CHAPTER 3

SEA SURVEYS

On 27 March when the 'Torrey Canyon' programmes of the Plymouth Laboratory were first discussed at a staff meeting there was one question that required an immediate answer. The question was this: to what extent is the crude oil which is escaping from the tanker and the detergents which are being used to disperse it affecting the planktonic plants and animals and the stocks of pelagic and bottom-living fish in the area of the polluted water? And so, in order to find out what was happening, it was decided to send the Laboratory's research vessel 'Sarsia', with a party of scientists on board, to the area of the Seven Stones to collect samples of water and of plankton for analysis and investigation. Trawl and dredge hauls would also be made for the examination of bottom-living fish and other animals.

CRUISE I

For some time past the Marine Biological Association had carried out five or six times a year a survey of the hydrographical conditions and plankton production of the western English Channel. A survey was in fact due on 28 March and to meet the needs of the occasion the route of the 28–30 March cruise was modified to work the stations shown in Fig. 4A. These included stations 1–5 of the regular survey, where the water was thought to be uncontaminated, together with stations A–M which lay within the area of visible or suspected contamination. At stations A, B, C, D, G, H, I and L a thin film of oil dotted with occasional patches of thicker oil covered the surface of the sea. Stations E and F, which were sampled on the morning of 29 March, were characterized by broken patches of rust-red oil (similar to that shown in Plate 7A), some $1\frac{1}{2}$–2 inches thick. Detergent was being sprayed at these stations and there was a strong smell of kerosene. Much more extensive areas of thick oil were found around stations J and K between 18.00 and 20.00 hours on 29 March. Because of the bombing of the 'Torrey Canyon' on this day the area north of a line from the Longships lighthouse to the Isles of Scilly had been closed to shipping. As the oil observed at stations J and K appeared from its direction of movement to have come from the closed area, it was thought at the time that this oil would have escaped treatment with detergent; but later calculations (as described in Chapter 8) show that the oil observed must have been released early on 27 March, and so would not necessarily have escaped spraying.

Distribution of detergent

At most of the stations water samples were taken in the normal way with hydrographic sampling bottles. At stations J and K, where samples were taken under the oil the open sampling bottle was lowered into the sea outside the oil area. The ship was then allowed to drift into the oil, and the bottle was closed. Finally the ship moved out of the oil and the bottle was raised.

Water samples taken on this cruise were sent to BP for chemical analysis of their detergent content. The analytical method used by BP measures the concentration of the *surface active* (*surfactant*) *component* of the detergent. It is important to bear this in mind in interpreting measurements given below since the two main components of the detergents, surfactant and solvent, may tend to separate at sea, the former sinking and the latter remaining near the surface and escaping by evaporation (Chapter 2). Samples were taken at seven depths between the surface and 70 m at station 2, at or near surface and at 50 m at stations A–D, at 1 m and 30 m at stations E–G and at the surface at stations H–M. With a single exception only, the results were completely negative, indicating that detergent was either absent or at most around 1 ppm. The only exception was station E at 1 m, where duplicated readings gave an equivalent of 1·2 and 6·0 ppm detergent (BP 1002).

This indicated that by 28–29 March the detergent might be accumulating locally to unwelcome concentrations, but it was not doing so at an alarming rate over a wide area.

Phytoplankton surveys

Tow-net samples of the small floating plants of the phytoplankton were taken at the surface, 5 m and 10 m at stations 2, 4 (uncontaminated water), A, B, C, D and M (under a thin oil film) and E (near to detergent-sprayed oil). They were examined on the ship under a microscope and were then stored at 5 °C for a more detailed examination in the laboratory on 30 March. Fig. 5 illustrates the appearance and size of some of the phytoplanktonic organisms referred to in this chapter.

PLATE 2

A comparison of detergent–oil emulsions in sea water 36 hours after the cylinders were shaken. Left to right: Houghton, BP 1002, Gamlen, Gramosol, Whittaker, Slipclean, Dasic, and control.

PLATE 3

A, Newly arrived splodges of oil deposited on sand at Marazion, 1 April. **B**, Marazion looking west after a gale, 5 May: strand lines of re-deposited treated oil mixed with fragments of torn weed.

PLATE 2

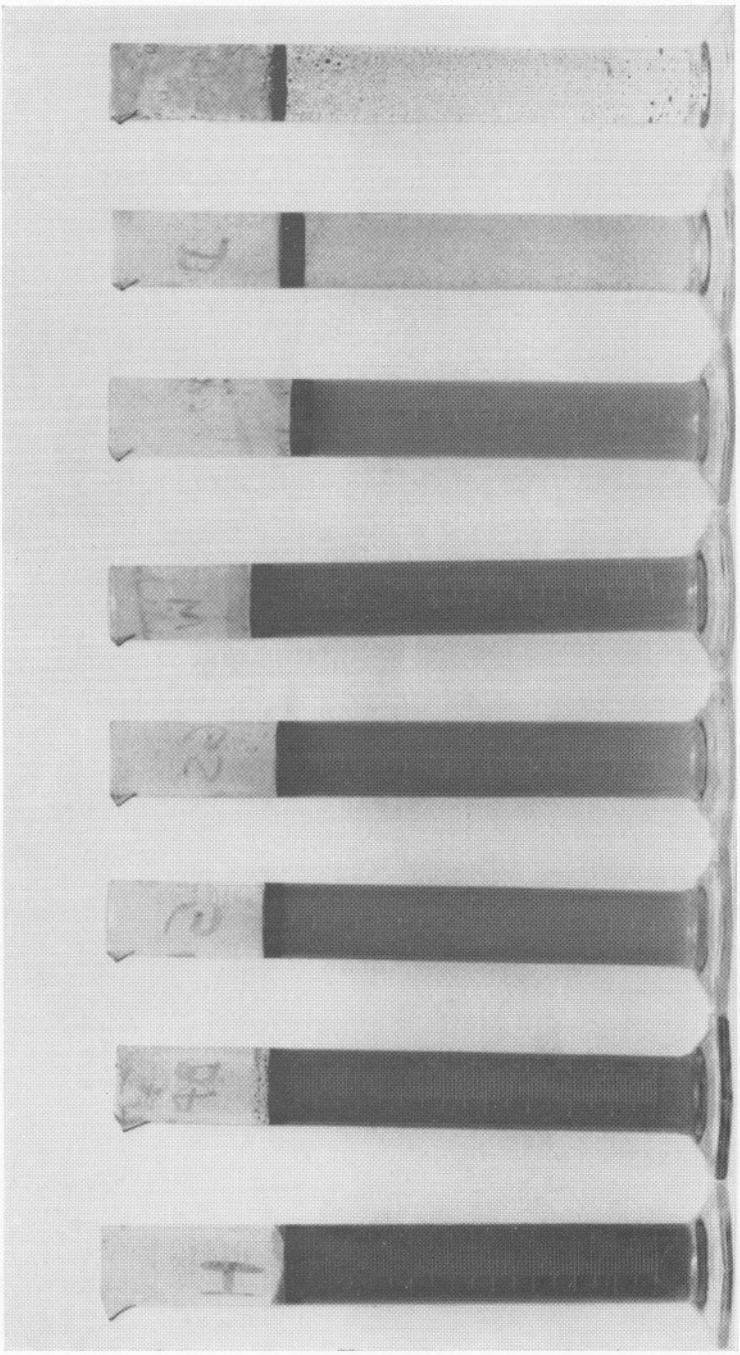

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PLATE 3

A

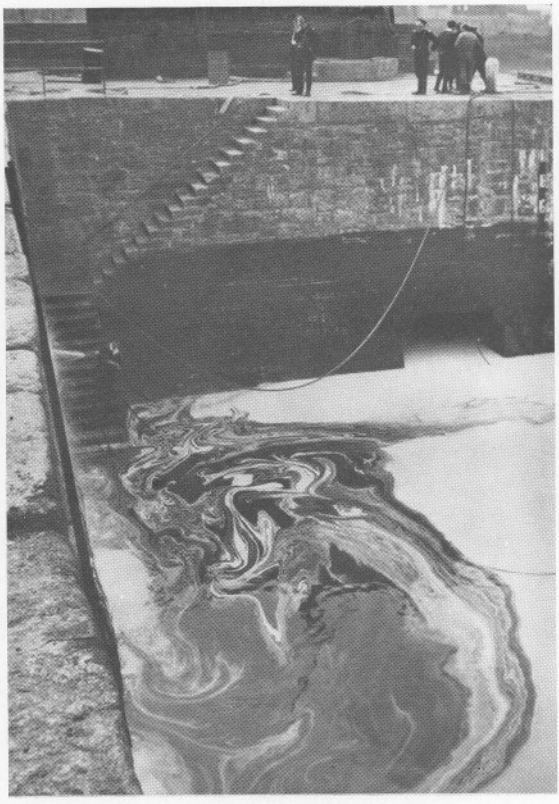
B

PLATE 4

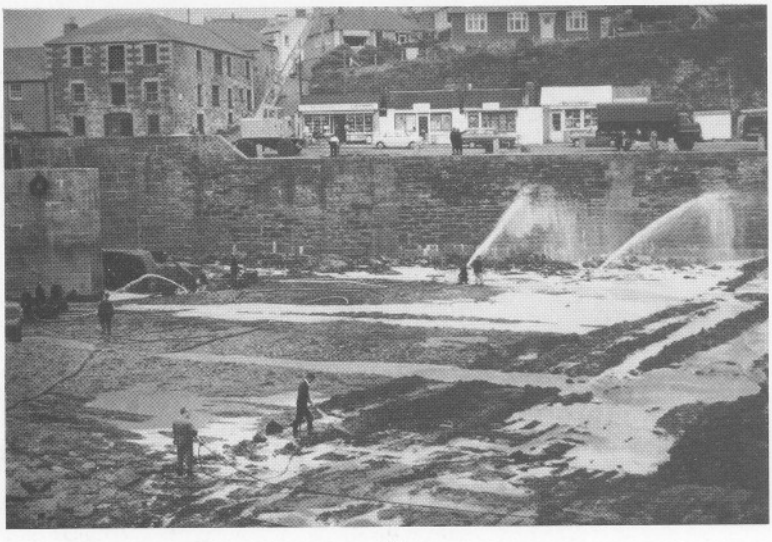
A

B

PLATE 5



A



B

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When the samples were examined on the ship and later on 30 March in the laboratory, all of them contained plant populations of the type normally found in the Channel in early spring and both diatoms (Bacillariophyceae) and dinoflagellates (Dinophyceae), appeared to be healthy at all stations. Cysts of the very small Prasinophyceae were examined with especial care for it was thought that their habit of floating on or near the surface might make them especially vulnerable to surface-sprayed detergent. They appeared, however, to be healthy at all stations except M, where some individuals of all the species in the group showed shrinking of the cell contents from the cell wall.

Thus, on first inspection, the phytoplankton was surprisingly normal. But, in order to test whether there might be delayed effects, specimens from the tow-net samples were cultured in the laboratory for a further week.

The first cultures contained cysts of the Prasinophyceae which had been picked out from the samples and placed in a stock culture medium. After seven days many had released viable motile cells. Only a few of the remaining cysts, however, were in a healthy condition and many of the younger cysts had died. This does not normally happen.

Four other series of cultures were also set up and the results are briefly reported. They were not aerated.

Series 1. Tow-net samples from stations A, B, C, D, E and M were cultured in equal volumes of the sample and culture medium. In three of the cultures most of the diatoms became abnormal or died within seven days; in the other three they remained healthy. The Prasinophyceae remained healthy in only one culture. Small colourless flagellates, on the other hand, prospered in all six cultures.

Series 2. Tow-net samples from stations A, B, C, D, E, M and 2 were cultured in one part volume of the sample to nine parts of the culture medium, a mixture favoured at Plymouth for the culture of diatoms and dinoflagellates. Except in two instances when a few diatoms appeared to be abnormal, all the organisms were healthy after seven days.

Series 3. Water samples from station J (under thick oil) and station D (where

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PLATE 4

A, Detergent spraying in a remote cove near the Lizard, 22 April. Detergent drums are being ferried by helicopter to the cliff tops, from where it is piped down to the beach. Note the large patch of white emulsion in the sea. **B**, Fishing Cove, Gunwalloe, 28 April, showing ridges bulldozed in the shingle for detergent treatment of this heavily-oiled beach.

PLATE 5

Cleansing operations at Porthleven Harbour, 28 April. **A**, Operator spraying detergent on harbour wall. The detergent is forming a white emulsion in the sea, with which are mingled streaks of re-separated oil and oil–water emulsion. **B**, Spraying detergent on the harbour walls at low tide. The floor of the harbour has been bulldozed.

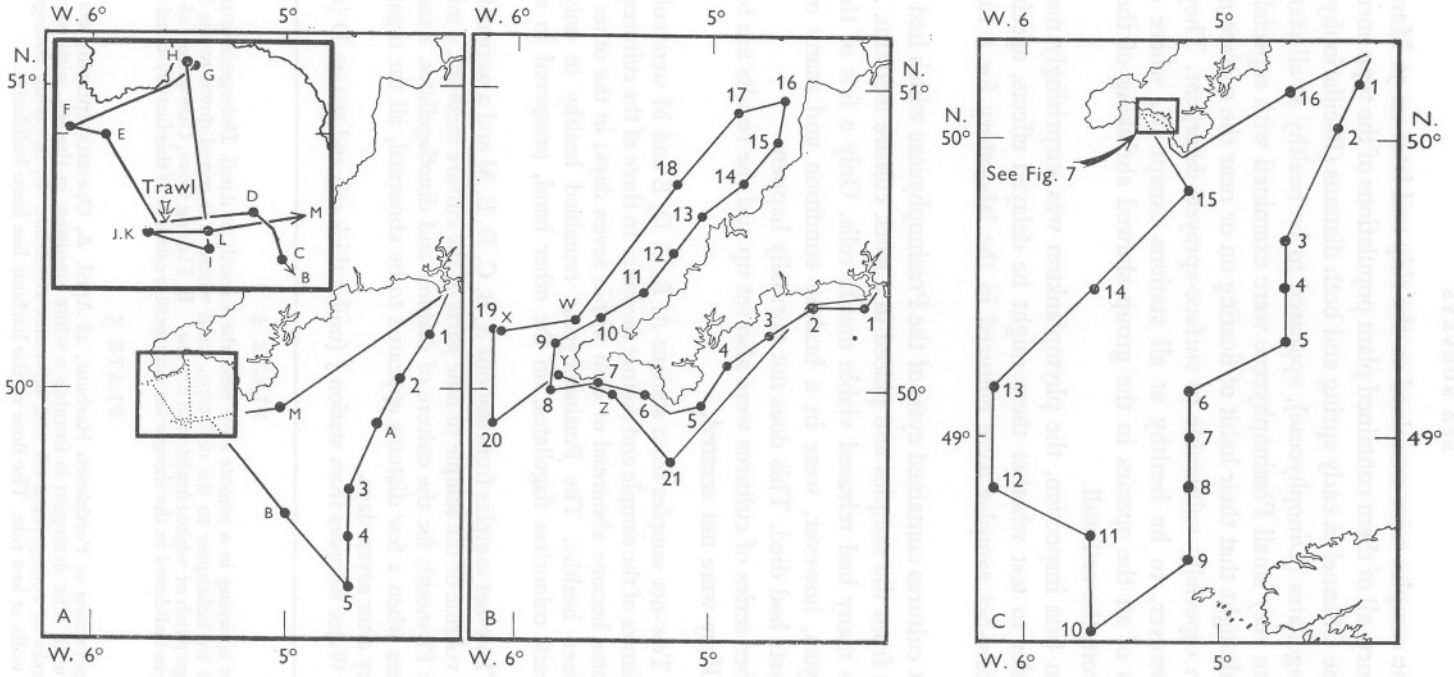


Fig. 4. Positions of stations on 'Sarsia' cruises. A, 28–30 March; B, 3–6 April; C, 11–14 April.

oil appeared to have been treated with detergent) were enriched with nutrients to encourage growth of the contained phytoplankton. All organisms were healthy after seven days.

Series 4. Water from stations J and D was filtered to remove the plankton and to the filtered water was added culture medium inoculated with planktonic algae grown in the Plymouth culture collection. Algae grown in an uncontaminated culture medium were used as controls.

The results of the series 4 tests span too many species to be set out in detail. A very brief summary of the results, however, is that, while the naked or scale-covered Prasinophyceae were killed in the stations J and D samples, the one species with a complete protective thecal covering that was tested grew better than in the controls. By and large all other forms prospered as well in the J and D water as in the controls.

The overall results and conclusions which follow from this phytoplankton survey may therefore be summarized as follows:

(1) There were deaths among the smallest flagellates (Prasinophyceae), often only after a period of some days in all the samples taken from areas of thin or thick oil cover, and there were no deaths at stations in the uncontaminated water. It is clear therefore that the Prasinophyceae can detect and respond to concentrations of toxic substances that are too low to be detectable by the method of chemical analysis that was available.

(2) Other phytoplanktonic algae (diatoms and dinoflagellates) were exposed at some stations to a lethal concentration of toxic substances; at others they were not. Those grown in the laboratory on a one-tenth concentration of the sea water in which they were taken survived. It may be concluded therefore that the concentrations of toxic materials in the water samples taken on cruise I were not much above the lethal level for the most delicate of the organisms examined.

(3) Most of the colourless flagellates were unaffected, and some of them grew rather better in the toxic sea water than in uncontaminated water.

Zooplankton surveys

Oblique tow-net hauls were taken at stations D and L (under thin oil) for the sampling of the plankton animals—mainly copepod crustaceans. The animals appeared to be of a normal abundance and all seemed healthy when examined immediately after capture.

Benthic organisms

Fish taken in the trawl at station D appeared to be healthy. No oil was found on the sea bed and there were no external signs of oil contamination

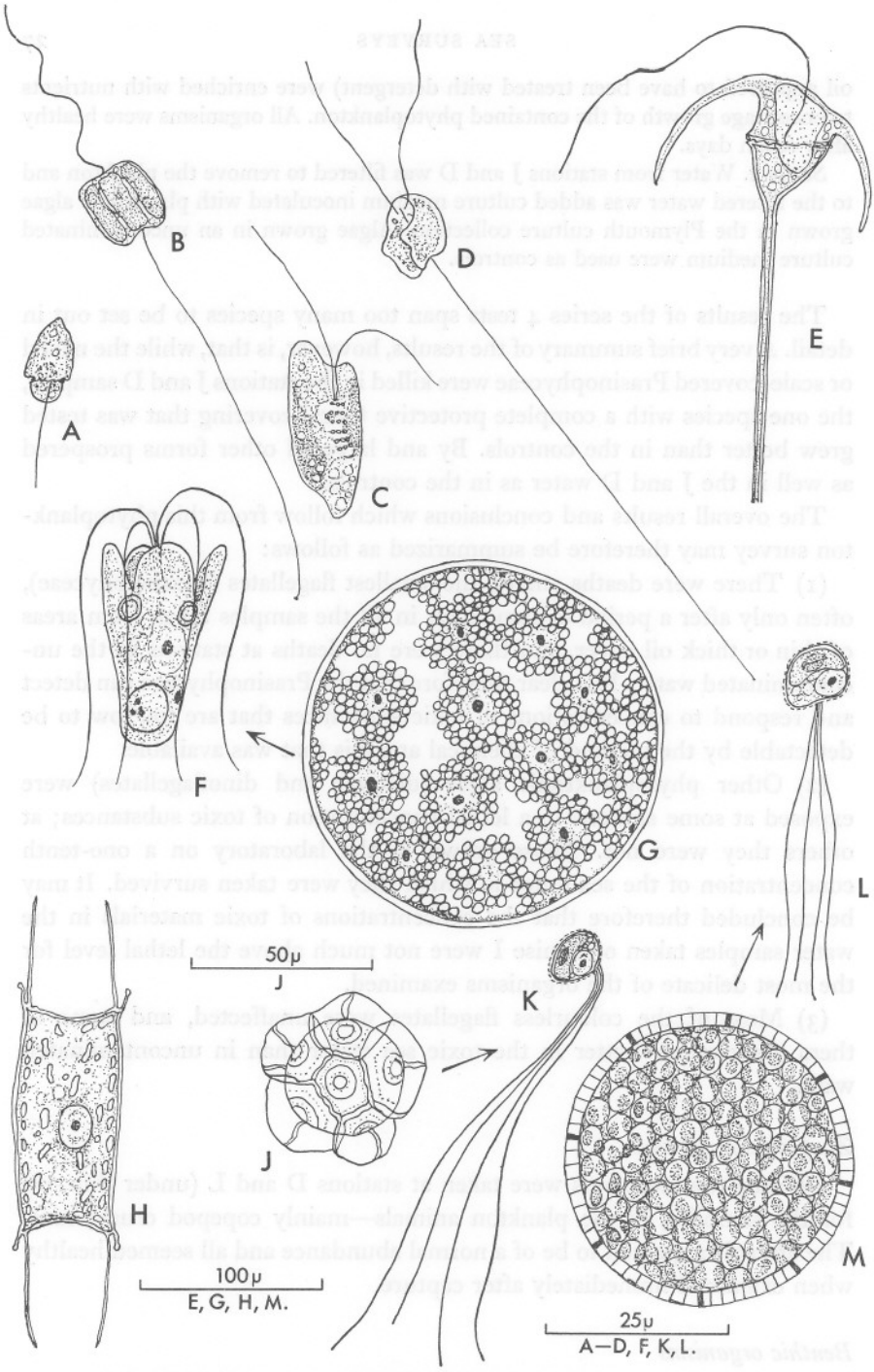


Fig. 5. Illustrations of some of the minute plants in the sea in the polluted areas. A, *Katodinium rotundatum* (Lohm.) Loeblich III (Dinophyceae). B, *Pseudopedinella* sp. (Chrysophyceae). C, *Cryptomonas maculata* Butch. (Cryptophyceae). D, *Chrysochromulina ephippium* Parke et Manton (Haptophyceae). E, *Ceratium tripos* (O. F. Müll.) Nitzsch (Dinophyceae). F and G, *Halosphaera minor* Ostenf. (F = motile phase) (Prasinophyceae). H, *Biddulphia sinensis* Grev. (Bacillariophyceae). J and K, *Pterosperma marginatum* Gaarder (K = motile phase) (Prasinophyceae). L and M, *Pachysphaera marshalliae* Parke (L = motile phase) (Prasinophyceae).

on any of the fish or visible traces of oil within the gut. Several different types were boiled and eaten. They were much appreciated and there were no subsequent ill effects.

Investigations consequent to the cruise I survey

The laboratory studies of the toxicity of oil and detergents reported in Chapter 7, none of which, however, had been undertaken at the time of the first exploratory cruise of R.V. 'Sarsia', show that many kinds of zooplanktonic organisms are in varying degrees susceptible to poisoning by detergents, the lethal doses depending on the detergent used, the concentration of the detergent, and the length of time the organisms are exposed to the toxic substances.

In addition, as is pointed out on page 145, laboratory experiments had shown that most of the very toxic organic solvent ingredient of the detergents tested is lost by evaporation within about two days. And so, although the first cruise of R.V. 'Sarsia' had demonstrated that the presence of oil on the sea and use of detergents had in the early stages produced little demonstrable adverse effect on any marine organisms, save for the smallest of the algae, it was not known how the continuation of spraying might alter the picture. It is possible also that seemingly healthy organisms might be harbouring deleterious effects which would only later become fully apparent. With these thoughts in mind it was decided to undertake further sea surveys and, at the same time, to carry out a series of laboratory experiments designed to examine the problem of possible long-term effects of detergents on planktonic organisms.

CRUISE II

On this cruise from 3 to 6 April twenty-one stations were worked with the Gulf III high-speed plankton sampler from Plymouth through the Seven Stones area round to Hartland Point on the north coast of Devon, and samples of water were collected. The stations at which samples were taken are shown in Fig. 4B.

Oil pollution was restricted to small patches, mainly of iridescent films containing a few small clots of thicker oil. They were present off the Lizard, near the Seven Stones, where surface and bottom 'drifters' were dropped, and off Trevose Head. Surface and bottom 'drifters' of plastic were dropped near the Seven Stones in the hope that they would drift with the oil and thus act as markers of the movements of the areas of contaminated water. These plastic 'drifters' are the modern version of the well-known drift bottles.

Table 3. *Detergent analyses*

Position	Station	Result
49° 56′N., 5° 02′W.	—	0
50° 10′N., 6° 04′W.	19 (W)	0
49° 56′N., 6° 01′W.	—	0
50° 03′N., 5° 47′W.	Y	+ve (3·3 ppm) and 0*
49° 59′N., 5° 30′W.	Z	0

* These two samples may have been half a mile apart.

Samples of sea water collected from the polluted area were sent to BP for analysis. The results expressed as detergent concentrations (ppm) are shown in Table 3.

Four sets of phytoplankton tow-net samples (W, X, Y, Z) were brought back from the cruise and were examined in the laboratory on 6 April. The diatoms and dinoflagellates appeared to be healthy in all the samples, but cysts of members of the Prasinophyceae showed abnormalities. At stations W and Y there was an abnormally large number of empty outer walls of a size not consistent with their being from normal cysts. These were probably young *Halosphaera* cysts which had burst and exuded their contents. At station Y, in particular, there were many young cysts of *Pterosperma* spp. which were dead or in an unhealthy condition. One species of *Halosphaera* (a delicate one) also appeared to be adversely affected. The sample from station X, on the other hand, showed relatively fewer empty outer walls from abnormal releases of contents and all cysts appeared healthy. An abnormal contraction of cyst contents was more noticeable at station Z than at the other stations, but even so some individuals of both *Halosphaera* spp. and *Pterosperma* spp. released viable motile cells in the normal way after four days in the laboratory.

Thus, the observations made during the second cruise revealed abnormalities in one class of algae, the Prasinophyceae, especially at station Y where large quantities of detergents had been used. As mentioned already (p. 25), cysts of this class tend to float on or near the surface and this would make them particularly vulnerable to substances such as oil and detergents poured on to the surface.

Quantitative samples of the larger plankton animals were collected with a modified Gulf III high-speed plankton sampler (Southward, 1962) on 4 and 5 April, one or two days after the cessation of detergent spraying of oil patches at sea. These samples were examined for young fish, fish eggs and the larger zooplankton 'indicator' organisms (Fig. 6).

At two of the stations (7 and 8) nearly all the pilchard eggs (90 per

cent) were dead, compared with a figure of about 50 per cent mortality at other stations where pilchard eggs were taken. Fish eggs tend to float near the surface of the sea and would thus be expected to show any deleterious effects of oil and detergent spraying. Young fish also tend to be found in the surface layers in the first few days after hatching. The numbers of young fish found in the samples taken on the second survey are shown in

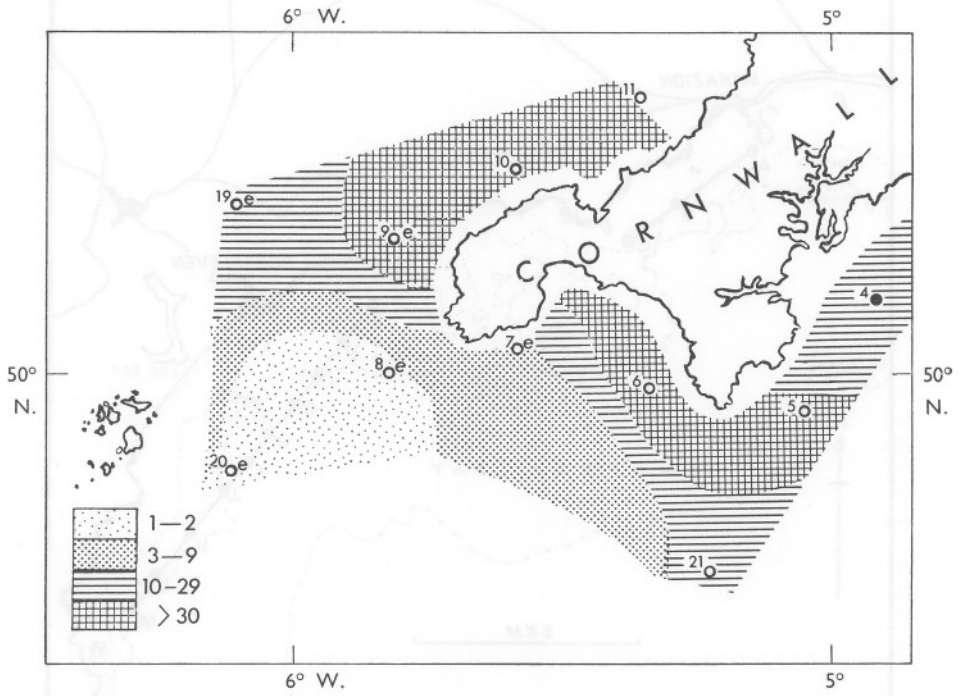


Fig. 6. Distribution of young fish (3–20 mm length) off West Cornwall, 4–5 April. Samples taken with modified Gulf III high-speed sampler, fitted with 40 m.p.i. net. Results are expressed as numbers per haul, corrected to a flowmeter reading corresponding to approximately 40 cubic metres of water filtered. All samples except one (solid black circle) were taken in daylight. The letter 'e' shows the occurrence of north-western type of plankton, a predominance of the arrow-worm *Sagitta elegans* and/or the presence of larvae of the starfish *Luidia sarsi*.

Fig. 6. It is obvious that young fish were scarce or absent in the area to the south and east of the Seven Stones, where detergent was used at sea. The lack of young fish in this area bears no obvious relationship to the type of plankton found and it seems an inescapable conclusion that the absence of young fish south of the Seven Stones and the observed mortalities of pilchard eggs at nearby stations was the effect of detergent spraying carried out one or two days before the planktonic samples were taken.

CRUISE III

On Cruise III (11–14 April) series of stations across the Channel and in the Mount's Bay area (Figs. 4c, 7) were worked. One series of observations was made as close inshore as practicable (stations A–M), to coincide with

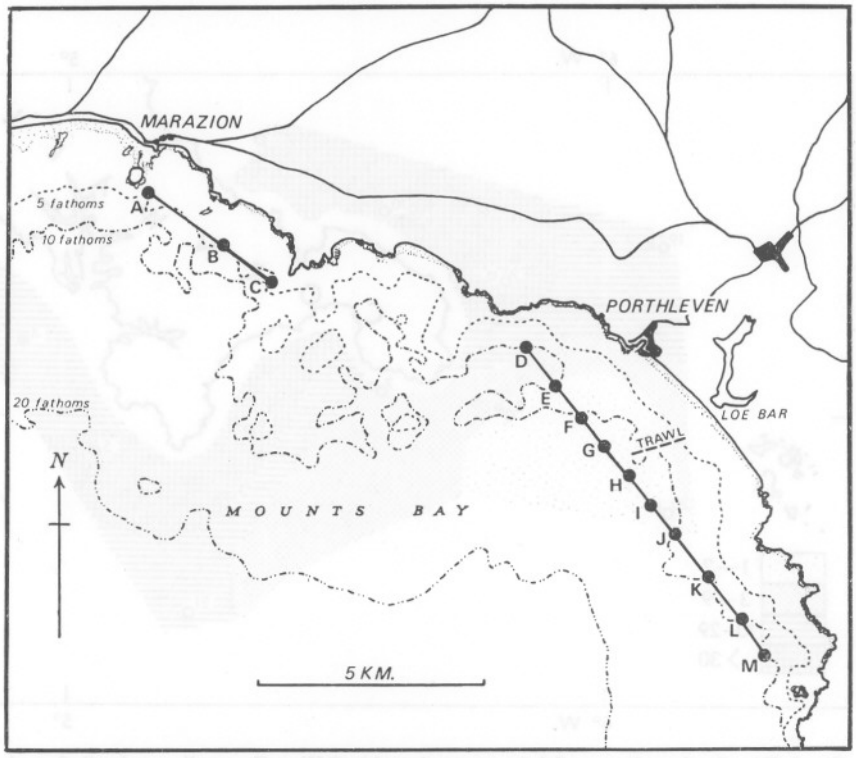


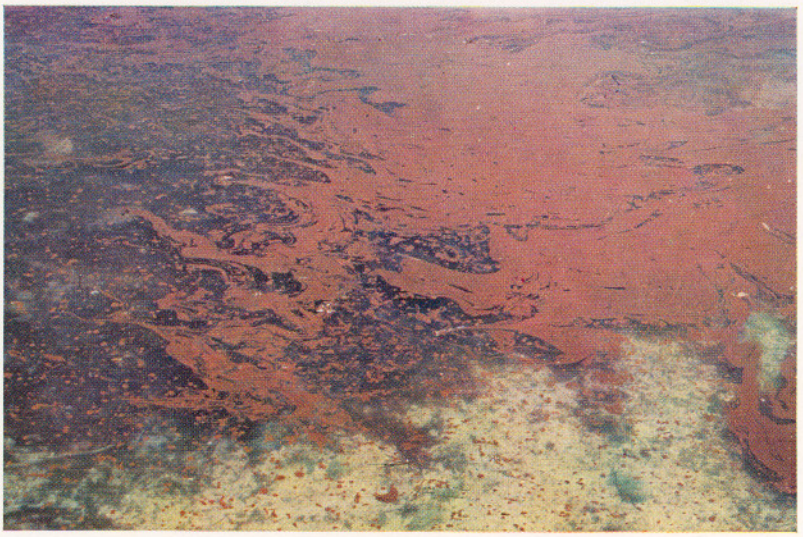
Fig. 7. Inshore stations worked by 'Sarsia' on 13 and 29 April.
The area shown here is indicated on Fig. 4c.

the activities of a party of aqualung divers working from the shore (see Chapter 6). At this time heavy detergent treatment was being applied in the Porthleven area.

Water samples from the Mount's Bay transect were again sent to BP for analysis, with the results, given in Table 4, expressed as detergent concentrations in parts per million.

In interpreting these figures it must be remembered that it was only the surfactant component that was being measured and that separation of surfactant from the solvent component may already have occurred. It is likely, therefore, that the detergent will have been underestimated at the surface

PLATE 6



A

B

C

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Table 4. *Detergent estimations in Mount's Bay (ppm)*

Calculated from surfactant values

	Mount's Bay stations												
	A	B	C	D	E	F	G	H	I	J	K	L	M
Surface	7·8	6·7	5·1	5·1	2·4	2·4	0	0	0	0	0	0	0
Mid-water	6·7	2·4	0	0	0	0	0	0	0	0	0	0	0
Bottom	44·0	28·0	0	0	0	0	0	0	24	0	0	0	0

stations, and many times overestimated at some bottom stations where surfactant was detected. There is no doubt that the two most westerly stations at least (A and B) had been poisoned to a considerable degree. The high mortality of bottom-living animals recorded in Chapter 6 is readily understood. The toxic properties of the water in Mount's Bay clearly decreased eastwards, but zero readings should not necessarily be taken that no significant concentrations of the detergent (or some component of it) occurred.

Water samples from the same area were sent to Professor D. E. Hughes, of the Department of Microbiology, University College of South Wales and Monmouthshire, Cardiff, who reported that no oil-degrading bacteria were detectable. Such organisms are normally present in the sea in small numbers (ZoBell, 1963), and multiply as soon as any suitable substrate is provided. The present few results are too limited to be taken as indicating an effect of the detergent on oil-degrading bacteria in this area. The general subject of the effects of detergents on oil-degrading bacteria is being investigated by Gunkel (see p. 82).

On the cross-channel transect (Fig. 4C) no oil pollution was observed at stations 1 and 2. Stations 3–6 were worked during the hours of darkness, but no oil was observed during the stops on station. An oil film with occasional lumps—characteristic of oil treated at sea—was first observed at station 7 and this was found all the way along the route until just before station 12. Around station 8 there was an extensive area of thick oil (Plate 7A). This was of the same colour and general appearance as the oil observed on the first cruise, and once again it had a strong smell. Surface and bottom drifters were put down in this contaminated area.

PLATE 6

A, Trégastel-Plage (Côtes du Nord), 21 June. Oil–water emulsion which had re-separated after detergent spraying drifting on to the beach. **B**, Salt marsh near Trégastel (Côtes du Nord), 21 June. A line of dark brown patches of re-separated oil deposited on the beach already blackened by the initial pollution. **C**, Mullion Harbour, 6 April. Underwater photograph of an oil–water emulsion weighted with sand on the sea bed in the harbour mouth. Note the separated globule floating beside the main mass.

Phytoplankton tow-net samples were taken at stations 2, 4, 7 and 9–15, and examined immediately on return to the laboratory on 14/15 April. They contained organisms in varying quantities, but were all normal except that, as on previous cruises, there were some stations (2, 4 and 7) where the representatives of the Prasinophyceae were dead or abnormal.

SUBSEQUENT CRUISES

Later cruises by R.V. 'Sarsia' could not be diverted for long from normal oceanographic research work. However, some effort was devoted in three later cruises to a search for patches of oil that had disappeared to the south (see Chapters 8 and 9).

Water samples were taken on cruises on 28–30 April and in mid-May for oil content analysis of apparently clean water, at stations across the mouth of the English Channel. A closing water-bottle placed horizontally was used to sample the surface layer (top 10 cm at most). These samples contained crude oil at concentrations of 0·007–0·014 ppm at the end of April and 0·004–0·009 ppm in May. Subsurface samples contained negligible amounts of oil, no oil being detected in samples from 5 and 50 m depth (the lowest limit of detection being about 0·003 ppm).

We are indebted to the Superintendent, Admiralty Materials Laboratory for these analyses and also for the information that at a station 10 miles south of Portland Bill (*ca.* 280 kilometres up Channel from the Seven Stones) in surface samples taken weekly the concentration of crude oil was 0·003 ppm or less in March and April 1967, rising to 0·005 in June and returning to 0·003 in July, which is similar to the oil content of Channel waters sampled during recent years.

THE SEA SURVEY OBSERVATIONS IN RETROSPECT

The relatively little detected damage suffered by planktonic organisms in the western English Channel following the release of oil from the 'Torrey Canyon' and its treatment with detergent seemed, at the time of the surveys, to be rather surprising in view of the magnitude of the oil release and the large quantities of detergent used in an attempt to disperse the oil at sea. However, now that the circumstances of the pollution are better known it is possible to take a more informed view of its consequences.

Experiments reported in Chapter 7 show that many of the smaller planktonic organisms may be killed in a matter of a few hours in concentrations of detergent of 1–10 ppm. Zooplankton, however, are mostly active organisms which undergo marked vertical migrations and might well

escape toxic surface water by swimming downwards. But the more passive members of the plankton may really not have been so harmfully affected as might at first appear. Let us consider.

About 500000 gallons of detergent were used during the fourteen days or so of the sea-spraying operations. If all the detergent that had been used were spread evenly through the top 5 m of water (where the damage was mainly done) at a concentration of 1–10 ppm, an area of water 20–200 square miles would have been contaminated. Damage of this extent, bad, but far from catastrophic, was visualized at first.

But this is a wholly unreal picture, for detergents in sea water rapidly lose much of their toxicity (Chapter 7) and the patches of high concentration formed in the areas of spraying remain, for a time at least, coherent and do not readily disperse (Chapter 6). In Chapter 7 it is reported that the toxicity of detergents is mainly due to their aromatic components and in open dishes these are largely lost by evaporation within a period of from two to five days. Since in the sea the maximum solubility of aromatic hydrocarbons is of the order of 30–800 ppm the dissolved aromatics could, it is true, persist as a highly toxic system. But winds of a strength sufficient to achieve sufficient vertical convection to bring about a mixing to 5 m would also evaporate the toxic aromatics very rapidly from the sea surface to the air.

The effect of spraying oil patches, therefore, is to produce patches or tongues of oil and water charged with detergent which could be driven 30 miles or more downwind by a steady fresh breeze (Beaufort 6) lasting for two to three days. During this time much of the toxicity due to aromatics would be lost, though there would be a small proportion of aromatics remaining in true solution. In detail, much will depend on the stratification, cellular structure, and dynamic stability of the water, and these are dependent in turn on the relative sea and air temperatures by night and by day, and on the strength of tidal and residual currents. Thus, after a very few days, planktonic organisms are subject in the main to the much-diluted non-volatile and much less toxic surfactant constituents of the detergents.

The subsequent history and possible effects on organisms of these more persistent substances have not been studied during the present investigations.