CHAPTER 4

SHORE SURVEYS—ROCKY SHORES

On the Cornish coast there are two main types of substratum: (1) the rock of cliff bases, platforms, reefs or boulders, and (2) beach deposits usually of clean sand, or sometimes of pebbles. Rock is essentially stable whereas sands shift with the tides. On sandy shores there are seasonal changes, in that parts of the beach build up during the spring and summer under relatively calm conditions and are removed again during stormier periods of autumn and winter. Such different types of substratum obviously demand different cleansing procedures. The initial amount of exposure to, and damage to life by, detergent differs widely on rock and sand as does the degree to which the detergent persists. As, however, the two types occur in close proximity at any one locality this chapter is to some extent geographical in its approach. Attention is focused first on the more rocky shores; observations on sandy shores being given in the following chapter. Estuaries form yet a third type of habitat with quite different cleansing problems. The 'Torrey Canyon' pollution fortunately did not affect any of our major estuaries, but such effects as were seen are mentioned in Chapter 5.

ARRIVAL OF THE OIL

An account by a resident at Marazion stated that there was a smell of oil for a day before any actually arrived on the shore on 25/26 March. Dark blobs were seen silhouetted in crashing waves, and close inshore there was so much oil on the sea that the waves were smoothed, while elsewhere it was choppy with tan-coloured instead of white breakers (cf. Plate 13B). The receding tide left a band about 5 metres wide of 'chocolate icing' (elsewhere described as 'chocolate mousse'). Some of this oil was washed off by the next tide, but some was left adhering to the seaweeds *Fucus* and *Porphyra*. Oil tended to be washed off barnacles but to be left in crevices on the rocks. Further landfalls of oil extended and thickened the coating, and then with gale-force winds behind a very high spring tide oil was flung right up the sea-walls and cliffs. But much of the oil brought into Marazion Bay did not settle, owing to a change of wind.

Along the coastline from the Lizard to Trevone pollution was general but far from continuous. A stretch of about ten miles of the coast on the west side of Mount's Bay, as well as many lesser areas, escaped. Winds concentrated the oil on to west-facing shores, or towards the eastern end of bays facing north or south, pushing it into localized areas on a beach or into small coves. Later changes of wind direction caused more general pollution of northward-facing shores. This ghastly mess of oil, like thick blankets of 'chocolate mousse', presented a very different problem from the black tarry lumps of oil previously familiar along the drift line. Plates 3A, 8, 13 and 14 convey the appearance of the oil on the shore soon after arrival better than could any description.

Sennen was seen seven tides after the first oil-fall, and while more oil was still arriving and before any use of detergent. The boulders at high water were completely smothered in oil: the layer was estimated as about 1 cm thick, less on slopes, more in hollows (Plates 13A, 14A). On the sand there were large areas of oil about $\frac{1}{2}$–1 inch thick covering perhaps 50 per cent of the middle shore. At Gunwalloe Fishing Cove the oil was driven along the shore (Plate 4B), concentrated so that the breaking waves looked as if they were almost composed of oil, and their turbulence was markedly suppressed (Plate 8A). They swirled among the rocks, depositing a coating of oil on everything animate and inanimate. On the shingle they left a sticky blanket 1–2 inches thick which sank only slightly among the pebbles. But nowhere on the Cornish coast was oil nearly as thick as that which settled on parts of the Brittany coast (see Chapter 9, p. 160).

The 'chocolate mousse' was a mixture of oil, sea water and probably also detergent sprayed on at sea. Statements that this coating, usually referred to simply as oil, was up to 2–3 feet thick must have referred to very localized corners, or be erroneous. Oil floating on water in pools or, for example, in Porthleven harbour, could give a very misleading impression. Thicknesses and the area covered were very difficult to estimate and were subject to changes with each tide. Depths mentioned here were of oil seen after a few tides.

In most places the early deposits were mainly in the high-water zone and in the splash zone, but at Trevone where the oil was deposited on 29/30 March under calmer conditions the blanket of oil half an inch or more thick was spread over a wider tidal zone.

Treatment on the shore by detergents, usually hosed down with fresh water, produced milky streams running down the sands or retained in the rock pools (Plates 1B, 10A). It was this detergent mixture and neat detergent which proved so lethal to the fauna and flora.

As more oil arrived from the sea or was dispersed by detergents from one place to another pollution became more general. Even so there were stretches of shore and localized areas which escaped completely, providing a reservoir of organisms from which recolonization by the next generation of their larvae or spores can take place.

The zeal of the detergent users was such that even the most remote coves were often eventually tackled (Plate 4A), being incorrectly considered as the source from which 'new' oil was appearing. It is much more likely that the secondary deposit of oil on 'cleansed' beaches was in fact due to oil washed back by onshore winds or buried oil coming up from beneath the sands.

The map (Figs. 8–10) presents a synthesis of data from all reliable sources. It is based almost entirely on observations from Marine Biological Association workers, supplemented by records from the Nature Conservancy and from an Admiralty worker. The relative amounts of oil at different places are represented conventionally and were somewhat difficult to assess, but there seems little doubt that oil-falls were heaviest at Sennen Cove. The region of Cape Cornwall received a great deal and St Ives (Porthmeor Beach) had an exceptionally heavy plastering (Plate 8B), though the harbour and nearby beach escaped. Passing northwards along the coast there seemed to be rather less oil, but, owing to attempts to clean it during the long spell of northerly winds, relatively much more detergent was used, over a prolonged period. The degree of damage to life was much the same in all heavily treated areas. Two sharp spells of westerly wind caused heavy pollution along much of the eastern shore of Mount's Bay, but cleansing operations in this area were greatly helped by the long spell of northerly winds. The ten-mile stretch of coast from Penzance south-westwards escaped entirely and very little oil was deposited east of the Lizard. Only a few places, difficult of access, or lightly polluted, were left untreated by the end of the operation. Because detergent was distributed and used partly by the army and partly by local authorities (with frequent changes of personnel on the beaches) it has proved impossible to be exact about the amounts of detergent applied in the different areas and used on particular beaches. Figures are given (see page 42) for a few places where they seem to be reasonably reliable. For approximate totals of oil and detergent on Cornish beaches see Chapter 8. An essential contribution to the cleansing operations was made by the fire services using pressure hoses for delivering fresh water, or occasionally sea water, to wash the detergent and oil down the shore to meet the incoming tide. The methods of application varied widely as did the conditions and times relative to the tide. Local geography and weather were important. All these could make a great deal of difference to the effect on the flora and fauna as well as to the efficiency of oil removal.

AREAS STUDIED

Marine Biological Association workers between them visited sixty-five sites, many of them several times. Field work began on 28 March, and frequent journeys were made to West Cornwall until mid-May, since when studies have been continued by sporadic visits. The main sites studied are listed in Table 5.

The south coast is, in general, much the more sheltered from intensive wave action, has more localities with good weed cover, and is probably the richer in variety of species. The north coast is more open to powerful wave attack, tends to have on its rocky shores more barnacle and mussel coverage and less weed cover, and, while harbouring many plants and animals that are commoner there than on the south coast, is less rich in its variety of species.

On exposed shores the boulder zone near high water and also the inter-tidal sands have but a limited fauna. These were at first the hardest hit regions, but the spreading of the contamination, due largely to the use of detergent, meant that many rocky shores and sands became mildly contaminated over nearly the whole of their tidal range.

Some of the places, particularly those on the north coast, and especially Trevone, have been visited regularly for a number of years by scientists from the Plymouth Laboratory, while for others there are detailed records of some of the commoner plants and animals which go back to the late 1940s and early 1950s (Crisp & Southward, 1958; Southward & Crisp, 1954, 1956; Southward, 1967) and in some cases to the 1930s (Fischer-Piette, 1936; Moore & Kitching, 1939). There was therefore a good background of information available for detecting and assessing changes in the intertidal fauna and flora which could be attributed to the effects of oil pollution or of the cleansing operations.

From the field data currently available, a fourfold comparison has been attempted of shores or patches of them which (1) were completely untouched and unspoilt, (2) had oil pollution alone, (3) had both oil pollution and detergent treatment, and (4) were affected by detergent but had never had any oil contamination.

Detailed surveys are given of two areas, Marazion and Trevone. Apart from visits paid by members of the Plymouth staff to Marazion, regular surveys were made by a local resident, Mrs S. Vaidya. Her studies of the algae and the commoner shore animals gave valuable continuity to the observations which covered a period of 20 weeks from the arrival of the first oil. This shore provided a range of habitats and showed a gradation of the effects of moderate pollution. In this it contrasted sharply with

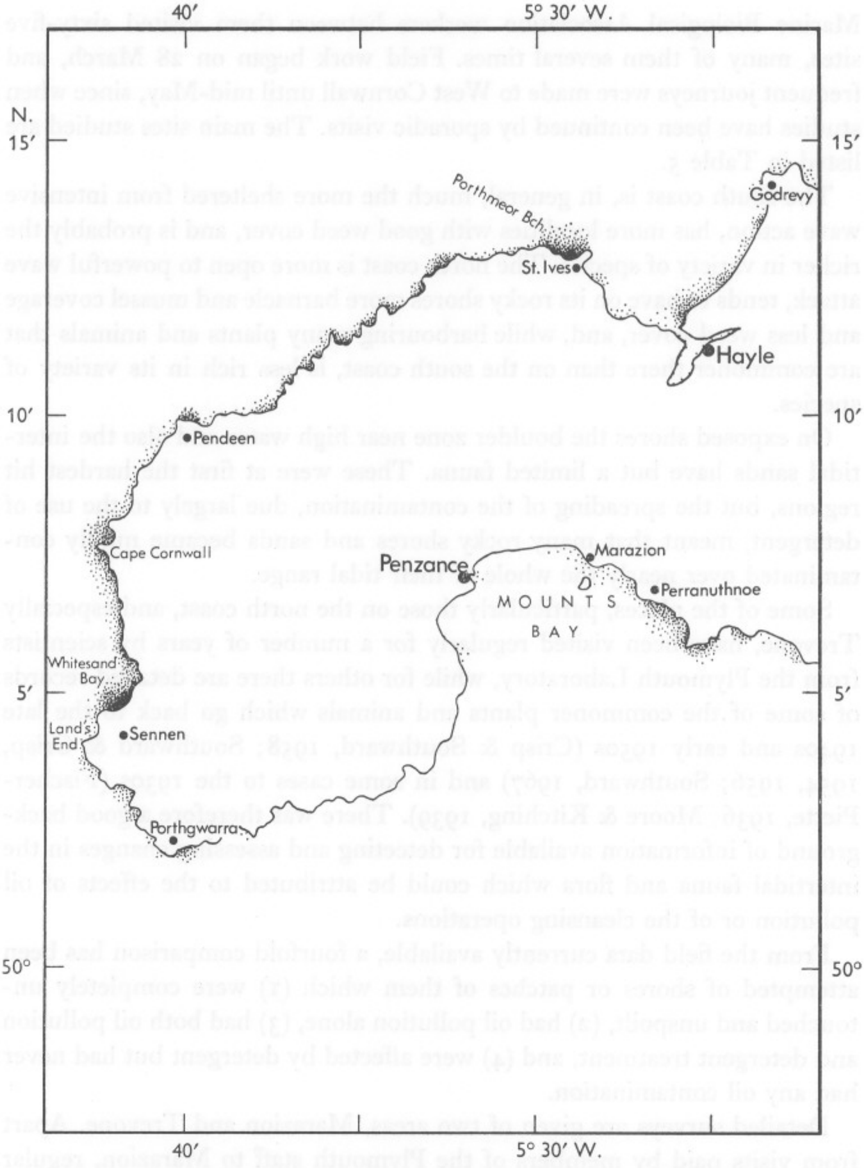


Fig. 8. The maps in Figs. 8–10 show the chief places studied by M.B.A. workers, and the amount of oil deposited on the beaches. The density of stipple indicates the relative degree of oil pollution. Scale, 2·5 kilometres to 1 cm. (approx. 4 miles to 1 inch).

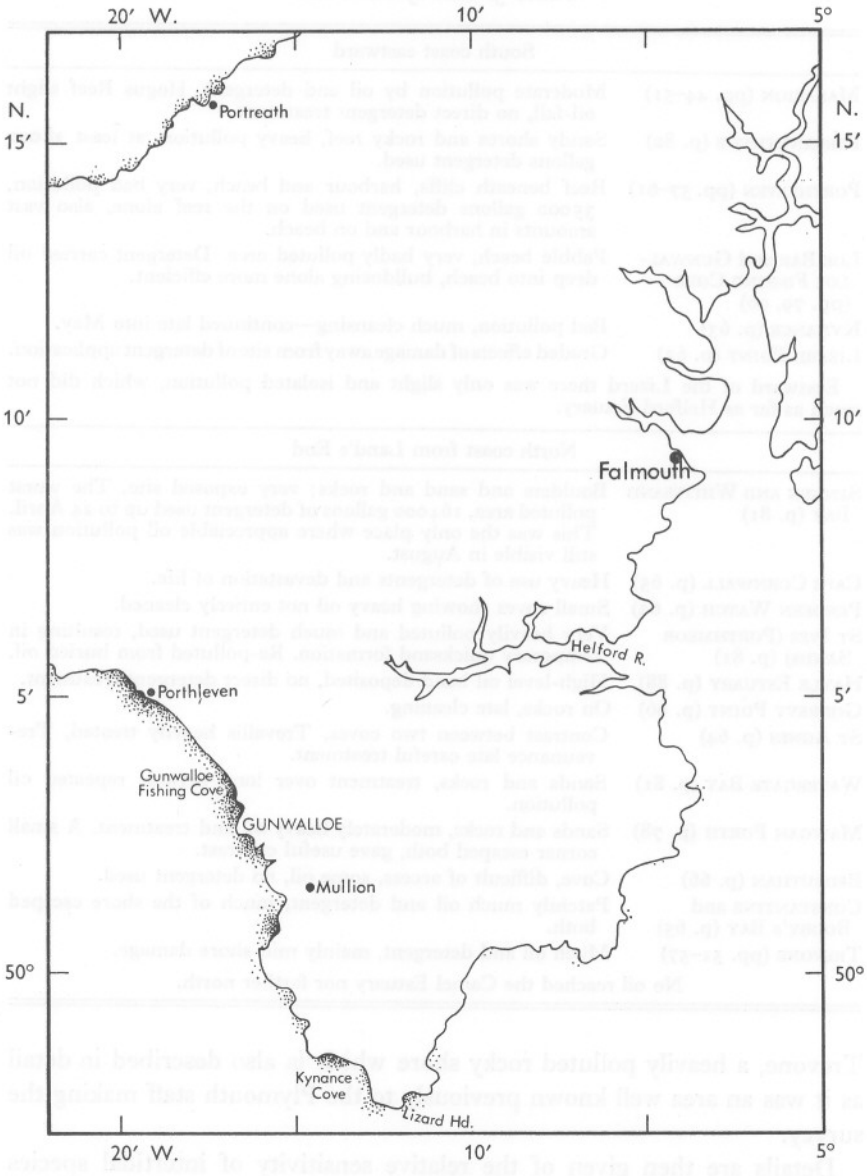

20′ W.
10′
5°
N.
15′
10′
5′
50°
Portreath
Falmouth
Helford R.
Porthleven
Gunwalloe Fishing Cove
GUNWALLOE
Mullion
Kynance Cove
Lizard Hd.

Fig. 9

Table 5. *List of main sites*

	South coast eastward
MARAZION (pp. 44–51)	Moderate pollution by oil and detergent. Hogus Reef slight oil-fall, no direct detergent treatment.
PERRANUTHNOE (p. 82)	Sandy shores and rocky reef, heavy pollution, at least 38000 gallons detergent used.
PORTHLEVEN (pp. 57–61)	Reef beneath cliffs, harbour and beach, very bad pollution, 35000 gallons detergent used on the reef alone, also vast amounts in harbour and on beach.
LOE BAR and GUNWALLOE FISHING COVE (pp. 79, 90)	Pebble beach, very badly polluted area. Detergent carried oil deep into beach, bulldozing alone more efficient.
KYNANCE (p. 63)	Bad pollution, much cleansing—continued late into May.
LIZARD POINT (p. 62)	Graded effects of damage away from site of detergent application.
Eastward of the Lizard there was only slight and isolated pollution, which did not reach as far as Helford Estuary.	
	North coast from Land's End
SENNEN AND WHITESAND BAY (p. 81)	Boulders and sand and rocks; very exposed site. The worst polluted area, 164000 gallons of detergent used up to 24 April. This was the only place where appreciable oil pollution was still visible in August.
CAPE CORNWALL (p. 65)	Heavy use of detergents and devastation of life.
PENDEEN WATCH (p. 62)	Small coves showing heavy oil not entirely cleaned.
ST IVES (PORTHMEOR SANDS) (p. 81)	Very heavily polluted and much detergent used, resulting in temporary quicksand formation. Re-polluted from buried oil.
HAYLE ESTUARY (p. 88)	High-level oil band deposited, no direct detergent treatment.
GODREVY POINT (p. 66)	On rocks, late cleaning.
ST AGNES (p. 64)	Contrast between two coves, Trevallis heavily treated, Trevaunance late careful treatment.
WATERGATE BAY (p. 81)	Sands and rocks, treatment over long period; repeated oil pollution.
MAWGAN PORTH (p. 78)	Sands and rocks, moderately heavy oil and treatment. A small corner escaped both, gave useful contrast.
BEDRUTHAN (p. 66)	Cove, difficult of access, some oil, no detergent used.
CONSTANTINE and BOOBY'S BAY (p. 65)	Patchily much oil and detergent, much of the shore escaped both.
TREVONE (pp. 51–57)	Much oil and detergent, mainly mid-shore damage.
No oil reached the Camel Estuary nor farther north.	

Trevone, a heavily polluted rocky shore which is also described in detail as it was an area well known previously to the Plymouth staff making the survey.

Details are then given of the relative sensitivity of intertidal species found damaged by heavy pollution, especially from Porthleven (p. 57). Further examples of graded effects of damage are given, and then follow data collected from places where there was oil but no use of detergent. A summary of the conspicuous effects of heavy pollution is based on many observations on these and other sites (p. 67). Observations connected with

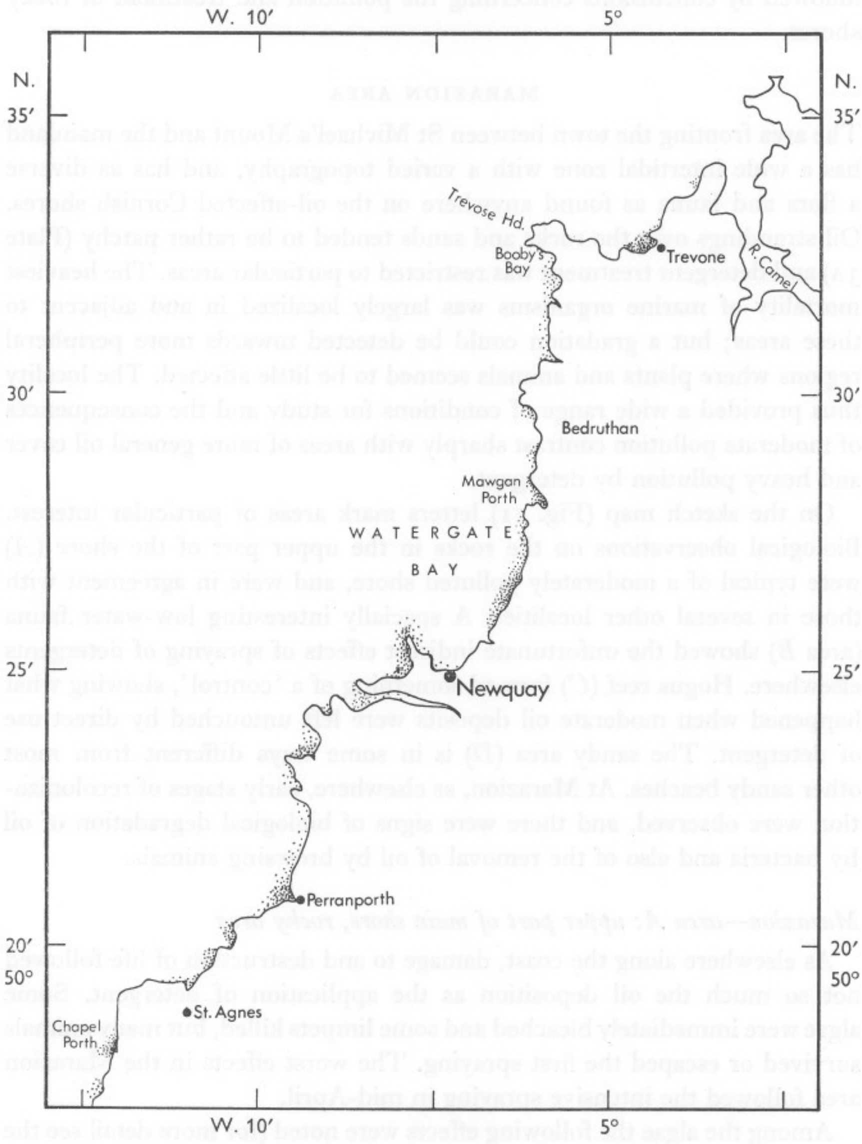


Fig. 10. The coast northward of that shown in Fig. 9.

the recovery and recolonization phase of rocky shores are summarized, followed by conclusions concerning the pollution and treatment of rocky shores.

MARAZION AREA

The area fronting the town between St Michael's Mount and the mainland has a wide intertidal zone with a varied topography, and has as diverse a flora and fauna as found anywhere on the oil-affected Cornish shores. Oil strandings over the rocks and sands tended to be rather patchy (Plate 3A) and detergent treatment was restricted to particular areas. The heaviest mortality of marine organisms was largely localized in and adjacent to these areas; but a gradation could be detected towards more peripheral regions where plants and animals seemed to be little affected. The locality thus provided a wide range of conditions for study and the consequences of moderate pollution contrast sharply with areas of more general oil cover and heavy pollution by detergent.

On the sketch map (Fig. 11) letters mark areas of particular interest. Biological observations on the rocks in the upper part of the shore (*A*) were typical of a moderately polluted shore, and were in agreement with those in several other localities. A specially interesting low-water fauna (area *B*) showed the unfortunate indirect effects of spraying of detergents elsewhere. Hogus reef (*C*) formed something of a 'control', showing what happened when moderate oil deposits were left untouched by direct use of detergent. The sandy area (*D*) is in some ways different from most other sandy beaches. At Marazion, as elsewhere, early stages of recolonization were observed, and there were signs of biological degradation of oil by bacteria and also of the removal of oil by browsing animals.

Marazion—area A: upper part of main shore, rocky area

As elsewhere along the coast, damage to and destruction of life followed not so much the oil deposition as the application of detergent. Some algae were immediately bleached and some limpets killed, but many animals survived or escaped the first spraying. The worst effects in the Marazion area followed the intensive spraying in mid-April.

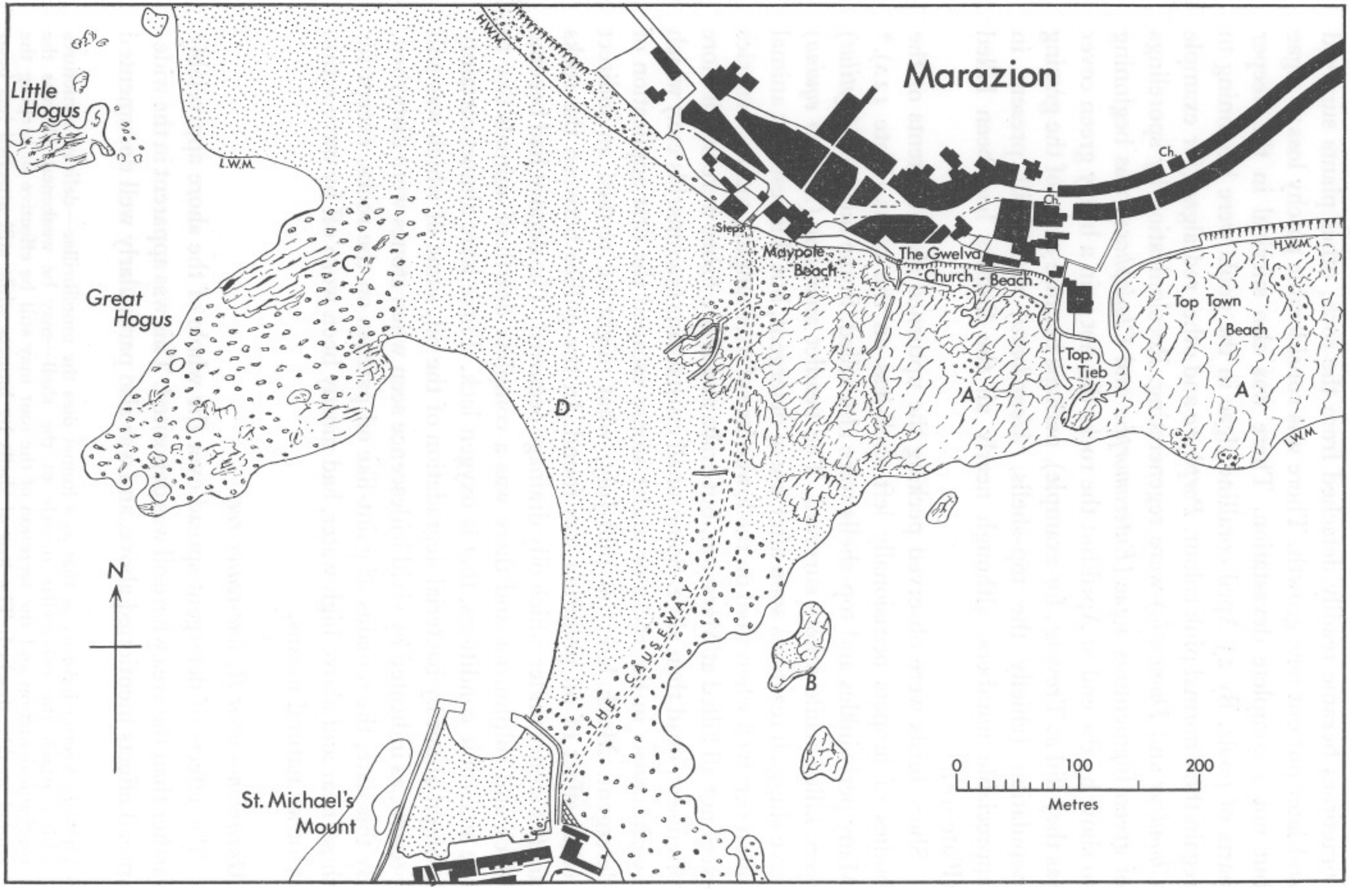
Among the algae the following effects were noted (for more detail see the account of algae at Porthleven, p. 58). Green filamentous algae were rapidly bleached as were encrusting coralline algae, particularly at the rims of pools where the detergent formed a toxic surface layer. Oil tended to cling to the thin fronds of laver (*Porphyra*), which after a few weeks became brittle and was washed away. The fucoids did not at once show the full extent of the damage; tips were soon discoloured (Plate 15C), later they often lost the blade of the frond, to be reduced to a midrib or stipe, and even this sometimes became readily detached from the rock; other plants survived and later put out new growth. There was considerable patchy loss of algae but not a complete devastation. There was also survival in the deeper parts of pools. By 23 April coralline algae in the pools were beginning to regain their normal pink colour. *Porphyra* and other red algae (for example *Chondrus* and *Dumontia*) were regenerating. Recolonization by sporelings of green filamentous algae (*Enteromorpha* and *Cladophora*) was beginning to show by the end of April but the rocks did not gain a heavy green cover (as they did at Trevone, for example), perhaps because some of the grazing population (chiefly the top-shells, *Monodonta*) were still present in appreciable numbers, although nearly all the limpets had been killed (Plate 9A).

Shore birds were observed pecking the upturned shell contents or the bodies of limpets occasionally left shell-less on the rocks (Plate 12A).* Many periwinkles and top-shells were also killed. Some mussels (*Mytilus*) were killed while others survived. The beadlet anemone (*Actinia equina*) gave sluggish reactions soon after use of detergent, but this resistant animal often survived when sited on the lower face of overhanging rocks. Barnacles were not all killed at Marazion, but crabs and shore fishes were much more often seen dead than alive. Some small crustaceans (gammarids etc.) which live in cracks in the rocks or under stones escaped the first application of detergent. Much later, in mid-July, what might be termed an indirect lethal effect of oil pollution was found. In the gullies between the rocks are flat stones under which oily drainage occurred. The deposit had become black and sulphurous and there was a complete dearth of animals due to the anaerobic conditions, that is oxygen lack. These were almost certainly brought about by bacterial degradation of the oil, some of which was still present, as indicated by vivid iridescence seen when stones were disturbed. By this date, the remains of paint-like oil patches on the rocks, except for those near and above high water, had mostly been worn off by wave action or other natural means.

Marazion—area B: low-water reef

The effects of detergent spread over the whole of the shore appreciably farther than the area where oil was deposited. This was apparent in the widespread effects mentioned above, and was also particularly well documented

* Dr Vera Fretter informs us that as a limpet dies the tonofibrillae—delicate structures which attach the columellar muscle to the shell—may be weakened whereas the mechanical suction and the secretion of the foot may still be effective in keeping the animal weakly attached. The loss of shells by limpets while still attached has been observed when they die in aquaria. It is not a specific effect of the detergent.



Marazion
H.W.M.
Ch.
Ch.
Little Hogus
L.W.M.
Steps
Maypole Beach
The Gwelva
Church
Beach
H.W.M.
Top Town Beach
Top Tieb
A
A
L.W.M.
C
Great Hogus
D
B
THE CAUSEWAY
N
0
100
200
Metres
St. Michael's Mount

Fig. 11

Table 6. *Summary of main events at Marazion*

(1) Oil deposited chiefly near high-water springs and in splash zone 25/26 March. Strong smell from volatile fraction of oil, which was ginger brown on arrival, gradually turning black on sea walls.

(2) First use of detergent 27 March chiefly at the town end of the Causeway, near the Top Tieb harbour, and between them, i.e. Maypole and Church beaches, also under the Mount.

(3) Lesser deposits of oil in splodges at high-water neaps during next few days (see Plate 6A, Maypole beach, 1 April). Subsequent tides (neaps) left thin layer of oil, which could be found over wider mid-tide zone.

(4) Widespread thin coating of oil on rock platform below the Gwelva and on Top Town Beach and in pools east of Causeway, 12 April. This oil was more viscous and mahogany-coloured. Probably some which had come out of emulsion after treatment elsewhere and was now redeposited.

(5) Moderate use of detergent on upper part of shore during mid-April; this moved most of the recent oil, some patches remained and there was still some buried in the sand (Maypole, Church and Top Town Beaches).

(6) Elements of oil–detergent mixtures were reappearing daily on the shore and on 26 April brown oil slicks with a detergent smell were close offshore.

(7) Secondary pollution after gale in early May (Plate 3B) on a long stretch of previously uncontaminated beach to west of area covered by map.

(8) Very heavy and extensive kelp (torn weed) deposited on sand (Maypole Beach to Great Hogus) by same gale, a normal seasonal occurrence.

(9) First faint signs of recovery, some return of pink colour to pools and of recolonization by very short green algae on rocks which lacked their normal browsing fauna, observed during last week of April.

(10) General greenness, especially on ungrazed rocks early July.

(11) Practically all oil removed by natural means from Hogus Rock by mid-July.

(12) Beach in full use by holiday makers, oblivious of such traces of oil as remain.

(13) Buried oil upshore being released by spring tides of larger amplitude, resulting in much stray oil and frothy oil seen in sea, 9 August.

(14) Abundant young fucoids replaced green weeds in early autumn in area *A*. Neither present in area *C*.

Caption for Fig. 11 opposite.

Fig. 11. Map of Marazion Beach showing places referred to in text. *A*, Upper and mid-tide rock platform with pools (see nos. 2, 4 and 5 of Table 6). *B*, Low-water reef, rich faunistically, no direct use of detergent, but showing serious indirect effects. *C*, Hogus Reef—patches of oil deposited 25/26 March, never any direct use of detergent, browsing fauna survived and helped in oil removal. *D*, Sand, some fauna affected temporarily at low level by detergent drifting with the tide. Buried oil at top of beach.

in the damage done to the low-water reef zone in the bay west of the Causeway, accessible only at very low tide. This area had been examined by M.B.A. scientists on 28 February and a rich and abundant fauna recorded. On 28 March it was free of oil. But by the time it was visited on 28 April, after the main period of detergent application upshore, a considerable change had occurred. Of the previously abundant snakelocks or opelet anemones (*Anemonia sulcata*) there were now very few and those present were only half expanded, with column and tentacle shrunken and not showing typical turgidity. The habitat had been especially interesting and rich in lucernarians, delicate little stalked jellyfish which live attached to weeds. Four species, one of them present in thousands, had been seen in February, but now they had all completely disappeared. Many of the algae, including the oarweed, a *Laminaria*, were unhealthy, with large irregular bleached patches of damaged tissue. The red weeds *Chondrus crispus* and *Calliblepharis jubata* were unusually pale or showed bleaching or abnormal red discoloration of the fronds. On this occasion a small colony of the very local hermit crab *Clibanarius misanthropus* was found in a pool. Among seven specimens there was a shell containing a dead individual. In natural conditions shells containing dead hermit crabs are never found. This example was probably a detergent victim.

Although there had been no oil deposited on this site and no direct application of detergent, polluted water could not have failed to have reached it, and direct visual evidence of this was obtained when it was noted on 28 April that an oily film had accumulated against all windward facing rock projections.

Marazion—area C: Hogus Reef

Great Hogus is a reef cut off from the shore at about half tide. The original oil-fall, in discontinuous patches, had been moderate (up to approximately ½ cm thick) and confined to the northern end of the reef (area *C*). During the succeeding weeks the rock received only insignificant

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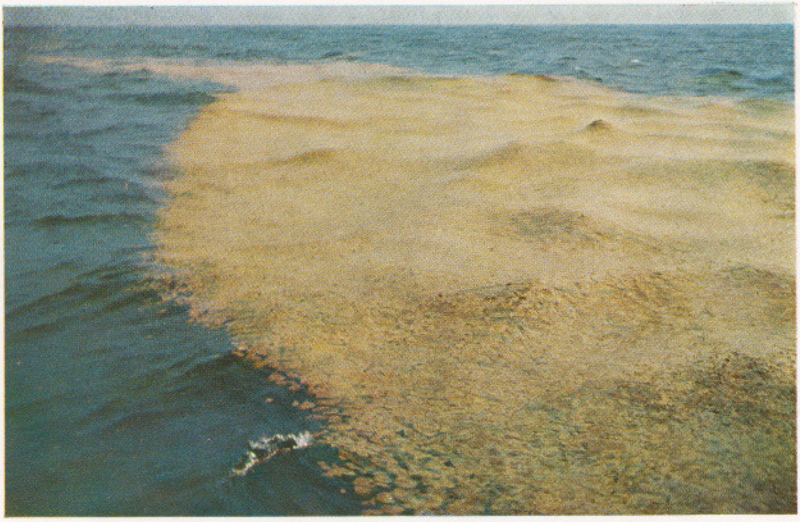
PLATE 7

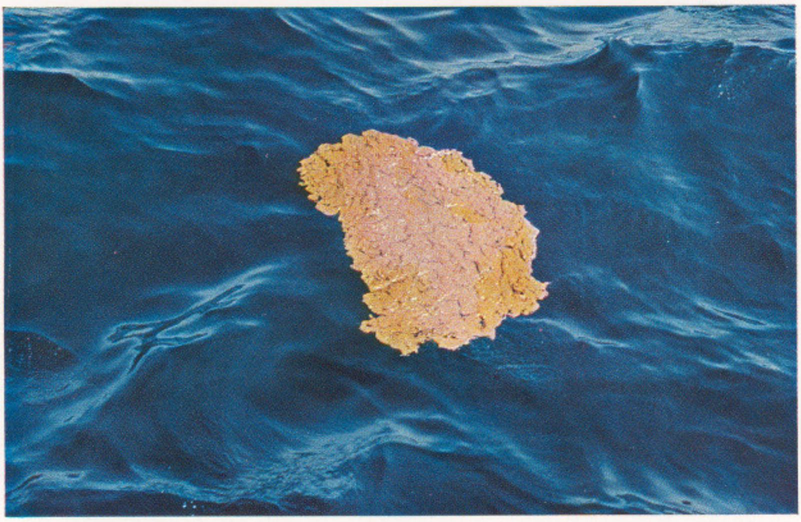
A, Oil emulsion on the sea surface about 20 miles north of Ushant, 12 April. **B**, Isolated patch of oil emulsion, about 1 metre across, floating a few miles south-west of Ushant at 48° 22·6′ N., 05° 16′ W., 18 May. **C**, Bay of Biscay, west of Pointe du Raz, 47° 22·6′ N., 05° 20·5′ W., 12 May. Part of a dense patch of untreated oil emulsion, some 100 square metres in area and perhaps 15 cm thick.

PLATE 8

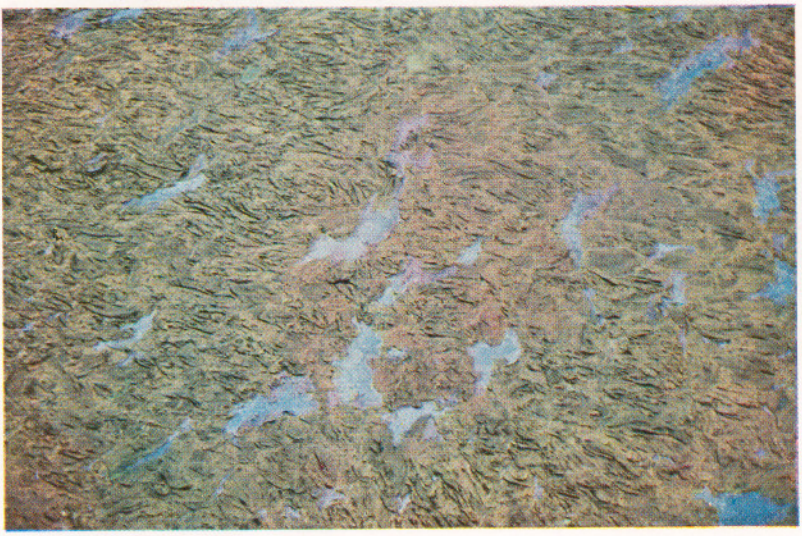
A, Gunwalloe Fishing Cove, 30 March. Breaking wave heavily loaded with oil emulsion. **B**, Porthmeor Beach, St Ives, 28 March. Beach polluted with untreated oil, deposited by receding tide, prior to any cleansing operations. In the foreground the reflection of the sky on the oil makes it appear blue.



A



B



C

(*Facing p.* 48)

PLATE 8

A

B

additions of oil and detergents were never directly applied to it. It is probable, however, that the reef would on occasion have been washed by sea water containing detergent in low concentration when beach-cleaning operations were being carried out on the upper part of the tidal zone, some 300 metres distant.

Throughout the survey the absence of dead plants and animals in area *C* was in strong contrast to area *A*. On 28 March the flora and fauna seemed but little affected. Limpets which lay under a thin coating of oil were alive (Plate 9B) and reacted to touch, and some grazing tracks of top-shells through the oil were observed. Some of the limpets could be detached more easily than usual, and many of the top-shells (*Monodonta lineata*) had retracted within their shells and were remaining inactive at the bottom of pools.

Five days later the gastropod population of limpets, top-shells, periwinkles and dog-whelks, as well as small crustaceans, appeared to be entirely normal. Limpets gave their normal adhesion reaction, and *Monodonta* which had been taken to the laboratory on 28 March were now fully active. Oil patches were now somewhat thinner and darker. There was no evidence that any deaths of limpets or *Monodonta* had occurred as a result of the oil deposit. Indeed later in April limpets with their shells and the underlying rock still oil-coated had survived unscathed. Whatever indirect effects may have occurred temporarily during the height of the cleansing activities in mid-April, they had left no traces by 5 May, and limpets which had previously been photographed on a rock (Plate 9B) were all in their original seats. A hardened film of oil still covered shells and rocks seeming to offer inhospitable feeding conditions, for their usual food supply of algae and diatoms was smothered. If these could grow at all on the hardened surface of the oil, they were too scarce to be detected. That some of the limpets had in fact been grazing could be seen from the small partially cleaned areas around them (central limpet in Plate 9B; see also Plate 9C). A small boulder with four limpets attached was taken to the laboratory. These limpets had already cleaned a small area around themselves (cf. Plate 17B) and they continued to feed, browsing on the oily deposit and producing faeces containing oil. The presence of benzene-ring compounds in the faeces was demonstrated chemically. Similar observations were made on top-shells (*Monodonta*) and limpets (*Patella*) living on oily rocks at Perranuthnoe. They too produced oily faeces. The gut contents contained much brown-coloured matter, but the oily part could be distinguished by its solubility in benzene and by its taking up Oil Red O. The proportion of oil intake by these animals was estimated as about 20–30 per cent in *Patella* and 5–50 per cent in *Monodonta*.

When Hogus Reef was re-visited on 19 July the population of limpets and *Monodonta* was fully as abundant as before. It was very difficult to find an empty limpet seat (some always occur on normal shores). Practically the only traces of oil, now black, which could be found were on some of the *Monodonta* and limpet shells; the rocks and barnacles were clean. The oil may have been removed to some extent by wave action, but the distribution of the remaining traces is strongly suggestive that browsing played an important part in the cleaning, removing oil from the surfaces and binding it into small packages of faeces. As such, among other detritus, it would be readily accessible to bacterial oxidation. It is thus seen that the normal browsing fauna, left unkilled by detergent, can be effective cleaning agents, at least on rocks not too heavily oiled which are under water for some part (in this case about a third) of the tidal period. These observations confirm those made by George (1961) at Milford Haven.

Marazion—area D: sandy area

These sands differ in some ways from the usual Cornish sandy beaches which are of clean and often coarse sand (see Perranuthnoe fauna). A great deal of storm-torn seaweed is washed up here every year and much carted away by farmers; the 1967 kelp crop was normal and not considered by them to have been influenced by recent pollution. The sand here must receive much algal detritus and is greyish as a result; it also contains more silt than most beaches, thus making for stability. It is thus able to support an abundant polychaete worm population which was examined on 28 April. On this date there were only faint traces of detergent in the form of films on the surface of standing water near low-tide mark but no smell of detergent could be detected in the sand itself. The fauna within the medium-grade sand of which this beach is composed did not appear to have been affected. At about mid-tide level were bristle-worms, including lugworms (*Arenicola*), *Nerine* spp. and *Glycera convoluta*, all of which had survived such indirect effect of detergent as they may have encountered. *Arenicola* could have cut itself off from polluted water by ceasing to ventilate its burrow for a time. A single specimen of a sphaeromid crustacean and several of the bivalve mollusc *Venus striatula* were also found at this level. The *Venus*, though found on the surface, were apparently healthy.

At a low level on the same shore on 28 March, four specimens of the razor-shell *Ensis siliqua* had been found: three were protruding from their burrows and one was lying moribund on the sand (Plate 20A). This quite abnormal behaviour was attributed to effects of detergent spraying the previous day; two of the razor-shells recovered at least temporarily when put in clean sea water in the laboratory. As a result of the use of detergent there was considerable destruction of *Ensis siliqua* in Marazion Bay during April (see diving record, p. 113). Large numbers of recently dead razor-shells were found thrown up in the drift line—gulls and a pair of crows were seen feeding on them. The sensitivity of this species to detergent was borne out elsewhere (Porthleven, Watergate, etc., and see toxicity tests, p. 137). As well as *Ensis*, the bivalve *Mactra stultorum* was also involved to some degree, the greatest number of empty valves being observed under the Mount on 16 April.

Another animal showing the effects of detergent, as elsewhere, was the heart-urchin, *Echinocardium cordatum*. The fragile dead tests do not normally remain long on the shore. Occasional ones were found during April, but towards the end of the month they were quite unusually numerous. This evidence of sensitivity is in agreement with the findings in the sublittoral zone at Porthleven (p. 140, and Plate 24). The last three animals mentioned are essentially shallow-water species, and as such they are probably much more sensitive to adverse factors (such as detergents) than are strictly intertidal species. The reported survival of many of the shore-living species may therefore give a false impression of the tolerance of marine organisms as a whole to potential poisons.

Razor-shells would be unable to close up completely as, for example, can mussels, which are therefore able to survive moderate doses of detergent (see p. 69).

TREVONE

The value of the Trevone survey derives mainly from the detailed knowledge which we had beforehand of the shores of this region and from the reliance that could therefore be placed in making surveys within this locality on 'before and after' comparisons. Trevone (Newtrain Bay to Porthmissen Beach) received a heavy oil pollution on 29 and 30 March (Fig. 12). The oil was said to be more than half an inch deep over all the rocks, with some patches of similar depth on the sands of Porthmissen Beach. Elsewhere there was a thin layer, and at first none at high water. When the first brief survey was made on 10 April, the shore had been subjected to detergent treatment for four days. There was a film of oil on the rocks at high-water neaps, and mixture of sand and oil up to a foot thick between high water of neaps and springs where spraying was in progress. A thinner film of oil was still present at the mid-tide level and on the seaward reefs near the sewer outlet. Water samples from pools on the lower part of the shore were not toxic, but a sample from a pool at high-water neaps, close to spraying operations, contained oil, about 60 per cent fresh water and (by bioassay) 700–800 ppm of detergent.

The only organisms in the vicinity that seemed unaffected at the time were the two common barnacles (*Chthamalus stellatus* and *Balanus balanoides*), mussels and fucoid algae. Some red algae were dying, 50 per cent or more of all three species of limpets had been killed, while most, if not all, top-shells, periwinkles and dog-whelks were already dead. No anemones

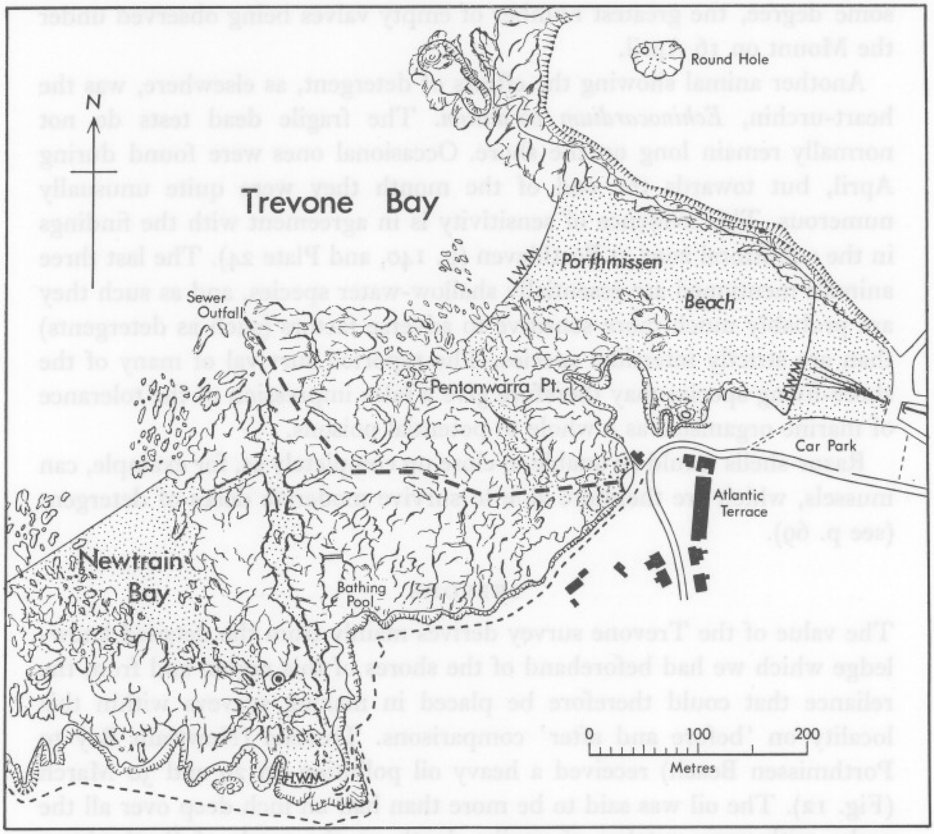


Fig. 12. Map of heavily oil-polluted and detergent-treated rocky and sandy shore at Trevone. – – –, Approximate line of sewer pipe. ⊙, Position of photographs reproduced in Plates 10B and 11 in Newtrain Bay.

were seen (alive or dead), nor intertidal fish, but among dead animals collected were the worm *Perinereis cultrifera*, the crabs *Carcinus maenas*, *Cancer pagurus*, *Porcellana platycheles* and the rare hermit crab *Clibanarius misanthropus*. Trevone was the only known locality for the latter on the north coast.

On 15 April firemen were still hosing detergent in fresh water over the rocks and sand of the rocky shore faced by Atlantic Terrace (Plate 10A), and the sand here was full of oil. Porthmissen Beach, the main sandy beach adjacent to the car park, which had also been affected badly in places, was still being treated. Streams of fresh water mixed with detergent were flowing down it and a few workers were turning over the sand. But the main work had been done and the sand looked clean, though smelling strongly. The rocks to the west around the bathing pool and in Newtrain Bay had already been treated, but over some areas a thin film of oil remained.

Much biological damage had obviously been done to the mid-tidal region extending roughly from high- to low-water neaps, the region where the most intensive spraying had taken place. Rocks were denuded of molluscs and detergent-filled pools had only dead algae in them. Drifts of limpet shells, with and without soft parts inside, and separated soft parts, were washed with other molluscs into gullies, also one or two dead fish, dead crabs and a dead *Nephthys* worm. *Patella aspera* with flesh inside, and large tufts of *Fucus serratus* growing on these limpet shells, had here been washed up from lower levels or from pools. Around the bathing pool and near the Newtrain gully, where the oily film on some rocks perhaps indicated that spraying had been less intense, the damage seemed to be less severe. Even so, most limpets were easily detached by hand and the shells often lifted cleanly away from the soft parts on the rock (Plate 12A) (see p. 45). Among the dead algae found on 21 April were the green *Ulva* and red *Gracilaria* and *Ceramium*.

On 23 April, some days after the cessation of spraying, all the loose limpets had gone (Plate 12B) and only a few seated in sheltered crevices and on rocks still thinly covered with oil remained firmly attached. Everywhere many thousands of fresh clean limpet seats were clearly visible. Some examples of each of the top-shells *Monodonta lineata* and *Gibbula umbilicalis* survived, a mere remnant of their former abundance. Beadlet anemones, *Actinia equina*, although reduced in number, were fairly plentiful in pools and on oiled rocks in the Newtrain and bathing-pool regions. Here also the deeper pools contained *Bifurcaria bifurcata*, *Corallina officinalis* and other algae in apparently normal condition. Only one snakelocks anemone, *Anemonia sulcata*, usually common, was seen, unattached and looking sickly. Mussels on rocks near the sewer outfall, where a little oil was present, were as abundant as usual and alive, but scarcely any specimens of the dog-whelk *Nucella lapillus*, which in this area feeds mainly on mussels and is normally very common, could be found. Inactivated dog-whelks were lying loose and empty shells were seen (Plate 15B). Almost all the limpets had gone, leaving clean seats everywhere on the rocks. This visit coincided with low water of a good spring tide, and it was encouraging to find all the plants and animals at the lowest levels more or less normal. Underneath stones at the lower end of Newtrain gully were good growths of the ascidian *Botryllus* and, among other animals sheltering beneath stones were the crabs *Portunus puber*, *Carcinus maenas* and young *Cancer pagurus*, and some shore fishes including blennies and several *Lepadogaster lepadogaster*. The starfish *Asterina gibbosa* was present but no living sea-urchins (*Psammechinus miliaris*) were seen, though dead ones were found washed up in the gully. Similarly at the highest shore levels on the east side of Newtrain Bay, where it seemed that oil and detergent had not penetrated, there was a normal fauna with *Patella vulgata*, *Littorina saxatilis*, *L. neritoides* and *Chthamalus stellatus* all alive.

The visit on 29 April confirmed this general picture of a devastated middle shore flanked by relatively unaffected upper and lower regions. Individual *Actinia* and *Monodonta* which had been specially noted previously were still in the same positions, and on the walls of the gully some patches of the sponges *Halichondria panicea* and *Hymeniacidon perlevis* survived. The floor of the Newtrain gully, however, contained moribund *Gibbula umbilicalis*, *Monodonta lineata* and *Patella vulgata* amid a drift of shells.

Certain shallow rock pools which had often been examined and photographed had been known to contain *Actinia equina*, *Anemonia sulcata*, *Gibbula*, *Patella*, *Littorina littorea*, *Nucella*, *Corallina*, *Lithophyllum*, tufts of *Enteromorpha* and other seaweed. Small crabs, occasional prawns and small blennies were also among the usual inhabitants. After the detergent treatment, these pools for several weeks contained only beadlet anemones, *Actinia*, tufts of young *Bifurcaria*, *Corallina* and one or two other small algae. A microscopic slimy brown alga and diatoms began to coat over the apparently dead encrusting calcareous algae (*Lithophyllum*) and limpet scars. By July very young fishes and tiny crabs were hiding in the weed and one fair-sized gemmed anemone (*Bunodactis verrucosa*), one adult *Gibbula umbilicalis* and one *Littorina littorea* were seen.

In August 1966 a small patch of rock in Newtrain Bay, situated at roughly mid-tidal level, had been photographed to show the fauna (Plates 10B, 11A). This patch approximately 45 × 35 cm. set within a sloping rock face of about 100 square metres area was readily identifiable by the rock structure and photographed again on 23 April 1967 (Plate 11B). The rock still had traces of oil on it but had undoubtedly been heavily sprayed, though tufts of coralline algae, such as that shown in the photographs, were still soaked in oil and were dead. The single *Monodonta* shown in the photograph of 23 April was alive and in the same place on 29 April. The detergent treatment had almost completely cleared the rock of living organ-

Table 7. *Animals in areas photographed at Trevone* (Plates 11 A, B)

Species	Number present August 1966	Number present 23 April 1967
Actinia equina	1	0
Chthamalus stellatus	Many	Few (dead?)
Mytilus sp.	2 or 3 very small	1
Patella vulgata	24 medium and small	0
Monodonta lineata	11	1
Gibbula umbilicalis	1	0
Littorina saxatilis	4	0

isms and the two photographs are typical of the whole area before and after the spraying. Table 7 lists the animals shown in the two photographs (Plate 11 A, B).

On a further visit on 14 May 1967 a count was made of the surviving organisms on this particular rock face of approximately 100 square metres. There were 41 *Actinia*, 34 *Monodonta*, 2 *Patella*, a few *Gibbula*, a few small *Mytilus*, no *Littorina*, and it was almost cleared of acorn barnacles. The whole rock face looked strangely bare compared with its normal appearance.

The mussel-covered rocks near the sewer outfall, once drab-coloured, had a greenish look, due to young growths of *Enteromorpha* and *Ulva*, which mingled with brown growths of *Ectocarpus* and diatoms. These growths covered rocks and mussels and were particularly well developed in pools and all wet places.

The rocks at Pentonwarra Point which had been intensively treated with detergent, but had not been examined previously, had many areas with freely hanging byssal threads showing where mussels had been killed and had fallen off (Plate 15 A). Acorn barnacles had also been extensively destroyed, and the rocks were almost bare of life.

On 14 May sandy patches opposite Atlantic Terrace were still extremely oily with a strong smell, in Newtrain gully there was only a slight smell, less than before, and similarly on Porthmissen beach. Here the sand looked clean on the surface, but digging in the cove on the west side revealed a dark grey oily layer of sand having a strong smell of detergent. For the significance of this see page 81.

The rocky shore at Trevone was reinvestigated on 9 June. A few patches of hardened oil were seen around mid-tide level, and some small (2 cm in diameter) spots of new, soft oil were present at high water. The smell of detergent appeared to come mainly from the grassy cliff top where detergent drums had stood, but there were distinct traces of it in the coarse sand opposite Atlantic Terrace at the highest level of the tides.

Most of the fucoid algae had survived the cleansing treatment, and some re-growth of *Corallina* had begun in the pools. The overall effect, however, was of greenness, due to the unprecedented growth of *Enteromorpha* which had developed freely in the absence of limpets and other grazing molluscs. The growth was heaviest at low-water and mid-tide level, with some scattered patches above this level.

The few surviving limpets (less than one per 10 square metres) could easily be recognized from a distance, as they each occupied 'clearings' in the growth of green weed (Plate 17A). *Monodonta* was the commonest surviving mollusc, but a few *Gibbula umbilicalis* and *Nucella* were present. The beadlet, *Actinia*, was the only anemone observed. Settlement of young of the barnacle *B. balanoides* was quite heavy, and had continued after the cleansing operations as shown by their occurrence on limpet seats.

A month later on 9 July *Enteromorpha*, and in the lower places *Ulva*, were much further developed. An unusual carpet of vivid green covered almost the whole of the rocky shore from about half-tide level downwards (Plate 16B). Nothing like this has been seen here before (Plate 16A). Surviving mussels on rocks near the sewer outfall had almost disappeared beneath the green weeds growing on their shells. On the tops of the reefs near the sewer outfall the green algae were replaced by purplish-brown *Porphyra*, growing just as abundantly on rocks and mussels. Here and there a few solitary limpets or *Monodonta* still kept clear little areas of rock (Plate 17A).

Many of the oil film patches which had remained on high-level rocks after cessation of spraying had now gone, destroyed by natural agencies. Others were breaking down; they contained tiny grains of sand and could readily be rubbed off, often without staining the finger.

On this sunny July day Porthmissen Beach was crowded with holiday-

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PLATE 9

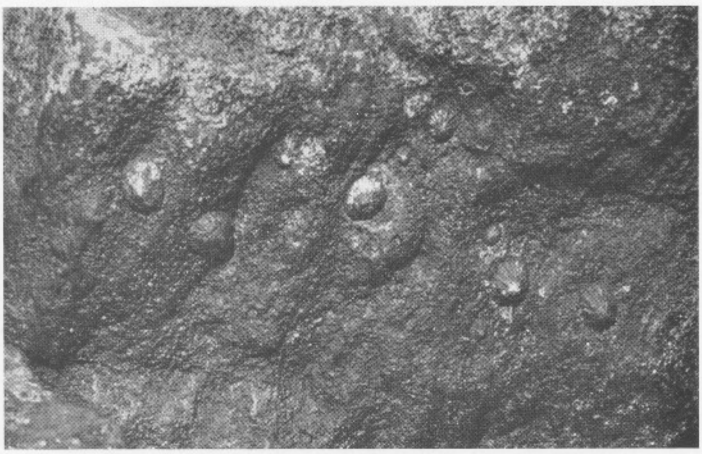
A, Marazion, Church Beach, 5 May. Treated rocks, on which all limpets had been killed, but top-shells (*Monodonta lineata*) had largely survived. Old limpet seats show as oval pale areas. **B**, Marazion, Church Beach, 5 May. Hogus Rock. Resident limpets surviving in oiled band, where the rock had not been treated with detergent. Note that the shells of the limpets are wholly or partly covered with oil. Oil has been grazed from the rock-face around the limpet in the centre of the picture. Others show it to a lesser extent. **C**, Limpet tooth-marks in a film of oil on a vertical rock-face at Trevone, 9 June. This photograph shows how the natural grazing activities of limpets will help to cleanse a rocky shore, providing the animals are not killed or damaged by detergents.

PLATE 10

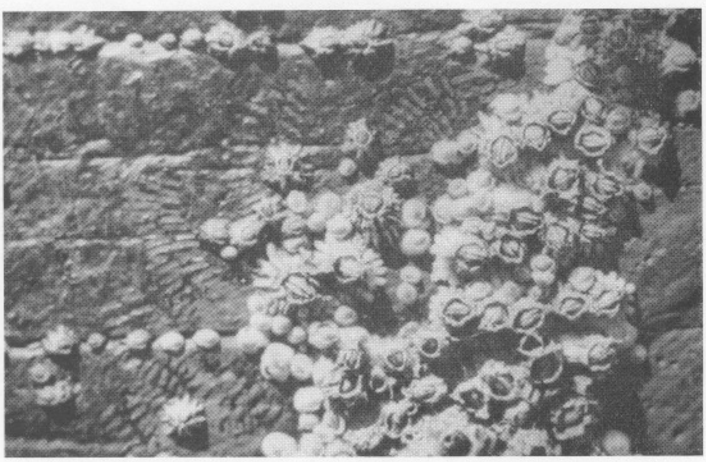
A, Spraying detergent on rocks and sandy patches opposite Atlantic Terrace, Trevone, 15 April. Note the white emulsion of detergent in the rock pools. At extreme top right men are spraying from Pentonwarra Point. **B**, Sloping rock-face in Newtrain Bay, Trevone, on which a count of surviving organisms was made on 14 May (p. 55). The white rectangle marks the site of the photographs reproduced in Plate 11.

PLATE 9

A



B

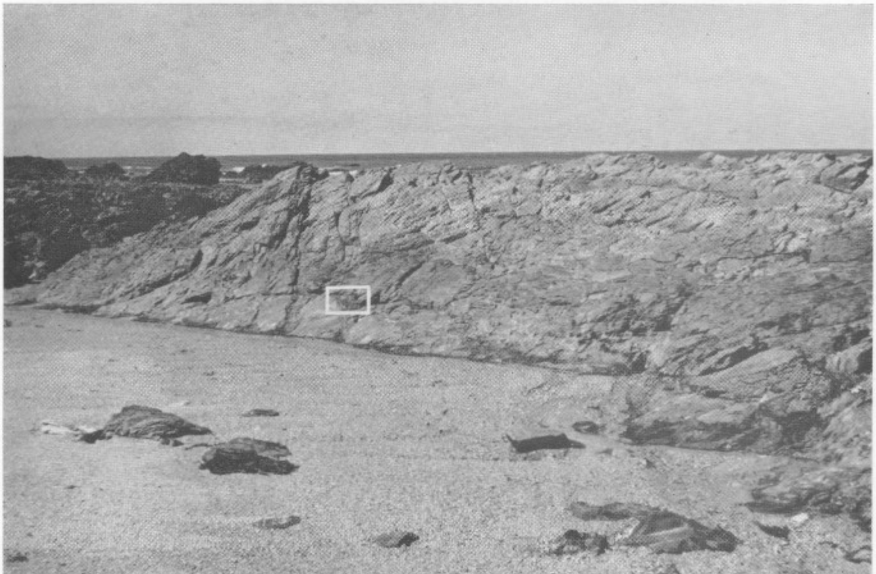


C

(*Facing p.* 56)

PLATE 10

A



B

PLATE II

A

B

A

B

(*Facing p.* 57)

makers and children were happily playing even in the still stained and still slightly smelly sandy patches opposite Atlantic Terrace. For them the shore was back to normal.

RELATIVE SENSITIVITY OF DIFFERENT SPECIES—PORTHLEVEN REEF

The field aspects of this problem were best studied at a place where the first visits could be paid while spraying was still in progress. The badly polluted area of Porthleven Reef (Fig. 17) was therefore chosen.

The first oil came in on 25/26 March on a high spring tide with a gale and was thus thrown about 20 feet up the cliffs to the thrift and turf. Lichens were largely smothered under this persistent blackening deposit. The bulk of the oil was near the base of the cliffs but on subsequent days much more oil was deposited—some of it probably being oil that had been washed out of the nearby harbour (see Plate 5A, B)—so that nearly the whole reef had a slippery film of oil. Detergent was applied mainly in the higher regions of the shore, the most heavily treated area being between the monument on the cliffs and the harbour entrance (a distance of $\frac{1}{2}$ km.) where it is estimated that a total of about 35000 gallons of detergent were used in the eight days between 4 and 12 April and on 25 and 27 April. Sea water and not fresh water was used to hose down these rocks after spraying, thus simplifying the understanding of the cause of mortality. The shore here consists of a rock platform gently sloping from above mid-tide level to below low water. It is crossed by deep gullies running seawards from the base of the cliffs. Some of the gullies consist largely of a series of pot-holes but others contain loose rocks and patches of gravel. Between the gullies there are some rock pools and individual pot-holes. The gullies were very efficient in transmitting concentrated detergent from the upper part of the shore to the low-tide region.

PLATE 11

A, A small area of mid-tidal rock at Newtrain Bay, Trevone, photographed in August 1966 to show the typical fauna of limpets, top-shells, etc. **B**, The same area of rock photographed on 23 April 1967 after treatment with detergent to remove oil. One top-shell and one small mussel (indicated by arrow) survive (see Table 7, p. 55).

PLATE 12

A, Mid-tide limpets at Newtrain Bay killed by detergent. Shells have been lifted off two of them leaving their soft parts *in situ* on the rock. Photographed 15 April, some days after cessation of spraying and typical of innumerable neighbouring limpets at that time. **B**, Scars of the same limpets eight days later. Photographed 23 April and typical of many rocks of the mid-tidal region after the washing away by the sea of limpets killed by detergent. Limpets on oil-coated rocks not detergent treated survived not far away.

The algae were most seriously damaged by the detergent at the higher levels on the shores. A high proportion of the *Porphyra umbilicalis* plants growing on the higher rocks were killed; so also were the *Enteromorpha* plants in the high-level pools. *Corallina*, with its associated epiphytes, and the encrusting calcareous algae on the bottom of these high-level pools were also killed (Plates 15C, 18A), but at mid-tide only their tips and some of their epiphytes were killed, while near low water the *Corallina* and its epiphytes appeared healthy. In the mid-tide pools the *Bifurcaria* and *Cystoseira* plants were either killed or had the young growing apices destroyed.

The fucoid vegetation on the rocks and its associated algal undergrowth was also more seriously damaged or destroyed at the higher levels. *Fucus spiralis* appeared to be more easily killed by the detergent than either *F. vesiculosus* or *F. serratus*. Even so, dead plants of all three species were recorded and a high proportion of the remaining fucoids higher on the shore had their young growing apices destroyed. In other areas *Pelvetia canaliculata* reacted to the detergent in a similar way to *Fucus spiralis*. *Ascophyllum nodosum*, rather local on these exposed shores, appeared to show fewer ill effects. At the lower levels on the shore the *Fucus vesiculosus* and *F. serratus* appeared healthy and the receptacular tissue was apparently undamaged.

Some of the algal species growing on the rocks beneath the fucoids appeared to have suffered little except some plants of a few of the species growing at the higher levels which had received the concentrated detergents.

The species of algae least affected by the detergent were: *Ahnfeltia plicata*, *Chondrus crispus*, *Cladostephus spongiosus*, *Dilsea carnosa*, *Furcellaria fastigiata*, *Gigartina stellata*, *Kallymenia reniformis*, *Laurencia pinnatifida*, *Polyides rotundus*, *Pterosiphonia complanata*, *P. thuyoides*, *Rhodymenia palmata*, *Schizymenia dubyi*, *Scytosiphon lomentarius*.

On the other hand many of the plants belonging to the following species had either been killed (bleached or tips bleached) or appeared very unhealthy: *Acrosiphonia arcta*, *Acrosorium uncinatum*, *Apoglossum ruscifolium*, *Callithamnion* spp., particularly *C. tetricum* on rock-faces, *Ceramium* spp., *Cladophora rupestris*, *Cryptopleura ramosa*, *Delessaria sanguinea*, *Dictyota dichotoma*, *Ectocarpus* spp., *Gastroclonium ovatum*, *Gracilaria verrucosa*, *Halurus equisetifolius*, *Hypoglossum woodwardii*, *Jania rubens*, *Laurencia hybrida*, *Lomentaria articulata*, *Membranoptera alata*, *Plocamium vulgare*, *Plumaria elegans*, *Polysiphonia* spp., *Ulva lactuca*. Lower on the shore, however, apparently healthy plants of most of the above species could still be found.

At low water in the *Laminaria digitata* zone the fronds of many of the

Laminaria plants were completely bleached, or green in colour, and the reproductive parts of their fronds had been killed, but a large number of plants still appeared healthy and bore living reproductive tissue. The young *Himanthalia* plants, *Cladostephus verticellatus*, *Furcellaria fastigiata*, *Phyllophora crispa* and *P. brodiaei*, all appeared to be in healthy condition.

It will be seen from this short description that the damage sustained by the algae has been extensive. For any one species (for example, *Corallina*) there is a gradation of effect, damage being most severe at the higher levels of the shore where the toxic concentration was greatest. It can also be seen that not all the species are equally sensitive: thus the very delicate filamentous membranaceous red algae seem to be particularly susceptible and in some cases have been completely destroyed.

A gradation of effect and variation in sensitivity to the detergent is also exhibited by the animals of the reef. Although there was much oil on the shore when this reef was seen on 30 March, the animals did not appear to have been affected. However, when the reef was again visited on 7 April, three days after detergent treatment started, most of the animals were dead or moribund. On subsequent visits on 11, 26 and 28 April far fewer dead animals were found because many had been washed along the gullies into deeper water or had been eaten by birds. This removal of dead animals to deeper water was confirmed by the divers (p. 109). This has meant that much of the evidence rapidly disappeared and may explain the absence of some species, such as small crustaceans. From material which was collected, the following list of the more common dead animals was made.

ANEMONES. The beadlet *Actinia equina* and the dahlia anemone *Tealia felina* are possibly the most resistant animals on the shore, being commonly found alive, and on 26 April they were found in pools between the tidemarks which appeared to be devoid of all other animals. Some *Anemonia sulcata*, *Sagartia elegans* and *Cereus pedunculatus* were found dead; few survived.

POLYCHAETE WORMS. *Lepidonotus clava*, *Eulalia viridis*, *Nereis pelagica*, *Perinereis marioni*, *Eunice harassii*, *Lysidice ninetta*, *Marphysa sanguinea*, *Arabella iricolor*, *Dodecaceria concharum*, *Potamilla reniformis* and *Dasychone bombyx* were found moribund or dead on 11 April and one or more specimens of practically all species were found alive later. To some extent these are examples of animals which live in micro-habitats, in crevices or among weeds deep in pools, where they would have been able to stay away from the worst of the poisonous water, but laboratory experiments showed that these worms were fairly resistant to poisoning by detergent.

CRUSTACEA. Dead *Ligia oceanica* and *Orchestia* sp. were littered among the rocks at high water. The larger mobile crustaceans, the lobster *Homarus* *vulgaris*, and crabs *Porcellana platycheles*, *Cancer pagurus*, *Portunus puber*, *Xantho incisus*, *Pilumnus hirtellus* and *Carcinus maenas* were completely wiped out, only one living specimen of the last-mentioned and toughest crab being found. No shrimps or prawns were ever found nor were any gammarids seen. Barnacles appeared to have survived well on the main part of the reef, but near the old boat-house extensive patches of *Chthamalus stellatus* had been killed in this particularly bad area (Plate 19A).

MOLLUSCA. The limpet population that had been killed comprised the three species of *Patella* in about the following proportions: *P. vulgata* 70 per cent, *P. intermedia* 20 per cent, and *P. aspera* 10 per cent. Of these three species together about 10 per cent were still alive on 11 April between the zones of mean low water and mean high water, whereas on 28 April there were none left alive in this main stretch of shore, there being only a few survivors at low-water springs and in the spray zone. An idea of the original abundance of the gastropods may be gained from counts which were made of dead bodies in two pot-holes on 7 April; these were only about 20 cm in diameter and 20–30 cm deep. Their combined contents included 269 *Patella* spp., 21 *Nucella lapillus*, 15 *Nassarius incrassatus*, 13 *Gibbula umbilicalis*, 10 *Gibbula cineraria*, 2 *Ocenebra erinacea*, and 1 *Monodonta lineata*. Other species of gastropods found dead were *Patina pellucida*, *Calliostoma zizyphinum*, *Tricolia pullus*, *Littorina littorea*, rissoid sp., *Trivia monacha* and *Aplysia punctata*. The sea hare, *Aplysia*, which would have been coming up the shore to spawn, was found alive on each visit, and was also surprisingly resistant in laboratory tests. Though there was high mortality among the gastropods between tide-marks some may have been only inactivated and recovered later (see p. 49). By 28 April only a few *Patella*, *Nucella* and *Monodonta* remained. Elsewhere *Monodonta* was a conspicuously resistant mollusc, perhaps because it has a very efficient operculum and is able to close itself off from the environment, in marked contrast to *Patella* (Plate 9A). A limpet as soon as it ceases to hold its shell firmly against the rock would have all its delicate gills and the mantle edge—a large area—at once exposed to poisonous water, drawn in to its mantle cavity by ciliary activity. It is not therefore surprising that limpets are so vulnerable. The dog-whelk, *Nucella*,* has an operculum but does not seem to close it properly: despite this a few specimens were found alive on each visit, and at the end of April eggs were seen near low-water mark.

* Far more specimens of *Nucella* were found on the reef in October–November than in April–June. Apart from mature specimens their shells nearly all showed a marked groove (usually with inner teeth formation) after which new growth had clearly been added. This is unusual in normal habitats (Moore, 1936) and would seem beyond doubt to indicate that these *Nucella* had passed through a period of inactivity. They were probably washed into the depths of gullies at the time of spraying and took some weeks to recover. Similar grooved specimens were found on other detergent-treated shores.

The chiton, *Acanthochitona crinita*, was found dead and one found alive in its habitat under stones.

Among bivalve molluscs, no living specimens of the saddle oyster *Anomia ephippium* were recorded. Several living specimens of the very small species *Lasaea rubra* and *Turtonia minuta* were found among *Corallina* in the low-water region. A few of the crevice-dwelling *Hiatella striata* were also found alive, in addition to dead specimens. No mussels (*Mytilus*) were recorded from this shore. They were sporadic in their occurrence and are much more characteristic of the exposed northern coast, where they were found to be quite resistant to oil alone and to moderate doses of detergent, but not to repeated intense treatment. They can close up efficiently for hours at a time, but when open they draw large quantities of water through their mantle cavity, and thus might be sensitive to low concentrations of poison.

ECHINODERMATA. Many fragments of the starfish *Marthasterias glacialis* were found, but neither it nor the cushion-star *Asterina gibbosa*, nor the little urchin *Psammechinus miliaris*, were ever seen alive on the reef.

FISHES. The common blenny, *Blennius pholis*, the Cornish sucker-fish *Lepadogaster lepadogaster* and *Conger conger* were found dead; only one living fish was seen, on 26 April, and on 28 April what appeared to be healthy eggs of a shore fish were collected. It seemed as if the occasional active animal visited the shore.

On 8 May all mobile crustaceans were still missing (see page 71 for recolonization by them). There were a few *Actinia* and a few *Monodonta* and one or two specimens of *Patella* surviving in favoured places. Barnacles appeared to have survived well and there was some settlement of young *Balanus balanoides* taking place on clean surfaces. Such oil as was still present was in the form of a surface-hardened film.

We can see therefore that, as a result of the large amounts of detergent used on the Porthleven Reef, there had been widespread mortality of intertidal animals and plants.

As was pointed out on page 59, there is difficulty in finding evidence of dead animals, as their bodies are quickly washed away or eaten. In the case of active forms it is not easy to tell if their absence may not in fact be due to escape rather than death. The following records are therefore included here.

At Gunwalloe Fishing Cove on 2 April while there was much spraying the following dead fish were found: *Blennius gattorugine*, *B. pholis*, *Cottus* sp., *Gaidropsaurus* sp., *Zeugopterus punctatus*, *Ammodytes immaculatus*. One small lobster, starfishes and crabs were also collected.

In Porthleven harbour abundant dead sand eels, *Ammodytes*, had been seen and on Sennen beach twenty sand eels were washed up.

OTHER ROCKY AREAS

Of the shores so far studied in detail Trevone and Porthleven have shown the effects of heavy detergent treatment. Marazion had only moderate damage and graded effects were seen, and there was an area on Hogus where the oil was never treated. Some further examples will amplify the observations already recorded.

Graded effects of spraying

Graded effects could be seen in the proportion of dead and of living members of one species, and in the extent to which the more or the less resistant species had been able to persist.

The first area, Polpeor Cove, close to LIZARD POINT, is one previously well known to the investigators. By 8 May this cove had received much oil and probably a generous amount of detergent, the effect of which had seemingly spread beyond the original limits of the oil. The rocks to the immediate east of Polpeor Cove (at the Lizard itself), are partly sheltered from wave action by numerous outer reefs exposed at low tide, and before the 'Torrey Canyon' pollution the fauna and flora were very rich. The outer most accessible reefs at the point seemed relatively unaffected and the best-known reef seemed absolutely unchanged, though there was a slight film of oil in places towards high water. However, as the survey progressed round the point into Polpeor Cove the influence of the detergent became apparent. At first only the green algae and hermit crabs were missing; then all the limpets in pools and most of the top-shells disappeared, though in these tide pools the encrusting calcareous red algae and *Corallina* were alive. Closer into the cove, however, all these algae were dead and the pools were coloured white, and there were signs of mortality among the barnacles. In the cove itself, particularly on the rocks close to the old lifeboat slip, it was difficult to find a single living animal. Here even the barnacles were killed and the fucoids were dying; and the especially rich flora of the iridescent alga *Cystoseira* in the pools was very much reduced, only the bare stipes being visible, and these apparently dying.

In the vicinity of PENDEEN WATCH on the north coast there are several small coves which became badly polluted with oil. Cleaning was first carried out on the east side towards Portheras Cove, Morvah. The cleaning operations were later extended and, by the time of the final visit on 9 May, rather light spraying had been carried out over most of the area but there were still some oil-covered rocks on the east side. These rocks supported a good population of mussels and barnacles even though other animals as well as the green algae had vanished. Nearer the more heavily cleaned areas, the barnacles began to show increasing mortality until close to the sandy coves even the hardiest of the barnacles, *Chthamalus stellatus*, were dead. In such places all the red algae had been killed and even *Fucus vesiculosus* (form *evesiculosus*) appeared to be dying.

In contrast to these barren shores to the east of Pendeen, Enys Cove to the west of the lighthouse showed hardly any deleterious effects, although there were traces suggesting that a small cleansing party had used a few drums of detergent where the small stream entered the cove. In spite of cleaning operations there was still a thick film of oil at high-water springs and a thinner layer extending down to mid-tide level. Most of the limpets and all of the barnacles seemed to be completely unharmed and patches of the green *Enteromorpha* were flourishing near high-water mark. Spat of *Balanus balanoides* were settling on oil-free patches of rock and periwinkles were present.

At FISTRAL BAY, NEWQUAY, the rocks of the Headland, as well as the sandy bay as a whole, had received much treatment and by 27 April most of the red and green algae were already dead, though some plants of the red alga *Gigartina* survived on vertical faces. On flat surfaces even the fucoid algae seemed to be dying. All the limpets had been killed. More than 50 per cent of the mussels had been removed from the rocks, leaving their byssus threads behind (cf. Plate 15A). On 22 April the empty shells had been conspicuous in the adjacent beach material. More than 50 per cent of the barnacles had died, including most of the *Balanus balanoides*, and all the purple-tinged *B. perforatus* of the more shaded and sheltered gullies. The settlement of young *B. balanoides* had begun on the seaward edges of reefs cleaned earlier. A few damaged anemones (*Actinia*) were still holding on.

On the south coast at POLDHU COVE there was still oil on the rocks on 7 April, though detergent had been used. The rocks on the north side of the bay showed a fairly good fauna, with limpets and anemones surviving in spite of a coating of oil, but the reefs on the south side were virtually denuded of animals. The oil fall and therefore the detergent treatment had probably been heavier on this side of the bay, while the direction of outflow of the tide and therefore of detergent drift may have affected this side more. The situation with regard to the organisms was relatively unchanged on 27 April. A similar state of affairs was seen at MULLION. It is thus seen that, although some areas were virtually stripped of living organisms, yet there are nearby regions which were relatively unaffected.

KYNANCE COVE suffered fairly heavy pollution during the first few days, and when examined on 20–22 April still showed much oil present on the rocks and in the sand (Plate 1C). Rocks at the centre and eastern end of the cove had been heavily sprayed and further spraying was carried out well into May. On the large central reef all of the limpets and most of the mussels had been killed. Barnacles (mainly *Chthamalus stellatus*) showed nearly 100 per cent mortality and even many of the *Balanus perforatus* near low water were killed. The few snakelocks anemones (*Anemonia sulcata*) seen were in poor condition and none at all were seen on subsequent visits. Only a few beadlet anemones (*Actinia equina*) survived on this reef, some of them in the depths of pools. In some pools the encrusting calcareous algae were killed, in others they survived. The *Corallina* had turned white and later disintegrated, and other algae were also lost; thus the denuded pools offered no cover for small active forms such as young fish and prawns, which would usually hide in these pools as the tide recedes. Some of the *Pelvetia* and *Fucus vesiculosus* (form *evesiculosus*) were a rusty brown colour, with fronds disintegrating (cf. Plate 15C). Some seem eventually to have died, others recovered. Not all these mortalities were observed until a later visit on 25 May.

In contrast to the heavily sprayed central and eastern reefs, on rocks to the north and west of the cove much of the flora and fauna remained untouched, though the rocks were still oily in places on the April visit. However, some 10 per cent of the mussels were gaping and probably dead.

Near ST AGNES are two coves—TREVALLIS, which was heavily polluted and received intensive treatment, and TREVAUNANCE, which had less oil, but where, owing to the private owner being averse to the use of detergent, the cove was at first not treated, and the common rocky fauna was reported to have survived well. Detergent was eventually used at Trevaunance, sparingly and with care, with little resulting damage to life. (For conditions later in the season see page 73)

Effects of oil without detergent

It had been amply demonstrated that treatment by detergent causes high mortality. It was therefore very interesting to try to observe what happened in the short term and in the long term if oil pollution were left untreated. In only a few sites was this possible because of the immense amount of detergent used even in remote places. However, in the first few days of pollution places were visited where oil was still untouched from the land.

The account by Richardson & O'Sullivan (1967) in which they compare the effects of pollution at PORTHGWARRA and SENNEN before and after treatment was certainly borne out by our findings. The oil alone rarely seemed to have any ill effects during the first few days. At CAPE CORNWALL, however, moribund limpets under oil were observed; it is possible that they had been smothered very thickly with oil, or that the oil which

PLATE 13

A

B

PLATE 14

A

B

b

a

c

C

(*Facing p.* 65)

enveloped them contained detergent sprayed at sea and retained in more than usual quantity. The volatile and more poisonous fraction of detergent sprayed at sea would probably usually have evaporated away, and the observations already quoted are in keeping with the opinion that oil alone as it arrived on the shore was not harmful. This is not to say that crude oil, before it has lost its own volatile and acrid-smelling fractions, would not be toxic. A very thick layer would interfere with respiration and spoil normal food supplies for browsing animals. On sloping rock surfaces the oil deposit was usually not more than about 1 cm thick and soon became thinner. So far as limpets are concerned, they are unable to remain closed off from their environment for very long: the adductor muscles relax occasionally, thus lifting the shell very slightly. The viscous oil would not readily be drawn in under the edge of the shell by the ciliary currents in the mantle cavity, whereas detergent, alone or diluted in sea water, would creep in much more readily and be liable to kill the limpet. That this type of oil alone is not toxic to limpets is seen by the fact that they ingest it and pass it through their guts. This had already been noted with limpets from Hogus Reef, Marazion (p. 49), where the persistence of the full population into at least July is clear proof of the harmless nature of the oil to them. Evidence of limpets eating oil was seen also at Godrevy, Trevone (see Plate 9c) and elsewhere. That they could derive any food value from the oil seems unlikely.

The survival of mussels under heavy oil was seen at Booby's Bay, in the first few days of pollution. On many occasions it was noted that oil remained among small mussel shells on rocks from which it had obviously been present more generally and had been washed off. In the absence of heavy detergent treatment these mussels had survived. At Portreath, in

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PLATE 13

A, Whitesand Bay, Sennen, 28 March. Heavy oiling on boulders in the high-water region shortly after the initial deposition. Oily sand seen beyond. **B,** Whitesand Bay, north of Sennen, 20 April. Oil-laden breakers in the foreground depositing oil on the shore to form characteristic wave marks. Note the contrast in the colour of the oily breaker with those behind. The mass of oil already treated at least once is being carried back on the shore by the rising tide.

PLATE 14

A, Sennen, 28 March. Viscous oil emulsion settled between boulders in the upper part of the shore. **B,** Booby's Bay, Constantine, 29 March. Newly settled oil–emulsion dripping over rocks in the high-water region. Soldiers are seen in the background manhandling a detergent drum in readiness to start cleaning operations. **C,** Oil-impregnated sand exposed along the upper shore at Sennen Cove on 23 August. A layer of sand impregnated with thick brown oil to a depth of about 15 cm is shown (*a*); this layer probably represents the beach level at the time of the oil deposition in late March. Subsequent to the deposition of oil, sand has accumulated on the upper shore covering the oiled sand and boulders (*b*). Water draining from this sand above the impermeable oil layer is removing oil and redepositing it below as a thin layer on the sand surface (*c*).

pools which had a film of oil, mussels were found alive and behaving normally, even though the mantle cavity contained globules of oil.

It was difficult to find areas on which oil had been left untreated. Up to 10 May no detergent appeared to have been used at GODREVY POINT itself. Most of the oil was in the form of a partly dried black surface layer about 2 mm thick coating the sides of gullies from extreme high water to mid-tide. Beneath the surface layer the oil was still brown and semi-liquid, and care had to be taken when walking on it. Below mid-tide the oil film was much thinner and light brown in colour. It appeared to be eroding away, the erosion being helped by feeding activities of the limpets, the tooth marks of which could be clearly seen in places (Plate 9C).

As far as could be seen, the main deleterious effect of the oil on the fauna was physical rather than chemical. Where the layer was thick enough barnacles had been smothered, but more than 90 per cent of them had managed to clear an opening in the oil film. These were found to be in good condition when examined in the laboratory, and the gut did not appear to contain any oil. There were a few deaths among the *Balanus balanoides*, but *Chthamalus stellatus* seemed to be unaffected. Monterosso (1930) has shown that the latter is capable of surviving two months anaerobiosis under a film of petroleum jelly, and its survival in the present circumstances is not therefore surprising (Plate 19B). Some mortality had occurred among the limpets on one vertical rock-face that had received heavy contamination by oil, but otherwise there were no obvious differences in the fauna and flora of oily rocks and adjacent uncontaminated surfaces.

It was known that at BEDRUTHAN, although much oil had entered the cove, relatively little had been stranded. Two patches had been photographed from the cliff top on 15 April. No detergent was used in the cove, which is difficult of access. It was interesting to see what had happened on these rocks after several months, and on 11 August they were examined from the shore. The patches of rocks which had been oiled were still recognizable, but the oil was much reduced, probably chiefly by sand abrasion, though the activities of limpets had undoubtedly played a part. On this very exposed shore they were practically the only browsers. A few *Littorina saxatilis* were also present. Rocks on which there was still a nearly complete cover of oil (with sand embedded in it) were seen to have no limpets (Plate 18B). Rocks which were nearly clean had several limpets on them, there being markedly cleaner areas near the limpets and immediately round them (Plate 17B). Most of the limpet shells had some traces of oil on them, but the contrast of still-oily limpets on clean rocks was not as marked here as it had been on Hogus, probably because of the greater importance of physical abrasion in this sandy exposed habitat.

These examples of cleansing of oil-polluted rocky shores without the use of detergent strongly support the observations by George (1961) in Milford Haven. It is a great pity that more areas were not left to be cleansed by natural agencies, not only because much time, trouble, money and shore life would have been saved, but also because such areas would have provided better 'control areas' to contrast with sites lethally sprayed and cleansed. Moderately polluted areas and remote and inaccessible stretches of shoreline could well have been left untreated, as in fact were the coves below precipitous cliffs on National Trust property between Navax Point (near Godrevy) and Portreath.

Between PORTHTOWAN and St Agnes Head lies another stretch of coast which received appreciable oil, but where detergent spraying was strictly localized and applied with care. This also lies on National Trust land. In Chapel Porth Cove the oil was reported as up to 2 inches thick on 29 March. There would have been rather less on adjacent rocks along the open stretches which were left unsprayed. In early September barnacles and limpets were surviving on the oil-blackened rocks near high water, but very little oil was left at lower levels. The fauna in the cove itself had suffered, as indicated by the absence of limpets, and the rocks were still a little oily. To the south of Chapel Porth the boundary between the unsprayed National Trust land and the detergent-treated shore adjacent to Porthtowan was clearly marked. In July and August the boundary was shown by a change from rocks having normal fauna and flora to unusually green rocks where *Enteromorpha* had developed prodigiously in the absence of browsers (see page 71).

The effects of very heavy oil-cover left untreated by detergent can perhaps better be studied on polluted parts of the Brittany coast (p. 168).

SUMMARY OF EFFECTS OF HEAVY DETERGENT TREATMENT

This summary is based on the numerous sites visited by several observers from Plymouth. Where spraying had taken place, the beaches or coves were usually identifiable at a distance by the numerous empty brightly coloured drums, or, if these had been removed, by patches of dead grass killed by spilt detergent, the smell of which persisted for months, quite apart from the smell persisting in the sands for at least three months. Evidence of deaths of animals in sandy shores is not readily obtained, the macrofauna always being very scarce in typical clean sands. On rocky shores the effect could be assessed over wide areas by simple inspection, so the following account applies chiefly to the latter.

Even if the shores had not been known previously, the ecologists visiting them had a knowledge of what might reasonably be expected to be present. Where detergent had been used in any quantity the evidences of mortality could clearly be recognized and these signs were repeated all round the coast. The loss of limpets was at once obvious because of the many empty limpet seats, or 'scars', conspicuous in pools and detectable elsewhere (Plates 9A, 12B, 18A). Dead barnacle shells persisted for some time (Plate 19A), and, although it is usual to find a small number of dead and empty shells at times, a mortality of 50 per cent or more was clearly due to an unusual cause. Mussel shells gaped when dead. The rotting flesh did not take long to disappear, but, even when the shells had broken away, clumps of short straw-coloured byssus threads persisted for a few weeks, showing where mussels had died (Plate 15A). The absence of living winkles, top-shells and dog-whelks and the presence of many fresh shells of these and other species (Plate 15B) indicated the fate of such animals as have persistent hard parts. The absence of living crabs, shrimps, etc., and shore fishes might have been due in part to their quitting affected areas, but if killed their bodies would soon have been eaten by scavenging shore birds. Gulls were indeed seen feeding on dead limpets, even in water discoloured by detergent. In the early days of the disaster the presence of bleached weeds, particularly *Enteromorpha*, *Porphyra* and *Corallina*, and of discoloured wracks (fucoids), were sure signs of damage (Plates 15C, 18A). Later in the season an abnormal growth of the green weeds, developed in the absence of the normal browsing gastropods (Plate 16B), was seen on numerous polluted shores, but this evidence had to be examined carefully as it had in fact been an unusually good season in most localities for the growth of *Enteromorpha*. This greenness will probably not be a persistent feature, though the signs are that other algae will become unusually abundant before the browsing animals can recolonize the areas denuded of them (see Southward, 1964).

SUMMARY OF REASONS FOR SURVIVAL FROM DETERGENT POISONING

The occurrence of unharmed patches of shoreline with a full complement of species may be attributed to good fortune of geographical position. One side of a bay or even of a more localized rock formation often escaped both the oil and the subsequent effects of spraying. The drift of detergent from the upper part of a beach often affected one side of a cove and not the other because of the direction of tidal currents. The low-tide zone usually received no direct detergent treatment, and the mixtures which ran seawards while the tide was low were often channelled in gullies.

In moderately treated areas, differences of micro-habitat could be very important. The fauna on the undersurface of overhanging rocks quite often escaped, as did also some animals living in narrow crevices. In pools, the oil, detergent and fresh water all tended to stay on the surface, so that plants and animals in the depths of a pool stood a better chance of surviving. Animals, such as worms, burrowing in the depths of a fairly firm deposit (for example Marazion, area *D*) were probably below the level of influence of the poison.

The normal exigencies of shore life are such that only resistant species have been selected to live intertidally. Their adaptations often help, too, in their survival in poisonous water. The contrast between intertidal and sublittoral animals will later be apparent (Chapter 6). Animals which can close themselves off from their environment within resistant shells are at a great advantage, for example barnacles, mussels, and gastropods with well-fitting opercula. Limpets are at a disadvantage where poisonous water is involved, being dependent on maintaining a close adhesion to the rock during their period of exposure to the air. The beadlet anemone is normally able to survive long exposure to air, perhaps because of its mucoid cover: it was also a remarkably resistant animal to the unusual conditions of poisoned water. Some animals appear to be physiologically resistant; for example, the polychaete and oligochaete worms, despite their relatively unprotected bodies, were found to survive quite well. Such evidence as we possess suggests that nematodes also survived well, as would be expected from their known capacity to survive under difficult conditions.

This subject is discussed also on page 135 in relation to laboratory toxicity tests (Chapter 7) and with regard to sublittoral fauna (Chapter 6).

RECOVERY AND RECOLONIZATION

In most localities the existence of areas and pockets of surviving plants and animals gives hope of an eventual and perhaps an early recolonization and return to normal. How long this will be cannot be predicted, as natural balances have been upset even where there has not been complete destruction of life. These unharmed areas provide local sources for the spores of algae. Larvae of many shore animals often spend some weeks, if not months, in the plankton, in which case there is no question of immediate local recolonization. For mobile shore animals, such as fishes and crabs, and even for wandering gastropods, these local patches are important.

Where oil was left on rocks its fate was part of the recovery of the habitat. The very thin oily film which had often remained after cleansing was neither so persistent nor so continuous as to prevent some settlement of alage and barnacles by the end of April. Brown oil films between tide-marks on rocks and boulders were still occasionally present here and there after several months. They had either been missed by detergent or secondarily redeposited. The oil underwent a gradual change, developing a hardened skin, and the film decreased in thickness. Though dark on the surface it remained, for a time, light-coloured and fluid below, and it often had sand embedded in it. The decrease in quantity seemed to be due in part to some erosion by wave action, assisted by sand abrasion, and perhaps in part by evaporation, not to mention the action of browsing animals where these had survived. In the splash zone there was also a decrease in the blackened oil, so that by mid-summer it had become inconspicuous, looking not unlike the black lichen *Verrucaria*. This oil, too, was weathering away and the tiny winkles of this zone, *Littorina neritoides*, including (in August) some recently settled (under 2 mm), were found living on and among the black oil patches (see also page 72).

Flora

On the main part of the shore the algae will be considered first, because in addition to their own intrinsic interest they form an essential part of the habitat for the fauna, supplying cover and direct or indirect food supply for many animals. Most of the fucoids were not completely killed, commonly sprouting irregularly from distal parts. Thus in areas only moderately affected no great overall change was apparent.

On a completely denuded reef at SENNEN, where there had been repeated cleansings late into the summer, a very few fucoids were beginning to sprout in lateral clusters of tiny blades from the stipe. *Ascophyllum* was in a somewhat better condition, thus confirming a difference apparent elsewhere earlier in the season. Other reefs at Sennen, treated only lightly at an early stage were in marked contrast to this barren reef; on them recovery had brought the larger fucoid algae back to normal by mid-summer.

Where damage was more severe a distinction has to be made between recovery, often from basal parts very closely applied to or actually in the rock and recolonization by sporelings. An example taken from MAWGAN PORTH is typical of rocks in the mid-tide zone at many other places. Rocks which had lost their cover of *Porphyra* and *Enteromorpha* during April by mid-May had occasional strap-shaped fronds of the former, up to 6 inches long. These must have regenerated from basal parts of the *Porphyra* phase or from the filamentous 'concocelis' phase on the rocks. By mid-August these regenerated plants were common and well grown but darkly pigmented and reproductively immature. Besides the *Porphyra* there had developed a very thick coating of *Enteromorpha*, from growth already started by mid-May. This was one of the many places where there had been heavy loss of the browsing fauna with consequent rich development of the sporelings of green algae. A remarkable greenness was seen also, for example, at Porthleven, Cape Cornwall and Trevone. *Enteromorpha* and *Ulva* normally reproduce by frequent cyclical production of spores and they are prone to show very good growth in fine calm spells, so that reports of unusual greenness on the shores must be interpreted with care. Near Porthtowan a stretch of rocky coast which had been sprayed with detergent was markedly green in contrast to an adjacent unsprayed stretch with normal fauna and few green algae. As *Enteromorpha* dies soon after sporing and is soon reduced by storms the unusual greenness will not persist indefinitely. Sporeling fucoids (up to 3 cm) were becoming dominant in some affected areas (e.g. Trevone) by early September. The disturbance of balance, because of the lack of browsing fauna, may take a few years to redress. Elsewhere oil-spills have eliminated browsers and resulted in the abundant growth of the larger more persistent algae—for example, on the Californian coast (North, Neushul & Clendenning, 1965).

The recovery of algae in pools was very variable according to the degree of pollution. In mild cases there were early signs of recovery of calcareous encrusting algae, while it seems that *Corallina*, which grows relatively slowly, will take much longer to recover. Sporelings of *Ectocarpus* (a filamentous brown alga) were sometimes much in evidence, especially in the absence of browsers. The redevelopment of algae within tide-pools will be of importance to the life of the pools as a whole.

Fauna

There was evidence that some animals that suffered partial damage by detergent recovered in the field (gastropods on Hogus, p. 49, *Nucella*, p. 60). If there has been any cumulative poisoning to living animals it is not a phenomenon which could have been studied in the field in this present survey.

We have attempted to detect both the re-invasion of a denuded habitat by active adult animals and the recolonization by young stages—often, but not necessarily, of sedentary forms.

First there are the active swimmers, which may normally come and go with the tides. By 23 June some swimming crabs (*Portunus puber*) and shore fishes (*Blennius pholis*) had returned to Porthleven reef. Small fishes and active crustaceans need to have algal cover before they are likely to return. They were noticeably absent at Kynance from bare pools in July, while elsewhere (Trevone and Cape Cornwall) they were seen in August in pools previously barren and now surrounded by green algae. Animals which by their own efforts could crawl a short distance might also be washed from undamaged areas on to previously denuded patches, where grazing forms would find a new growth of algae. The more resistant gastropods (*Nucella*, *Gibbula*, *Ocenebra*, *Monodonta* and *Littorina*) had become more frequent again as early as 23 June on the reef at Porthleven. Some juvenile winkles (*Littorina littorea*) were found in pools at Kynance on 23 July from which they were certainly absent on 20 May, but these species had by no means regained their former abundance. Both at Porthleven and Mawgan Porth, a few limpets had apparently wandered a short distance into unoccupied territory.

The recolonization by a new generation is dependent on the presence of a suitably oil-free and unoccupied area of substratum, and on the availability of the larvae. So far no newly settled limpets have been seen, but their main time for settlement is in the early months of the year and therefore no recolonization is expected before 1968. Other shore species often have larvae in the plankton in the spring and summer months, and of these species newly settled *Littorina saxatilis* and *L. neritoides* have been found. Many recently metamorphosed crabs were seen in 23 June at Porthleven, and larger ones at Sennen and Cape Cornwall in August.

Special attention has been given to the settlement of barnacle spat, since its abundance can be compared with what we know from previous years (Southward, 1967). It is clear that in general the larvae were not killed by the concentrations of detergent that they encountered at sea (see p. 93 and experiments on toxicity in Chapter 7). Moreover, it is probable that the planktonic larvae had either been liberated into the sea before pollution occurred, or else had come from adjacent unpolluted areas. Any differences from previous years could well be accounted for by difference in the direction of winds between the time of liberation of nauplii (first-stage larvae) and of settlement. In Cornwall, the settlement of *Balanus balanoides* occurs once a year in April and sometimes early in May. Along the south coast, in Mount's Bay in particular, including Porthleven, it settled more heavily than in previous years, occurring equally well in localities which had suffered pollution and those which had escaped. Along the north coast, settlement was not quite so heavy this year. The larvae require an oil-free surface on which to settle. Some were found on the seaward end of reefs which had been cleaned, for example, at Fistral Bay, Newquay, at Trevone, and at Enys Cove, near Pendeen. Where groups were seen occupying empty limpet seats it was a sure sign that they had settled in an area which had at some stage been affected by detergent. At Mawgan Porth they were found developing well on 14 May, being especially numerous on an uncontaminated area, whereas at Watergate none were seen in suitable situations, but here cleaning had been delayed until nearly the end of April. For this species as a whole the pollution does not seem to have had any serious effect.

On 11 August a recent settlement of another species of barnacle, *Chthamalus stellatus*, was seen at Trevaunance in the mid-tide zone. Rocks at the same tidal level in the adjacent cove at Trevallis (where there had been heavy spraying) were smothered in green algae. In this part of the barnacles' tidal range its sites were therefore pre-occupied, but this may be only a very slight local effect as the species also settles abundantly higher on the shore later in the season.

SUMMARY AND CONCLUSIONS ON ROCKY SHORES

The lethal effects on the flora and fauna of heavy detergent treatment have been summarized above on page 67. Their seriousness for shore life is beyond dispute. Some of the reasons for escape or survival are set out on page 68. While in some places shore life escaped completely and serious damage was localized, yet the effects of detergent spread well beyond the extent of the original oil pollution. The second, man-applied pollutant was far more damaging than the accidental one. Recovery and recolonization is in progress but it may take some years before the normal balance of the population and the intricacies of the food chains are restored.

It has been seen that prolonged and repeated treatments do much harm even in a short space of time, and, while a region can recover gradually from one such onslaught, chronic oil pollution followed by repeated detergent treatment must do permanent damage. If large-scale and indiscriminate use of detergent were ever permitted as a standard method of treatment of oil-falls, shore life on one part of the coast after another could be disrupted and recovery would be far more prolonged and difficult. The risk of the loss of rare species and of species at the northern or southern limit of their geographical range would also be much greater.

We still do not know if there may be any long-term cumulative effects from the detergent persisting in the sands (see page 80).

Our survey shows that this type of *oil alone* has done little harm to shore life, and if the oil is left untouched there is clear evidence that browsing gastropods such as limpets and top-shells may remove and ingest oil without ill effects to themselves. The relative importance of the browsing fauna compared with physical agencies such as wave and sand abrasion, as well as evaporation, will depend on the locality and the tidal level. But left to themselves these physical and biological agencies have been able to effect the complete removal of moderate oil pollution in some places in three to four months. Above the tide level aerial weathering is the chief agent on rocks. In other places the covering growth of salt-marsh plants (see page 89) has been remarkably effective in rendering the untreated oil innocuous and inconspicuous by the end of the summer.

The use of detergent should be considered only on shores of high recreational value, and then only after mechanical removal of as much oil as possible has been attempted (see page 90). It should be used in limited amounts and with care. The time of application relative to the tide and wind is of importance both for the efficacy of the detergent in making emulsions and for minimizing damage to shore life. The problem would of course be simplified if non-toxic detergents could be developed for general use. On other shores much greater advantage should be taken of natural cleansing.