CHAPTER 5

SHORE SURVEYS—SANDY SHORES AND ESTUARIES

SANDY SHORES

On sandy bays the oil arrived at first in drifts of generally half an inch up to a few inches thick in the high-water zone, often localized on one side of the beach. Some sank into the sand, making layers like sticky coffee grounds, and as such it was not difficult to scoop up (see page 170). This treatment was applied in a few places, the sand being dumped inland. For example, at MAWGAN PORTH some was put on marshy hinterland whence any eventual slow exudation would ultimately reach the sea, but where decomposition of the concentrated buried oil will be extremely slow. At TREVAUNANCE the owner of the mineral rights shovelled it up, putting it in an old mineshaft near the sea, where there is presumably no risk of contaminating springs and inland water supplies.

By far the more usual method was to push the oil back into the sea, by hosing or by using earth-moving equipment (Plate 4B). Deep furrows were made and the oil mixed with detergent was hosed down the shore. Alternatively, sand was shifted to near low water or into a stream where it was sprayed or otherwise mixed with detergent. This resulted in some oil being carried away to the sea as a dirty emulsion, especially if there was an offshore wind, but it also spread unemulsified oil and detergent in various degrees of dilution and depth over the sands of the whole beach. In some places temporary quicksands were produced.

Wave action frequently buried untreated brown oily layers a few inches or even feet below the surface by depositing clean sand on top. There is a normal seasonal accumulation of sand at the top of beaches during the summer. This accumulation of clean sand helped greatly to give a 'cleansed' appearance to the shores. Offshore, water turbulence would occasionally mix oil and sand together so that the oil would be weighed down and has been seen resting on the bottom by divers (Plate 6C).

This movement of sand was clearly seen at SENNEN, where the whole of the boulder zone along the beach of Whitesand Bay had been exposed when the very heavy pollution of oil was deposited over the entire shore at the end of March (Plate 13A). By mid-summer sand had covered a great many of these boulders, but in July and August it was beginning to be eroded away and sticky oily layers were again appearing (Plate 14C).

This buried oil presented a considerable problem to the cleansers. Up to 24 April alone 164000 gallons of detergent had been used at Sennen and activities were continued at intervals during the early part of the summer as more oil drained out from among the boulders or otherwise reappeared.

The wisdom of the use of detergents on sandy beaches had been called in question, so, in addition to field observations, various laboratory experiments were set up to investigate the physical effects of oil and detergent in sands.

SOME PHYSICAL PROPERTIES OF SANDS CONTAINING OIL AND DETERGENT

Various experiments were devoted to the situation that might develop when oil, oil–detergent emulsions, and detergents themselves were in contact with sand.

The effect of oil alone on a sandy beach was examined by adding 5 ml Kuwait crude oil to the top of sand held in a glass column 3·75 cm in diameter. The sand was obtained from the shore at Duckpool (North Devon), an area free from the present oil pollution. The column was open at the top and the bottom, and was plugged with glass wool to prevent the sand flowing out. Tidal cycles were then simulated by mechanically raising and lowering the column in and out of sea water within a large measuring cylinder, the cycle time being 22 minutes. At the end of some 40 cycles, the oil had penetrated the top 3 cm of sand, but had not become further dispersed. Further cycling did not lead to more dispersion of the oil, and it seems likely that on the shore, in the absence of wave action, oil will not penetrate deep into sand and could therefore best be removed by mechanical means (see page 170; Plate 28c). A similar experiment was set up, with the addition of 2 ml of BP 1002, and in this case the oil–detergent emulsion spread throughout the column in a short time. On beaches treated with detergent, oil has been found dispersed through a considerable depth of sand (see page 81).

The effect of detergent alone on a beach sand was also examined. Simple experiments were carried out in which weighed amounts of sand were shaken up with solutions of detergent in sea water, and then allowed to settle. A significant amount of the solvent was adsorbed on to sand, whereas less surfactant was adsorbed.

Other experiments, where detergent was added to watch-glasses with and without sand and the rate of evaporation followed by weighing at intervals (Fig. 13), showed that the rate of evaporation was less in the presence of sand, a result which again indicates adsorption by the sand grains.

It seemed probable from these results that retention of the solvent by adsorption on to the sand particles would prolong the period during which the sand would be toxic to organisms living in it. Moreover, the adsorbed solvent is not readily washed out from sand, as the following experiment shows: 100 g of sand were placed in a 500 ml flask and 1 ml of detergent added before the flask was filled with sea water and shaken; repeated washing of the sand by fresh sea water was carried out at intervals and, after

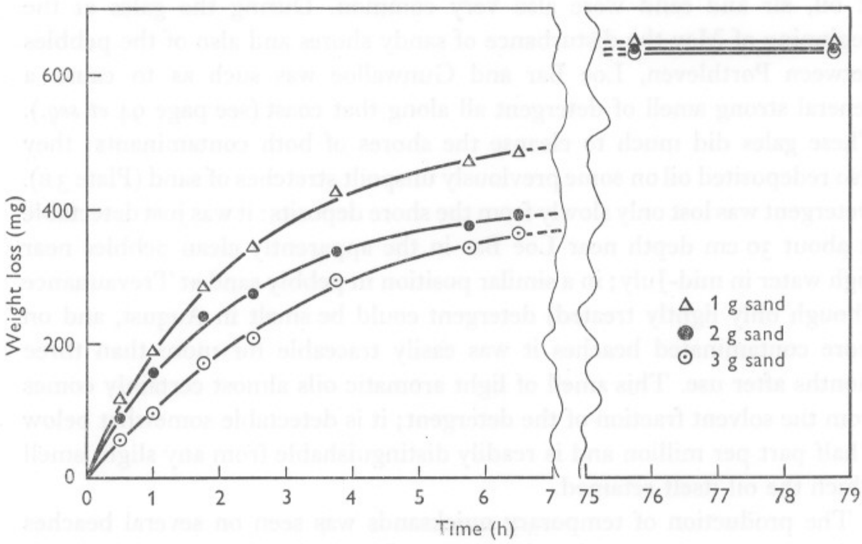

Fig. 13. Rate of loss of solvent from open watch-glasses containing different weights of sand.

nine changes over seven days, 10 ppm of solvent was still present in the supernatant water while, after eleven changes, 4 ppm was present. Such experiments indicate that a number of tidal cycles and frequent flushing would be required to remove the solvent from beaches where the sand has been impregnated by detergent.

In another experiment sand 'castles' were made from uncontaminated sand soaked in detergent solutions of various strengths and all equally well drained. The experiment showed that the cohesiveness of the sand was markedly reduced by detergent even at 10 ppm concentration, presumably by alteration of the surface tension of the interstitial water. To this lack of cohesion may be added the flotation of oil-covered sand grains to which air is readily attached. Together they could give rise to enhanced mobility of sand under wave action. This is a fortunate feature in that more oil and detergent would be washed out of the sand than if the physical properties had not been affected. Large movements of sand both up and down the shore have been noted, but whether or not these were abnormal is impossible to say without reliable long-term knowledge of the particular shores.

Some other field observations are especially relevant here. After the dispersal of detergent and oil through the sands quite unusual amounts of floating sand grains were noticed (similar to the little raft of sand grains seen in quiet corners soon after the turn of the tide) (see Plate 21 A). Scums of oil, air and sand were also very common. During the gales at the beginning of May the disturbance of sandy shores and also of the pebbles between Porthleven, Loe Bar and Gunwalloe was such as to cause a general strong smell of detergent all along that coast (see page 94 *et seq.*). These gales did much to cleanse the shores of both contaminants; they also redeposited oil on some previously unspoilt stretches of sand (Plate 3 B). Detergent was lost only slowly from the shore deposits: it was just detectable at about 30 cm depth near Loe Bar in the apparently clean pebbles near high water in mid-July; in a similar position in pebbly sand at Trevaunance (though only lightly treated) detergent could be smelt in August, and on more contaminated beaches it was easily traceable for more than three months after use. This smell of light aromatic oils almost certainly comes from the solvent fraction of the detergent; it is detectable somewhat below a half part per million and is readily distinguishable from any slight smell which the oil itself retained.

The production of temporary quicksands was seen on several beaches and was very pronounced at Porthmeor Beach, St Ives (see below). In Brittany quicksands were produced by oil alone.

The physical properties of sand deposits and some of their effects on the fauna have been studied by Chapman (1949). So far in our study only the purely physical effects of the use of detergent on sand have been considered, but there may be indirect biological effects in addition to the direct toxic effects on organisms living in the sand.

Oil content of sand

Rough estimates of the oil content of samples of oiled sand collected at various sites were made by weighing the sample, removing moisture by keeping at 37 °C until constant weight was attained, and removing oil by successive washing with solvents (petroleum ether and cyclohexanol). Very oily sand from Sennen contained 17 per cent by weight of water and 11 per cent by weight of oil; less heavily polluted sand from Porthmeor, St Ives, 8 per cent of water and 2–4 per cent of oil. Sand containing only 0·5 per cent oil was collected from an area where a quicksand had formed around rocks at Porthmeor. In general, where there is more than 2 per cent of oil by weight of sand, the sand appears very heavily oiled, and oil can be squeezed out. The sand above high water at Sennen contained 0·6 per cent of oil (13 June). It felt oily and discoloured the hand, as did the sand collected earlier from Porthmeor. The lowest oil content was found in the surface layers at low water at Perranuthnoe (0·1 per cent). Oil present in similar small amounts in sands at low water was seen on digging pits in several beaches, where oil globules and an iridescent surface to the water-table were often observed. Similar traces of oil were present well into the autumn.

FURTHER OBSERVATIONS ON SANDY SHORES

An intensive study of a particular beach could have given useful information, but, because of shifting and mixing of sands under natural shore conditions, reliable quantitative work would have been difficult. It was not undertaken in the early stages of the survey partly because of lack of time and partly because of the distance of these shores from the Plymouth Laboratory. To make such a programme worth while some control over spraying activities would also have been desirable. As these factors were lacking, data collected from various beaches give an idea of the influence

Table 8. *Improvement in sand conditions at Mawgan Porth*

Date	Oil in sand (% oil/dry wt. sand)	Condition of water-table	Detergent
22 April	Brown layers and bands left after oily sand removed (on other shores 1–5 % oil in similar layers)	In area of quicksand and pools, oil floating on white detergent solution	Very strong smell in quicksand
14 May	Grey layers in above areas. Oily to touch. One sample 0·42 % oil	Iridescence in all parts, some blobs of oil on water collecting in pits. Quicksand area still 'soft'	General smell, chiefly subsurface
11 June	Vague greyness in above areas could be due to mixing or addition of sand. No widespread grey layer down to 30 cm	Iridescence general but less marked in pits. Quicksand area recovered	General, below surface, less marked than earlier
11 August	Grey layers at 20–40 cm over practically whole beach, surface in wide deep ripples, stability during calm spell. One sample 0·67 % oil	Ripple pools in firm sand with traces of oil on floating sand	Faint smell subsurface, not confined to grey layer

Eurydice: several seen near low water 14 May; general over whole beach 11 August.

of treatment of sands over a period of time. MAWGAN PORTH is given as an example of the use of various methods and their effects on a moderately polluted sandy shore. For details see key to map (Fig. 14).

Observations at MAWGAN PORTH were confirmed by some at WATERGATE, which had received repeated oil-falls and prolonged treatment, spraying and bulldozing of sand to low water. There was relatively more oil and detergent in the water-table in May and June, and no grey sand was seen in subsurface layers in some thirty pits on 14 May. The impression was that recovery was taking place but not so rapidly as at Mawgan Porth. The temporary quicksands gradually recovered. At ST IVES, PORTHMEOR BEACH had been heavily coated with oil from top to bottom (Plate 8B). From 28 March an enormous amount of detergent was used right through April into May, resulting in a temporary quicksand, and an immense amount of sand had been shifted mechanically. The beach was in full use by holiday-makers during the summer and only very slight traces of oil could be found by mid-August, but gales early in September disturbed much buried oil and the beach was again closed while oily sand was carted away. The very heavy pollution and prolonged cleaning at SENNEN and WHITESAND BAY has been mentioned above. In July and August there were widespread subsurface layers, often smelling distinctly of hydrogen sulphide, as well as brown oiliness in places, and oil was being redeposited on the surfaces of boulders, running out on to the sands (Plate 14C) or washing back as oily rims at wave edges. Despite this the beach was being used by holiday-makers.

At PERRANUTHNOE there is a long sandy stretch below low clay cliffs with flanking rocks. It was heavily polluted with oil: 34700 gallons of detergent

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PLATE 15

A, Trevone, 14 May. Byssal threads of mussels destroyed by direct spraying of detergent. Barnacles, *Chthamalus stellatus*, have also been killed. Some weeks later this rock was thickly covered with *Enteromorpha*, similar to the condition seen on Plate 16B. **B**, Trevone, 23 April. A few days after spraying with detergent dead and dying dog-whelks (*Nucella lapillus*), top-shells (*Gibbula umbilicalis*) and limpets (*Patella*) found in a rock corner near the sewer outfall. **C**, Trevone, 23 April. Damaged algae after spraying with detergent. Species of *Fucus* have been reddened and subsequently little but the midribs of the fronds survived. The coralline weed *Corallina officinalis* and the encrusting coralline *Lithothamnion* sp. have been killed and bleached.

PLATE 16

A, Sewer rocks, Trevone, summer 1955. Normal appearance in the summer with brown fucoids, limpets and top-shells, etc. **B**, Sewer rocks, Trevone, 9 July 1967. Intensive growths of *Enteromorpha*, *Ulva* and some *Porphyra* (at highest levels) on the rocks and mussels, consequent upon destruction of most limpets and top-shells (see also Plate 15B). A few limpets and top-shells survived and the occasional clean patches of rocks are mainly due to their grazing activities (see Plate 17A). (N.B. These rocks were most probably not actually sprayed with detergent. They were affected by detergent washed over them from spraying nearby. This diluted detergent killed limpets and top-shells but the mussels survived.)

PLATE 15

A

B

C

(*Facing p.* 80)

PLATE 16

A

B

were used up to 18 April, and a further 2555 gallons before 10 May, but by 20 May spraying had stopped completely. On 28 April there was a widespread thin layer of oil on the sands and in the water-table. Between this visit and one on 10 May the strong south-west gales had carried away much sand from the top of the beach, exposing previously buried rocks. It is not known if this would have been a normal occurrence after such a gale at this time of year or if it might more probably be associated with abnormal mobility of the sands due to detergent treatment. Much torn weed was heaped up and also deeply mixed in the sand. Sand cores were taken and pits dug along a transect from high- to low-water marks to examine the fauna (see page 86 and Plate 21 B). The water-table contained floating oil at all levels down the beach; thin iridescent layers of oil often with thicker brown blobs collected in the pits. There were also discontinuous patches of thicker oil below clean sand. No grey sand layers were seen on 10 May a week after the gales, and there was no sulphide layer down to a depth of 60 cm. Near the base of the cliffs the sand was saturated with detergent. On later visits to Perranuthnoe grey oily layers were found, indicating that here as elsewhere decomposition of the oil was progressing. On 8 August the water-table still contained oil blobs on an iridescent layer, but the sulphide layer was now at around 40–50 cm below the surface. It seemed to be less oily, and less conspicuous except near low water.

BIOLOGICAL DEGRADATION

When the grey layers in the sandy shores were first found it was strongly suspected that biological degradation had been proceeding, both of the oil and of the detergent. Evidence for this important microbiological activity was sought and is given below.

Specialized bacteriological work was not carried out at Plymouth in the present survey as there was no member of the staff qualified to undertake such work. We are therefore grateful to experienced workers from other laboratories for their co-operation.

Dr W. Gunkel, of the Biologische Anstalt Helgoland, kindly permits us to give a brief account of his yet unpublished results. He collected twenty-three samples from different places on Cornish beaches towards the end of May and examined them at once for their bacterial content. In most sand samples there was obvious oil present and a smell of detergent (the exact amounts in the samples have not yet been determined). The numbers of aerobic oil-decomposing bacteria were determined using a dilution method without agar and with no carbon source other than the oil. Most oil-decomposing bacteria were found in samples which were heavily

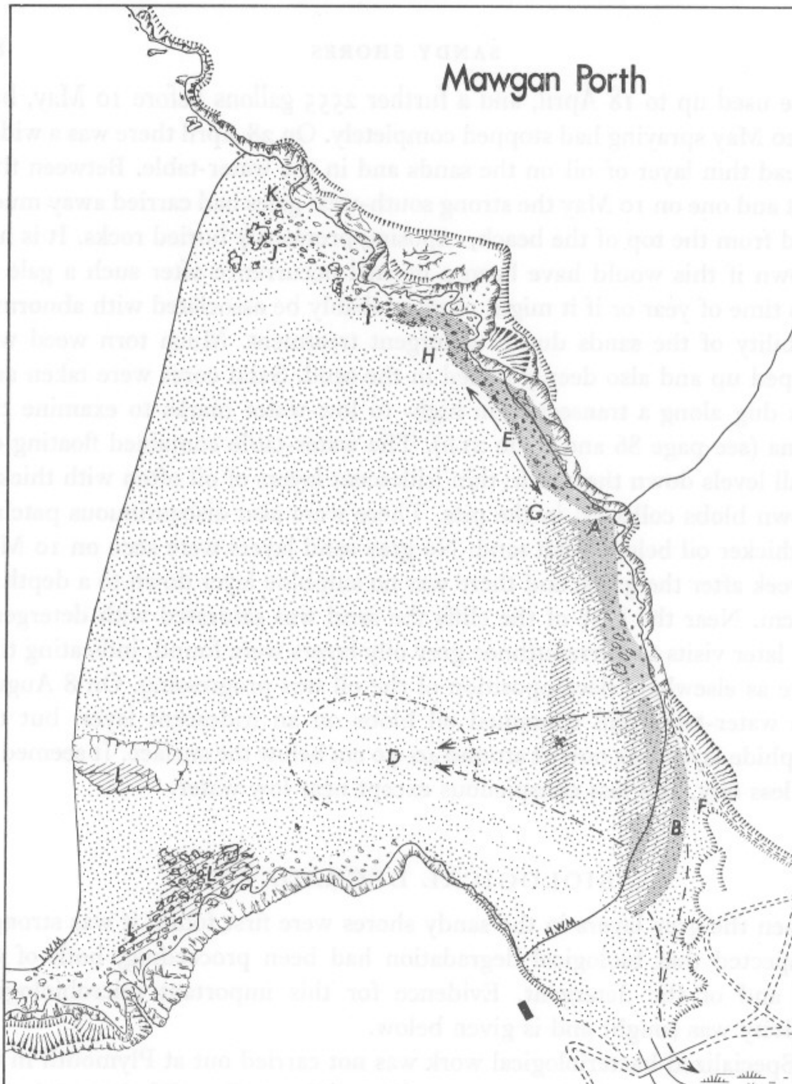

Fig. 14. Cleansing operations at Mawgan Porth. Scale 200 metres = 2·9 cm. The map shows low-tide conditions. High-water mark is above the boulder zone at the base of the cliffs except in the south-east part of the bay where there is sand rising into dunes. The main stream enters in the south-east corner and there is a side stream near *A*.

A Main area of contamination, $\frac{1}{2}$ inch of oil on rocks and boulders either side of *A*.
B, Patches of oil on sand $\frac{1}{2}$ inch thick, carted away and dumped on marshland in direction of *C*.
D, Sand pushed seawards, mixed with detergent and washed in stream.
E, Hosing with fresh water and detergent of main contaminated area. Boulders denuded of life, end of April.
F, Fires made of oil and drift-line weed (only a very small amount of oil destroyed).
G, Quicksand developed here, sand full of detergent and oil, April–May.
H, Milky stream at each low-tide period during hosing.
I to *J*, Boulders denuded by indirect detergent action. These, and those between *A* and *I* became very green with algae, June onwards.
K, Unspoilt 'control' area, not affected by detergent owing to direction of outflow.
L, Light spraying and some detergent damage.
x, Grey sand collected here, 14 May.

Sand over whole bay contained oil and detergent in May. Grey layer general in August after calm spell.

polluted or even consisted mainly of oil. The surprisingly high numbers found were much greater than ever experienced before elsewhere, the most numerous being over 400 million per 1 ml of wet sediment.

At Sennen: $1{\cdot}15 \times 10^8$, $6{\cdot}00 \times 10^6$, $2{\cdot}15 \times 10^6$, $4{\cdot}65 \times 10^6$;
Gunwalloe Fishing Cove: $3{\cdot}75 \times 10^7$, $4{\cdot}65 \times 10^6$, $9{\cdot}3 \times 10^6$;
Marazion Beach: $4{\cdot}65 \times 10^5$;
Pendeen: $8{\cdot}6 \times 10^6$;
Trenow Cove: $4{\cdot}2 \times 10^8$;
Prah Sands: $4{\cdot}65 \times 10^4$ (apparently no oil).

The so-called total number of other bacteria (heterotrophic-proteolitic types) was also determined. The average number of oil-decomposing bacteria ranged from about half to nearly three times as many as the other aerobes.

The only sample from which oil-decomposing bacteria were absent was of water from a rock pool which had much detergent in it. Subsequent experiments at Helgoland using bacteria from sea water (oil-free) showed that detergents, such as were commonly used against marine oil pollution, are capable of killing most oil-degrading bacteria even when used in fairly low concentration, e.g. 10 ppm. However, some bacteria survived even at 100 ppm and multiplied rapidly. At least some of them can use detergent as their only source of carbon. This must have happened on the shore except where detergent concentrations were very high as in the rock pool mentioned above. Because of the very high numbers of bacteria it is possible to assume that a fairly high rate of bio-degradation was taking place on the shores. In sand this process is not likely to be limited by the available nitrogen and phosphorus—as it may be in the sea (Gunkel, 1967). However, oxygen is likely to become a limiting factor. The presence of grey layers in the sand indicates an anaerobic condition subsequent to the activities of the main aerobic degraders. Aeration due to sand movement or water exchange would be important for the continuation of aerobic decomposition. Mechanical ploughing could help.

The development of grey layers was an abnormal and conspicuous feature of contaminated beaches from May and June onwards. The sands of a typical north Cornish beach are clean, i.e. with very low content of organic algal detritus, and, being generally devoid of silt, they are relatively mobile and well aerated. They do not normally develop grey sulphide layers because there is insufficient organic matter to provide sulphur for bacterial reduction. Such grey layers are characteristic of habitats rich in organic matter (Bruce, 1928).

In May sand-core samples and pits revealed only brown layers of buried oil, no grey layers being present on several beaches (Watergate, Sennen, Perranuthnoe). Later digging revealed grey layers in places where there was known to have been oil. On microscopic examination of grey sand no algal fragments could be found, but there was a film of oil around the sand grains. The deposits were oily to the touch and smelt distinctly of the solvent fraction of the detergent. From some of the darker samples—for example, from Sennen—there was an unmistakable smell of hydrogen sulphide, and from near Sennen harbour the deposit was quite black. Table 9 shows percentages of oil in dry wt of sand (estimated on 14 August).

Table 9. *Oil in grey sands*

Sand from	Collected	Oil (%)	Appearance
Trevone	14 May	1·08	Dark grey when collected, surface became light, wet part became darker
Mawgan Porth	14 May	0·42	Grey when collected, became paler
Mawgan Porth	11 August	0·67	Grey when collected, became paler overnight
Watergate	14 May	13·91	Rich brown when collected, grey speckles developed on keeping

These samples were used in some simple bacteriological tests at Plymouth. Greying caused by bacteria (unidentified) working on oil anaerobically was confirmed under laboratory conditions. This seemed to show that destruction of oil may continue to some extent after oxygen is depleted. The intensity of greyness is of course not directly related to the oil content but rather to the lack of oxygen developed in relatively stable or deep sand. Under aerobic conditions black iron sulphide is decolorized by simple chemical oxidation. Grey sand samples from Sennen were found to contain only 20–50 ppm of sulphur in wet sand. This was kindly assessed at the Marine Sciences Laboratories, Menai Bridge, for us through Dr G. D. Floodgate to whom we are indebted for discussing the following matter. Kuwait oil contains about 2·5 per cent sulphur in various organic combinations, some of which are likely to be attacked by appropriate bacteria. This combined sulphur is mostly divalent so that its liberation as hydrogen sulphide is neither an oxidation nor a reduction. As a further source of hydrogen sulphide there could be anaerobic sulphate reduction by other bacteria which derive energy from oxidation of organic matter, in this instance paraffins and aromatic compounds in the oil or detergent. Any destruction of the oil in these two ways is, however, likely to be of less importance than the far more efficient aerobic processes whose existence on the shores was established by Dr Gunkel.

That the beaches are becoming cleaner is beyond doubt. How much of this is due to bacterial degradation on the oil and how much to the washing out of oil from disturbed sands by wave action is unknown. The widespread presence of oiliness in the water-table and the smell of detergent suggests that a significant amount remained in the beaches below the normal level of disturbance in summer calm weather. During the autumn, until at least November, undegraded oil was still present on the very badly polluted beach at Sennen. Detergent treatment, by spreading oil thinly through a beach, may have aided bacterial oxidation of the oil.

The enrichment of the sand by oil and by all fractions of the detergent led to a great increase in the bacterial flora. This process may have been assisted by the poisoning of many or perhaps all of the smaller interstitial fauna which feed upon bacterial films on sand grains. As toxicity is lost and as oxygen becomes available again the way will be open for the re-entry of an interstitial fauna of microscopic predators.

FAUNA

In contrast with other shore environments mentioned in the previous chapter, it may be pointed out that these clean sandy beaches, being unstable and low in organic food content, do not support much animal life. The commonest detectable animal is a temporary inhabitant, the isopod crustacean *Eurydice pulchra* (about 3–6 mm long). When the tide is up it swims above the sand. As the water recedes it may be seen whizzing about in the ripple pools on sandy flats and leaving tracks before burying itself below the surface. Some specimens were seen on various visits to suitable sandy shores throughout the survey, but proper assessment of abundance would have been quite impracticable. It is, however, certain from the abundant tracks in pools at Mawgan Porth on 11 August that there was a numerous population over the whole of the lower part of the shore, in sand which still contained some oil and detergent, as indicated by discoloured floating sand grains and the faint smell. Toxicity tests on *Eurydice* (juveniles of *E. pulchra*) indicated that its survival after detergent treatment was above average for crustaceans (p. 134). All were killed at about 10 ppm after 24 hours exposure; at 5 ppm four out of five survived when transferred to clean sea water, while all survived at concentrations below this. In early days (23 April) a concentration of 4 ppm was found in sea water at either end of the bay on an incoming tide at least 24 hours after any spraying. Thus some individuals of the species would have been subjected to lethal conditions locally both in the sea water and in the sand, but some had survived (*Eurydice* were seen on 14 May near low water). The species had repopulated the whole beach by August. Although the sand still retained some detergent during the summer the animals would have spent twice daily periods in almost uncontaminated water. Single large individuals of *Eurydice* spp. were also found at Sennen on 23 August despite markedly grey layers in the sand below them.

We have only scattered records of other members of the sparse macro-fauna. Numerous sand eels were found dead at Sennen and Gunwalloe while detergent was being used. Empty carapaces of the small burrowing crab *Pirimela denticulata* were unusually common at Watergate soon after spraying as were also the empty tests of the heart-urchin, *Echinocardium cordatum*, and empty razor-shell (*Ensis siliqua*) and *Mactra* shells. All these animals are typical of clean sandy shores.

At Perranuthnoe, on 10 May, examination was made for fauna along a transect down a shore where there had been heavy treatment. Near high-water mark numerous small living oligochaetes and a few living nematodes were found where the water-table smelt strongly of detergent. At low-water mark similar fine sieving produced a live spionid worm. This suggests, as does evidence from Marazion and Porthleven and from toxicity tests, that worms can be fairly resistant to, as well as perhaps able to avoid, detergent damage. Animals under 1 mm in length, chiefly small crustaceans and nematodes, can be found by sieving many washings from normal sand through a fine net (see Delamare Deboutteville, 1960). At Perranuthnoe scarcely any fauna in this size-group was found, some dead foraminiferans and at one station live nematodes. At Sennen in August, similar washings produced a single nematode and three specimens of two species of *Eurydice* but no harpacticid copepods or cumaceans. It seems therefore that for the present at least there is a dearth of micro-fauna. At Sennen the production of hydrogen sulphide in subsurface layers might well be partly responsible.

THE INFLUENCE OF DETERGENT ON THE SETTLEMENT OF LARVAE AND THE RECOLONIZATION OF SANDS

Sabellaria is a polychaete worm whose behaviour at metamorphosis and settlement requirements had been previously investigated (D. P. Wilson, unpublished). It settles on rocky reefs protruding from sandy shores, building colonies of tubes of sand grains cemented together by an organic secretion. The crawling stage of the larva (about $\frac{1}{2}$ mm long) settles readily in the presence of sand containing this cement. Here, therefore, was a clear-cut reaction on which the influence of detergent could be tested on a polychaete living associated with sand—the most suitable organism available at the time, though not a species typical of the sparse macro-fauna living in open sandy shores.

Ground-up and well-washed fragments of *Sabellaria* tubes were soaked in solutions of BP 1002 at 1000 ppm and 10 ppm for 90 minutes, and then thoroughly and repeatedly washed in clean sea water so that it could reasonably be expected that only adsorbed traces of detergent would remain. This sand was put into glass dishes of filtered sea water, and thirty crawling-stage larvae added to each as well as to a control dish with untreated sand made from *Sabellaria* tubes. When examined the next day the sand from the strongest solution was found to have had a marked detrimental effect, causing both delay in settlement and abnormalities of form and behaviour from which there was no recovery. Sand which had originally been treated with 10 ppm had caused but little difference in behaviour from that seen in the control dish (where there had been about 50 per cent settlement), healthy larvae continuing normal activity.

Five days later the sand which had originally been treated with 1000 ppm BP 1002 and had proved to be toxic was compared with newly prepared sand from *Sabellaria* tubes freshly treated, as before, with 1000 ppm and with 100 ppm followed by washing, and with an untreated control, using a fresh batch of larvae. The formerly toxic sand was found to have lost its poisonous effect, being similar to the new control, while the larvae in the other two dishes showed some abnormal effects, presumably from adsorbed detergent.

Hence it would seem that the major part of the toxicity of adsorbed detergent could be dissipated fairly rapidly (see page 145). However, in this case a very small amount of sand was lying in a shallow dish of sea water and conditions for loss of toxicity were therefore very different from those on the shore, where the bulk of the deposit retained traces of detergent for months. These experiments with *Sabellaria* have shown that even a trace of detergent present in or adsorbed on sand may well interfere with settlement and hinder recolonization perhaps for a year, because larvae of a species normally settle during a limited period of a month or two at a particular season of the year.

For microscopic animals whose habitat should be thought of in terms of individual sand grains, detergent both in the interstitial water and adsorbed on the grains is of much more significance than for larger animals which draw in water supplied from above or only burrow in the sand while the tide is out. The re-establishment of the full normal population involves all sizes of organisms: microscopic bacteria, protozoans (including ciliates and foraminiferans), and small crustaceans (including harpacticids and cumaceans), as well as those visible to the naked eye such as the isopod *Eurydice* and small worms, and finally the more obvious macro-fauna such as the occasional bivalve mollusc, burrowing crab and heart-urchin. Studies on the recovery to normal physical and chemical conditions and on the recolonization of a sandy shore should include all these size-groups and work is in progress.

DRIFT LINE

The drift-line zone is evident on sandy shores where various small crustaceans and fly larvae play a useful part on the shore by acting as scavengers. Thick oil deposits at this level probably incapacitated and killed these small mobile creatures, but the sand hoppers (*Talitrus*) bury themselves in the sand, so some would probably be able to escape. Signs of damage from detergent were seen at Constantine where sand hoppers were found in a lethargic state at the base of the sand dunes soon after spraying. The same species was also found dead in quantity at Sennen.

It has already been reported that at Porthleven Reef *Ligia* and *Orchestia* were seen dead in quantities. They too are chiefly scavengers of the high-water zone.

In the Hayle Estuary the upper drift line was the only region badly affected by oil. It was left untouched by detergent and therefore formed an interesting 'control' area in which good recovery was observed in August (see below).

Very oily weed was sometimes thrown up. It is reported to have been collected and burnt at Mawgan Porth. This is a useful activity and practicable where quite small quantities of oil are concerned and dry weed is available, and providing burning is done well away from people as the fumes from partially burnt oil are considered noxious. It was not more widely attempted because of the trouble involved in the disposal of such a minute part of the oil stranded from the 'Torrey Canyon'.

ESTUARIES

The only estuaries to be polluted by oil were the small ones of the Gannel at Newquay and the Hayle Estuary. (Work on these is being carried out by the Nature Conservancy's Coastal Ecology Section.)

In the Hayle Estuary oil was carried in on one of the very high spring tides, 28/29 March, and left as a blackening rim chiefly on walls and to some extent on saltings. Owing to a special request from the power station and to representations from biologically interested bodies no detergent was used within the estuary though there was lavish use on the sands at the mouth of the river. Traces of this were probably carried up some gullies where, on 30 March, some dead and moribund rag-worms (*Nereis diversicolor*) and some small crustaceans (*Corophium volutator*, and *Gam-*

marus spp.) were collected. When examined on 10 April the rich worm fauna in the sandy flats seemed unharmed. These worms form an important food supply for birds, one branch of this estuary being preserved as a bird reserve. Animals scavenging in the drift line would have encountered a blackened sticky mess of limited width and therefore perhaps not of much consequence to the area as a whole. When inspected in mid-August the black oily rim was still visible on the vertical walls around the estuary and harbour but aerial weathering had reduced it considerably. In places the orange lichen *Xanthoria* was growing through the oil (Plate 18c). The sticky deposit in the drift line had become innocuous and inconspicuous. Perennial salt-marsh plants, sea-plantain, beet, sea-aster and grasses had grown through it and annuals such as sea-milkwort and spurry—though delayed in developing—were spreading over the oil residue. The normal drift-line fauna of small jumping amphipods (*Orchestia*) and woodlice (*Oniscus*) were common under stones. These scavengers had perhaps not recovered by reproduction to a full normal abundance but they did not now seem incommoded by the texture of the oil residue. Where this had been washed by recent spring tides the crumbly oil and sand was being carried away. These are good examples of recovery by natural means in the absence of the use of any detergent.

At Hayle a boom was erected but no further oil approached the area after the first high-level pollution. The problem might have been much more serious had oil been driven in on a lower tide, or had detergent been used on these stable sandy flats in this enclosed area of water. It is here further stressed that it would be far worse than the effects seen on open sandy shores where, in contradistinction to estuarine conditions, instability of deposit and frequent complete changes of water have meant that oil and detergents are being washed or oxidized away (p. 84).

Oil pollution along the north coast did not extend quite as far as the Camel Estuary nor enter it. On the south coast the Helford Estuary (with oyster beds) was also beyond the limits of pollution. Great attention had been given to preparing a boom and suction-clearing apparatus should any oil arrive. Mopping up with straw was also considered. No detergent would have been used, not only because of its direct lethal effect on the oysters but because the spreading of a thin film of oil over the mud would have interfered with the surface micro-flora living there as well as affecting the infauna, thus seriously upsetting the food-chains for a long period, both for the oysters and for the life of the estuaries as a whole.

Local authorities should be aware of the disastrous results which the use of detergents in estuaries could produce since two Ministries have already stressed the dangers of applying detergents in estuaries and harbours (as well as of applying neat detergent on rocks, etc.). Moreover, a general directive was issued that detergents should not be used in estuaries to combat 'Torrey Canyon' oil.

CONCLUSIONS ON THE USE OF DETERGENT AND OTHER METHODS OF TREATMENT OF SHORE AND ESTUARINE DEPOSITS

It may again be stressed that by good fortune the exposed conditions on the Cornish sandy shores were such as to lead to the ready flushing out of detergent and dispersed oil, providing the aeration necessary to aid bacterial decomposition without the production of much unpleasant smell of hydrogen sulphide. Had pollution occurred on more stable sheltered beaches and a similar enormous amount of detergent been used in dispersing the oil to depths (see experiment, page 76) the position would have been very different at the end of the summer. Likewise, if detergent had been used in estuaries and other enclosed waters, very long-term damage would have resulted.

We have seen evidence that oil left untouched as a black rim around Hayle Estuary at and above high tide has weathered and become innocuous in the absence of the use of detergent.

The removal of as much oil as possible *before* the use of detergent has proved worth while even on the few shores (Mawgan Porth and Trevaunance) where it was tried, and such procedure would have been an even more advisible method of dealing with oil on more stable sands or muds. On the shingle at Gunwalloe Fishing Cove it would have been possible to scrape up much oil from the surface if it had been attempted before detergent had been applied. The use of detergent caused the oil to sink very deeply into the beach so that very extensive mechanical shifting of shingle seawards was eventually necessary.

Some oil would be bound to remain, and, to aid its decomposition by bacteria, dispersal is desirable. This might well be accomplished much more cheaply by ploughing or otherwise mechanically mixing the oil and sand without the addition of detergents. There was no sandy beach on our Cornish coasts where detergents were not used which could be examined as a 'control'. Even if the cost of the procedure is ignored, the use of detergent is by no means the only and not necessarily the best way of treating oil on beaches. Other methods of treating sandy beaches were seen in Brittany (Chapter 9).