoma balthica 257
11.4 Discussion 264
11.5 References 272

Appendix 1 Investigations 277
Appendix 2 Scenes from the Tsesis oil spill 285

EDITORS' NOTE

Support for the editing and publication of this report was provided by the Outer Continental Shelf Environmental Assessment Program (OCSEAP). Since most of the scientifically important results of the Tsesis study will appear in journal articles, with a more thorough review process, the current document is intended primarily for use by government scientists and managers who are involved in environmental issues of oil and gas development, and specifically in decisions and legislation related to oil pollution.

It was with the above purpose in mind that this scientific report was organized. It begins with a condensed description of the spill and the study that followed and becomes progressively more detailed. Three levels of detail are represented by the Abstract, Chapter 3, and the Research Reports. Chapter 1, dealing with matters of executive and management concern, is highlighted by section 1.6, which reviews the mistakes and successes and makes recommendations for the future management of spill follow-up studies and environmental protection. Chapter 2 was added to address such questions as "so what?", or in general the potential overall significance of the incident, by attempting to put it into ecological perspective. The study was heavily supported by OCSEAP with the objective of putting the incident into perspective for Alaska as well as the Baltic, where the spill took place. Since OCSEAP is a goal-directed program, with basic research applying to the environmental assessment of Alaska, the validity of the spill research concept is judged by the value of such connections.

Chapter 3 integrates and highlights the most important scientific results and major conclusions of the overall study and places them in a position for quick reference.

Although it was not possible to include a separate section detailing the daily clean-up operations performed by the Swedish Coast Guard, such information is summarized in Section 1.2. It is impossible to separate the effects of an oil spill from the mitigating or sometimes damaging effects of the cleanup.

Overall editing of the report was done in numerous locations in Sweden, the United States, and Kenya. Detailed editing of the research reports (Chapters 4-11) was performed mainly in Sweden, although many additions and revisions were made to address comments from the U.S. editor and reviewers of the first draft. Chapter 5 was written and edited in the United States. The report was produced by team effort, with information integrated from various sources. Individual contributions could not always be credited separately. The editors are responsible for any omissions, ambiguities and technical errors and, in sections without named authors, also for factual errors and conclusions, whereas the authors of Chapters 4-11 are responsible for the scientific content of their reports. For the purpose of identifying any such problems, feedback would be appreciated from anyone who is inclined to comment.

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or, concerning sections 4-11, to individual authors (addresses in section 1.3)

ABSTRACT

On October 26, 1977, the Soviet tanker Tsesis struck a rock in the fairway while inbound through the archipelago off Södertälje, Sweden (northern Baltic proper). During the next few days she released about 1100 tons of oil, mostly a No. 5 fuel oil, but also some bunker oil. Due to a quick and efficient response by the Swedish Coast Guard, and unusually favourable circumstances, the clean-up operations recovered most of the oil, leaving only about 400 tons in the enclosed archipelago, visibly oiling an area of 34 km^2.

Within a day after the grounding, a cooperative international scientific investigation was launched to cover important aspects of the spilled oil's ecological effects on plankton, benthos, fish, littoral and supralittoral communities, as well as the chemical and biochemical processes of weathering, bioaccumulation and depuration. The area was one which had been relatively well studied in the past as the site of several marine biological programs. The spill study was initiated rapidly enough to have some littoral sites surveyed immediately before impact by oil--an example of the "ideal" oil spill study.

The direct effects on the plankton included decreased zooplankton biomasses in the immediate vicinity of the tanker. Within days, increased phytoplankton biomass and primary production, as well as bacterial abundance, were noted in a larger area surrounding the tanker. Here zooplankton abundance and biomass were apparently not affected in spite of considerable contamination of zooplankton by oil droplets. No contamination or harmful effects on pelagic fish could be demonstrated. In a small bay near the spill site, oil concentrations of 60 µg/l were found in the water below a weathered oil slick. After one month, all parameters measured in the pelagic zone had returned to normal values.

Damage to bird life and the littoral zone was alleviated by the season of the spill. The supralittoral zone showed little damage when surveyed the following summer. In the littoral zone, no effects on the algae were seen, but the fauna of the most heavily oiled coastline

showed direct effects. Crustaceans were especially hard hit, but less than a year later, recovery was well underway. Oil analyses of mussels, Mytilus edulis, showed that oil had reached a larger area than was visibly impacted. Extremely high oil levels were found in Mytilus after the spill, and a year later Tsesis oil was still evidenced in the mussels.

Sediment traps deployed in the area collected material strongly contaminated with oil for the first weeks after the spill, demonstrating that oil was rapidly transported to the benthos. A minimum sedimentation of about 20 tons of oil was estimated. About two weeks after the spill, when the first samples were taken on deeper (30m) soft bottoms, oil impact was already extensive. At the most heavily affected station, motile macrofauna were greatly reduced, possibly through emigration. The sedentary species remained, and no increase in their mortality was demonstrated. Macoma balthica showed high oil levels over a large area, even at stations where no clear impact was shown by macrofauna community composition. All meiofauna groups, except the nematodes, were also reduced at the most affected station, and there was evidence of high mortality of ostracods. A few months after the spill, the few remaining gravid amphipod (Pontoporeia affinis) females at the most affected station showed an increased frequency of abnormal eggs. The recovery of the deep soft bottoms after oil damage proved slower than for other systems studied. About ten months after the spill, neither macro- nor meiofauna at this station showed any recovery, and oil levels in Macoma balthica were higher than immediately after the spill.

In June, seven months after the spill, the herring showed less spawning and lower hatching success in the oiled area than in a reference area. This might be due to factors other than oil and needs confirmation.

The chemical analysis by Gas Chromatography (GC) and Mass Spectrometry (MS) showed rapid weathering of the Tsesis oil, and all oil found either in biota or in sediment trap material was altered in composition, but identifiable as Tsesis oil. Depuration in Mytilus and Macoma showed more rapid elimination of the aliphatic than the aromatic fractions. The trimethylbenzenes were identified as a fraction particularly resistant to degradation. The oil analyses proved invaluable for correct interpretation of the ecological data.

1. Executive Summary

CHAPTER 1: EXECUTIVE SUMMARY

The contents of this report result from a number of unusual circumstances, which provided a truly unique opportunity for the scientific investigation of a medium-sized oil spill in a marine environment. Although the disaster of a tanker grounding can hardly be called fortunate, its location, circumstances, and timing were fortuitous. The sections that follow will describe the unusual opportunity provided by the unfortunate grounding of the Tsesis, and will discuss in general some important lessons for the management of oil spills.

1.1 Development, Early History and Cleanup of the Spill

(Olle Lindén and John Kineman)

At 11:05 a.m. on October 26, 1977, the Tsesis ran aground while entering the Södertälje ship channel in the archipelago about 50 km south of Stockholm, Sweden. The position of the grounding was approximately latitude 58° 49.7'N and longitude 17° 43.8'E (Fig. 1.1). The location is shown on the general chart of the area (Fig. 1.2) and on the detailed chart of the ship channel (Figs. 1.3).

The 19,334 dwt., 165-m long tanker, Tsesis, was owned by a Soviet government shipping company in Ventspils, Latvia, and was enroute from Ventspils with 17,575 tons of a medium grade fuel oil. The ship had unloaded part of the cargo at Stockholm and was bound for the industrial city of Södertälje with a pilot when she struck the Käringklabben shoal, immediately southeast of Fifong Island, in the southern part of the ship channel. The submerged rock which the Tsesis struck was uncharted at 6.5 m depth, whereas the draft of the ship before grounding was estimated to be about 8.5 m.

On grounding, the ship was badly damaged and seven cargo tanks were ripped open (Figure 1.4). The punctured tanks contained a total of 6400 tons of a straight run #5 fuel oil. This oil had a density of 0.9022 at 20°C and was derived from Russian crude oil. It apparently contained enough of the original light crude fractions to allow it to emulsify.

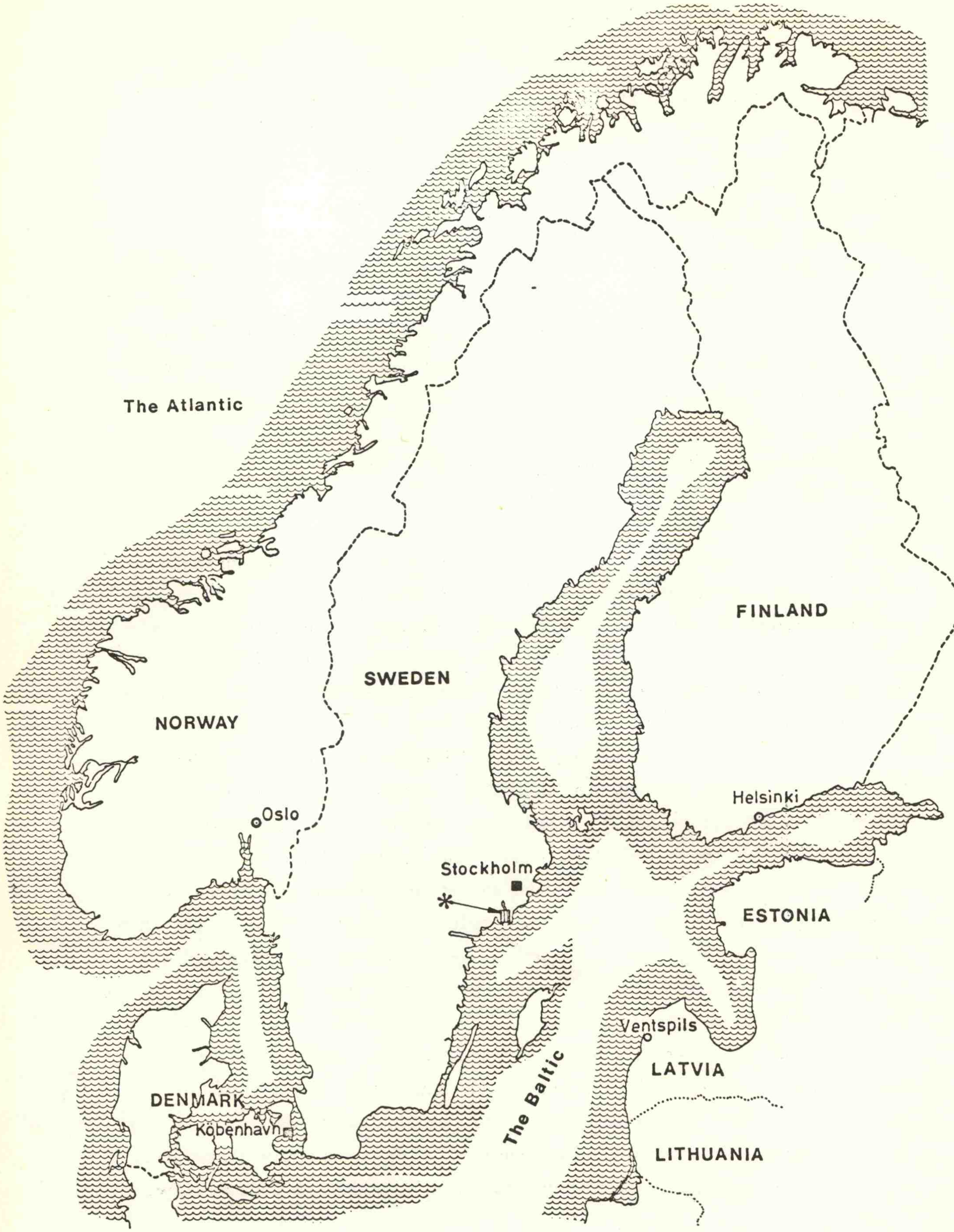


Fig. 1.1 **The Nordic Countries**

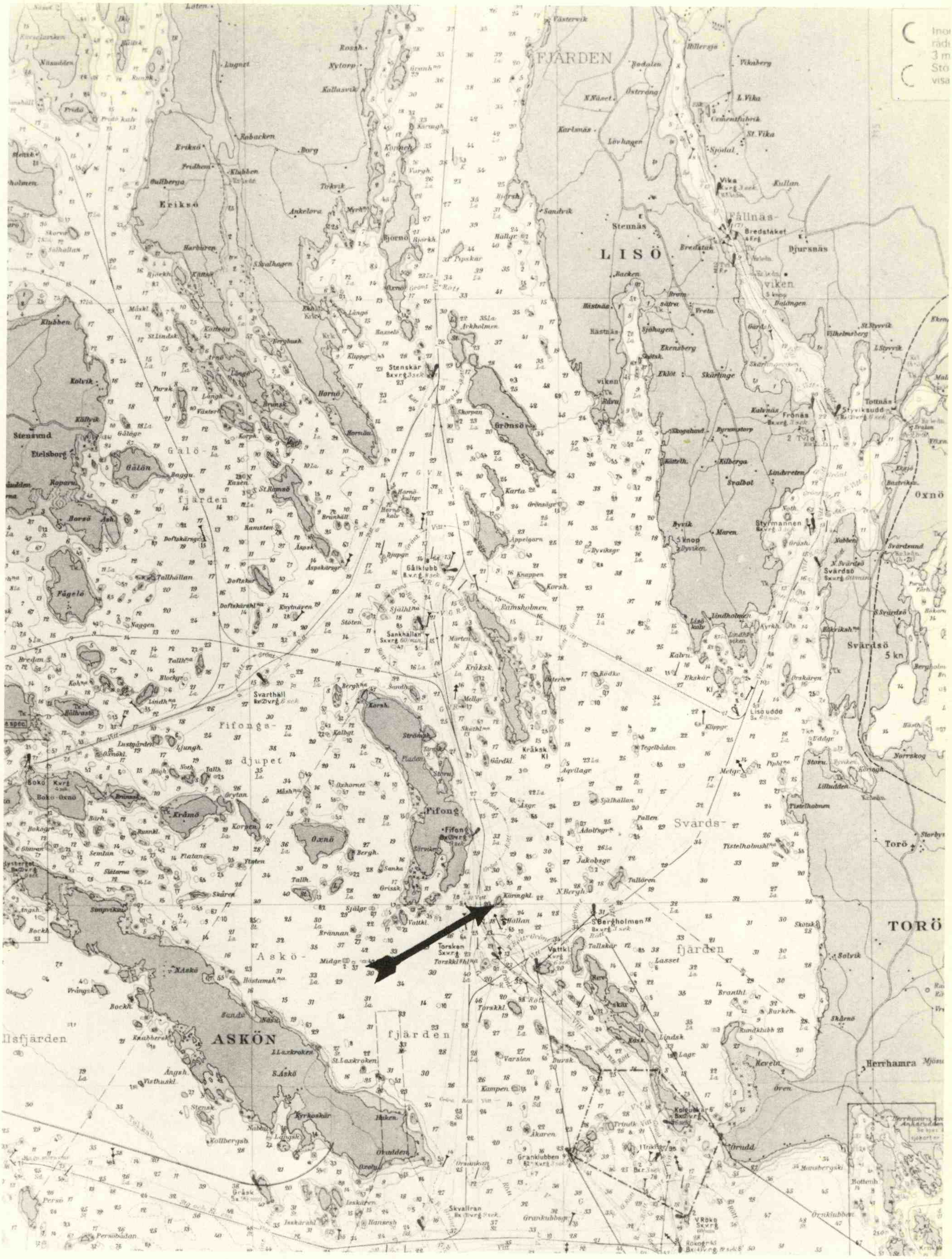


Fig. 1.2 General chart of the area of Tsesis grounding.

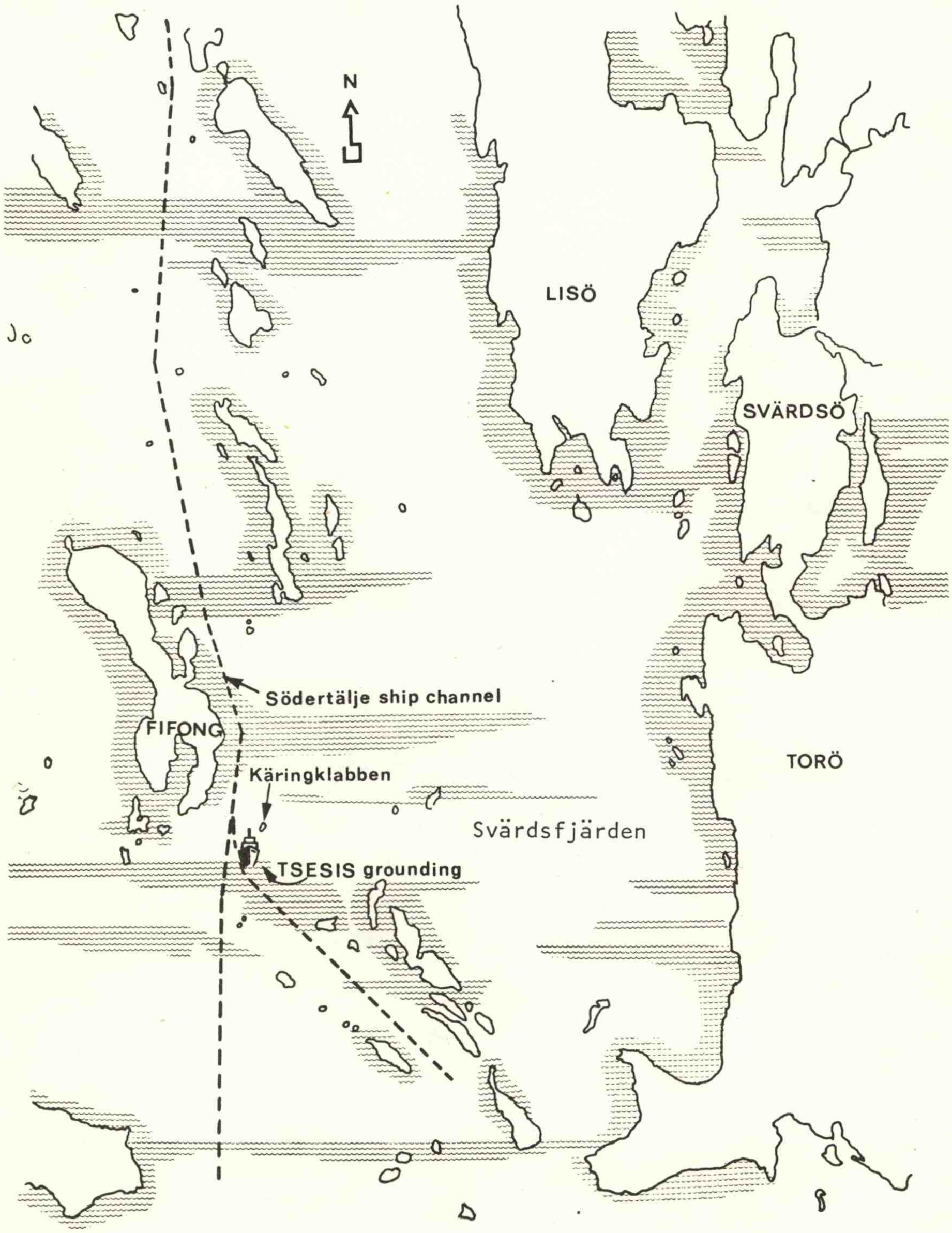
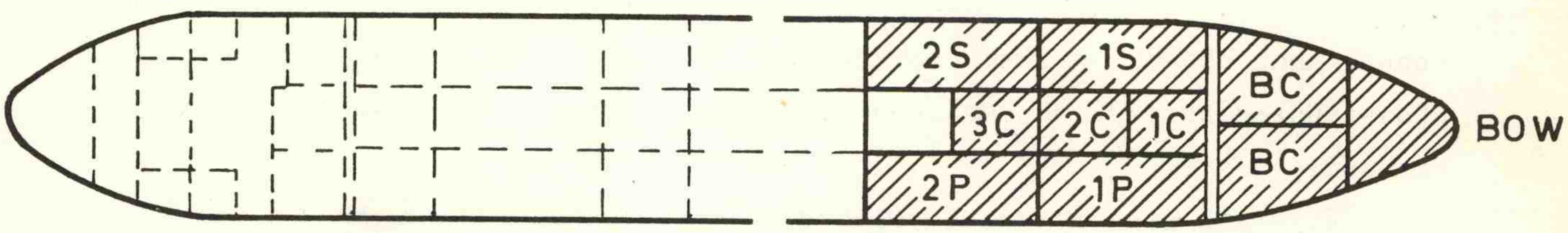


Fig. 1.3 Detailed chart of ship channel.



BC = Bunker C
S = Starboard
C = Center
P = Port

= Tanks damaged on grounding

Fig. 1.4 TSESIS TANK LAYOUT

This increased its stability and made recovery more difficult because of the greater volume. Furthermore, the viscosity of the emulsion remained very low in a sea temperature of 8°C, so that it behaved like an un-emulsified oil and remained difficult to contain. In addition to the seven cargo tanks, the port and starboard bunker tanks were also damaged, leaking an unknown quantity of Bunker C.

Oil leakage began immediately after grounding, and the oil was blown by westerly winds of 2 to 4 m/s (5 to 8 mph). About 1½ hours after the accident, the Coast Guard and pilots arrived and deployed containment booms. Within another four hours, special units from the Coast Guard arrived and deployed high seas booms on the leeward side of the ship.

Early the next morning, October 27, crews began recovery of the oil, using suction pumps, skimmers, and other clean-up equipment (see footnote), but shortage of support tanks for the deposition of the re-

---

Footnote: The Swedish Coast Guard reports that the following material was used during the Tsesis clean-up operations:

1. Containment booms: High seas booms, Sea-pact 3 (1500 m)
   " " " Bravur (200 m)
   Coastal booms Expandi (2500 m)
   Addition booms were deployed by local agencies.
2. Coast Guard ships: 7 oil combatting vessels
   7 Coast Guard cutters
   2 motor boats
   4 work boats
3. Other ships: 4 tugboats
   4 barges
   5 tankers
4. Oil recovery equipment: 2 Vikoma skimmers
   8 Komara skimmers (hydraulic)
   3 Vacuum pumps
   1 Lockhead skimmer
   3 belt skimmers adjusted to combatting vessels
   1 Marco oil recovery unit
   1 Petrolina belt skimmer
   1 Oil recovery unit (screw type)
   1 Framo-unit for "lightering" on-top
5. Other equipment: 8 containers
6. Reserve supply (not used): Approx. 1700 m containment booms, 2 Vikoma skimmers, 1 Framo unit, dispersants.

Detailed information on the organization, control and evaluation of the clean-up techniques employed can be obtained from Captain Sven Uhler, Swedish Coast Guard Service, Fack, S-103 10, Stockholm, Sweden.

covered oil delayed the work. Shortly after noon, the Soviet tanker Talsy, a sister ship to Tsesis, arrived to assist in "lightering"; however, this ship was refused permission to off-load Tsesis oil because it had not been cleaned properly, and the danger of explosion was high. Swedish authorities ordered barges, which arrived later that day, allowing the recovery of oil inside the high seas boom to continue.

Throughout the period, wherever floating oil was being transported, trajectories were mainly dependent on wind and topography. This greatly simplified tracking the surface oil, especially since the winds remained steadily from the west until October 28.

The part of the oil that had already escaped before any booms arrived hit the shores of Torö, east of Svärdsfjärden, during the afternoon of October 27th (see map, Fig. 4.9). Periodically the wind became strong enough to cause complete failure of containments, even when the booms were in place. Additional booms were deployed along shorelines, in sounds and in other areas where recovery of oil might be successful. In some cases the oil was directed into bays where it could be collected from the shores or from the sea. In all, about 6,600 m of containment booms were used.

In the early morning of October 28 a Swedish tanker arrived, providing greater storage capacity than the barges and, therefore, allowing the recovery of oil to continue. The wind still complicated the work as it turned southwest and increased in velocity to 4.5 to 5.8 m/s (10 to 13 mph). This was responsible for complete failure of even the nearshore booms, and the change in wind direction caused beach pollution farther north along the shores of Lisö Island (see photos, Appendix 2).

During the following days, the recovery of oil continued both in the proximity of the ship and in bays and sounds throughout the area. A few hours after noon on October 31st, Tsesis was towed off the rock where it had been firmly grounded for 5 days. She was then anchored in Svärdsfjärden (see Fig. 4.9 for map) until November 3, when she was finally towed from the area for extensive repairs in Stockholm. The winds remained steady from the south through November 1st.

About three weeks after the grounding, the Coast Guard reported no more floating oil in the area. By that date, a total amount of approximately 1700 m^3 of liquid material, including oil, water, debris, etc., had been recovered. Taking into account that samples of the spilled oil contained 18 to 76% water, the Coast Guard estimated that 600 to 700 tons of whole oil were actually recovered. It is difficult to determine the quantity of the remaining oil because accurate tank soundings were not available. However, a reasonable estimate could be made that the total volume of the spill was somewhat larger than 1000 tons (Table 1.1). This implies that about 400 tons were left in the environment after the initial clean-up operation. Some of this oil could be found adhering to rocks, stones, and mud beaches along 18km of shoreline. The area of impact is shown in Figure 4.10.

Table 1.1 The quantity of oil in the damaged tanks

Tank	Quantity of oil (m^3) [1]
Bunker C tanks	
Starboard bow	unknown
Port bow	unknown
Cargo tanks	
Starboard 1	1162
Starboard 2	1419
Center 1	91
Center 2	1087
Center 3	58
Port 1	1200
Port 2	1400

[1] m^3 = 6.29 barrel = 0.902 metric ton (20° C)

1.2 The Scientific Study and Participating Institutions

The circumstances of the Tsesis incident contributed to the eventual involvement of three institutions in the short and long term studies that followed. These were the Swedish Askö Laboratory, The Swedish Water and Air Pollution Research Institute (IVL), and the U.S. National Oceanic and Atmospheric Administration (NOAA); the involvement of each is described below.

The Tsesis oil spill was unusual in that the grounding was in the study area of an existing marine science program. This meant that scientists were already on-scene with extensive historical knowledge of the system, logistics and facilities were in place and ready, and a sampling program was in progress, requiring only modification to suit the circumstances and needs of the oil spill study. The Askö Laboratory, supported with personnel from the University of Stockholm, is situated on the Island of Askön only 4 km from the site of the grounding. The main project carried out by the laboratory since 1971, sponsored by the Swedish Natural Science Research Council, has been "Dynamics and Energy Flow in the Baltic Ecosystem." The project's objective has been to create a complete ecological model of the Baltic where the flows of energy and matter (representing basic processes such as inflows of light energy and nutrients, feeding, sedimentation and mineral cycling) tie together the various storages of plants, animals and chemical matter. Another research project, in progress by the Askö Laboratory, was concerned with the ecological effects of the waste water from a sewage plant. This plant is located about 25 km north of Askö in the fjord "Himmerfjärden". It was found that the fjord and the archipelago outside it, with its algal fringe, can act as a filter or "sink", retaining some of the nutrients and releasing a "cleaner" water into the open Baltic. This project originated in 1972, sponsored in part by the Swedish Environment Protection Board. The oil spill from the tanker Tsesis occurred on the boundary where these two well-documented investigation areas overlap.

It was also natural that a cooperation between the Askö Laboratory and the Swedish Water and Air Pollution Research Institute (IVL) would follow the Tsesis grounding--the Askö Laboratory had the necessary intimate ecological background knowledge of the area and IVL had the needed experience in oil spill research. The physical proximity and close personal connections between the two institutions helped even more. IVL is an environmental research institute, financed jointly by the Swedish government and industry. Its oil pollution unit is located at Studsvik on the mainland, not far from Askö. Researchers at IVL have conducted oil pollution research since 1971 and have investigated spills worldwide as part of a special U.N.F.A.O. response team. On the morning after the spill, when the Askö team arrived on scene to start the investigation, Mats Notini from IVL was included and played an important role in the planning and conduct of the research. Later, Dr. Olle Lindén, then on leave from IVL, functioned for two months as project leader for the Askö Laboratory investigation. He continued to play an active and helpful part in the investigation, even after his return to IVL, serving as liaison officer between the Swedish investigators and NOAA.

The unlikely participant in the Tsesis investigation was the United States Department of Commerce, National Oceanic and Atmospheric Administration (NOAA). Within this organization at the time of the Tsesis spill, the Outer Continental Shelf Environmental Assessment Program (OCSEAP), funded by the Bureau of Land Management (BLM), maintained an oil spill response project in Boulder, Colorado, under the management of David Kennedy. The mission of this Spilled Oil Research (SOR) Team was to take scientific advantage of oil spills having a significant research potential. The main objectives of the team at the time of the Tsesis incident were to study trajectories of oil spills (under the scientific leadership of Dr. Jerry Galt) and chemical fates in the water column (chief scientist, Dr. James Mattson). In addition, Lt. John Kineman of the NOAA Corps was given the task of investigating the "addition of a biological component" to the response team, since the sponsoring organization (OCSEAP) was interested in encouraging research on the biological effects of acute oil spills. The ultimate purpose of the SOR project within OCSEAP was to relate, by analogy, the study results from

actual oil spills to theoretical problems in the environmental assessment of Alaska. These interests, and the unique situation created by the Tsesis incident, formed the basis for international cooperation between Sweden and the United States. As a matter of routine, the Tsesis incident was evaluated by the SOR Team for research potential. It was concluded that enough oil would remain in the enclosed area for chemical studies of the water column, and that the proximity and participation of the Swedish institutions mentioned would afford an excellent opportunity to investigate the feasibility of various biological studies as part of a coordinated program. Discussions, via conference phone and in meetings, ensued to refine the experiment design. These discussions included Dr. Wilmot Hess (Director of the Environmental Research Laboratories of NOAA), Dr. Rudy Engelmann (Director of OCSEAP), Dr. Douglas Wolfe (Deputy Director of OCSEAP), David Kennedy, Elaine Chan, Dr. Jerry Galt, Dr. James Mattson, Dr. Peter Grose, and Lt. John Kineman from the U.S. and Dr. Bengt-Owe Jansson in Sweden. On the day following the spill, the Askö Laboratory (Dr. Jansson) received a request from the OCSEA Program, through the U.S. State Department, for permission to send a team of oil spill scientists to study the spill. The Askö Laboratory welcomed this offer, and the response coordinator, Lt. John Kineman, with two chemists, Dr. James Mattson and Robert C. Clark Jr. (MS), participated in the short-term phase of the spill study. David Kennedy coordinated the direction, communication and logistics for the NOAA team from the project office in Boulder, Colorado. Lt. Kineman, as biological coordinator for the OCSEAP SOR program and later as acting project manager, coordinated the U.S. part of the Tsesis long-term study and participated in evaluation meetings in Sweden and the U.S. The major element of this coordination was the funding of hydrocarbon analyses performed under contract to OCSEAP by Dr. Paul Boehm (principal investigator) of Energy Resources Company Inc. (ERCO). Because of the participation of NOAA, the Tsesis study included advanced hydrocarbon analyses of biota and sediments. Without these analyses the ecological investigations made by the Swedes would have lost much of their value and in some cases would even have been impossible to interpret correctly.

1.3 List of scientific personnel with major participation in the Tsesis oil spill study

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1.4 Acknowledgements

The support of all funding authorities (See Section 1.5) is gratefully acknowledged. During the acute phase of the spill, the Research Laboratory (U-lab) of the Swedish Environment Protection Board also supported the investigation through the offices of Gunnar Guzikovski and Paul Anderson, and the Swedish Coast Guard provided valuable assistance throughout the investigation.

The hard work of the technical and administrative staff of the Askö Laboratory was a prime requisite for a successful study. The first draft was typed by Kerstin Ernquist, Maureen Moir, Jane Sjölander and Almaz Terrefe. Bibi Mayerhofer and Lis Klöve-Björklund helped with many of the illustrations. Leif Lundgren and Ulf Aneer helped in the field with collection of samples. Carl-Henrik Bagger and Bernt Abrahamsson commanded R/V Aurelia. Inger Hafdell and Ann-Britt Holm sorted macrofauna and Kerstin Rigneus phytoplankton samples. The team of Askö scientists, led by Dr. Bengt-Owe Jansson (Director of Askö Laboratory), who participated in the initial investigation and study plan design included, apart from the authors of this report (listed in section 1.3), the following persons: Dr. Sven Ankar, Hans Cederwall, Åke Hagström, Ruth Hobro, Nils Kautsky, Inger Wallentinus and Fredrik Wulff. During this initial phase the U.S. NOAA/OCSEAP SOR team provided invaluable guidance concerning both oil spills in general and sampling for hydrocarbons in particular. The administrative staff of OCSEAP also assisted with administrative help and typing interim reports, contracts for the chemical analysis, communications, and drafts of the report. These people include Wanda Power, Rosalie Redmond, Kay Jentsch, Norene Easton, Rosa Echard, and Mary Venis. Susan Rothschild typed the corrections and final copy. Final editing and coordinated proofing was done by Marian Cord, who supervised the report through the stages of publication.

At several points in the process of applying for funds to continue the chemical backup of the study, and in the process of producing this document, program descriptions were written and circulated to reviewers for comment. These reviews and comments were very helpful in evaluating

the studies and priorities for funding the chemical backup. Subsequent reviews contributed significantly to the current draft of this report. The help of the following reviewers is gratefully acknowledged (reviewers of this report are marked with an asterisk):

Dr. Jack Anderson, Battelle N.W.

Dr. Donald Malins, Environmental Conservation Division, Northwest Marine Fisheries Service, NOAA

Dr. Charles T. Krebs, St. Mary's College

Dr. George J. Mueller, Institute for Marine Science, University of Alaska

Dr. Steve LeGore, NALCO Environmental Sciences

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*MS. Robert C. Clark, Jr., NMFS, NOAA

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In addition to other acknowledgements mentioned above, the U.S. NOAA/OCSEAP SOR Team wishes to express appreciation to the following offices and personnel for crucial assistance during the activation phase of the team's response: The Associated Press wire desk in Denver, Colorado, cooperated in providing initial and subsequent news releases; Mr. Tuner, working with the On-Scene Coordinator in Sweden, provided information and facilitated contact with Askö Laboratory; Dr. Åke Hagström, of Askö Laboratory, provided the first thorough description of scientific activities on-scene and facilitated further coordination; Dr. Bengt-Owe Jansson, gave continuous information on spill conditions, initial

approval to work with the Askö Scientists, enthusiastic support for U.S. participation, and a warm reception to the U.S. Team upon arrival in Sweden; Mr. Kinter of the Environmental Office of the U.S. State department provided needed assistance in obtaining official clearances for U.S. participation; Mr. L.-E. Örtegren, Science Advisor at the Swedish Embassy in Washington, assisted with official clearances; CDR Roland Engdahl, Swedish Coast Guard, On-scene Coordinator at the Tsesis incident, gave willing approval for the presence of U.S. scientists; Dr. Wilmot Hess, Director of NOAA's Environmental Research Laboratories, approved OCSEAP participation in the Tsesis study; CDR Richard Alderman, of the NOAA office of International Affairs, assisted in obtaining clearance in spite of an oversight in initiating contact with his office; Dr. D. Lee Alverson, Director of the Northwest and Alaska Fisheries Center, and Dr. Donald Malins agreed to provide a chemist to join the OCSEAP team; Dr. Bill MacLeod of NWAFS Analytical Facility, made preparations to participate in the SOR Team response and later assisted in oil chemistry analysis; Dr. Thomas Austin, Director of the Center for Experimental and Data Analysis, approved the participation of Dr. James Mattson; Mr. James Murphy of the State Department Passport Office in Washington, D.C. expedited a passport for one participant; and finally, all personnel at the Askö Laboratory provided a pleasant atmosphere to work and live in. Special thanks go to Kerstin Ernquist, who helped with supplies and living arrangements and to Carl-Herman Bagger, captain of the research vessel Aurelia.

Finally, thanks must go to Dr. Rudolf Engelmann (Director, OCSEAP) and Dr. Douglas Wolfe (Deputy Director, OCSEAP) who supported both the original concept of research response to oil spills and the coordinated effort reported herein.

1.5 Funding

Initial financial support of the Askö Laboratory study was provided by the Swedish Coast Guard and later by the Swedish Environment Protection Board, which guaranteed resources for investigation of the acute phase for a duration of one month and then requested a program for further investigation of the long-term effects. A proposal based on existing knowledge of the ecological conditions in the area was submitted and tentatively accepted; however, no funds could be found. Consequently, the investigation ceased for almost six months except for an investigation of the Fucus fauna, carried out by IVL on a separate grant (see section 7.2) and some unfinanced sampling activities by interested and public-minded Askö scientists. Later, the Askö Laboratory was asked to submit a new proposal to the Swedish Environment Protection Board because new funds had become available. By then, the original proposal had become obsolete, and a pilot study had to be carried out to provide the necessary information for planning a continued study of those parts of the ecosystem that still showed evidence of persistent oil impact. The chemical back-up funded by OCSEAP was dependent on the biological program, and so also required stepwise approval.

In all, the Askö Laboratory investigation has been financed through grants from the Swedish Environment Protection Board (Grants No. 7-548/77 and 7-548/78, a total of 260,000 Swedish Crowns), the Swedish Coast Guard (50,000 Swedish Crowns) and Sven and Dagmar Salens Stiftelse (110,000 Swedish Crowns). The IVL Fucus fauna study (Section 7.2) was supported through a separate Swedish Environment Protection Board grant to Mats Notini (75,000 Swedish Crowns) and an equivalent matching grant from IVL. IVL has also directly supported this study through Dr. Lindén's continued participation after the original Askö grant was expended. Finally, the NOAA-OCSEA Program has supported the study through its own personnel and by funding the oil analyses. The total NOAA investment was approximately 70,000 U.S. Dollars, which were BLM funds administered by OCSEAP. The combined investments totaled approximately 900,000 Swedish Crowns or 200,000 U.S. Dollars.

1.6 Lessons learned for the management of oil spill investigations

(Olle Lindén, Ragnar Elmgren, Lars Westin, and John Kineman)

Oil spills are no longer thought of as unlikely chance events, but rather as predictable results of the transport of oil by sea. New dialogue has been suggested to reflect this change in outlook, specifically to begin discussing the "management" of oil spills. This emphasizes the recognition that future spills will occur and implies the need for an organized approach to the conduct of events that follow. The Tsesis oil spill study was primarily an ad hoc planning effort, except for the fortunate existence of an ongoing marine science program. It was also a unique experience on the part of the local scientists involved--a typical situation for significant oil spills that have occurred to date. If the eventual transition is to be made from ad hoc planning to contingency management of events (including research) following the predictable and possibly larger future spills, a determination of important lessons to be learned from each incident is necessary. A number of these lessons, made apparent during the Tsesis study, are summarized for the purpose of improving future management of environmental investigations of oil spills.

1. Funding sources need to be identified in advance. In retrospect, it is obvious that the uncertainty of funding for this investigation seriously hampered its successful realization. For a considerable and probably very important period of time, the major part of the studies was halted due to lack of financial support.

   Funding sources should be established immediately. This can be done, for example, by setting up a fund financed by a tax on imported oil (cp. the U.S. "super fund" legislation) from which institutions and individuals could seek restitution for oil spill damages to natural resources and ecosystems. This fund would also be used for the support of research following oil spills to determine the extent of the damage. Such a plan has received much discussion in the United States and a similar method of financing has also been suggested in Sweden (MIST, 1979).

Furthermore, the level of funds allocated for the scientific study of an oil spill must not be based solely on gross factors such as the size of the spill or the degree of publicity, as has often been the case. The Tsesis study has shown that many factors are important in determining the seriousness of even small to medium pollution incidents. These include topography, water depth, oceanographic conditions, season, life stages, type of oil, degree of oil trapping, effectiveness of mitigative measures, species and communities insulted, and so on, forming a large matrix. The establishment of a reliable general fund will allow the initial scientific investigation to proceed quickly to evaluate elements of this matrix and to focus on the construction of a follow-up program that is the most scientifically competent.

2. Contingency research planning is needed. The Tsesis study was launched in a few days. Few of the local scientists involved had any experience with oil pollution studies. During the first days and weeks after the spill, a number of important processes took place rapidly in the affected area and had to be studied while in progress. Under such circumstances it is not surprising that important sampling at one site was neglected while scientists were occupied at other sites. In specific regions where future spills are likely, as with the Södertälje strait and archipelago, local scientists must perform careful advance planning. The plan should list the different investigations to be carried out; materials and sampling equipment needed for the various investigations should be listed and procured. The plan should designate experienced personnel and institutions capable of performing the studies; a project leader should be appointed and a center designated for the coordination of the various investigations (see Pollack and Stolzenback, 1978).

It is not reasonable, however, to expect spills to occur close to existing facilities, as with Tsesis; this fact is the basis for the scientific support capability which was established in NOAA. A

properly coordinated physically responsive group can perform the initial scientific evaluation and construct the follow-up program. In the case of local contingency research plans in high risk areas (such as the Södertälje shipping channel), details of the study can be laid out in advance and the study narrowed according to the events of the spill. For less pre-studied areas or for readiness in general, it is necessary to lay out a flexible scientific capability. The initial investigation (quick response) will have to include some method for rapidly learning the important aspects of the environment unluckily chosen by the spill, and then determining the parameters that are most important to measure in that case. A plan that is flexible enough to fit a variety of situations, but rigid enough to comply with practised and proven methods, is the ultimate goal. The follow-up program should incorporate early, and to a maximum degree, the capabilities of local or available institutions.

Furthermore, the approach described recognizes the importance of the short-term phase of the study. Results of seemingly similar incidents can be diverse, and the ability to predict or understand the extent of effects from a given incident will depend heavily on detailed knowledge of the initial conditions of the spill and the local environment. Also, it is always desirable to obtain an indication of pre-spill conditions; but the rapidity with which processes occur during the first few days (for example, the transport of Tsesis oil to the benthos) means that immediate sampling is often the only way. In any but the most ideal conditions (e.g., Tsesis) a pretrained, quickly responsive scientific investigating team is needed. An additional benefit of such a response group is the established capability to evaluate a variety of acute pollution incidents.

In the Tsesis incident, the need for a special response group was compensated by the fortuitous proximity of the Askö laboratory

and the existing marine science program. Still, the U.S. scientists, who responded for limited objectives only, re-learned the importance of precise and comprehensive pre-planning of experiments. Procedures that are developed enroute or on-scene are likely to be incompletely thought out. Yet, it has been the tendency of response programs to fail to adequately emphasize the necessary research and development of experiment designs and field procedures. For example, the possibility of problems in using plastic bag samplers (chapter 5) has been hypothesized for some time; yet, the procedural limitations of this sampling technique were not defined until after the loss of important data and considerable expense. Quick scientific response is a valid strategy, but only proven techniques and procedures should be used. Their development and documentation must be adequately supported in advance and strictly adhered to in the field.

3. Further development is needed for sampling techniques. The largest gap in the field capability at the Tsesis site (and at other recent oil spills) was the lack of an adequate sea water sampler for low level hydrocarbon analysis. The best results were obtained by Scuba, using glass containers (protected during surface entry); but this procedure is not usually practicable and is often dangerous during the early stages of the spill when sampling is most important.

Furthermore, the Tsesis investigation revealed that large quantities of oil can be sedimented through the water column. The use of sediment traps are therefore recommended in future studies (see Section 3.3.1). However, before this can be employed on a matter of course basis at oil spill studies, some further careful study should go into trap design and a determination made of trapping efficiency--especially the possibility of overtrapping, which could lead to erroneous balance calculations.

Thirdly, because of the importance of the observed transport of oil to the benthos, it is apparent from the Tsesis study that a strong need exists for a specialized sediment (benthic) sampler which will properly represent the uppermost, thin, and often flocculent layer for hydrocarbon analysis. This was the final piece of the puzzle that could not be added in the case of Tsesis, because of the inadequacy of existing samplers for this purpose.

It has been suggested and demonstrated repeatedly at oil spills, that the proper expenditure of funds on necessary research and development before the study can result in a great financial saving as well as make the difference between a successful experiment and a failure. These three high priority research and development projects should receive funding as soon as possible. The source of such funding is most logically a government program with legislated responsibility for environmental protection or research. In the United States possible candidates are the U.S. Coast Guard, U.S. Environmental Protection Agency, or NOAA.

4. The scope of the scientific investigation must not be limited administratively. The effects of oil spills in various environments will probably never be fully classifiable. Controlling factors are too numerous. Therefore, only a competent response team can properly evaluate the environmental significance of a particular spill and determine what kinds of studies are needed to detect and understand what may be happening to the system. The contingency plan must cover a broad spectrum of possibilities from which some will be selected at the time of the spill.

Each spill study reveals new phenomena. A very significant finding of the Tsesis study was that a relatively small spill of a medium weight fuel oil can be acted upon to produce rapid transport of large quantities of oil to the benthos, where, out of sight and beyond mitigative measures, it can have significant effects for a

long time. The mechanism behind this transport is also important, as is the possibility that effects observed in the benthos (and elsewhere) can propagate through the system. It is clear that all aspects of the environment must be considered, with adequate concern for the less visible aspects of the spill.

Attention cannot arbitrarily be directed toward commercial species, endangered species, or other aspects of the environment that may reflect changeable social values at the time. Social values determine what aspects are of greatest interest and are perhaps a significant focus of the study, but only the investigative team can determine which, sometimes subtle, parameters should be measured. Some examples illustrate this:

- Often the effects on highly mobile species (however important commercially or aesthetically) are hard to demonstrate because of the difficulty of resampling the same individuals or knowing well enough what they have been exposed to. However, effects may be similar to those observable in sessile or less mobile species. This may have been the case with bottom fish as opposed to herring.
- The characteristics of various organisms can make them good or poor indicators of various factors. The benthic macrofauna species, Macoma balthica, are the easiest to sample and analyze, and they are characteristically resistant to damage; this makes them excellent biological indicators of the level of "insult" to the benthic community because they stay alive long enough to represent possibly high concentrations or repeated exposures (Shaw et al., 1976). Their use alone, however, would lead to the erroneous conclusion that effects were slight although concentrations were high. By looking also at the more sensitive meiofauna and the crustacean macrofauna, as was done in the Tsesis study, significant effects

could be demonstrated. Conversely, the level of insult would be hard to demonstrate on such sensitive organisms which tend to be killed or to emigrate. For the purpose of this report, the word "insult" is being used to indicate something different from "exposure", "effect", or "impact". Although the ambiguity of these terms will probably not be totally resolved by this definition, "insult" here should be thought of as the amount of harmful substance that penetrated an organism's natural, first line defenses (e.g. skin, shells, exoskeletons, etc.). This would include "body burden" and coating of sensitive areas, but not, for example, coating of shells. As a further example, water column concentrations may be said to "insult" filter feeders. "Effects" can be migration, death, metabolism changes, etc. "Impact" will be used to refer to the entire picture: exposure, insult, and effect.

1.7 References

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2. Perspective

CHAPTER 2: PERSPECTIVE

It is important that each pollution incident be viewed in the context of the environment in which it occurred. Only then can the significance of pollution incidents and the importance of studies be recognized. This chapter provides some environmental considerations which attempt to place the Tsesis incident into perspective.

The Tsesis spill obviously has implications for the Baltic, where the spill took place; in addition, a discussion is provided which compares the situation with environmental conditions in Alaska, the focus of which was the underlying justification for U.S. support.

2.1 Baltic Perspective

(Ragnar Elmgren, Lars Westin, Olle Lindén)

During the last decade a number of valid studies on various effects of oil spills in marine environments have been carried out. These studies have dealt with extremely large and spectacular spills as well as spills of a more normal size. In few instances, however, have more than a few aspects of a spill been studied, and often the concern has been with littoral systems or bird populations. Few studies have attempted to illustrate the total effect of an oil spill on all the various parts of the ecosystem (COMS, 1978; Kühnhold, 1978). The Tsesis study was an attempt to do so and also represents one of the few studies carried out in the Baltic or in brackish waters in general.

The Baltic Sea is one of the largest areas of brackish water in the world, with a surface area of 366,000 km^2. It is the largest extensive area of low but stable salinity, mostly within the β-mesohaline range (5-10 $^{o}/oo$ S = 0.5 - 1% salinity). The fluctuations of the surface salinity are small in spite of occasional powerful injections of North Sea water, which greatly affect the salinity of the deeper Baltic waters. A salinity gradient exists from north to south, from 2-3 $^{o}/oo$ S, in the innermost Bothnian Bay, to about 15-20 $^{o}/oo$ S in Kiel Bay. Tides are almost entirely absent.

There is also a gradient in climate, from subarctic conditions and more than six months of ice cover in the coastal zone of the extreme north, to a more maritime climate with an average of only a month of coastal ice in the south. Salinity is the most important controlling factor for the ecology of the Baltic Sea. The organisms are present in an osmotic environment, which allows only a limited number of euryhaline marine and fresh-water organisms and a few brackish-water specialists to establish themselves in the inner Baltic. The high osmotic stress, therefore, results in a simple ecosystem with just a few dominant species. The classic generalized "Remane's curve" (Remane, 1934) shows a marked species minimum at 6-7 $^{o}/oo$ S. For further information, the reader is referred to the following general reviews of the ecology of the Baltic Sea: Remane, 1934, 1940, 1958; Sergerstråle, 1957; Zenkevitch, 1963; Jansson, 1978.

There has been an increase in tanker traffic in the Baltic Sea, both with respect to the frequency of ships in the area and to tonnage. From April 1976 the new buoyed-off fairway at Darss Sound at the entrance of the Baltic Sea permits tankers of up to 160,000 tons (dw) to enter. The extreme risk of huge spillages when ships of this size enter the Baltic is obvious. The shallow and imperfectly sounded waters increase the risk of grounding. Also, the poor visibility due to prevailing weather conditions during most of the year, as well as the high frequency of ships sailing in the area, increases the risk of grounding and collision. Totally, at least 1,000 spills with a calculated volume of about 100,000 tons are reported each year (Engdahl, 1976). Accidents involving spillage of oil are permanent phenomena in the Baltic.

In heavily congested areas, such as the entrance of the Södertälje ship channel, spills are also very frequent. Less than 8 months before the grounding of Tsesis, another accident resulting in a spill of 100-200 tons of medium grade (No. 5) fuel oil occurred about 5 km north of the Tsesis rock, but most of the oil drifted north into Himmerfjärden, and the area most heavily oiled by Tsesis was only lightly touched (as shown also by the relatively low pre-Tsesis-spill hydrocarbon levels in Mytilus in this area, see section 11). About four months after the grounding of

the Tsesis, another tanker carrying 35,000 tons of oil grounded some 100 km to the northeast, also releasing substantial quantities of oil. This oil did not reach the area investigated in this report.

The spill site was located on the Swedish coast of the northern Baltic, roughly 65 km south of Stockholm. The archipelago here is relatively narrow and open to the Baltic, with a number of small barren skerries. Depths in the area are variable with a mean of 25-30 meters. The surface salinity is quite stable at 6-6.5 °/oo S, and increases by 1 °/oo at 40 m depth. Surface temperatures vary from below 0°C in winter to a maximum of about 21-22°C in hot summers. This area is therefore representative of mean Baltic conditions and fairly typical of coastal areas with respect to hydrography, hydrology, and topography.

It should be recognized, therefore, that not only are the Tsesis results significant for understanding or predicting the effects of spills in the Baltic, but also the methods and capabilities refined during the study may be directly applicable to future Baltic spill studies. The need for performing holistic ecological studies on the effects of oil spills in the Baltic has been explained in section 1.6. The Baltic environment is unique, so that the environmental risks must be studied before significant widespread damage becomes a fact. If this is not accomplished before a "catastrophic" incident, or its equivalent in accumulated smaller ones, it will then be too late to benefit from many of the lessons.

The Tsesis incident was the second largest spill in the Baltic Sea to date. Since the spill occurred in an archipelago characterized by thousands of islands, inlets, rocks, and shoals, a significant length of shoreline was impacted, while topography and hydrography contained the spill in a relatively small, shallow area. In areas such as this (typical of the Baltic) low exchange rates, low energy wave conditions, and near zero tidal energy mean that the removal and degradation of oil is very slow. Low temperatures especially in the bottom layers, makes evaporation of the acutely toxic, volatile aromatic hydrocarbons very slow. Furthermore, there are indications that the low salinity may play a part in prolonging the residence time of the lighter aromatic compounds

(Lindén, unpubl.). There is little doubt that the cold, stagnant bottom waters of the Baltic, with low oxygen levels due to partial eutrophication and a pronounced halocline, will slow the degradation of oil that reaches the bottom below the halocline and cause it to be retained longer in the sediments. In general, conditions could hardly be worse for repeated oil spills. The chemical analysis of Macoma balthica has supported the possibility that Tsesis oil has been deposited in reservoirs where it degrades slowly and is, at times, resuspended. There are indications that a slow accumulation of petroleum hydrocarbons in the sediments is already a wide-spread phenomenon in the Baltic (Rudling, 1976).

It may be important to note, especially when making comparisons between the Tsesis experience and other oil spills, that the effect of the Tsesis spill on the marine environment was seasonally dependent. The spill occurred during what was probably the least critical of all time periods both from the point of view of the aquatic biota and from the point of view of human habitants (consequently there was less pressure for short term remedial and cosmetic activity).

2.2 Alaskan perspective

(Ragnar Elmgren and John Kineman)

"The prediction or assessment of pollution effects on the basis of observations extrapolated from one environment to another is seldom supported by adequate data. Unfortunately, however, few data on pollution effects exist for most areas and species, which has led to the use of information from areas that may be dissimilar in critical respects." (Evans and Rice, 1974)

The above quotation defines the basic fallibility of intersite comparisons, but serves as a reminder that, nevertheless, the pressing requirements for oil and gas development have made such comparisons necessary. It is therefore important that 1) study areas are selected which are most comparable to those being assessed for development; and 2) the comparisons are thoroughly analyzed.

The Baltic shares some important biotic and abiotic oceanographic features with Alaskan coastal waters. The geographical extent of the Baltic, from about 54°N to about 66°N, coincides largely with that of Alaskan waters, resulting in similar annual pulses of incident solar radiation as a forcing function for pelagic primary production at comparable latitudes. As in Alaskan waters, there are large differences in climate between the southern and northern Baltic. The northernmost Bothnian Bay features near-arctic conditions and is ice-covered for more than half the year in the archipelagos, whereas in the much milder climate of the southern Baltic near-coastal ice is generally present for only one or two months. Water temperatures below about 20 m depth in the Baltic Sea are also comparable to Alaska. Below this depth, near-arctic conditions prevail throughout the year (annual mean temperature about 2-5°C, peak temperature around 10°C during the late autumn storm mixing).

Many Baltic macrobenthic species have taxonomically closely related counterparts in Alaska. The similarity between Baltic and Alaskan macrobenthos is especially striking when comparisons are made with inshore samples from Prudhoe Bay in the Beaufort Sea (Feder, 1976), but some dominant species are also shared with fauna of the Bering Sea (Alton, 1974) and the coastal areas of Prince William Sound, an

embayment of the Gulf of Alaska (Feder and Paul, 1977). In many cases where the species are not identical or their identity is questionable, the genera are the same (see Table 2.2.1). It is well known that the species occurring in the Baltic are tolerant of lowered salinities, this is presumably true of many of their counterparts in Alaska, even though the Alaskan species usually live in full salinity sea water. While salinity is known to be a major factor controlling distribution in the Baltic, it apparently is not a major factor in Alaska, except in isolated cases.

However, there are also important differences between the two regions which must be kept in mind when comparisons are made. The Baltic is nearly a-tidal, whereas the tidal range in most Alaskan waters is generally large. This gives the shorelines entirely different physical and biological characteristics. Also, due to the absence of tides and a relatively short fetch across the Baltic, turbulent mixing is lower. This results in the rapid warming of Baltic surface waters in late spring to early summer, with the thermocline forming at about 15-20 m depth. The surface layer generally reaches temperatures of 15-18°C in summer, but inshore, and in exceptional summers even offshore, temperatures may temporarily exceed 20°C. Although there are locations in Alaska where some of the physical conditions of the surface water are similar to those in the Baltic (for example, the narrow tidal range in the Beaufort Sea), community level comparisons will probably be best in the deeper (below 15-20 m) zones (the soft bottoms).

The salinity characteristics of the two regions clearly differ, with the only analogous areas in Alaska being at the head of estuaries and fjords adjacent to glaciers, where melt-water and runoff will at times create mesohaline conditions similar to the Baltic. However, the Baltic is unlike most estuarine areas of lowered salinity (including those in Alaska), because the salinities vary little during the year (generally less than ±1 o/oo S). This allows some species of marine origin to penetrate to surprisingly low salinities.

A final differentiating feature of the Baltic is the salinity stratification of the Baltic proper (also observed in some bays of the

Table 2.2.1

Species and genera shared between the northern Baltic Sea and the coastal waters of Alaska. The list is far from complete.

Group	Baltic Sea	Alaska
Plants (Flora):		
Phaeophyta:	Fucus vesiculosus	same
Chlorophyta:	Cladophora glomerata	same
Animals (Fauna):		
Priapulida:	Halicryptus spinulosus	same
Polychaeta:	Pygospio elegans	same
	Terebellides stroemi	same
	Nereis diversicolor	N. zonata
Mollusca:	Macoma balthica	same
		Macoma calcarea
		Macoma nasuta
	Mya arenaria	same
	Mytilus edulis	same
Crustacea:		
Ostracoda	Paracyprideis fennica	Most probably circum-
	Heterocyprideis sorbyana	polar species also present in Alaska
Mysidacea	Mysis relicta	Mysis spp.
Isopoda	Saduria entomon	same
Amphipoda	Pontoporeia affinis	same
	Pontoporeia femorata	same
	Gammarus zaddachi	same
	Gammarus locusta	same
Decapoda	Crangon crangon	C. spp.
Bryozoa:	Electra crustulenta (syn. Membranipora crustulenta)	Membranipora spp.
Fish:	Coregonus nasus	same
	Coregonus lavaretus	Coregonus autumnalis
		Coregonus sardinella
	Myoxocephalus quadricornis	same
	Gadus morrhua	G. macrocephalus
	Platichtys flesus	P. stellatus
	Clupea harengus membras	Clupea harengus pallasi

Aleutian Islands), which leads to stagnation and oxygen deficiency at depths below 60-70 m and a consequent severe reduction of the bottom fauna below this zone. The area exposed to Tsesis oil did not include depths below 60 m, however.

The ecological importance of the above differences cannot be completely evaluated at present, due to lack of experimental data; however, as in the case of studies in controlled ecosystems, some differences may be desirable for the conduct of specific studies. A comparison of significant stresses (Table 2.2.2), for example, suggests that some stresses commonly imposed on marine communities and organisms in Alaska, are either negligible or held constant in the Baltic. This implies a more "controlled" situation in the Baltic and may help to isolate the effects of the spill from other perturbations. On the other hand, as shown in Table 2.2.3, the major differences combine to suggest a longer retention time and slower degradation of oil at the Tsesis site than at most places in Alaska.

Although there are important differences in physical conditions between the Baltic and Alaskan coastal waters, the similarities mentioned initially still indicate that oil pollution studies in the two areas have important problems of common interest, such as:

1. Oil degradation in waters of very low temperature, especially studies of oil degradation in deeper (below 20 m) Baltic soft bottoms; these should be highly relevant for Alaskan environmental impact studies.
2. Community level effects in the deep soft bottoms.
3. Vulnerability of shared species (Table 2.2.1), some of which have been shown to be exceptionally susceptible to oil pollution, e.g., Pontoporeia femorata (Rohrbacher-Carls, 1978).
4. Problems connected with oil spills in ice-covered areas.
5. Problems connected with oil spills in osmotically stressed environments.
6. Problems connected with oil spills in environments with a high number of islands (fjords, bays, etc.) that create long coastlines in a small area.

Table 2.2.2 Comparison of significant stress factors

Stress Factor	Alaska	Baltic (spill area)
1. Brackish salinity (stressful for both fresh and saltwater organisms)	Occurs in isolated areas such as bays within Prince William Sound and varies greatly with time and depth (3-4m fresh water lens forms from glacial and snow melt and run-off)	Relatively uniform throughout local areas; constant stress for most organisms.
2. Salinity fluctuations	Significant in isolated areas: seasonal and dependent on mixing	Small: allows even stressed organisms to exist beyond their normal range.
3. Low temperature of bottom water	Significant seasonal variation inshore, but not in deeper waters	Relatively constant with time and location.
4. Sediment load	Seasonally high from glacial runoff and adjacent to major river systems, such as the Yukon and Copper Rivers	Low
5. Other pollutants	Low	Significant

Table 2.2.3 Factors affecting the elimination of oil from the environment

Factor	Alaska	Baltic (spill area)
Oxygen deficiency of bottom water	Rare (only in isolated bays in Aleutians)	Significant below halocline: very thin oxidized layer, sometimes totally anaerobic conditions
Tide and wave energy (Combined)	High along outer coastal areas (but variable with area; low in the Arctic).	Low
Turnover of water mass	Frequent, typically well mixed	Less frequent: pronounced thermocline and halocline
Other factors (bacteria, photo-oxidation, penetrability of bottom sediments, etc.)	---------- differences not well known ----------	

The two large regions compared here are geographically extensive and internally very heterogeneous. For these reasons detailed comparisons with the Tsesis study should preferably be made for individual regions within Alaskan waters, with due regard to the specific features of the region. The above highly generalized comparisons were intended mainly to indicate that more detailed comparisons can be meaningful.

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3. Scientific Summary and General Discussion

CHAPTER 3: SCIENTIFIC SUMMARY AND GENERAL DISCUSSION

(Olle Lindén, Ragnar Elmgren, Lars Westin and John Kineman)

3.1 Background

Few field studies of oil spills in the Baltic Sea are available. The Palva accident in 1969 was the object of a study at Åbo University (Pelkonen and Tulkki, 1972). One year after the spill, no observable damage was found in the coastal zone, but it should be noted that the accident occurred at the very end of the archipelago of Finland's south-western coast, a highly exposed area.

The only previous study of the long-term effects of an oil spill in the area exposed to Tsesis oil (Notini, 1977) has been a 5-year study of the recovery following a spill at Gästviken, Muskö. The bay was severely contaminated with 400 tons of medium and heavy heating oil from the grounded Irini in the month of October 1970. A widespread recolonization of the littoral fauna occurred quickly in the first summer after the oil spill. The less rapidly moving organisms, such as mussels and snails, reestablished themselves during the following years. Four years after the oil spill, no effects could be discerned in the ecological system of the Fucus belt zone in the bay, but the oil which was incorporated into the sediments of the bottom remained and was not significantly degraded. The oil that remained on the beaches had been drastically altered. The rapid recuperation of the bay is explained in part by the large effort made to remove the oil by mechanical means, by the small size of the bay, by the good water exchange properties, and by the closeness of undisturbed areas which could serve as sources for recolonization.

The studies mentioned above appear to illustrate the importance of the relationship between energy in the system, oil degradation, and ecological recovery. This relationship has been described convincingly by several authors, including E.H. Owens (1978) and E. Gundlach et al. (1978). Quantitatively, the largest oil catastrophes have all occurred in areas of high energy, for instance, Metula 1974 (Straughan, 1977), Santa Barbara 1969 (Straughan, 1971), Torrey Canyon 1967 (Southward and

Southward, 1978), Monte Urquiola 1976 (Wennergren, personal communication), and Amoco Cadiz 1978 (Hess, 1978). The recuperative ability of communities in the affected coastal areas is surprising. The smaller spills in protected environments, such as Florida 1969 in Buzzards Bay, Massachusetts (Sanders, 1978), often have the stronger locally acute as well as long-term effects. Well documented examples of this principle exist for isolated parts of a system, such as salt marshes (Krebs and Burns, 1977; Baker et al., 1977) and sediments in areas with low water-exchange rates (Mayo et al., 1978; Teal et al., 1978). In such areas, the aromatic hydrocarbon compounds have been shown to be most persistent (Vandermeulen and Gordon, 1976).

The Irini study suggested, quite logically, that an important relationship exists between recovery rate and the proximity of source areas for re-colonization. This implies that the areal extent and patchiness of defaunation are also important factors in determining the rate of recovery. Spill studies to date have not shed much light on this aspect.

3.2 Discussion of results and major conclusions

In the supra-littoral zone, faunal and floral surveys were carried out about 8 months after the accident. In general these studies showed no obvious remaining effects either on the invertebrate fauna of the beaches or on the various land plant species along the shores. These results, at least with respect to the flora, are in accordance with the findings in other studies (e.g. Baker, 1971). It is interesting to note that the only remaining damage in this area had obviously been caused during the clean-up operations (for example, deep wheel-tracks from dump trucks). One important factor in explaining the absence of effects in the supra-littoral zone might be that the oil spill occurred at a season characterized by extremely low standing stocks and production rates of animals and plants in the system.

The studies of the impact of the oil on the littoral zone indicates substantial acute damage to all macrofauna species of the Fucus belt.

Based on field observations by divers, the disappearance of the Fucus belt macrofauna was due to death and/or narcosis. Along the shores of Torö and parts of Lisö, mass mortality occurred among littoral crustaceans. After 12 months, considerable recovery had taken place, presumably through immigration of amphipods and isopods from refuge areas. Isopods of the genus Iaera were, however, an exception. In several places, no recovery at all of Iaera could be observed. This could probably be explained by the fact that these animals are extremely thigmotactic, and are never found swimming in the free water. The recovery process of the littoral zone faunal composition was one of both migration and multiplication of surviving individuals. The gammarids were, for instance, totally lacking at a contaminated station in November. In June, they showed high abundance in all belts, but only 8% of the samples contained adult individuals (corresponding frequency for reference stations was 75-80%). The isopods Idothea remained in the area in low frequency in November, but reproduced in June and were subsequently found in higher frequency, especially in the Cladophora belt.

The molluscs of the littoral zone do not appear to have suffered drastic mortality. Instead, bivalves and gastropods seem to have re-entered the algal zones after some time of immobilization on the bottom.

Even if the recovery of the littoral fauna is incomplete, the results obtained so far would indicate that a complete recovery of all fauna representatives can be predicted within 2 to 3 years. In addition to results of the Tsesis investigations, this statement is supported by the findings of Notini (1978) when studying the recovery of an oil polluted bay in the Stockholm archipelago. Here, the recovery took 3 to 4 years after the spill, which occurred under much the same conditions as the Tsesis spill.

The metabolism studies of the Fucus community did not reveal any definite effects on community metabolism in the affected area. This may have been due to the considerable variation of the background values.

Comprehensive studies on the long-term effects of oil in littoral communities indicate that the damage can be very great and can persist for prolonged periods of time. The thorough work of Southward and Southward (1978) on the effects of the Torrey Canyon oil spill of 1967 shows that serious effects, manifested as absence of several faunal species and abnormal and excessive growth of algae, were evident even after 8 years. After 10 years, the situation was still not normal with respect to the diversity of fauna. Evidence from Baja California during the wreck of the Tampico Maru indicates that species were still absent and the balance of the littoral community was not restored 16 years after the accident (North, 1973).

The most important differences between these spills and the Tsesis spill, with respect to the effects in the littoral zone, are mainly results of the quantity and composition of the spilled oil and the technique used during the clean-up operations. The observations after the Torrey Canyon spill indicate that the longest lasting effects could be observed at the heavily oiled rocks, which received repeated applications of toxic dispersants (Southward and Southward, 1978). The severe effects during the wreck of the Tampico Maru were caused by the large amounts of highly toxic diesel oil (North, 1973). Also, at the Tsesis site, the biological effects of the spill were minimized by low biological activity and low temperature and by the decision not to use oil dispersants. The oil spill happened at the start of a season with low activity in the littoral zone. The low temperature and ice cover in January and February minimized plant and animal activity, and many individuals died in accordance with the natural seasonal pattern. During these 3 to 4 months of low activity, before the spring growth started, some of the remaining oil in the littoral zone may have been washed out, and the toxic fractions may have been diluted. Thus, the effect was less than it might have been if the oil spill had occurred in the beginning of the growing season in April, May or June.

The accumulation of petroleum hydrocarbons in littoral bivalves (Mytilus) is a very rapid phenomenon. During large spills in coastal areas, bivalves frequently demonstrate such accumulation (Blumer et al.,

1970; Straughan, 1977; and others). The analysis of the tissues of blue mussels showed extremely high concentrations (up to 3% of fresh weight) of petroleum hydrocarbons to be present the first months after the spill. It is noteworthy that the Tsesis oil was found to be present in mussel tissues in the entire area of Svärdsfjärden. Thus the contaminated area was much larger than initially assumed, based on visual observations.

The depuration of oil from contaminated bivalves is a process governed by several factors, such as size of the initial spill, composition of the oil, the temperature, filtration rates and filtration behavior and physiological state of the animal (Fossato and Canzonier, 1976; DiSalvo et al., 1975; Stegeman, 1974; Stegeman and Teal, 1973). Studies have shown that acutely acquired petroleum is fairly rapidly released (Fossato and Canzonier, 1976; Anderson, 1975; Kanter, 1974; Lee et al., 1972; and others). In contrast, chronically accumulated hydrocarbons are retained for comparatively longer periods of time (Boehm and Quinn, 1978; DiSalvo and Guard, 1975).

The Tsesis oil was released gradually, although perhaps not completely, from the Mytilus tissues, during the year following the spill. This agrees with observations after the West Falmouth oil spill, that shellfish from the spill area continued to show a fuel oil hydrocarbon pattern for several years (Blumer et al., 1970; Blumer and Sass, 1972; Teal and Farrington, 1976).

The pattern of depuration of the Tsesis oil from Mytilus indicated a somewhat more rapid release of the aliphatic fraction compared to the aromatic hydrocarbons. This is in general accordance with the findings of Blumer et al. (1970) and Stegeman and Teal (1973). In general, the chemical analysis of oil in blue mussels has proven to be a good measure of the extent of the littoral insult resulting from the Tsesis spill.

Weathered Tsesis oil sedimented to the bottom in quantity within days after the spill, as shown by sediment trap data. These together with the oil analysis of Macoma balthica from a number of stations, show that the exposed area was much larger than originally suspected, including areas which were considered clean by visual inspection or biological sampling. The extent of the area where visible slicks were observed is

clearly not a reliable indicator of the total area affected. Within this affected area (shown by oil analysis), benthic macrofauna community responses varied from a slight and temporary decrease in abundance of motile species, especially Pontoporeia femorata, to a drastic and lasting reduction in amphipods (Pontoporeia affinis and P. femorata). The disappearance was possibly caused by emigration from the contaminated area, since very few dead specimens were found. In laboratory experiments, Pontoporeia affinis has been shown to actively avoid oil contaminated sediments. However, even at the most affected station, the sedentary macrofauna species remained with no observed increases in mortality. The few remaining gravid amphipods showed a statistically significant increase in the number of abnormal eggs at the most affected station.

Of the meiofauna, all taxonomic groups except the nematodes showed abnormally low abundance at the most affected station and there was evidence of greatly increased mortality of ostracods following the spill.

As late as August and September the following year, 10 months after the spill occurred, there was still no sign of recovery of the affected groups of macro- and meiofauna. The oil content of Macoma balthica, which had initially shown some decrease, increased again in August to values even higher than the highest recorded earlier, one month after the spill. Whether this increase is a real increase due to a new influx of oil, presumably mobilized from shallower sediments, or just an expression of considerable patchiness in the oil distribution, is uncertain. It supports the hypothesis that the breakdown of oil in such sediments is very slow, and that a prolonged period may be needed for full recovery.

Because of the long life-cycle (two years) and non-migrating behavior of ostracods, the effects of the oil on the soft bottoms will remain for at least two years. Most other meiofauna groups have a much shorter life-cycle and can recolonize the bottoms shortly after the oil is degraded. The amphipods, P. affinis and P. femorata have a more mobile lifestyle and are expected to invade the area very quickly after the oil is degraded.

The pelagic study covered only the acute phase of the spill, essentially the first month after the grounding. Valid oil concentration results were obtained from only two water column samples during this period. These two samples suggested concentrations of around 60 µg/l of micro-dispersed oil droplets under a weathered and fully emulsified part of the Tsesis oil slick. The phytoplankton biomass generally increased in the affected area, but it could not be shown whether this was due to increased growth rates or to decreased zooplankton grazing. Correspondingly, primary production was elevated. Phytoplankton species composition showed little change. Zooplankton were found to be heavily contaminated (internally and externally) by oil (50% of the specimens were visibly contaminated with oil droplets in the first week, 20% after three weeks); although no reduction was found in the standing stock, either for zooplankton or ciliates, except in the immediate vicinity of the ship. Bacterial abundance increased in the spill area, but here, too, it was inconclusive as to whether this was due to decreased grazing pressure or to increased growth rates.

The most interesting result of the pelagic study was the high oil content (up to 0.7%) found in sediment trap material during the first two weeks after the spill. This was true also for sediment traps deployed in an area windward of the tanker, where no oil slicks were ever observed and which had been thought to be little affected by the spill. Within a week the oil in the sediment traps was significantly altered by weathering. The minimum extent of the impacted area can be estimated to be 42 km^2 from oil analysis of sedimented material and of Mytilus and Macoma. By extrapolating from the sediment trap data it is possible to give a minimum estimate of 19 tons of oil reaching the sediment. An amount of 40 tons, which is not unlikely, would be 10% of the estimated total amount remaining after oil recovery operations had ceased.

One month after the spill all parameters measured in the pelagic system were essentially normal (phytoplankton, zooplankton, bacteria, oil content of sedimenting material). This indicates the relatively short duration of oil impact from a moderate spill in the pelagic system. Acute effects on the fish could not be demonstrated.

The fish species occurring in the area show both local and long distance migrations. Pelagic species (herring, sprat, cod, etc.) show the longest migrations. Littoral species and demersal fish from deep soft bottoms show local migrations (Westin, unpubl.). These are seasonal and largely a change of biotope. Thus the season governs the composition of the fish fauna in any given biotope.

The largest fish concentrations during the season of the Tsesis spill occurred in the pelagic system, where large concentrations of herring are normally found in the general area of the spill (Aneer et al., 1978). However, echosounding surveys in the area failed to demonstrate avoidance behavior by the herring and analyses showed no oil contamination of locally caught herring.

Possible effects of oil on the local fish fauna are thus likely to be mainly indirect, long-term, and difficult to detect. The impoverished littoral and benthic fauna in the impacted area obviously results in decreased food availability. The oil contamination of bivalves such as Mytilus edulis and Macoma balthica is likely to cause oil contamination of fish utilizing these food items (e.g. the flounder, Platichtys flesus, which preys on Macoma in this area). The most important effect of the spill on fish is likely to be found in species or life stages that are subject to long-term exposure.

The herring in the Askö area spawn on exposed, fairly shallow bottoms, and an investigation of the main June spawning, half a year after the spill, showed both lower frequency of spawning and lower hatching rate in the spill area, but not a significant increase in the number of malformed larvae. The oil spill is not, however, the only possible explanation for these results.

3.3 Recommendations for spill research contingency plans

The people involved in the Tsesis oil spill investigation have made a number of observations which may help in working out contingency research plans. These are:

1. The pelagic system: The most important finding in the pelagic study was the sedimentation of oil. Thus, sediment traps should be a standard instrument in the study of the environmental impact of oil spills, wherever their deployment and retrieval are physically possible. With deployment sooner (within 1-2 days after the spill) and a larger number of traps, it would have been possible to make a much better estimate of the amount of oil reaching the benthos--a measurement of crucial importance in estimating the extent and duration of the impact of oil on the ecosystem (also see section 1.6).

Another crucial measurement in the pelagic zone is the composition and concentration of oil in the water column. Where such measurements can be made and tied to other observations, for example, the presence of oil droplets in association with zooplankton (Chapter 4), important information on the mechanism of oil transport through the water column can be produced. Due to the problems of sampling, however, it is not yet practicable to survey large areas of the water for hydrocarbon analysis in a way that is statistically adequate. If a proper sampler can be devised (see section 1.6), its use will be of greatest value in conjunction with plankton, bacteria, littoral, and sedimentation studies to establish level of exposure as a basis for interpreting other phenomena.

The study of plankton showed increases in bacterial and phytoplankton biomass, but it failed to elucidate the mechanism behind the increase. Higher sampling frequency, especially at the reference stations, might have helped, as might more "frequency of dividing cells" (FDC), measurements of bacterial growth rates. Clearly defined bacterial composition studies would certainly improve the assumption that bacterial increases are due to oleophilic species. Perhaps an equally important experiment would be to analyze the feeding rate of zooplankton from the area. This might demonstrate whether oil reaches the benthos mostly after ingestion by zooplankton and incorporation into fecal pellets or by direct adsorption to detrital and mineral seston particles, which then sediment. The relation between dispersed particles, suspended sediments, and zooplankton feeding behavior should be investigated thoroughly.

The greatest single problem in the pelagic studies was the accurate prediction of the natural variability to be encountered and a subsequent statistical design that would adequately remove this mask. For example, the FDC measurements provide a good example of when significant differences may indeed have existed between polluted and reference stations, but sample frequency was too low to detect it. It is true that very often field logistics may preclude a truely adequate statistical design; in such cases it would be advisable to evaluate whether or not a lesser effort will produce any usable results. Conducting fewer experiments with better statistical designs may be more advantageous. These comments also apply to areas other than the pelagic zone. Statistical design for field experiments is thoroughly discussed in a recent work by Moore and McLaughlin (1978).

In most oil spills, direct impact on the pelagic system will be of short duration (less than a month). The most important measurements in the pelagic zone, therefore, will be those helping to define its importance as a medium that transports oil to other less resilient systems, such as the benthos or the littoral zone. However, this is not meant to understate the importance of effects on pelagic larvae and other plankton, which might be of long term or trophic significance depending on the circumstances of the spill.

2. The littoral system: The net-bag method for sampling in the Fucus belt has proven to be an efficient method of surveying the effects on the littoral macrofauna. Studies of the effect of oil on littoral and supra-littoral communities, particularly on plants, are warranted as a means of evaluating the damage caused by the spill. These zones are especially sensitive to various methods of cleanup, and so studies should be included which assess the effectiveness or additional damage of cleanup methods.

In situ (e.g., suspended) bio-assays were not attempted during the Tsesis study, although they have been recommended at times (MITRE, 1978). It is believed that in cases where direct studies of organisms in place are possible, such as Tsesis, fewer doubts are inherent than with bio-assays; thus studies of the existing system should be considered first. Furthermore, when samples and transects can be done

post-spill but pre-exposure, as was done after the Tsesis grounding, the study is of course, most ideal. This requires rapid response and accurate trajectory predictions.

3. The deep soft bottoms: Since the Tsesis study showed that oil can reach the benthos within days, immediate sampling is necessary as an indication of pre-spill conditions (see section 1.6). The amphipods and the ostracods, both crustacean groups, were especially sensitive to oil. The amphipods probably emigrated from the affected area, while most of the ostracods probably died. Repeated sampling soon after the spill would be necessary to confirm such conclusions.

The oil analysis proved invaluable in the interpretation of the biological responses, and for this the sediment trap data and the Macoma balthica samples were particularly useful. Macoma have been suggested as ideal indicators of oil pollution and the Tsesis study supports this idea. The most reliable indicator of the insult was the contamination of Macoma by oil. The second most reliable were changes in macro- and meiofauna community composition. Whereas Macoma are well suited for registering an oil insult to the area, other species are far more sensitive for registering ecological effects. Therefore, a well balanced (ideally holistic) study of the macro- and meiofauna is required to give a totally accurate picture.

The oil distribution seems to have been quite patchy, and at least a rough mapping of the affected area would have been highly desirable. It may not be feasible, however, to perform such a mapping in a statistically reliable way. For this reason, the importance of patchiness and possible "refugia" is difficult to study, although it is likely that recovery rates depend strongly on the proximity of source areas for recolonization. Areal extent of the affected area can be established by sampling a grid of stations, taking one sample per station. Such a survey would require expensive analyses, but would, perhaps, permit greater economy in later analyses by identifying the most desirable sites for the more detailed studies. The location of areas of poor degradation should receive attention as possible reservoirs for pollutants.

The benthic zone in general, from the standpoint of damage and recovery, seems to merit much greater attention in future oil spill studies than it has characteristically received in the past.

4. The fish fauna: The seasonal influence on the migratory behavior of the fish makes the effects of an oil spill dependent on the season of the year. Adult fish can possibly avoid high concentrations of oil; therefore, the greatest effects are to be expected largely in those earliest life stages that are subjected to prolonged oil exposure.

Most fish species of economic importance along the Baltic coast spawn in the spring and early summer. An oil spill just before or during this period will have a maximal effect on reproduction. Investigations during this period should be concentrated on spring-spawning herring, where differences in hatching success are relatively easy to investigate. During other seasons, effects should be sought primarily in species with slow roe development and/or spawning on deeper soft bottoms, where oil effects probably persist for a longer period of time. Also, the accumulation of oil in food animals, especially on deep soft bottoms, may result in bioaccumulation in fish feeding on those food items. This should be studied in connection with future spills.

No acute fish mortality was observed following the spill. A large mortality of small fish (probably gobies) in the littoral was, however, observed about a month after the spill by local residents. This implies that observations of fish should cover a longer period than the acute phase of the spill.

5. Integration of disciplines and studies: It is absolutely necessary to have high caliber analytical chemistry available on an interactive basis with the biological studies. Samples in the Tsesis investigation were collected and preserved from the beginning, with attention to minimizing extraneous contamination or introduction of other ambiguities, to preserve the integrity of the samples for later analysis. The storage of samples in anticipation of the funding for their analysis proved to be an excellent investment. The chemistry eventually showed the nature of the insult, which was necessary to properly interpret biological effects.

However, chemical analysis alone is not sufficient. Chemistry by itself can indicate levels of insult, but the high cost of analysis necessitates the establishment of analytical priorities. When biological studies are conducted, highest analytical priority must be given to those samples which can best elucidate observed biological phenomena. In the Tsesis investigation, having the biologists perform sampling for chemical analysis worked well. Instructing biologists on specific chemical sampling procedures to avoid contamination or other ambiquities was not a problem, and this seems to be the best way to ensure that the chemistry and biology are fully integrated in time, location, and purpose. Although it is not a serious disadvantage to have a large set of samples to choose from, the analysis of samples carefully chosen to support a specific study appears to be more cost effective than a broad survey approach where time and space correlations with the biological sampling are hard to ensure. It seems that, even though chemical analysis is essential, the biology program should dictate the priorities.

If the biology program cannot be complete (due to circumstances, logistics, or other reasons) it should at least be as cohesive as possible. Many conclusions of the Tsesis investigation required supporting results from a number of studies. This requires careful planning.

6. Implementation: Spills do not usually occur in convenient locations. The problems of responding to an accidental spill in most cases, Tsesis excepted, necessitate a quick responding investigative team to assess the situation and select appropriate follow-up studies (see section 1.6). In the case of local contingency research plans in high risk areas (such as the Södertälje shipping channel), details of the study can be laid out in advance and the study narrowed according to the events of the spill. For less pre-studied areas or for readiness in general, it is necessary to lay out a flexible scientific capability. The initial investigation (quick response) will have to include some method for rapidly learning the important aspects of the environment unluckily chosen by the spill, and then determining the parameters that are most important to measure in that case. A plan that is flexible enough to fit a variety of situations, but rigid enough to comply with practised and proven methods, is the ultimate goal.

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4. Impact of Oil on the Pelagic Ecosystem

CHAPTER 4: IMPACT OF OIL ON THE PELAGIC ECOSYSTEM

(Sif Johansson)

4.1 Introduction

Hardly any study has verified severe oil-induced effects on the pelagic ecosystem following an actual spill (Sanborn 1977, Michael 1977, Kühnhold 1978). Existing knowledge is derived mostly from laboratory experiments using unrealistically high concentrations of oil. In such experiments, phytoplankton clearly react in a very diverse manner. Even within the same taxonomic group two species can react in a totally opposite manner (Prouse et al., 1976; Winters et al., 1976; Dennington et al., 1975; Mironov, 1968; and others). Depending on the composition and physiological status of the phytoplankton community and the type of oil used, primary productivity can be inhibited, stimulated or affected not at all when exposed to realistic concentrations (H'siao et al., 1978; Bender et al., 1977; Gordon and Prouse, 1973).

Comparatively few investigations have dealt with effects on primary production, biomass and species composition at the same time. In large plastic bag (CEPEX) experiments, Lee et al. (1977) found that the relative dominance of a diatom Cerataulina bergonii, had decreased from 50-95% in control bags, to only 10% in oil contaminated bags in 8 days. The decrease was followed by an increase of microflagellates and, despite a lowered total biomass, primary production increased. This was explained to be a result of higher growth rate among microflagellates.

Conover (1971) following the wreck of the Arrow reported oil contaminated zooplankton in situ. Droplets of oil had been ingested or adhered to the feeding appendages. Though as much as 10% of the total oil spill was estimated to be associated with zooplankton, no apparent effects could be detected. Parker and Watson (1969) observed ingestion of oil by zooplankton, both experimentally and in situ and also found no harmful effects.

Lee et al. (1977) in enclosed experiments showed oil-induced minor alterations, i.e., an increased abundance of ciliates and rotifers. A

lower growth rate for copepods was also indicated, but the total standing stock remained unchanged.

4.2 Material and methods

4.2.1 Sampling stations

Two stations in the spill area (IV and V, see map, Fig. 4.1) were selected for intense monitoring during the month following the spill.

The area in which station IV was located was directly exposed to surface oil slicks only once, when a minor slick, which had been released from the tanker on removal from the area on November 3, drifted quickly by. In the area northeast of the grounding site, at station V, large oil slicks occurred during the first week after the accident. Even at the end of the investigation period minor oil slicks were seen drifting in this area.

Immediately after the grounding, zooplankton net hauls were taken at a station close to the grounding site (station II). Bacteria were also sampled once at stations II and III (October 31).

Two stations, I and VI, enclosing the spill area, are regularly sampled by the Askö Laboratory. The research programmes include all parameters sampled in the spill area and thus data from these stations could be utilized for reference. Lack of resources limited the sampling, which unfortunately hampered statistical analysis of the results.

The salinity in the impacted area varied between 6.6 and 7.0 ^{o}/oo S in the surface water and between 6.6 and 7.9 ^{o}/oo S at 20 m depth. The temperature in the water gradually decreased, from 8.4^{o}C to 6.4^{o}C at the surface and from 8.4^{o}C to 6.9^{o}C at 20 m depth, from November 1 to November 17.

4.2.2 Methods

4.2.2.1 Phytoplankton

Phytoplankton were collected with a plastic tube 20 m long, carefully avoiding surface oil films. All samples were preserved with Lugol's solution containing acetic acid. Phytoplankton were counted

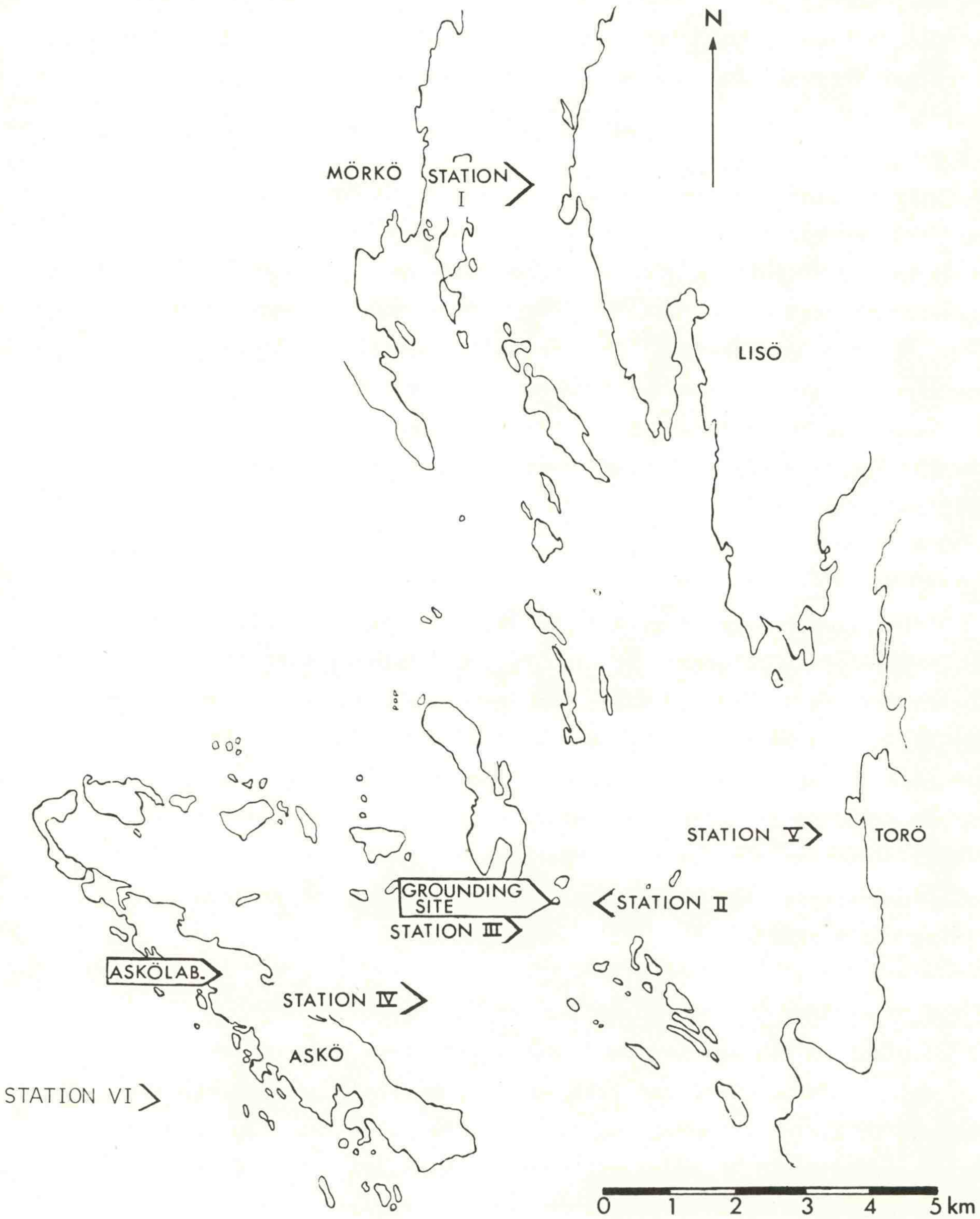


Fig. 4.1 Position of stations II, III, IV, V and the reference stations I and VI.

using the Utermöhl (1958) technique. Small cells (<10 µm), with 1-4 flagellas, belonging to Chrysophycea, Cryptophycea and Chlorophycea we e counted collectively and are referred to as monads.

4.2.2.2 Primary production

Water samples were collected, while carefully avoiding surface oil films, and incubated for four hours at 0, 1, 2, 4, 6, 8, 10, 15, and 20 m depth. Dark bottles were incubated at 0 and 20 m depth. Measurements were carried out as described by Larsson and Hagström (1979). Four µCi of carrier free $NaH^{14}CO_3$ were added to all bottles. After incubation, 10 ml of the samples were transferred to scintillation vials, and counted in Instagel (Packard Instruments) in an Intertechnique SL 40 liquid scintillation counter. The uptake of carbon was calculated according to Gargas (1975).

4.2.2.3 Bacteria

Bacteria were sampled at a depth of 2 m using a sterile Niskin water sampler. At reference station VI the number of bacteria was determined in an integrated water sample (equal aliquots of water from 0, 5, 10, 15 and 20 m were pooled - a standard procedure in the routine programmes at these stations (see Hagström et al., 1979). The bacteria were preserved in formaldehyde containing acridine orange and counted in an epifluorescence microscope, as described by Hagström et al. (1979). They also described the method used for determining the frequency of dividing cells (FDC).

4.2.2.4 Zooplankton

Zooplankton was sampled by vertical net hauls from bottom to surface, using a UNESCO WP-2 net with 90 µm mesh size. Special efforts were made to avoid contamination from surface oil films. The samples were preserved in 4% formaldehyde buffered with hexamine. Counting and species determination were performed using an inverted microscope.

4.2.2.5 Sedimentation

Sediment traps, a PVC cross with 20 cylindrical glass tubes (Ø 26 mm, length 200 mm), were positioned at a depth of 20 m. The sedimented matter was divided in two parts; one was used for determination of dry weight and the other was transferred to a glass jar (cleaned with hexane) and stored deep frozen until analysed for oil.

4.3 Results

4.3.1 Phytoplankton

4.3.1.1 Phytoplankton biomass

At both reference stations, total phytoplankton biomass remained fairly constant, around 600 mg C m^{-2}, throughout the period (Fig. 4.2). In the impacted area phytoplankton biomasses were mostly more than a factor of two higher in the two weeks following the spill, but gradually decreased and approached the level at the reference stations by the end of November. There is no significant difference between the two stations (IV and V) in the impacted area ($p = 0.32$, rank sum test according to Dixon and Massey 1969:345), but valid statistical comparisons between the impacted area and the reference stations cannot be made, due to the long time spread and few measurements at the latter stations (see Fig. 4.3).

4.3.1.2 Phytoplankton species composition

At all stations monads constituted 75 to 90% of the total biomass and diatoms 10 to 15% (dominating species: Coscinodiscus granii and Skeletonema costatum) throughout the investigated month. The remaining few percent were peridineans (Gymnodinium sp. and Gyrodinium sp.). A few species belonging to Cyanophycea and Chlorophycea were also present, but their contribution never exceeded one percent. This is not an abnormal phytoplankton composition for autumn in this area (Hobro, in press).

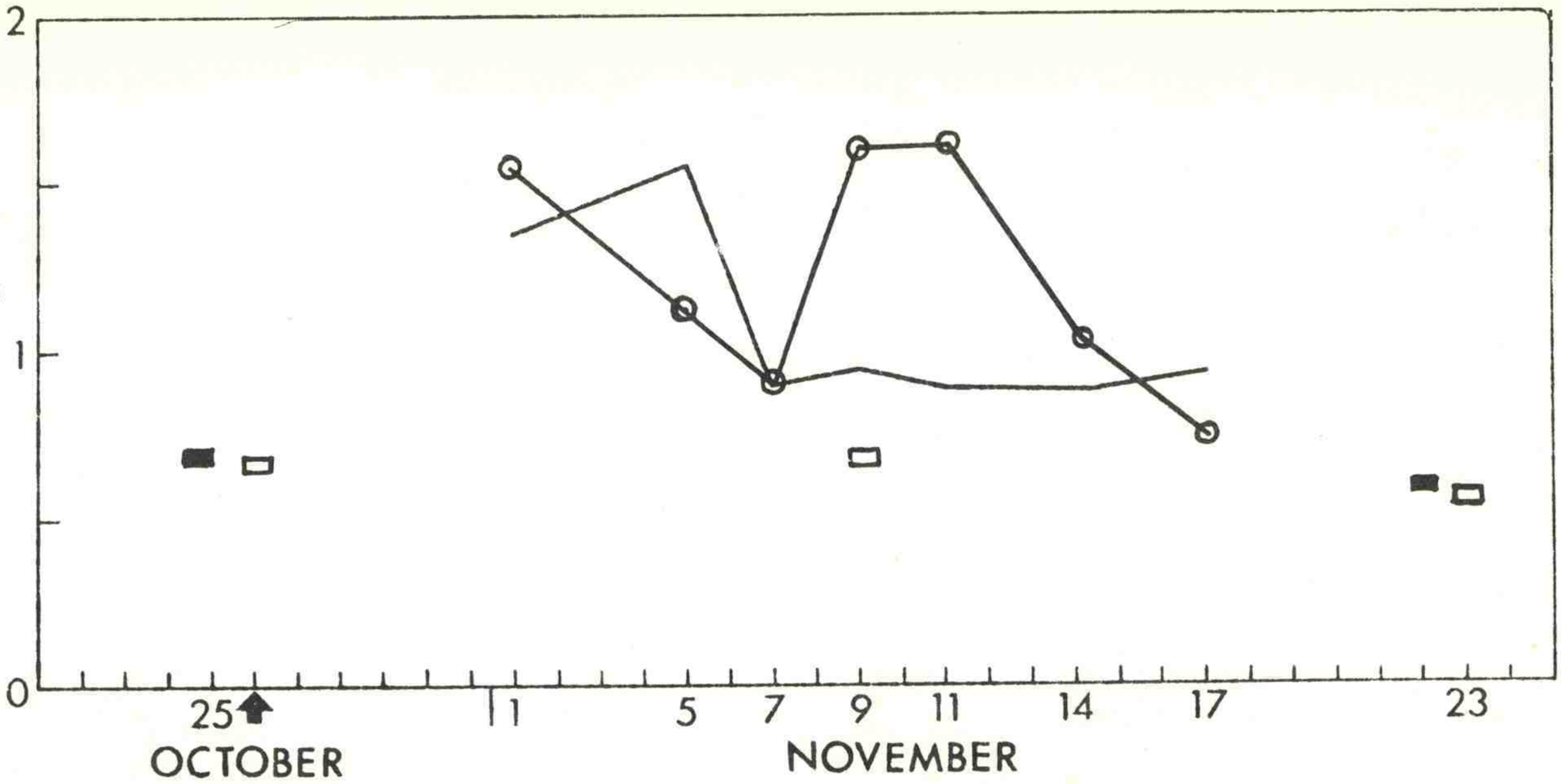


Fig. 4.2 Phytoplankton biomass, gC m^{-2}, at stations IV (—), V (o—o) and the reference stations VI (▭) and I (▬). Date of grounding is marked with an arrow.

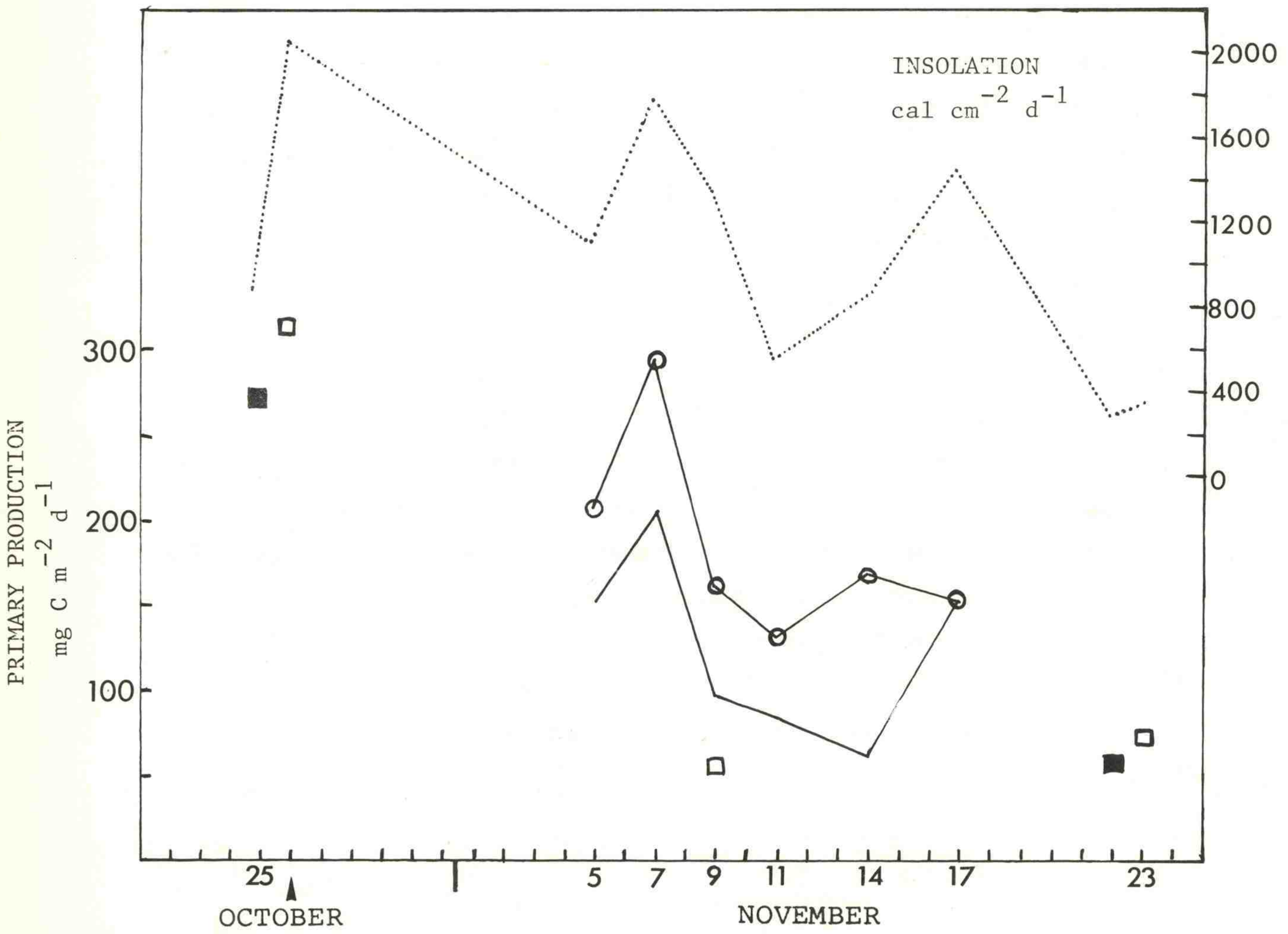


Fig. 4.3 Primary production, mg C m^{-2} d^{-1}, at stations IV (—), V (o—o), and reference stations VI (▭) and I (▬). Insolation values (dotted line) are scaled at the right. Date of grounding is marked with an arrow.

4.3.2 Primary production

The reference stations showed the normal autumnal decrease in primary production, compared to unpublished Askö Laboratory data from six previous years, with values at the end of November only one fourth of those at the end of October (Fig. 4.3). The primary production in the impacted area tended to be higher compared to values from the reference stations. Fluctuations were induced by changing light conditions, (dotted line in Fig. 4.3), as indicated by the rather clear correlation (linear regression, $r = 0.45$, $N = 17$, all stations combined) between insolation and primary production per biomass (Fig. 4.3 and 4.4). Station V in the most contaminated area, normally had higher primary production than station IV, and the difference borders on statistical significance ($p = 0.06$, sign test, Dixon and Massey, 1969: 335-340).

4.3.3 Bacteria

The total number of bacteria was higher at the contaminated stations than at the reference stations (Fig. 4.5). Five days after the grounding there were about three times as many bacteria at stations II and III (1.15×10^6 ml^{-1}) compared to station VI (0.35×10^6 ml^{-1}). In November, the difference was a factor of about two. Hagström et al. (1979) reported the standard deviation of bacterial counts to be 9 ± 4%, which supports the reality of the observed differences. The difference in sampling strategy is unlikely to influence the results markedly, since bacteria are rather uniformly distributed in the water column during this time of the year (Hagström et al., 1979). In a comparison with data from the same time of year from both station VI (1977 and 1978) and two stations (1977) in the more eutrophicated area north of station I, the bacterial counts from the oiled area stand out as unusually high (Hagström et al., 1979; Larsson and Hagström, pers. comm.).

The measurements of the frequency of dividing cells (FDC) showed no clear differences between stations (Table 4.1).

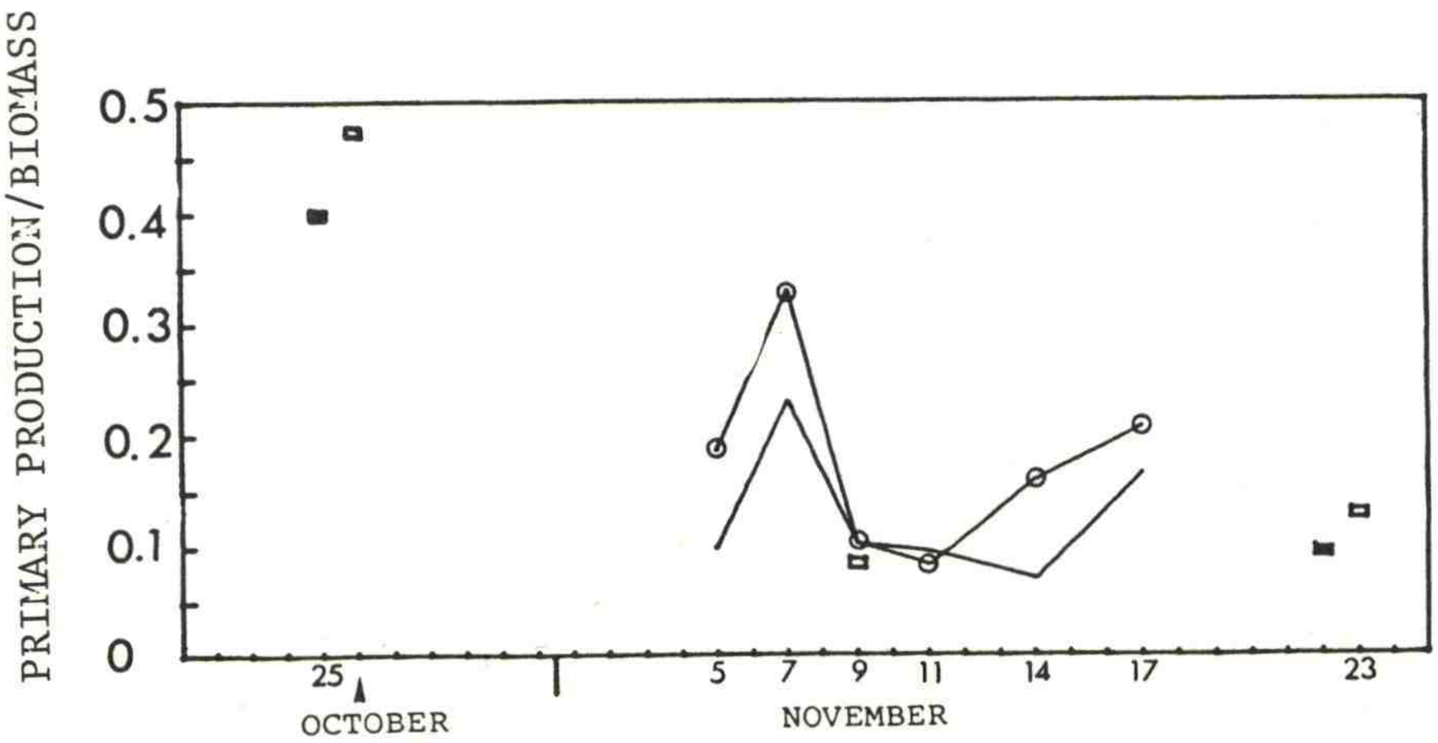


Fig. 4.4 The production per unit of biomass at stations IV (—), V (o—o), and reference stations VI (⊏⊐) and I (▬). Date of grounding is marked with an arrow.

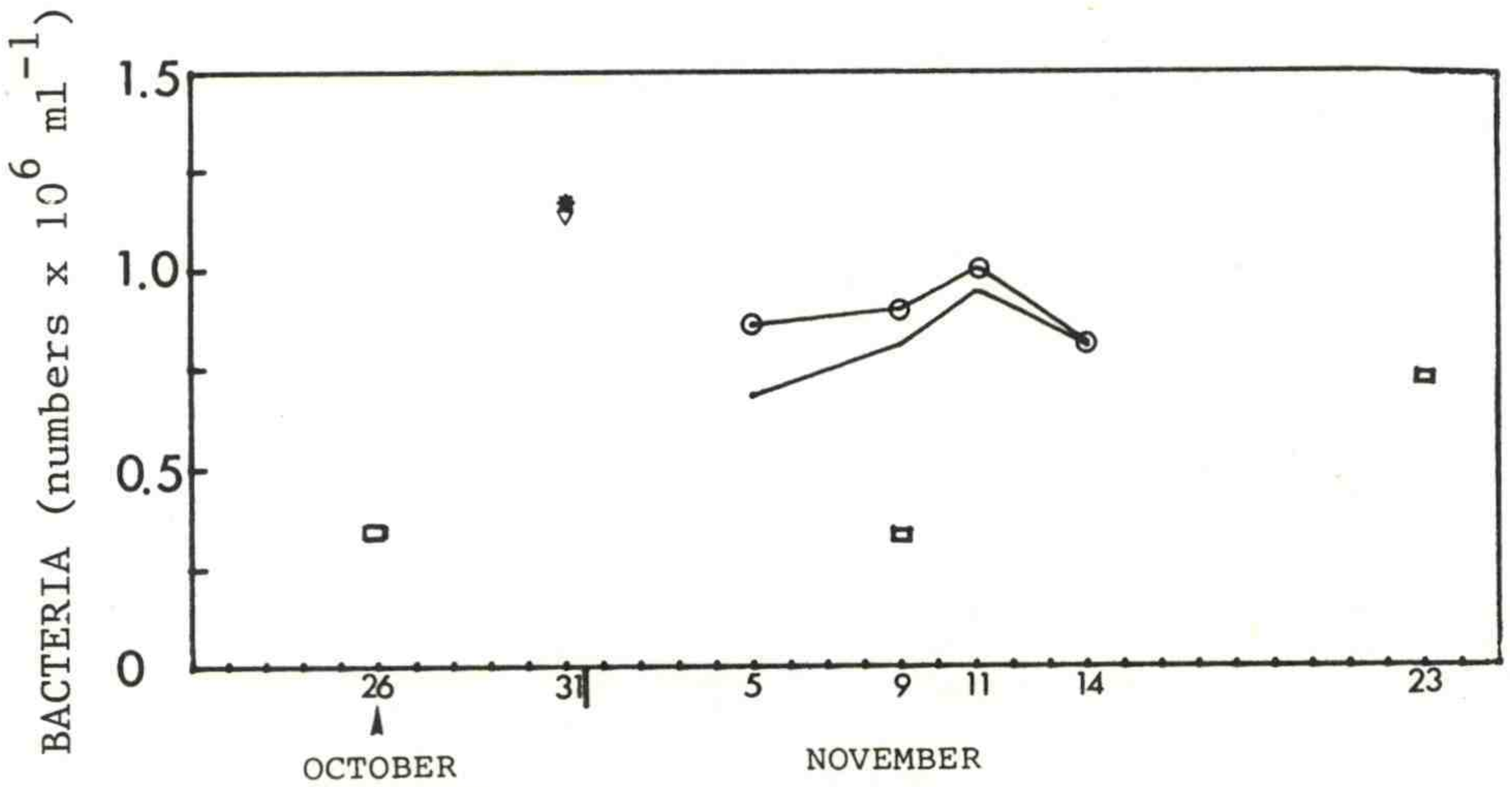


Fig. 4.5 Bacteria, numbers x $10^6 ml^{-1}$, at stations IV(—), V (o—o), II (•), III (▽) and at reference station VI (⊏⊐). Date of grounding is marked with an arrow.

Table 4.1 Frequency of dividing bacterial cells (FDC)

Date	FDC%				
	reference	oil stations			
	VI	II	III	IV	V
Oct. 26	2.3				
31		1.8	1.7		
Nov. 5				1.7	2.2
9	2.2			1.9	3.3
11				1.8	1.8
14				1.6	2.0
23	1.0				
mean	1.83			1.75	2.32
S.D.	0.72			0.13	0.67

mean of polluted area (II-V)	2.04
S.D.	0.54

4.3.4 Zooplankton

The ciliate biomass showed no consistent differences between the stations (Fig. 4.6). The net zooplankton biomass (Fig. 4.7) did not diverge from the reference stations, except very near the tanker (station II) in the days immediately following the spill. The zooplankton community was mainly composed of copepods (Acartia spp., Eurytemora sp. and Temora longicornis) and rotifers (mainly from the genus Synchaeta). No changes in the genus or species composition or in the developmental stages of copepods could be found.

The zooplankton was found to be contaminated with oil droplets. Oil was mostly observed adhering to the furca or the feeding appendages but was also found in the gut. Approximately 50% of the net zooplankton was contaminated during the first weeks after the grounding. After three weeks about 20% were still contaminated.

4.3.5 Sedimentation

The amount of sedimented matter in the impacted area is shown in Table 4.2, and was relatively high during the first weeks after the spill, 6-9 g dry weight $m^{-2}d^{-1}$. From mid-November on, rates were decidedly lower, 3-4 g dry weight $m^{-2}d^{-1}$. At reference station VI, rates were somewhat lower at the beginning of November but higher at the end of the investigation period.

Calculations based on the results from the oil analysis shown in Table 4.2, Fig. 4.8, show the amount of oil sedimented per square meter per day. The high amount of oil found in sedimented matter also at station IV, located more than 2.5 km upwind of the tanker, is notable.

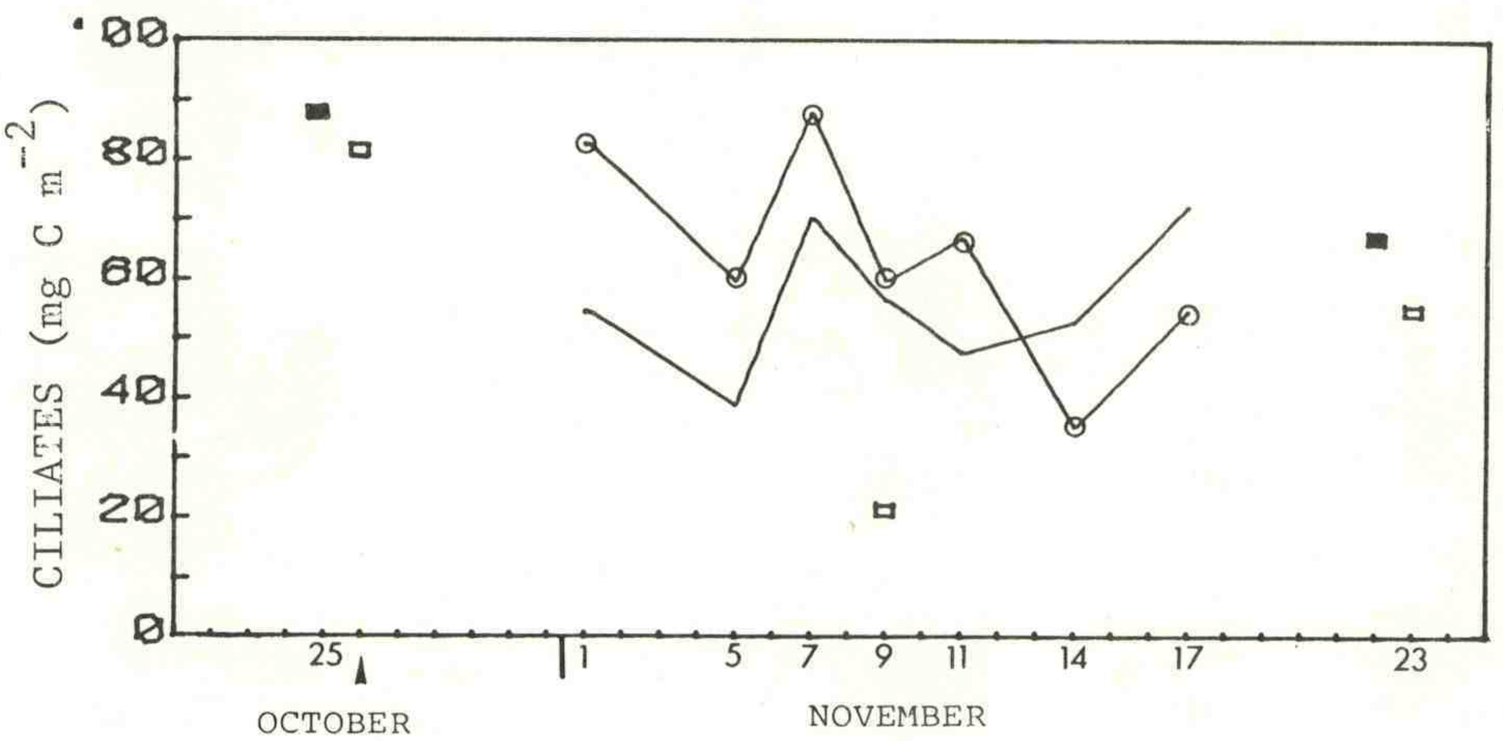


Fig. 4.6 Ciliate biomass, mg C m^{-2}, at stations IV (—·), V (o—o), and reference stations VI (▭) and I (▬). Date of grounding is marked with an arrow.

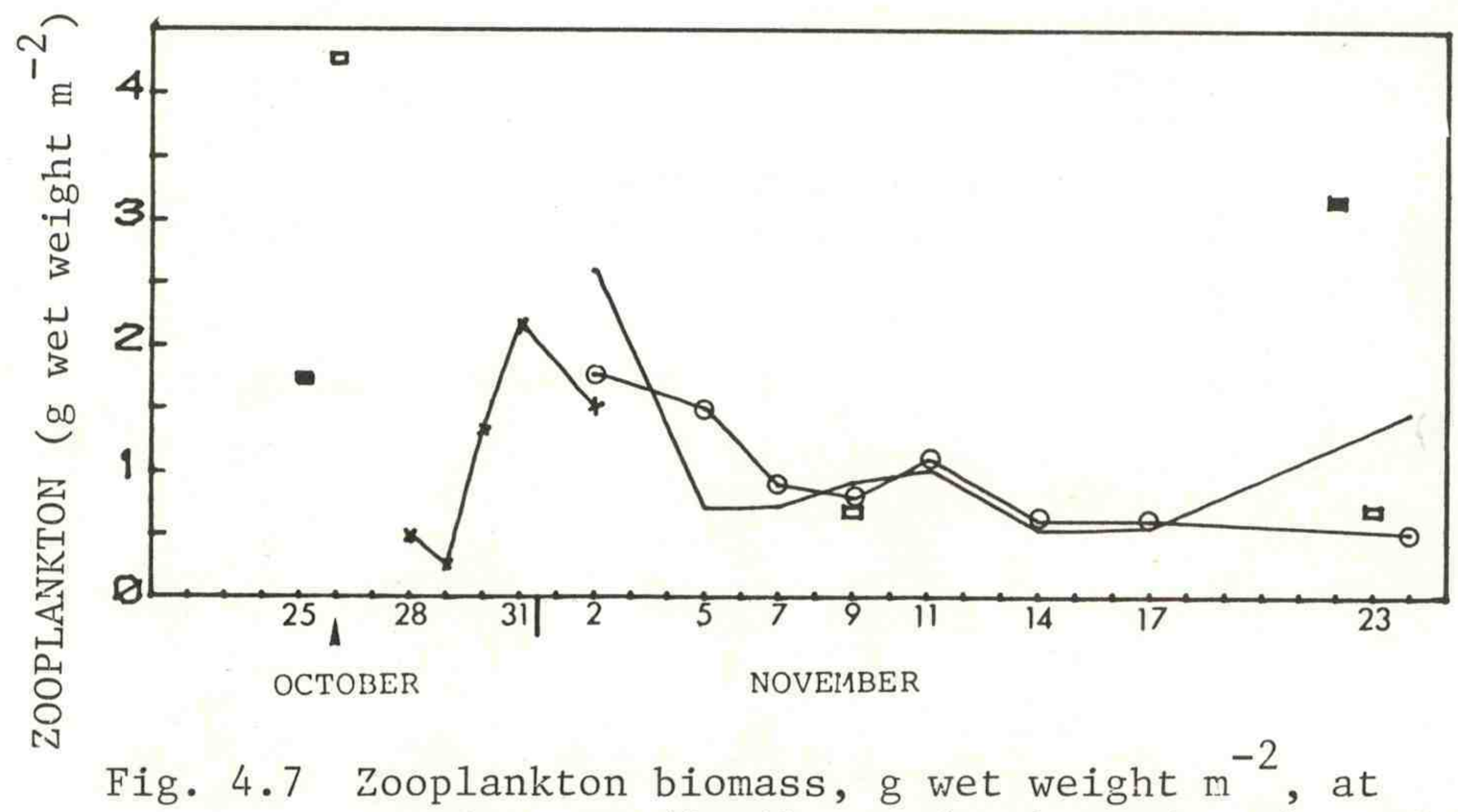


Fig. 4.7 Zooplankton biomass, g wet weight m^{-2}, at stations II (*—*), IV (——), V (o—o), and reference stations VI (▭) and I (▬). Date of grounding is marked with an arrow.

Table 4.2 Amount of oil in dry weight of sedimented matter, and total amounts of sedimented oil per square metre (per day and per period)

Station	Period	Sed. matter g dry wt $m^{-2}d^{-1}$	Conc. of oil $\mu g\ g^{-1}$ dry wt of sed.(x)	Sed. oil mg $m^{-2}d^{-1}$	Sed. oil mg m^{-2} $period^{-1}$
V	Nov. 1 - Nov. 9	8.6	7,265	62.5	500
	Nov. 9 - Nov. 17	5.7	2,073	11.8	94
	Nov. 17 - Dec. 14	3.9	843	3.3	89
II	Nov. 2 - Nov. 9	-	4,779	(38.0)(xx)	(266)(xx)
	Nov. 9 - Nov. 17	6.6	2,816	18.6	149
	Nov. 17 - Dec. 21	2.9	189	0.5	17
IV	Nov. 2 - Nov. 9	7.3	3,939	28.7	201
	Nov. 9 - Nov. 17	9.1	63	0.6	5
	Nov. 17 - Dec. 21	2.0	104	0.2	7

(x) From chapter 11.

(xx) Data on amount of sedimented matter missing. Amount of sedimented oil is calculated using the mean value at stations IV and V.

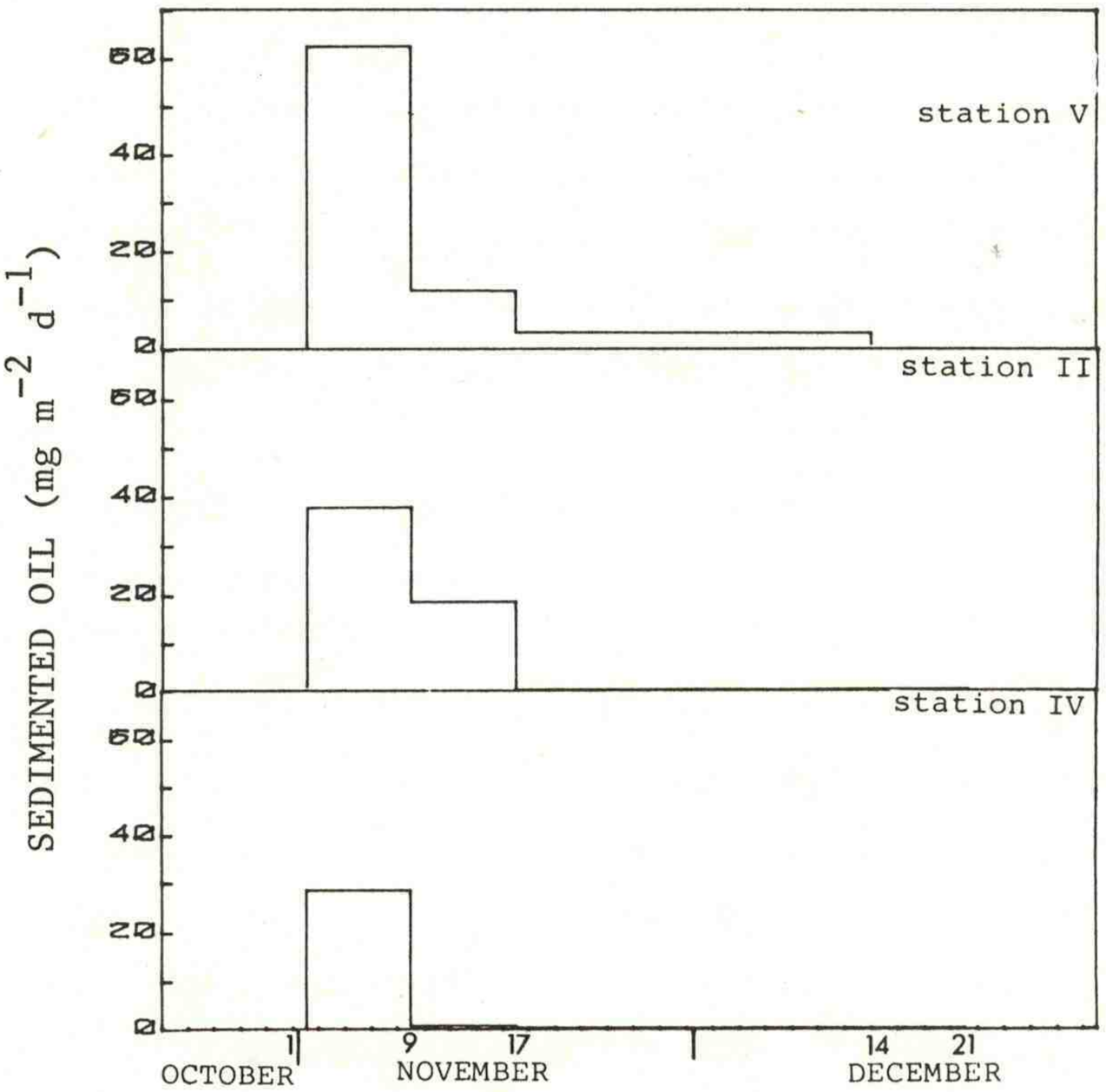


Fig. 4.8 Sedimented amount of oil, mg m^{-2} d^{-1} at stations V, II and IV.
Calculated as explained in Table 4.2.

4.4 Discussion

The pelagic system is first to suffer from an oil spill. Depending on local geography, distance from shores, windstress, etc., the exposure of the pelagic system to oil will change over a period of time. Soon after release from the tanker the oil starts to change both chemically and physically, e.g., volatile fractions evaporate and soluble fractions enter the water phase. The rate of this process decreases rapidly with time. Combined with a continuous dilution this weathering will limit the period of detectable ecological effects.

The results from this study show only minor effects on the pelagic system. Changes in species composition could not be detected either in the phytoplankton or the zooplankton community. The phytoplankton biomass almost certainly increased in the affected area. This may have been due to decreased zooplankton grazing or increased growth rate. The existing data on productivity per unit biomass indicated a normal ratio, and the fact that zooplankton was found to be heavily contaminated with oil (50% of specimens with visible oil droplets in the first week, 20% after three weeks), mainly on the feeding appendages, makes decreased zooplankton grazing the more probable explanation. Similar results were found after the blow-out on the Ekofisk Bravo platform (Lännergren, 1978).

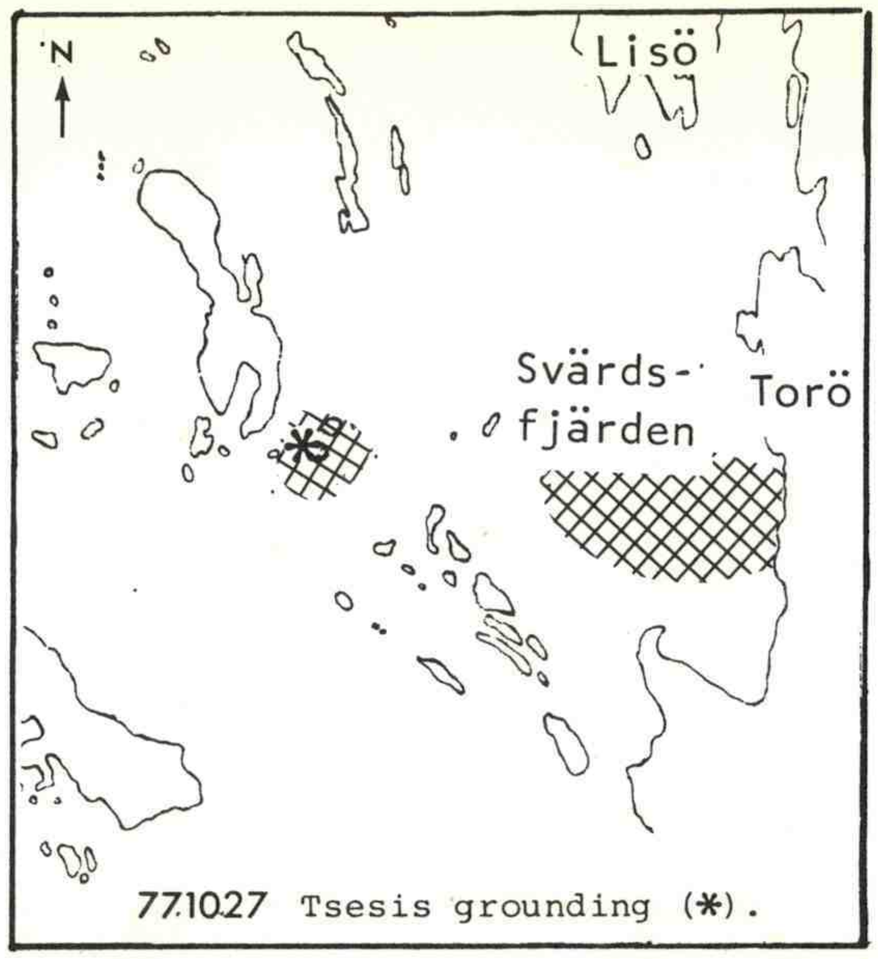
No significant differences in zooplankton composition or biomass could be detected, except at station II immediately after the spill, when two measurements from separate days (Oct. 28 and 29) showed a drastically lowered biomass. Gyllenberg and Lundqvist (1976) have shown that zooplankton, when exposed to oil, either try to escape or enter a state of "narcosis". Either of these mechanisms could explain the very low biomasses near the wreck.

Bacterial abundance increased in the contaminated area. It is however, impossible to judge whether this was a consequence of increased growth rate or decreased grazing. An effort was made to estimate bacterial growth rate from the frequencey of dividing cells (Table 4.1), but no clear differences were found between polluted and unpolluted areas.

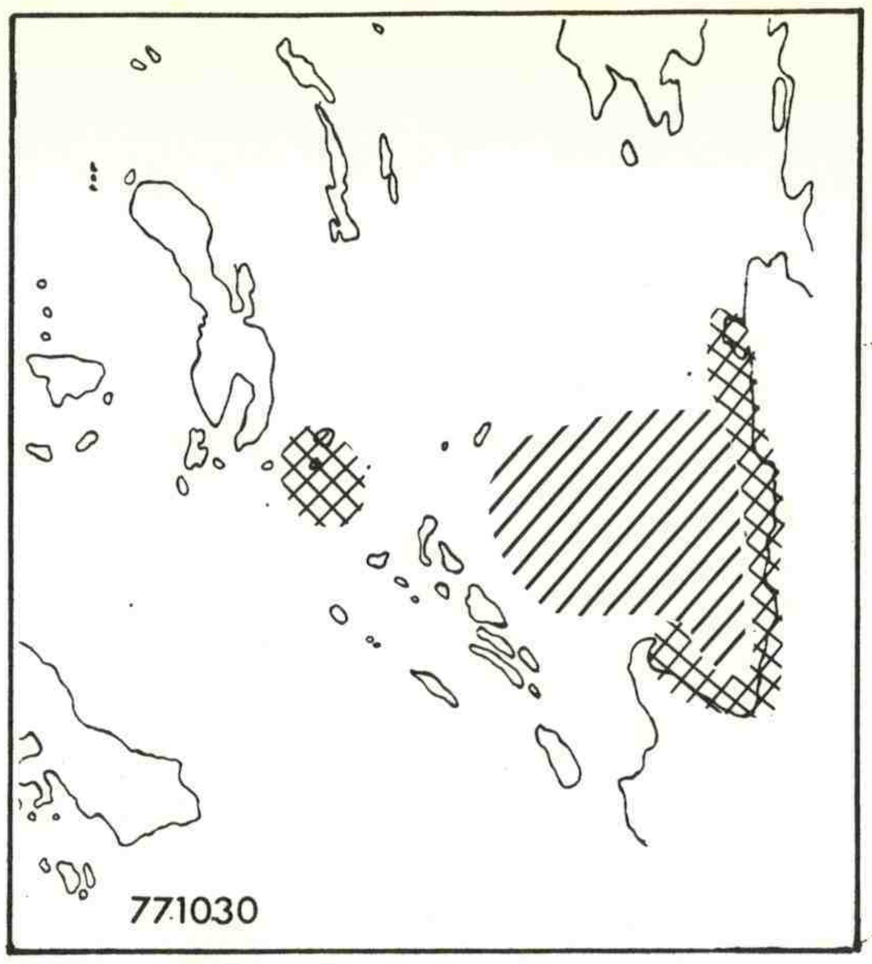
Perhaps the most interesting results from the pelagial study were obtained from the sediment traps. During the first period of sediment trapping (Nov. 1-9), very high amounts of oil (up to 0.7%) were recorded in the sedimented matter. This was also true for station IV situated about 2.5 km windward of the tanker. Unfortunately, no traps were positioned before November 1st, which leaves the period just after the spill, with potentially high sedimentation of oil, uncovered. This is likely to be a larger source of uncertainty in the following calculations, than the methodological uncertainties inherent in all attempts at measuring sedimentation. Between Nov. 9 and Nov. 17 there was still a substantial oil content in sedimented matter at stations II and V, whereas at station IV practically no oil was found. From Nov. 17 onward, oil was still found in sedimented matter from station V, probably as a consequence of release from the shores due to waves and cleaning operations.

Several mechanisms can facilitate sedimentation of oil, e.g., weathering of the oil leading to increased density, adsorption of oil to particles, or ingestion by zooplankton. Conover (1971) found oil incorporated in zooplankton fecal pellets, a mechanism which, through the relatively high sinking rates of fecal pellets, will accelerate sedimentation. In the present case it is, however, unlikely that zooplankton itself or the production of fecal pellets significantly contributed to the sedimentation of oil. At this time of year zooplankton biomasses are low, near the yearly minimum. A more probable path is sedimentation through adsorption to detritus particles, since seston levels in the area are normally high in the autumn, due to wind-induced re-suspension of bottom sediment. Only two days before grounding, the area was subject to fairly strong southwest winds. Wind speeds of up to 10-14 m/s also occurred several times during the acute phase of the spill.

The sediment trap data make it possible to estimate roughly the amount of oil leaving the water phase through sedimentation. The affected area has been estimated as the area inside a line connecting the outermost points where oil has been found, either through visual observation (Fig. 4.9) or by direct measurements of oil. A total area of 42 km^2



771027 Tsesis grounding (*).



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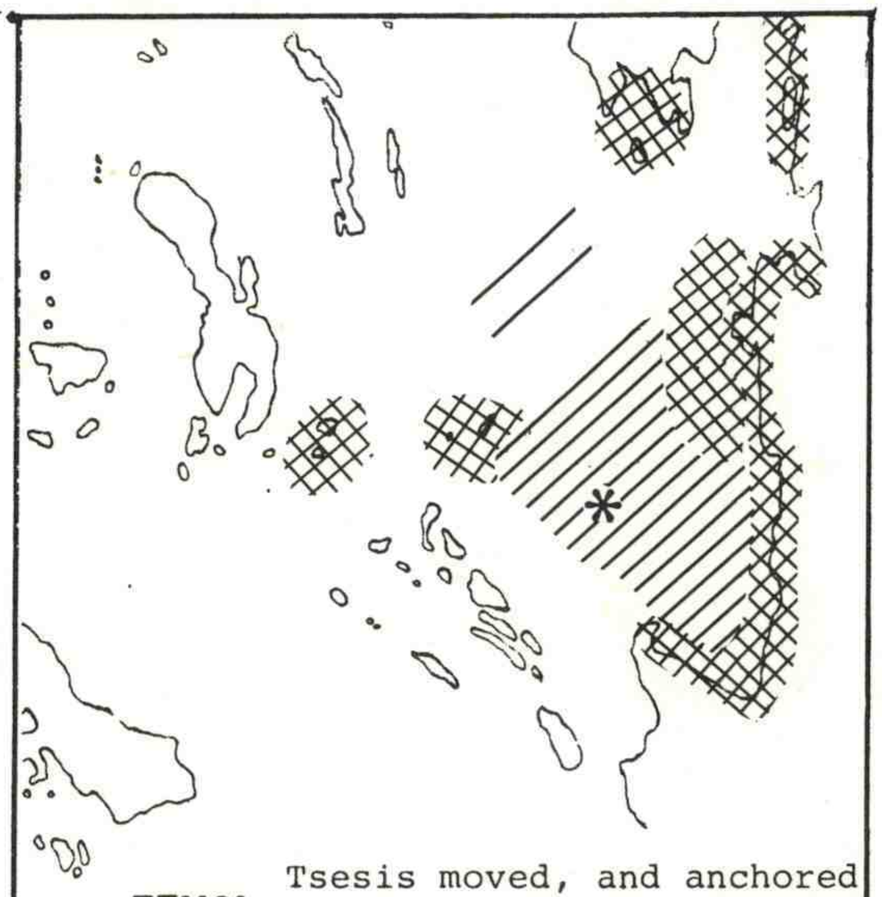
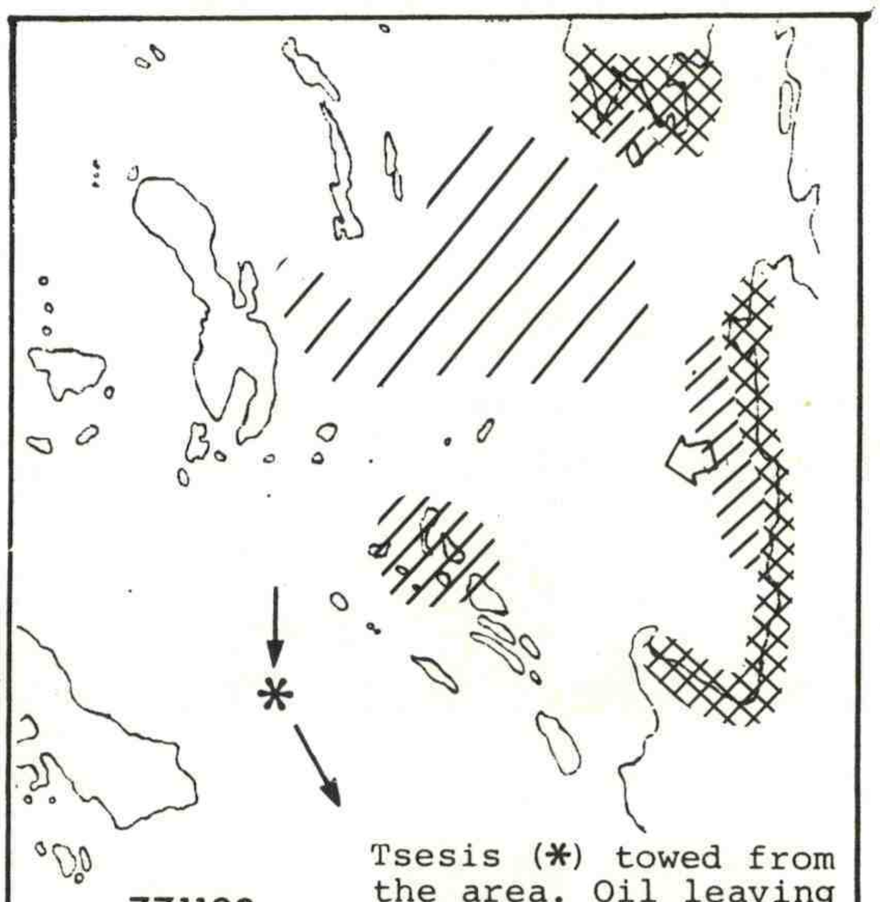
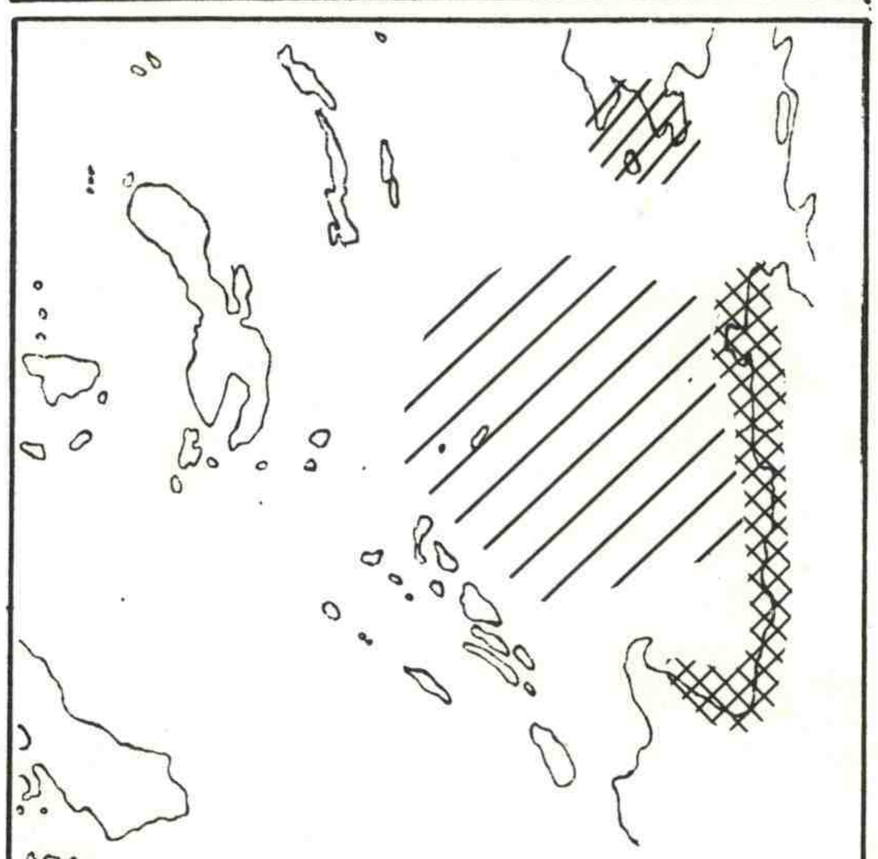


771101 Tsesis moved, and anchored in Svärdsfjärden (*).



771103 Tsesis (*) towed from the area. Oil leaving the shores.



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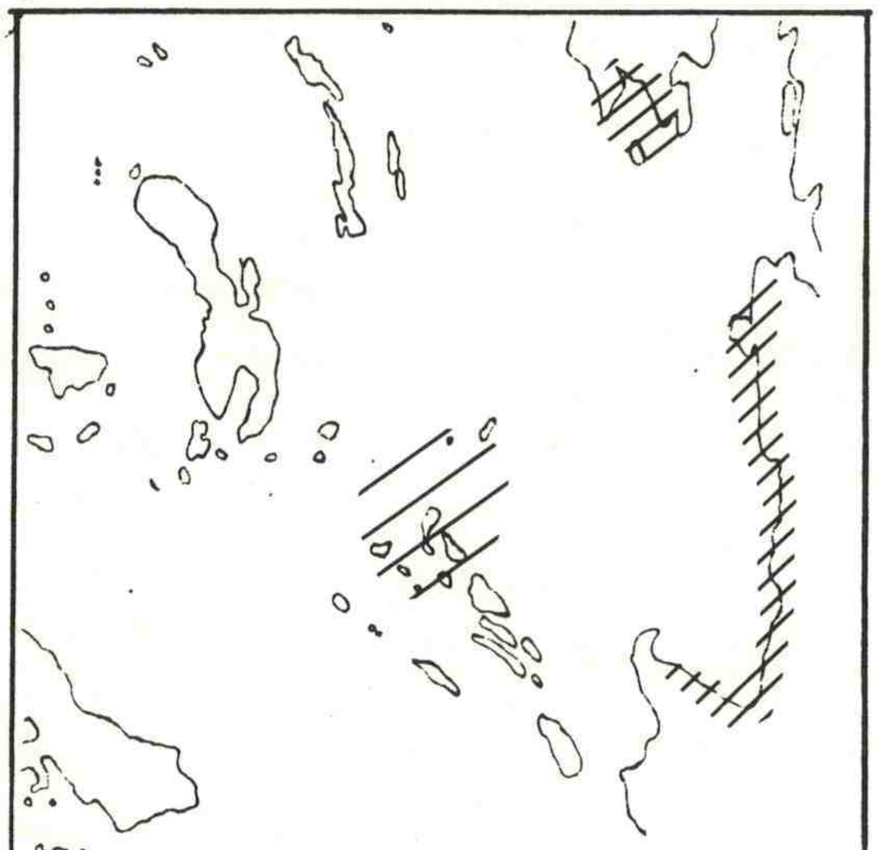

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0 1 2 3 4 5km

Fig. 4.9 Maps showing the extent of oil slicks, based on observations during field work.

⊠⊠⊠ heavy oil slick

//// unbroken oil film

/ / / bands of oil floating on the surface

was affected (see Fig. 4.10). Using this area and the data presented in Table 4.2, a total sedimentation of 19 tons of oil was calculated for the period November 1 to December 21. Most probably this value underestimates the sedimentation since: 1) No data exist for the five days immediately following the spill, probably the period with the highest sedimentation rates; and 2) the affected area is certainly underestimated, as not enough samples were taken for an adequate mapping. Thus the true sedimentation is likely to be considerably higher, possibly in the 30 to 60 ton range.

4.5 Conclusions

1. The effect on the pelagic system was moderate and of short duration - within one month all measured parameters were essentially normal.
2. Phytoplankton biomass increased in the contaminated area.
3. Bacterial numbers increased in the contaminated area.
4. Zooplankton were found to be heavily contaminated with oil.
5. Sedimentation of oil to the benthos was calculated to be at least 19 tons for an estimated affected area of 42 km^2 (both numbers are minimum estimates).

4.6 Acknowledgements

The advice and support of Ulf Larsson, Askö Laboratory, during the field work and the writing of this report are deeply appreciated and thanks are due him and Ruth Hobro for placing unpublished results from the Askö Laboratory's routine measurements from the reference stations (I and VI) at the author's disposal. Dr. Åke Hagström, Department of Microbiology, University of Umeå, provided practical help as well as advice, without which none of the bacterial data could have been obtained.

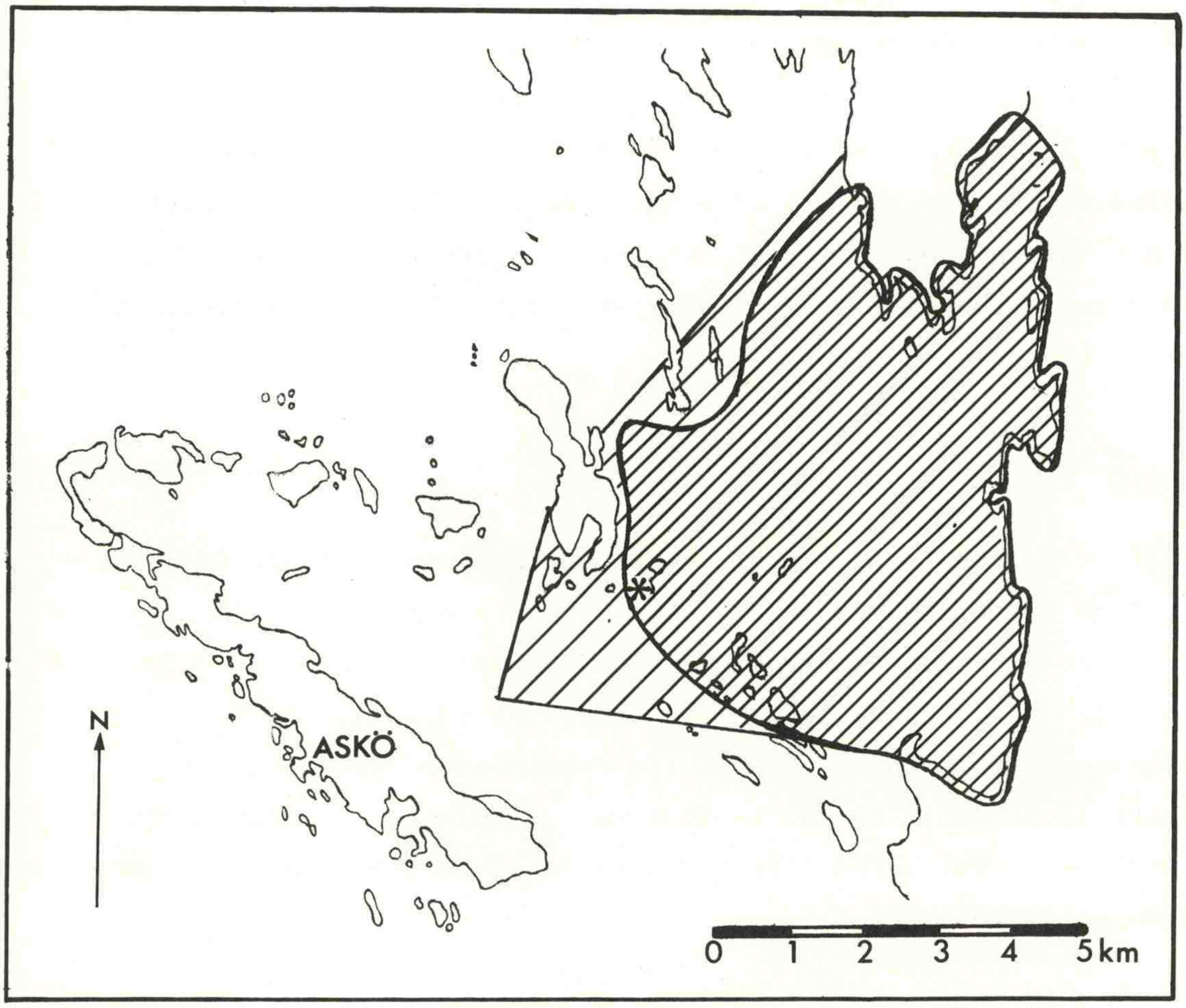

Fig. 4.10 The affected area, estimated to be 42 km^2. Area(///), in which oil was observed on the surface (see Fig. 4.9), estimated to be 34 km^2. Area (/ /) bounded by lines connecting stations where oil was analytically demonstrated (additional 8 km^2).

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5. NOAA Acute Phase Experiments on Pelagic and Surface Oil

CHAPTER 5: NOAA ACUTE PHASE EXPERIMENTS ON PELAGIC AND SURFACE OIL

(John Kineman, 5.1, 5.3-5.5; Robert C. Clark, Jr., 5.2)

The major events leading to the NOAA/OCSEAP Spilled Oil Research (SOR) Team response to the Tsesis incident have been mentioned in the Executive Summary. The present section describes the short-term phase activities of the U.S. team.

5.1 Experiment Design

Objectives were limited to investigating the accommodation of oil in the water column below a contained oil slick, and subsequent downstream decay. It was envisioned that this would require locating a significant quantity of pooled (or boomed) oil, then sampling the oil and the water at various depths and times to determine accommodation and composition over time.

Secondly, to determine downstream decay, the plan called for sampling at various depths in the water column, while following a parcel of water as a "Lagrangian" drift study. The original plan also called for determining currents, using sampling over a period of 8-12 hours (for each experiment) and extracting water samples in the field.

After arrival on-scene, and during the two days in the field, modifications were made to the original experiment design to adapt to existing conditions. The chemistry program that was carried out is outlined below:

A. Oil chemistry studies
   (1) Surface oil samples were taken for:
      a. estimation of the degree of emulsification
      b. estimation of the density of the free oil
      c. estimation of the asphaltic content based on the hexane insoluble residue

(2) Samples of the cargo oil were taken for:

a. analysis of chemical composition for reference to future samples and for weathering studies

b. determination of the physical chemistry of the oil

B. Water column studies

(1) Lagrangian drift samples (repetitive sampling of a dyed parcel of water) to determine dispersion of subsurface oil down-current from a contained surface slick.

(2) Eulerian sampling at biological stations established by the Swedish scientists, to determine concentrations at various times.

(3) Water column samples in an area known to have been heavily polluted and since blown clear of floating oil, to determine subsurface hydrocarbons remaining several days after the passage of a floating oil slick.

(4) Water column samples below a moving oil slick (emulsion) to determine waterborne hydrocarbons.

(5) Filtration of various samples to determine particle size distributions of accommodated oil under various conditions.

(6) Extraction of selected split samples with both hexane and $CC\ell_4$, to compare methodologies of UV-fluorescence.

C. Aerial mapping of visible floating oil, concurrent with sampling.

5.2 Hydrocarbon analysis associated with the Tsesis oil spill

During the NOAA team response, petroleum samples were collected, and duplicate sets were distributed to Energy Resources Company, Inc. (ERCO) and the Northwest and Alaska Fisheries Center (NWAFC). This section describes the analysis performed at the NWAFC (information from the ERCO set is reported in Chapter 11).

Although the water content of the mousse samples varied from 12% to 76% by volume (Table 5.2.1), the normal paraffin distribution of the water-free oil fraction of all three of the mousse samples was identical, within experimental accuracy, to the cargo sample (Table 5.2.2). The cargo sample had been collected after the oil had been off-loaded from the Tsesis and shipped to its original destination at Södertälje. The

Table 5.2.1

Mousse Samples Collected from the *Tsesis* Spill

Sample	Date Collected	Water Content(%) Analysis 11/2/77	12/20/77	C_n 90%(1)	C_n 50%(1)	Fractions by Gravimetry(%) Saturated	Unsaturated & aromatics	Insolubles	n-C_{14-37} by GLC (%)	n-C_{17} / pris	n-C_{16} ratio (2)	CPI(2) 14-20	20-36
Cargo Oil	11/4/77	-	1	9.8	11.8	50	45	5	8.4	1.8	7.5	1.1	0.96
Recovery Tank	10/27/77	18,18	12	9.9	11.9	48	44	8	8.9	1.9	7.8	1.1	0.94
Boom near *Tsesis*	10/31/77	76,76	75	10.9	12.6	52	45	3	8.9	2.0	7.5	1.1	0.96
Svärdsfjärden	11/1/77	72,73	67	10.8	12.6	42	40	18	7.5	2.0	7.2	0.96	1.00

(1) See Blumer et al., 1973.

(2) See Clark and Finley 1973.

Table 5.2.2

n-Paraffin Hydrocarbons in Tsesis Oil Samples (ppm, water-free whole oil)

Hydrocarbon	Cargo Oil	Recovery Tank	Tsesis Boom	Svärdsfjärden
10	278	8	115	44
11	4,480	6,060	1,540	602
12	7,480	8,100	5,020	6,120
13	13,800	14,000	10,100	10,200
14	15,000	16,000	14,300	13,200
15	14,100	15,300	14,400	11,500
16	11,300	11,400	11,900	10,500
17	9,610	10,300	10,700	7,520
pristane	5,230	5,360	5,770	3,720
18	6,570	7,490	7,980	6,160
phytane	4,820	5,260	5,330	4,890
19	5,950	6,100	6,560	5,810
20	4,660	4,470	4,670	4,520
21	3,040	3,370	3,330	3,050
22	2,960	3,130	3,190	2,670
23	1,970	3,000	2,270	1,880
24	1,660	1,860	1,950	1,570
25	1,520	1,420	1,630	1,280
26	1,410	1,350	1,410	1,240
27	851	922	880	813
28	660	728	787	677
29	818	788	812	798
30	534	690	649	587
31	215	302	352	260
32	182	158	200	163
33	265	238	184	191
34	369	400	342	344
35	618	446	595	503
36	127	218	205	161
37	60	73	27	76
Total hydrocarbons	120,000	128,000	117,000	101,000
$\underline{n}$-C_{14_37}	84,500	89,400	89,300	75,000
$\underline{n}$-C_{17}/background	4.0	4.0	3.9	4.0
$\underline{n}$-C_{28}/background	1.3	1.3	1.3	1.3
$\underline{n}$-C_{17}/pristane	1.8	1.9	2.0	2.0
$\underline{n}$-C_{18}/phytane	1.4	1.4	1.5	1.2
$\bar{C}_{n}$ 50%	11.8	11.9	12.6	12.6
Major hydrocarbon	14	14	15	14
%	12%	13%	12%	13%

mousse sample (Recovery Tank) containing 12-18% water, had been collected the second day of the spill from a barge tank after the oil had been vacuum-pumped from the sea surface inside a containment boom placed immediately adjacent to the grounded vessel. Residence time of the free oil was estimated by the Askö scientists to be on the order of minutes to perhaps as long as an hour.

The oil collected on the east side of Svärdsfjärden had been carried there by the wind and was estimated to have been exposed to weathering for at least three days. The sample from the boom near the grounded Tsesis may have been more intermediate in age due to its close proximity to the grounded vessel.

There appears to have been a slight degree of weathering of the n-paraffins below n-C_{18} in the oldest oil collected in Svärdsfjärden, although this evaporative loss was slight. For example, the equivalent n-paraffin carbon number where environmental losses of 50% are evident in the unresolved envelope under the n-alkane peaks (using the method of Blumer et al., 1973) shifted from 11.8 n-paraffin equivalent carbon numbers for the unweathered oil, to 12.6 for Svärdsfjärden oil. The saturated and unsaturated hydrocarbon contents of the oil in the boom near the vessel and the oil taken from the recovery tank were similar to the cargo oil, but the oil from Svärdsfjärden showed a marked decrease in both fractions with an apparent increase in material not recovered from the silica gel/alumina chromatography. This result suggested an increase in polar material in the Svärdsfjärden sample which had the longest time available for weathering. The plotted n-paraffin patterns show nearly identical shapes, though there is visual evidence for some possible loss below n-C_{18} in the more heavily weathered Svärdsfjärden slick mousse sample (Fig. 5.2.1).

5.3 Water samples with a sterile bag sampler

Details of the water column study (methods and results) are not reported here because the data were invalidated by a sample processing error. All water column sampling performed by the U.S. team was done using a Niskin sterile plastic bag, "Butterfly" sampler. This sampler

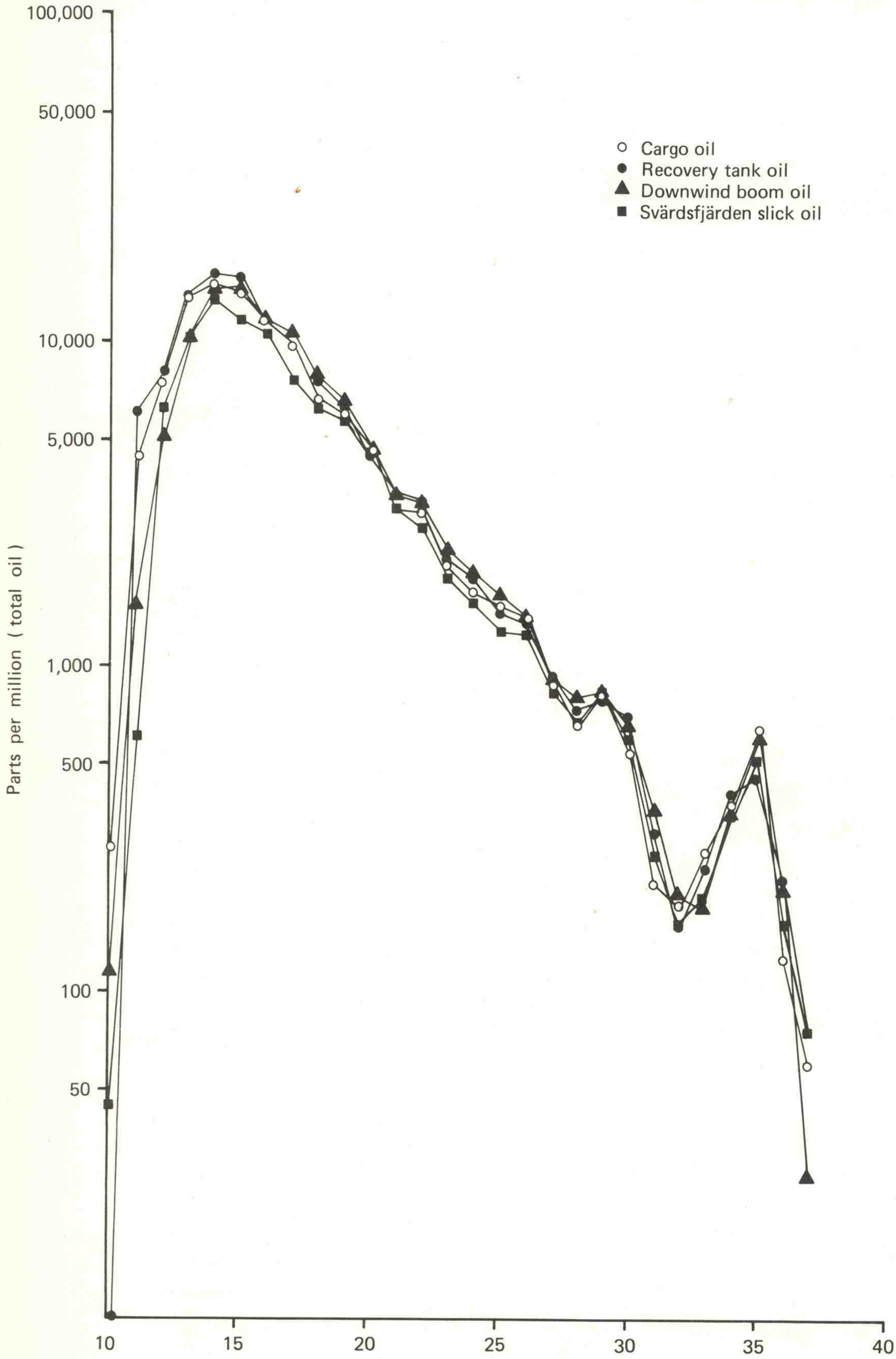

Fig. 5.2.1 Normal paraffin distribution of water-free oil fraction of three mousse samples and cargo oil.

has been used successfully in previous and subsequent oil spill investigations (e.g., Argo Merchant and Amoco Cadiz); however, in the Tsesis study, water samples were allowed to remain in the sample bags (albeit refrigerated) for times ranging from one day to one week. The analysis of the water sample extracts and subsequent chemical evaluation of the effect of the plastic bags, have been reported by Boehm and Feist (1977, 1978) under contract to OCSEAP. The major conclusions of this study were:

(1) Organic compounds begin leaching from the sample bags almost immediately, reaching levels of 50-100 µg/l well within 24 hours.

(2) Gas chromatography and fluorescence results confirm that losses of sampled hydrocarbons (water soluble fraction of the Tsesis cargo) occur after 15 minutes of interaction with the sampler, and are total after 36 hours.

(3) The Tsesis data set cannot be interpreted due to the effects of the polyethylene bags. The spectra of many Tsesis samples are identical to that of the bag leachate. Those few samples which exhibited spectra similar to Tsesis oil, "Type B", revealed only very low concentrations. Considering the effect of the plastic bag, this presence of hydrocarbons (other than bag leachates) in some samples, would be the probable result of either high initial concentrations in the environment or relatively short storage times.

It was unfortunate that SOR Team personnel also instructed Swedish scientists on the use of the plastic bag sampler, and encouraged those procedures over the use of glass jars in all water column sampling for hydrocarbon analysis. Later success using the plastic bag sampler at the site of the Amoco Cadiz spill is attributed to the immediate (within 2 minutes) transfer of the sample water to glass containers.

5.4 Water column data from two scuba-obtained glass jar samples

5.4.1 Results of Analysis:

Two samples obtained in glass jars by Mats Notini during the first few days of the Tsesis incident were analyzed as part of the above mentioned analytical work performed by ERCO. These were samples A-1 (1 meter depth) and A-2 (0.5 meter depth) taken on 11/1/77 at position D, in the enclosed bay at Lindholmen (see Fig. 7.1.1). Analysis (Boehm and Fiest, 1977) by UV-fluorescence indicated peak concentrations (at 310 nm) of 50.9 µg/l and 58.2 µg/l respectively. Both samples exhibited spectra, classified as type "B", similar to whole Tsesis oil. These two samples were not included in the first set that was selected for GC/MS analysis to identify compositional elements, and as this omission could not be corrected later, it was necessary to rely on the fluorescence spectra to infer that the contaminant was indeed Tsesis oil.

Comparing these spectra statistically (above 308 nm), the correlation coefficient between the water sample spectra and the whole oil spectra is about 0.97. The greatest differences, although slight, appear as lower concentrations of the lighter fractions.

5.4.2 Discussion:

The two glass jar samples provided the only valid water column hydrocarbon concentration data. This sampling was done underwater, thus avoiding some of the problems of through-the-slick contamination. There is little question that direct sampling underwater incurs the least chance for contamination if careful procedures are followed. Although statistically insufficient, the two samples seem reliable in themselves, and can be useful as indications if assumptions can be made about variability. Analytical variability (including the extraction precedures) can be determined from analysis of replicate extractions of the same sample. Differences between replicates of 2l samples ranged from 0 to 4 µg/l, implying good analytical and procedural control.

Environmental variability can not be determined from the plastic bag data. However, circumstances in the sample area (for the two glass jar samples) would lead one to expect a fair degree of homogeneity. The bay was small, enclosed, and shallow; the wind was directly into the entrance of the bay, therefore trapping the oil and providing an unchanging source (except for weathering). Also, the oil was in a stable, emulsified form, and mixing was low and uniform (no areas of high wave action or turbulence). There was time and the proper circumstances for factors to progress toward equilibrium. It is therefore consistent that, even with an hour between sampling times, the two concentration values were very close together.

If these numbers are to be useful, it is important to note the environmental conditions under which they were produced. The samples were taken in the afternoon of the day after oil had first reached the site. The trajectory of the oil can be inferred from observations of the time that oil reached various shores (section 1.2 and Fig. 4.9) and from wind data (currents were minimal and tides were absent, so that trajectories were primarily wind driven). As recorded by SOR Team personnel, on board the research vessel Aurelia, the wind on the day of sampling (11/1/77) was steady at 10 m/s from 165° T all morning. In the afternoon the wind increased to 12-14 m/s but did not change direction. Throughout the previous day (10/31/77) the wind was steady from 180° T at 10-15 m/s. With such winds, it was virtually impossible for the site to receive fresh oil from the Tsesis, but rather the oil was that which had previously blown against the rocky shores of Lisö Island. This deduction agrees with observations made by the Swedish scientists on 10/27, 10/30, and 11/1 (Fig. 4.9). Therefore, the oil had weathered between two and five days, traveled a total distance of about 10 km, and had been trapped for a while enroute, interacting with a rocky shore.

Surface oil chemistry data (section 5.2) indicates that the Tsesis oil emulsified very rapidly, and all oil samples taken away from the immediate vicinity of the ship were close to fully emulsified. It is therefore quite certain that the oil in the bay when Notini's samples were taken was "mousse" containing about 75% water.

At the time of sampling, swells were approximately 15-20 cm, developed over a short (7 km) fetch, and waves were estimated at 10-15 cm (SOR Team data). Mixing energy was thus low, so that one would not expect the mechanical entrainment of large droplets of oil.

The slight losses of the lower weight molecules indicated by the fluorescence spectra, is similar to Clark's observation of losses in the surface mousse (section 5.2); indicating that the surface mousse is the likely source of the water column contamination. The great compositional similarity of the water column contamination with this mousse (probably even greater than that shown for whole oil) indicates two possibilities: accidental contamination of the sample jar by surface mousse, or the presence of micro-dispersed oil in the water column (the water soluble fraction would not be similar to whole oil). Accidental contamination of the sample jars would be expected to result in highly variable concentrations. The nearly identical, low-level concentration values observed (one hour apart) would be an unlikely coincidence if resulting from accident, although additional data or more than two samples are needed to state this conclusively. Oil in micro-dispersed form, however, was also observed during this time period adhering to and being ingested by zooplankton (Chapter 4). The sedimentation trap results (Chapter 11) further suggest particulate oil in the water column.

5.4.3 Conclusion

It can be concluded that concentrations of Tsesis oil of 50 to 60 µg/l were observed by fluorescence at ½ and 1 m depths in low mixing energy conditions, below a captured slick which was fully emulsified and which had weathered for 2 to 5 days. This oil was most likely micro-dispersed particles from the surface mousse. The oil in the water column (as with the surface mousse) bore great similarity in composition with the cargo oil, except for slight losses of the lighter molecules. This similarity can be attributed to the rapid emulsification reported by Clark (section 5.2), which retarded evaporative losses and other forms of physical weathering.

5.5 Aerial mapping of visible floating oil

An aerial overflight was made on 11/1/77 by Dr. James Mattson, and the visible extent of surface oil was documented by photography using a Nikon 35 mm camera equipped with a time-recording data bank. The flight path and extent of surface oil are shown on Fig. 5.5.1. Some of the photographs appear in Appendix 2.

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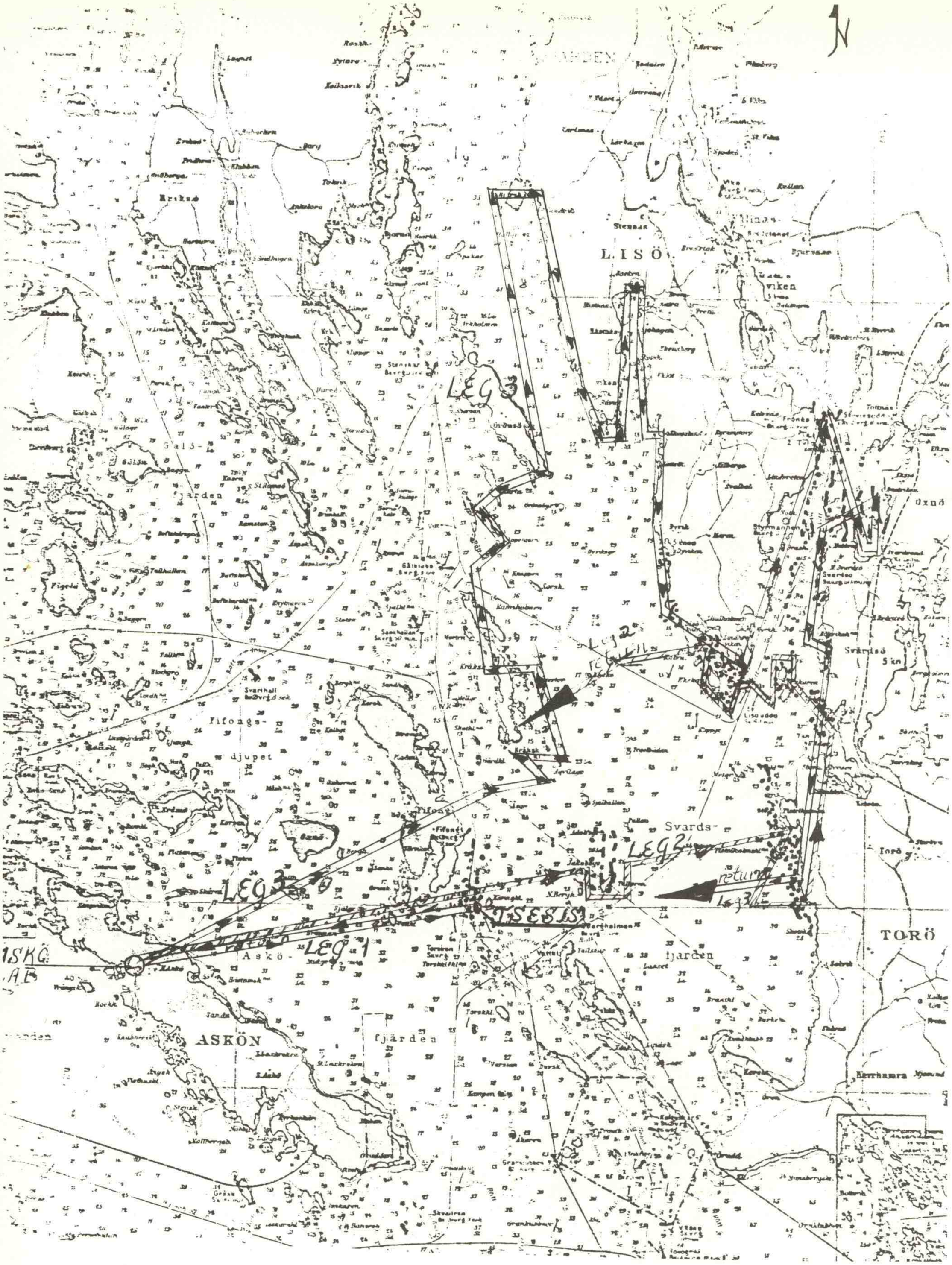

Figure 5.5.1 Aerial reconnaissance on November 1, 1979; wind from the south. Areas with heavy visible oil concentrations are indicated by dots. Light sheen is not indicated.

6. Impact of Oil on Deep Soft Bottoms

CHAPTER 6: IMPACT OF OIL ON DEEP SOFT BOTTOMS

(Ragnar Elmgren, Sture Hansson, Ulf Larsson and Brita Sundelin)

6.1 Introduction

6.1.1 Background

Since the Torrey Canyon catastrophe in 1967, millions of dollars have been invested in research on the biological effects of oil pollution of the seas. Innumerable scientific papers, summarized in many books and reviews (e.g. GESAMP 1977, McIntyre and Whittle 1977, Cowell 1977), have resulted. Most of these studies have, however, been concerned either with the surface layer of the sea, where plankton, fish and fish eggs as well as sea birds may be affected by a spill, or with the intertidal zone, where stranded oil may cause extensive destruction of the natural communities. Relatively little attention has been given to the effects of oil on subtidal benthos communities, even if a few good field studies exist (e.g., Addy et al., 1979; the West Falmouth oil spill study, Sanders, 1978). These few studies are all, however, concerned only with the benthic macrofauna, while the smaller meiofauna is totally ignored, even though its importance in energy flow terms is often similar to that of the macrofauna.

This general picture is also valid for the Baltic Sea. Furthermore the Baltic ecosystem has so many unique features, that the usefulness of studies from tidal and more fully marine areas for risk evaluation concerning various types of pollutants in the Baltic is questionable. Almost the only study of oil impact on a Baltic soft bottom community is that by Leppäkoski and Lindström (1978), and treats continuous oil pollution from a refinery, rather than an acute spill situation. The small study of the Palva spill by Mustonen and Tulkki (1972) should perhaps also be mentioned, even though it is rather inconclusive.

This comparative dearth of information is the more unfortunate, as studies from the intertidal zone show that recovery from an oil spill is slowest in fine sediment environments, where oil may persist virtually

unchanged in the deeper, oxygen-free layers for at least five to ten years (Krebs and Burns, 1977). This persistent oil continues to present a hazard to the biological community, preventing its return to pre-spill status, and constituting a potential source of slow, continuous oil leakage to surrounding areas (Vandermeulen and Gordon, 1976).

6.1.2 The spill area

The Tsesis spill occurred in an area where benthic data have been collected since 1972 by Ulf Larsson, Askö Laboratory, in connection with a study of the environmental impact of the large modern sewage plant "Himmerfjärdsverket". Pre-spill macrofauna data were already available, while meiofauna samples are stored and will be sorted later if funding becomes available. Furthermore, the benthos of the Askö area has been treated in detail in a number of earlier papers (Cederwall, 1977, 1978; Ankar, 1977; Ankar and Elmgren, 1976; Elmgren, 1976) so that the background knowledge for the study of the oil spill was exceptionally good.

Stations 20 and 21 (see map, Fig. 6.1) were generally sampled for macrofauna once a year in October-November (i.e. at about the time of the spill) starting in 1972. The depth of the stations were: station 15: 44-45 m, station 20: 32-33 m, station 21: 28-29 m, and the bottom substrate, mud at all the stations. Stations 20 and 21 are located in an area, "Svärdsfjärden", which is cut off from exchange of deep water with the open Baltic by a sill of about 20 m depth between Askö and Torö, whereas Station 15 is outside this sill.

6.2 Methods

6.2.1 Sediment sampling

Cores for oil analysis of surface sediments were collected using either a modified Kajak core sampler (Kajak et al., 1965) of 80 mm internal diameter (10 Nov. 1977, station 1 and 2; 17-31 August 1978, station 14, 15, 20, 20C, 20D) or the Askö corer, also used for meiofauna sampling (inner diameter 22 mm, used for all other samples). The top 2 cm of the sediment were extruded into hexane-washed glass bottles and kept deep-frozen until analyzed. On 4 December 1978, further cores

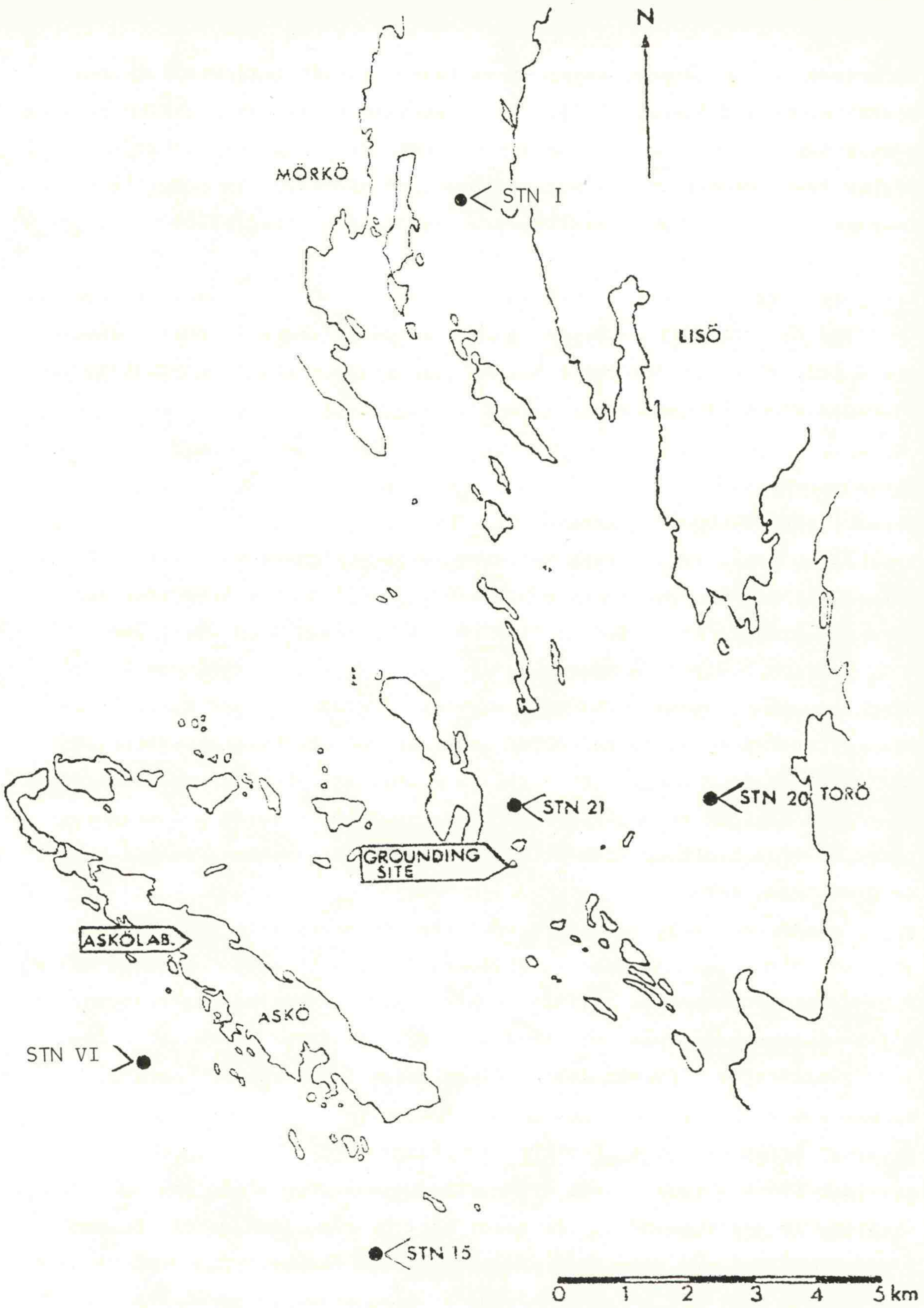

Fig. 6.1 Map of investigation area, showing main benthos sampling stations.

were taken at Station 20 using an experimental sampler, similar in principle to that of Craib (1965). This sampler rests on a tripod. It slowly lowers the core tube into the bottom sediment only after the tripod has come to rest on the sediment, thus decreasing the risk of surface loss due to a pressure wave. These cores were sliced into layers of 0-0.5 and 0.5-1 cm.

The oxygen content of the water above the sediment was also measured (Winkler titration) for the Kajak core sampler (the Askö corer contains too little water). Reference values for oxygen content were taken from stations I and VI (see map Fig. 6.1).

6.2.2 Macrofauna

6.2.2.1 Macrofauna sampling

The macrofauna sampling followed the recommendations of the Baltic marine biologists (Dybern et al., 1976). A 0.1 m^2 van Veen grab was used and 8-10 samples from Station 20 (except only 3 in 1972) and 3 samples from Station 21 (except only 2 in 1977) were taken and sieved live through 1 x 1 mm metal mesh sieves. The animals and sieve residues were preserved in 4% formaldehyde solution buffered with hexamine and stained with Rose Bengal, to facilitate sorting. Biomass was determined after at least three months of preservation, as formalin wet weight, after careful blotting with filter paper. Each taxon and sample was weighed separately.

Animals for oil analysis were collected using either a van Veen grab or an Ockelmann dredge (Ockelmann, 1964) with a mesh size of 450 µm, as were the Pontoporiea affinis females used for estimating frequency of abnormal eggs. Animals for oil analysis were stored in hexane-cleaned glass bottles or aluminum foil and kept deep-frozen until analyzed.

6.2.2.2 Reproduction of Pontoporeia affinis

The spill occurred just before the normal copulation period for Pontoporeia affinis and P. femorata. Egg-bearing females of the dominant species P. affinis were collected on 17 February and 9 March 1978 at the most strongly impacted of the initially sampled stations (No. 20, see map, Fig. 6.1) and at an unaffected reference site (No. 15).

The total number of eggs and the frequency of eggs, showing either abnormal development or no differentiation at all, were noted.

6.2.3 Meiofauna

Meiofauna was sampled using an Askö core sampler (described in Appendix 1 in Ankar and Elmgren, 1976). Generally 5 core samples of 3.9 cm^2 and at least 7 cm length were obtained at each station, but only 3 have been sorted. Sediment cores were preserved whole in 4% formaldehyde solution buffered with hexamine and with Rose Bengal added to stain the animals (see Dybern et al., 1976). Further treatment also followed BMB recommendations (Dybern et al., 1976) i.e. meiofauna was delimited by a 1 x 1 mm metal mesh sieve as the upper limit (to exclude macrofauna), and by a 40 x 40 µm metal mesh sieve as the lower limit, with intermediate 500, 200 and 100 µm sieves used to facilitate sorting, subsampling and biomass estimation.

Each composite sample was first sieved through 1 and 0.5 mm sieves, and then split into light and heavy fractions by repeated decantation (as in Elmgren, 1973). Before sorting, the light fractions were sieved through a 200 µm sieve and then subsampled as follows (in a sample splitter according to Elmgren, 1973 "sample divider"): 100 µm fraction 1/8, 40 µm fraction 1/64. The finest light fraction (40 µm) was sonified (Thiel et al., 1975) for 25 seconds before sorting. The heavier fractions were sieved through a 100 µm sieve (generally after sonification) and the retained fraction sorted in its entirety. The finest heavy fraction was discarded since earlier checks have shown it to be virtually devoid of animals (Elmgren et al., 1979).

Samples for counts of dead and live ostracods were collected on 17 February and 9 March at Stations 15 and 20, using the Ockelmann dredge, and subsequently sieved through a 500 µm sieve before sorting and counting.

6.3 Results

6.3.1 Sediment samples

No oil hydrocarbons which could be identified as Tsesis oil could be found in any of the sediment samples (see section 11). The results

of the oxygen analyses are given in Fig. 6.2. The few bottom water oxygen analyses made at station 20 do not deviate markedly from measurements made at closer intervals at reference station VI and station I farther into the "Himmerfjärd". That the bottom water values are slightly lower is only natural, since the other analyses were made on samples taken farther from the bottom (an ordinary water sampler, not a corer was used).

6.3.2 Macrofauna

6.3.2.1 Macrofauna community response

Two stations were followed in detail (Stations 20 and 21, shown in map, Fig. 6.1). Results are given in Figs. 6.3-6.8.

As can be seen in Figs. 6.3 and 6.7 the effects of the oil spill have to be evaluated against a background of gradual change during 1972-77 due to eutrophication caused by the "Himmerfjärd" sewage plant. The most important component of this change is a gradual increase in abundance and biomass of Macoma balthica at both stations, most clearly marked at Station 20 (see Fig. 6.7). This trend is even stronger farther up the "Himmerfjärd" closer to the sewage plant (Larsson, pers. comm.).

The November 1977 sampling, carried out 16 days after the start of the spill, showed a dramatic and statistically significant reduction in total macrofauna abundance at station 20 (Fig. 6.3). On this occasion a smell of oil was noticed from several of the grab samples. At Station 21 also, the abundance was lower than during any of four preceding years, but this difference was difficult to test statistically due to the lower number of samples taken at this station. The reduction was mostly due to an almost total disappearance of Pontoporeia affinis and P. femorata and the polychaete Harmothoe sarsi from Station 20 (Figs. 6.4, 6.5 and 6.6). All these decreases are statistically significant ($p < 0.001$ when November 1976 and November 1977 are compared, Rank-sum test according to Dixon and Massey, 1969:344). The amphipods (but not the polychaete) were also reduced at Station 21, but far less drastically. The total macrofauna biomass at both stations was dominated by the

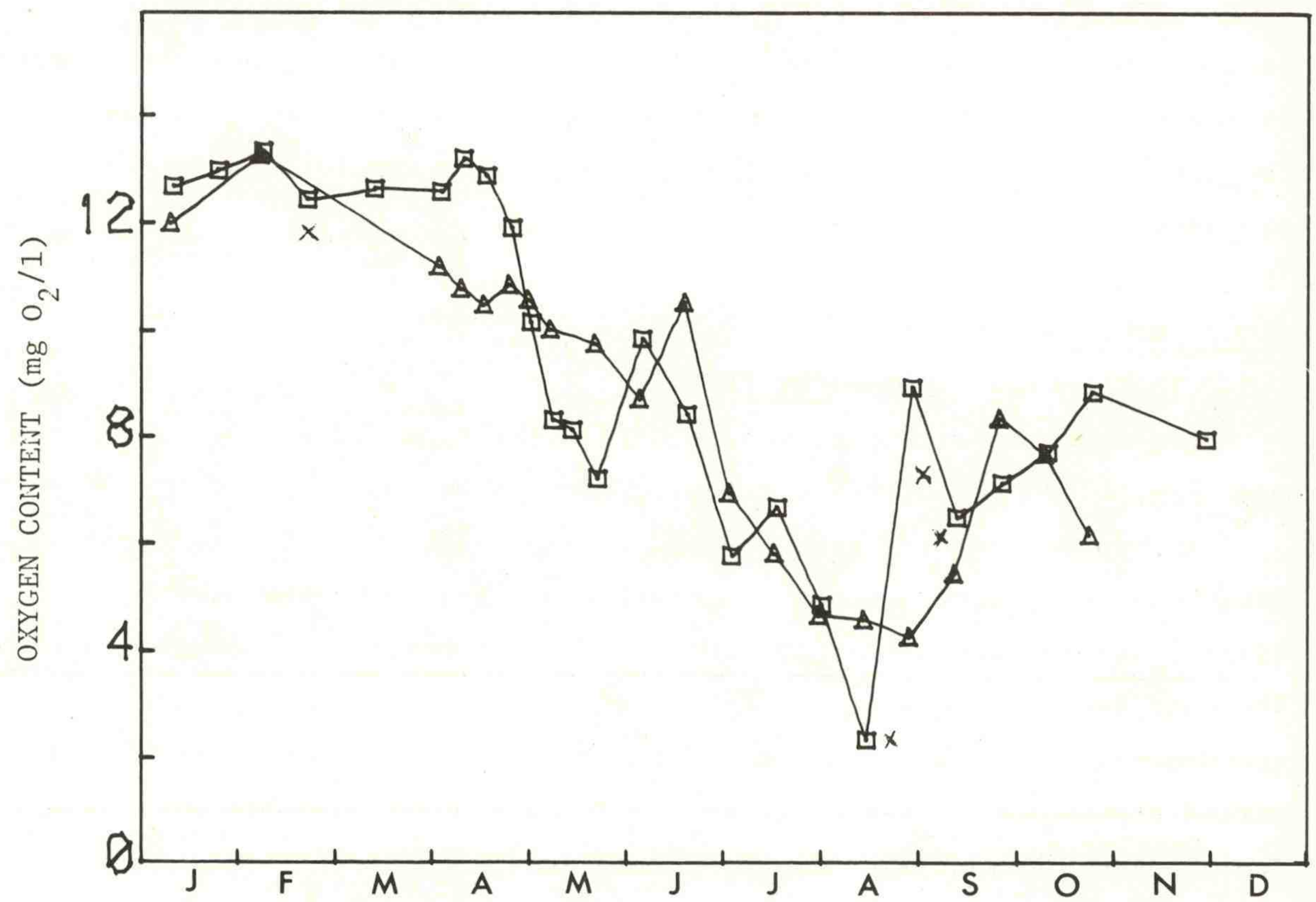

Fig. 6.2 Oxygen content (mg O_2/1) in the bottomwater at reference station VI (38 m), □, SW Askö and at reference station I (50 m), △, in the Himmerfjärd, and at station 20, x, during 1978. For station locations, see Fig. 6.1.

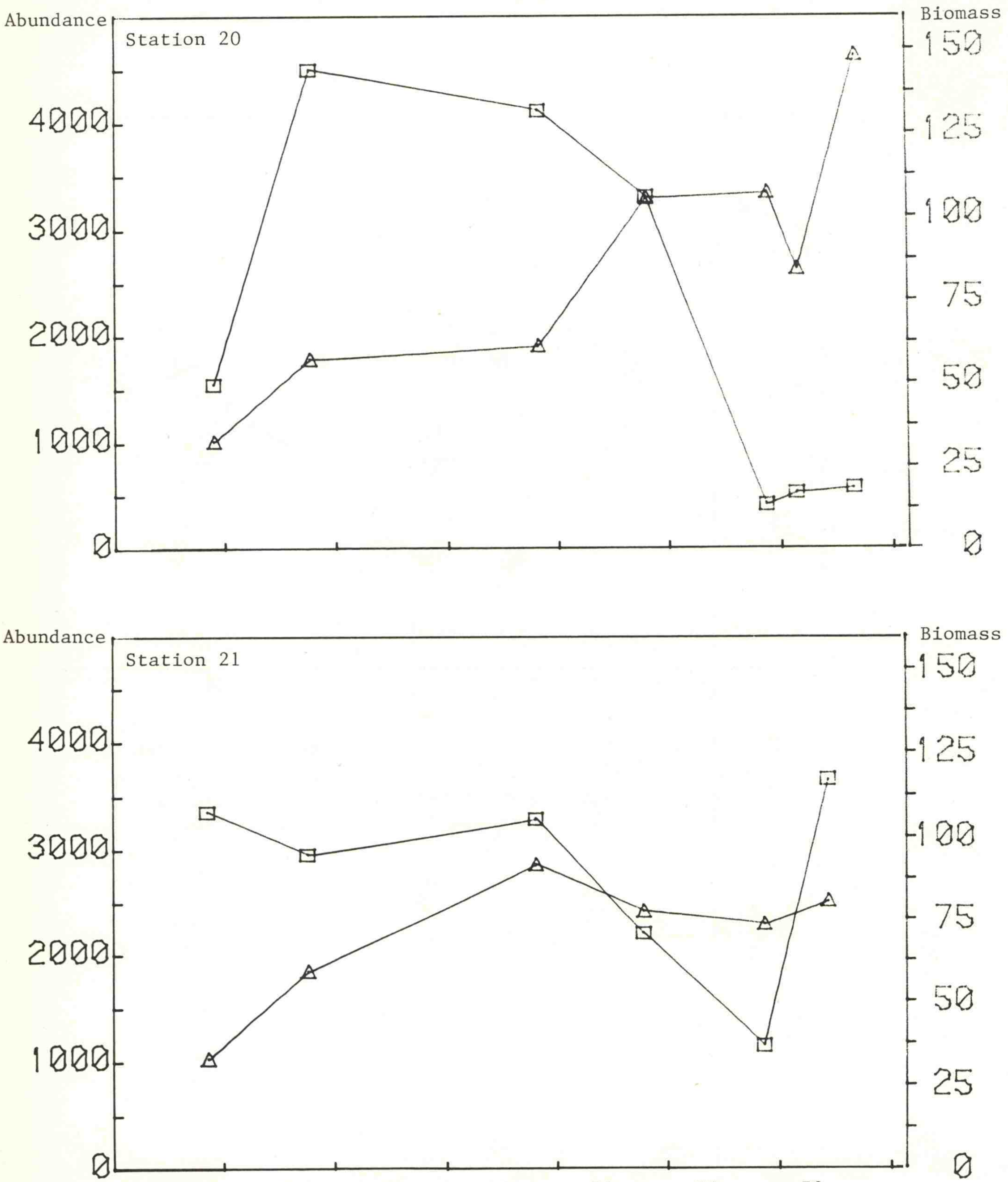

Fig. 6.3 Total macrofauna at stations 20 and 21.

-[]- abundance (no./m^2)
-Δ- biomass (g/m^2)

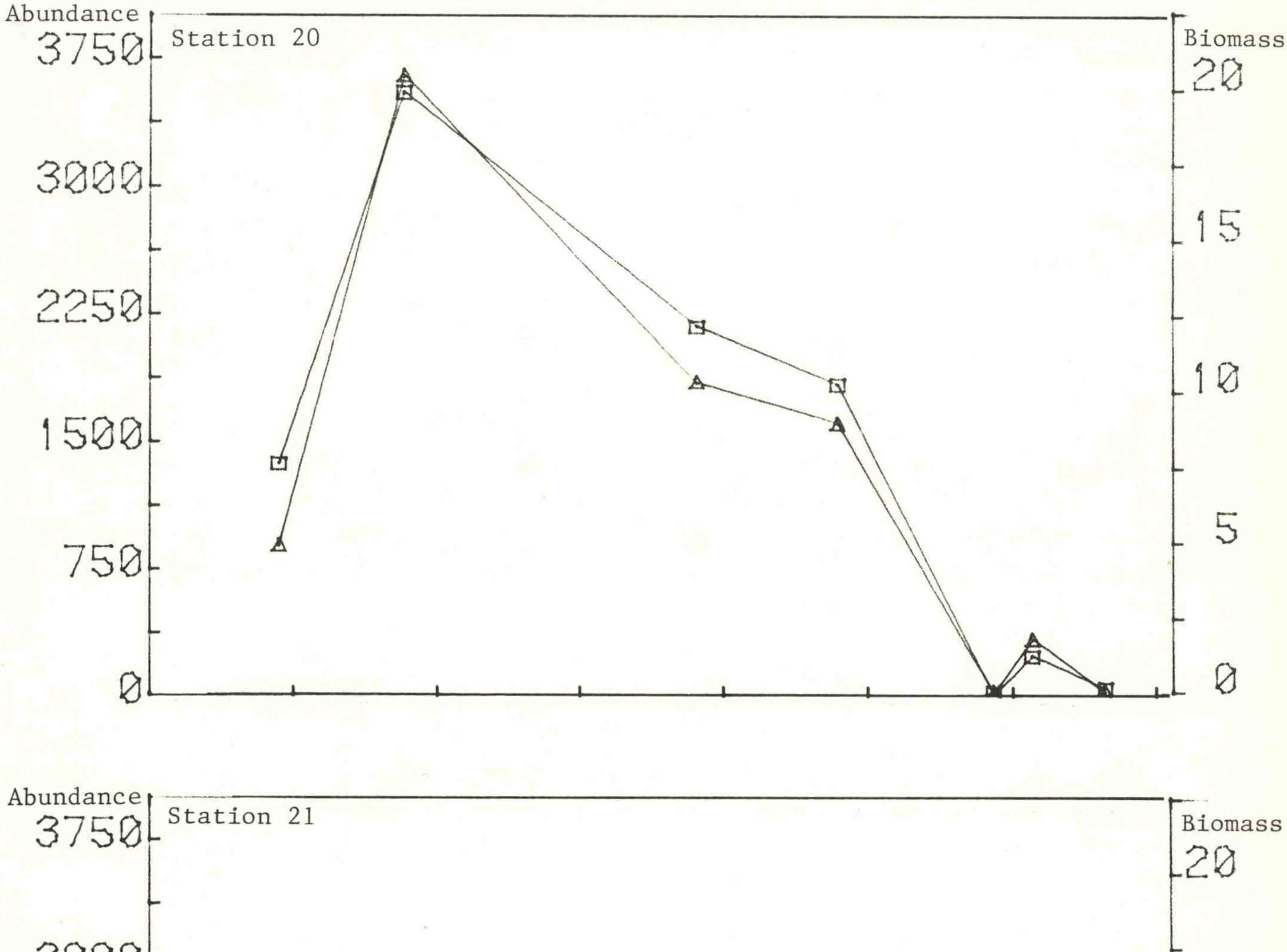

Fig. 6.4 Pontoporeia affinis at stations 20 and 21.

—□— abundance (no./m^2)

—△— biomass (g/m^2)

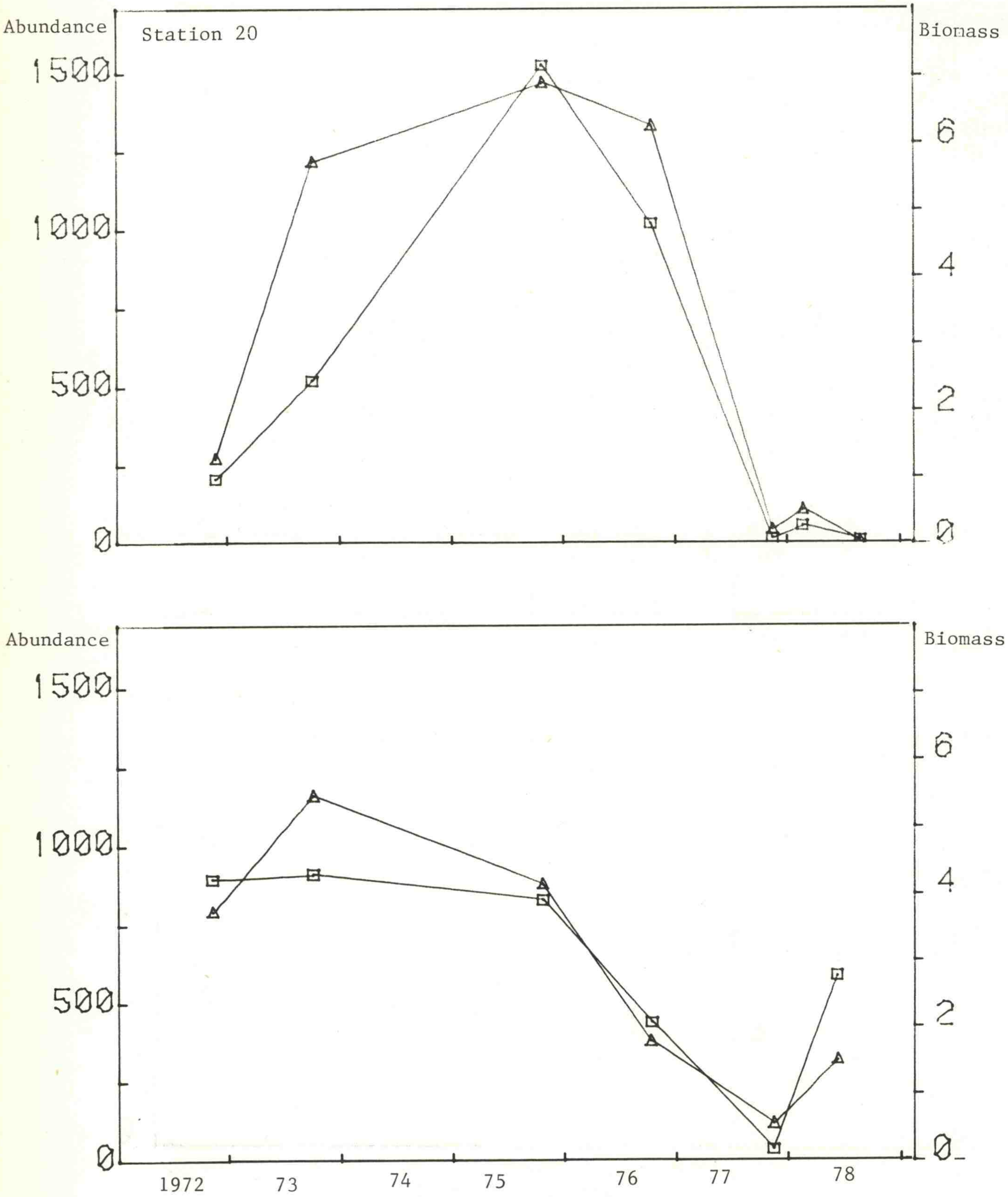

Fig. 6.5 Pontoporeia femorata at stations 20 and 21.

—□—abundance (no./m^2)

—△—biomass (g/m^2)

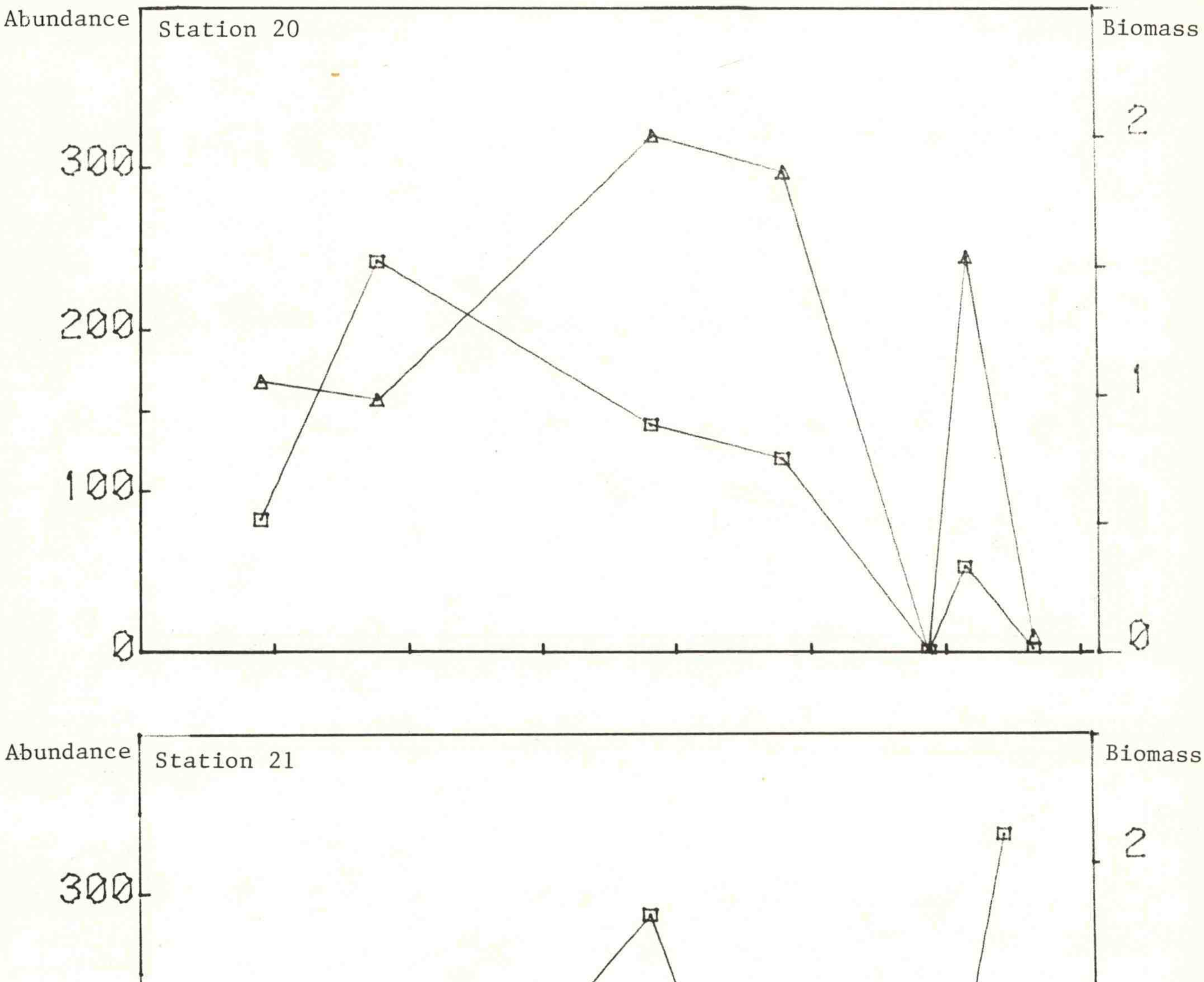

Fig. 6.6 Harmothoë sarsi at stations 20 and 21

—□— abundance (no./m^2)

—△— biomass (g/m^2)

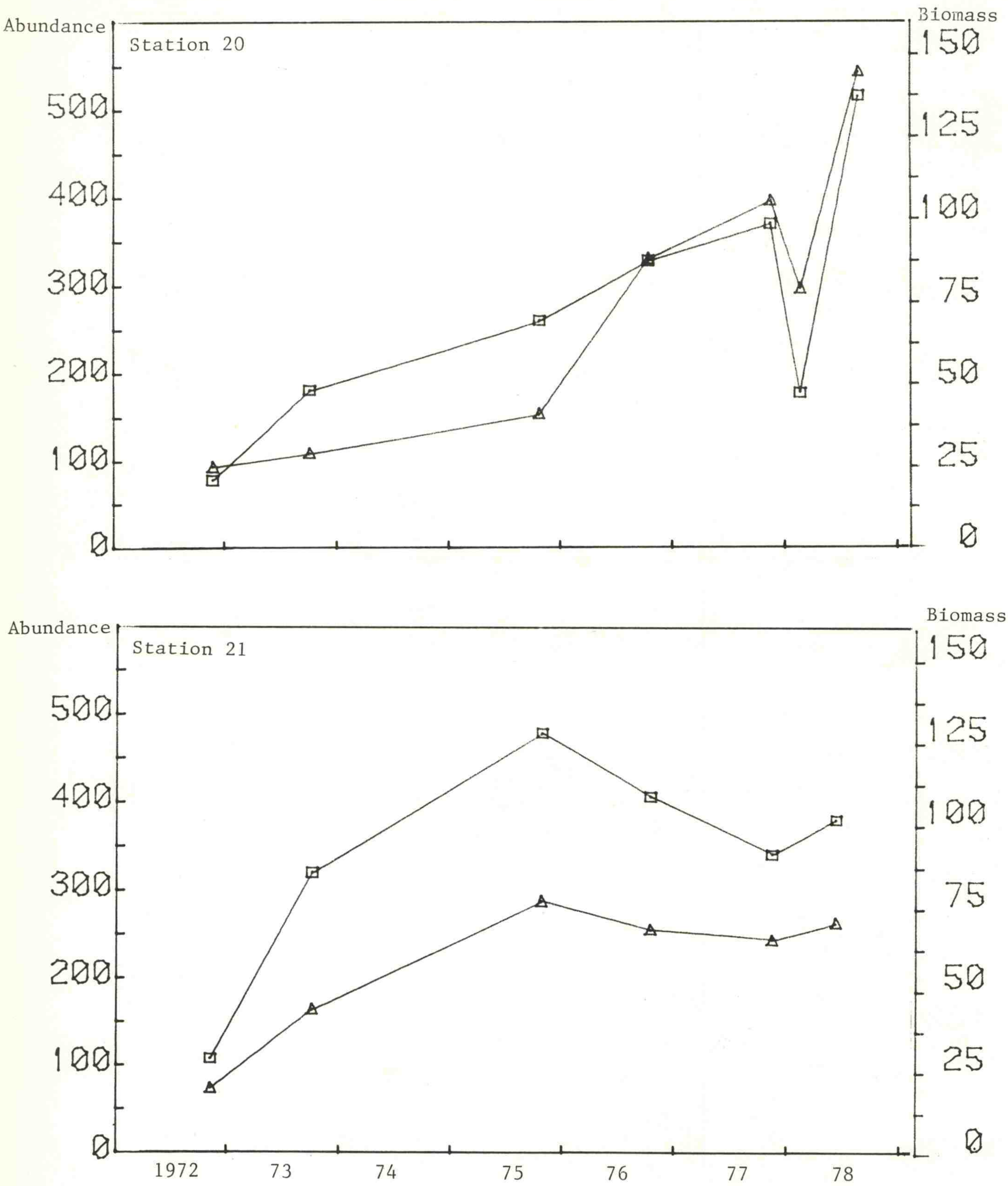

Fig. 6.7 Macoma balthica at stations 20 and 21.
—□—abundance (no./m^2)
—△—biomass (g/m^2)

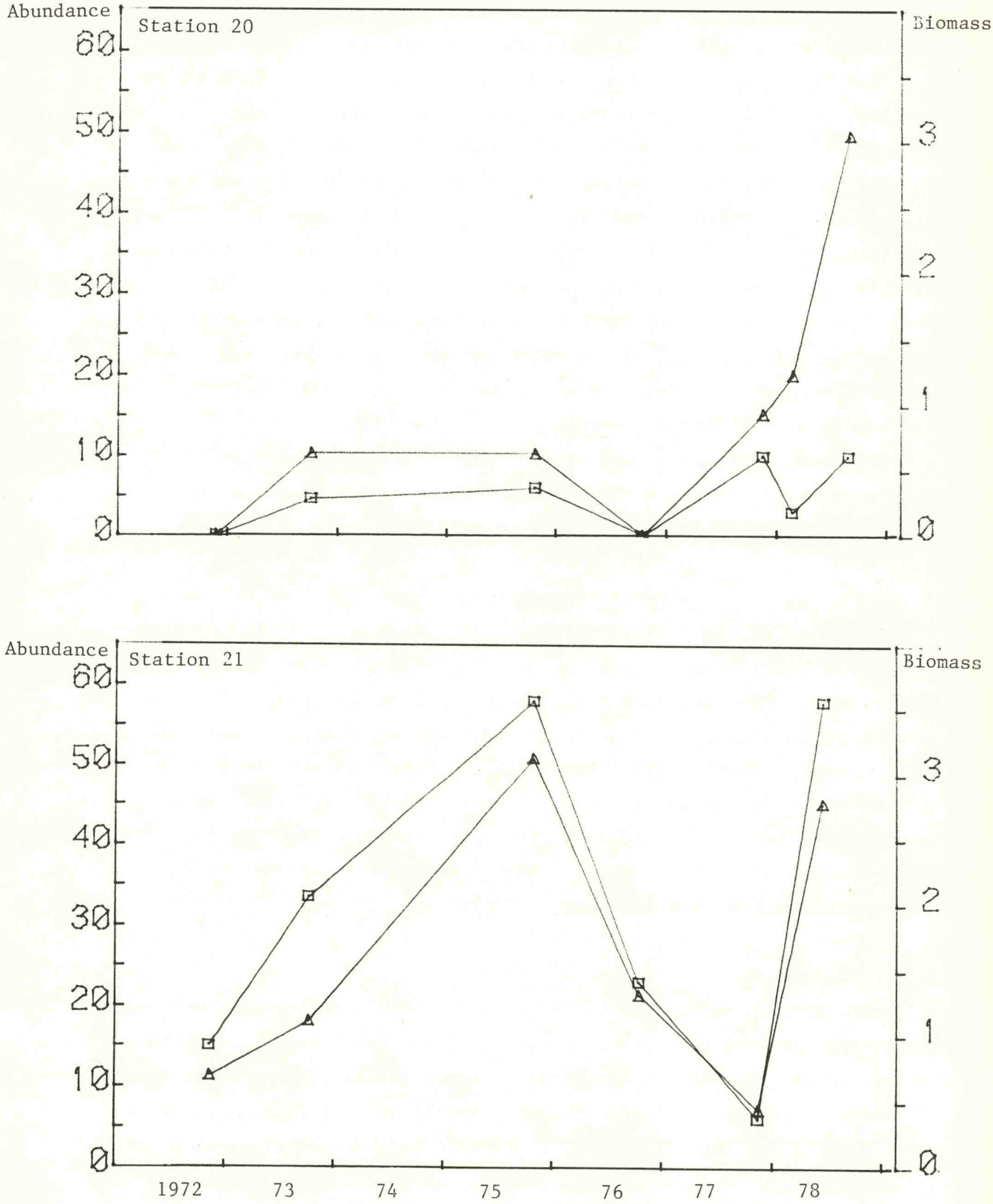

Fig. 6.8 Halicryptus spinulosus at stations 20 and 21.

—□—abundance (no./m^2)
—△—biomass (g/m^2)

bivalve Macoma balthica (Fig. 6.7) which showed no decline. The same was true of the priapulid Halicryptus spinulosus (Fig. 6.8), which is the last of the five macrofauna species normally found at these stations.

Station 20 was sampled again in February and August 1978. The February sampling showed slightly higher abundance of amphipods and Harmothoe but instead, a decrease in Macoma and Halicryptus. In August, amphipods and Harmothoe were once again virtually absent while Macoma and Halicryptus now showed an increase. These small variations are statistically significant for both Pontoporeia spp. as well as for Macoma and Harmothoe ($p < 0.005$, Rank-sum test for several samples namely November 1977, February and August 1978, Dixon and Massey, 1967:345), but not for Halicryptus.

Station 21 was revisited in June 1978. This time all species showed abundance values which differed little from what had been normal during November in earlier years (Figs. 6.3-6.8).

6.3.2.2 Pontoporeia affinis reproduction

In spite of the drastic reduction in Pontoporeia affinis population density at Station 20, it was possible to collect a small number of gravid females for determinations of egg numbers and frequency of non-developing embryos (Figs. 6.9a-b). The total percentage of abnormal plus undifferentiated embryos was about 10% at Station 20, but only about 1% at reference station 15, far from the oil spill (Table 6.1). This difference is statistically significant ($p < 0.05$) using a normal approximation to a rank-sum test, that combines the information from both sampling occasions (Lehman, 1975:5-23 and 132-141).

6.3.3 Meiofauna

Meiofauna samples were sorted from Station 20 in November 1977 and February, March, August and September 1978 and from Station 21 in November 1976 (one year before the spill). Since the macrofauna at station 21 seemed to show some influence from the spill, another reference station was selected for the meiofauna. Station 15, at a depth of 41-44 m, was selected as most representative, even though it is about 10 m deeper

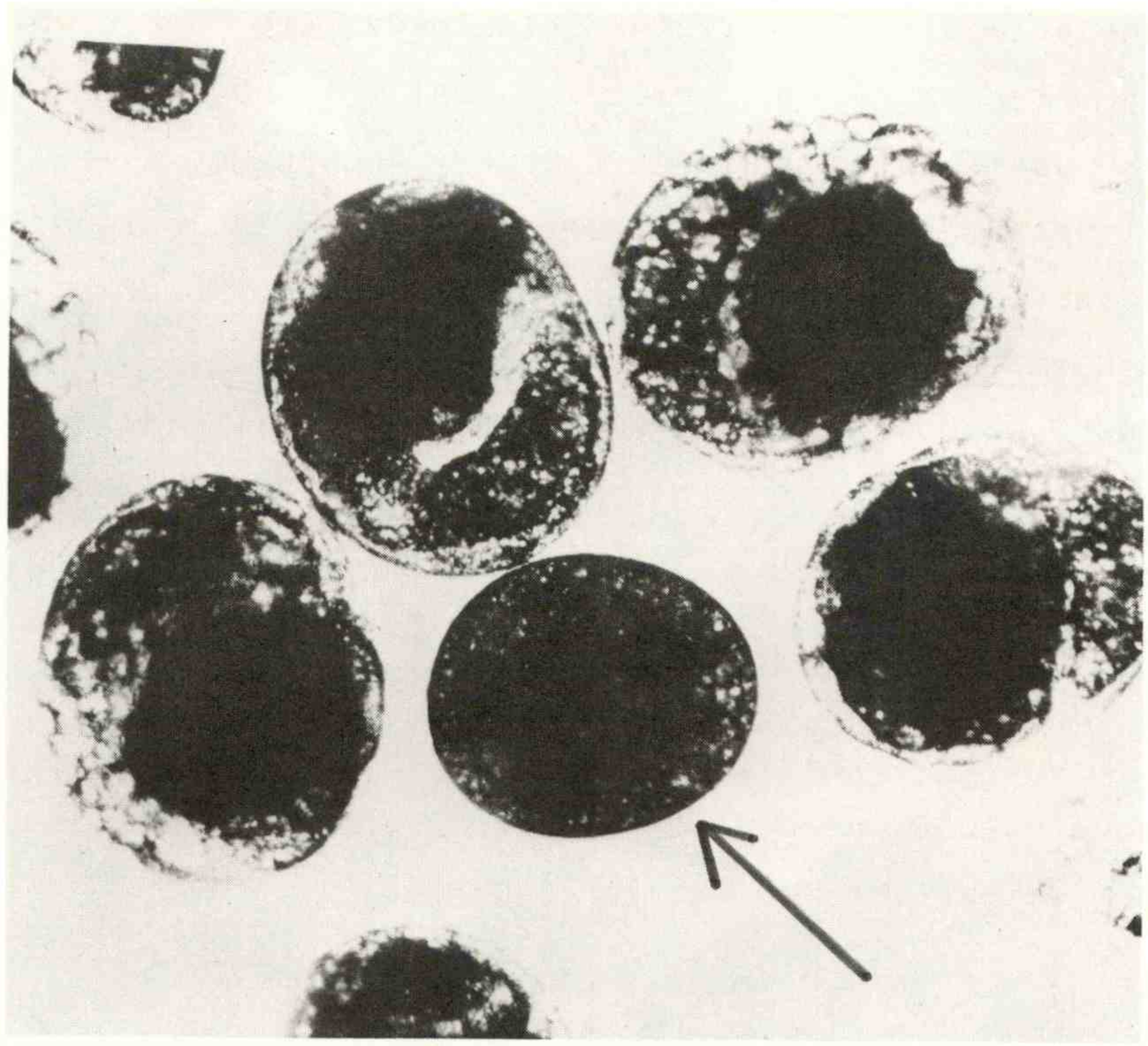

Figure 6.9a. Embryos from Pontoporeia affinis, collected at station 20 in the impacted area. Most of the embryos are abnormal, and one egg (arrow) is not differentiated.

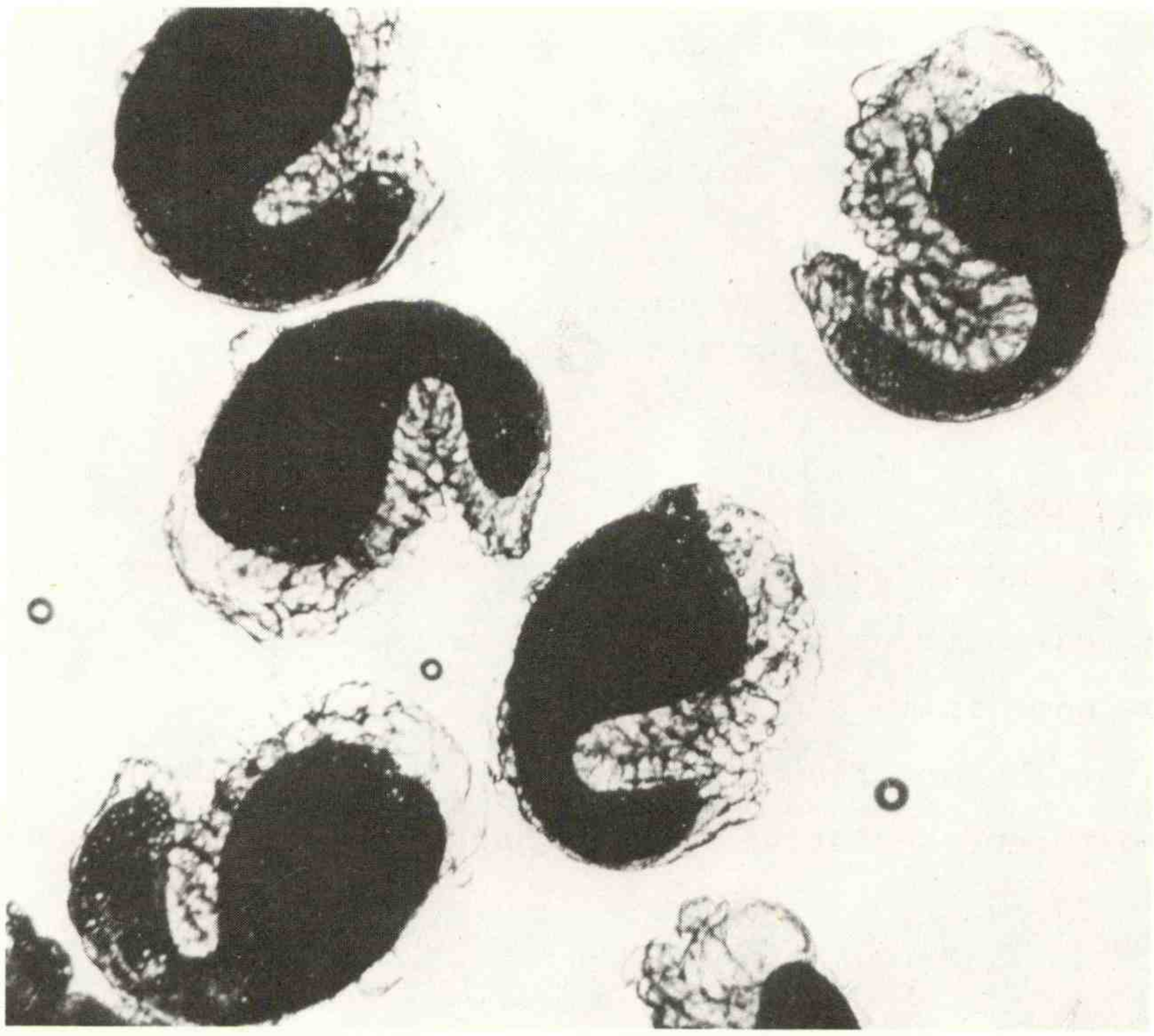

Figure 6.9b. Normally developed embryos from the reference station (no. 15).

Table 6.1 The occurrence of malformed embryos and undifferentiated eggs in gravid Pontoporeia affinis females caught at two stations, one in the oil-polluted area (station 20) and the other in a reference area (station 15).

Sampling date: 780217						Sampling date: 780309					
Station 20			Station 15			Station 20			Station 15		
Number of eggs			Number of eggs			Number of eggs			Number of eggs		
total	abnormal	% abnormal	total	abnormal	% abnormal	total	abnormal	% abnormal	total	abnormal	% abnormal
57	8	14.0	25	1	4.0	44	44	100	51	0	0
51	0	0	24	0	0	59	0	0	35	0	0
72	7	9.7	47	0	0	52	0	0	50	1	2.0
40	1	2.5	31	1	3.2	55	2	3.6	43	0	0
66	0	0	39	0	0	29	0	0	45	0	0
18	18	100	44	1	2.3	39	0	0	$\bar{x}$=44.8		
55	3	5.5	50	0	0	67	1	1.5	SD= 6.4		
72	1	1.4	$\bar{x}$=37.1			55	2	3.6			
45	1	2.2	SD=10.6			36	0	0			
53	2	3.8				35	1	2.9			
44	0	0				47	1	2.1			
72	0	0				64	2	3.1			
$\bar{x}$=53.8						20	10	50			
SD=16.0						30	1	3.3			
						41	3	7.3			
						31	1	3.2			
						51	1	0			
						55	0	0			
						55	0	0			
						$\bar{x}$=45.5					
						SD=13.0					

than station 20. Samples from March, June and August 1978 have been sorted and this station has been followed intermittently since 1971. Pre-spill samples from further sampling occasions are available from all stations, but could not be sorted within the budget available.

As is normal in fine sediments, nematodes totally dominated the meiofauna abundance at all stations and sampling occasions (Fig. 6.10 - 6.13). Except for an exceptionally low nematode value at Station 20 in March 1978 there were no statistically significant differences in nematode abundance between the stations. It is perhaps worth noting that the proportion of large nematodes was consistently higher at Station 20 than at Station 15 during the post-spill period.

The ostracods often constitute the larger part of the meiofauna biomass in deeper Baltic soft bottoms (c.f. Ankar and Elmgren, 1976, for the Askö area), even though they are much less numerous than the nematodes. At both station 21 (November 1976 pre-spill) and station 15 (post-spill reference station) moderate to high ostracod numbers were found (5-17 x 10^4 ind/m^2) whereas station 20 had very low ostracod abundances on all post-spill sampling occasions (1-3 x 10^4 ind/m^2). (See Fig. 6.11).

The rest of the meiofauna comprises a wide assortment of taxa, such as Foraminifera, the hydroid Protohydra leukartii, Turbellaria, Kinorhyncha, harpacticoid copepods and juvenile macrofauna (so-called temporary meiofauna - mostly Macoma balthica, Harmothoe sarsi and Halicryptus spinulosus larvae, but part of the year also juvenile Pontoporeia spp.). Each single group was too scarce in the samples for definite trends to be observed, but as an aggregate all these "others" (total meiofauna excluding nematodes and ostracods) showed a much lower abundance at station 20 (post-spill) than at stations 21 (pre-spill) and 15 (post-spill reference) (See Fig. 6.14).

The Ockelmann dredge samples collected in February and March showed a much higher proportion of live ostracods in relation to total ostracods (live + "recently" dead) at station 15 than at station 20, where only few live specimens were found (see Fig. 6.13). The difference between the stations was highly significant on both occasions ($p < 0.0001$, χ^2-test).

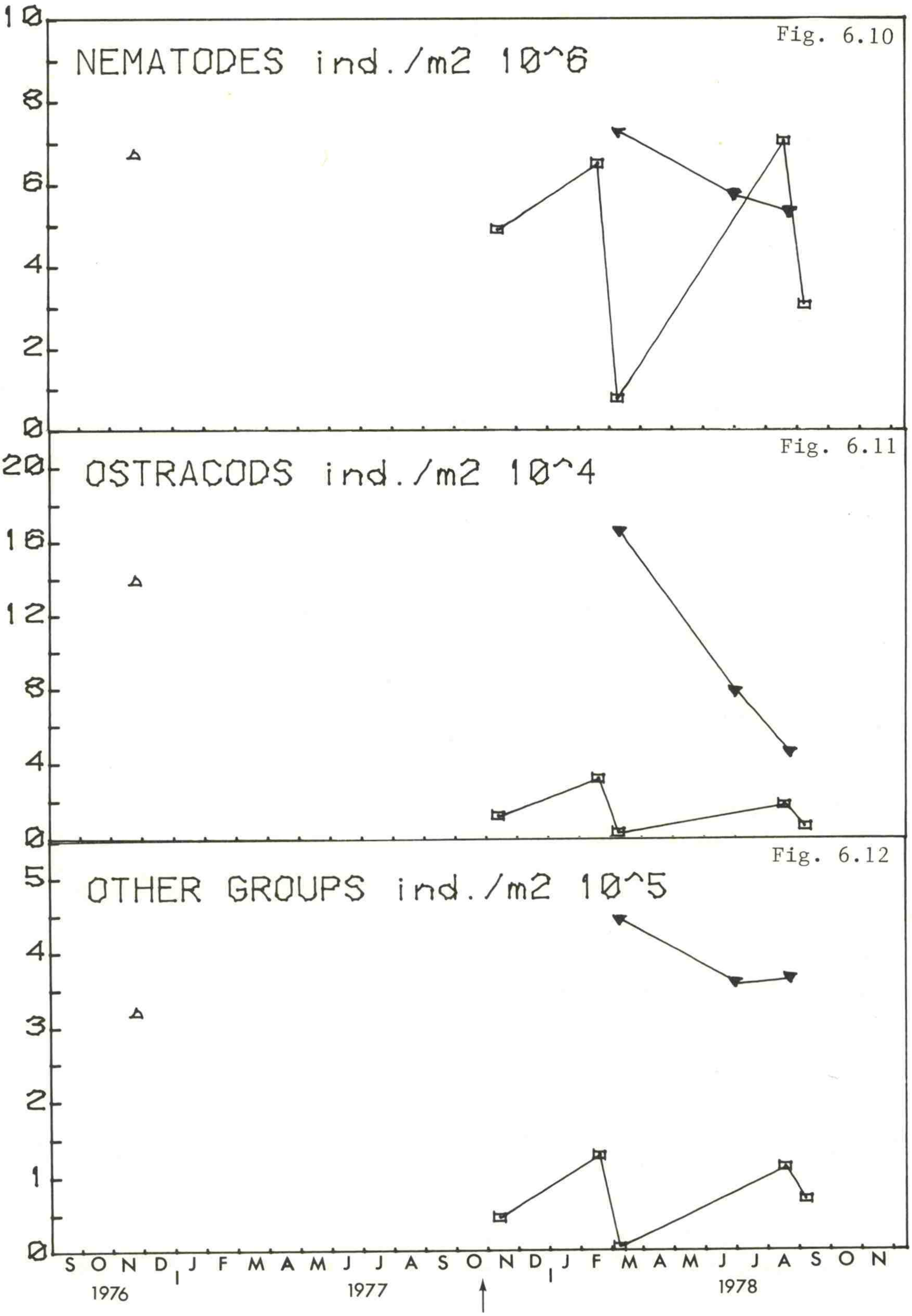

Fig. 6.10 - 6.12 Abundance of nematodes, ostracods and other groups (excluding nematodes and ostracods) at station 20 (□) and station 15 (▼). Data in 1976 from station 21 (△). Arrows indicate grounding of Tsesis.

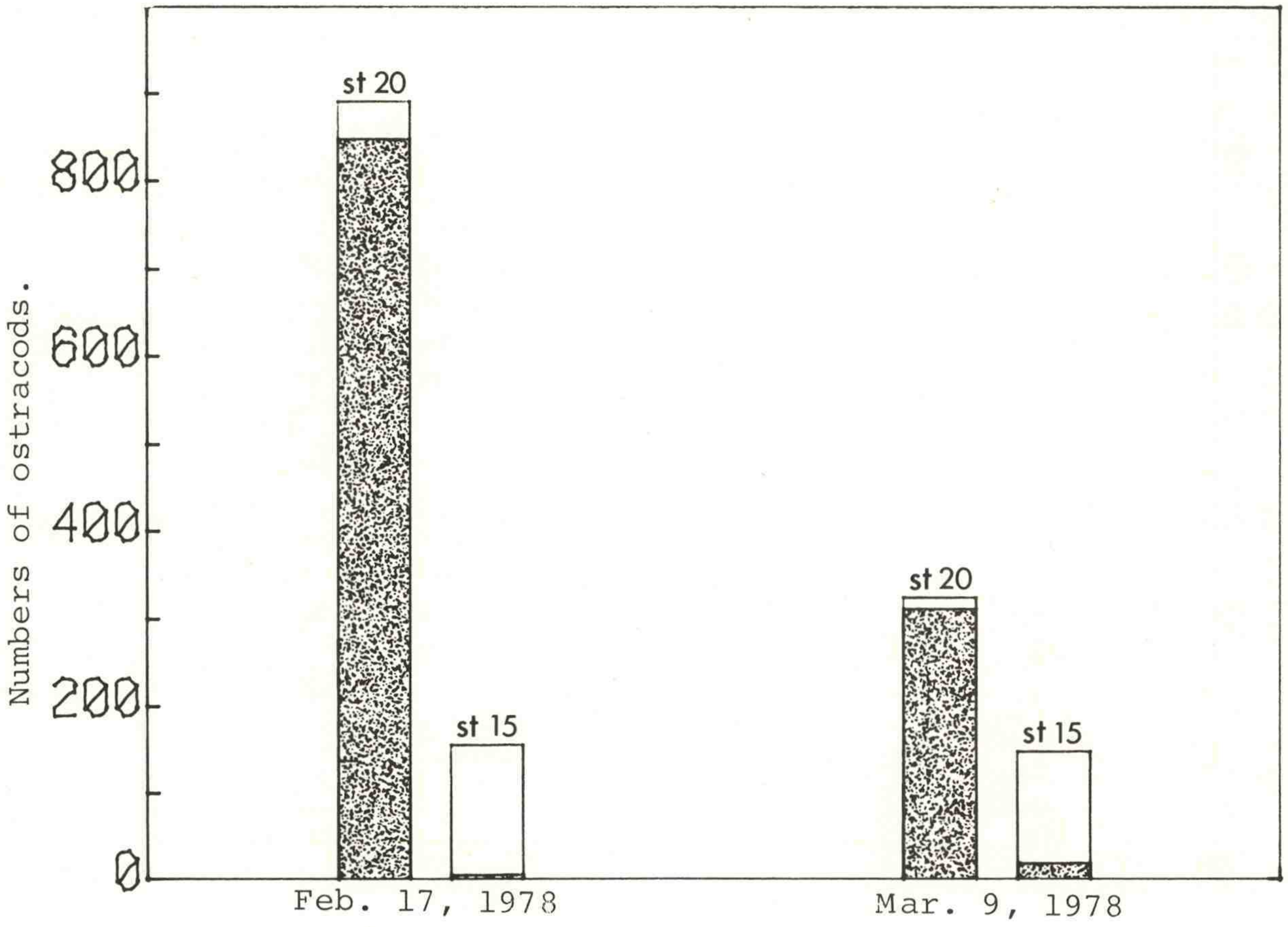

Fig. 6.13 Live (white) and dead (stained) ostracods in dredges (mesh size 450 µm) from station 20 and station 15, February 17 and March 9, 1978.

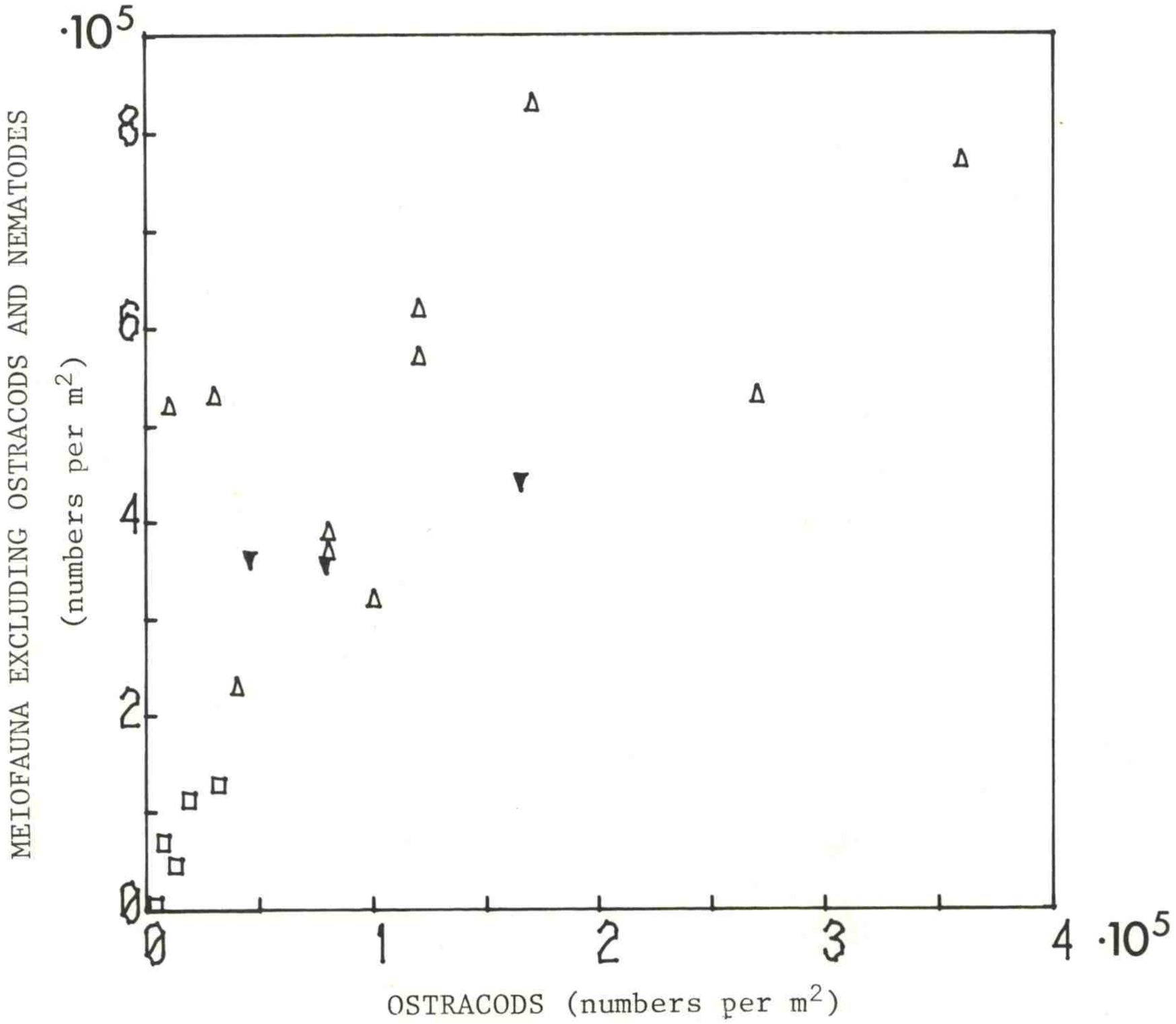

Fig. 6.14 Abundance of ostracods versus abundance of other meiofauna groups (excluding nematodes and ostracods) in the Askö - Landsort area. (□) Data from station 20 (mean of three cores). (▼) Data from station 15 (mean of three cores). (△) Data from the Askö - Landsort area. Data from single cores taken at randomly selected stations in the depth range 25 to 45 m.

6.4 Discussion

6.4.1 Sediment samples

No Tsesis oil hydrocarbons could be identified with certainty in any of the sediment samples. Nevertheless, we can state with certainty that oil must have reached the sediment surface, since 1) the sedimenting material in the water column contained large concentrations (up to 0.7%) of oil, especially in the first week after the spill; 2) large Macoma balthica collected not only at station 20 but also at other stations (e.g., 5, 6 and 8) contained considerable quantities of oil hydrocarbons within about a month after the spill, when the first Macoma samples for oil analysis were collected (see Section 11 for details); and 3) a smell of oil was detected from several grab samples at Station 20 in November 1977.

The failure to find oil in the sediment samples can probably be explained by several interacting factors. Newly sedimented oil will be concentrated in the uppermost flocculent surface layer of the sediment, and this layer is not well sampled by gravity corers such as those used in the present investigation (cf. McIntyre 1971, Elmgren 1973). The sampling efficiency of the Askö corer for meiofauna has been tested by Ankar and Elmgren (1976). For the non-nematode meiofauna, which tend to live in the floccular top sediment, the efficiency was only 38-61%. The Kajak corer has been shown to be even less efficient (Hallberg, Bågander and Elmgren, unpublished). After the sampler had been brought to the surface, it is highly likely that there was even further loss as the water, with its suspended load of oil-contaminated surface floc, was poured off from above the sediment, prior to extrusion and sectioning of the cores.

Finally, the sediment contained fairly high concentrations of biogenic hydrocarbons and in some cases unidentified anthropogenic hydrocarbons as well and this tended to swamp the signal from the newly sedimented oil hydrocarbons. This is especially likely since sections as thick as 2 cm were used for all early sediment cores.

6.4.2 Macrofauna

6.4.2.1 Macrofauna community response

The drastic reduction in macrofauna abundance at station 20 after the spill left little doubt that this was a direct effect of the oil. The three species which decreased in abundance were all vagile forms that may have emigrated from the area most heavily influenced by the oil. Initially it was thought this a more likely explanation of their virtual disappearance than direct mortality, since very few remains of dead animals were found in the benthos samples taken 16 days after the grounding of the Tsesis. Assuming that oil would take a couple of days to reach the bottom in quantity and that mortality would not have been instantaneous (that would probably have required oil levels high enough to kill Halicryptus and Macoma also), any animals killed by the oil would have had to disappear almost without a trace in about one week, which was not very likely at a bottom water temperature of 7°C, at least not for the cuticle-covered amphipods. Yablonskaya, (1947, quoted in Winberg 1971) found that Chironomus larvae were still recognizable after 30 days at 5°C, and after 12 days at 10°C. Later simple aquarium experiments with dead Pontoporeia affinis, kept in natural sediment at field temperature, have indicated that 1-2 weeks might indeed be enough time for the dead animals to disappear almost completely (Sundelin, unpubl.). That amphipods actively avoid oil-contaminated sediments has been shown experimentally by Percy (1977) for Onisimus affinis and the same is true for Pontoporeia affinis (unpublished experiments by M. Notini, pers. comm.) and probably also for P. femorata (Atlas et al., 1978). At present it is therefore impossible to say with certainty whether most of the amphipods emigrated or died.

The only natural environmental perturbation that could have been expected to give a reduction of the macrofauna as drastic as that found at station 20 would have been a period of oxygen deficiency during the autumn or late summer preceding the spill. The reduced sediment surface and fairly low oxygen values found at station 20 in summer 1978 (post-spill) could be taken as indicating that even lower oxygen values might have occurred the year before. However, several lines of evidence contradict this hypothesis. First, bottom oxygen values at the three permanent stations in the "Himmerfjärd" were unusually good during 1977

(Larsson, unpubl.), even in the heavily eutrophicated innermost parts of the Himmerfjärd, where bad oxygen conditions are normal in late summer and early autumn. Second, oxygen deficiency would not have resulted in a decrease in Harmothoe sarsi, which normally is the macrofauna species most tolerant towards oxygen deficiency in the northern Baltic proper (e.g., Cederwall, 1978). Finally, since there is no question of any oxygen deficiency occurring after the breakdown of the thermocline in early October 1977 or before late summer 1978, one would have expected considerable re-invasion by Pontoporeia and Harmothoe from the surrounding areas during the 9-10 months of good oxygen conditions. There is little evidence of such an immigration to station 20, the variations noted being more likely due to the natural patchiness of the benthos (since Macoma balthica which is sedentary also varied). The continued presence of repellent oil hydrocarbons in the sediment indicated by continued high hydrocarbon levels in Macoma balthica from station 20 could, on the other hand, easily explain the absence of immigration during the first ten months following the spill.

The impact of the oil spill on the macrobenthic community at station 20 was clear, but not totally catastrophic. While total abundance declined drastically, due to the reduction in abundance of Pontoporeia (both species) and Harmothoe, there was little change in biomass, since this is dominated by Macoma balthica, which did not decrease. The abundance of the two macrofauna species without swimming ability, and with generally low mobility, Macoma and Halicryptus, seem to have been little influenced by the spill, even though Macoma, at least, showed considerable contamination by oil hydrocarbons (see Section 11). The relatively low sensitivity of Macoma balthica to oil pollution, coupled with its ability to take up hydrocarbons from the sediment, makes it an excellent indicator of the level of oil pollution to which a soft bottom station has been subjected. This supports the value of M. balthica as an indicator of oil pollution, as suggested by Shaw et al. 1976, 1977, and supported also by Taylor and Karinen, 1977.

Since the reduced species are the most productive (highest P/B ratios, Cederwall, 1977), and are the most preferred food for the local fish fauna (Aneer, 1975), the change in energy flow patterns must have been drastic at the most heavily impacted station.

Before the total effect on the local ecology can be evaluated, a better estimate of the heavily impacted area is needed. A sampling in June 1978, near (less than 1 km from) station 20, but in slightly shallower water (31 instead of 32-33 m) showed an almost normal macro-and meiofauna. This fact indicates that the strongly affected area may be fairly small, or at least that the effect may be rather patchy in its distribution (and presumably much more pronounced on sedimentation bottoms than on transport or erosion bottoms).

6.4.2.2 Pontoporeia affinis reproduction

An increased frequency of abnormal development or non-differentiating eggs in Pontoporeia affinis seems to be a very sensitive indicator of toxic substances in the aquatic environment, since Sundelin (unpublished) has also found effects at very low levels of cadmium in the water (5 ppb). Nevertheless, this effect is likely to be of only minor ecological importance, unless the area affected by oil is very large, since nearly all Pontoporeias seem to have left or died at the most heavily impacted station.

This is an interesting example of so-called "effects monitoring" (ICES, 1978). In this case it seems that when the sub-lethal effect had reached a level that could be statistically demonstrated (increase of non-normal eggs from about 1 to 10%), the macrofauna community had already changed so drastically, that the impact was immediately obvious and beyond the need for confirmation by statistical testing. The total community thus seems to have been a better integrator of environmental impact than a particular physiological parameter of a single species - even a highly sensitive one. This agrees with the suggestion by Mann and Clark (1978) that whole systems are better indicators of oil pollution than single species.

6.4.3 Meiofauna

The meiofauna material suffers from lack of pre-spill data from station 20 (pre-spill samples are available but have not yet been sorted). All post-spill cores collected at station 20 are exceptionally low in both ostracods (Fig. 6.11) and other non-nematode meiofauna (Fig. 6.12), when compared both to station 15 and 8 other mud stations in the 25-45 m depth range (taken from a survey of the Askö-Landsort area by Ankar and Elmgren, 1976; Fig. 6.14). Pre-spill macrofauna data shows station 20 to be a rather normal station (except for a trend of increasing biomass of Macoma balthica, due to eutrophication), and there is thus no reason to expect it to have harbored an aberrant meiofauna. This would suggest that the extremely low post-spill meiofauna values are a direct oil effect. For the ostracods, with their protective shells, it is also possible that some recently dead animals were counted as live (since the samples were counted after preservation).

The dredge samples of large ostracods taken in February and March show a much higher proportion of live ostracods at the reference station 15 than at the spill station 20, where only few live large ostracods were found (Fig. 6.13). This is not directly comparable to the results from the meiofauna cores (where a 40 µm sieve was used) since only the largest ostracods were included, (0.5 mm screen), but it represents a much larger sample, and is therefore probably more reliable. There is thus some evidence of a high mortality of ostracods and other non-nematode meiofauna following the spill, but not enough to be entirely conclusive. The ostracod species concerned, and most of the other meiofauna, lack swimming ability, and could not have emigrated from the area.

The continued low abundance of all meiofauna except nematodes, for 10 months following the spill, also indicates the low post-spill populations to be an oil effect, since a great development of the meiofauna would normally have been expected after the reduction of the competing macrofauna. For most of this period oxygen conditions were good, and contributed no alternative explanations for the low non-nematode meiofauna at station 20.

The post-spill meiofauna samples from station 20 are similar in many aspects to the meiofauna community found after several months of oil addition (190 ppb average of No. 2 fuel oil) to MERL experimental ecosystems (MERL = Marine Ecosystems Research Laboratory, Graduate School of Oceanography, University of Rhode Island, USA. In press by Elmgren et al., also Grassle et al., 1978). Similarities include almost total dominance by nematodes after prolonged oil exposure and very rapid and drastic reduction in ostracod numbers following exposure. A detailed comparison of the two data sets will help in evaluating the usefulness of experimental ecosystems for studying and predicting the effects of oil and other pollutants in the marine environment.

6.5 Summary and conclusions

Considerable amounts of oil reached the sediment within a week at the most heavily affected stations, as shown by sediment trap data (see Section 4). After one month, oil analyses of Macoma balthica showed contamination with oil at several, widely separated stations. The macrofauna community responded drastically at station 20, and probable short-term effects were seen also at station 21. The vagile macrofauna, especially the amphipods died at or emigrated from the most affected station (No. 20). The few remaining gravid amphipods showed an increased frequency of abnormal eggs. No reduction in abundance or biomass was found in Macoma balthica or Halicryptus spinulosus. All meiofauna except the nematodes was drastically reduced at station 20 and a large kill of ostracods seems to have taken place relatively soon after the spill. In spite of these clear ecological effects, no Tsesis oil hydrocarbons could be conclusively demonstrated in the sediments, probably due to inadequate sampling methods. Neither the affected macrofauna, nor the meiofauna showed any evidence of recovering within the 9-10 month period after the spill so far studied.

6.6 Suggested further studies

The Tsesis spill clearly offers an unusual opportunity to monitor the recovery of a benthic soft bottom after moderate damage by oil pollution. Good pre-spill data are available for the macrofauna and can be obtained for the meiofauna. The following studies are planned:

1. To work up available pre-spill meiofauna samples from stations 15, 20 and 21 and more post-spill cores from stations 20 and 21. Station 20 has the highest priority.
2. To continue sampling stations 20 and 21 for meio- and macrofauna until recovery at station 20 is complete.
3. To survey the affected area. This will be done in summer 1979 by means of a grid of about 40 van Veen grab samples, covering the suspect area. Macrofauna and large meiofauna (0.5 mm sieve) will be analyzed. This may locate areas where the impact on the benthos community has been even more drastic than at station 20. If so, then at least one of these should be included in the future sampling program (2 above).

6.7 Acknowledgement

The expert statistical help of Ann-Sofi Matthiessen, Department of Statistics, University of Stockholm, was greatly appreciated.

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7. Impact of Oil on the Littoral Ecosystem

CHAPTER 7: IMPACT OF OIL ON THE LITTORAL ECOSYSTEM

7.1 Introduction

(Mats Notini)

When an oil spill occurs in coastal regions, littoral communities are often severely damaged (Southward and Southward, 1978; North et al., 1965; Blumer et al., 1971). However, as Michael pointed out in 1977, more studies of long-term and low-level effects of oils on basic community processes are needed. The degree and duration of the injuries vary depending on the quantity and quality of the oil reaching the shore line. The clean-up techniques employed when removing the oil may also significantly affect duration and degree of damage.

The residence time of the oil in the littoral system is dependent on the energy input in the area and mechanical energy (e.g., wind and wave action, presence of ice) is the single most important factor (Owens, 1978).

The Tsesis ran aground in shallow, narrow waters and large amounts of the oil could not be prevented from reaching the nearby shores during the first hours and days after the accident. Therefore, extensive effects on the littoral communities could be predicted.

On the second day following the accident (October 27), quantitative "pre-spill" sampling of the Fucus fauna was made at four as yet unaffected stations (Section 7.2). Three of these stations were later hit by the oil spill. Sampling and studies of the effects of the oil on these stations and three complementary stations were repeated at intervals during the first year following the spill.

Another type of study carried out in the littoral zone at the same seven stations is reported in section 7.3. Here, the fauna and flora of the typical vegetation belts (i.e. Ceramium, Fucus and red algal belts) and Mytilus belts along the bottom slope were sampled according to the technique described by Dybern et al. (1976). With this method not only the plants themselves but also the animals dwelling in the algae and those living on the bottom below are sampled. This sampling was carried out in November 1977 and June 1978.

The third type of study carried out in the littoral zone concerned in situ measurements of community metabolism according to the method described by Guterstam, 1977 (Section 7.4). This investigation was carried out during the acute phase of the accident.

7.2 Effects on Fucus macrofauna

(Mats Notini)

7.2.1 Introduction

The extensive archipelagos of the Baltic cover about 6% of its surface area. The bladder wrack Fucus vesiculosus is the dominating seaweed of the archipelagos all around the Baltic.

There is no question as to the central role played by this alga in the ecological system of the Baltic sea. The net production of the bladder wrack in the area of Askö has been estimated for September to be about 20% of the entire plant plankton production. The annual production of the seaweed is probably higher, since macroalgae grow also when the plankton biomass is low (Guterstam, 1977). It has a maximum density at a depth between 0.5 and 2 m. This zone contains a great variety of ecological niches and is probably the most diverse and productive habitat in Baltic shallow waters (Jansson and Wulff, 1977). More than 70% of the macroorganisms of the Baltic sea occur at one time or another in this belt (Haage, 1969). The food chains of about 50 species of fish and 40 species of birds run through this area (Jansson, 1974).

In the enclosed Baltic sea and its extensive archipelagos the diverse ecosystem of the Fucus belt is never far away. Therefore, any major oil spill in this area will reach this system within hours or at the most a few days. A recent study indicated drastic and long-term effects of an oil spill in this system (Notini, 1978). Almost the entire fauna belonging to the Fucus zone was wiped out and recruitment was found to take several years. This spill occurred at the same season of the year (October 1970) about 30 km northeast of the Tsesis grounding.

7.2.2 Materials and methods

Quantitative samples of the Fucus belt macrofauna were taken at 7 stations in an area 2 to 10 km from the Tsesis. The locations of the stations and the ship are shown in Fig. 7.2.1.

Three of the stations (A, B and C) are located on the west shore of the island Torö. These were the shores first hit by the oil spill, on the day after the accident (October 27).

The two stations D and E were reached by the oil after approximately 5 to 10 days, respectively. Stations F and G are both situated within 2 km of the grounding place. F is located on the small island of Tallören east of Tsesis. Although the oil spill during the first days drifted towards that island most of the visible oil passed it on both sides. Station G north of Tsesis was never visibly oiled but on some occasions slicks drifted close by.

The samples were taken by the so-called plastic-bag method. A diver slipped a plastic bag over a randomly chosen Fucus plant at the selected location. The water was strained off and the bag with its content of algae and animals was transported to the laboratory for deep freezing. Five samples were collected on each sampling occasion. The individual samples were later thawed and analyzed by standard methods. Thus, the composition and biomass of the fauna, the distribution of sizes, the growth of the algae, and other items can be studied.

The preliminary results presently available are based on a first inspection of 104 of the total 212 samples (Table 7.2.2.1). So far the animals in these samples have been counted and classified into systematic groups. Arithmetic means of density of the normally most abundant groups are given, whenever possible with 95% confidence intervals.

During the first year following the spill Mytilus edulis were collected for oil analysis at the same 7 stations.

7.2.3 Preliminary results

A drastic decrease of the total Fucus macrofauna took place along the shore that was first hit by the oil spill (on October 27). During the following two weeks the arithmetic means of the density figures were

TSESIS

Fig. 7.2.1 Location of stations used in the littoral studies

Table 7.2.2.1 Fucus Bag Sampling

	Number of samples taken						
	Station:						
Date of sampling	A	B	C	D	E	F	G
10.27.77	(5)[x]		(5)[x]	(5)[x]			(5)[x]
11.02.77				(5)			
11.09.77	(5)		(5)	(5)	2(0)	5(0)	5(4)
11.15.77		(5)					
12.14.77	(5)	(5)	(5)	(5)	5(0)	(5)	5(0)
5.02.78	5(0)	5(3)	(5)	5(0)	5(0)	(5)	5(3)
6.20.78	5(1)		5(0)	5(0)			5(0)
8.28.78	5(0)	5(0)	5(0)	5(0)	5(0)	5(0)	5(0)
10.30.78	5(0)	5(3)	(5)	5(0)		5(0)	(5)

[x] pre-spill samples

( ) number of samples examined

only 8-10% of the pre-spill situation at stations A and C. Station B between these two stations was probably affected in the same way (Fig. 7.2.3.1). During the same period no such decrease occurred at the "reference" Station G. Station D, which was hit by the oil four days later, showed a possible decrease in magnitude of 40-50% although the variations in the samples were high. Samples from stations F and E have not been sorted yet, but observations during diving operations in the area indicated less acute damage compared to stations A, B and C.

In spite of the initially heavy degree of oil pollution, a significant recolonization of the Fucus fauna had already started in the middle of December 1977 at Stations A and C. At Station C the total number of macrofauna specimens in October 1978 was of the same order as in October 1977 before the oil hit the station. At Station G also, the "reference" station, the situation in October 1977 and 1978, respectively, was very much the same. The process of recolonization seemed to be slower at Station B and possibly at Station D.

The crustaceans Gammarus spp., Idotea spp. and Iaera spp. (Fig. 7.2.3.2, 7.2.3.3 and 7.2.3.4, respectively) were all drastically reduced by the oil. The specimens of the amphipod Gammarus spp. were sorted into two length classes, > 10 mm and < 10 mm (Fig. 7.2.3.2). The preliminary results show no differences in the effect of the oil on these two groups. In November 1977 Gammarus spp. was totally missing or significantly reduced at all examined stations hit by the oil (Stations A, B, C and D) compared to the pre-spill situation in October. But a recolonization had already started in December 1977 at stations A and D. The isopods Idotea spp. and Iaera spp. (Fig. 7.2.3.3 and 7.2.3.4) were not totally missing in the November samples, but individuals remaining were very few. At station B Iaera spp. was completely missing both in December and in May, half a year after the accident. Recolonization by Idotea spp. at the same station seemed likewise to be a slow process. However, in October 1978, one year after the Tsesis ran aground, a considerable recolonization of both species had taken place at station B.

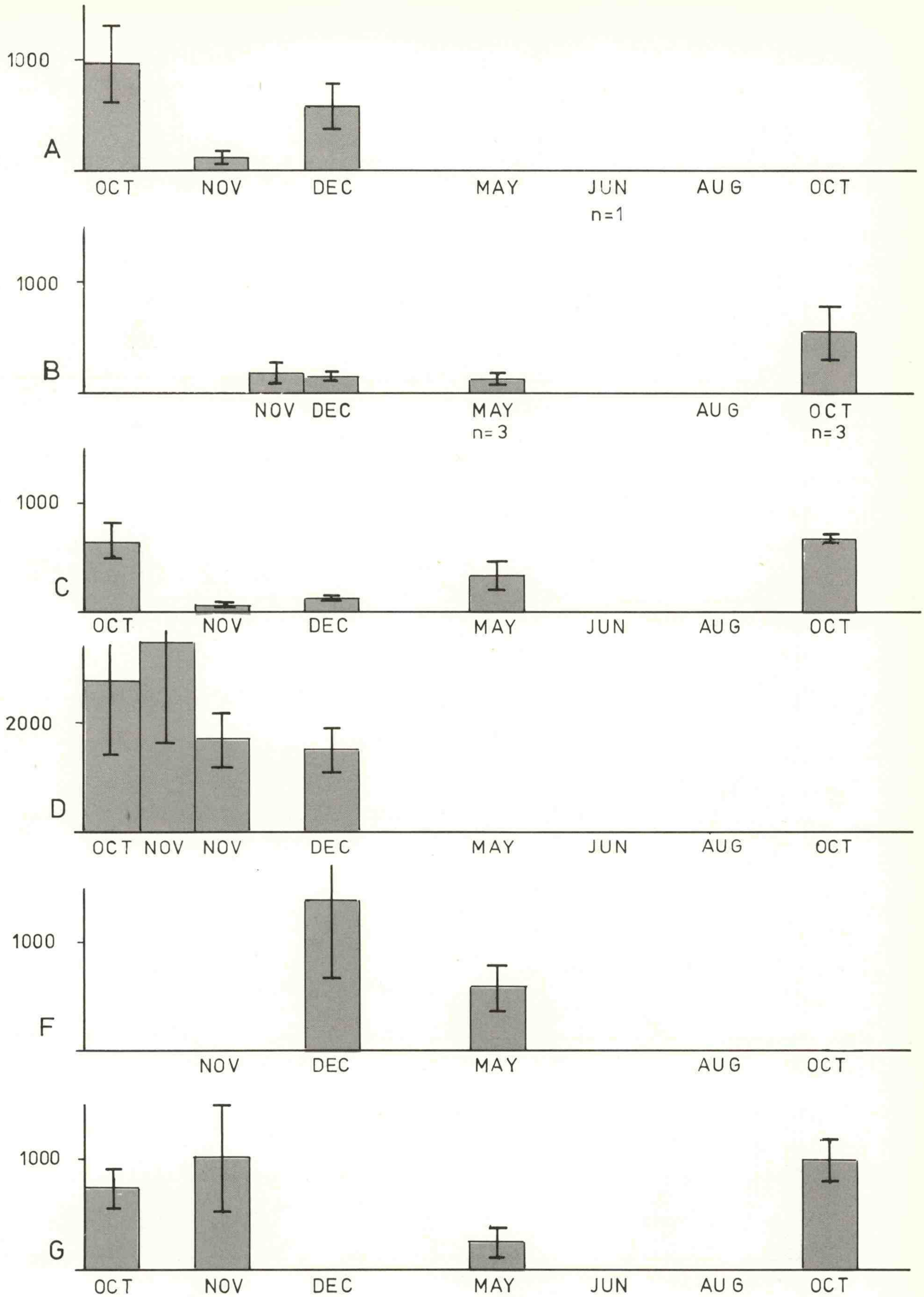

Fig. 7.2.3.1 Total number of macrofauna specimens in Fucus samples first year following the spill. I = 95% confidence interval for population means.

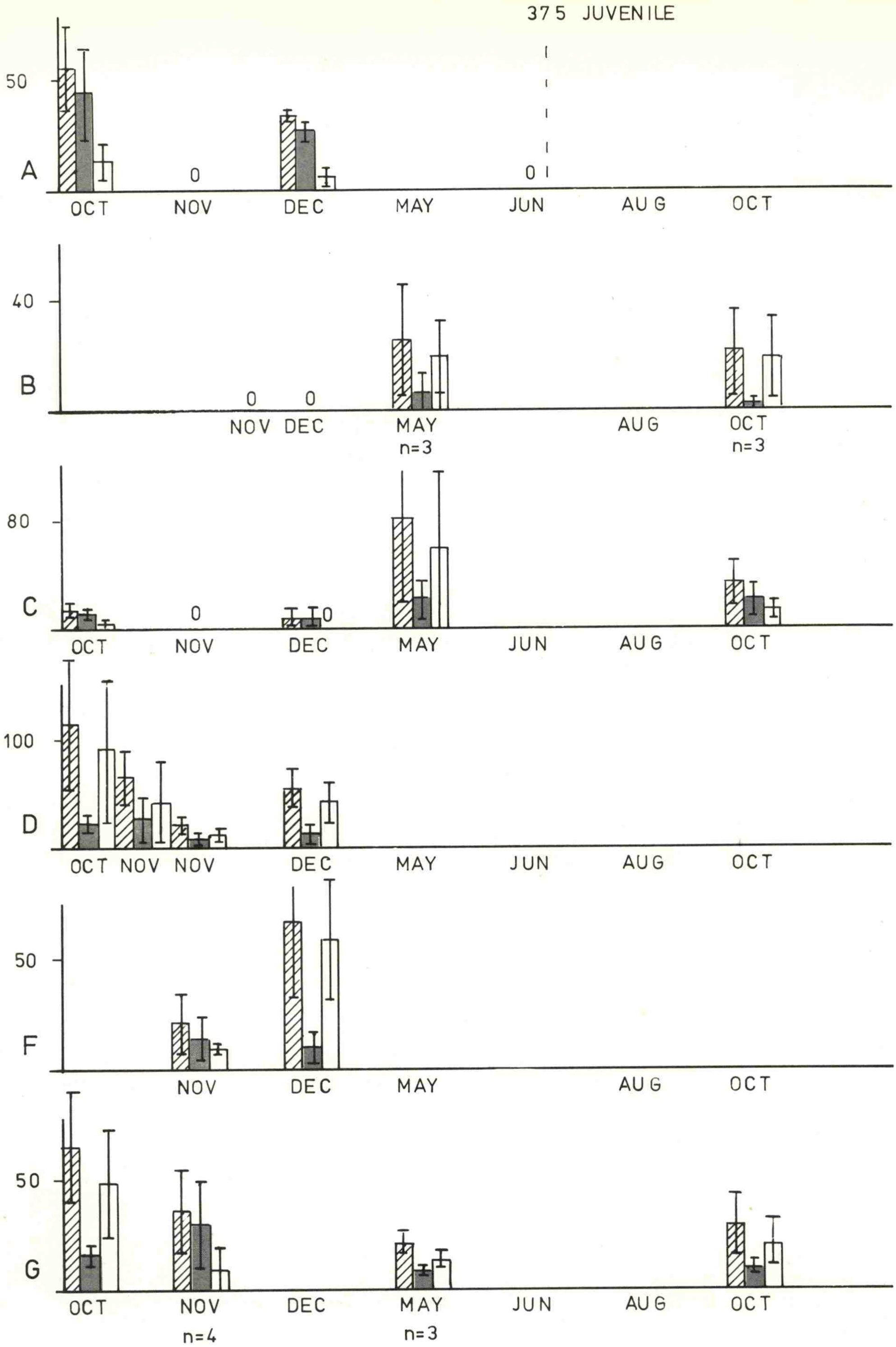

Fig. 7.2.3.2 Number of Gammarus spp. in Fucus samples first year following the spill. I = 95% confidence interval for population means.

▨ = total number ■ = adults > 10 mm

□ = juveniles < 10 mm

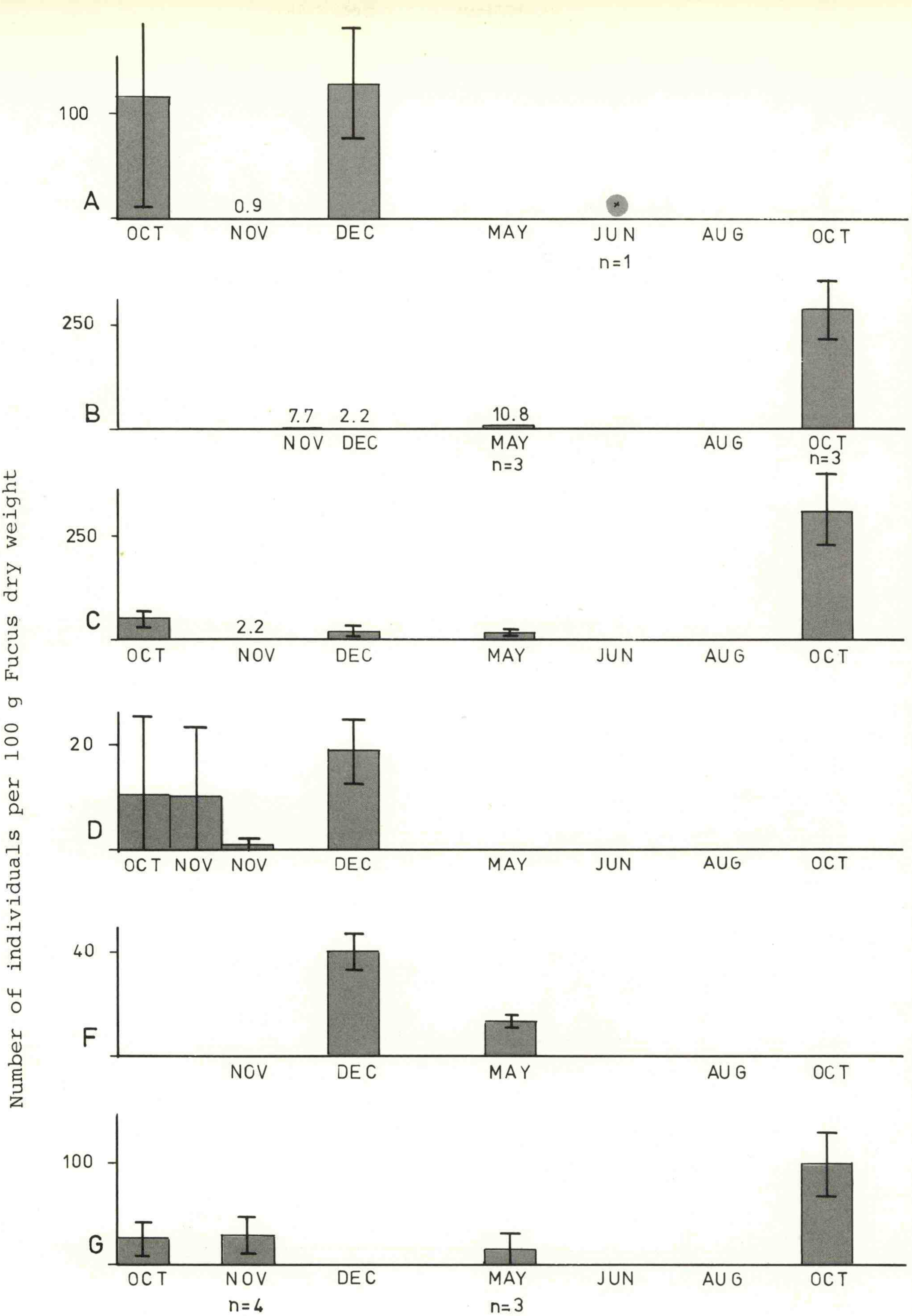

Fig. 7.2.3.3 Number of Idotea spp. in Fucus samples first year following the spill. I = 95% confidence interval for population means.

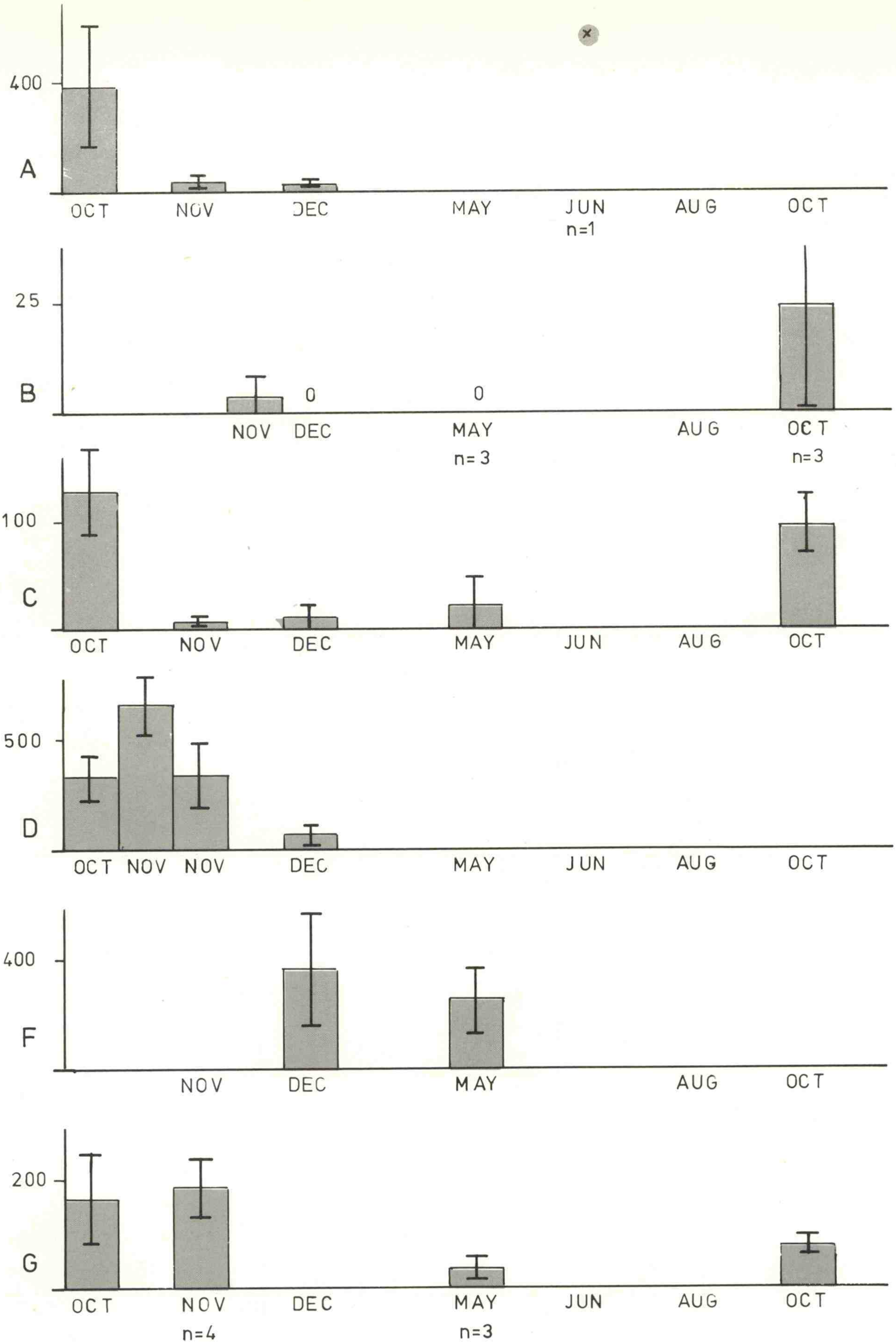

Fig. 7.2.3.4 Number of Iaera spp. in Fucus samples first year following the spill. I = 95% confidence interval for population means.

The dominating bivalve in the area, Mytilus edulis, showed great fluctuations in the Fucus samples, both within a sample set and between the sets (Fig. 7.2.3.5). However, a decrease in density figures in November compared to October due to oil was found. During the same period no such decrease occurred at Station G. The effects are there but closer analysis of the collected data is needed. When the Mytilus edulis from stations C and G are sorted into two groups (> 5 mm and < 5 mm), comparison of these size groups strongly indicates a mortality of small individuals (< 5 mm) at Station C (Table 7.2.3.1).

The abundance of Theodoxus fluviatilis, the dominating gastropod in the area, also decreased significantly during the first months following the spill (Fig. 7.2.3.6), but at station C recolonization was very slow. In October 1978 the mean density figures were still significantly lower than in October 1977.

7.2.4 Discussion

Unfortunately, sorting and examination of Fucus samples is very time consuming. At present 49% of the collected Fucus samples have been inspected. In spite of this the available data presented here strongly indicate drastic effects on the Fucus macrofauna in the area. The abundance of all macrofauna species, with the possible exception of the barnacles Balanus improvisus, decreased during the acute phase at stations affected by the oil. Comparison with the reference station G on the island of Fifong shows no such decrease there during the same period.

The degree and duration of the damage varied at the different stations. From the results available, station B and C were probably the stations most affected, followed by station A. Station D showed a smaller degree of acute effect and a preliminary look at the samples from station E shows the same type of results. This may be explained by the fact that the oil reached these locations 5 to 10 days after the oil spill occurred. Therefore, this oil had been weathered for a longer period of time compared to that at stations B, C and A. Both these stations (D and E) are situated in shallow bays with low water exchange. They are the most protected of the stations studied here. Therefore the

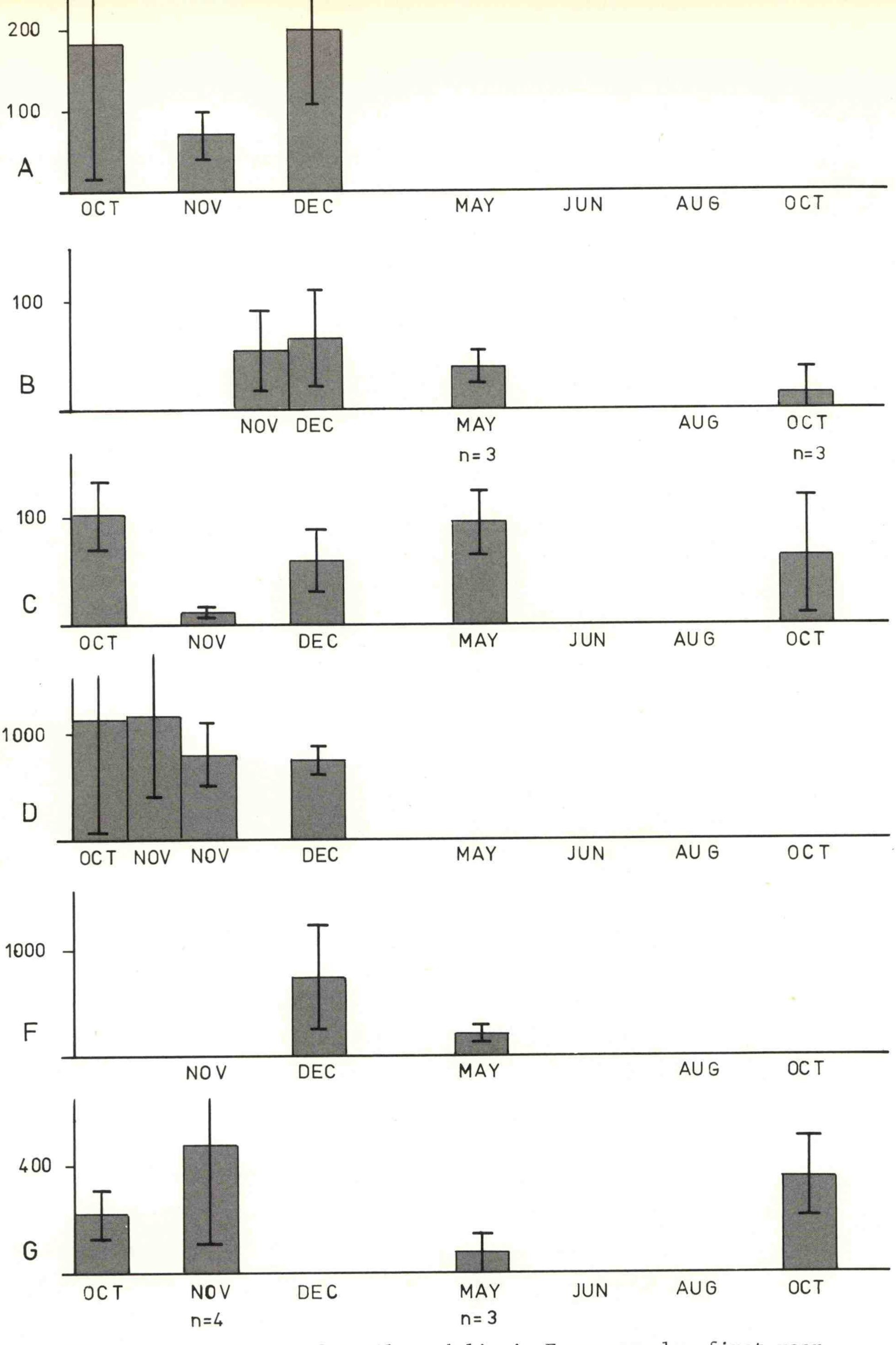

Fig. 7.2.3.5 Number of Mytilus edulis in Fucus samples first year following the spill. I = 95% confidence interval for population means.

Table 7.2.3.1 The Percental Distribution of Mytilus edulis in 2 Size Classes at 2 Stations

Date	Station C		Station G	
	> 5 mm	< 5 mm	> 5 mm	< 5 mm
10.27.77	71.6	28.4	44.2	55.8
11.09.77	99.2	0.8	38.9	61.1[x]
12.14.77	100	0	-	-
05.02.78	85.6	14.4	81.6	18.4[xx]
10.30.78	90.8	9.2	18.0	82.0

[x] based on 4 Fucus samples

[xx] based on 3 Fucus samples

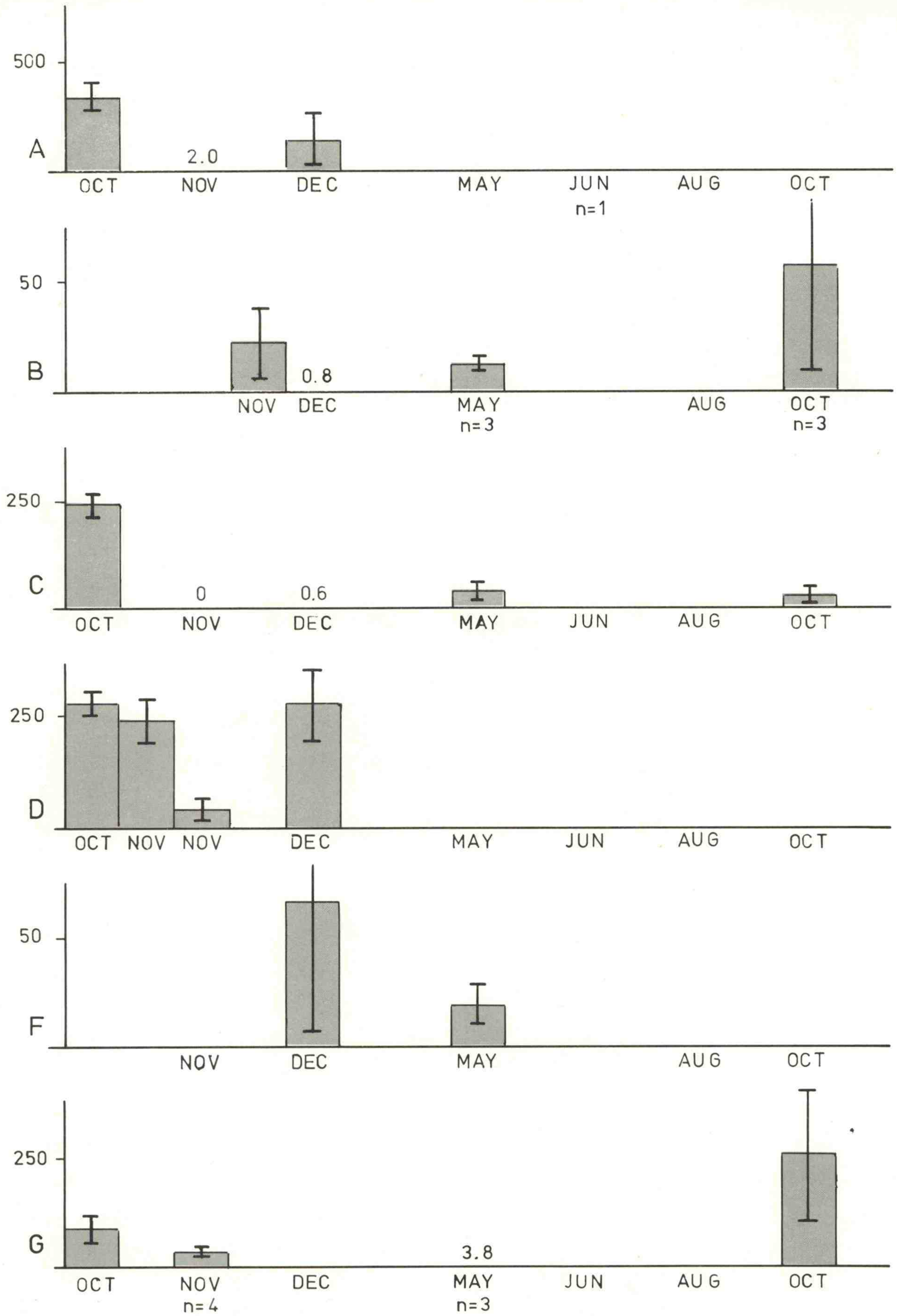

Fig. 7.2.3.6 Number of Theodoxus fluviatilis in Fucus samples first year following the spill. I = 95% confidence interval for population means.

long-range effects may be of the same magnitude as at the other stations, as the residence time of the oil in the littoral system is dependent on the energy in the system (Owens 1978).

The relatively fast recolonization of Station A may be explained by the fact that this station was exposed to oil during a comparatively short period of time. Due to a change in wind direction on October 28 the drift of oil towards shore stopped. Thus, this station was exposed to the drifting oil spill for less than 24 hrs. In December 1977 a significant increase of most faunal species had already occurred at station A.

Only one genus, Iaera, did not increase during that period. This may be explained by the low mobility of these small animals. At Station B, in the center of the polluted area, recolonization of this species had not started in May 1978.

Crustaceans are without doubt sensitive to oil pollution (Notini and Hagström 1974; Lindén, 1976; Notini, 1978) and many of them must have died during the acute phase of the Tsesis oil spill. The results from this study indicate that the recolonization of these species to a great extent is due to a horizontal migration from the unaffected areas.

The early recolonization of the molluscs was, however, largely dependent on the vertical recolonization by surviving individuals. These were narcotized during the acute phase of the spill. By wave action they were swept down from the Fucus plants to the bottom. Later, the surviving individuals recovered and reentered the Fucus. As indicated in Table 7.2.3.1, the mortality among small Mytilus edulis seemed to be higher than that among larger individuals. Similar observations have been made in previous studies (Notini, 1978).

Bivalves have been found useful for monitoring petroleum input since they reflect the concentration and relative amounts of different hydrocarbons in the water (Lee, 1977). They are able to bioaccumulate, but cannot metabolize hydrocarbons in their tissues. Thus, the Mytilus samples from the different stations in this study are of great interest since they make it possible to estimate dose and response data in situ as well as the background oil contamination before the spill. These

preliminary data indicate Station C to have had the highest concentration of oil in water during the acute phase. But the samples also indicate relatively high amounts of aromatic hydrocarbons in the tissues of Mytilus from Station G. Together with data from sediment traps and Macoma balthica, this shows that Tsesis oil must be considered widely spread in the area. Station G can thus not be considered as a "non-affected" station, even though the samples of the Fucus fauna showed no clear reduction of the fauna.

The data presented here clearly demonstrates drastic effects on the animal life of the Fucus community. On the other hand recolonization at several stations started soon after the acute phase.

7.2.5 References

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7.3 Effects on the phytal ecosystem

(H. Kautsky)

7.3.1 Materials and Methods

Seven stations were chosen to represent the entire area contaminated by the oil spill (Fig. 7.2.1). Most stations were placed in coves as it was expected that these would hold the oil for a longer time and the pollution effect would be higher and easier to detect. In some cases the oil was, in fact, forced into the coves with the help of spill-booms. All seven stations, including a reference station (G) with no visible oil spill, were sampled in November 1977 and resampled in June 1978. From the June sampling only 3 stations have been sorted (B, D and G).

Sampling was done by SCUBA divers, using the technique described in Dybern et al. (1976) and by Jansson and Kautsky (1977). The vegetation coverage and the Mytilus edulis coverage were estimated visually. The vertical extent of each identified belt was noted. Within each zone, quantitative samples were taken at random. In November, the sampling sites were marked with bricks; in June, random sampling was made in the vicinity of these bricks in order to facilitate comparison between November and June samples. Square frames with a side of 15, 20 or 50 cm were used depending on the kind of vegetation dominant in each belt. The samples in November were sorted and dried shortly after collection; in June the samples were frozen and sorted later.

The samples were analyzed for species composition, abundance and biomass. The results are given in individuals per m^2 or in g dry weight per m^2.

7.3.2 Results

7.3.2.1 Field observations

November: At the most contaminated stations B, C and D (see Fig. 7.3.1) no free-swimming animals could be observed. At location B an oil smear was identified on Mytilus edulis down to a depth of 4 m.

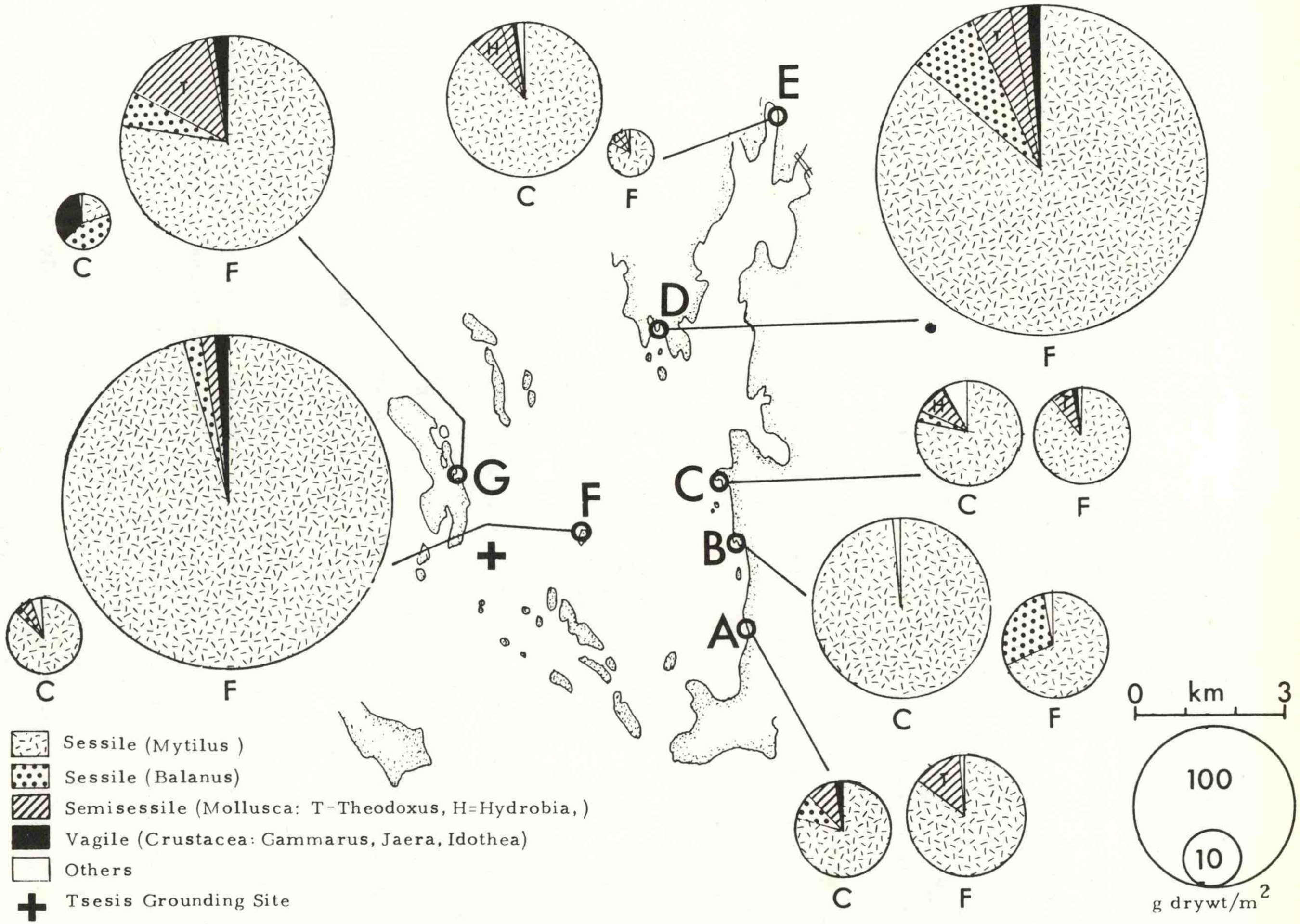

Fig. 7.3.1 Results for Cladophora (C) and Fucus (F) from samplings at seven stations in November 1977 and June 1978; samples were analyzed for species composition, abundance and biomass.

June: The sulphur bacterium Beggiatoa, which is an indicator of reduced bottoms, is not uncommon in the area, especially in depressions with stagnant water, often at the bottom of the littoral slope. At the oil polluted stations, Beggiatoa covered greater than normal areas even on flat bottoms in June 1978. A higher frequency of Mysidae could be observed at the reference station G and around the Askö Laboratory (adjacent area) than at contaminated stations. A peculiar growth of the tips of Fucus vesiculosus was also observed at station B and in lower frequency at Station C. It looked as if young plants had settled on the old degraded plant tips. On the shore at station B, a beach clean-up was carried out in June, causing a light oil film on the surface water. Samples taken on the deep Mytilus bottoms (8 m depth) visibly contained oil. The Cladophora belt was a bit broader in June, probably due to low water during spring.

7.3.2.2 Calculations from collected data

November: A summary of biomass and frequency of dominating animal groups in the Cladophora and Fucus belt in November is made in Table 7.3.1. In some vegetation belts at the most contaminated stations, animal species groups, common at the reference station, were absent (Table 7.3.2). The frequency of vagile (and semisessile) forms was very low at stations B, C, D, E and F, probably as a direct response to oil contamination. The mussel Mytilus edulis dominated the biomass in the entire area. At the reference Station G about 20% of the total biomass in the Fucus belt consisted of other species. The vagile forms contributed only a few per cent. In the Cladophora belt about 40% of the total animal biomass consisted of vagile forms. At all other stations Mytilus together with Balanus improvisus dominated the fauna biomass totally, particularly at stations B and F. The vagile forms played a minor part.

June and comparisons with November: The dominating plant species from three vegetation belts are listed in Table 7.3.3. Only five species dominated the biomasses in the specific zones. Cladophora glomerata replaced Ceramium tenuicorne in the shallowest zone (C), and Pilayella

Table 7.3.1 Number of plant and animal species found and total biomass in the different vegetation belts. A comparison between November 1977 and June 1978. The percentual change is also given.

	Depth	PLANTS 0.6 m			1-2 m			-1.5 m		1.5-2 m			3 m	6-8 m		12-15 m		2 m	4 m
BELT		Cladophora			Fucus			Fucus random		Ceramium+Mytilus			Mytilus	Mytilus		Mytilus deep I		Mytilus deep II	Ruppia	Mytilus
Station		G	B	D	G	B	D	B	D	G	B	D	G	G	B	G	B	G	G	D
No. of species	Nov.	3	2	-	4	3	3	1	2	1	1	1	2	-	-	-	-	3	1	
n/m^2	June	8	3	7	5	4	4	5	4	5	5	4	4	4	6	(1)	4	7	-	
Change %		167	50	-	25	33	33	-	100	400	400	300	100	-	-	-	-	133	-	
Biomass gdwt/m^2	Nov.	18	45	-	905	199	534	-	497	13	11	2	10	-	-	-	-	102	1	
	June	42	75	38	990	417	768	619	235	60	74	30	37	9	5	0	+	188	-	
	S.E.	3	8	5	306	11	61	113	31	-	30	6	-	3	2	-	-	20	-	
Change %		138	67	-	9	110	44	-	-53	356	528	1210	270	-	-	-	-	84	-	
		ANIMALS																		
No. of species	Nov.	7	4	-	11	8	7	-	8	8	6	5	8	-	-	-	-	7	7	
n/m^2	June	9	4	8	13	11	11	11	11	9	12	11	13	15	12	9	13	11	-	
Change %		43	0	-	18	11	57	-	22	12	100	120	62	-	-	-	-	57	-	
Biomass gdwt/m^2	Nov.	18	166	-	162	43	659	-	143	1142	1833	1555	2304	-	-	-	-	294	506	
	June	6	4	7	64	71	118	83	23	779	1073	957	1516	1478	815	863	374	266	-	
	S.E.	3	1	2	27	7	19	28	1	-	341	187	-	138	51	171	20	65	-	
Change %		-70	-98	-	-61	+65	-82	-	-84	-32	-42	-38	-34	-	-	-	-	-9	-	

S.E. = Standard error of mean + = less than 0.5 - = no sampling

Table 7.3.2 The abundance of the dominant animal species at stations B, D, and G (reference) in November 1977 and June 1978.

ABUNDANCE
% share
> 50 +++
> 5 ++
> 1 +
> 0 (+)

	FIFÅNG (G)						N. SKÖTSKÄR (B)						LINDHOLMEN (D)					
	November			June			November			June			November			June		
	C[x)]	F[x)]	M[x)]	C	F	M	C	F	M	C	F	M	C	F	M	C	F	M
Mytilus	++	++	++	++	++	++	+++	++	+++	++	+++	+++		++	++	++	++	++
Balanus	+	++	+		+			+++	++		+	++		++	++		+	+
Macoma											(+)	(+)						(+)
Cardium		+	++		+		+	(+)	(+)		(+)	(+)		+	+	(+)	(+)	+
Hydrobia spp		(+)	++	++	++	+++	+	+	(+)		++	+		++	(+)	++	++	++
Theodoxus		++	+	(+)	++	+		+	+	++	++	+		++	+	++	++	++
Lymnaea stagnalis		(+)																
L. peregra		(+)		(+)	+	+		(+)	(+)		(+)	(+)					(+)	
Idothea	+	++	+	+	+	+	+	(+)		++	+	+		+		++	+	(+)
Iaera	+++	+	++	++	++	++						(+)[xx)]		(+)		++	++	+
Gammarus spp	++	++	++	++	++	(+)				+++	++	++		+		++	++	+
Calliopus				(+)								(+)						
Mysidae					(+)						(+)						(+)	
Plathyhelminthes	+	(+)			(+)	(+)		(+)			(+)	(+)					(+)	(+)
Oligochaeta											(+)							
Prostoma	(+)					(+)												
Chironomidae				++												++	+	+
Trichoptera					(+)													
Pisces juvenile					+						+							
No. of species	7	11	8	9	13	9	4	8	6	4	13	12	-	8	5	8	12	11
Total abundance/m² absolute ± S.E.	±6764	2744	14124	2335 ±946	3757 ±1346	23423	10296	1116	17336	444 ±220	3966 ±456	15340 ±3272		18732	21428	2351 ±489	7315 ±785	26099 ±5373

x) C = Cladophora belt 0.6 m depth
F = Fucus & Fucus "random" belt 1-2 m depth
M = Ceramium & Mytilus belt 2 m depth

xx) one individual, probably artifact

littoralis and Ectocarpus confervoides played a greater role in the deeper zone (M) in June as compared with November. This was most likely due to normal seasonal succession. Fucus vesiculosus, which is perennial, dominated the middle zone (F) all year round. There were more plant species in June at all stations, compared to November, and the increase was similar in all vegetation belts (Table 7.3.1). At station B, however, the change in species in the Cladophora belt was only one third of the change at station G. Generally the number of species was higher at station G.

The plant biomass had increased in the area at all examined stations (Table 7.3.1). It is remarkable that at station B, the Cladophora biomass was about double that of the two other stations analyzed (Table 7.3.3), but the increase from November to June was only about half of that at station G (67% compared to 138%).

The animal diversity increase was somewhat higher at the contaminated stations compared to the reference station. This was particularly obvious in the Ceramium + Mytilus belt. The reason for this increase in diversity is partly that species which were eliminated in November had recolonized the area in June (Tables 7.3.1 and 7.3.2). New seasonal species also appeared at all stations.

The animal biomass decreased at most sampling sites. The decrease was drastic at station B (98% change) in the Cladophora belt due to the disappearance of most of the Mytilus. The increase of biomass in the Fucus belt (65% at station B) was due to recolonization by Mytilus. In the other vegetation belts the change at the contaminated stations B and D was approximately similar to the reference station G (Table 7.3.1).

The percentage of vagile animal forms of the total abundance and biomass in the different belts changed drastically at the contaminated stations B and D (Fig. 7.3.3 and Table 7.3.4). Figure 7.3.3 shows the percentage and biomass of dominating animals in the Cladophora (C), Fucus (F) and Ceramium + Mytilus (M) belts in November and in June. Figure 7.3.3 and Table 7.3.4 show a recolonization by vagile forms. The percentage of vagile forms had more than doubled in all samples from stations B and D in June. At Station G, only 40% of the samples doubled their share of vagile forms.

Table 7.3.3 The percentage of the total biomass contributed by the dominant plant species at stations B, D and G (reference) in November 1977 and June 1978.

PLANTS % share of total biomass ±S.E.	FIFÅNG (G)						N. SKÖTSKÄR (B)						LINDHOLMEN (D)					
	November			June			November			June			November			June		
Species	C	F	M	C	F	M	C	F	M	C	F	M	C	F	M	C	F	M
Cladophora	70			94±6	+	3				88±6	+	1+1				78±10	+	+
Fucus		100		(+)	97±30			100			99±16	20±15		98±2		(+)	98±24	1±1
Ceramium	24	+	100	2±0.1	+	65	100		100	2±2	+	4±3		2±1	100	18±1	+	73±16
Pilayella + Ectocarpus		(+)		4±2	3±2	26		(+)			7±3	+ 45±3			(+)		2±1	1+1 26±4
Rivularia	6			(+)	(+)		(+)				(+)							
Enteromorpha						(+)		+									1±1	
Nemalion										3±0.01								
Dictyosiphon				(+)													1±1	
Chorda				(+)													1±1	
Eudesme				(+)														
Furcellaria						6						30±21						
Ruppia		(+)																
	100	100	100	100	100	100	100	100	100	100	99	100	-	100	100	101	99	100
Tot. biomass g dry weight m^{-2}	18	905	13	42	990	60	45	199	12	76	518	74	-	516	2	38	590	30
No. species	3	4	1	8	5	5	2	3	1	4	5	5	-	3	1	7	4	4

\+ = under 1%
(+) = under 1%, observed in the sample

C = Cladophora/Ceramium belt 0.6 m depth
F = Fucus + Fucus random belt 1-2 m depth
M = Ceramium + Mytilus belt 1.5-2 m depth

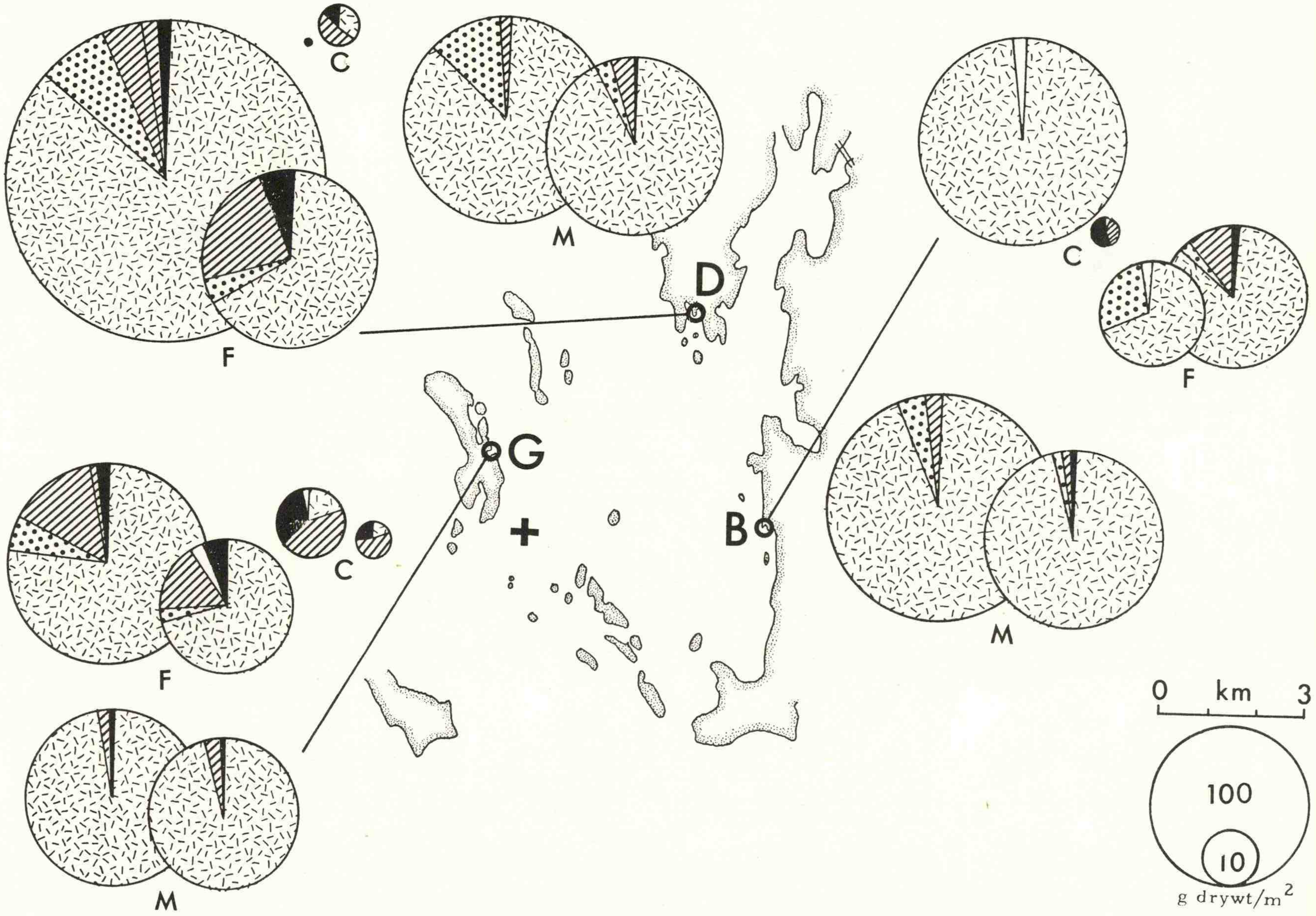

Fig. 7.3.2 Percentage and biomass of dominating animals in the Cladophora (C), Fucus (F), and Ceramium + Mytilus (M) belts in November 1977 and June 1978. See Fig. 7.3.1 for key to markings.

Table 7.3.4 The percentage of total animal biomass for the sessile, semisessile, and vaginal forms in the investigated vegetable belts at stations B, D and G. A comparison between November 1977 and June 1978 with the percentage change indicated.

% Share of Total biomass

BELT		Cladophora			Fucus			Fucus rand.		Ceramium+Mytilus			Mytilus	Mytilus deep I		Mytilus deep II		Ruppia	Mytilus
Station		G	B	D	G	B	D	B	D	G	B	D	G	G	B	G	B	G	D
SESSILE	Nov.	63	99	-	83	98	96	-	92	97	98	99	99.7	-	-	-	-	78	91
	June	20	6	34	76	93	84	82	58	96	98	94	97	92	97	94	89	63	-
	Change %	-69	-94	-	-8	-5	-12	-	-37	-1	+ 0.4	-5	-2	-	-	-	-	-19	-
SEMISESSILE	Nov.	0	1	-	15	2	4	-	7	3	2	1	0.3	-	-	-	-	22	9
	June	54	40	52	17	6	14	18	30	4	1	6	2	7	3	6	10	36	
	Change %	++	4378	-	15	216	271	-	307	28	-33	663	600	-	-	-	-	67	-
VAGILE	Nov.	36	0.3	-	2	0	0.6	-	1	0.5	0.1	0	0.02	-	-	-	-	0.8	0.02
	June	26	54	14	7	1	2	0.4	12	0.4	0.4	0.2	0.6	0.1	0.01	0.1	0.6	1	
	Change %	-27	17867	-	200	++	267	-	1070	-20	300	++	2900	-	-	-	-	25	-

++ = return of species

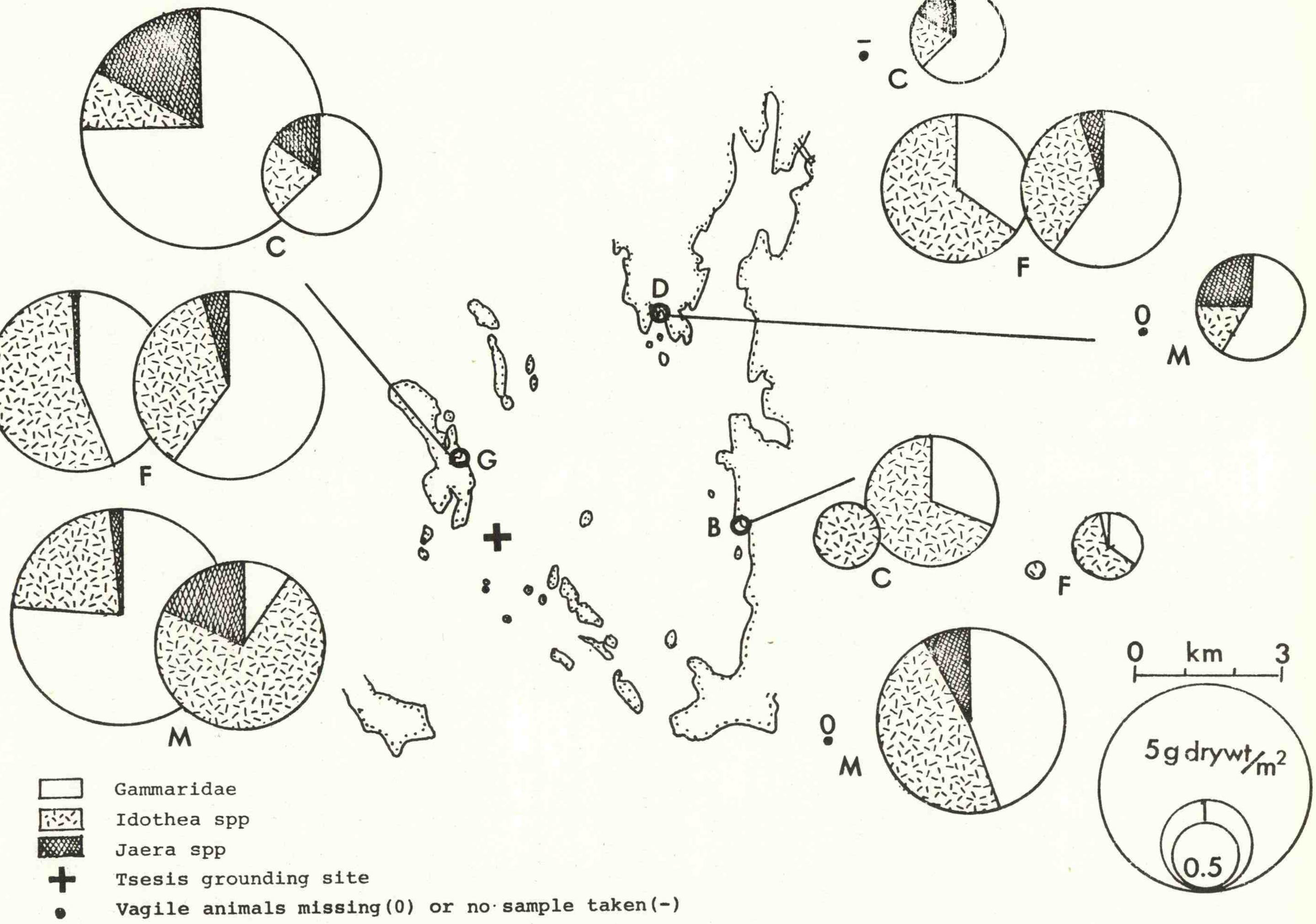

Fig. 7.3.3 Comparison of animal biomass and composition of the vagile fraction in November 1977 and June 1978. For further explanation see Fig. 7.3.2

The percentage of abundance and biomass of dominating and vagile species is shown in Tables 7.3.5a and b. Gammarus spp. and Iaera spp. had a very low share of the abundance in November. In many vegetation belts they were totally absent, for example at station B. In June, Iaera was still missing at that station, except in the Ceramium + Mytilus belt, where a single individual was found.

In June, gammarids occurred in high abundance at all stations (Table 7.3.3 and 7.3.5a). Most of the gammarids were juveniles. Only 8% of the samples contained adult individuals at Station B. Corresponding frequencies for stations D and G were 75% and 80%, respectively.

7.3.2.3 Comparison with data from oil analysis of Mytilus edulis

The oil content of Mytilus edulis at different times of the year is given in section 11.3.1 and Tables 11.1 and 11.2. The analyses showed a low level of oil before the contamination (10/27/77), and a drastic increase after the spill. The oil content then decreased during the year as shown by successive analyses. The high mortality/absence of all vagile forms mentioned above at the contaminated stations in November corresponds well with the high oil content analyzed in Mytilus. The return of vagile forms indicates a healthier environment. This is also indicated by the decreasing oil content analyzed in Mytilus.

7.3.3 Discussion

The vegetation, animal diversity and biomass for each vegetation belt usually showed higher values at the reference Station G, especially in November but also in June (Tables 7.3.1, 7.3.2, and 7.3.3). Station G may be considered to be a typical station for the area. No previous investigations in the surrounding area indicate that it would be extreme in any way (Haage, 1975, 1976; Jansson, 1974; Jansson and Kautsky, 1977, Kautsky, 1974; Wallentinus, 1976). The parallel work of Notini also corroborates this (section 7.2).

No effect of the oil spill on the benthic macrovegetation was observed. The same observations were made in the Baltic by Notini (1978) and Ravanko (1972). They investigated accidents which happened at the same season, before the spring growth.

Table 7.3.5a

The percentage of total abundance for some animal species, sensitive to oil contamination, in the vegetation belts investigated in November 1977 and June 1978. The percentage change is indicated.

% share of abundance (n/m^2)/sample		0.6 m			1-2m			1-1.5 m		1.5-2 m			3 m	6-8 m		12-15 m		2 m	4 m
BELT		Cladophora			Fucus			Fucus rand.		Ceramium+Mytilus			Mytilus	Mytilus deep I		Mytilus deep II		Ruppia	Mytilus
Station		G	B	D	G	B	D	B	D	G	B	D	G	G	B	G	B	G	D
Mytilus	Nov.	19	93	-	19	19	38	-	57	19	65	48	-	-	-	-	-	29	65
	June	6	20	13	18	53	26	60	9	29	77	30	60	45	46	41	53	19	-
	Change %	-69	-78	-	-4	+183	-30	-	-85	+55	+19	-38	-	-	-	-	-	-34	-
Gammarus	Nov.	9	0	-	9	0	1	-	1	16	0	0	2	-	-	-	-	5	0.5
	June	22	60	48	44	15	24	6	47	1	6	2	10	1	0.2	3	2.2	3	-
	Change %	152	++	-	397	++	1762	-	5775	-95	++	++	308	-	-	-	-	-40	-
Iaera	Nov.	67	0	-	3	0	0	-	0.2	6	0	0	0	-	-	-	-	0	0
	June	28	0	16	12	0	6	0	13	7	0.1	3	14	1	0	0.2	0	4	-
	Change %	-59	0	-	259	0	++	-	6550	18	++	++	++	-	-	-	-	++	-
Idothea	Nov.	1	2	-	10	1	2	-	5	0	0	0	0	-	-	-	-	7	0
	June	2	10	21	3	2	2	1	3	1	1	0.1	1	0	0	0	0	1	-
	Change %	46	482	-	-70	200	6	-	-35	++	++	++	++	-	-	-	-	86	-

Table 7.3.5b The percentage of total biomass for some animals, sensitive to oil contamination, in November 1977 and June 1978.

% share of total biomass (g drywt)/ sample		0.6 m			1-2 m			-1.5 m		1.5-2 m			3 m	6-8 m		12-15 m		2 m	4 m
		Cladophora			Fucus			Fucus rand.		Ceramium+Mytilus			Mytilus	Mytilus deep I		Mytilus deep II		Ruppia	Mytilus
Station		G	B	D	G	B	D	B	D	G	B	D	G	G	B	G	B	G	D
Mytilus	Nov.	20	99	-	78	68	87	-	89	96	94	87	91	-	-	-	-	78	91
	June	20	6	34	74	90	77	82	56	96	96	92	94	91	94	91	89	63	
	Change %	-2	-94	-	-5	33	-12	-	-37	-0.5	3	6	3	-	-	-	-	-19	
Gammarus	Nov.	27	0	-	1	0	0.2	-	0.2	0.4	0	0	0.02	-	-	-	-	0.4	0.02
	June	16	16	9	4	0.3	1.3	0.2	7	0.04	0.1	0.1	0.3	0.06	0.005	0.1	0.002	0.2	
	Change %	-40	++	-	290	++	550	-	3350	-90	++	++	1400	-	-	-	-	-50	-
Iaera	Nov.	6	0	-	0.01	0	0	-	+	0.01	0	0	0	-	-	-	-	0	0
	June	4	0	2	0.2	0	0.1	0	0.5	0.1	0.003	0.03	0.1	0.01	0	0.003	0	0.1	-
	Change %	-37	0	-	1900	0	++	-	( )	900	++	++	++	-	-	-	-	++	-
Idothea	Nov.	3	0.3	-	1	0.1	0.3	-	1	0	0	0	0	-	-	-	-	0.4	0
	June	5	38	3	2	0.5	0.8	0.2	4	0.3	0.2	0.02	0.2	0	0	0	0	0.7	-
	Change %	93	12400	-	85	400	168	-	438	++	++	++	++	-	-	-	-	75	-

The peculiar growth of Fucus observed at station B was probably an effect of the low water which exposed the Fucus tips to the air, causing the protective mucilage layer to dry out. This layer may prevent the Fucus plants from being damaged by contamination. The Fucus plants is rather resistant to light and heavy fuel oil exposure, as shown in outdoor laboratory tests (Ganning and Billing, 1974; Notini, 1978).

Results from station B indicate a doubling of the Fucus biomass. This can probably be explained by the heterogeneity of the Fucus belt at that station. A very small change in the sampling site could change the results drastically. It is expected that the Fucus belt would not increase as much as the results indicate. The increase of Fucus biomass (40%) at station D (Fucus belt) might be explained in the same way.

The increase of animal biomass in the Fucus belt at station B in June was caused mainly by increased numbers of Mytilus. These may be the same individuals which were removed and transported from the shallower situated Cladophora belt due to narcosis from oil contamination or through mechanical stress during the cleanup operations on the shore. It could also be due to the larger Fucus biomass sampled.

Some crustaceans, which have a hydrophobic wax layer on their cuticle, are very sensitive to oil contact (Notini and Hagström, 1974). This may explain the drastic decrease of the crustaceans (vagile forms) at the oil-contaminated stations in November.

The rapid recruitment of vagile forms from adjacent areas in the Baltic has also been observed by Pelkonen and Tulkki (1972) and Notini (1978). This is also indicated by the high proportion of young individuals at the contaminated station.

The lack of chironomid larvae at station B (Table 7.3.3) may be an effect from the oil spill as these organisms have proved to be sensitive to oil contamination (Bengtsson and Berggren, 1972). However, the sampling was too small to allow any definite conclusions.

The results of the oil analysis from the reference station G are confusing. The high oil content in Mytilus is not correlated with absence of vagile forms as at the visibly contaminated stations.

This study has indicated a rapid recovery of the phytal system. The oil spill occurred at the beginning of a season of low activity in the phytal zone. The low temperature and ice cover from January to March minimize plant and animal metabolism and growth. Many individuals usually die during winter due to senescence. During these 3-4 months of low activity, before the spring growth started, parts of the remaining oil in the littoral were probably washed out and the toxic fractions diluted. Thus the oil spill did not affect the fauna and flora of this system as much as if the spill had occurred in the beginning of the growth season, in April to June.

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7.4 In situ respiration of three littoral communities near the Tsesis oil spill

(Björn Guterstöm)

7.4.1 Introduction

In order to determine if the oil had affected the community metabolism *in situ* measurements in plastic bags were made on three typical littoral communities of the northern Baltic:

1. the *Fucus vesiculosus* community
2. the *Mytilus edulis* community
3. the "shallow soft bottoms" with *Macoma balthica* and *Hydrobia* spp. as the dominating macrofauna components.

7.4.2 Methods

Part of the communities were enclosed in plastic bags (Ø = 0.5 m, volume 30-70 litres, Fig. 7.4.1, details see Guterstöm, 1977) using SCUBA diving. The oxygen consumption was measured with a YSI oxygen electrode on several occasions over a 24 hr. period.

Experiments were run at the most contaminated stations and at a similarly exposed, "unpolluted" reference station. Further data from these stations are presented in sections 7.2 and 7.3. Due to failure of the Mytilus experiment at the reference locality, these results were compared with results from laboratory experiments.

7.4.3 Results and discussion

The results from the three communities investigated show a typical picture with relatively low respiration at this time of the year (November, Table 7.4.1). Only the Fucus communities at two oil polluted localities showed higher respiration than similar unpolluted localities (Table 7.4.1). An increased respiration due to exposure to oil at increasing concentrations was found in outdoor experiments with F. vesiculosus from the northern Baltic (Ganning and Billing, 1974). The shallow soft bottoms showed the same respiration at both localities. The same was found with Mytilus from oil polluted localities compared with mussels from unpolluted areas.

At the oil polluted localities oil could be seen in the plastic bags after the incubation periods as it had floated up as small drops under the plexiglass covers of the plastic bags in all experiments. In June 1978 oil was still leaching out of the investigated sediments.

Due to the low biological activity during the winter and the few replicates in each experiment, no significant difference in respiration could be found. As shown in Chapter 11 (Tables 11.1-11.4) and discussed in section 7.2.4, the "unpolluted" reference station was later found also to have been contaminated by the oil, even though not by visible slicks. Any effects which might influence the community respiration through changes in animal populations would therefore be expected to be found during the following summer and autumn. Notini (1978) found lower macrofauna populations at oil polluted Fucus communities of the northern Baltic compared to unpolluted communities.

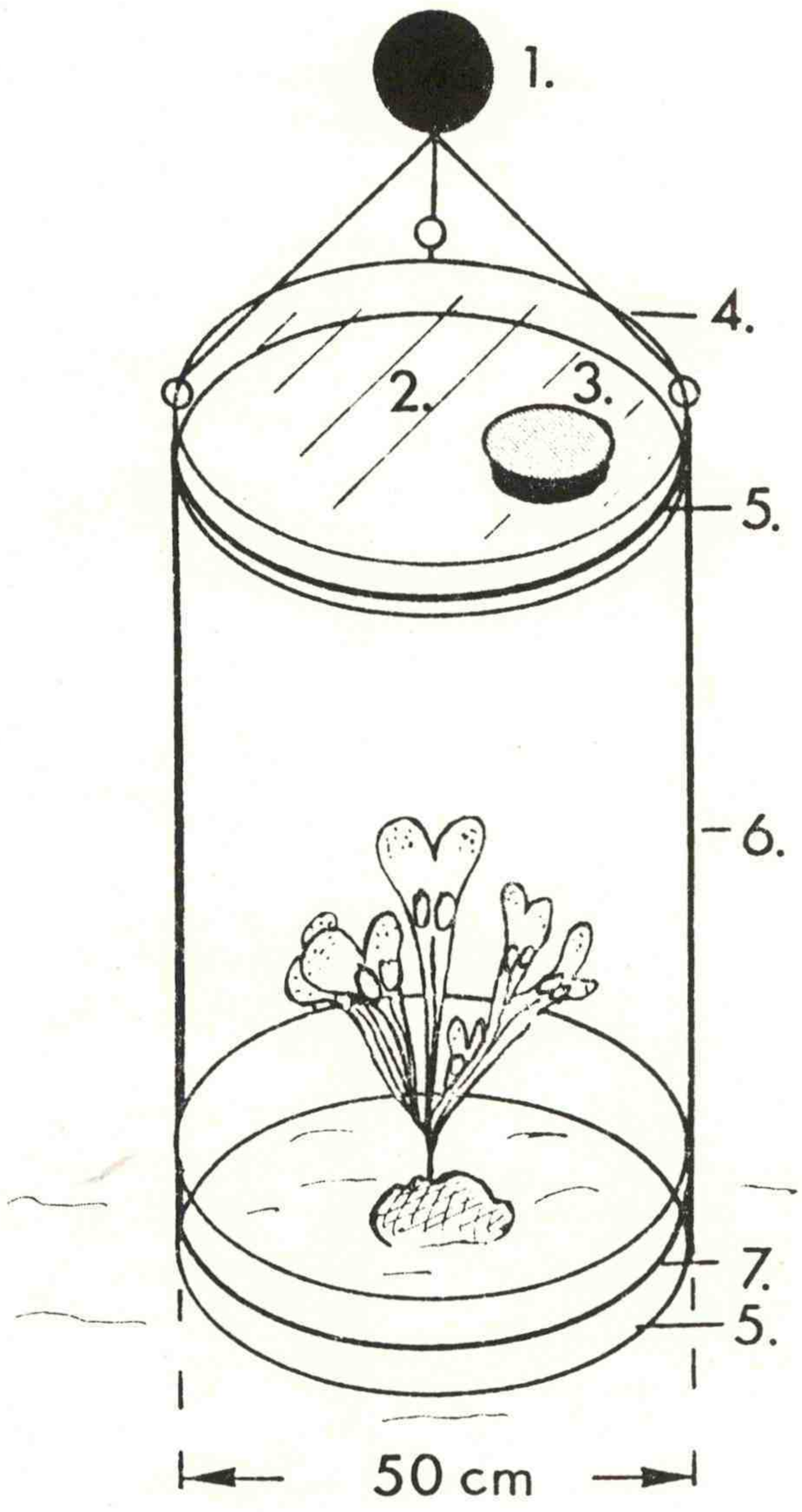

Fig. 7.4.1 Plastic bag 1: buoy 2; plexiglass lid 3; stopper 4; upper ring 5; rubber band 6; plastic 7; lower ring (open).

Table 7.4.1 In situ respiration of three oil polluted littoral communities near the Tsesis oil spill compared with unpolluted communities in the same area. Reference station underlined.

Locality (see Fig. 5.1.1)	Date	Temp. (°C)	Respiration ($mg\ O_2\ g\ dr.wt^{-1}\ h^{-1}$)	Biomass (g dr.wt)	
Fucus vesiculosus (1.5 m depth)					
D	1-2.11.77	8.0	0.29	79	Fucus
D	2-3.11.77	8.0	0.38	79	"
G	2-3.11.77	8.0	0.16	80	"
B	14-15.11.77	6.8	0.07	43	"
B	14-15.11.77	6.8	0.17	27	"
G	14-15.11.77	6.8	0.04	131	"
Mytilus edulis (2 m depth)					
D	1-2.11.77	8.0	0.10	237	Mytilus incl. shell
D	2-3.11.77	8.0	0.06	72	"
B	9.11.77	7.8	0.09	176	"
Laboratory	17.11.77	7.7	0.10 ± 0.0	n = 10 ind. (recalculated from Sec. 10.2)	

			$mg\ O_2\ m^{-2}\ h^{-1}$	$Ind.\ m^{-2}$	Macrofauna ($dr.wt.\ g\ m^{-2}$)
"Shallow soft bottoms" (1 m depth)					
D	16-17.11.77	6.4	18.4	4669	234
D	16-17.11.77	6.4	24.5	14616	52
G	16-17.11.77	5.5	20.9	7917	106

As oil is still present and is leaching out of the bottoms investigated here, the respiration of these littoral communities is probably influenced to some extent.

7.4.4 References

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8. Impact of Oil on the Supralittoral Zone

CHAPTER 8: IMPACT OF OIL ON THE SUPRALITTORAL ZONE

8.1 Damage to shore vegetation

(Anders Lindhe)

8.1.1 Introduction

This study was not begun until the middle of June and by then all the affected coastline including all the fine-grain sediment shores suitable for field study had been cleaned up. This was also true of the bay near Lisökalv which was supposed to be left undone. Accordingly, traces of damage by oil upon the vegetation were mostly masked by the mechanical effect of the cleanup. Any sites for studying the long-term effect of oil upon vegetation could, for the same reason, not be found. Since the cleanup on land was mostly mechanical, the effect of chemicals could not be studied. A rough estimate of the acute effects of oil on plants could, however, be gained by studying some non-cleaned areas in the Stockholm archipelago affected by oil from the ship Oktavius. The rest of the work was devoted to studies of the cleanup measures from a biological point of view.

8.1.2 Methods

The field work consisted of visits to different oil-affected and cleaned-up areas during June, July and August. In early summer, sites in the Stockholm Archipelago (at Värmdölandet and some nearby islands), affected by oil from the Oktavius and Michail Kalinin oil spills, were studied. The Oktavius oil had been on the shore for about as long a time as the Tsesis oil, though it was of a slightly different type. The Michail Kalinin oil, thin diesel oil, had only been on the shore for a couple of weeks when the studies were made. Some fine-grain sand shores on Torö and Svärdsö, heavily affected by Tsesis oil, were also visited at this time. These sites were revisited at the end of summer when the entire coastline between Ören on southern Torö and Höviksholmarna on Svärdsö were investigated on foot. The firm, "Saneringsa Konsult", is thanked for valuable assistance with transport and information.

8.1.3 Results: Acute effects on vegetation

In general the plants seemed to be astonishingly little affected by growing on or in close contact with heaps of oil on the shores. This impression is characteristic of all the areas and different types of oil studied. At places with a dense layer of oil, however, the plants showed frequent signs of abnormality or injury. It is, of course, impossible in any one instance to distinguish with certainty between effects caused by oil or, for example, by parasites or local variation in water supply. However, the following observations have been made several times and are, with fair reliability, oil-dependent.

Filipendual ulmaria and Lysimachia vulgaris were very dwarfish when growing on soil heavily impregnated with oil. Seedlings of these growing through a thick layer of oil also showed strong malformations. Deformities were also observed in Valriana officinalis and Tussilago farfara. Discoloration, reminiscent of water shortage, was noted in Festuca rubra, Agrostis stolonifera, Atriplix latifolia and Equisetum arvense when the plants were on or close to oil on the shore. Some specimens seemed less sensitive and Cirsium arvense was found on several occasions growing on thick heaps of oil without visible effects.

8.1.4 Some comments on the clean-up methods

In the Torö-Svärdsö area there are several different types of shore. Rocks, stone, gravel and sand, in places exposed to wave action, and fine-grain sediment shores with reeds in more sheltered bays.

Rock dominated areas: The only vegetation are lichens and microscopic algae. No attempts were made to estimate how these were affected by oil. On these kinds of shores the oil, which soils the rocks with a more or less thick covering, is removed by spraying with water at high pressure, scrubbing with oil-dissolving chemicals or steam treatment, which makes the oil easy-flowing. All methods, however, only transfer the oil to the water. It is hardly possible to take care of and destroy all the oil on these shores and, instead take all possible measures to prevent the oil from reaching them.

Stones: These shores are less steep than the rocky ones and, for this reason, can hold more oil. The vegetation consists of sparse stands of plants rooted in the finer sediment between stones. The greater part of the oil can be collected by suction pump and spades after which a more careful cleanup takes place as described above for rocks. Stones, too contaminated for cleaning, can also be removed. One of the problems with this kind of shore is that some oil always percolates to the gravel between the stones and is out of reach of cleaning. In time, this oil is likely to bleed and pollute the water below. Clean-up operations are difficult and very time consuming and so, if possible, the oil should be prevented from reaching these shores also.

Gravel and sand: These shores are rare in the area. Stable parts often carry a complete covering of vegetation. If oil affects this, it is harvested and removed. Filthy sand and gravel are also dug up and carried away. A particular example of a sandy beach is Reveln near Ören on southern Torö. The entire point is made up of sand with gravel on the northern shore and fine sediment on the western side. The area is protected on account of the rich bird life in spring and autumn. The ground on the point is very sensitive to wear. Unfortunately, heavy vehicles have been used in connection with the cleanup operations and deep tracks, which will be slow to heal, have resulted. Also, the traffic across the point has not been properly channeled, which might have lessened the damage. It would have been best to arrange transport by boat. However, the cleaning of the beach proper is satisfactory and the re-visit in August showed that the shore vegetation was recovering quite nicely.

Fine grain sediment: These shores are found in sheltered bays, and if ungrazed, are dominated by common reed. Being very level they can hold much oil. During the cleanup after the Tsesis accident, the oil was actively steered into such bays where it was collected by suction pump, and the oil saturated reeds were harvested and removed. Any remaining oil was raked together and destroyed. Several places like these were visited in June and re-visited in August. The impression was that the vegetation was very little damaged. The reeds recovering after

harvesting seemed completely normal and on re-visiting it was not always easy to distinguish oil affected and non-affected sites. Even the smaller species seemed to have recovered - for instance Myosotis palustuis and (at Värmdö) the tiny annual Montia fontana. Thus clean-up operations on these shores seem to have worked very well. The oil was taken away from the area to be destroyed instead of being washed back into the sea and the cleaned areas seemed to recover fairly soon.

8.1.5 Concluding remarks

No very significant oil-induced vegetation damage could be demonstrated in this study. One cannot however eliminate the possibility that some effects will show only after a considerable period has elapsed. What will happen to the oil that has been left in the soil despite the cleanup? How is it broken down and into what substances? Are any of these more toxic than the oil itself? Are some substances so slowly accumulated by roots and rhizomes that injuries will not show until much later? These and other important questions can only be answered by further studies including experimental field work.

Cleaning operations must aim towards removal and destruction of the oil. Pollution of rocky and stony shores must for this reason be minimized by channeling the oil towards sheltered bays at an early stage when this is at all possible. This will also prove to be economically beneficial since cleaning of rocks and stones is very time consuming. Absorption of the oil using bark splinters and sowing of grass, which have been tried in some places, seem very doubtful methods from a biological point of view since the oil will remain with unknown consequences. The results will at best give rise to unnatural systems with species poorly adapted to the gradients of shore salinity.

8.2 Effects on the supralittoral fauna

(Maria Foberg)

8.2.1 Introduction

The importance of having knowledge on the effects of an oil spill, not only in the water but also on the adjacent areas above the waterline, is quite obvious since few investigations have been carried out for this purpose, especially in the Baltic Sea. In order to obtain comparable samples the wrack bed was chosen as a sampling area as it was a biotope which occurred at several of the stations.

8.2.2 Materials and methods

Three supralittoral stations situated close to stations B, C and D and one close to the reference station G (Fig. 7.2.1) were investigated during the first two weeks of August 1978, over nine months after the spill. On two occasions - August 2 and August 8 - six pit-fall traps containing water and detergent (used for decreasing the surface tension) were placed in the wrack bed at each station for 24 hours. At the same time two quantitative samples were randomly taken at each station with a frame (20 x 20 cm) so that 10-15 mm of the upper part of the ground material was included in the sample - making a total of 12 traps (10 at station G since two were lost) and 4 quantitative samples from each station.

The samples were sorted (the quantitative first by hand and then with a Tullgren apparatus, as described in Backlund, 1945), determined to taxonomic group (family), in some cases to species, and counted. In those cases where a large number of spring-tails (Collembola) were found it was not possible to determine every individual. Instead a subsample was examined and the systematic groups recorded. A comparison between number of individuals and number of systematic groups at the different stations was made (Tables 8.2.1, 8.2.2).

The number of individuals in the quantitative samples was recalculated to 100 g wrack dry weight. All newly hatched isopods, which were presumably caught while still clinging to their mother, were left out of the calculations, but the numbers are given in Table 8.2.3 (and later in Table 8.2.6).

Table 8.2.1 Occurrence of systematic groups and number of individuals in the pit-fall traps at the four stations. Figures after ± are standard error of mean.

Stn	Average No of ind/trap	Number of traps	Average No of syst grp/trap	Total No of syst grp
B	20±6	12	8±2	28
D	30±5	12	9±1	29
C	39±8	12	10±1	30
G	57±9	10	12±2	33

Table 8.2.2 Percentual distribution of the different groups of animals found in pit-fall traps at the four stations. The column "other" includes Orthoptera, Thysanoptera (Insecta) and Myriapods.

	Stn B (Norr Skötskär) %	Stn D (Lind-holmen) %	Stn C (Tistel-holmen) %	Stn G (Fifång) %
Insecta:				
Collembola	2.1	24.2	4.1	3.5
Hemiptera	0	4.5	0.4	8.5
Hetereptera	0	0.2	0.4	0
Coleoptera, adults	5.9	4.2	6.6	3.9
" larvae	0.7	0	3.9	0.7
Hymenoptera:				
Parasitie	1.3	0.8	0.4	2.3
Formicidae	24.4	18.5	0.9	5.7
Apidae	0.4	0	0	0
Diptera:				
Brachycera	21.0	6.2	17.4	21.2
Nematocera	3.8	4.2	3.2	1.4
Crustacea:				
Porcellio scaber	23.1	22.8	6.7	1.9
Orchestia gammarellus	0	0	0.2	10.4
Arachnoidea:				
Araneae	6.7	12.6	54.7	39.2
Arcarina	2.5	0	0	0
Opiliones	0	0.6	0	0
Other	2.1	0.6	1.1	1.2

Table 8.2.3 Total number of individuals (x) caught in the traps at the four stations and percent (%) frequency of occurrence.

Number of Traps	Stn B 12		Stn D 12		Stn C 12		Stn G 12	
	x	%	x	%	x	%	x	%
INSECTA								
Collembola fam. Entomobryidae	1	8	65	100			9	20
" Poduridae	3	17	8	17	9	33		
" Isotomidae			13	17	10	8	11	50
" Sminthuridae	1	8						
Thysanoptera fam. Thripsidae			1	8				
Hemiptera								
Homoptera fam. Aphididae			16	42	2	17	42	70
" Cicadellidae							6	40
Heteroptera fam. Lygaeidae					2	17		
" " , Scolopostethus sp.			3	17				
Coleoptera fam. Carabidae			9	50				
" " , Pterostichus niger	1	8			14	67	10	50
" " , Harpalus sp.					1	8		
" " , Metabletus sp.					1	8		
" Hydrophilidae, Cercyon sp.					11	50	3	20
" Staphylinidae	1	8	3	25				
" Silphidae, Thanatophilus sp.	9	25			2	17		
" Ptiliidae					2	17	7	40
" Scarabaeidae, Geotrupes sp.					1	8		
" Elateridae			1	8				
" Nitidulidae	3	25						
" Coccinellidae			1	8	1	8		
" Curculionidae			1	8			2	10
larvae (mostly Pterostichus niger)	16	42			17	67	4	40
Hymenoptera fam. Ichneumonidae					1	8	4	40
" Braconidae, Syncrasis fucicola	1	8	2	17			3	30
" " , Pemphredon lugubris	1	8						
" Proctotrupoidae, Basalys sp.							1	10
" " , Tricopria sp.							2	10
" " , Codus sp.							1	10
" " , Trimorus sp.							1	10
" Diapriidae, Diapria sp.	2	17					1	10
" Pteromalidae, Urolepis maritima					1	8		
" Formicidae, Myrmica rubra	3	17	1	8			6	30
" " , Formica fusca	4	25	2	8			8	50
" " , F. rufa	5	25	4	33			1	10
" " , F. ruginodes	1	8						
" " , Lasius niger	45	67	58	92	4	33	17	50
" " , Camponotus herculeanum			1	8				
" Apidae, Bombus sp.	1	8						

Table 8.2.3 (cont'd)

		x	%	x	%	x	%	x	%
Diptera									
Brachycera fam.	Dolichopodidae	4	17	5	25	45	83	80	80
"	Phoridae	8	42	3	25	2	17	2	20
"	Pipunculidae							1	10
"	Syrphidae					1	8		
"	Sciomyzidae			1	8				
"	Ephydridae	8	33			3	17	4	20
"	" , Ephydra macellaria alandica	1	8						
"	Agromyzidae	22	75	8	42	18	83	24	60
"	Chloropidae	1	8	1	8	2	8	1	10
"	Tachinidae					1	8	1	10
"	Muscidae	2	17	2	17	1	8	7	20
"	" , Coenosia mollicula			1	8				
"	" , Dexiopsis lacteipennis					1	8		
"	" , Lispe tentaculata	2	17			1	8		
"	Anthomyiidae	1	8					1	10
"	Scatophagidae					2	17		
"	" , Scatophaga litorea	1	8	1	8	4	25		
Nematocera fam.	Corethridae	1	8			1	8		
"	Chironomidae, adults			11	42	9	42	3	20
"	" , larvae					5	8		
"	Mycetophilidae	4	33	2	17	1	8	3	30
"	Cecidomyidae	3	17	2	17	4	17	2	20
unidentified		1	8						
Orthoptera fam.	Acrididae	2	17					3	20
CRUSTACEA									
Isopoda	Porcellio scaber, adults	55	100	81	92	31	83	11	70
"	" , newly hatched	81	8						
Amphipoda	Orchestia gammarellus					1	8	59	70
ARACHNOIDEA									
Aranae fam.	Linyphiidae	8	33	26	67	171	100	205	100
"	Lycosidae	8	42	18	50	84	92	17	60
"	Gnaphosidae, Micaria sp.			1	8				
Acarina fam.	Ixidae, Ixodes ricinus	6	17						
Opiliones				2	17			1	10
MYRIAPODA									
Chilopoda fam.	Lithobidae, Lithobius sp.					1	8		
Diplopoda fam.	Iulidae	2	17						
CASTROPODA									
Stylommatophora fam.	Arionidae							2	20
MAMMALIA									
Insectivora fam.	Soricidae, Sorex sp.							1	10

The orders found were: Insecta: Thysanoptera, Collembola, Orthoptera, Hemiptera, Coleoptera, Hymenoptera and Diptera. Crustacea: Isopoda (Porcellio scaber) and Amphipoda (Orchestia gammarellus). Arachnoidea: Araneae, Arcarina and Opiliones. Myriapoda: Diplopoda and Chilopoda. Oligochaeta: Plesiopora and Gastropoda: Stylommatophora.

The genera Pachydrilus and Enchytraeus (Oligochaeta) have not been taken into consideration and were left out in all calculations. This was due to the difficulty of obtaining reliable abundance estimates for these highly contagiously distributed animals. The estimated numbers are given in Table 8.2.4 and percent distribution in Table 8.2.5.

8.2.3 Description of the stations

At station B and D there was a small belt of totally dry wrack only a couple of centimeters deep and 15 cm wide, which, according to Backlund (1945), could be characterized as a wrack string. The wrack consisted almost exclusively of Fucus vesiculosus with some Cladophora. At these two stations a few oil slicks could be seen on some stones but not in the wrack. Station B, one of the most heavily contaminated stations, was subject to cleanup in the middle of June 1978, during which time parts of the ground were dug up and turned over.

At station C, also heavily contaminated, a rather large slick of oil was found in one of the quantitative samples. Here, the wrack accumulation was much larger, about 10-15 cm deep and 50 cm wide, consisting of decaying wet wrack.

At station G, the reference station, the wrack bed was similar in size to that at C and consisted of decaying wet wrack. At this station there was a bed of reed adjacent to the sampling area, and as a result the wrack contained much material from Phragmites australiensis.

8.2.4 Results

8.2.4.1 Pitfall traps

At station G there were more individuals and systematic groups in each trap as well as a higher total number of systematic groups found

Table 8.2.4 Occurrence of systematic groups and number of individuals in the quantitative samples at the four stations. Figures after ± are standard error of mean.

Stn	Average No of ind/100g wrack (dry weight)	Number of Samples	Average No of syst grp/ sample	Total No of syst grp	Estimated No of Enchytr/Pachydr per sample
B	85±23	4	7±1	11	200
D	57±31	4	6±3	13	250
C	175±93	4	8±2	13	2000
G	162±25	4	10±2	13	4000

Table 8.2.5 Percent distribution of the different groups of animals found in the quantitative samples at the four stations.

	Stn B (Norr Skötskär) %	Stn D (Lind-holmen) %	Stn C (Tistel-holmen) %	Stn G (Fifång) %
Insecta:				
Collembola	2.2	12.8	30.9	42.9
Hemiptera	1.5	0	0.4	0.2
Coleoptera, adults	5.1	2.4	2.4	6.7
" , larvae	0.7	0	0.4	0.5
Hymenoptera:				
parasitic	0	0.8	0	0.2
Formicidae	0	0.8	0	0.2
Diptera:				
Brachycera, adults	0.7	0	0.2	0
" , larvae	2.2	7.2	5.7	1.8
Nematocera	0.7	3.2	0.4	0
Crustacea:				
Porcellio scaber	40.9	45.6	14.1	2.0
Orchestia gammarellus	0	0	0	1.8
Arachnoidea:				
Araneae	2.2	2.4	10.8	6.3
Acarina	33.6	23.2	34.8	37.2
Myriapeda	10.2	1.6	0	0

compared to the other stations. For more detailed data see Table 8.2.1 and Fig. 8.2.1.

The percentual distribution of the different groups of animals (Table 8.2.2, Fig. 8.2.3) shows some similarity between station B and D and between station C and G, respectively. At station B and D, Formicidae (ants) and the species Porcellio scaber (woodlouse) dominated -- at B together with Diptera (flies and gnats) and at D with Collembola (spring-tails), while at station C and G, Araneae (spiders) were strikingly dominant, followed by Diptera. The gammarid Orchestia gammarellus was frequent only at station G where it comprised 10.5% (59 individuals) of the total number of individuals found, while at station C the corresponding figure was 0.2% (1 individual). No gammarid could be found at the other stations.

At station G there also seemed to be more parasitic hymenopteras and cicadas (Homoptera) than at the other stations. The little woodlouse Porcellio scaber appeared in small numbers at station C and G compared to stations B and D.

In one of the traps at station G a shrew (Sorex sp.) was found in company with some fleas. These latter were not included in the calculations.

8.2.4.2 Quantitative samples

The average number of individuals/100g wrack dry weight at stations G and C was two to three times higher than at stations B and D (Table 8.2.6). The total number of systematic groups found was 11 at station B and 13 at each of the other stations (Table 8.2.4, Fig. 8.2.2).

The percentual distribution of the systematic groups (Table 8.2.5 and Fig. 8.2.4) in this case also showed a similarity between stations B and D and stations C and G, respectively. Porcellio scaber was clearly dominant at station B and D, followed by Acarina (ticks), while Araneae seemed to be less frequent at these stations. Myriapoda (millepedes) made up 10.2% of the total number of individuals found at station B while at C and G this group could not be found either in the quantitative samples or in the traps. At station C and G Acarina and

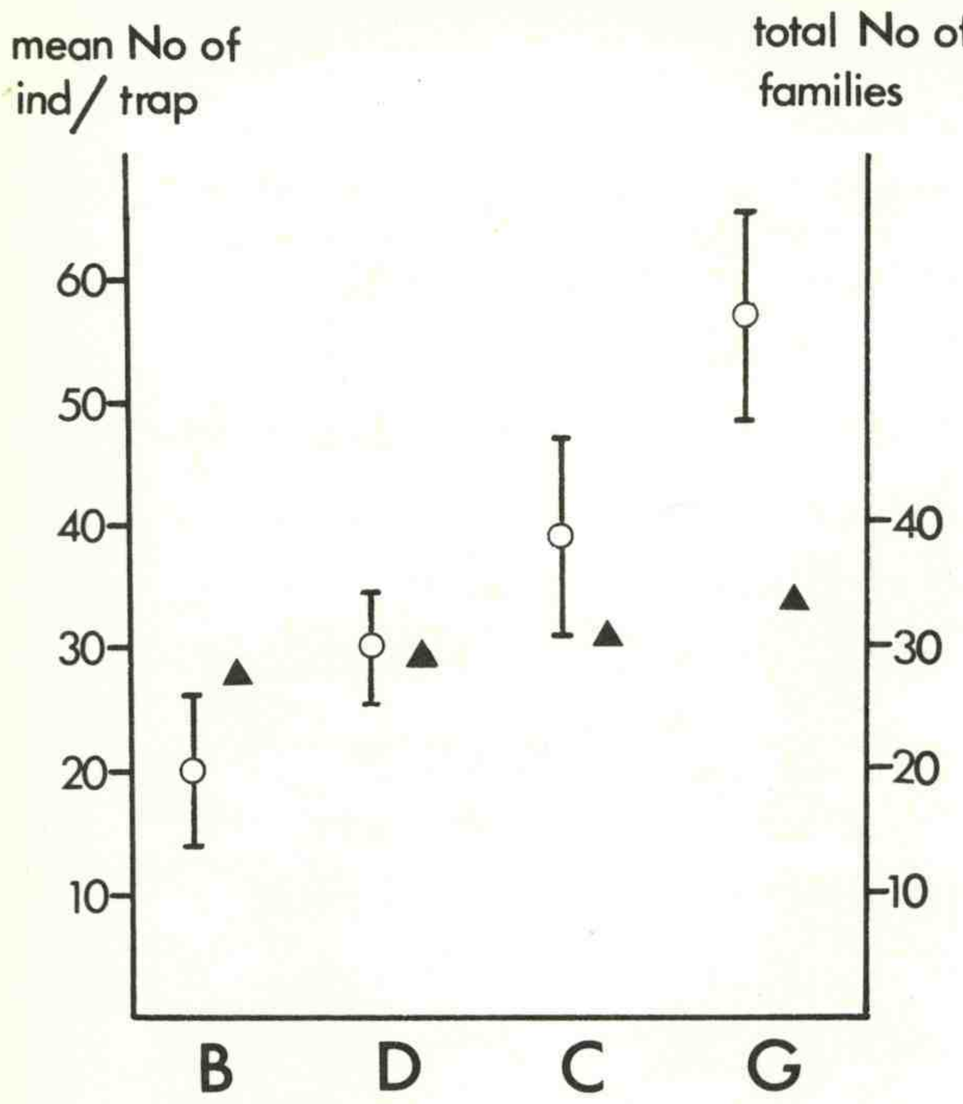

Fig. 8.2.1 Average number of individuals (±standard error of mean) in the pit-fall traps (o) and total number of systematic groups (▲) at the four stations.

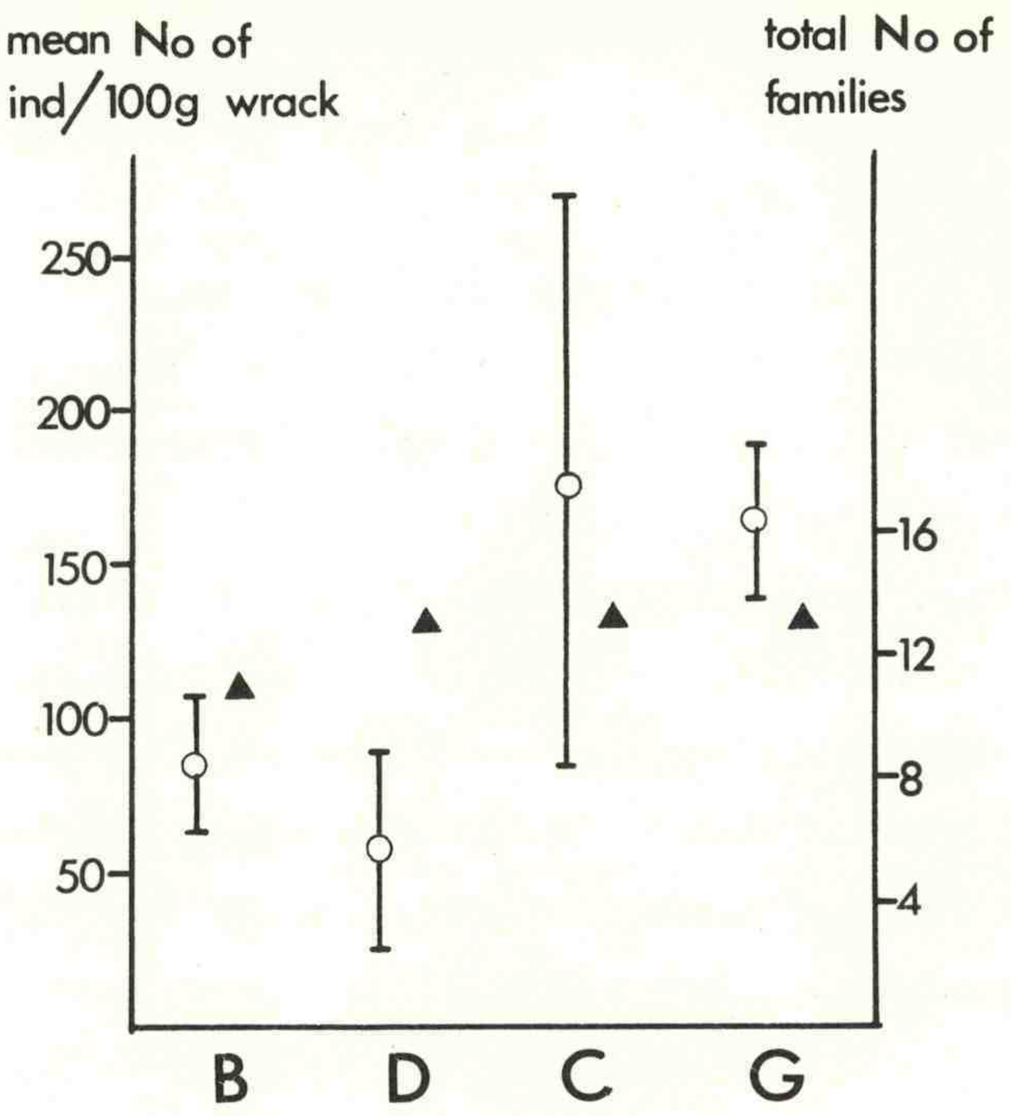

Fig. 8.2.2 Average number of individuals/ 100g wrack, dry weight (o) (±standard error of mean) and total number of systematic groups (▲) in the quantitative samples at the four stations.

Table 8.2.6 Total number of individuals (x) occurring in the four quantitative samples at the four stations and percent occurrence frequency (%).

	Stn B		Stn D		Stn C		Stn G	
	x	%	x	%	x	%	x	%
INSECTA								
Collembola fam. Entomobryidae	3	25	9	75				
" Poduridae			4	50	5	50	399	75
" Isotomidae			3	25	153	25		
Hemiptera								
Homoptera fam. Aphididae	2	25			1	25	2	50
Heteropotera unidentified					1	25		
Coleoptera fam. Hydrophilidae					8	100	7	75
" Staphylinidae	2	50	2	25	4	50	5	75
" Ptiliidae	3	25	1	25			50	75
" Nitidulidae	2	50						
larvae	1	25			2	25		
Hymenoptera fam. Ichneumonidae							1	25
" Braconidae					1	25		
" Proctotrupoidae							1	25
" Formicidae, Lasius niger			1	25			2	50
Diptera								
Brachycera " Agromyzidae	1	25			1	25		
larvae	3	50	9	75	29	100	17	100
Nematocera " Chironomidae			3	50	1	25		
" Cecidomyidae	1	25	1	25				
CRUSTACEA								
Isopoda Porcellio scaber, adults	56	100	57	75	72	100	19	100
" " , newly hatched	79	50	44	50	4	25	10	25
Amphipoda Orchestia gammarellus, adults							17	75
" " , newly hatched							15	25
ARACHNOIDEA								
Aranae fam. Linyphiidae	3	75	3	25	52	100	59	100
" Lycosidae							3	50
Acarina fam. Ixidae, Ixodes ricinus	46	100	29	75	178	100	346	100
MYRIAPODA								
Diplopoda fam. Iulidae	14	75	2	25				
OLIGOCHAETA								
Plesiopora Pachydrilus sp. and Enchytraeus sp. (estimated numbers)	200	75	250	100	2000	100	4000	100

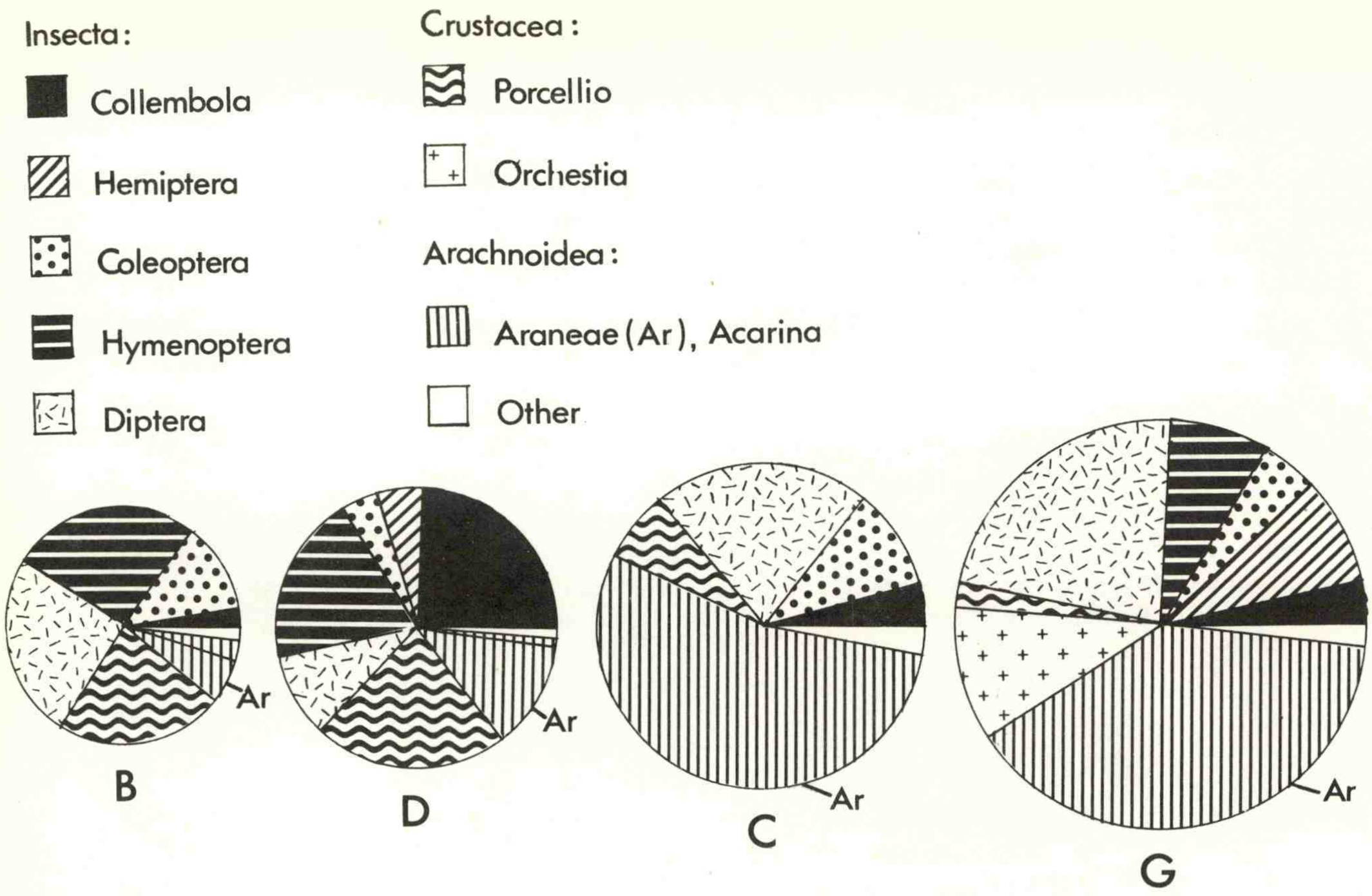

Fig. 8.2.3 Percentual distribution of the different groups of animals in the pit-fall traps at the four stations. The area of the circles is correlated to average number of individuals per trap.

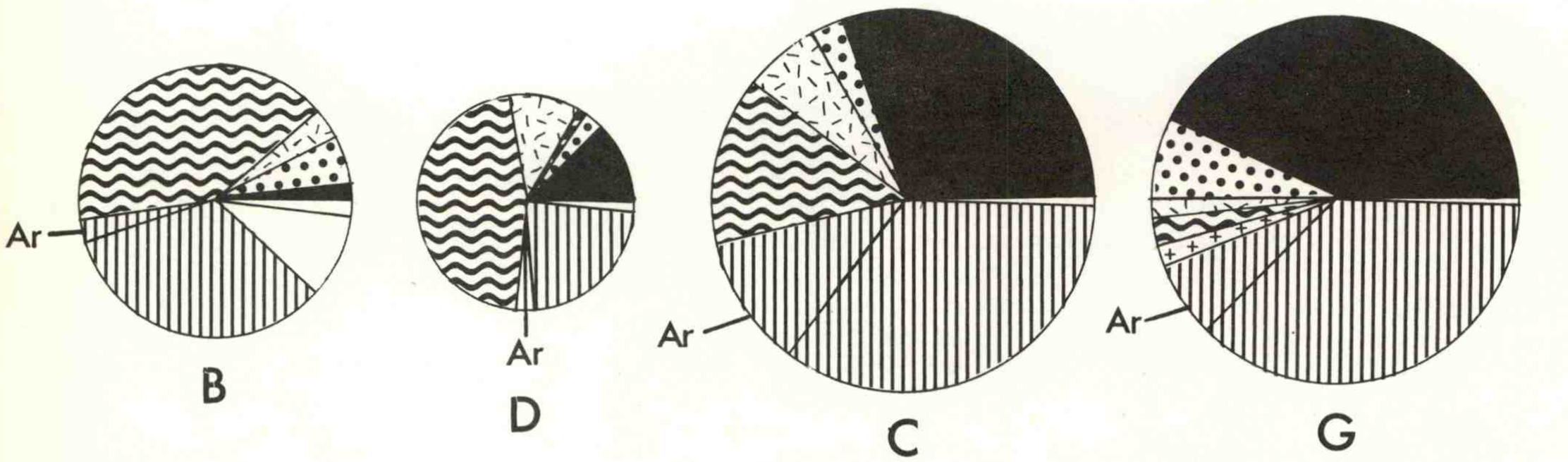

Fig. 8.2.4 Percentual distribution of the different groups of animals in the quantitative samples at the four stations. The area of the circles is correlated to average number of individuals/100g wrack, dry weight.

Collembola were the dominant groups. Station G showed a low number of Porcellio scaber, only 2.0% while the gammarid Orchestia gammarellus appeared at this station exclusively.

8.2.5 Discussion

The result of the pit-fall trap study shows that the total number of systematic groups was somewhat higher at the reference station and that the average number of individuals caught was 1.5 to 3 times higher than at the other stations. The quantitative samples however, show that the total number of systematic groups was similar for all stations except station B, which had a slightly lower figure. The average number of individuals per 100 g wrack was clearly higher at station G compared to stations B and D, but a little lower than at station C. This could be due to the wrack at G being too wet for some animals, which would explain the low number of Porcellio at this station (Backlund, 1945). The fact that the gammarid Orchestia was frequent only at G and absent at the contaminated stations might be a result of the oil spill, but it could also be a consequence of the humidity of the wrack at G (Backlund, 1945). This does not explain the almost complete absence of this species at C, where the wrack was as wet as at G. The differences in humidity of the wrack are clearly shown by the abundance of the group Plesiopora (Oligochaeta) which demands humidity for thriving (Backlund 1945). This group is much more frequent at G and C (about 27,000/m^2 and 13,000/m^2 resp., estimated values) than at B and D (about 1,100/m^2 and 1,300/m^2 resp.). The largest part of this group was Pachydrilus sp. and the rest Enchytraeus sp. Pachydrilus is a typical animal of the seashore and abundant in wrack beds, being the main food source for many animals living there, e.g., spiders of the genus Erigone sp. and larvae of the coleopteran Cercyon sp. (Backlund, 1945).

Most of the flies (Brachycera) in the quantitative samples were larvae because the adults are able to fly and thus escaped capture. The great number of flies in the traps could be due to their being attracted by the smell of the detergent, as most of them are not true inhabitants of the seashore (Chinery, 1976). Species which truly belong to this

biotope, for instance Lispe tentaculata (family Muscidae), Dexiopsis lacteipennis (family Muscidae, according to Hugo Andersson, Lund, pers. comm., not known in this county before), Scatophaga litorea (family Scatophagidae), and Ephydra macellaria alandica (family Ephydridae) contribute only 10% of the total number of flies while Dolichopodidae and Agromyzidae made up the major parts (49% and 26%, resp.). Some of the flies are parasites on other insects, e.g., individuals of Phoridae (Chinery, 1976) and Tachinidae (Lindroth, 1967). One individual of the family Pipunculidae was found at Station G. Members of this group are known as parasites of cicadas (Homoptera) (Lindroth, 1967) and were found only at this station.

Some of the parasitic hymenopteras are fly parasites, e.g., Tricopria sp. and Trimorus sp. These were also found at Station G where the greatest number of flies occurred. The only hymenoptera species which truly belongs to the shore is Urolepis maritima which appeared at Station G. Most of the Ichneumonidae would seem to have come from the woods (Cederholm, pers. comm.). Perhaps these were also attracted by the detergent. According to Backlund (1945) nearly every wrack bed contains parasitic hymenopteras living on dipterous larvae.

The high number of ants (Formicidae) at Stations B and D could be explained by ant hills in the wood beyond the shores.

A greater part of the spiders consisted of the species Oedothorax retusus, (family Linyphiidae), small web-spinning spiders which are found especially in littoral vegetation and on the surface layer of wrack (Backlund, 1945). The genus Erigone (family Linyphiidae) was also found. One third of all the spiders was made up of Lycosidae, hunting spiders which probably live to a greater extent on flies (Backlund, 1945). The genus Arctosa, Trochosa and Pardosa were also found.

All of the ticks found belonged to the species Ixodes ricinus, which live in decaying organic material and lay their eggs in the ground vegetation (Ursing, 1971). At Station G there was more vegetation around the wrack bed, which could have influenced the number of aphides (Aphididae) which occurred here in larger numbers than at any other station. One species (Hyalopterus pruni) has for instance Phragmites as a summer host (Lindroth, 1967). It is possible that the individuals found belonged to this species, but no further examination was made.

The dominant group of Coleoptera (beetles) were carabides of the species Pterostichus niger followed by Hydrophilidae of the genus Cercyon, common in decaying wrack on shores (Chinery, 1976). These occurred only at Stations C and G, where the humidity was high, since they feed on even wetter wrack than Orchestia (Backlund, 1945). The family Ptilidae was also frequently found, some species of which are very common in wrack beds (Backlund, 1945). Staphylinides, of which many species live on shores and feed on Diptera larvae, also occurred in the samples as well as Nitidulidae, which lives on decaying material (Chinery, 1976).

In all calculations the newly hatched individuals of Porcellio and Orchestia were omitted. At station B there were 81 newly hatched Porcellio (among 19 adults) still clinging to the mother adult in one trap, and in one quantitative sample there were 75 newly hatched individuals of the same species among 6 adults at the same station. If these had been taken into account, the average number of individuals in each trap would have increased to 27 (instead of 20), just a little less than at the other stations and the average number of individuals per 100 g wrack would then become not 85 but 158. This would make the figure comparable to that at station G. In fact, for the small amount of material examined the differences in number of individuals and systematic groups between the stations are not so large that they could not be explained by the natural variation caused by the environment. The wrack bed is a relatively variable environment, strongly affected by storms. Nevertheless it was of a similar nature throughout the whole area investigated during the sampling period, so that a comparison could be made between the stations.

The humidity is a factor of great importance to the animals living in the wrack itself (Backlund, 1945). Water makes the wrack much softer and more accessible and therefore easier to eat. Orchestia for example cannot eat hard and dry wrack (Backlund, 1945). Another important factor influencing the wrack fauna are the interactions over the "boundaries" to adjacent biotopes (Backlund, 1945). At station G for example the bed of reed comprises another biotope containing other types of animals supplying immigrants to the wrack fauna. Thus the surrounding biotopes influence wrack beds both quantitatively and qualitatively.

The low number of individuals at station B could be a result of the oil spill but it is more likely a result of the ground being turned over during the clean-up procedure, a measure which destroyed the wrack more or less completely. Since there were no storms during this period, when Fucus might have blown ashore, the remaining wrack bed became rather diminished, and this in turn influenced the animal life.

8.2.6 Conclusions

Unfortunately no similar investigation had been made in this area either before or directly after the accident, which makes it difficult to draw firm conclusions. The present investigation indicates, however, that the oil spill from Tsesis has not had any great and long lasting negative effects on the fauna of the wrack belts of the shore. It seemed to recover rather quickly, due both to the short generation time and the vagility of the animals. Another important factor was the time of the accident. It took place in the late autumn when many animals had already left the upper, most affected part of the ground in preparation for hibernation. Had it happened in the early spring it is possible that the results would have been different and shown longer lasting effect.

8.2.7 Acknowledgements

The following persons deserve thanks for great help with examination of the animals: Dr. Carl-Cedric Coulianos (Brachycera and Coleoptera), Dr. Torbjörn Kronestedt (Araneae), Dr. Lennart Cederholm (Hymenoptera) and Dr. Hugo Andersson (Brachycera).

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9. Impact of Oil on Local Fish Fauna

CHAPTER 9: IMPACT OF OIL ON LOCAL FISH FAUNA

(Sture Nellbring, Sture Hansson, Gunnar Aneer and Lars Westin)

9.1 Introduction

From earlier echo sounding surveys (Aneer et al., 1978) it is known that pelagic fish (herring, Clupea harengus membras, L. and sprat, Sprattus sprattus L.) are very abundant in the spill area during late autumn and winter. It is also known that herring spawn in the archipelago in the spring. In view of the not inconsiderable local commercial fishery, the following questions were of interest after the spill: Were the pelagic fish still present in the area and were the fish contaminated by the oil? Did the oil affect the spawning grounds and the hatching results (c.f. Lindén, 1976)?

9.2 Material and methods

To investigate the occurrence of pelagic fish in the polluted area, echo sounding surveys were carried out on four occasions (11 November 1977, 15 December 1977, 11 January 1978, and 12 April 1978). The survey routes are illustrated in Fig. 9.1.

Herring were caught with gill-nets or by trawling. Organs (gills, stomachs) and whole fish from the reference and affected areas were deep-frozen for oil analysis.

In order to investigate spawning grounds, 100 randomly chosen non-polluted stations and 20 polluted stations were visited in June 1978 (about seven months after the spill) by SCUBA divers to see if any spawning had taken place. At each station, the divers investigated the bottom from the shoreline down to a depth of about 10 m.

At stations in the affected area where spawning had taken place and at four non-polluted reference stations, egg samples were taken for hatching in the laboratory. At each station two samples were taken by cutting and removing sections of algae with attached roe. In the laboratory the two samples were mixed and ten sub-samples of about 50-100

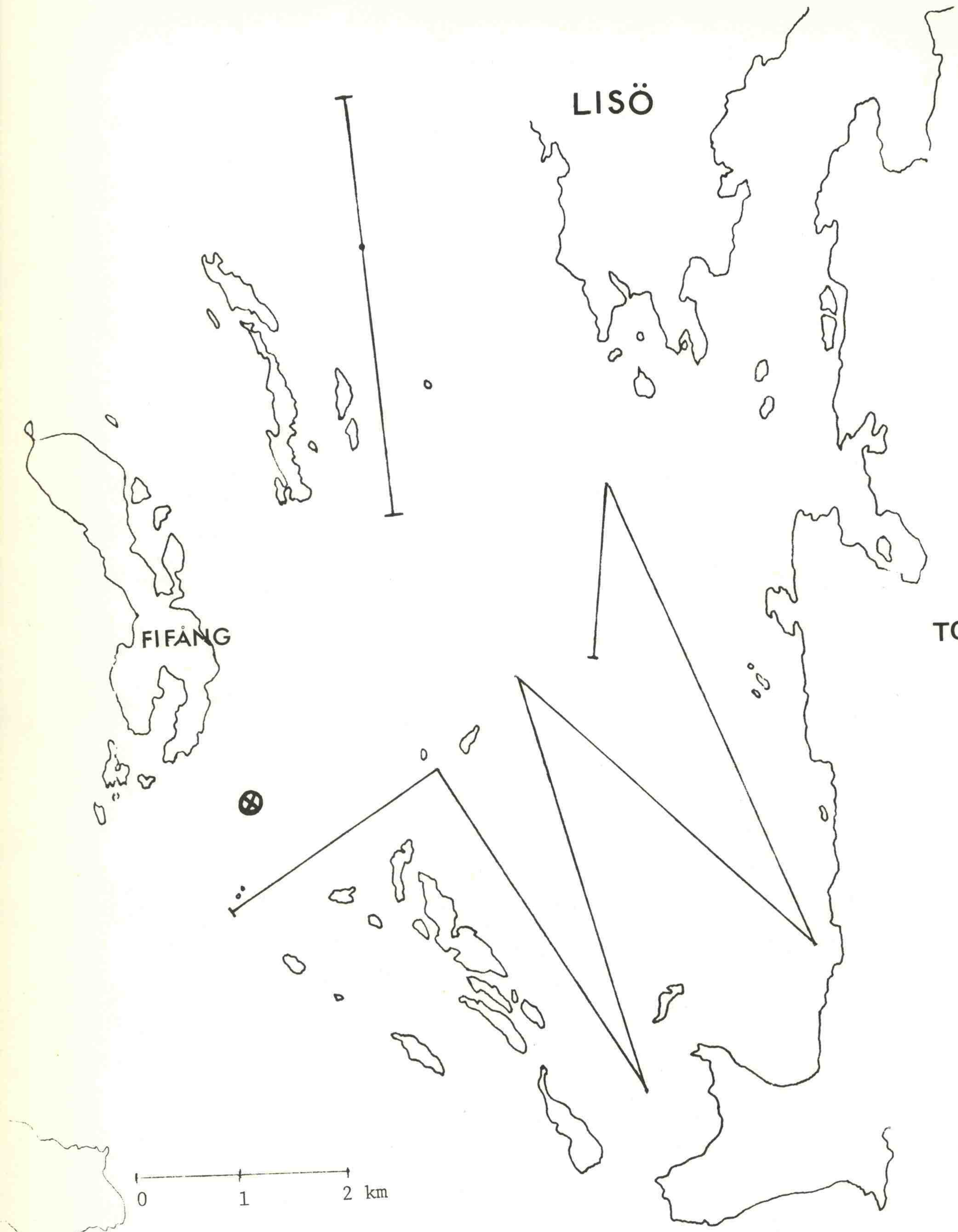

Fig. 9.1 Echosounding survey routes (scale 1:50,000).

⊗ = Tsesis

—— = Survey routes

eggs each were placed in hatching chambers with a volume of about 100 ml (Fig. 9.2). These were kept in the hatching chamber system for 7-12 days. Two or three days after the appearance of hatched larvae in a chamber, the contents were removed and preserved in 4% formaldehyde for later examination. The temperature in the chamber system was between 10 and 14°C, corresponding to the in situ temperature for that time of year. The oxygen content of the water in the hatching chambers was almost saturated.

9.3 Results

The echo sounding surveys did not indicate any decrease or disappearance of pelagic fish within the oil spill area. Furthermore, chemical analysis of herring organs and whole fish showed no indication of oil contamination (Boehm, pers. comm.).

The frequency of spawning grounds was lower in the contaminated area than in the reference area (20%, n =20 and 45%, n =100). (Fig. 9.3 and 9.4). A χ^2 test was carried out (χ^2 = 3.3, d.f. = 1) and the result was found to be significant at the 7% level.

There was no significant difference in the number of malformed larvae. Only two larvae with enlarged areas anterior to the yolk sac were found in two samples from the polluted area (picture, Lindén, 1976).

The hatching results are presented in Table 9.1. These are divided into two columns, representing two different counting methods. The first column (observed hatching) gives the percentage of hatched larvae. The second column (theoretical hatching) gives the percentage of hatched larvae plus the percentage of eggs with live nearly hatched larvae. The hatching of eggs from one reference station, Jutskär, was unsuccessful. This was probably due to a severe fungal infection, the causes of which are unknown. As can be seen in Table 9.1, the average hatching success was lower in the oil polluted areas. The hatching success of eggs from Tistelholmen, the most affected area, was extremely poor, about 20% (theoretical hatching).

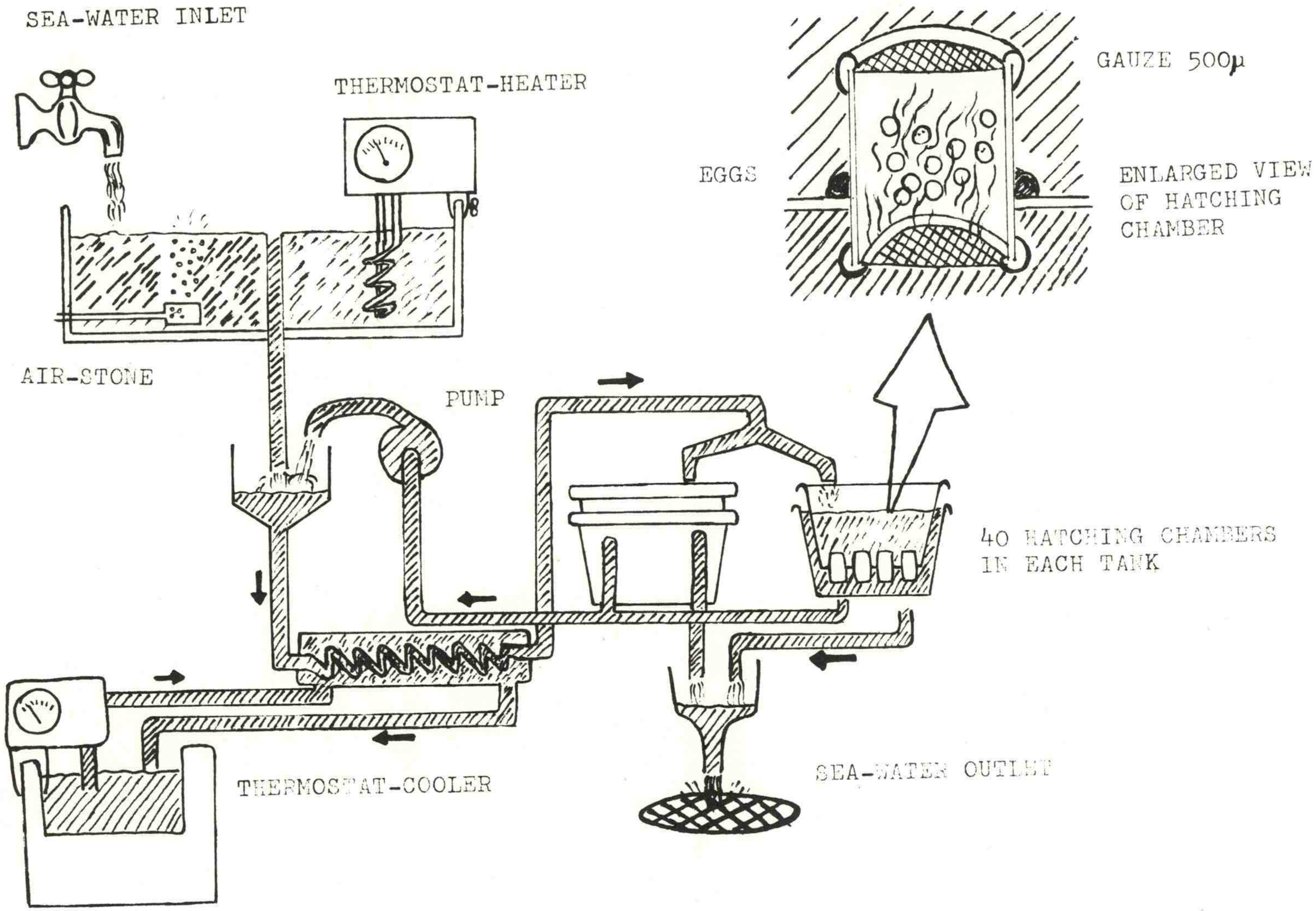

Fig. 9.2 Fish egg hatching chamber system (as used in the oil spill investigation).

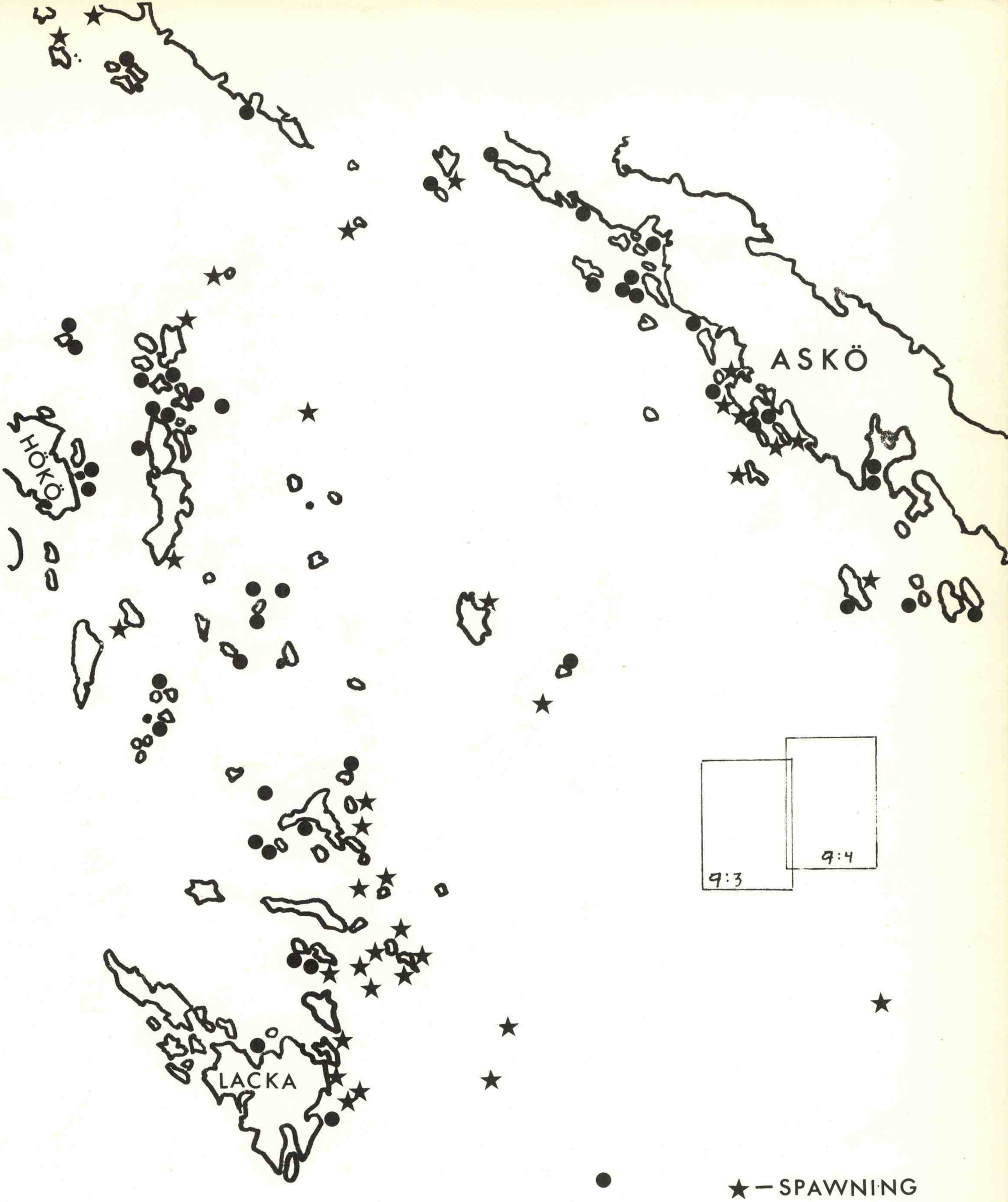

Fig. 9.3 Stations investigated for spawning by herring

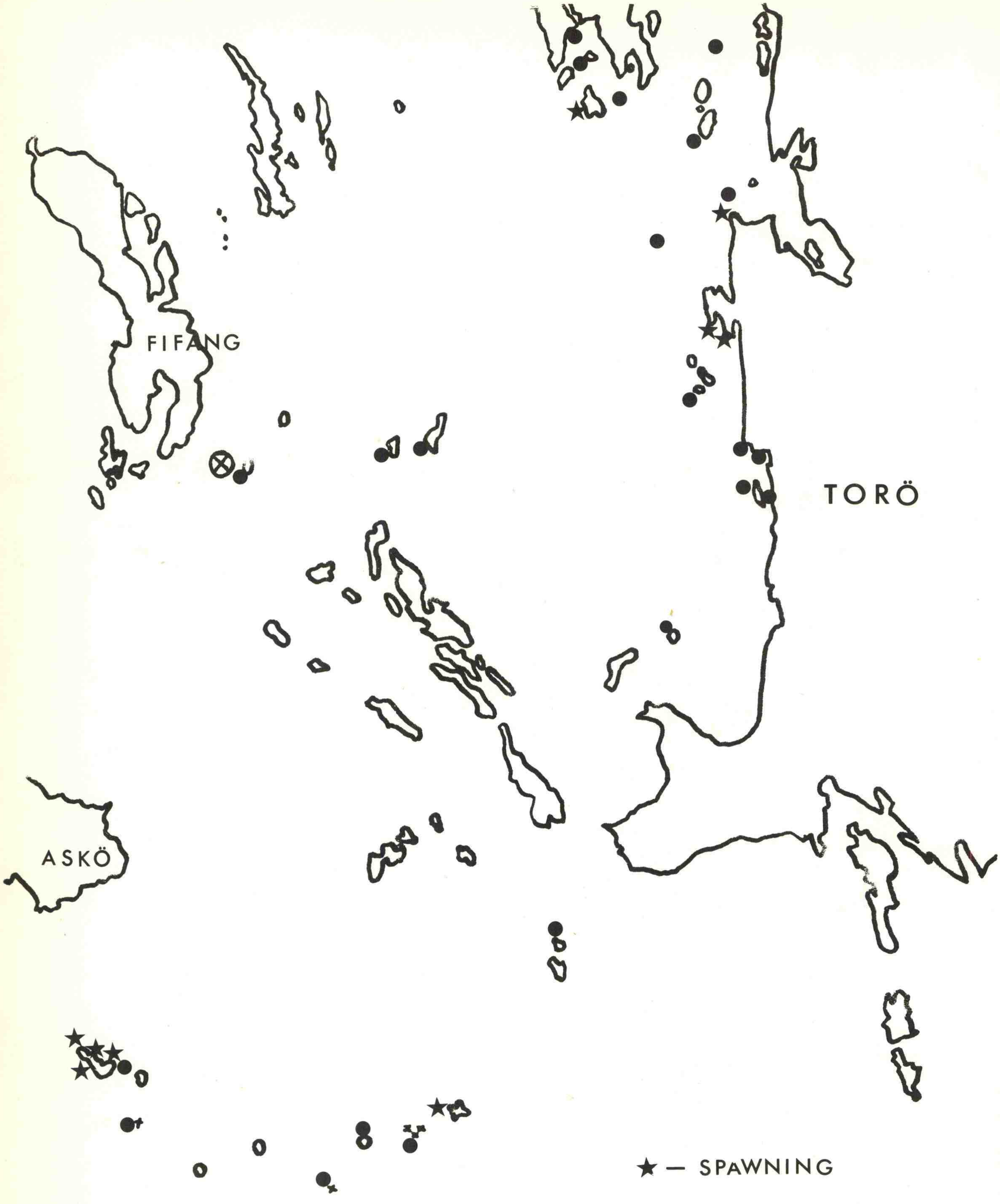

Fig. 9.4 Stations investigated for spawning by herring.
⊗ = Site of Tsesis grounding

Table 9.1 Hatching success of herring roe at different stations.

Locality	Date	% hatching (mean) observed	% hatching (mean) theoretical	N
Polluted area:				
Storudden	13-20/6	49.5	75.2	4
Storudden	13-22/6	54.7	58.7	6
Ekskär	13-20/6	41.6	45.1	10
Tistelholmen	13-20/6	0.0	0.0	1
Tistelholmen V	15-22/6	9.0	32.3	5
Tistelholmen V	15-27/6	22.6	22.6	5
Tistelholmen V	20-27/6	5.5	22.3	10
Tistelholmen V	22-29/6	9.2	16.9	10
Reference area:				
Jutskär	13-20/6	0.05	1.7	10
Sundsbådarna	16-22/6	14.9	70.9	3
Sundsbådarna	16-27/6	81.2	81.4	7
Vrångskär	20-27/6	40.6	40.6	5
Vrångskär	20-29/6	27.9	27.9	3
Persö	29/6-6/7	94.3	95.1	15
oil total (pooled)		24.4	34.7	
control total (pooled)		53.9	58.4	

observed: percent hatched larvae.
theoretical: percent hatched larvae and nearly hatched eggs.
reference stations underlined.

All the reference and affected stations were compared statistically using the rank-sum test (Dixon and Massey, 1969:344). It was found that hatching success was significantly higher in the reference area (theoretical hatching, z = -2.74, 0.007 > P > P 0.006, observed hatching, z = -2.96, 0.0032 > P > 0.0026). It is worth noting, however, that one of the polluted stations, Tistelholmen, gave highly variable results, with significant differences between the three sampling occasions (rank-sum test for several samples (Dixon and Massey 1969:345), H observed = 97.9, d.f. = 2, H theoretical 94.6, d.f. = 2, p << 0.01 in both cases).

9.4 Discussion

The analysis of herring did not indicate any contamination by oil (Boehm, pers. comm.). However it would be of great interest to trace the path of the oil through the food chain by carrying out oil analyses on flounder (Pleuronectus flesus). These fish feed mainly upon Macoma balthica and the blue mussel (Mytilus edulis) both of which have been shown to contain considerable amounts of oil.

The low frequency of spawning by herring in the affected area may indicate effects of oil pollution. It may, however, also be due to the differences that undoubtedly exist between the polluted and reference areas as regards exposure and sediment type distribution on the fairly shallow bottoms, where herring spawn was found.

On comparison, it is clear that the hatching of herring eggs was less successful in samples from the oil affected area. Significant differences also between samples from within the polluted area may, however, indicate that factors other than oil pollution may have influenced hatching rate. One such factor, repeatedly observed in the hatching experiments, was fungal infection of the roe. From previous studies it is known that the presence of benthic crustaceans decreases the amount of fungal growth on fish roe (Oseid, 1977). In the spring after the oil spill, hardly any adult Gammarids were present in the polluted area. It is therefore possible that their absence led to increased fungal attack on fish roe.

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10. Laboratory Studies Carried Out in Connection with the Spill

CHAPTER 10: LABORATORY STUDIES CARRIED OUT IN CONNECTION WITH THE SPILL

10.1 Introduction

In connection with the Tsesis oil spill some laboratory studies were carried out on animals brought to the Askö laboratory from the affected area. The reason for these investigations was to provide information on possible sublethal effects of the oil on organisms in the area.

Three types of investigations were carried out:

10.2 Respiratory measurements on the mussel Mytilus edulis.

10.3 Measurements of byssus formation by Mytilus edulis.

10.4 Burrowing behavior in the clam Macoma balthica.

10.2 Respiration measurements on the mussel Mytilus edulis

(Sture Hansson)

The rate of energy turnover in organisms is known to be affected by pollutants. One indication of oil-induced effects on the energy turnover would be changes in the respiration rate. However, measurements of the respiration rate alone cannot be used to determine how energy turnover is affected as a number of other components in the budget might also be affected, e.g., growth rate or food ingestion.

10.2.1 Materials and methods

Mussels were collected by SCUBA diving from the upper 3 m at oil polluted littoral stations and from the same depth range at an unpolluted reference station by means of a dredge from the shore. The mussels and 2 liters of the surrounding water were collected in ethylene containers which were sealed underwater to avoid contamination by the surface oil slicks.

In the laboratory the mussels were allowed to acclimatize for 2-4 hours before the start of the experiment. The temperature during the experiments did not differ by more than two degrees from that in situ, and field temperature and salinity varied negligibly between stations.

Animals from unpolluted localities were incubated in clean water, while those from polluted localities were incubated in water collected together with the mussels.

The measurements were made on specimens with a mean shellfree dry-weight of 31 mg (S.D. = 8 mg, shell length = 17-22 mm). Single specimens were incubated for 50 to 150 minutes in syringes with a volume of 10 ml and a diameter of about 15 mm.

In order to study the acute effects of high oil concentrations, fresh mussels were incubated in a laboratory prepared oil-in-water mixture. This mixture was prepared from 10 ml of Tsesis oil and 900 ml sea water which was mixed using a magnetic stirrer for 18 hours at 20°C. The water phase served as an incubation medium and was used both undiluted and diluted (1:10) and was added fresh at the start of the incubation. Mussels incubated in uncontaminated Baltic sea water were used as a reference.

The oxygen concentration was measured in control syringes with both polluted and unpolluted water which had been incubated as long as the syringes with animals present. These values were then subtracted from measurements with animals present, before the oxygen consumption of the mussels was calculated. Concentrations were determined with a Radiometer oxygen electrode (D 616) connected to a Radiometer PHM 716 with a PO_2-module, PHA 930.

10.2.2 Results

Data from the respiration measurements are presented in Tables 10.2.1 and 10.2.2 and illustrated in Fig. 10.2.1.

The respiration rates of M. edulis from different localities, and those from the experiments with different incubation water, were examined with Bartlett's test (Bailey 1976:189) and with analysis of variance (Dixon and Massey, 1969:156-162) in order to determine whether variances or means were significantly different. When variances in the measurements from all stations (polluted and unpolluted) were compared no differences were found ($\chi^2 = 8.17$, df = 6). However, in testing the means by analysis of variance, a p-value between 0.005 and 0.001 ($F_{(6:58)} = 4.098$) was obtained rejecting the hypothesis that all the samples came from populations with the same respiration rates.

Table 10.2.1 Respiration rates of M. edulis from oil-polluted stations. The respiration rates are expressed on a shell-free dry-weight basis and given as means and with 95 percent confidence intervals. The results are illustrated in Fig. 1, n = number of specimens used. % O_2 = mean oxygen concentration at the end of the experiment. For location of the stations, see Fig. 7.2.1. The reference station was close to the Askö laboratory.

Station	Oil polluted	Date	Temp. °C	n	Dry weight (mg) Mean	s.dev.	% O_2	Respiration rate (µg O_2/g x h) 95 % confidence int.	Mean
Reference Stn	Not polluted	771109	9	13	27	7	73	594 - 770	682
Station E	Heavily polluted	771109	9	10	36	5	52	402 - 581	491
Station D	Heavily polluted	771109	9	8	34	11	63	335 - 689	512
Station F	Heavily polluted	771109	9	10	35	10	44	460 - 586	523
Station G	Lightly polluted	771114	9	10	44	6	76	542 - 761	651
Station C	Heavily polluted	771114	9	10	36	6	78	558 - 712	635
Station B	Heavily polluted	771114	9	10	33	7	77	645 - 799	722

Table 10.2.2 Respiration rates of M. edulis incubated in clean and artificially oil-polluted water. (Abbreviations, see Table 10.2.1)

Incubation water	Date	Temp. °C	n	Dry weight (mg) Mean	s.dev.	% O_2	Respiration rate (µg O_2/g x h) 95 % confidence int.	Mean
Clean water	771117	8	10	26	7	78	558 - 782	670
Lightly polluted water (mixture clean:polluted water = 9:1)	771117	8	10	27	6	83	401 - 740	571
Oil polluted water	771117	8	10	23	5	86	387 - 675	531

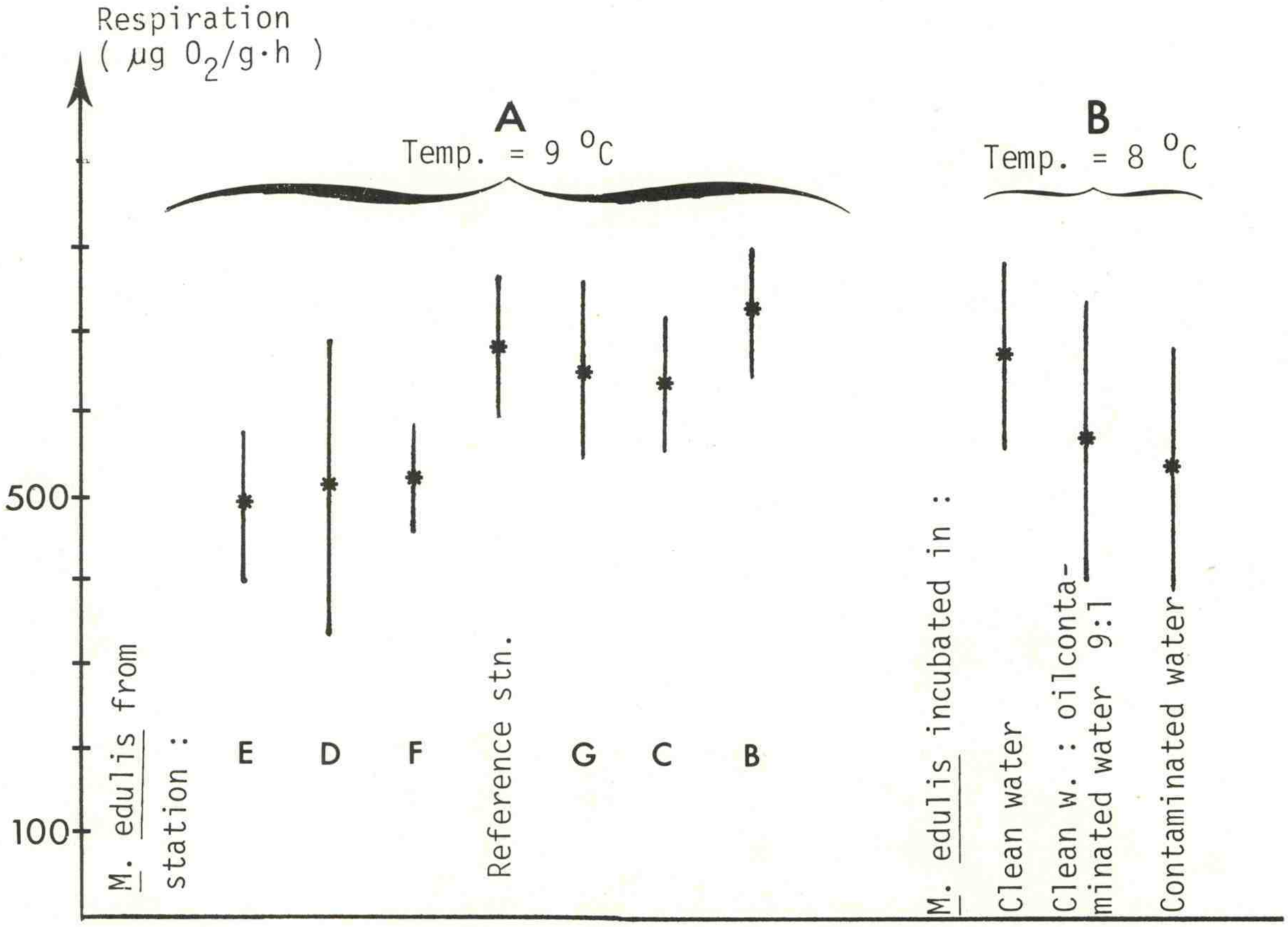

Fig. 10.2.1 Respiration rates (means with 95% confidence intervals) of Mytilus edulis from clean and oil-polluted localities(A) and of animals incubated in clean and artificially oil-contaminated water (B)

From Fig. 10.2.1 it can be seen that animals from three of the stations (D, E, F) showed lower respiration rates than animals from other stations. This result can, however, be explained by the fact that M. edulis from stations D, E and F were incubated in water with lower oxygen contents than those from the reference station (Table 10.2.1). It is known that low oxygen concentrations depress the respiration of Mytilus edulis (Bayne, Thompson and Widdows, 1976).

If the remaining stations (B, C, G) and the reference station (all had about the same oxygen content in the incubation water, Table 10.2.1) were compared no differences could be found between variances (χ^2 = 1.93, df = 3) or between means ($F_{(3:39)} = 0.85$).

The results from the experiment with Mytilus incubated in water with different oil-concentrations (Table 10.2.2) also failed to show statistically significant differences between variances (χ^2 = 1.44, df = 2) or means ($F_{(2:27)} = 1.26$).

10.2.3 Conclusions and discussion

According to this study, oil contamination of the water did not significantly change the respiration of Mytilus edulis.

However, due to the large variability in respiration, (mean values of approximately 650 µg O_2/g/h and standard deviations about 150 µg O_2/g/h), changes would have had to be large, in order to be detected. To detect, with a probability of 90%, a difference in respiration rate of about 20%, the sample size ought to be some 30 specimens (Dixon and Massey 1969, Table A-12a).

10.2.4 References

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10.3 Measurements of byssus formation by the mussel Mytilus edulis

(Olle Lindén and Maria Foberg)

Methods: Oil-affected mussels were collected in the littoral zone off Torö about one week after the grounding of the Tsesis. At this time large quantities of oil were floating on the surface. The mussels were collected by a diver at 4-5 m depth and brought to the laboratory in plastic bags. Care was taken to avoid contamination by the surface oil film. Reference mussels were collected close to the Askö laboratory in a similar but unpolluted biotope.

In the laboratory the mussels were allowed to acclimatize for a couple of hours. After this period mussels of two length-classes (juveniles: up to 10 mm, adults: over 10 mm) were placed on petri-dishes which were immersed in unpolluted sea water. Twenty to 25 animals of each length-class from each locality were exposed to a continuous flow of sea water in ~10 litre plastic jars.

The number of mussels byssally attached to the dish after 3, 4, 5 and 6 hours was noted.

Results and discussion: Fig. 10.3.1 shows the percentage of mussels byssally attached during the course of the experiment. Individuals from the impacted area showed decreased tendency to attach to the substrate. This tendency is more pronounced among adult individuals compared to juveniles.

Reduction or absence of byssus thread production in mussels (Mytilus edulis) or related species under the influence of oil, has previously been observed under laboratory conditions (Smith 1968, Swedmark et al. 1973, Eisler 1973, Lindén 1977). It is obvious that affected byssal activity under natural conditions must be considered a serious stress syndrome. Mussels incapable of byssal thread production will be unable to remain in their natural habitat as threads are used as mooring lines. They will consequently be washed away and their chances of reattachment at a suitable place are probably rather small. The experiments, although performed under laboratory conditions, indicate that the mussels in the impacted area were subjected to such effects.

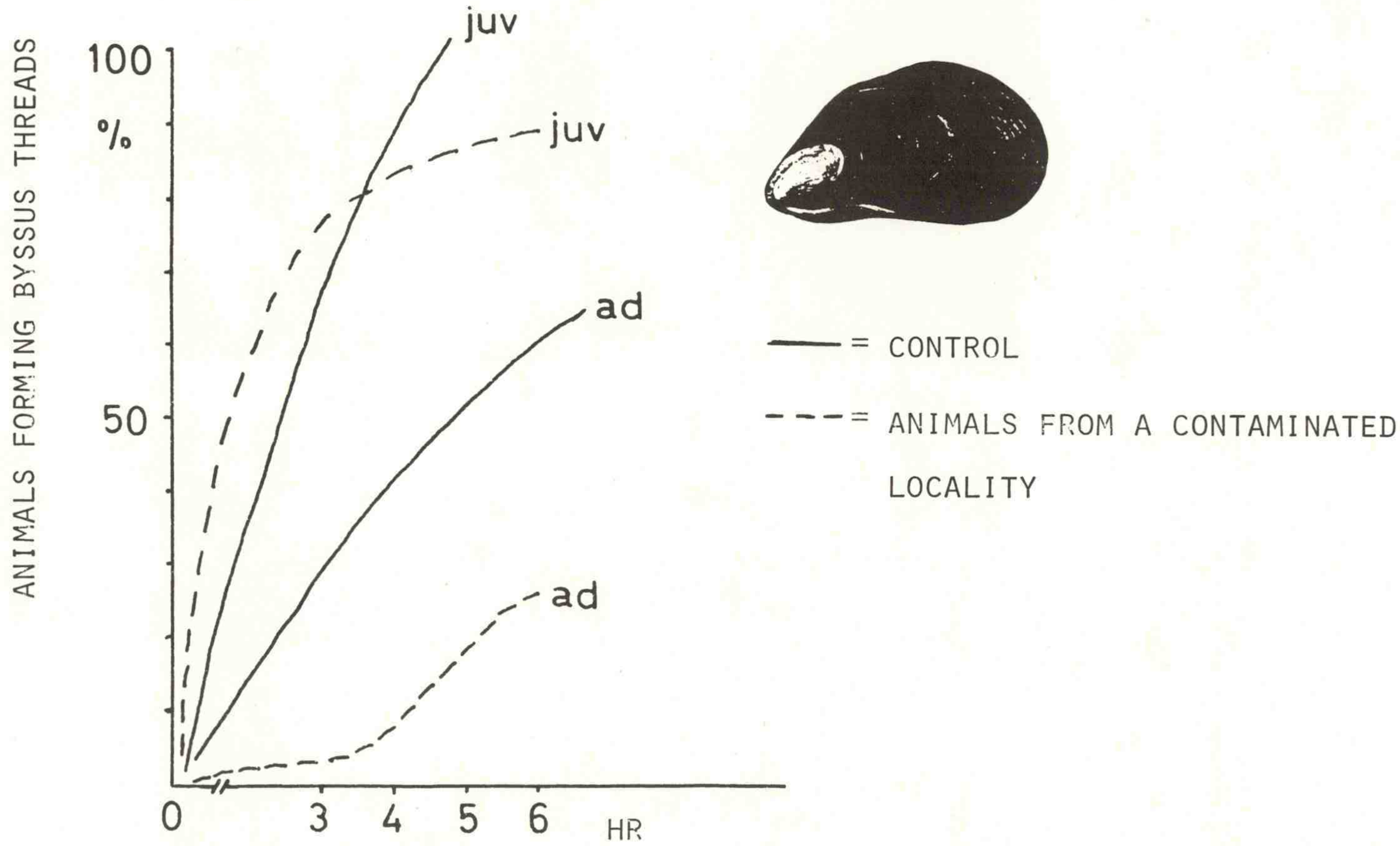

Fig. 10.3.1 Blue mussel (Mytilus edulis) tendency to form byssus threads
juv = juveniles and ad = adults

References

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Swedmark, M., A. Granmo, and S. Kollberg. 1973. Effects of oil dispersants and oil emulsions on marine animals. Water Res., 7(11): 1649-1672.

10.4 Burrowing behavior in the clam Macoma balthica

(Olle Lindén)

Methods: Oil-affected clams were collected at 15-20 m depth off Torö about one week after the grounding of the ship. At this time large quantities of oil were floating on the surface. The clams were collected by a diver and brought to the laboratory in closed plastic jars. Reference animals were collected off the Askö laboratory in an unpolluted area of similiar depth.

After acclimatization in the laboratory for 2-3 hours, about 20 clams of each of three length-classes (3-4 mm, 4-9 mm, 10-15 mm) from each locality were spread out over the surface of a 5 cm thick, uncontaminated sediment layer in several glass jars. The glass jars were immersed in basins containing unpolluted sea water. The number of clams that had buried themselves completely was counted at several time intervals.

Results and discussions. The rates of burrowing of the bivalve are shown in Figure 10.4.1. On the whole the control animals showed the highest burrowing rate, and all individuals had buried completely within 60 min. The animals from the polluted area showed a clearly decreased burrowing rate.

Affected burrowing behavior among clams under the influence of oil pollution has previously been reported by Shaw et al. (1976), Lindén (1977) and Taylor and Karinen (1977).

As this experiment was performed under laboratory conditions, the ecological consequences of the observed effects are still unproven. However, under natural conditions behavioral disturbances such as impaired burrowing will most probably, in the long run, be unfavorable for this organism. Clams unable to burrow normally may have their food finding affected as they are deposit feeders. Furthermore, the importance of burrowing behavior in the predator-prey relationship is obvious.

The results reported here have demonstrated that the clam Macoma balthica during the Tsesis oil spill may have been subjected to such sublethal effects.

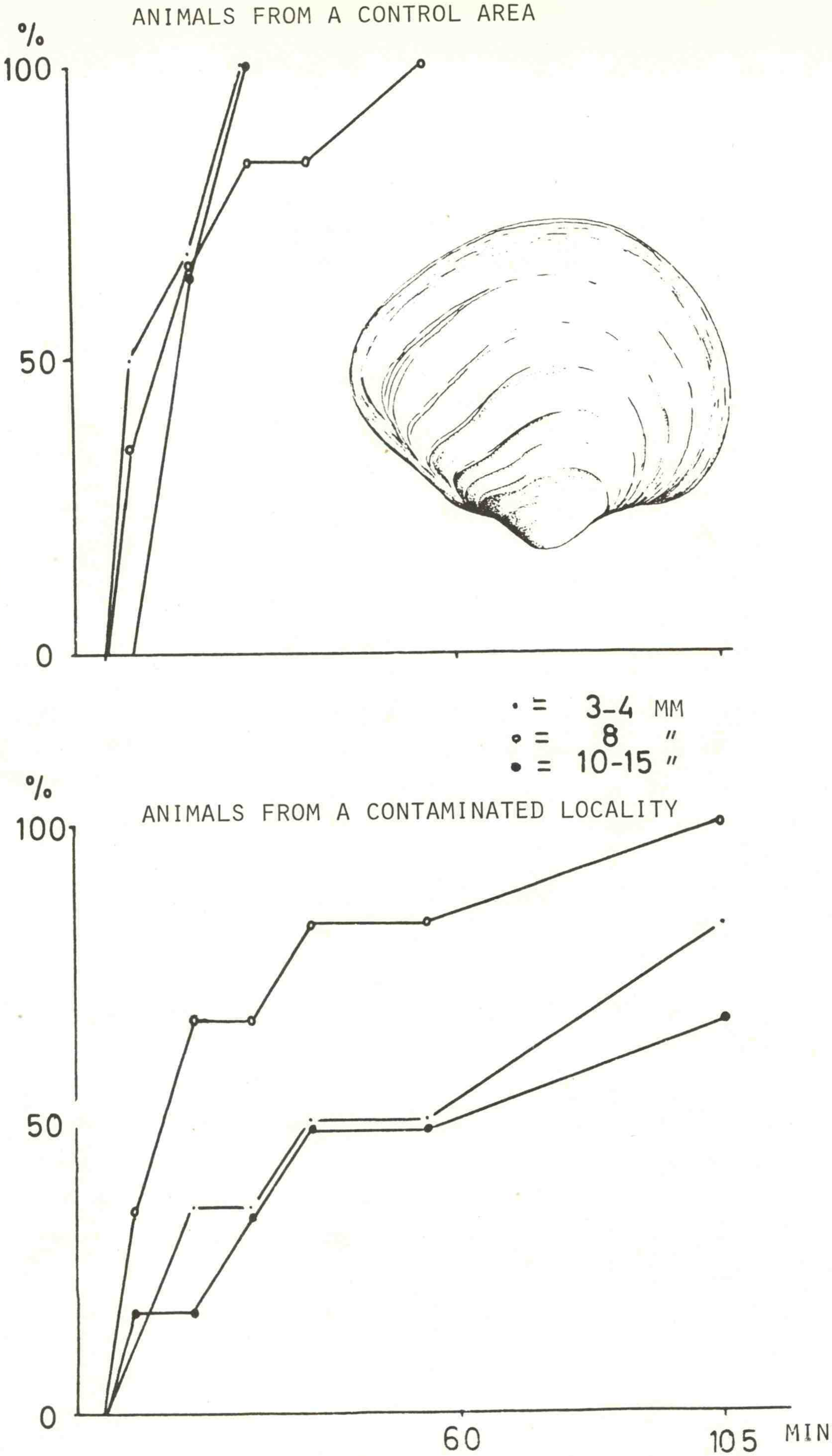

Fig. 10.4.1 Macoma balthica burrowing behaviour

References

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Shaw, D.G., A.J. Paul, L.M. Cheek and H.M. Feder. 1976. Macoma balthica: an indicator of oil pollution. Mar. Pollut. Bull. 7: 29-31.

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11. The Analytical Chemistry of *Mytilus edulis*, *Macoma balthica* Sediment Trap and Surface Sediment Samples

CHAPTER 11: THE ANALYTICAL CHEMISTRY OF MYTILUS EDULIS, MACOMA BALTHICA SEDIMENT TRAP AND SURFACE SEDIMENT SAMPLES*

(Paul D. Boehm, Judith Barak, David Fiest and Adria Elskus)

11.1 Introduction

It has become increasingly apparent in recent years that the temporal impacts of spilled oil in the marine environment become more prolonged when the fate of petroleum hydrocarbons includes transport into the sediment. Recent studies by Teal et al. (1978), Keizer et al. (1978), and Mayo et al. (1978) indicate that aromatic and aliphatic hydrocarbons from spilled petroleum persist in the sedimentary environment for substantial periods of time (years). While degradative processes, both chemical and microbial, act to alter the composition of the oil in sediment, the toxicants and carcinogens may persist in the sediment depending on factors such as sediment grain size, wave energy (Owens, 1978), and oxidation state of the sediment (Anderson et al., 1978).

There have been few field studies directly pertaining to the sedimentation of oil owing to natural processes. At least three processes can lead to the transport of petroleum from a positively buoyant state in the water column to negatively buoyant state reaching the sediment. First, some oils by virtue of an initial density close to that of water (e.g., Bunker C) can weather at sea, lose volatile or soluble components, and sink (Conomos, 1975). Such behavior was apparently observed after a Bunker C spill in cold water off the coast of Greenland (Mattson and Grøse, 1978). Secondly, oil can adsorb to living particulate matter or detrital particles and sink due to sedimentation. This process is dependent on the availability of sediment particles as well as the nature of the particulate matter (National Academy of Sciences, 1975; Meyers and Quinn, 1973; Poirier and Thiel, 1941). Another route of transport to the benthos is by ingestion of oil by zooplankters followed by fecal pellet transport (Conover, 1971). A further indirect process is deposition after landfall by seaward transport of beach and intertidal sediment with associated petroleum.

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* Work carried out by Energy Resources Co., Inc. under Contract No. MO-A01-78-4178 to OCSEAP.

Shaw et al. (1976) have suggested that Macoma balthica represents an ideal organism to monitor exposure of the benthos to pollutant input due to its deposit feeding behavior, while others have suggested that filter feeders (e.g., mussels, Mytilus species) are good indicators of oil in the aqueous environment due to their manner of processing large volumes of water.

Due to their widespread distribution in coastal waters, mussels (Mytilus sp.) have been closely studied in laboratory and field experiments for their responses to hydrocarbon pollutant exposures. Studies on the hydrocarbon chemical content of species of mussels have been performed relating to (1) background or chronic input levels in Mytilus galloprovincialis (Fossato and Siviero, 1974), M. edulis (Ehrhardt and Heinemann, 1975; Rudling, 1976), M. californianus and M. edulis (DiSalvo et al., 1975); (2) laboratory hydrocarbon uptake and depuration studies (Lee et al., 1972; Fossato and Canzonier, 1976; Kanter, 1974; Clark and Finley, 1975); (3) field transplantation (uptake and depuration) studies (DiSalvo et al., 1975; Fossato, 1975; (4) oil spills in the field (Grahl-Nielsen et al., 1978; Clark et al., 1978, among others). Mytilus sp. is a suspension feeder which processes large volumes of water to obtain food and in doing so is exposed to hydrocarbon and other pollutant compounds dispersed in the water or adsorbed to particulates. Mytilus itself is a food source for many animals, but in the Baltic it is not utilized by man. Furthermore its sedentary nature within the littoral community makes Mytilus populations both excellent markers of pollutant exposure within this zone as well as indicators of temporal recovery of the littoral zone.

This chapter concentrates on the extent of Tsesis oil exposure of the Mytilus edulis population and the long-term (1 year) tissue hydrocarbon burden of populations around the region affected by the Tsesis oil spills. For details on the spill, see section 1.2. Of particular interest were the changes in both the quantitative and qualitative nature of the aliphatic and aromatic hydrocarbon assemblages in the tissues. Macoma balthica, a prominent resident of the soft-bottom community, was used as an indicator of pollutant input to the benthos.

A year-long study of these animals together with supportive measurements from surface sediment and sediment trap samples will be the means to determine the chemical fate of oil from this spill and propose a descriptive model for the behavior of the oil after the spill.

11.2 Methods

11.2.1 Sampling

Sampling was carried out by the Swedish scientists from the Askö Laboratory, University of Stockholm, and the Swedish Water and Air Pollution Research Institute (IVL) as part of their ecological impact study. Sampling of Mytilus were obtained periodically from eight of the stations in the study area indicated in Figure 11.1 (B, C, D, E, F, G, I, J). Baseline chemical information was obtained by sampling at stations C, D, and G prior to the oil's landfall. A reference station J adjacent to the biological laboratory on Askö Island was sampled in October of 1978 after it became apparent that the original reference site G was indeed impacted by the oil.

Macoma samples were obtained in grab or dredge samples taken at nine soft-bottom stations shown in Fig. 11.1 (C, D, 2, 5, 6, 7, 8, 15, 20). Station 15 was chosen as the reference station not believed to be impacted by the Tsesis spill.

At each station at least 5 grams wet weight of Mytilus and Macoma tissue were obtained. Individual specimens measured from 1 to 3 cm and each sample for analysis consisted of 10 to 60 individuals. Samples were frozen after collection and transported using dry ice for preservation.

Sediment traps (see section 4.2.3.5 for details) were deployed at three stations in the area (II, IV, V). Sediment samples were collected as described in section 6.2.1. The collected material was stored frozen prior to analysis.

11.2.2 Sample Analysis

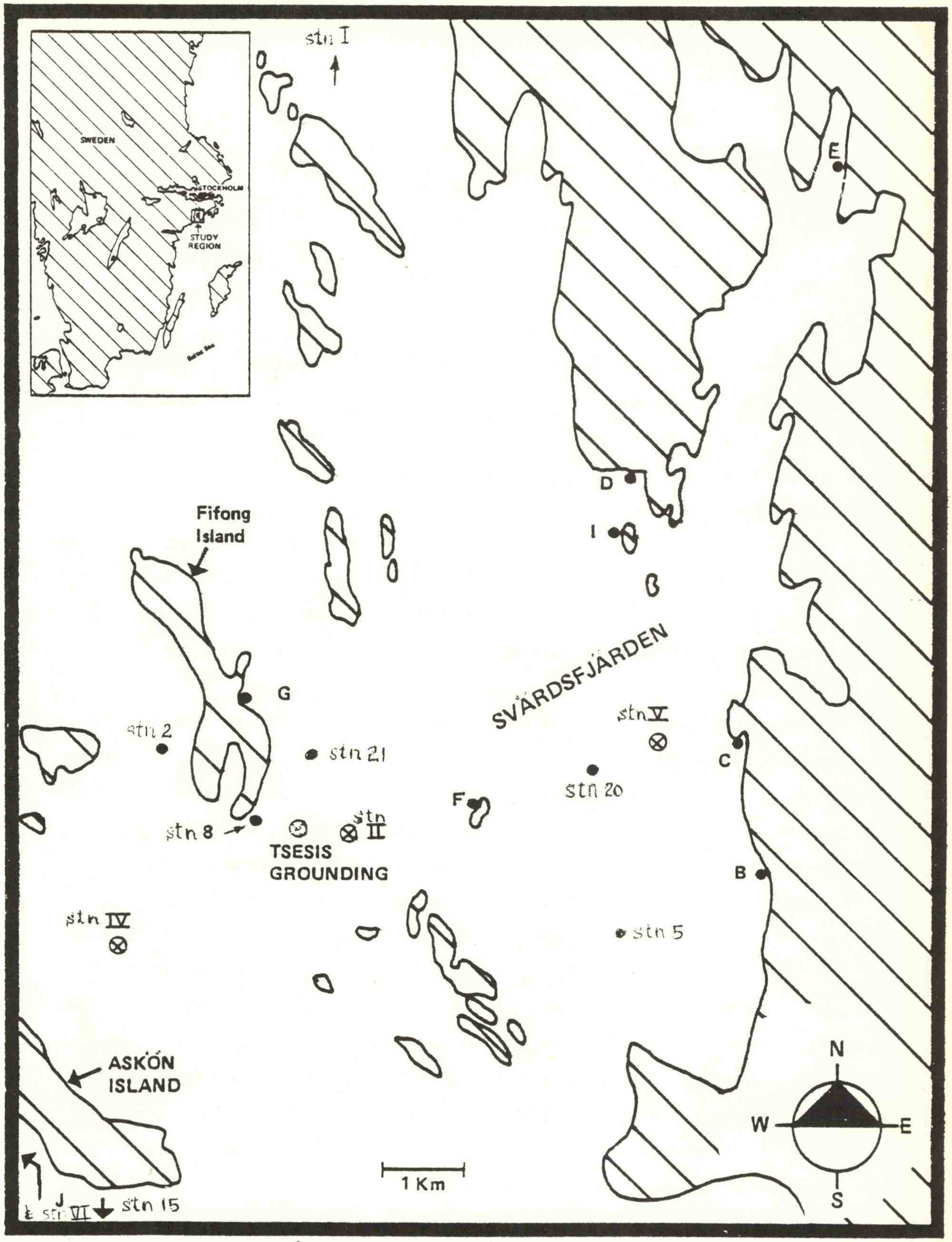
Once in the laboratory the shells of the frozen samples were rinsed with distilled solvent. The specimens were then shucked, tissues combined and weighed and added to 50 ml Teflon capped centrifuge tubes.

Figure 11.1

Map of Study Area and Station Locations

KEY

Roman numerals (I,II,III,IV,V,VI) = pelagic sampling stations
Arabic numerals(2,5,8,15,20,21) = benthic sampling stations
Capital letters (B - J, exc. H) = littoral sampling stations or benthic stations in the proximity of a littoral station.


SWEDEN
STOCKHOLM
STUDY REGION
stn I
E
D
I
B
SVÄRDSFJÄRDEN
stn V
C
stn 20
F
B
Fifong Island
G
stn 2
stn 21
58°49.7'N
stn 8
stn II
TSESIS GROUNDING
stn IV
stn 5
ASKÖN ISLAND
J
stn VI
stn 15
1 Km
N
W
E
S
17°43.8'E

The digestion, extraction, and fractionation schemes were similar to those developed by Warner (1976) except that the digestion was performed using a 0.5 N KOH/distilled water/distilled methanol system heated in a boiling water bath for 4 hours to achieve complete digestion and hence release of hydrocarbons from the cellular matrix. Internal standards were added prior to digestion and carried through the entire procedure (f_1 = androstane; f_2 = hexaethyl benzene). Standards were also added to sediment and sediment trap samples (see below). The digestate was extracted three times with distilled hexane in the centrifuge tube. The extracts were combined, concentrated to 0.5 ml, weighed on a Cahn electrobalance, and fractionated on an alumina over silica gel column (Boehm, 1978). Two fractions corresponding to the aliphatic or f_1 (hexane eluate) and the aromatic/olefinic or f_2 (methylene chloride eluate) hydrocarbons were obtained for gas chromatographic analysis.

Sediment samples were extracted using the method of Boehm and Quinn (1978) and fractionated as stated above. Sediment trap samples (~1 gram) were extracted in closed centrifuge tubes with a methanol-hexane solvent mix in a boiling water bath for 4 hours. The solvent was obtained, concentrated, and fractionated as stated.

Chromatographic fractions were concentrated to 50 µl and a 1 µl subsample was injected into a Hewlett Packard Model 5840A gas chromatograph equipped with a flame ionization detector. Samples were chromatographed in the splitless injection mode on a 15-m (0.25-mm i.d.) SE-30 glass capillary column (J and W Scientific; ~50,000 theoretical plates). The column oven was temperature programmed from 60° C to 275° C at 3° C per minute. The injection port and detector temperatures were 250° C and 300° C, respectively. Peak areas were obtained using a digital integration option which resets the baseline at every valley. Thus peak areas above the unresolved complex mixture (UCM) or hump were digitized. Peak area and retention time information for the sample peaks and the internal standard was transmitted using an HP 18861 digital interface to a PDP 10 computer which computed retention index and quantitative data according to programs developed at ERCO.

The unresolved complex mixture (UCM) was quantified using planimetry according to published procedures of Boehm and Quinn (1978) and Farrington and Quinn (1973), and relating its area to that of the internal standard through an integration unit to planimeter unit conversion factor.

Combined glass capillary gas chromatography/mass spectrometry was performed on a Hewlett-Packard 5985 GC/MS/computer system for peak identifications and quantifications, using selected ion monitoring. GC/MS was used primarily as a tool for investigating aromatic (f_2) hydrocarbon fraction contents of a selected set of tissue and sediment trap samples.

Quantitative GC/MS was performed on selected aromatic hydrocarbon samples, GC/MS response factors were computed by examining the instrumental response of a given amount of aromatic standard relative to that for the internal standard (hexaethyl benzene). Response factors for components for which no authentic standards were available (e.g. C_3 phenanthrene, C_2 and C_3 fluorenes, C_2 and C_3 dibenzothiophenes) were computed by extrapolation from the factors for parent and monomethylated compounds. Total ion currents for parent (M^+) peaks were obtained for each component of interest, relative response factors applied, and converted to concentration units by comparison to the internal standard amount.

11.3 Results

11.3.1 Mytilus edulis

All of the stations in the littoral zone were sampled from the time of the spill event through early May 1978. In addition, two of the stations C and D, along the eastern shoreline, and one near the spill off Fifong Island (G) were sampled prior to landfall of the oil (baseline samples) and through October of 1978. Results of these analyses are presented in Tables 11.1 through 11.4.

11.3.1.1 Aliphatic Hydrocarbons

The data in Table 11.1 document a very rapid uptake of Tsesis oil by the littoral bivalve Mytilus. Aliphatic hydrocarbon concentrations

TABLE 11.1

ALIPHATIC HYDROCARBON DATA ON MYTILUS EDULIS SAMPLES

SAMPLE	DATE	DRY WEIGHT	F_1 ALIPHATICS (µg/g) RESOLVED	UCM	TOTAL	PRIS	PHY	PRIS/ PHY	ALK/ ISO (13-18)
(C)	10-27-77	1.54	1.9	71.0	72.9	nd	0.08	-	-
	11-14-77	0.64	7,538.1	25,708.3	33,246.4	286.4	429.6	0.67	2.67
	12-14-77	0.32	1,138.8	13,087.8	14,226.6	102.5	133.4	0.77	0.06
	5-2-78	1.55	92.1	1,785.4	1,877.5	3.7	5.3	0.70	0.09
	6-20-78	0.62	25.1	799.8	824.9	1.7	1.3	1.34	0.45
	8-23-78	2.10	16.0	958.0	974.0	0.4	-	-	-
	10-30-78	2.24	3.3	958.0	161.3	0.2	0.3	0.67	0.30
(D)	10-27-77	1.39	2.5	20.3	22.8	nd	0.2	-	-
	11-30-77	2.88	1,388.8	6,258.1	7,646.9	49.3	83.9	0.59	1.79
	12-14-77	1.17	47.0	922.1	969.1	6.0	6.7	0.90	0.03
	5-2-78	1.75	74.0	923.0	997.1	1.2	1.7	0.70	0.26
	8-23-78	1.68	6.8	513.0	519.8	-	-	-	-
	10-30-78	1.79	2.5	65.5	67.0	-	-	-	-
(G)	10-27-77	1.89	2.7	79.7	82.4	0.2	0.05	3.5	-
	11-09-77	1.17	706.7	2,002.0	2,708.7	14.2	43.9	0.32	1.6
	12-14-77	0.96	86.5	688.8	775.3	5.6	7.0	0.80	0.3
	5-02-78	0.39	53.9	1,399.5	1,453.4	4.2	6.3	0.66	0.06
	8-23-78	1.71	66.0	687.0	753.0	6.6	10.1	0.65	0.16
	10-30-78	2.12	1.9	50.5	52.4	0.1	-	-	1.3
(B)	11-09-77	3.16	1,126.6	2,976.1	4,102.8	29.7	59.0	0.50	1.67
	12-14-77	1.14	267.2	2,187.2	2,454.4	19.5	29.1	0.67	0.06
	5-2-78	1.40	61.9	1,558.6	1,620.5	3.9	6.4	0.61	0.10
(E)	11-09-77	2.36	123.7	653.3	777.0	11.1	15.3	0.73	0.66
	12-14-77	1.31	177.9	1,911.4	2,089.3	23.1	29.2	0.79	0.06
	5-2-78	1.06	45.5	1,166.3	1,211.8	5.2	7.3	0.70	0.07
(F)	11-9-77	0.90	574.9	1,328.0	1,902.9	21.0	50.5	0.42	0.53
	12-14-77	0.89	92.9	1,012.7	1,105.6	9.7	13.5	0.72	0.03
	5-2-78	0.86	42.7	1,150.4	1,192.1	3.1	4.9	0.64	0.09
(I)	11-9-77	2.29	338.3	1,651.1	1,989.4	21.3	31.9	0.67	0.64
(J)	11-2-78	2.81	1.3	12.2	13.5	-	-	-	-
(Control) TSESIS oil		-	-	-	-	-	-	0.54	7.0

UCM=unresolved complex mixture; PRIS=pristane; PHY=phytane;
ALK/ISO= $\frac{\text{n-alkane-to-isoprenoid ratio over the range}}{\text{n-C}_{13-18}}$ (see also Table 11.5).

TABLE 11.2

AROMATIC HYDROCARBON GROSS PARAMETER CONCENTRATIONS IN MYTILUS EDULIS

SAMPLE	DATE	F_2 (AROMATICS) RESOLVED	UCM	TOTAL
(C)	10-27-77	1.7	14.8	16.5
	11-14-77	456.6	16,917.9	17,374.5
	12-14-77	297.5	21,275.0	21,572.5
	5-02-78	18.9	1,394.0	1,412.9
	6-20-78	5.6	461.7	467.3
	8-23-78	2.8	106.0	108.8
	10-30-78	14.0	426.8	440.0
(D)	10-27-77	2.5	46.0	48.5
	11-30-77	141.4	3,689.1	3,830.5
	12-14-77	11.7	852.9	864.5
	5-02-78	7.3	478.0	485.3
	8-23-78	2.8	56.7	59.5
	10-30-78	5.8	110.4	116.2
(G)	10-27-77	8.5	210.0	218.5
	11-09-77	99.6	6,236.7	6,336.3
	12-14-77	2.4	470.3	472.7
	5-02-78	12.3	1,366.3	1,378.6
	8-23-78	7.8	86.1	93.9
	10-30-78	5.0	48.5	53.5
(B)	11-09-77	174.7	4,636.6	4,811.3
	12-14-77	47.6	2,057.4	2,105.0
	5-02-78	23.4	894.1	917.5
(E)	11-09-77	1.9	858.0	859.0
	12-14-77	20.2	2,297.1	2,317.3
	5-02-78	44.8	1,418.8	1,463.6
(F)	11-9-77	68.0	3,015.0	3,083.0
	12-14-77	7.9	1,620.0	1,627.9
	5-02-78	12.2	1,053.1	1,065.3
(I)	11-09-77	9.8	2,400.1	2,409.0
(J)	11-02-78	3.3	12.3	15.6
(Control)				

TABLE 11.3

CONCENTRATIONS OF AROMATIC HYDROCARBON COMPOUNDS IN MYTILUS EDULIS AS DETERMINED BY GC/MS

STATION	DATE	NAPHTHALENES (µg/g)	PHENANTHRENES (µg/g)	DIBENZOTHIOPHENES (µg/g)
(F)	11-09-77	32.3	24.5	-[a]
	12-14-77	nd[b]	3.2	-
	5-2-78	nd	1.6	-
(D)	11-30-77	23.2	31.7	-
	12-14-77	0.1	7.9	-
	5-2-78	0.03	0.6	0.5
	8-23-78	0.15	0.08	-
	10-30-78	0.005	0.17	-
(B)	11-09-77	79.2	61.3	34.3
	12-14-77	3.4	14.0	14.1
	5-2-78	0.3	1.7	1.0
(G)	10-27-77 (Baseline)	nd	1.2	0.71
	12-14-77	0.82	5.4	1.8
	10-30-78	0.23	0.13	-
(I)	11-09-77	0.7	16.91	-

[a]Not searched.

[b]None detected.

TABLE 11.4

AROMATIC HYDROCARBONS IN MYTILUS EDULIS
GROSS PARAMETERS BY CAPILLARY GC
INDIVIDUAL COMPOUNDS BY GC/MS

		GROSS PARAMETERS (µg/g)			INDIVIDUAL COMPONENTS (µg/g)											
STATION	DATE	RESOLVED	UNRESOLVED	TOTAL	N	C_1N	C_2N	C_3N	P	C_1P	C_2P	C_3P	DBT	C_1DBT	C_2DBT	C_3DBT
(D)	10-27-77	2.5	46.0	48.5	nd	nd	nd	nd	nd	nd	0.02	0.03	nd	nd	0.6	0.10
	11-30-77	141.4	3,689.1	3,830.5	nd	nd	3.7	19.5	2.1	12.6	17.1	25.5	3.0	9.2	10.0	11.6
	12-14-77	11.7	852.9	864.5	0.07	nd	nd	nd	nd	0.2	1.4	6.3	*	*	*	
	5-2-78	7.3	478.0	485.3	0.03	nd	nd	nd	0.04	0.08	0.1	0.4	0.01	0.1	0.10	0.34
	8-23-78	2.8	56.7	59.5	0.01	0.08	0.06	nd	0.03	0.03	0.04	0.06	*	*	*	*
	10-30-78	5.8	110.4	116.2	nd	nd	0.01	0.02	nd	nd	0.05	0.12	*	*	*	*
(G)	10-27-77	8.5	210.0	218.5	nd	nd	nd	nd	nd	nd	0.23	0.56	nd	nd	0.14	0.57
	12-14-77	2.4	470.3	472.7	0.07	0.10	0.18	0.47	0.10	0.58	1.4	3.3	0.1	0.30	1.54	-
	10-30-78	5.0	48.5	53.5	0.09	0.06	0.09	0.03	0.01	0.04	0.03	0.08	nd	0.8	0.3	0.09
(B)	11-09-77	174.7	4,636.6	4,811.3	0.32	3.0	31.7	44.3	5.6	19.9	17.1	18.7	2.8	8.7	12.5	10.4
	12-14-77	47.6	2,057.4	2,105.0	0.50	2.2	0.5	0.7	0.2	1.7	2.7	9.6	0.1	0.7	5.5	8.0
	5-2-78	23.4	894.1	917.5	0.10	nd	0.2	nd	0.1	0.4	0.3	0.9	*	*	*	*
(F)	11-09-77	68.0	3,015.0	3,083.0	0.50	0.8	1.0	30.7	2.2	8.4	13.9	18.0	*	*	*	*
	12-14-77	7.9	1,620.0	1,627.9	nd	nd	nd	nd	nd	nd	0.8	2.4	*	*	*	*
	5-2-78	12.2	1,053.1	1,065.3	nd	nd	nd	nd	0.1	0.4	0.4	0.7	*	*	*	*
(I)	11-9-77	9.8	2,400.1	2,409.9	nd	nd	nd	0.7	0.31	3.3	4.0	9.3	*	*	*	*

Key: N = naphthalene; C_1N, C_2N, C_3N = methyl naphthalene, dimethyl naphthalene, trimethyl naphthalene; C_1P, C_2P, C_3P = methyl phenanthrene, dimethyl phenanthrene, trimethyl phenanthrene; DBT = dibenzothiophene; C_1DBT, C_2DBT, C_3DBT = methyl dibenzothiophene, dimethyl dibenzothiophene, trimethyl dibenzothiophene; * = not searched in GC/MS run; nd = none detected.

in living tissue exceed 30 mg/g at the most heavily impacted station C. Animals at the other shoreline stations D and E contain aliphatic hydrocarbon levels of 7.6 mg/g and 4.1 mg/g respectively during the November 1977 sampling. These values are 300 to 500 times the background hydrocarbon levels in tissues from these stations. Although depuration of aliphatic hydrocarbons appears to commence very soon after the initial impact in animals surviving the oil's landfall, it is not until 1 year after the event that tissue hydrocarbon levels appear to reapproach the background levels. However, examination of the detailed hydrocarbon composition of the tissues 1 year after the spill still reveals petroleum hydrocarbon inputs at some stations. This will be discussed.

High resolution gas chromatograms of the tissue hydrocarbon compositions reveal a rapidly changing suite of hydrocarbons in the mussels. Initially, tissues from the most heavily impacted stations appear to have taken up hydrocarbons very similar in composition to the spilled oil (Fig. 11.2a and 11.2b). However, all samples obtained in December, 2 months after the spill, reveal GC patterns indicating substantial alteration of the cargo oil pattern, with n-alkanes being preferentially degraded compared with corresponding branched and isoprenoid compounds (Fig. 11.2c and 11.2d). At several stations, most notably I, even the November tissue samples already exhibit notable preferential n-alkane degradation throughout the entire boiling range of the oil (approximately n-C_{10} through n-C_{30}). The GC of Fig. 11.2c illustrates such a case, where the isoprenoid hydrocarbons, having retention indices of 1370, 1460 (farnesane), 1560, 1650, 1710 (pristane), and 1812 (phytane), become chromatographically prominent due to their greater resistance to microbial degradative processes (Kator, 1973).

The rapid alteration in the tissue hydrocarbon composition from an essentially unaltered oil to an n-alkane-depleted, isoprenoid-enriched assemblage is the single most important aspect of the changing hydrocarbon chemistry of Mytilus tissue. This change is expressed in Table 11.1 as the ALK/ISO ratio, which is simply the ratio of n-alkane to isoprenoid hydrocarbons in the n-C_{13} to n-C_{18} boiling range. In the spilled cargo oil the n-alkanes predominate (ALK/ISO = 7.0). The most

Figure 11.2

Representative Glass Capillary Gas Chromatograms of Mytilus edulis Aliphatic Hydrocarbons

A - Baseline (pre-spill)

B - TSESIS cargo

C - November (Station B)

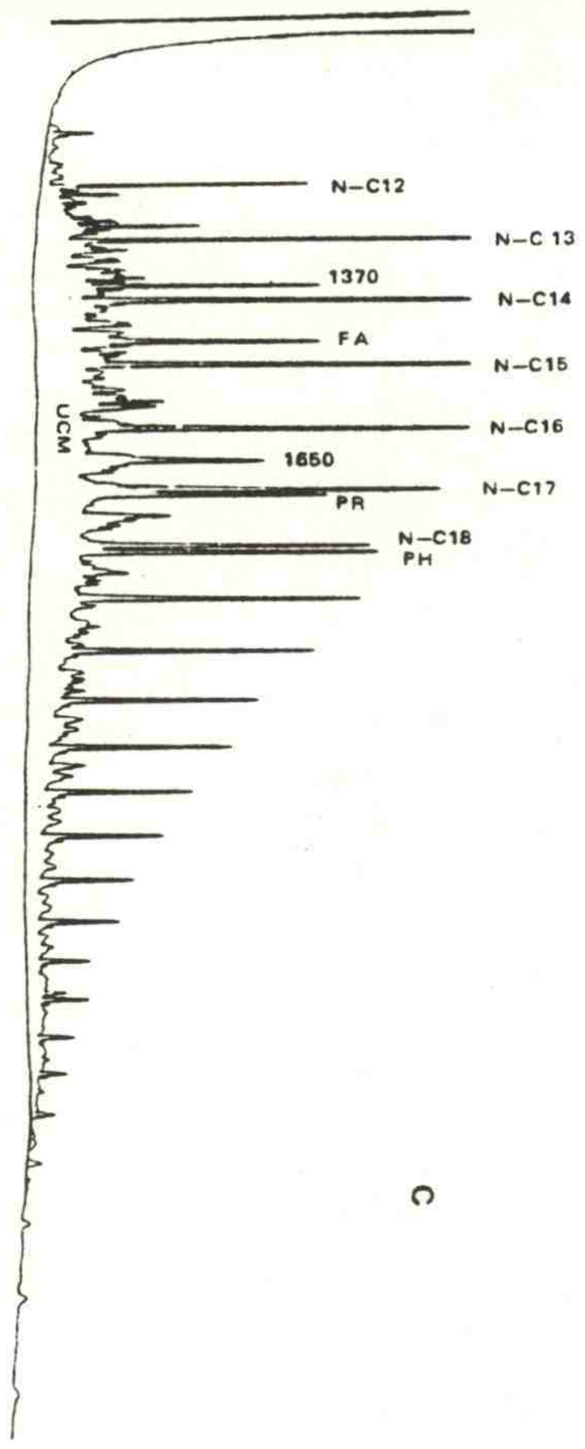
D - November (Station I)

E - December (Station B)

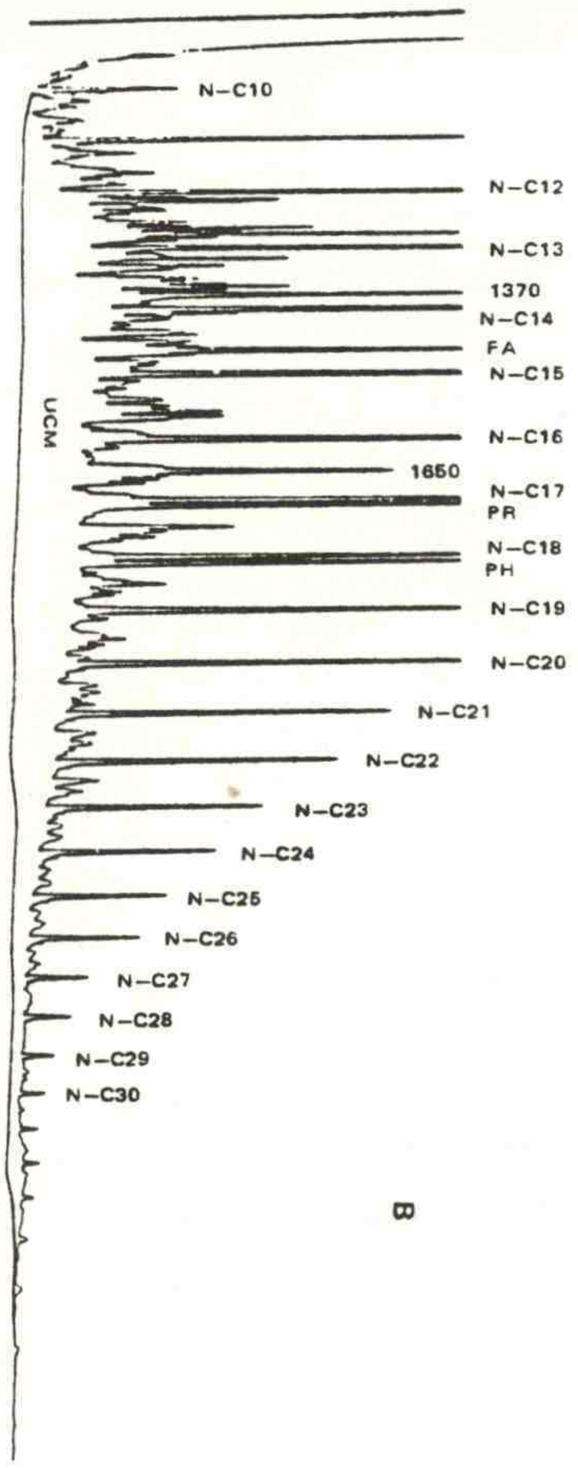
F - May 1978 (Station B)

G - October 1978 (Station C)

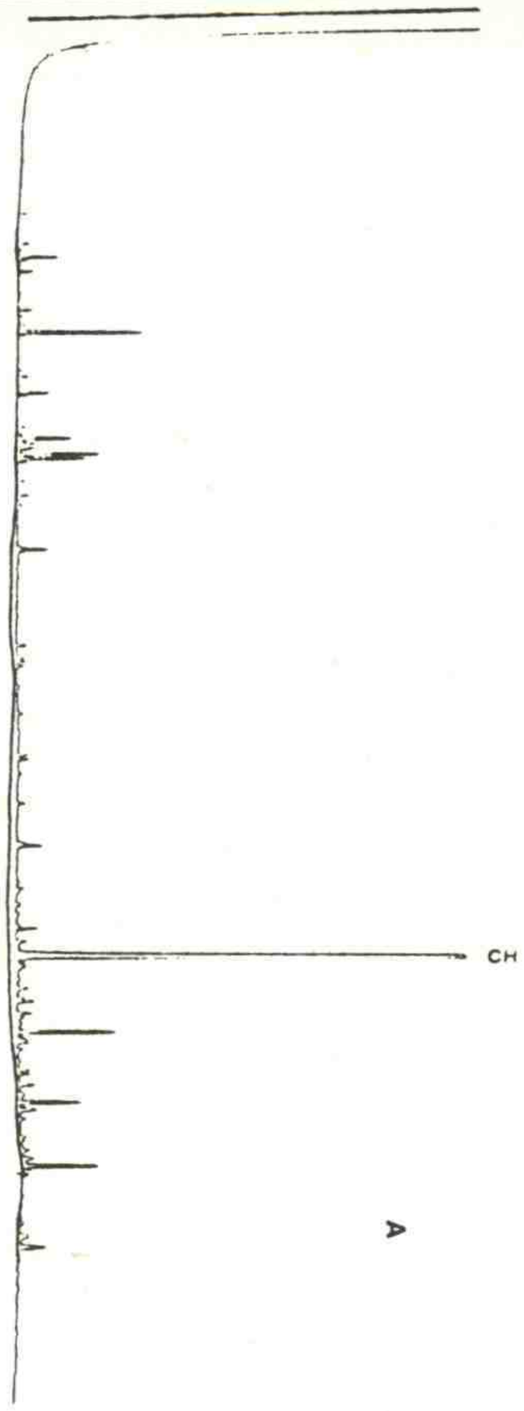
CH = cholestane (internal standard); n-C_x = n-alkane having x carbon atoms; FA = farnesane; PR = pristane; PH = phytane; UCM = unresolved complex mixture; 1370, 1460, 1650 = retention indices of these peaks


N-C12
N-C 13
1370
N-C14
FA
N-C15
UCM
N-C16
1650
N-C17
PR
N-C18
PH

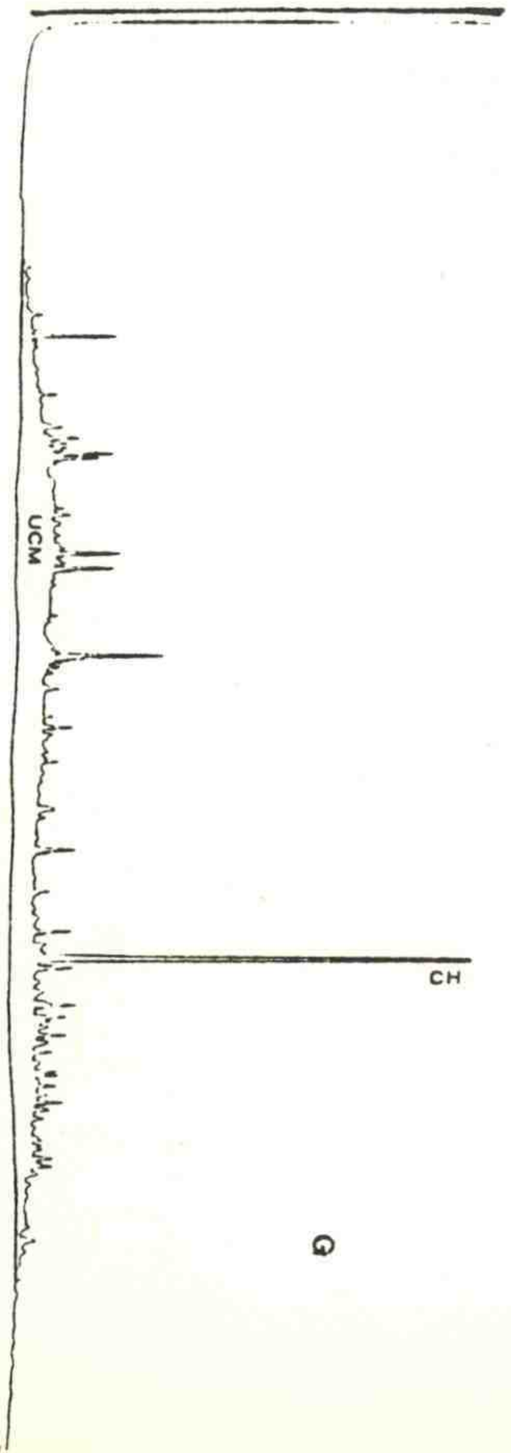
C


N-C10
N-C12
N-C13
1370
N-C14
FA
N-C15
UCM
N-C16
1650
N-C17
PR
N-C18
PH
N-C19
N-C20
N-C21
N-C22
N-C23
N-C24
N-C25
N-C26
N-C27
N-C28
N-C29
N-C30

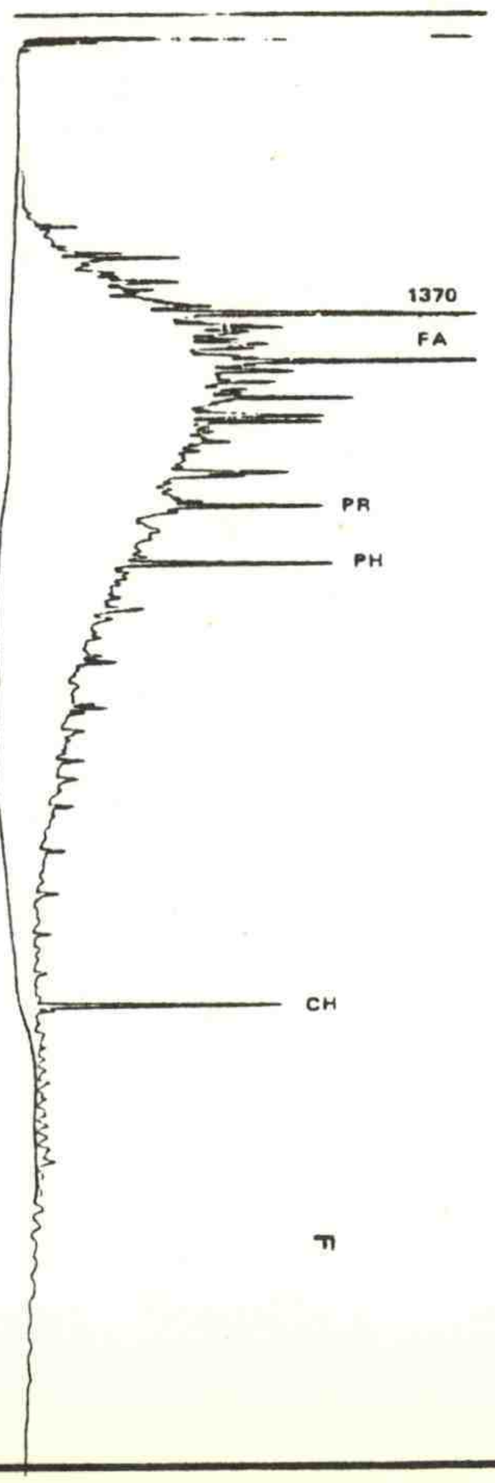
B


CH

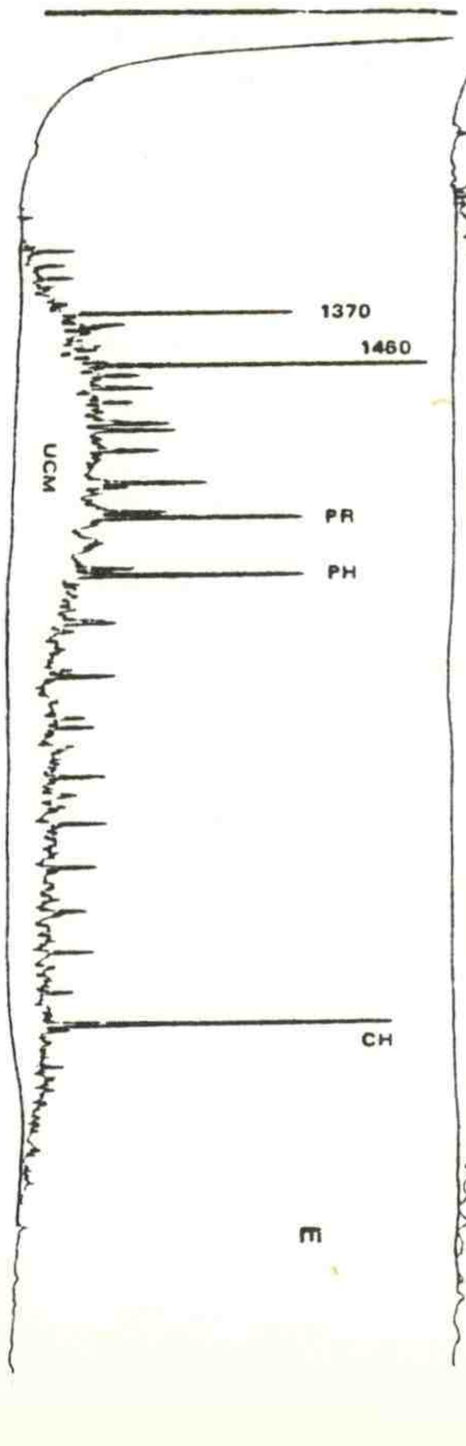
A


UCM
CH

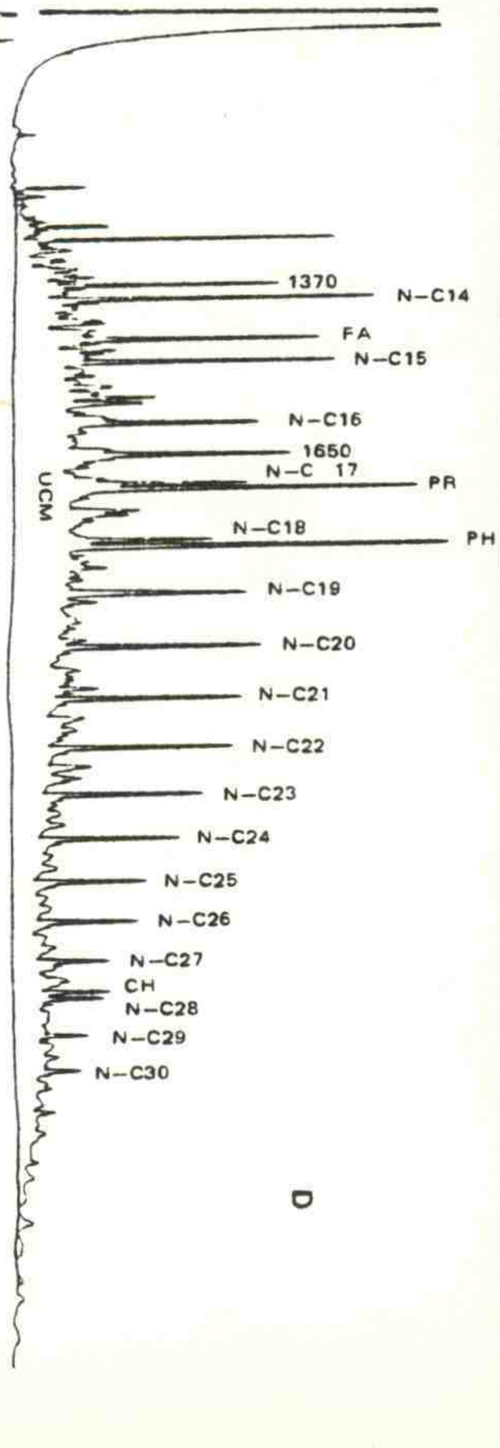
G


1370
FA
PR
PH
CH

F


1370
1460
UCM
PR
PH
CH

E


1370
N-C14
FA
N-C15
N-C16
1650
N-C 17
PR
UCM
N-C18
PH
N-C19
N-C20
N-C21
N-C22
N-C23
N-C24
N-C25
N-C26
N-C27
CH
N-C28
N-C29
N-C30

D

heavily oiled samples exhibit an ALK/ISO ratio from 1.7 at station B to 2.7 at C, both in early November. Thus, even at the earliest sampling period the petroleum hydrocarbons already exhibit an altered pattern.

Hydrocarbon GC profiles from particulate material in the water column in the region obtained from sediment trap deployments (see section on sediment traps) indicate that the oil sampled in the water during the first week in November also has been dramatically altered (see Fig. 11.6), presumably due to microbial degradation. Even the earliest trap samples obtained exhibit a degraded pattern (ALK/ISO = 1.0) and within 10 days all of the remaining oil dispersed in the water column has been severely altered (ALK/ISO = 0.1).

As previously mentioned, the gross hydrocarbon parameters indicate that Mytilus remaining in the region have eliminated most of the initial hydrocarbon burden 1 year after the spill and pre-spill levels are being approached (Table 11.1). However, GC profiles (Fig. 11.2G) of samples taken from station C in October of 1978 still exhibit significant levels of petroleum hydrocarbons albeit a degraded assemblage consisting mainly of UCM material.

11.3.1.2 Aromatic Hydrocarbons

After receiving an initial hydrocarbon tissue burden at levels of 5 mg/g to 20 mg/g at the most heavily oiled stations, levels in Mytilus decrease but remain at levels 100 times the background levels of the gross parameters (Table 11.2) 7 months after the spill. One year after the spill levels appear to approach background at all stations except the most heavily impacted station, C. However, a close examination of the gas chromatographic profiles of representative aromatic hydrocarbon fractions throughout the year reveals that residual petroleum material is still present in the tissues one year after the spill (Fig. 11.3). Therefore the gross hydrocarbon parameters (Table 11.2) can be misleading without a consideration of both the GC run and the detailed aromatic hydrocarbon composition. The latter was determined by subjecting a set of samples for combined gas chromatographic/mass spectrometric analysis and quantifying individual aromatic compounds which are otherwise obscured in the GC run due to their low levels relative to the entire suite of aromatic compounds.

Figure 11.3

Representative Glass Capillary Gas Chromatograms of Mytilus edulis Aromatic Hydrocarbons

A - Baseline (pre-spill, Station C)

B - TSESIS cargo

C - November 1977 (Station B)

D - December 1977 (Station C)

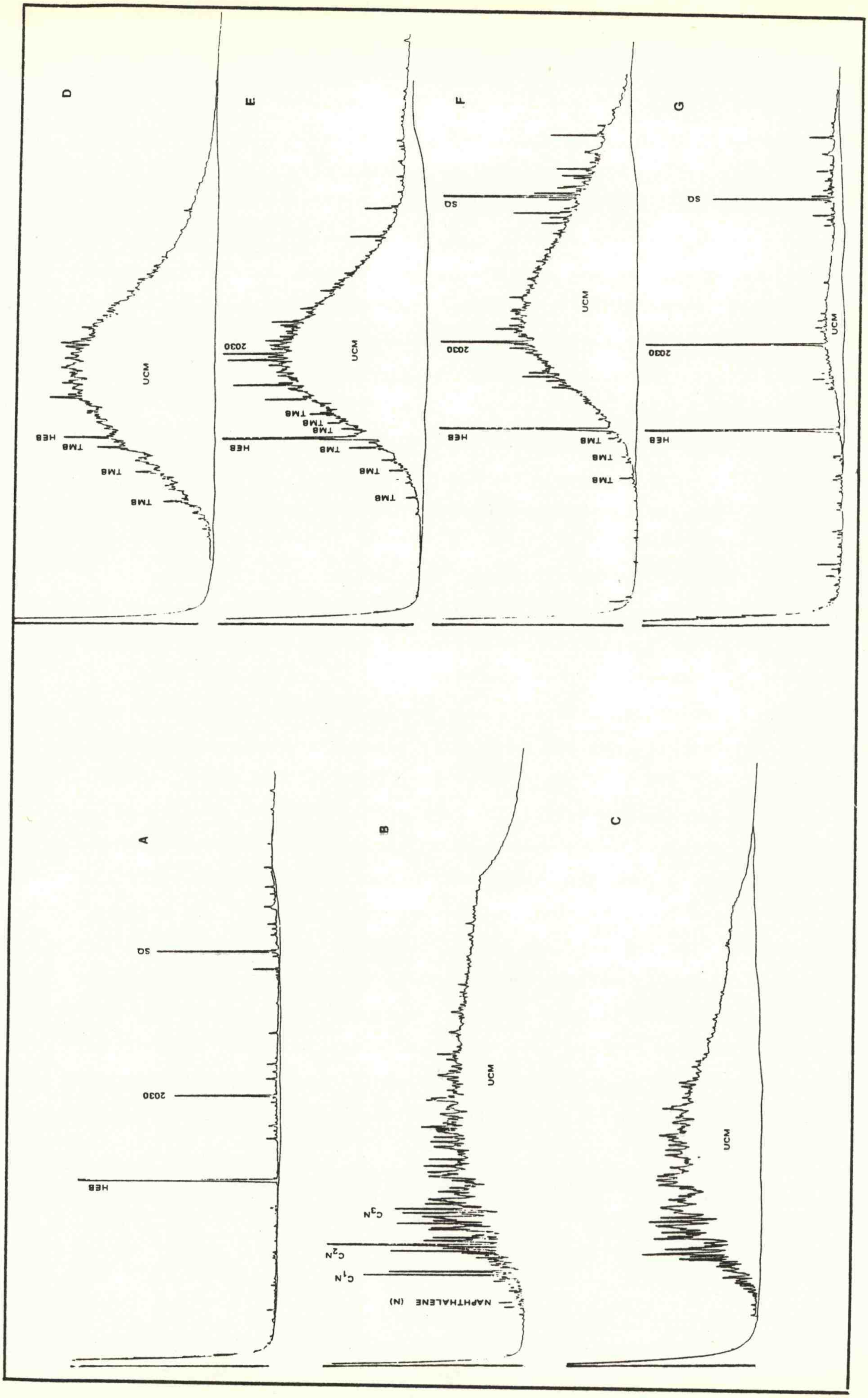
E - May 1978 (Station B)

F - October 1978 (Station C)

G - October 1978 (Station G)

TMB = substituted trimethyl benzene

HEB = hexaethyl benzene (internal standard)


A
DS
2030
HEB
NAPHTHALENE (N)
C_1N
C_2N
C_3N
UCM
B
UCM
C
UCM
D
UCM
TMB
TMB
TMB
TMB
HEB
E
2030
UCM
TMB
TMB
TMB
TMB
TMB
HEB
F
DS
2030
UCM
TMB
TMB
TMB
HEB
G
DS
2030
UCM
HEB

As can be seen in Tables 11.3 and 11.4, levels of individual hydrocarbon compounds initially as high a 40 µg/g decrease rapidly to the 3 µg/g to 10 µg/g level in December and to the 0.1 µg/g level in October of 1978. It is interesting to note that one of the baseline or pre-spill samples (station G) contains significant quantities of substituted phenanthrenes as well as the organo-sulphur compounds, the dibenzothiophenes. These are probably the residual aromatics from previous pollution events. The other baseline sample from station D also exhibits small quantities of substituted aromatics (see Fig. 11.3a) as well. After one year (October 30, 1978) it is apparent that pre-spill levels are being approached, although the detailed aromatic composition does not mirror the pre-spill composition; i.e., one year after the spill mussels still contain substituted naphthalenes whereas the pre-spill samples contained none.

As was the case for the aliphatic uptake patterns, the aromatic uptake profiles reveal temporal changes. On an absolute basis all aromatic components appear to have decreased substantially during the first month of post-spill depuration (Tables 11.2 and 11.4). On a comparative basis consider Fig. 11.4. Samples obtained after the first two weeks, post-spill, exhibit a slightly altered aromatic composition vis-a-vis the spilled oil. Soon thereafter the biphenyl and fluorene compounds decrease to non-detectable levels (May 1978) in the tissues and remain so until biphenyl reappears in tissues and, with the naphthalenes, assumes a prominent comparative importance one year after the spill. It should be noted that Fig. 11.4 presents the data on a comparative basis with the absolute sum of the total components in Fig. 11.4 decreasing throughout the year from 165.4 µg/g to 0.7 µg/g. During the year there appears to be a greater comparative loss of the naphthalenes, fluorene, and biphenyl, the lower boiling compounds, in addition to the parent organo-sulphur compound dibenzothiophene. The substituted dibenzothiophenes and substituted phenanthrenes are less readily depurated on a comparative basis.

The aromatic hydrocarbon gas chromatograms also reveal a series of substituted trimethylbenzene (TMB) compounds that are relatively long-

Figure 11.4

Comparative Plot of Aromatic Hydrocarbon Composition of TSESIS Oil and Mytilus edulis Normalized to Trimethyl Phenanthrene

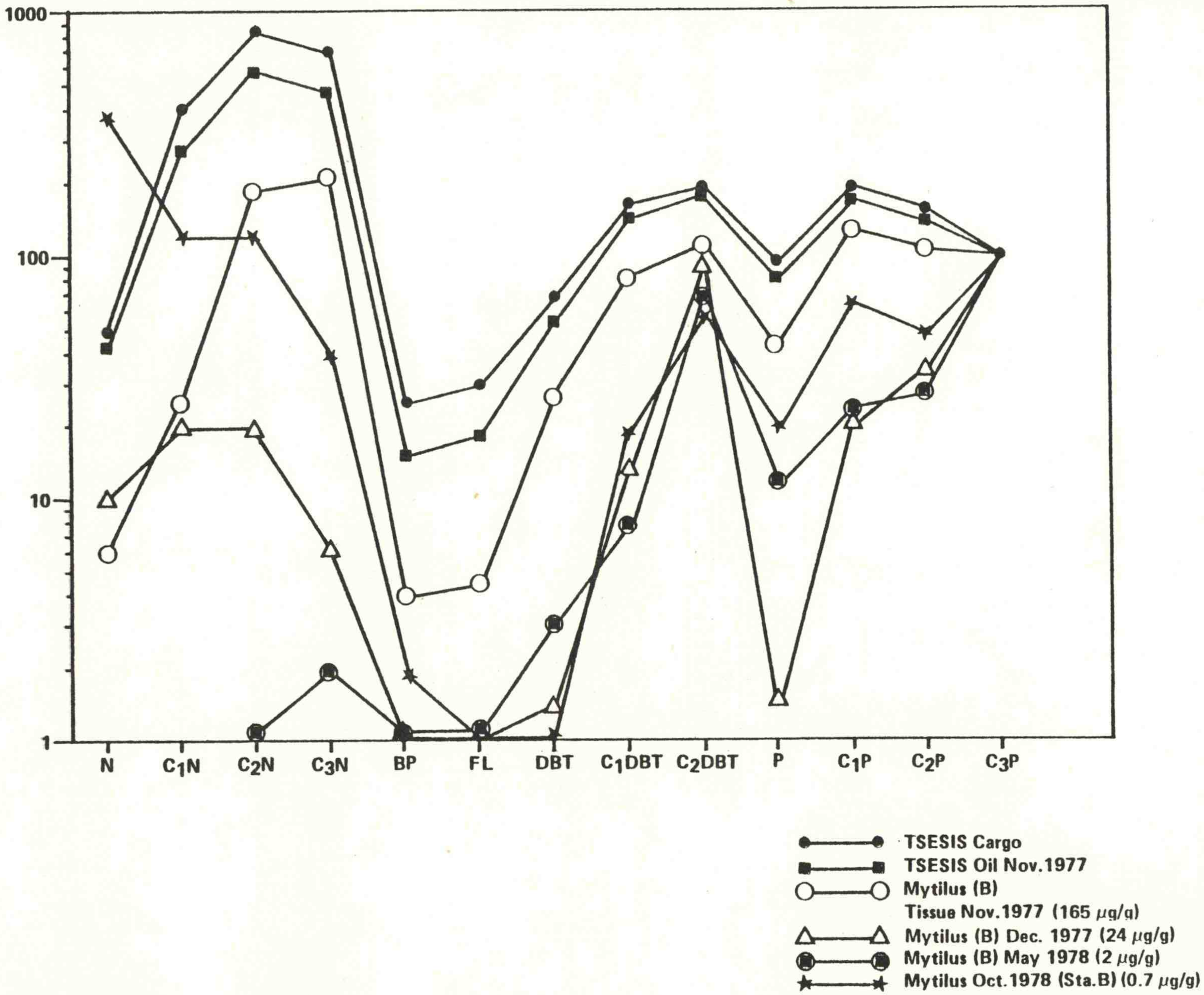
N, C_1N, C_2N, C_3N = naphthalene (N), methyl N, dimethyl N, trimethyl N

BP = biphenyl

F = fluorene

DBT, C_1DBT, C_2DBT = dibenzothiophene (DBT), methyl DBT, dimethyl DBT

P, C_1P, C_2P, C_3P = phenanthrene (P), methyl P, dimethyl P, trimethyl P


1000
100
10
1
N
C1N
C2N
C3N
BP
FL
DBT
C1DBT
C2DBT
P
C1P
C2P
C3P
TSESIS Cargo
TSESIS Oil Nov.1977
Mytilus (B)
Tissue Nov.1977 (165 μg/g)
Mytilus (B) Dec. 1977 (24 μg/g)
Mytilus (B) May 1978 (2 μg/g)
Mytilus Oct.1978 (Sta.B) (0.7 μg/g)

lived in the tissues. The structures of these compounds were examined by GC/MS. A selection search for m/e=133 (Fig. 11.5) shows that the series is present in the Tsesis oil although in relatively small amounts. However, the series emerges rapidly, presumably due to its retention by the organisms or due to difficulty in biotransformation, and persists until 1 year after the spill when analyses fail to reveal significant quantities of TMB compounds.

11.3.2 Sediment Traps

The material collected in the sediment traps at Stations II, IV, and V contains large amounts of weathered Tsesis cargo oil. Concentrations of Tsesis oil in the traps are presented in Table 11.5 and illustrate that the rate of deposition of oil through the water column is similar at the upwind station (IV), at the wreck site (II), and downwind in the direction of the movement of the visible slick (V). Thus, it appears that oil is dispersed in the water column, adsorbs to detrital material, is quickly weathered, and is redistributed by subsurface water movement through the study region. The petroleum hydrocarbon deposition rate was high during the second week after the spill (November 1 to November 9) and presumably was as high or higher during the last week in October. Thereafter the amount of petroleum hydrocarbons in the sedimented material decreased markedly and 1 to 2 months afterward the spill reached very low levels. At these low levels, petrogenic hydrocarbon inputs are non-detectable.

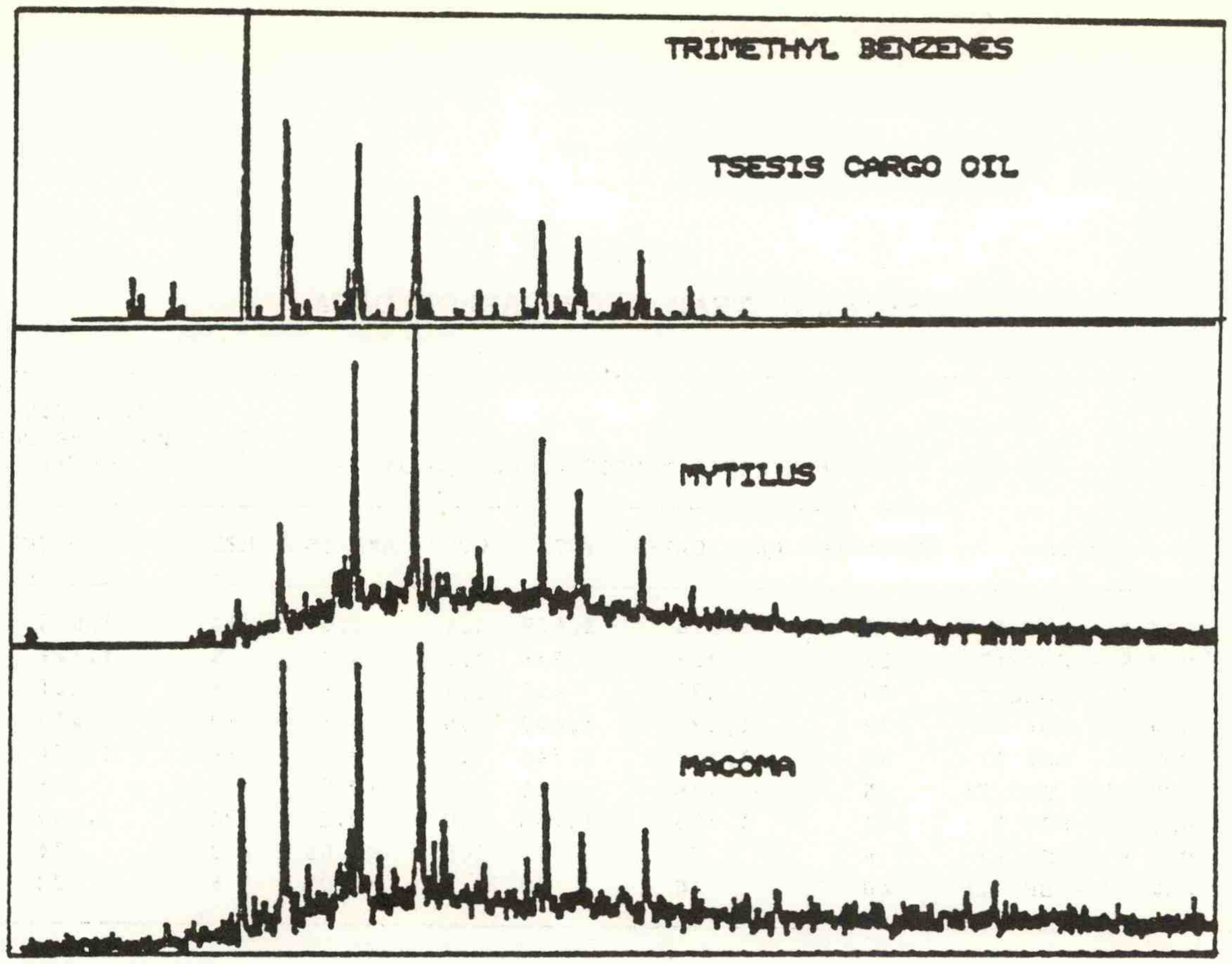
Very significant in terms of interpreting benthic as well as intertidal bivalve uptake patterns, are the detailed gas chromatograms of the hydrocarbon material found in the traps. As illustrated in Fig. 11.6 and 11.7, the spilled Tsesis oil that is sedimented has been significantly altered as early as 1 week after the spill. In the aliphatic fraction (Fig. 11.6), the n-alkane degradation has altered in oil's composition, presumably by microbial agents, to the point where the ALK/ISO ratio is 0.3 to 1.0, down from an initial value of 7.0. In addition, the increased importance of the UCM in these early deposition samples is evident from Fig. 11.6.

Figure 11.5

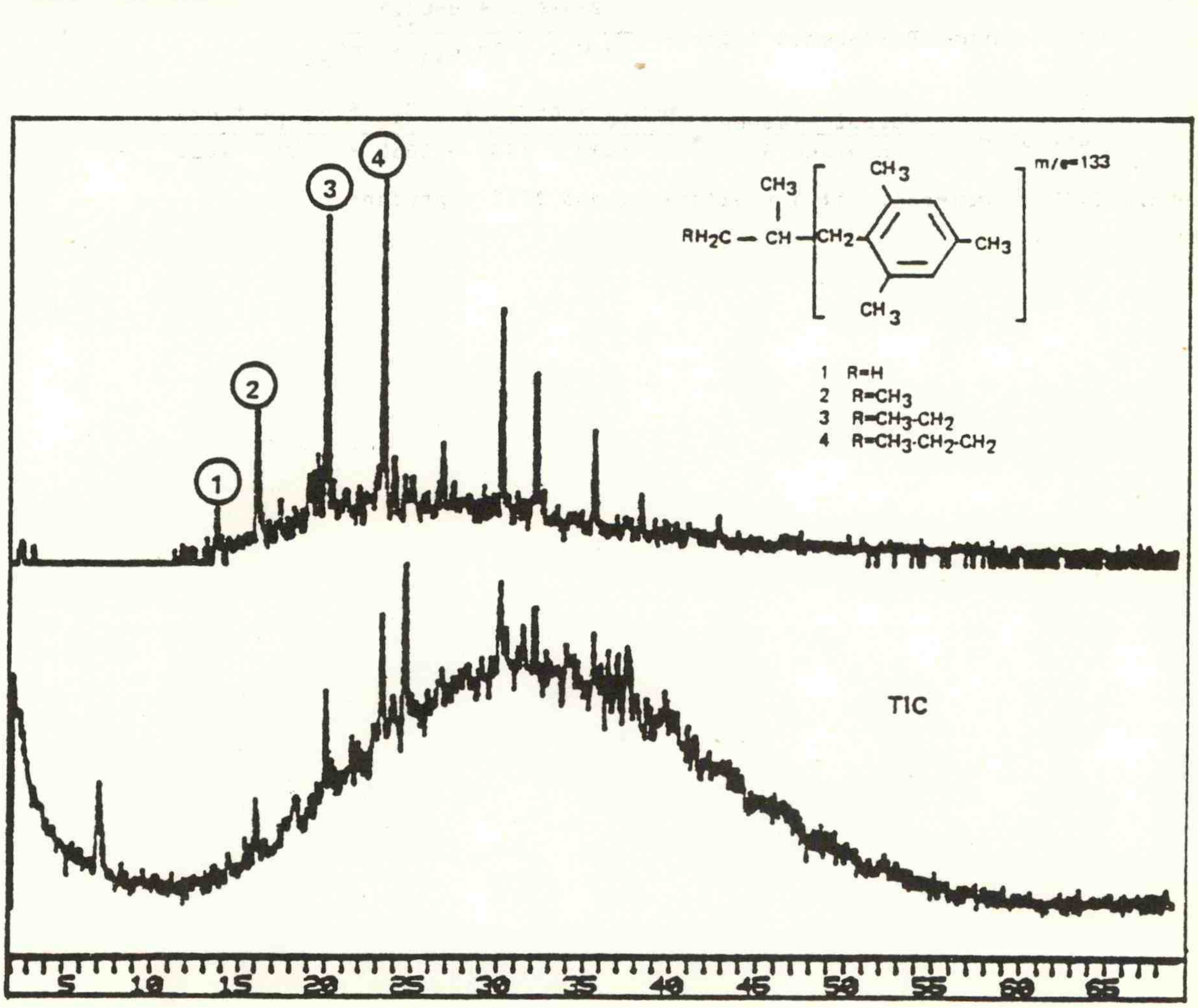
GC/MS Searches for Substituted Trimethyl Benzenes (TMB)

A - TMB (m/e 133) searches on respresentative Mytilus and Macoma samples

B - Display of m/e 133 search and total ion chromatogram


TRIMETHYL BENZENES
TSESIS CARGO OIL
MYTILUS
MACOMA

A


m/e=133
1 R=H
2 R=CH3
3 R=CH3-CH2
4 R=CH3-CH2-CH2
TIC
5
10
15
20
25
30
35
40
45
50
55
60
65

B

TABLE 11.5

SEDIMENT TRAP HYDROCARBON DATA

STATION	DATES	ALIPHATIC HYDROCARBONS (µg/g) RESOLVED	UNRESOLVED	TOTAL	CPI[a]	ALK/ISO[b]	AROMATIC HYDROCARBONS (µg/g) RES.	UNRESOLVED	TOTAL
V	NOV 1 - NOV 9	333	3,276	3,609	0.9	1.0	32	3,624	3,656
	NOV 9 - NOV 17	32	907	939	1.1	0.1	5	1,129	1,134
	NOV 17 - DEC 4	20	396	416	1.4	<0.05	3	424	427
II	NOV 2 - NOV 9	129	1,331	1,460	1.0	0.5	53	3,266	3,319
	NOV 9 - NOV 17	94	1,350	1,444	1.2	0.2	18	1,354	1,372
	NOV 17 - DEC 21	5	106	111	2.7	<0.05	2	76	78
IV	NOV 2 - NOV 9	102	1,783	1,185	1.0	0.3	24	2,730	2,754
	NOV 9 - NOV 17	6	20	26	1.5	<0.05	3	34	37
	NOV 17 - DEC 21	40	30	70	2.5	<0.05	6	28	34

[a] CPI = Carbon Preference Index = $\frac{2(n\text{-}C_{27} + n\text{-}C_{29})}{n\text{-}C_{26} + 2n\text{-}C_{28} + nC_{30}}$

[b] ALK/ISO = $\frac{\text{normal alkanes}}{\text{isoprenoids}} = \frac{n\text{-}C_{14} + n\text{-}C_{15} + n\text{-}C_{16} + n\text{-}C_{17} + n\text{-}C_{18}}{1470 + 1560 + 1650 + 1710 + 1812}$,

where 1470 = farnesane, 1710 = pristane, and 1812 = phytane.

Figure 11.6

Representative Glass Capillary Gas Chromatograms of Sediment Trap Aliphatic Hydrocarbons

A - TSESIS oil (November 2 - November 9)

B - Station IV (November 2 - November 9)

C - Station V (November 1 - November 9)

D - Station V (November 9 - November 17)

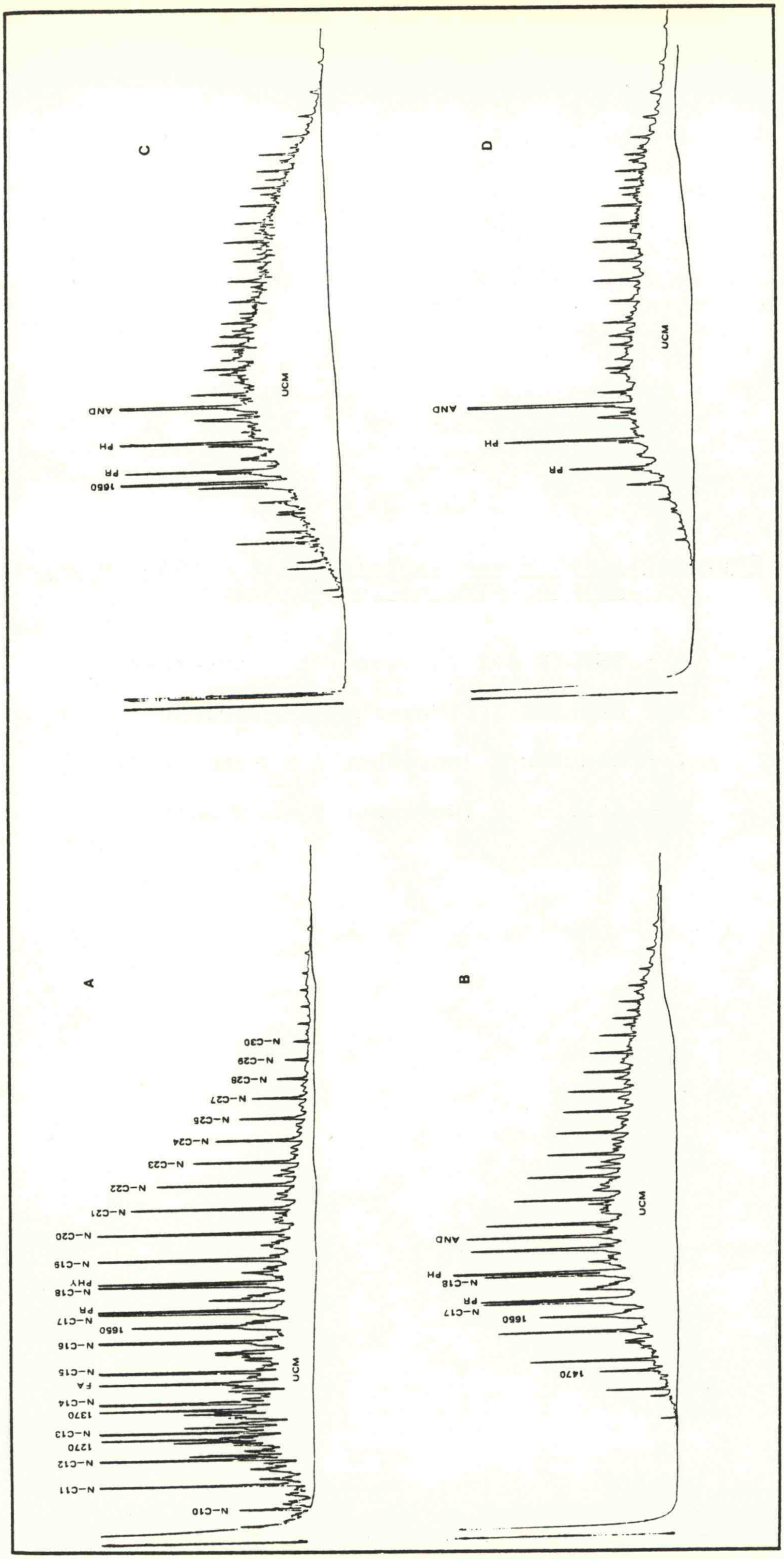

A
N-C30
N-C29
N-C28
N-C27
N-C25
N-C24
N-C23
N-C22
N-C21
N-C20
N-C19
PHY
N-C18
PR
N-C17
1650
N-C16
N-C15
FA
N-C14
1370
N-C13
1270
N-C12
N-C11
N-C10
UCM
B
UCM
AND
PH
N-C18
PR
N-C17
1650
1470
C
UCM
AND
PH
PR
1650
D
UCM
AND
PH
PR

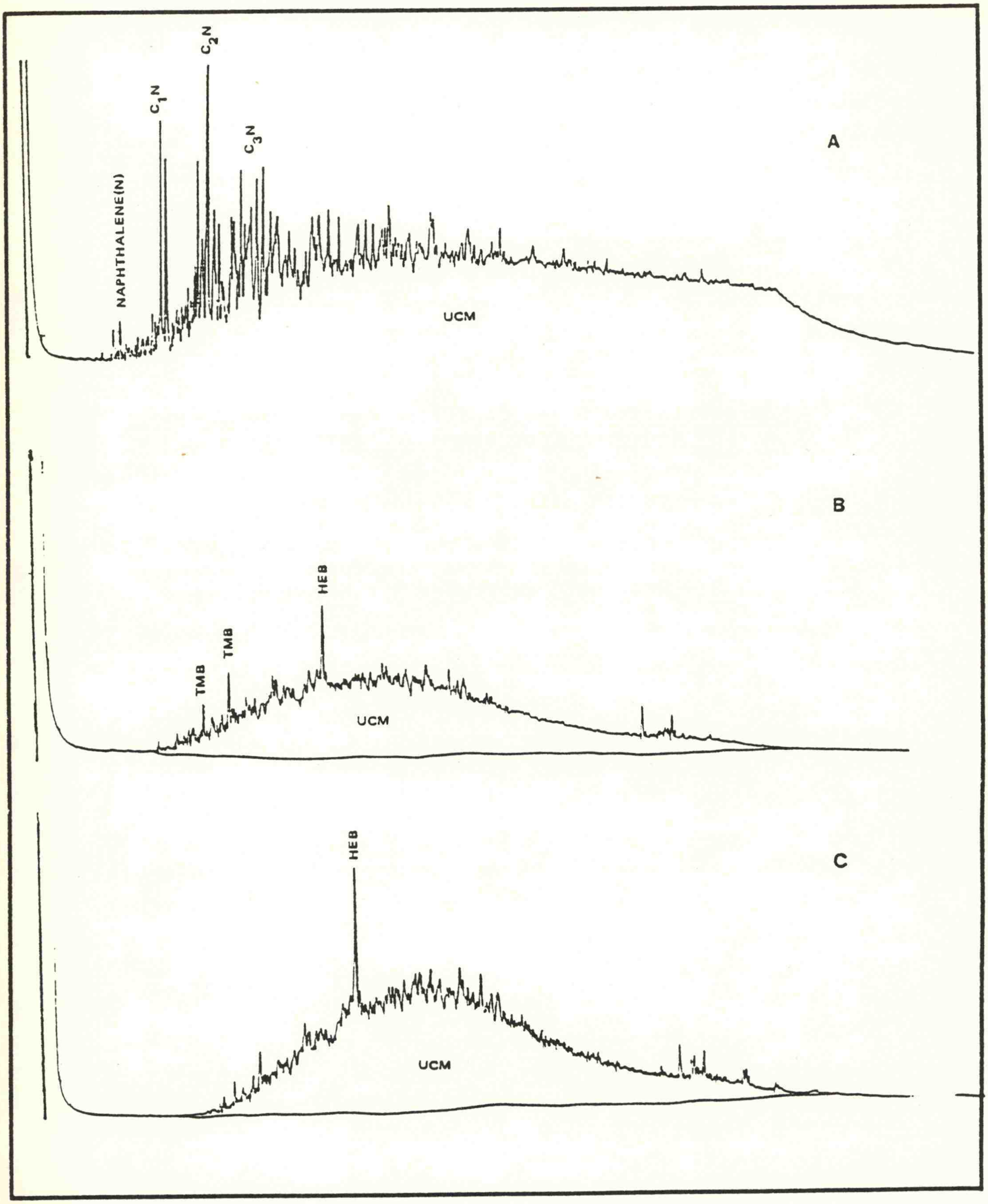
Figure 11.7

Representative Glass Capillary Gas Chromatograms of Sediment Trap Aromatic Hydrocarbons

A - TSESIS oil

B - Station II (November 2 - November 9)

C - Station V (November 9 - November 17)


NAPHTHALENE(N)
C_1N
C_2N
C_3N
UCM
A
TMB
TMB
HEB
UCM
B
HEB
UCM
C

Just as the ALK/ISO ratio describes the chromatographic composition of the n-C_{13} to n-C_{18} range, the carbon preference index (CPI) describes the nature of the n-C_{26} to n-C_{30} range. Alkanes within this range can indicate a petrogenic input (CPI $\cong$ 1.0) or, as the CPI increases above 1, it documents an increased input of terrigenous n-alkanes having their source in vascular plant waxes (Farrington and Meyers, 1975). With increasing time, the hydrocarbon material sedimented in the region more closely reflects these normal terrigenous inputs (Table 11.5), thus illustrating that direct petroleum deposition appears to occur only during the early post-spill period, perhaps on the order of 0 to 3 weeks. Thereafter, it is possible that deposition continues outside of the three station transects due to the slick movement.

The changes in the character of the aromatic hydrocarbon composition of the trap material are illustrated in Fig. 11.7 and 11.8. The GC profiles of the aromatic composition (Fig. 11.7) indicate that the amount of the resolved material decreases relative to the whole oil and, as was the case with the aliphatics, the UCM achieves a chromatographic significance. This was observed in the November Macoma and December Mytilus GC profiles as well. However, unlike the aliphatic hydrocarbon changes which appear to be microbially mediated, changes in the aromatics appear to depend on solubility considerations, the lower boiling compounds being preferentially lost.

The total amount of resolved material decreases rapidly (Tables 11.5 and 11.6). However, on a comparative basis, consider Fig. 11.8 which, like the corresponding consideration of the Mytilus and Macoma data, indicates preferential loss of the soluble naphthalenes, biphenyl, and fluorene compounds, and soon thereafter the dibenzothiophene parent compound (see also Table 11.6). Microbial activity would result instead in loss of or conversion of the methyl side chains in the various homologous series. The composition of the aromatic hydrocarbons in the traps is severely altered by the third week after the spill and consists mainly of the phenanthrene series and substituted dibenzothiophenes.

Figure 11.8

Comparative Plot of Aromatic Hydrocarbon Composition of Sediment Traps and TSESIS Oil Normalized to Trimethyl Phenanthrene

N, C_1N, C_2N, C_3N = naphthalene (N), methyl N, dimethyl N, trimethyl N

BP = biphenyl

F = fluorene

DBT, C_1DBT, C_2DBT = dibenzothiophene (DBT), methyl DBT, dimethyl DBT

P, C_1P, C_2P, C_3P = phenanthrene (P), methyl P, dimethyl P, trimethyl P

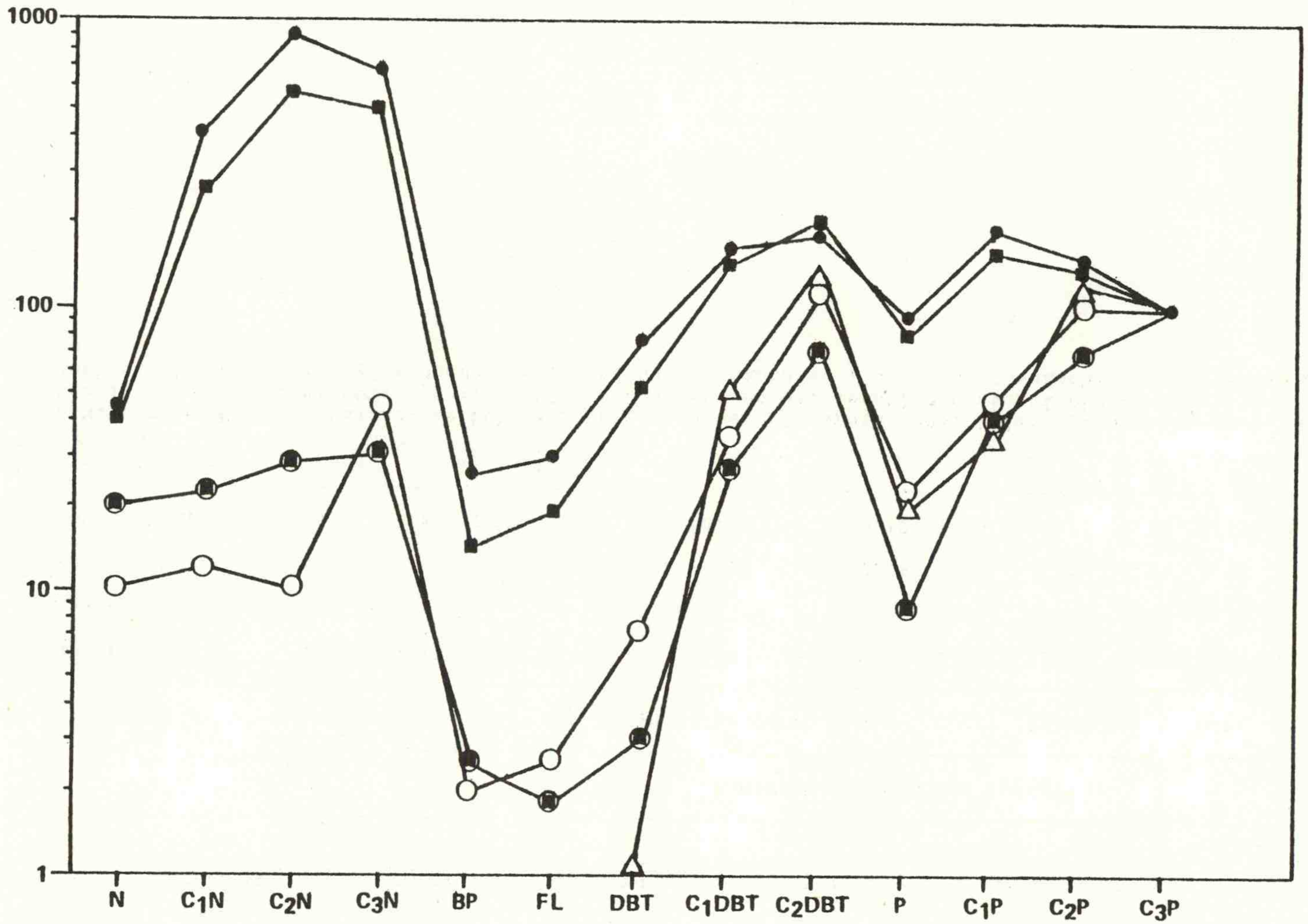

1000
100
10
1
N
C1N
C2N
C3N
BP
FL
DBT
C1DBT
C2DBT
P
C1P
C2P
C3P
TSESIS Cargo Oil
TSESIS Slick 1 Nov.
Sediment Trap Station V (Nov.2-Nov.9)
Sediment Trap Station IV (Nov.2-Nov.9)
Sediment Trap Station V (Nov.9-Nov.17)

TABLE 11.6

AROMATIC HYDROCARBON COMPOSITIONS OF SEDIMENT TRAP SAMPLES

STATION	DATES	TOTAL RESOLVED (µg/g)[b]	INDIVIDUAL COMPOUNDS (µg/g)[a]												
			N[c]	C_1N	C_2N	C_3N	BP	F	DBT	C_1DBT	C_2DBT	P	C_1P	C_2P	C_3P
V	NOV 1 - NOV 9	32	0.23	0.42	0.72	4.1	0.02	-	0.32	2.62	5.31	1.28	5.30	6.79	8.08
V	NOV 9 - NOV 17	5	-	-	-	-	-	-		0.14	0.28	0.11	0.30	0.77	0.74
IV	NOV 2 - NOV 9	53	0.97	2.51	4.30	6.20	0.18	0.19	2.76	2.61	7.44	1.05	7.12	9.80	16.90
II	NOV 2 - NOV 9	24	0.32	0.50	1.46	2.70	0.05	-	0.12	1.25	3.32	0.30	2.39	3.35	5.45

[a] From GC/MS runs.

[b] From GC runs.

[c] N, C_1N, C_2N, C_3N = naphthalene, methyl naphthalene, dimethyl naphthalene, trimethyl naphthalene; BP = biophenyl; FL = fluorene; DBT, C_1DBT, C_2DBT = dibenzothiophene, methyl dibenzothiophene, dimethyl dibenzothiophene; D, C_1P, C_2P, C_3P = phenanthrene, methyl phenanthrene, dimethyl phenanthrene, trimethyl phenanthrene.

11.3.3 Surface Sediments

Initially 15 sediment samples covering the entire region were analyzed by glass capillary gas chromatography and several subjected to GC/MS analysis for detailed aromatic hydrocarbon determinations. Although several different suites of hydrocarbons were observed in the extracts (see Fig. 11.9 and 11.10), no petrogenic inputs were observed that related to the spilled Tsesis oil. The UCM was a prominent feature in most of the chromatograms. The UCM material is generally ascribed to anthropogenic inputs from several possible sources, including urban particulates (Hauser and Pattison, 1972) and weathered petroleum from storm runoff, municipal sewage, and chronic oil spills (Van Vleet and Quinn, 1978; Boehm and Quinn, 1978; Farrington et al., 1978) and is observed in most silt/clay surface sediment in the region (Rudling, 1976). The dominant feature other than the UCM, in the GC traces, was the terrigenous n-alkanes n-C_{25}, n-C_{27}, n-C_{29}, n-C_{31}, and their dominance over their even carbon number neighbors, yielding CPI values from 2.5 to 5.4 (Table 11.7).

The absence of significant quantities of petrogenic hydrocarbons in the surface sediment (0 cm to 2 cm) was puzzling. It was hypothesized that the gravity corer used in the initial sampling might, on impact, blow away the fine floc layer, just on the sediment water interface, where newly deposited material resides. Also the depth of the sediment sampled (2 cm) might cause background levels of hydrocarbons (50 µg/g to 1,000 µg/g, Table 11.7) to obscure smaller quantities of petrogenic hydrocarbons (see also section 6.4.1).

A careful resampling was performed at Station 20 with a wide-bore corer which presumably disturbed the surface layer less. In addition, two sections, the 0 cm to 0.5 cm and 0.5 cm to 1.0 cm layers, were obtained for analysis. Again, the analytical results indicate no petroleum in the sediment, with the possible exception of one 0.5 to 1.0 cm section, which indicates an input of lower boiling n-alkanes to the terrigenous assemblage (Fig. 11.9a). If this is Tsesis-related hydrocarbon material, then it has been significantly altered.

Figure 11.9

Representative Glass Capillary Gas Chromatograms of Surface Sediment Aliphatic Hydrocarbons

A - Station 20 (0.5-1.0 cm) - 1,
29 November 1978

B - Station C, 20 December 1977

C - Station 20 (0.5-1.0 cm) - 2,
29 November 1978

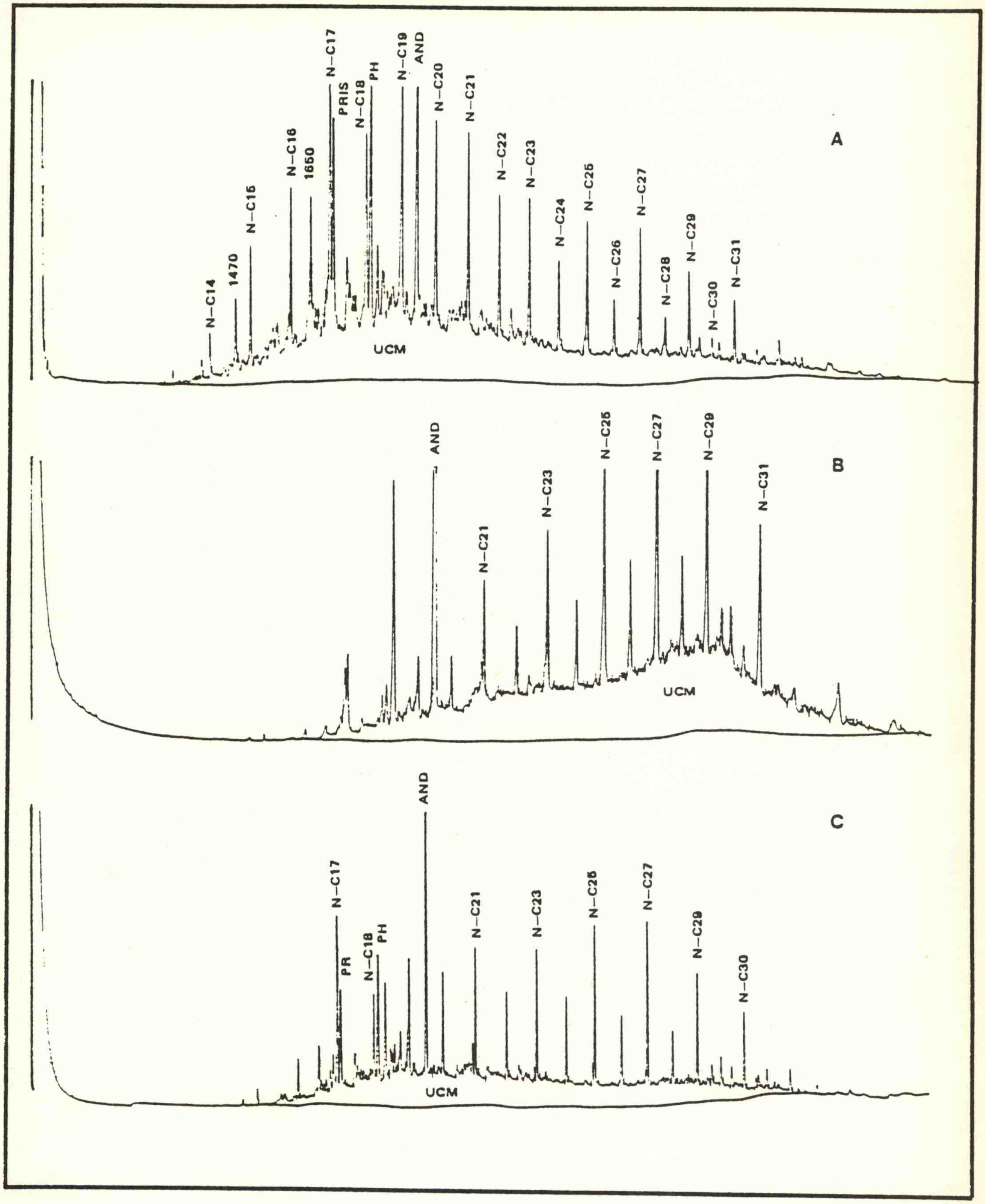

N-C14
1470
N-C15
N-C16
1660
N-C17
PRIS
N-C18
PH
N-C19
AND
N-C20
N-C21
N-C22
N-C23
N-C24
N-C25
N-C26
N-C27
N-C28
N-C29
N-C30
N-C31
UCM
A
AND
N-C21
N-C23
N-C25
N-C27
N-C29
N-C31
UCM
B
N-C17
PR
N-C18
PH
AND
N-C21
N-C23
N-C25
N-C27
N-C29
N-C30
UCM
C

Figure 11.10

Representative Glass Capillary Gas Chromatograms of Surface Sediment Aromatic Hydrocarbons

Station 20, 8 March 1978

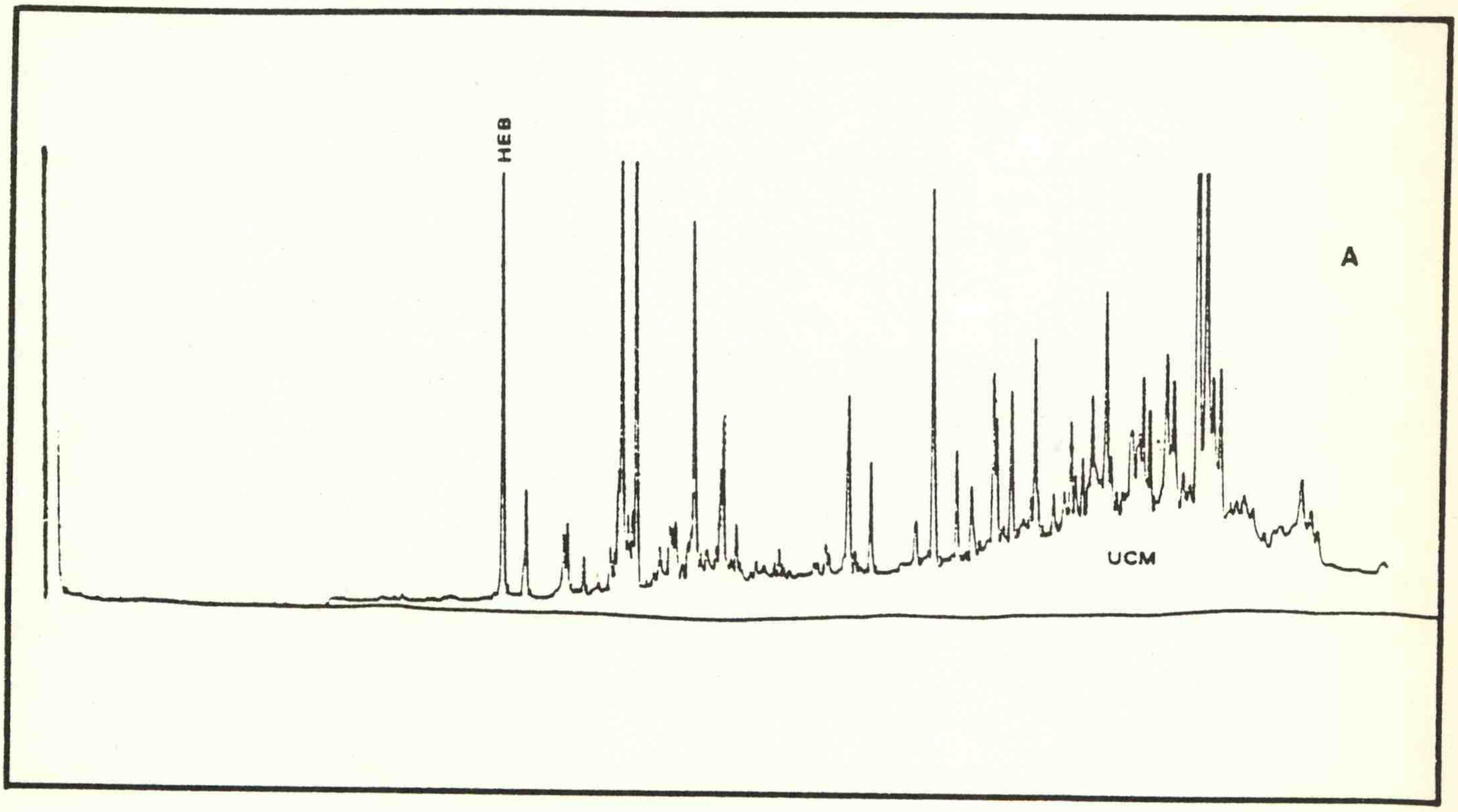

HEB
UCM
A

TABLE 11.7

HYDROCARBON CONCENTRATIONS IN SURFACE SEDIMENTS AS DETERMINED BY GC

STATION	DATE	DRY WEIGHT	ALIPHATIC HYDROCARBONS (µg/g)				AROMATIC HYDROCARBONS (µg/g)		
			RESOLVED	UCM	TOTAL	CPI	RESOLVED	UCM	TOTAL
(C)	11-24-77	3.02	3.3	23.0	26.0	3.3	1.0	21.8	22.8
	12-20-77	2.37	9.4	71.2	80.6	3.3	2.8	78.4	81.2
(2)	11-24-77	2.43	3.1	72.5	75.6	2.9	0.9	12.9	13.8
(D)	11-24-77	5.02	2.7	24.2	26.9	3.2	0.4	3.1	3.5
	12-20-77	2.58	4.1	20.2	24.3	2.9	0.4	9.4	9.8
(G)	11-24-77	1.32	7.0	16.3	23.3	5.4	2.6	38.9	41.5
(5)	11-24-77	4.97	3.1	39.6	42.7	3.8	2.2	25.4	27.6
	12-20-77	4.53	2.1	35.8	37.9	3.5	0.9	6.8	7.7
(6)	11-24-77	2.31	3.8	28.4	32.2	3.8	1.3	6.8	8.1
	12-20-77	4.33	2.7	6.2	8.9	4.3	-	-	-
(7)	11-24-77	1.99	8.1	97.4	105.5	3.1	2.3	33.3	35.6
	12-20-77	9.06	1.8	3.2	5.0	4.9	0.4	7.3	7.7
(8)	12-20-77	4.64	3.6	0.9	4.5	5.2	0.8	3.7	4.5
(20)	3-8-78	25.04	5.3	63.0	68.3	4.4	5.2	29.0	34.2
	6-6-78	7.45	6.8	79.0	85.8	4.1	8.8	44.0	52.8
	12-4-78 (0-0.5 cm)	2.59	4.3	56.9	61.2	3.2	11.7	68.3	80.0
	12-4-78 (0-0.5 cm)	1.09	9.8	155.5	165.3	3.3	28.0	75.1	103.1
	12-4-78 (0.5-1.0 cm)	0.40	81.2	396.3	477.5	2.6	96.5	553.4	649.9
	12-4-78 (0.5-1.0 cm)	2.22	18.6	105.0	123.6	3.2	17.5	44.2	61.7
	12-4-78 (0-0.5 cm)	1.89	6.3	64.3	70.6	3.5	10.2	58.9	69.1
(15)	11-29-78 (0-1.0 cm)	1.66	5.0	20.5	25.5	2.5	4.5	16.8	21.3

The aromatic hydrocarbon GC and GC/MS runs fail to indicate a chemical relation between either the spilled oil or the sediment trap material to the surface sediment. The GC trace of a typical surface sediment aromatic fraction is presented in Fig. 11.10 and shows mainly a series of large, unidentified biogenic peaks and some indication of a weathered petroleum input, as evidenced by small quantities of members of the phenanthrene homologous series (phenanthrene = 0.03 μg/g; methyl phenanthrenes = 0.07 μg/g, dimethylphenanthrenes = 0.03 μg/g; triethyl-phenanthrenes = 0.02 μg/g).

11.3.4 Macoma balthica

Macoma balthica samples were obtained from the soft bottom at 8 Stations indicated in Fig. 11.1 and at a control station 15 located south of Askö Island. In contrast to the Mytilus edulis hydrocarbon contents, which show dramatic increases and rapid and near complete depuration over the course of a year, concentrations in this benthic deposit feeder show a rapid but modest concentration increase to the 500 to 900 μg/g level in the aliphatic fraction and 500 to 1,700 μg/g level in the aromatic fraction. The initial uptake appears to be location-specific in contrast to the initial Mytilus behavior which is similar over the entire study area (see Table 11.1). The concentration information in Tables 11.8 and 11.9 indicates that while depletion of tissue hydrocarbon burdens may be occurring at stations D and 20 between November and December, for the most part Macoma continues to take up petroleum hydrocarbons with aliphatic hydrocarbon tissue levels clearly on the increase at stations 20 and 7 (Table 11.8) and aromatic levels increasing at stations D and 20 after a winter decrease (Table 11.9). Whether the depuration and re-uptake phenomenon is a function of reintroduction of petroleum-bearing particulates to these stations or can be attributed to aspects of the animals feeding rate and metabolic state is not apparent from the Macoma data or from sediment trap data which characterize sedimented material only through mid-December.

The hydrocarbon levels in Tables 11.8 and 11.9 should be viewed in relation to the control (station 15) levels. Furthermore, the August

TABLE 11.8

ALIPHATIC HYDROCARBON CONCENTRATIONS IN MACOMA BALTHICA

SAMPLE	DATE	DRY WEIGHT (g)	F_1 (Aliphatics) µg/g						
			RES.	UCM	TOTAL	PRIS	PHY	PRIS/PHY	ALK/ISO
(C)	11-30-77	1.65	131.2	790.5	921.7	13.9	17.5	0.79	0.17
(7)	11-30-77	1.52	53.2	194.3	247.5	6.1	8.3	0.73	0.12
	12-20-77	2.44	31.4	439.1	470.5	3.7	5.3	0.70	0.02
	6-7-78	0.44	59.4	623.1	682.5	10.7	15.3	0.70	0.01
(D)	11-30-77	2.32	35.0	479.3	514.3	5.9	9.2	0.64	0.06
	12-20-77	2.09	27.5	263.7	291.2	4.2	6.3	0.67	0.01
	6-7-78	1.45	93.3	741.2	834.5	11.3	16.3	0.70	0.09
(8)	11-30-77	1.38	55.8	367.0	422.8	0.9	1.3	0.69	0.09
	12-20-77	1.98	35.9	501.5	537.4	4.1	5.6	0.73	0.03
	6-7-78	1.18	50.1	500.8	550.9	5.5	10.6	0.52	0.04
(6)	11-30-77	1.18	78.5	380.7	459.2	7.5	10.3	0.73	0.25
	12-20-77	1.25	54.0	344.7	398.7	21.0	28.5	0.74	0.11
(2)	11-10-77	0.72	22.3	224.4	246.7	2.3	2.9	0.78	0.39
	6-7-78	1.22	30.4	212.5	242.9	4.5	7.6	0.60	0.10
(5)	11-30-77	1.72	73.7	578.8	652.5	9.8	13.8	0.71	0.07
	12-20-77	2.17	57.2	650.5	727.7	5.5	7.1	0.77	0.15
	6-8-77	0.43	60.4	432.1	492.5	9.6	15.0	0.64	0.02
(20)	11-30-77	1.36	01.4	519.2	620.6	22.7	30.5	0.74	0.07
	12-20-77	3.43	3.2	101.2	104.3	0.8	1.0	0.80	0.03
	2-22-78	0.64	12.7	239.0	251.7	2.2	3.5	0.62	0.01
	3-8-78	2.71	30.6	290.4	321.0	3.8	4.6	0.81	0.05
	6-6-78	0.81	70.1	506.2	576.3	8.2	12.8	0.64	0.10
	8-17-78a	1.74	68.6	1,613.1	1,781.7	20.7	32.5	0.64	0.15
	8-17-78b	1.74	91.12	1,417.0	1,787.4	19.8	41.6	0.48	0.07
	8-17-78c	1.56	37.08	1,150.6	1,287.7	21.4	35.7	0.60	0.06
(15) (Control)	2-21-78	0.47	15.1	131.1	146.8	0.3	0.2	1.5	0.30

TABLE 11.9

AROMATIC HYDROCARBON GROSS PARAMETER
CONCENTRATIONS IN MACOMA BALTHICA

SAMPLE	DATE	F_2 (AROMATICS) (µg/g) RESOLVED	UCM	TOTAL
(C)	11-30-77	69.3	979.5	1,048.8
(7)	11-30-77	7.3	358.6	365.9
	12-20-77	20.8	424.3	455.1
	6-7-78	21.5	401.2	422.7
(D)	11-30-77	14.4	1,692.9	1,707.3
	12-20-77	0.9	967.2	988.1
	6-7-78	40.8	1,031.9	1,072.7
(8)	11-30-77	33.0	721.9	754.9
	12-20-77	7.2	397.3	404.5
	6-7-78	35.7	385.6	421.3
(6)	11-30-77	37.5	763.4	800.9
	12-20-77	29.5	940.8	970.3
(2)	11-10-77	5.9	530.2	536.1
	6-7-78	16.3	140.8	157.1
(5)	11-30-77	11.6	759.1	770.7
	12-20-77	34.5	1,259.9	1,294.4
	6-8-78	22.0	526.1	548.1
(20)	11-30-77	28.1	1,248.5	1,276.6
	12-20-77	55.5	1,123.4	1,178.9
	2-22-78	13.1	595.5	608.6
	3-8-78	28.1	458.5	486.6
	6-6-78	31.4	344.8	376.2
	8-17-78(a)	503.7	1,081.2	1,584.9
	8-17-78(b)	282.9	1,382.4	1,665.3
	8-17-78(c)	178.7	1,786.2	1,964.9
(15) (control)	2-21-78	34.1	84.8	118.9

1978 Macoma sampling afforded the opportunity to determine the variation of gross parameter hydrocarbon levels within the population through triplicate analyses. In the aromatic fraction the resolved components exhibit a coefficient of variation of ± 51.6 percent ($\bar{x}$ = 321.8 µg/g ± 165.9) but the total concentrations varied by ±11.5 percent ($\bar{x}$ = 1,738.4 µg/g ± 200.3). The corresponding aliphatic hydrocarbon data yield values of ±17.7 percent ($\bar{x}$ = 165.6 µg/g ±27.1) and ±16.4 percent ($\bar{x}$ = 1,618.8 µg/g ± 287.0) for the resolved and total gross parameters.

The apparent reintroduction of petroleum hydrocarbons to the benthic environment is dramatically seen in the station 20 Macoma values. Initially, the Macoma population at this station received a petroleum input. This is shown in the high pristane and phytane levels in the tissue (Table 11.8) as well as the high levels of naphthalene and phenanthrene compounds (Tables 11.9 and 11.10) in the tissues. However, by the time of the first sampling (November 20 to November 30) what remains in the tissue has taken on the degraded oil composition, featuring relatively enhanced levels of the isoprenoids (Table 11.8, ALK/ISO ratio; Fig. 11.11) and the branched alkanes. Indeed this alkane-depleted GC pattern, common both to the second Mytilus sampling (December 14) and to some extent even the November Mytilus group (see Fig. 11.1b), as well as the sediment trap material (Fig. 11.6b), is also common to the Macoma populations in the entire impacted region. Samples from the control station 15 do not exhibit this profile but instead reveal indications of weathered petroleum in a higher boiling UCM overridden by small resolved components. It is not known whether an earlier Macoma sampling (e.g., early November) would have yielded a fresher, less degraded petroleum input. However, judging from the sediment trap chromatrograhic profiles, which indicate that sedimented material collected in early November already showed that the aliphatic hydrocarbon composition had been drastically altered, it can be hypothesized that little or no unweathered petroleum reached the benthos. By contrast, relatively unweathered petroleum impacted the littoral zone, but exposure to fresh oil even in this zone was short-lived.

TABLE 11.10

CONCENTRATIONS OF AROMATIC HYDROCARBON COMPOUNDS IN MACOMA BALTHICA AS DETERMINED BY GC/MS

STATION	DATE	NAPHTHALENES (µg/g)	PHENANTHRENES (µg/g)	DIBENZOTHIOPHENES (µg/g)
(20)	11-30-77	3.0	22.0	7.4
	12-20-77	1.3	24.6	-[a]
	03-08-78	0.2	3.9	5.1
	06-06-78	nd[b]	0.8	-
	08-17-78	0.5	2.7	2.3
(5)	11-30-77	2.7	15.0	7.8
	12-20-77	3.6	10.8	2.5
	06-08-78	nd	1.6	-
(2)	11-10-77	0.4	2.1	-

[a]Not searched.
[b]None detected.

Figure 11.11

Representative Glass Capillary Gas Chromatograms
of Macoma balthica Aliphatic Hydrocarbons
(Station 20)

A - TSESIS oil

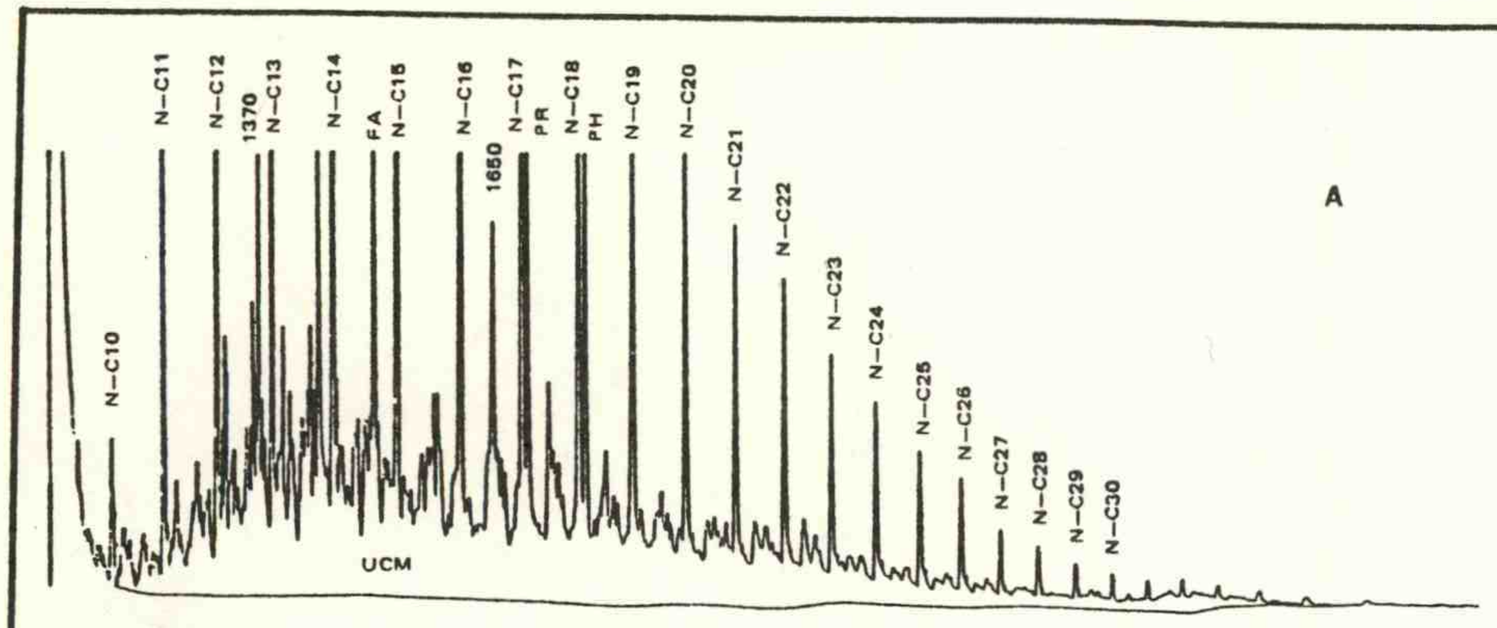
B - November

C - December

D - March 1978

E - June 1978

F - August 1978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N–C13
N–C14
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N–C15
N–C16
1650
N–C17
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PH
N–C19
N–C20
N–C21
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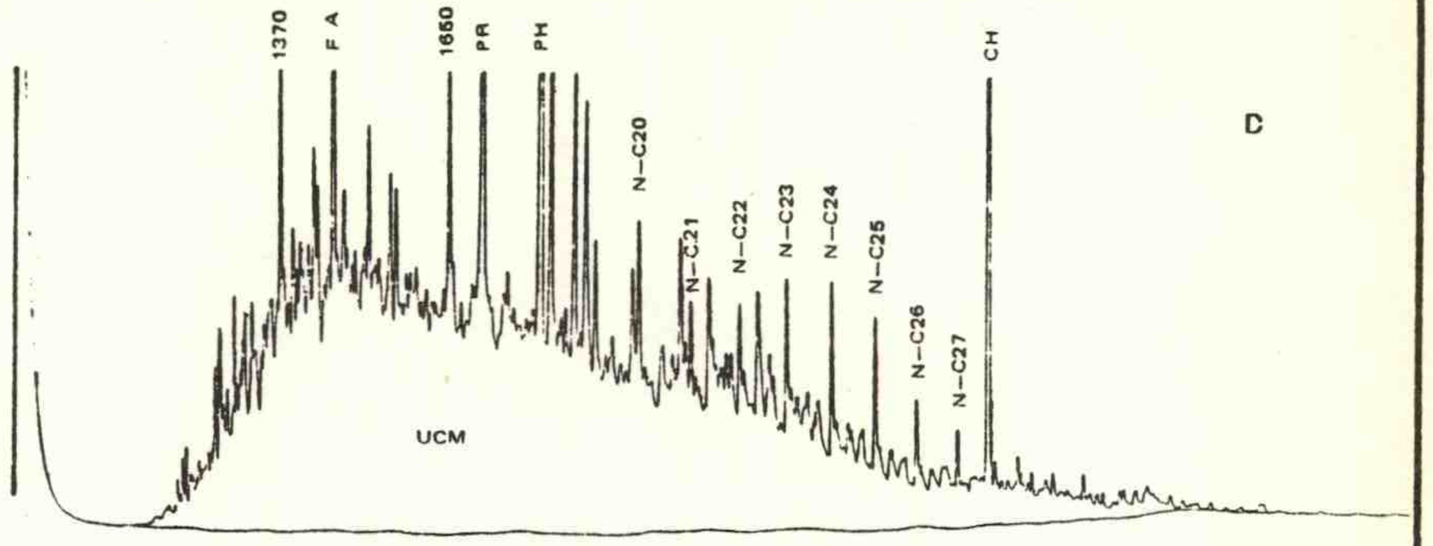
N–C29
N–C30
UCM
A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F A
1650
PR
PH
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N–C24
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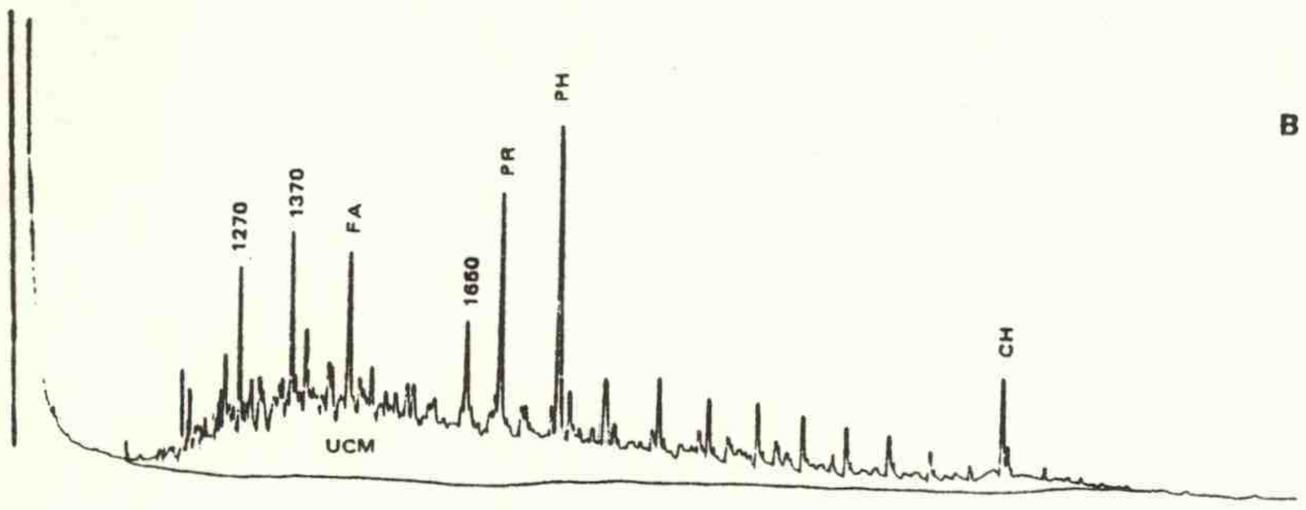
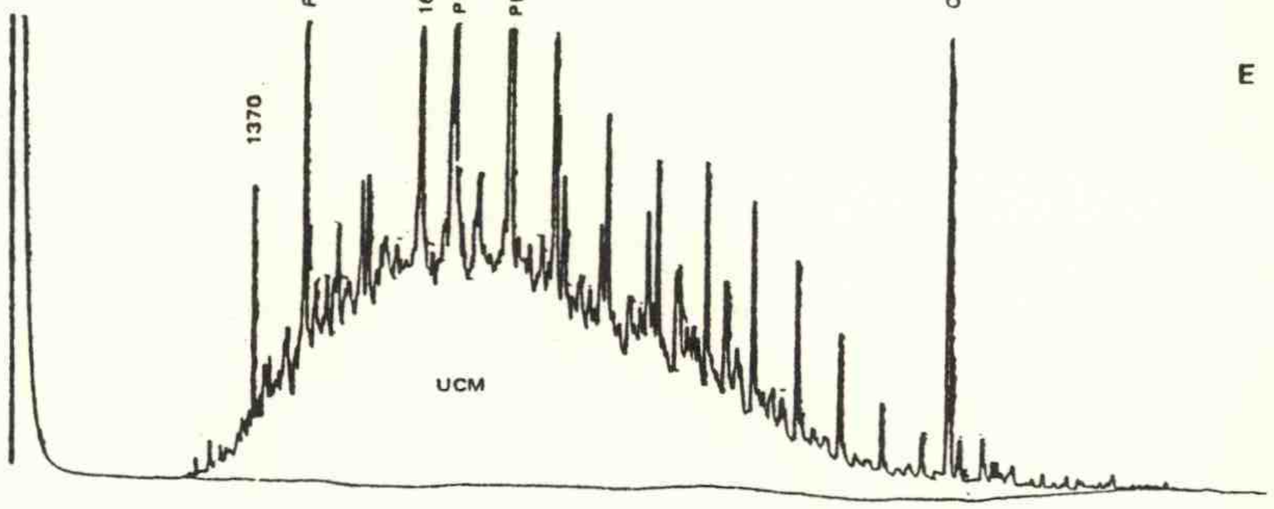
N–C27
CH
UCM
D


1270
1370
FA
1650
PR
PH
CH
UCM
B


1370
F A
1650
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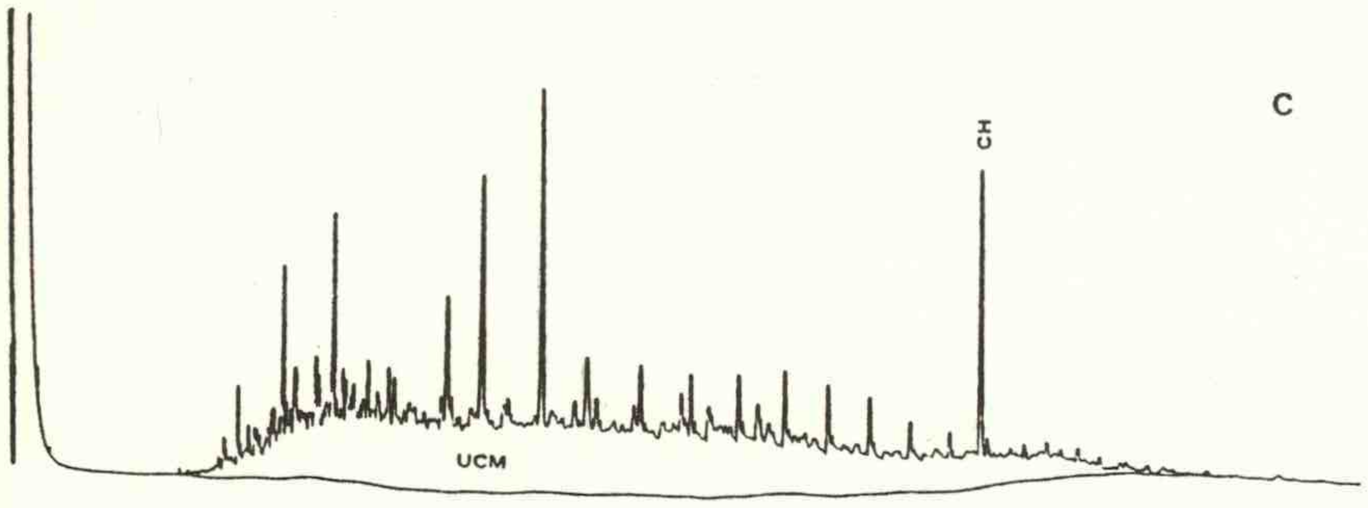
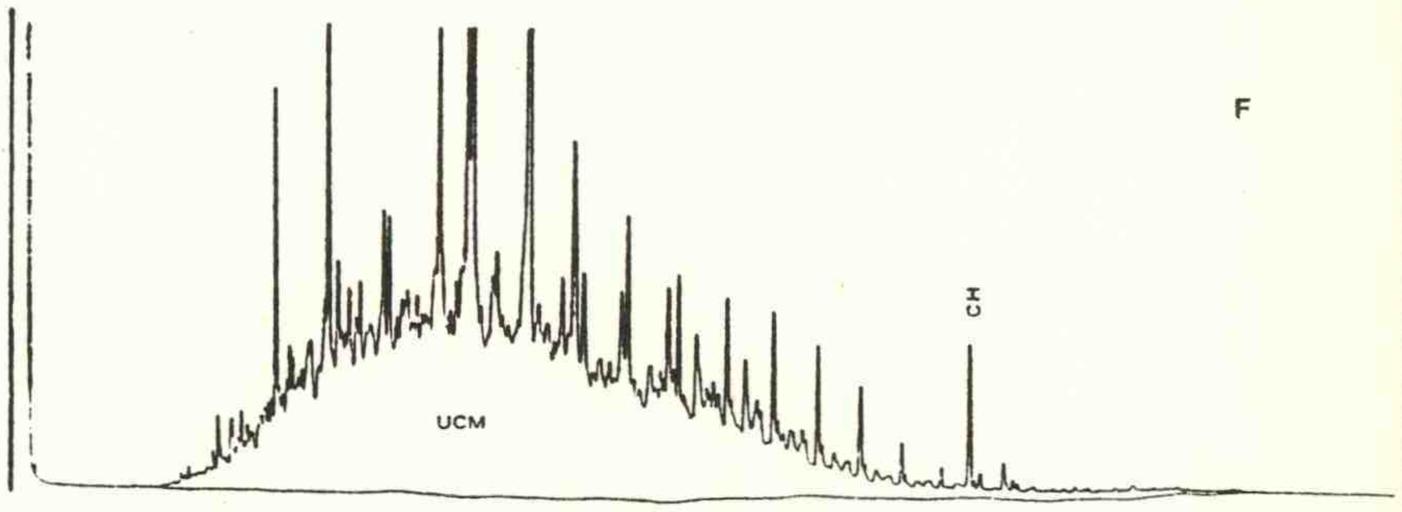
PH
CH
UCM
E


CH
UCM
C


CH
UCM
F

Hydrocarbon levels in Macoma first increase relative to control values, then decrease, and in June through August begin to increase again. Throughout the entire study period the aliphatic hydrocarbon compositions, as revealed by GC profiles, remain more or less the same with the branched alkane, isoprenoid compounds and unresolved complex dominating. This is true through August. That fact, coupled with the increase in absolute concentrations, indicates that weathered petroleum remains in the benthic system and is apparently resistant to further rapid degradation. Thus the chromatograms in Fig. 11.11 reflect this constancy in aliphatic hydrocarbon composition.

Data on the aromatic hydrocarbon levels at Station 20 (Table 11.10) also reveal a winter decrease followed by a summer reintroduction. Chromatographic profiles (Fig. 11.12 and 11.13) illustrate that the lower boiling compounds naphthalenes, biphenyl, and fluorene are depleted initially in tissue relative to the spilled oil, but in winter the relative aromatic composition is most like the sediment trap samples (Fig. 11.13) with the lighter end being more weathered. Although lower in absolute concentrations by August, the aromatic composition in the tissues remains generally constant throughout the study period (Fig. 11.12).

As was the case in the Mytilus samples the presence of the trimethyl benzene (TMB) series plays a prominent minor role in the aromatic hydrocarbon chemistry of Macoma throughout the study (Fig. 11.12). Buried in the overall Tsesis oil chromatograms, the TMB series emerges as other resolved components weather, indicating an interesting resistance to degradation both within the animals and in particulate or sedimented material comprising their food. As was the case for Mytilus, the TMB series is not present in the pre-spill or control environments.

11.4 Discussion

From the previous presentation of the analytical results of this year-long study one can piece together the chemical fate and effects of the Tsesis oil spill on the marine environment in the region.

Figure 11.12

Representative Glass Capillary Gas Chromatograms of Macoma balthica Aromatic Hydrocarbons (Station 20)

A - TSESIS oil

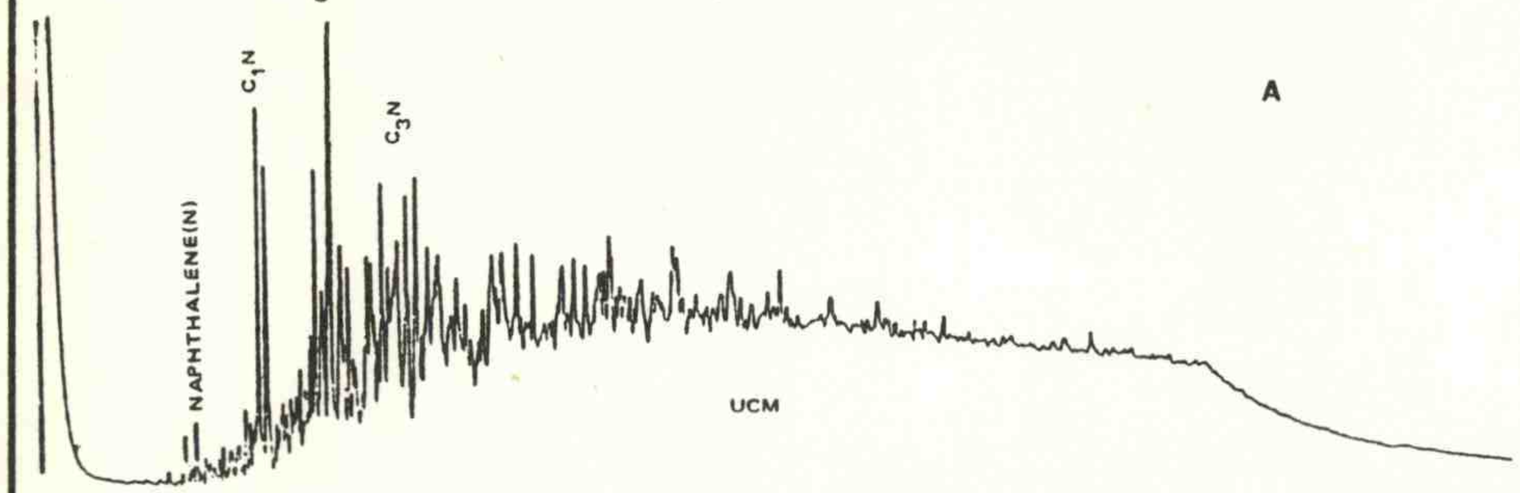
B - November 1977

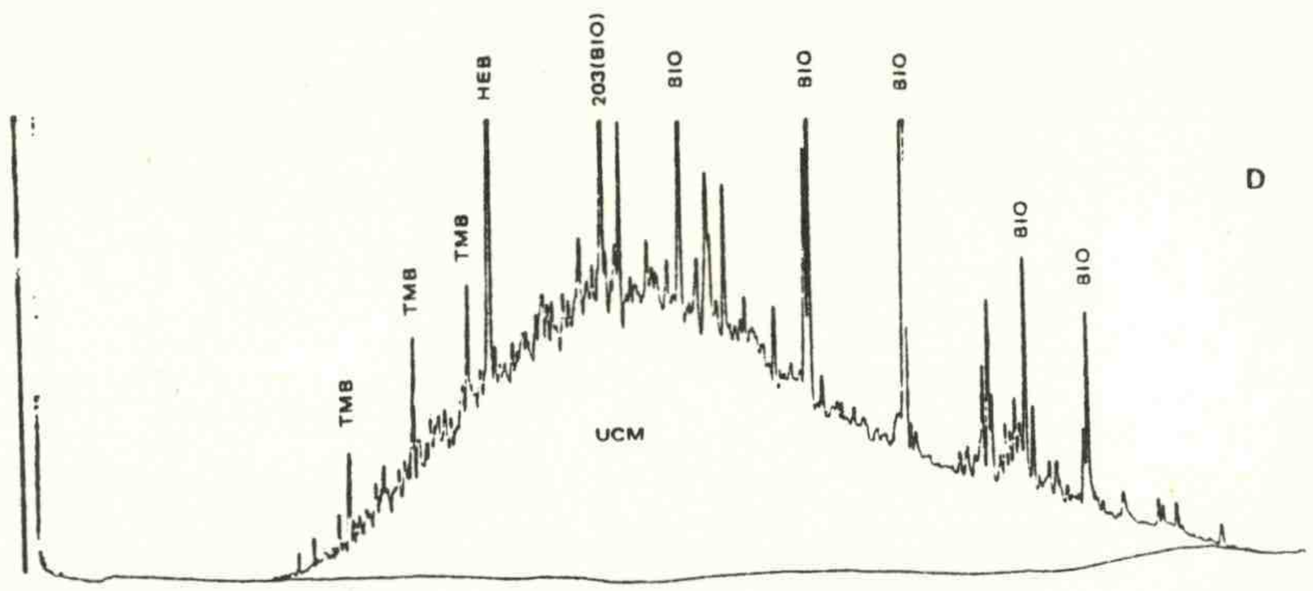
C - December 1977

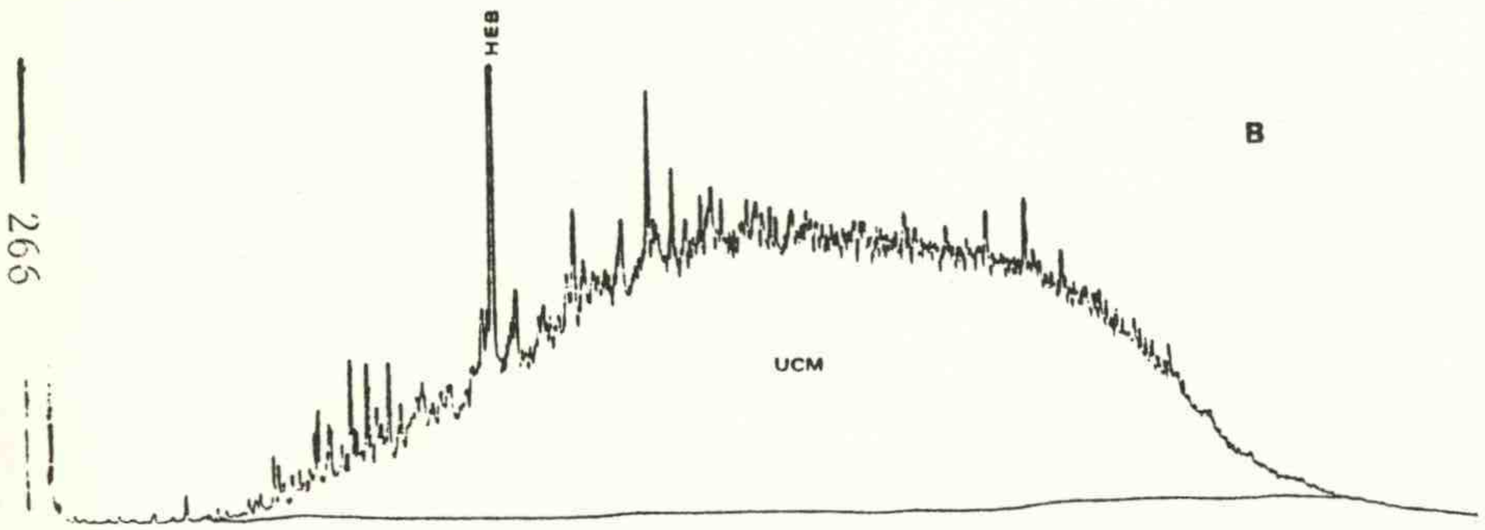
D - March 1978

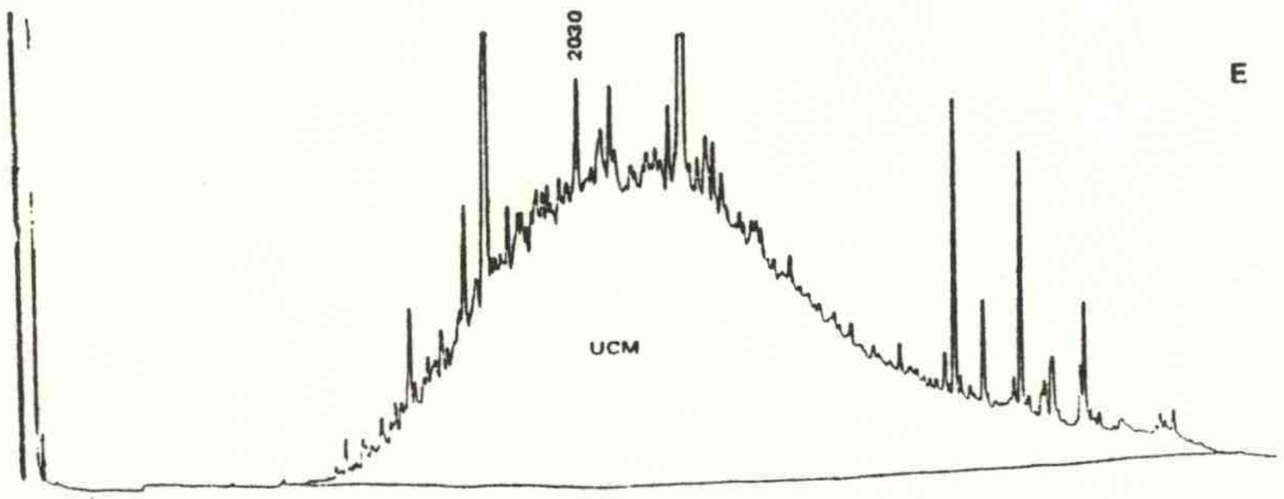
E - June 1978

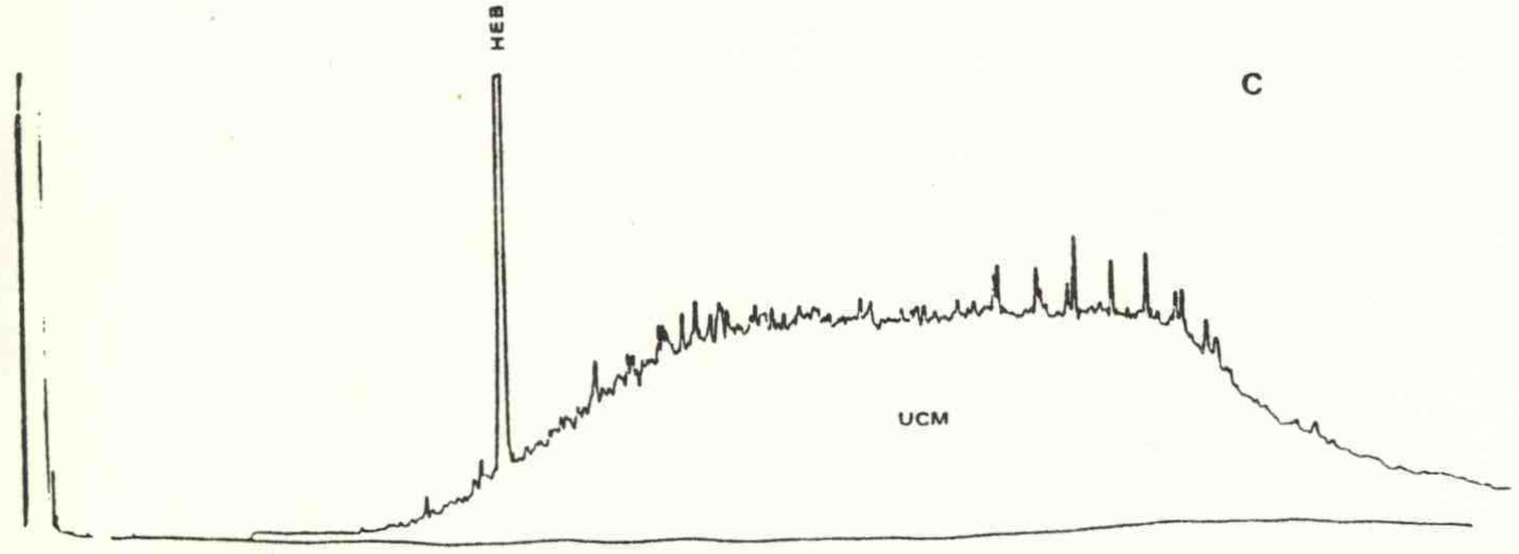
F - August 1978


A
NAPHTHALENE(N)
C1N
C2N
C3N
UCM


D
TMB
TMB
TMB
HEB
203(BIO)
BIO
BIO
BIO
BIO
BIO
UCM


B
HEB
UCM


E
2030
UCM


C
HEB
UCM

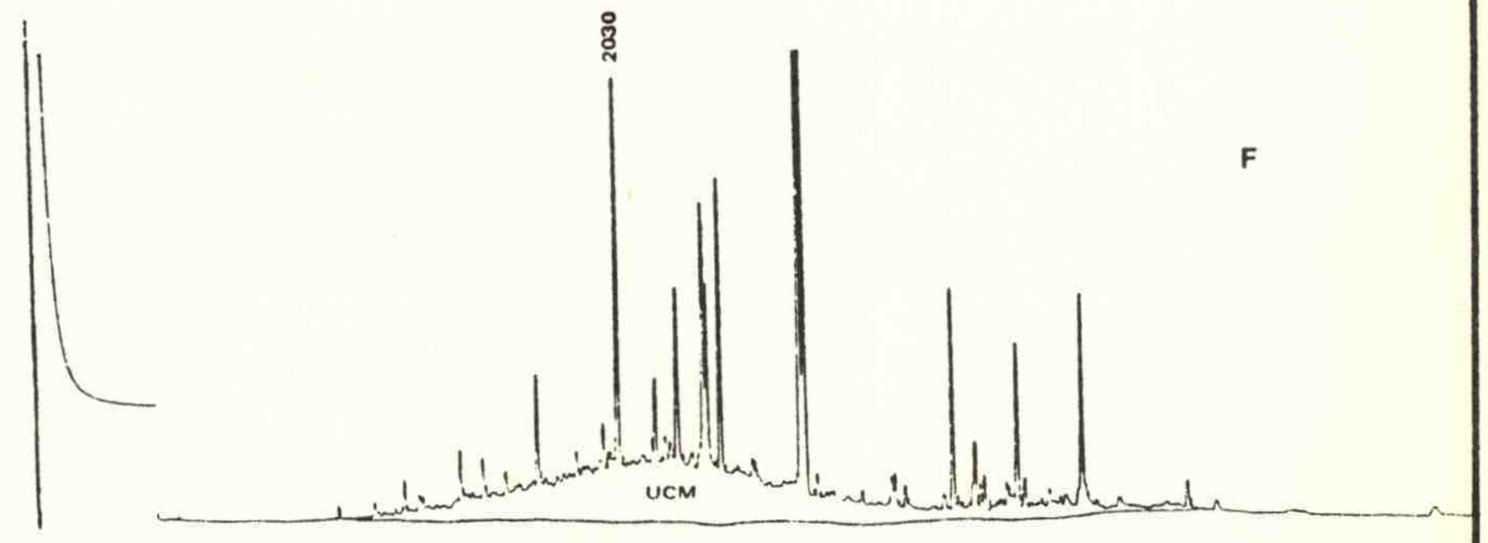

F
2030
UCM

Figure 11.13

Comparative Plot of Aromatic Hydrocarbon Composition of TSESIS Oil and Macoma balthica Normalized to Trimethyl Phenanthrene

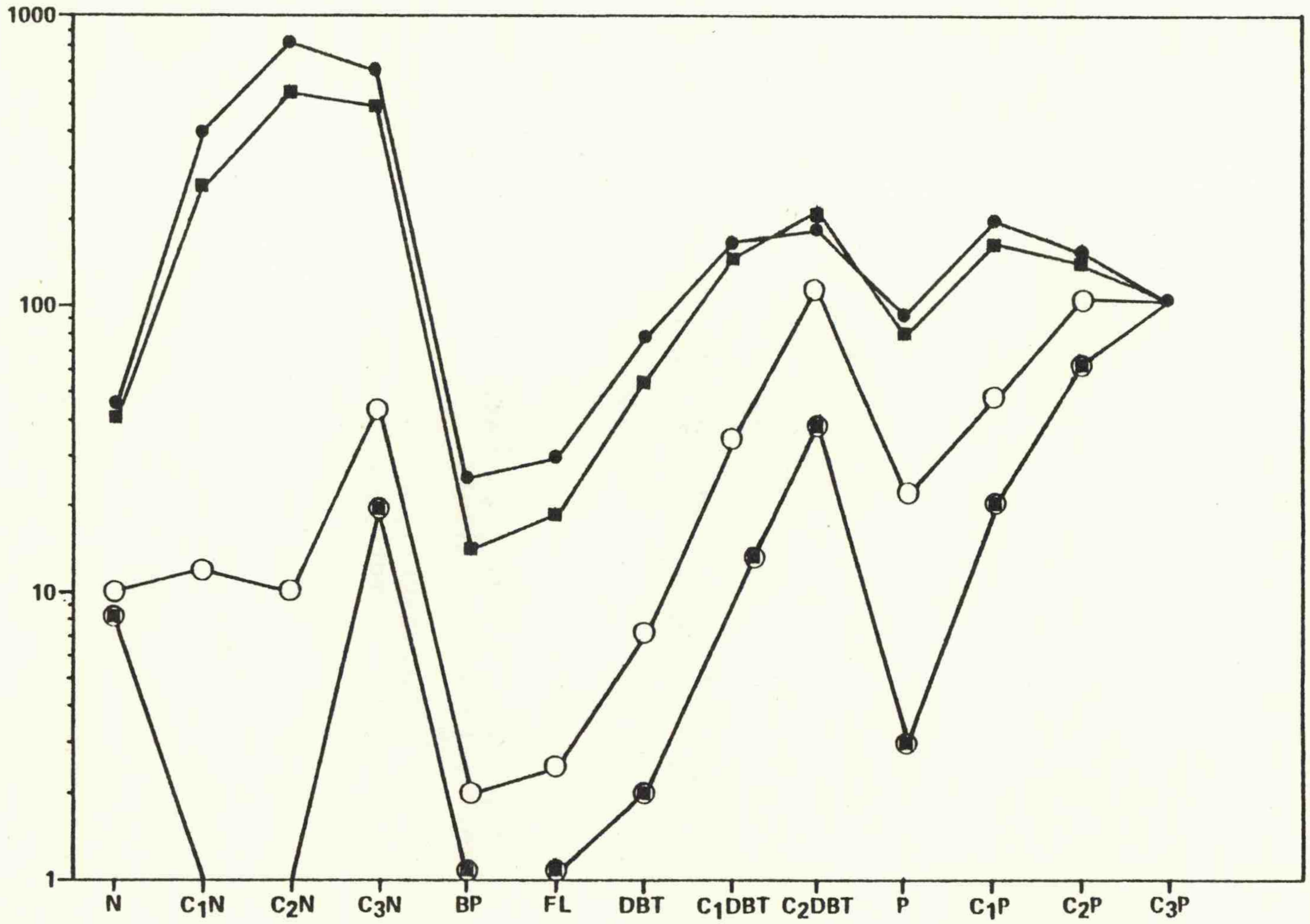
N, C_1N, C_2N, C_3N = naphthalene (N), methyl N, dimethyl N, trimethyl N

BP = biphenyl

F = fluorene

DBT, C_1DBT, C_2DBT = dibenzothiophene (DBT), methyl DBT, dimethyl DBT

P, C_1P, C_2P, C_3P = phenanthrene (P), methyl P, dimethyl P, trimethyl P


1000
100
10
1
N
C1N
C2N
C3N
BP
FL
DBT
C1DBT
C2DBT
P
C1P
C2P
C3P
TSESIS Cargo Oil
Spilled Oil-Nov.1
Sediment Trap Nov.2-Nov.9
Macoma-Nov. 20
Station 5

About 1,100 metric tons of oil were spilled in the region and about 700 tons were recovered during cleanup operations. The oil was driven by the prevailing winds to the northeast and, as a largely unweathered oil slick, impacted the coastline at stations D, B, C, and F. Here the littoral zone was severely impacted from a community standpoint (section 7). Concentrations of petroleum hydrocarbons in tissues were as high as 20,000 to 50,000 µg/g and at this level mortalities seem to have occurred (section 7.2).

As the slick passed through the region, significant quantities of petrogenic hydrocarbons were mixed into the water column and concentrations in the water as high as 50 µg/ℓ (greater than 100 times the background levels) were observed (Boehm and Fiest, 1978). In addition, oil dispersed in the water column was sedimented to the bottom presumably through (1) adsorption to detrital material and sinking and/or (2) ingestion of oil droplets by zooplankters followed by fecal pellet transport to the benthos. Visual scrutiny of zooplankters obtained during the early stages of the spill demonstrated that oil had been ingested by zooplankters in the water column (see section 4.3.4).

Oil remaining at the water's surface apparently underwent only slow degradation due to chemical and microbial weathering until landfall occurred. However, petroleum material dispersed in the water column underwent rapid bacterial degradation of the aliphatic hydrocarbons with n-alkanes being rapidly depleted relative to the isoprenoid compounds and rapid removal of the lighter aromatic fraction due to dissolution. Measurements of the bacterial populations following the spill indicate an increase in the bacterial population in the water column possibly due in part to the availability of oil as a carbon source (see section 4.3.3). Those stations receiving secondary impacts of the spilled oil (i.e., those receiving a secondary landfall of oil), most notably station G (at first this was designated as a control station due to no obvious landfall of the spilled oil), received a degraded oil as seen in the Mytilus tissues due to the longer residence of this petroleum material in the water.

Uptake patterns of the hydrocarbon material indicate that rapid depuration of fresh oil characterized the Mytilus samples during the early months of the spill and throughout the following year degraded Tsesis petroleum was present in Mytilus tissues. One year after the spill, much of the petroleum was gone from mussel tissue except at station C from which samples continued to exhibit aliphatic and aromatic petroleum hydrocarbons in their tissues. This was presumably due to the greater initial exposure of the Mytilus population to oil at this station. Macoma, on the other hand, received a sizeable petroleum impact during the early stages of the spill probably due to direct sedimentation of the oil. After apparent depuration occurred during the winter, a secondary impact was observed, especially at station 20. The transport path of this secondary oil might include (1) landfall, (2) sinking at the shoreline with age, and (3) transport and redistribution throughout the 30-meter-depth basin of which station 20 is at the bottom. It is possible that as the water temperature increased and pumping rates of both Mytilus and Macoma increased, the increased activity aided in the depuration of the former and recontamination of the latter.

The station 20 location appears to be at the focus of the benthic impact of the spill which is observed at all benthic stations (station 2 west of Fifong Island included) except for station 15, the control station south of the island of Askö. Macoma balthica appears to be an excellent indicator of pollutant input to the benthos. As was previously suggested by Shaw et al. (1976), Macoma apparently receives material identical in composition to that captured in the sediment traps. It is puzzling why, even with careful sampling of surface sediment, the direct confirmation of the presence of oil in sediment is ambiguous at best. Bieri and Stamoudis (1977) were also unable to directly confirm the presence of fuel oil in sediment in their experimental oil spill in spite of its obvious presence in benthic organisms. The hydrocarbon material present in the fine floc at the sediment/water interface is difficult to sample even with careful grab or core sampling. Thus, the sedimented hydrocarbons from the Tsesis spill may reside at this difficultly sampled, highly mobile pseudo-surface from which Macoma obtains

its food. This fact may also account for the drastic elimination of the important sensitive benthic crustacean, Pontoporeia spp., from station 20, and its failure to reoccupy the station as of August 1978 (see section 6.3.2).

The apparent contrasting behavior of Mytilus and Macoma vis-a-vis ingested oil may reflect more the duration of exposure and source transport route of the petroleum than any intrinsic differences in the two bivalve species. Depuration of acutely acquired hydrocarbons by Mytilus is apparently accomplished through flushing of water through the animal's gills. Other studies have shown that depuration of acutely acquired petroleum is fairly rapid though perhaps not complete (Fossato and Conzonier, 1976; Anderson, 1975; Kanter, 1974; Stegeman and Teal, 1973; Lee et al., 1972; among others). However, Boehm and Quinn (1978) and DiSalvo et al. (1975) have shown that chronically accumulated hydrocarbons are slow to be eliminated from bivalve tissues, thus suggesting that the duration of exposure is critical to the post-spill chemical recovery of a particular bivalve community. The transport and reintroduction to and long resistance time of petroleum in the benthic environment in the regions of the Tsesis spill may result in the much slower recovery of Macoma and the entire soft-bottom community from the effects of this spill, and in general points to the environmental complications caused by transport of petroleum to the benthos.

11.5 References

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Appendix 1

Investigations

Appendix 1: Investigations

PELAGIC INVESTIGATION

Station	Date (1977)	Depth	Samples[1] Pp	Ph	Z	B	S	Samples for oil analyses S	Degree of initial oil impact[2]
I (ref)	Oct 25	50	x	x	x				0
	Nov 22		x	x	x				
	Nov 22-Dec 14				x				
II	Oct 28	23-25		x					++
	Oct 29			x					
	Oct 30			x					
	Oct 31			x	x				
	Nov 02			x					
	Nov 02-09				x		x		
	Nov 09-17				x		x		
	Nov 17-Dec 21				x		x		
III	Oct 31				x				++
IV & V	Nov 01	IV:	x					IV:	+
	Nov 02	30-32		x					
	Nov 05	V:	x	x	x	x		V:	+++
	Nov 07		x	x	x				
	Nov 09	25	x	x	x	x			
	Nov 11		x	x	x	x			
	Nov 14		x	x	x	x			
	Nov 17		x	x	x				
	Nov 24				x				
	Nov 02-09					x		x	
	Nov 09-17					x		x	
	Nov 17-Dec 21					x		x	
VI (ref.)	Oct 26	36	x	x	x	x			0
	Nov 09		x	x	x	x			
	Nov 23		x	x	x	x			
	Nov 09-23					x			
	Nov 23-Dec 14					x			

Echosounding for fish in Svärdsfjärden was also undertaken on Nov 11 and Dec 15 1977, and Jan 11 and Apr 12, 1978. During the period 13-29/6, 1978, herring eggs were collected in the impacted area for laboratory experiments on hatching success and compared with eggs collected between 13/6-6/7 from an unpolluted area west of Askö Laboratory.

[1] Pp = Primary production
Ph = Phytoplankton
Z = Zooplankton
B = Bacteria
S = Sedimentation

[2] 0 = none
+ = light
++ = moderate
+++ = heavy

PHYTAL INVESTIGATION

Station	Date		Depth (m)	Samples mac. in Fucus	metab. stud.	quant. samp.	Samples for oil analyses M. edulis	Sediment	Degree of initial oil impact
A	Oct 27	'77	1-2	x					++
	Nov 09	"	"	x					
	Nov 15	"	profile			x			
	Dec 14	"	"	x					
	May 02	'78	1-2	x					
	Jun 20	"	"	x					
	Aug 28	"	"	x					
	Oct 30	"	"	x					
B	Nov 03	'77	profile			x			++-+++
	Nov 09	"	1-2				x		
	Nov 15	"	"	x					
	Nov 14-15	"	2		x				
	Nov 17	"	1-2		x				
	Dec 14	"	"	x			x		
	May 02	'78	"	x			x		
	Jun 13	"	profile			x			
	Jul 04	"	"			x			
	Aug 28	"	1-2	x					
	Oct 30	"	"	x					
C	Oct 27	'77	1-2	x			x		++
	Nov 09	"	"	x					
	Nov 14	"	2				x		
	Nov 15	"	profile			x			
	Dec 14	"	1-2	x			x		
	May 02	'78	"	x			x		
	Jun 20	"	"	x			x		
	Aug 23	"	"				x		
	Aug 28	"	1-2	x					
	Oct 30	"	"	x			x		
D	Oct 27	'77	1-2	x			x		+++
	Nov 01	"	profile			x			
	Nov 01-02	"	1.5		x				
	Nov 01-02	"	2		x				
	Nov 02	"	1-2	x					
	Nov 02-03	"	1.5		x				
	Nov 02-03	"	2		x				
	Nov 09	"	1-2	x					
	Nov 16-17	"	1		x				
	Nov 24	"	5-6					x	
	Nov 30	"	"				x		
	Dec 14	"	1-2	x			x		
	Dec 20	"	5-6					x	

PHYTAL INVESTIGATION (Cont.)

Station	Date		Depth (m)	Samples			Samples for oil analyses		Degree of initial oil impact
				mac. in Fucus	metab. stud	quant samp	M. edulis	Sediment	
D (cont)	May 02	'78	1-2	X			X		+++
	Jun 13	"	profile		X				
	Jun 20	"	1-2	X					
	Aug 23	"	"				X		
	Aug 28	"	"	X					
	Oct 30	"	"	X			X		
E	Nov 09	'77	1-2	X			X		
	Nov 10	"	profile		X				
	Dec 14	"	1-2	X			X		
	May 02	'78	"	X			X		
	Aug 28	"	"	X					
F	Nov 09	'77	2	X			X		+
	Nov 10	"	profile		X				
	Dec 14	"	2	X			X		
	May 02	'78	"	X			X		
	Aug 28	"	"	X					
	Oct 30	"	"	X					
G	Oct 27	'77	1-2	X			X		
	Nov 02	"	profile		X				
	Nov 02-03	"	1.5			X			
	Nov 09	"	1-2	X			X		
	Nov 14-15	"	1.5			X			
	Nov 16-17	"	1			X			
	Nov 24	"	11					X	
	Dec 14	"	1-2	X			X		
	May 02	'78	"	X			X		
	Jun 14	"	profile		X				
	Jun 20	"	1-2	X					
	Jul 05	"	profile		X				
	Aug 23	"	1-2				X		
	Aug 28	"	"	X					
	Oct 30	"	"	X			X		
I	Nov 09	'77	2				X		
J	Nov 02	'78	1-2				X		

mac. in Fucus = macrofauna in Fucus
metab stud. = metabolism studies
quant samp. = quantitative sampling
M. edulis = Mytilus edulis

BENTHAL INVESTIGATION

Station	Date		Depth (m)	Samples pre meio	Samples pos meio	Samples pre mac	Samples pos mac	Samples Pont, tera	Samples for oil analyses Macoma	Samples for oil analyses Sediment	Degree of initial oil impact
15 (ref)	Feb 17	'78	41-44					x			0
	Feb 21	"	"						x		
	Mar 09	"	"		x		x				
	Jun 20	"	"		x						
	Aug 23	"	"		x						
	Nov 29	"	"							x	
20	Nov 22	'72	32-33			x					+++
	Oct 03-04	'73	"			x					
	Oct 21-22	'75	"			x					
	Oct 12-13	'76	"			x					
	Nov 11	'77	"		x		x				
	Nov 30	"	"						x		
	Dec 20	"	"						x	x	
	Feb 17	'78	"		x		xx				
	Feb 22	"	"						x		
	Mar 08	"	"		x				x	x	
	Mar 09	"	"				x				
	Mar 17	"	"								
	Jun 06	"	"						x	x	
	Aug 17	"	"		x				x		
	Aug 23	"	"			x					
	Sep 06	"	"		x						
	Dec 04	"	"							x	
21	Nov 22	'72	28-29			x					+++
	Oct 03-04	'73	"			x					
	Oct 21-22	'75	"			x					
	Oct 12-13	'76	"			x					
	Nov 23	"	"		x						
	Nov 11	'77	"			x	x				
	Jun 07	'78	"				x				
2	Nov 10	'77	30						x		+
	Nov 24	"	"							x	
	Jun 07	'78	"						x		
5	Nov 24	'77	30							x	
	Nov 30	"	26						x		
	Dec 20	"	27						x	x	
	Jun 08	'78	"						x		
6	Nov 24	'77	20							x	++
	Nov 30	"	13						x		
	Dec 20	"	18						x	x	

BENTHAL INVESTIGATION (Cont.)

Station	Date	Depth (m)	Samples					Samples for oil analyses		Degree of initial oil impact
			pre meio	pos meio	pre mac	pos mac	Pont tera.	Macoma	Sediment	
7	Nov 24 '77	30							x	
	Nov 30 "	28						x		
	Dec 20 "	21						x	x	
	Jun 07 '78							x		
8	Nov 30 '77	26						x		+
	Dec 20 "	26						x	x	
	Jun 07 '78							x		
C	Nov 24 '77	22							x	++
	Nov 30 "	24						x		
	Dec 20 "	34							x	
D	Nov 24 '77	9							x	+++
	Nov 30 "	8.5						x		
	Dec 20 "	9						x	x	
	Jun 07 '78							x		
G (ref)	Nov 24 '77	11							x	+

pre meio = prespill meiofauna
pos meio = postspill meiofauna
pre mac = prespill macrofauna
pos mac = postspill macrofauna
Pont.tera. = teratological effects on Pontoporeia

Appendix 2

Scenes from the Tsesis oil spill

APPENDIX 2

Scenes from the Tsesis oil spill

Aerial photographs

from flight over path of

oil transport



Swedish Coast Guard vessels



Booms and skimmers deployed next to TSESIS



Swedish Coast Guard vessels



Straw used as sorbent material onshore



Oil, though extensive in this photograph, is often difficult to distinguish visually from grey and black rocks



Oil on rocky shore



Oil from surface in Svärdsfjärden



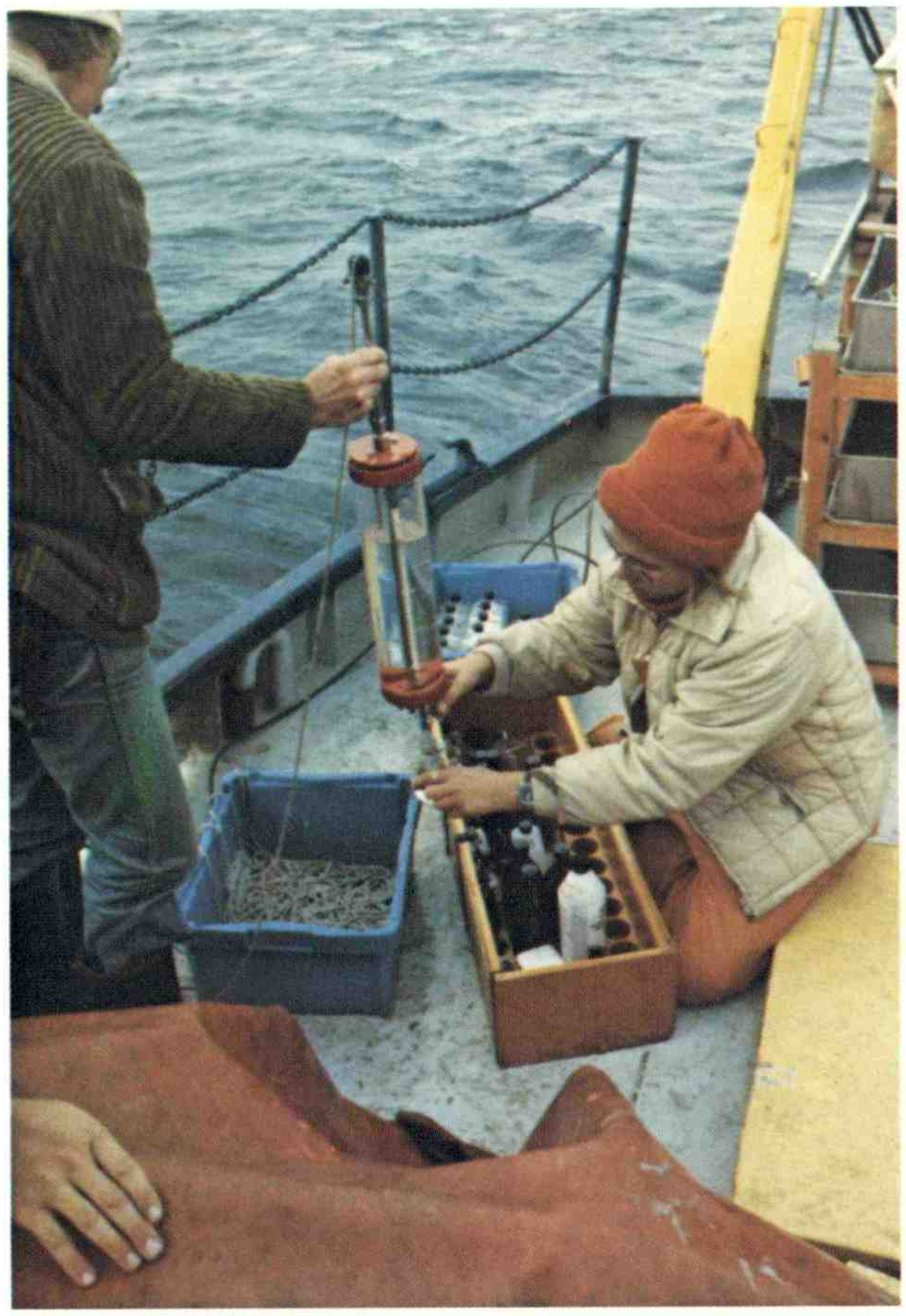
Wind was the dominant factor in the transport of TSESIS surface oil



Sampling operations on board the R/V AURELIA during the acute phase



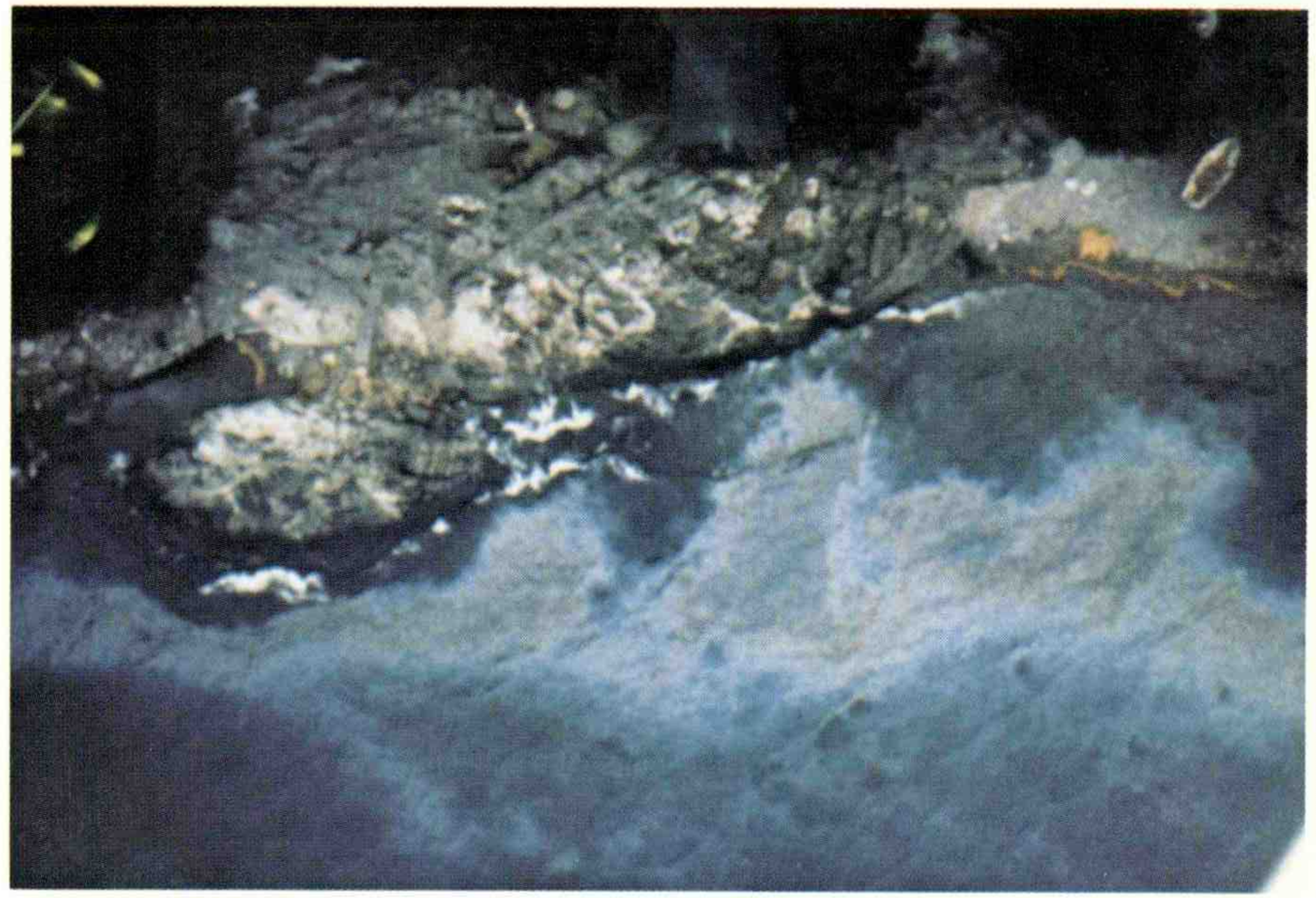
More sampling operations



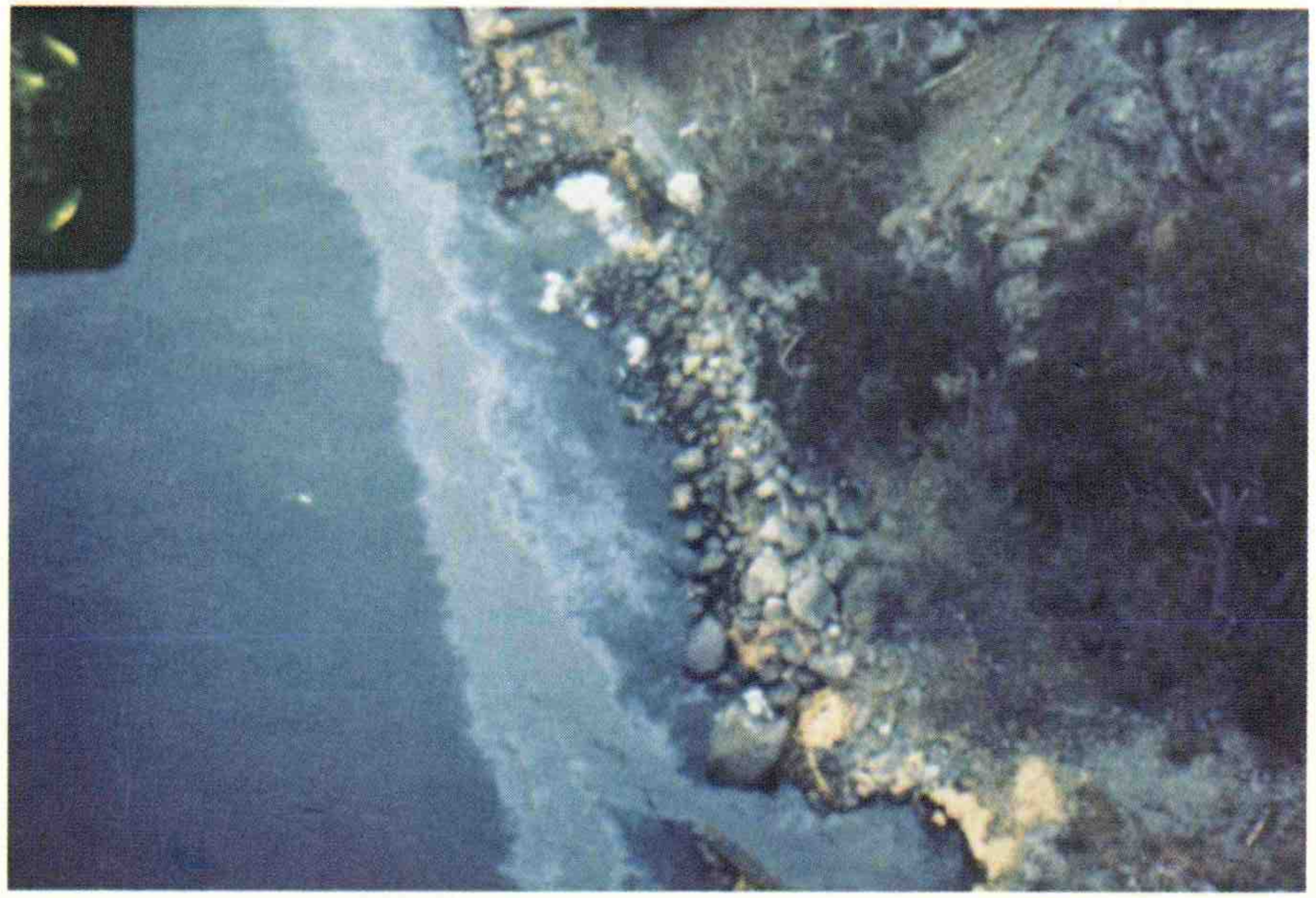
More sampling operations



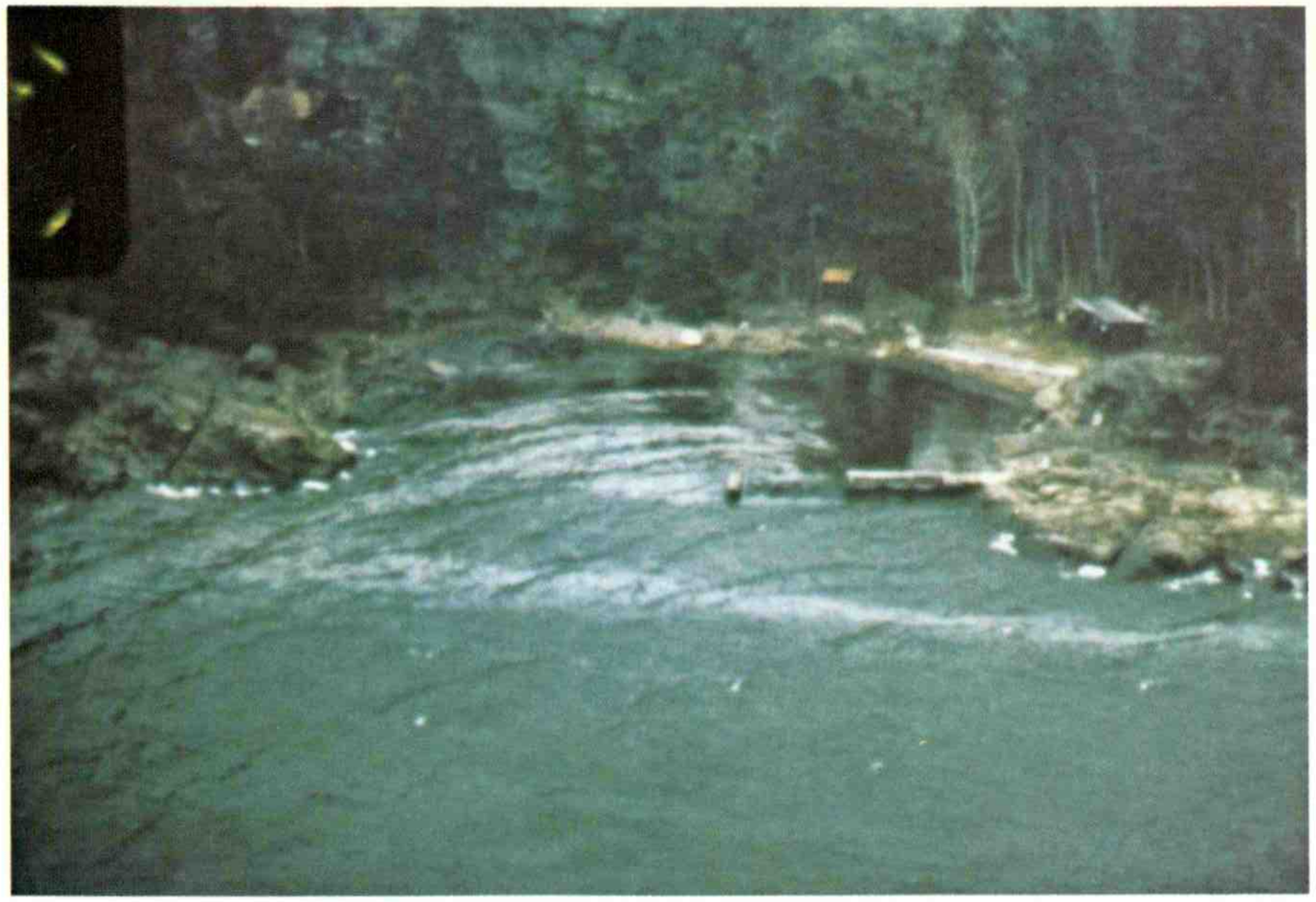
Seawall, Lisökalv



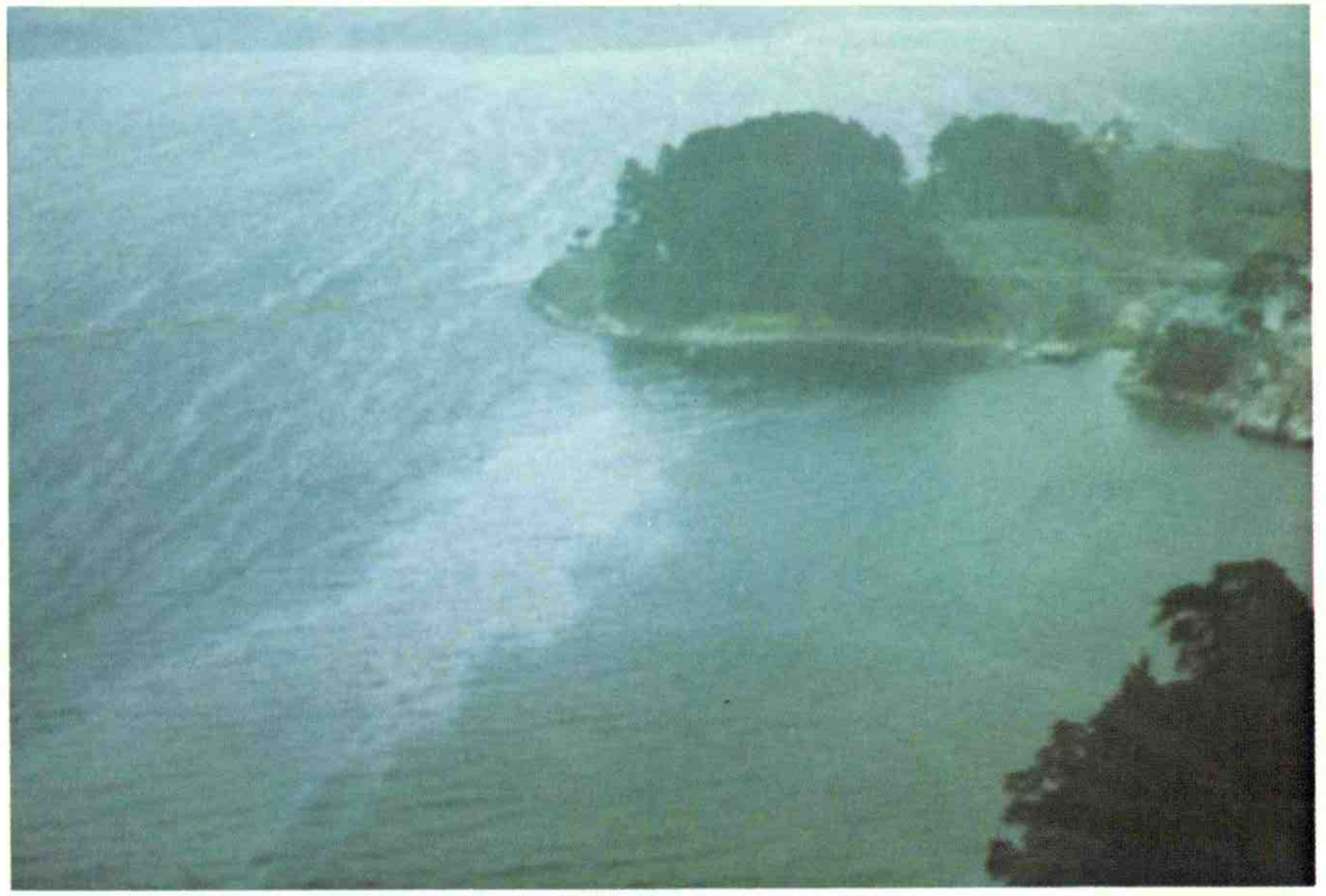
Closeup of oil south of Skogalund



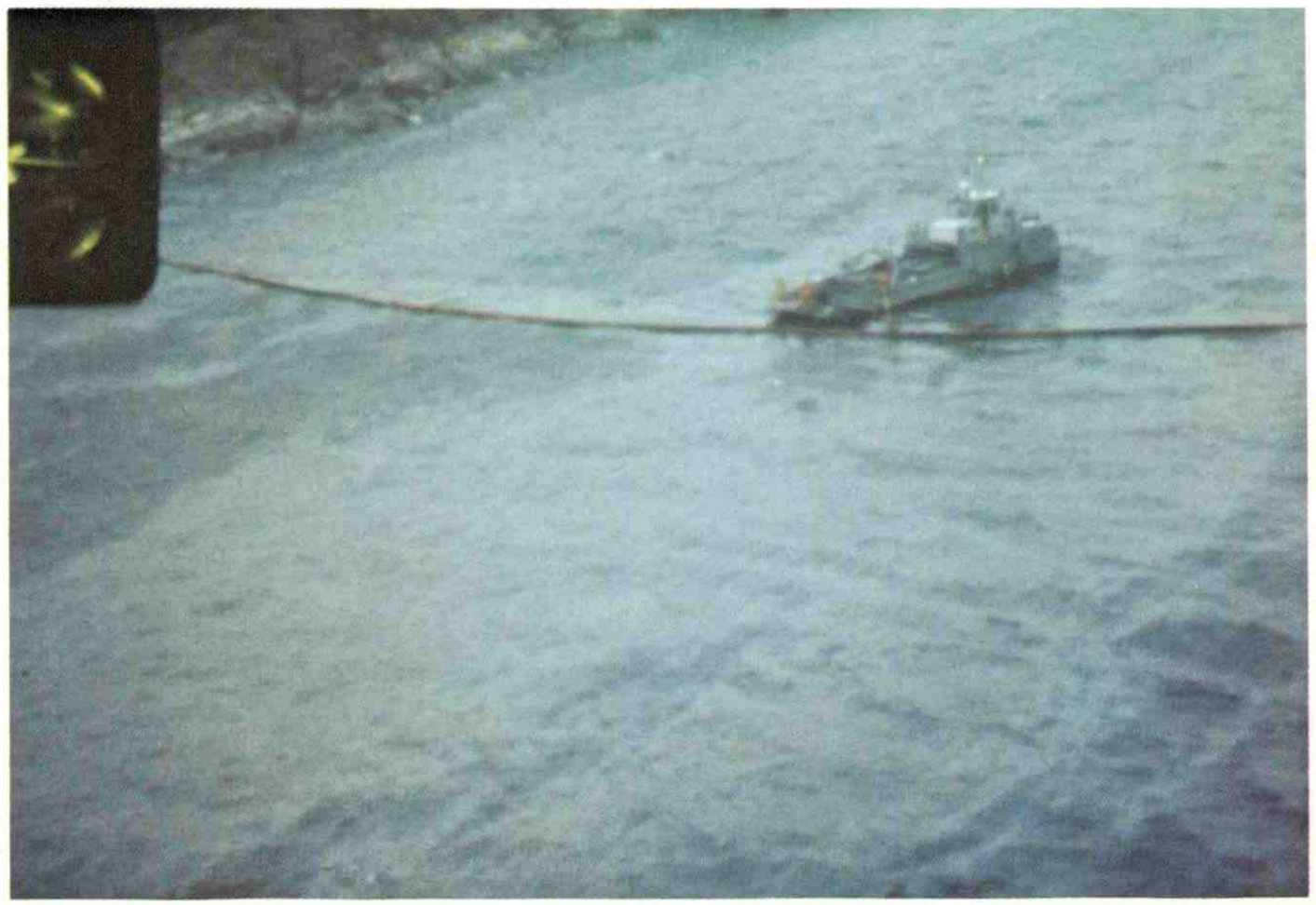
Near vertical view of cove, east side of Lisökalv



Cove north of Lisökalv



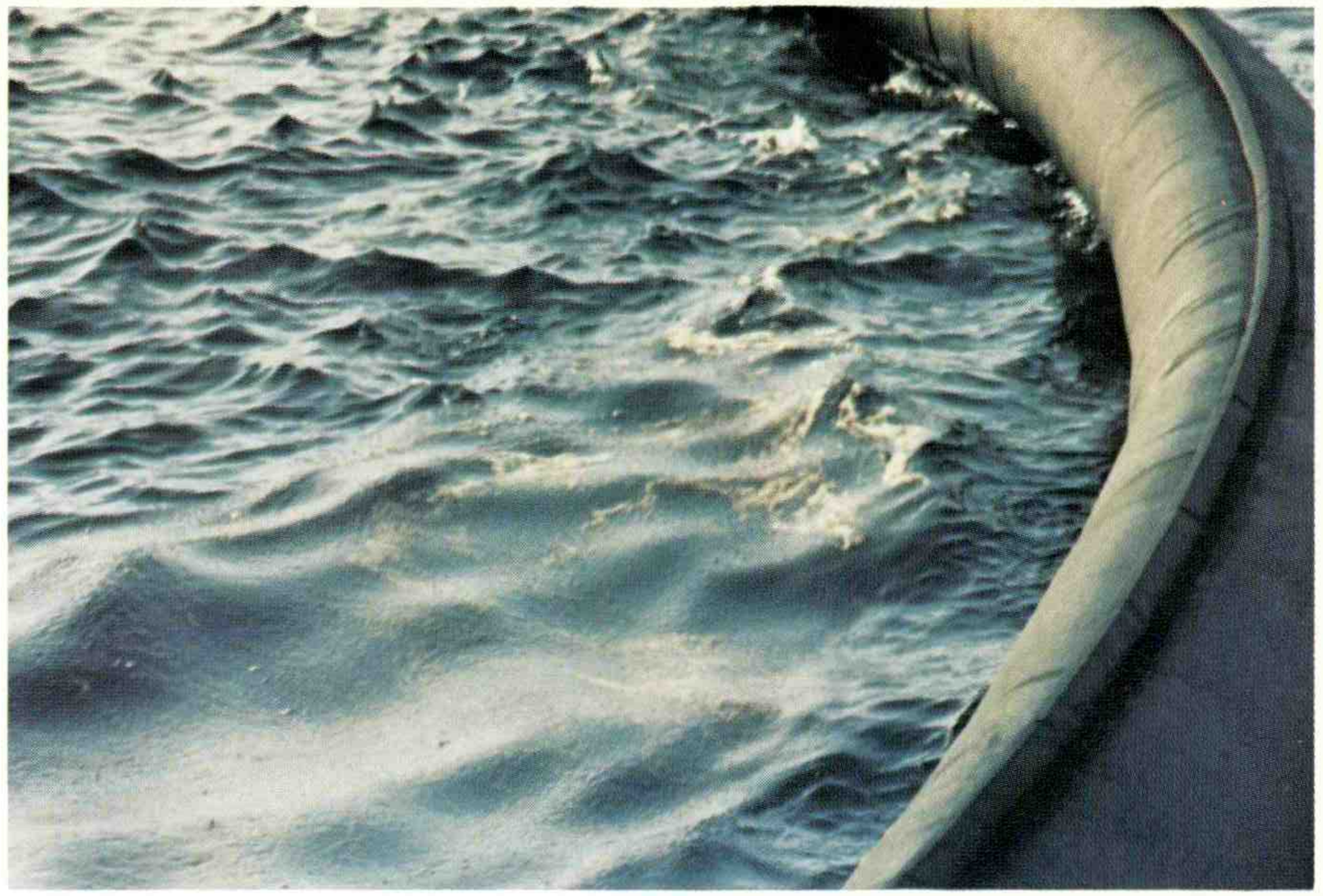
North side of Tistelholmen



Oil, barge, and skimmer in bay



Recovery of boomed oil near Tistelholmen. Partial boom failure may be due to the skimmer's prop wash. Wind is from the right in this photograph.



Downwind boom around TSESIS on November 1, 1979 (76% H_2O)



Surface oil in Svärdsfjärden on November 1, 1979 (76% H_2O)



Near vertical view of oil, S. Örskären Island



Closeup of oil, north tip of S. Örskären Island



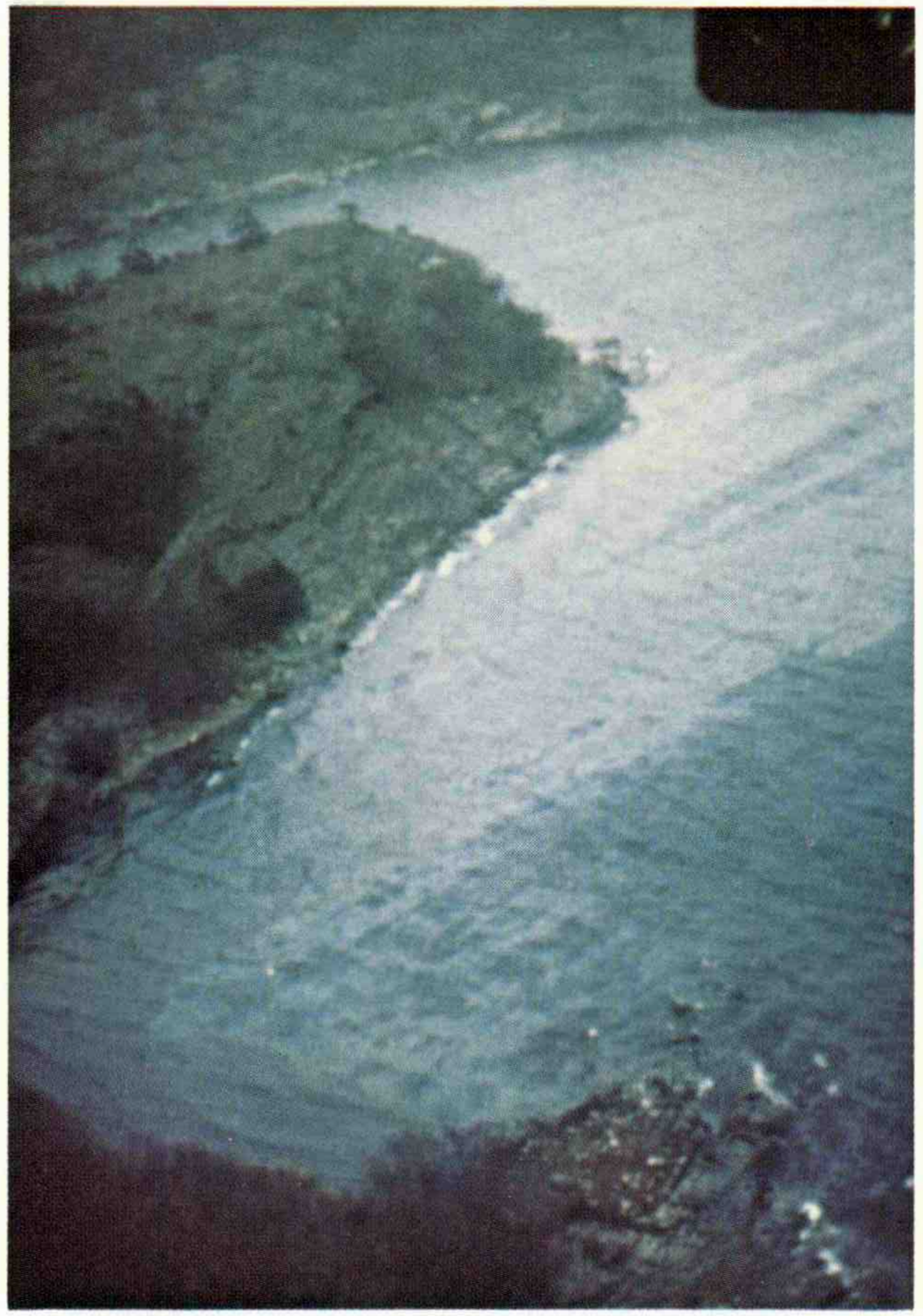
Closeup of oil and boat dock, S. Örskären Island



Boom from Svärdsö to Hökviksholmarna



Inlet east of Hökviksholmarna



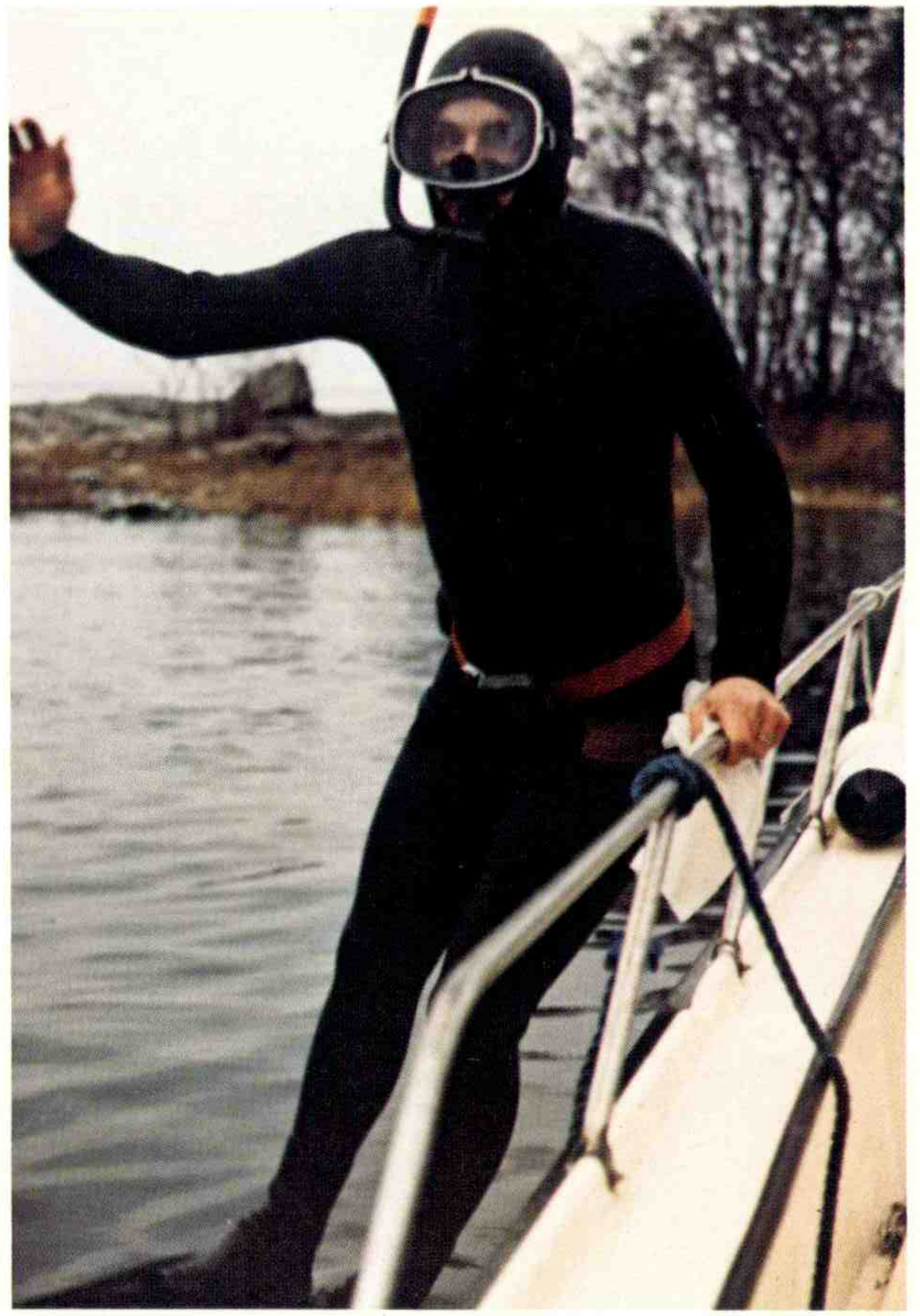
Oil impinging on westernmost cove of Tistelholmen



Due to the season, bird fauna were virtually unaffected. These were among the few seen in the polluted area.



Studies were conducted from the Askö Laboratories on Askön Island.



Most of the benthic and littoral sampling was done by Swedish divers.