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Observations on the Effects of Natural Oil Seeps in the Coal Oil Point Area [and Discussion]

Dale Straughan, D. H. Dalby, D. J. Crisp, J. M. Baker, A. J. Southward, A. D. McIntyre and J. H. Vandermeulen

Phil. Trans. R. Soc. Lond. B 1982 **297**, 269-283
doi: 10.1098/rstb.1982.0042

Phil. Trans. R. Soc. Lond. B **297**, 269–283 (1982)
Printed in Great Britain

Observations on the effects of natural oil seeps in the Coal Oil Point area

By Dale Straughan

Institute for Marine and Coastal Studies, University of Southern California, AHF 246, *Los Angeles, California* 90007, *U.S.A.*

Available data from population, community, and ecosystem studies from an area of natural marine oil seepage, Coal Oil Point, California, are reviewed and a hypothesis presented to explain the information. This suggests a relation that exists through time and space. Exposure to a large volume of petroleum results initially in total or almost total destruction of all organisms, followed by a stimulatory period, followed by a gradual return to 'normal'. The time taken for these cycles varies with species, and initial impact varies with the exposure to petroleum. The Coal Oil Point area is a mosaic of small units that are at different stages in this process owing to the patchy distribution of petroleum in space and time, patchiness of habitats, and patchiness of species distribution. This is a possible explanation for the apparent overall enrichment observed in some communities in the area.

Introduction

The well documented natural marine oil and gas seeps (National Academy of Sciences 1975) provide an ideal location in which to examine ecological changes in the presence of long-term exposure to petroleum. However, few studies, in comparison with the large number of studies conducted after oil spills, have been reported from these areas. The exposure of these areas to petroleum is long and relates to geological rather than human timescales (Emery 1960). Therefore, if some of the sublethal effects that are often predicted to result from long-term exposure to pollutants occur after long-term exposure to naturally occurring petroleum compounds, these effects should be recorded in the natural oil seep areas. Most ecological studies have been conducted in the natural oil seep areas centred at Coal Oil Point in southern California (figure 1).

Limitations on field studies

Some problems associated with field studies can limit interpretation, use and extrapolation of data, and Lewis (this symposium) reviews problems common to most field surveys. Some problems, though, are of specific interest to oil seep research.

Rate of exposure to petroleum

Petroleum is unequally distributed in space and time at Coal Oil Point. Petroleum seepage varied from 11 to 160 barrels (*ca.* 1.7–25.4 m^3) per day during a single month from a specific seep in the Coal Oil Point area (Allen 1969). Some oil and gas seeps are only intermittently active (Ventura & Wintz 1971). Variability in petroleum distribution was documented through surface observations of insoluble petroleum in the intertidal zone (Straughan 1976*a*), surface observations combined with analysis of sediments in the intertidal zone (Straughan 1977*c*), replicate samples of benthic sediments in the Coal Oil Point area (Straughan 1974), and through replicate samples of organisms for tissue analysis (Straughan 1976*b*; Rossi *et al.* 1979). The latter observation is complicated by possible differences in petroleum retention between individuals of the same species. The best estimation of exposure rates can be measured for the burrowing infauna in submerged sediments. Analysis of the sediments in which the organisms are collected should provide a good indication of levels of petroleum exposure.

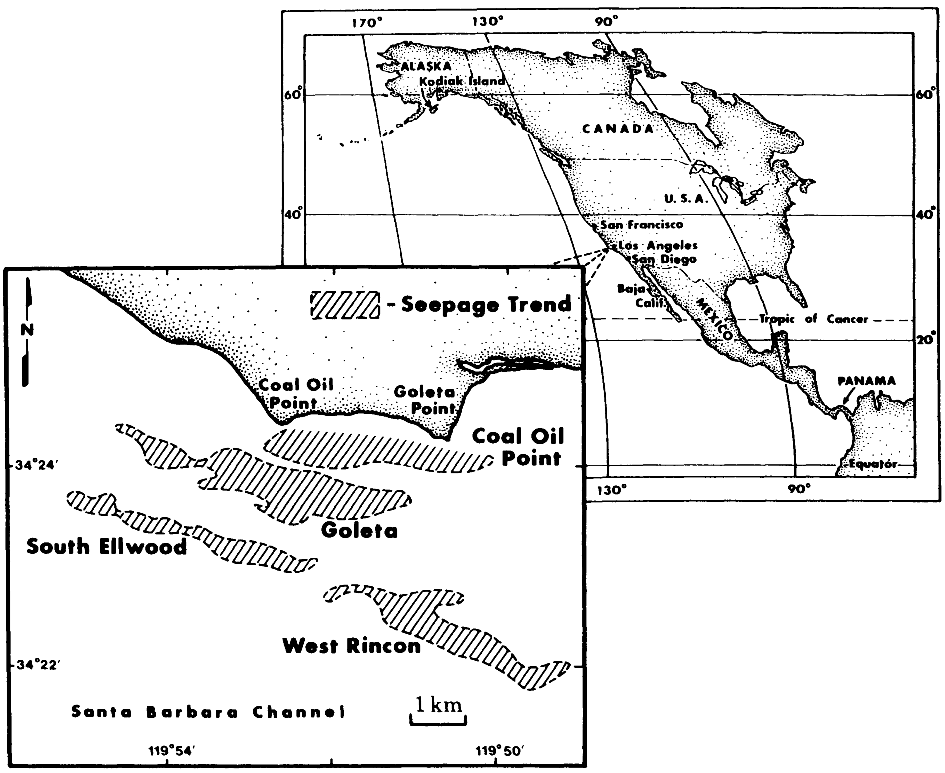

FIGURE 1. Location of major oil seep area in southern California with position of major oil seepage trends. (After Fischer & Berry (1973).)

Method of exposure to petroleum

This depends on the organism in terms of its habitat location and habits, and on the form in which the petroleum reaches it.

For example, the subtidal burrowing infauna is usually exposed to weathered petroleum incorporated in the sediments, but at times may be exposed to pieces of tar or wet petroleum buried in the sediments, or both. An intertidal filter-feeding organism could be exposed to petroleum gases, soluble or dispersed petroleum, liquid or 'solid' petroleum.

Tar also forms a hard substrate suitable for the settlement of marine organisms: several species of barnacles and algae are found on rock platforms covered with dry tar at Goleta Point (Straughan 1976*a*) and gooseneck barnacles have been collected on stranded pieces of tar on sandy beaches in southern California.

Biological problems

Foremost of the biological problems is due to the fact that most marine species have pelagic larvae. The available data on water circulation patterns and marine life cycles suggest that there is a wide distribution and mixing of pelagic larval forms. For example, larvae of the sand crab, *Emerita analoga*, which commonly occurs along southern Californian beaches including those in the Coal Oil Point area, have been collected up to 225 km offshore (Johnson 1939). Most organisms have therefore not lived within a specific oil seep area for a number of generations.

Adults of marine animals are more mobile than often believed. For example, studies on tagged *E. analoga* in the area between Coal Oil Point and Goleta Point showed that they could move along the beach in the direction of the longshore drift over 100 m per day (Dillery & Knapp 1969).

It is difficult to delineate the area where organisms are exposed to oil seepage. Most organisms in the Santa Barbara Channel are probably exposed to natural oil seepage. Laboratory experiments on the tolerance of the mussel, *Mytilus californianus*, indicate that only organisms close to oil seeps are exposed to high enough doses of oil to produce a measurable response. In this particular case, *M. californianus* from Coal Oil Point had a higher than background tolerance to exposure of large doses of Santa Barbara crude oil, while *M. californianus* from Santa Barbara (22 km to the east of Coal Oil Point) had a tolerance to large doses of Santa Barbara crude oil that was within the background range reported in other studies (Kanter *et al.* 1971; Kanter 1974; Straughan 1976*b*).

Sampling strategy

Field studies are typically designed to compare 'experimental' and 'control' areas, a gradient of areas from 'experimental' to 'control' conditions, or a combination of both approaches. In the Southern California Bight, sampling strategy is complicated by the widespread distribution of petroleum hydrocarbons in the sediments. Reed *et al.* (1977) state that 'low to high concentrations of petroleum hydrocarbons...have been detected in nearly all benthic and sandy intertidal sediment samples collected from the Southern California Borderland'. Any 'control' area that is not exposed to petroleum hydrocarbons will therefore be located some distance from the 'experimental' area. This will introduce other differences between the 'experimental' and 'control' sites. A multivariate approach, with numerous 'experimental' and 'control' sites with extensive measurement of abiotic and biotic variables, is therefore required in these studies.

Coal Oil Point, southern California

Petroleum

The response of organisms is related to the type of petroleum released into the ocean. Seep oil from the Coal Oil Point area has an asphaltic base. Gas chromatography of samples shows a large unresolved envelope in addition to the lighter hydrocarbon peaks (figure 2). There is weathering of lighter ends, particularly in the saturate fraction, between seepage and the formation of beach tar. The subtidal sediments generally show a further loss of the lighter saturate fraction, with even less resolution of peaks in the remaining envelope (figure 3).

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However, areas surrounding the actual seeps contain liquid petroleum, which has a composition more similar to the seep oil (figure 2) than the other sediments in the area (figure 3).

Four major seepage trends were identified on the continental shelf at Coal Oil Point (Fischer & Berry 1973). There are variations in the composition of petroleum released from different seeps and at different times (for examples see Kanter 1974; Spies *et al.* 1980).

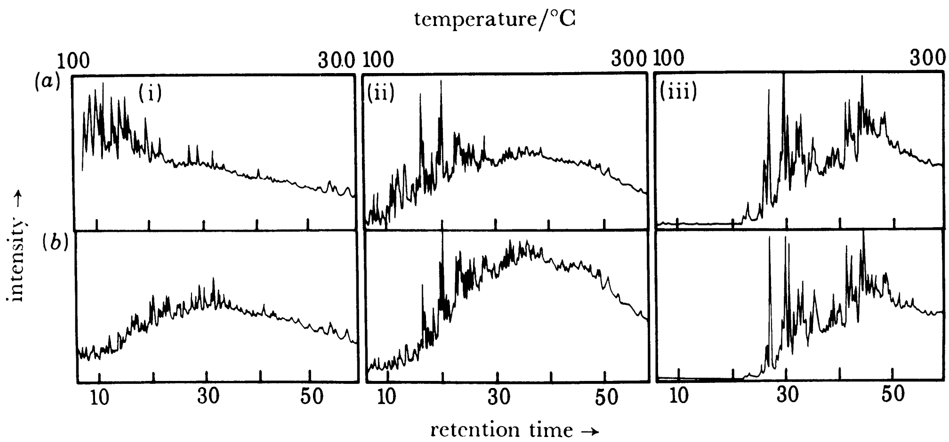

FIGURE 2. Gas chromatograms of (i) saturated, (ii) aromatic and (iii) sulphur components of petroleum samples from (*a*) an oil seep and (*b*) beach tar at Coal Oil Point. Analysis by J. Scott Warner.

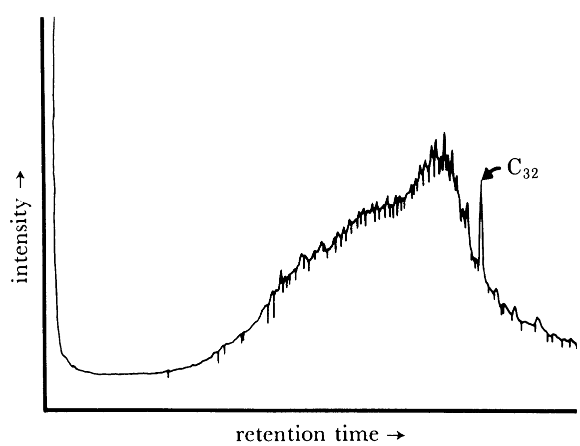

FIGURE 3. Gas chromatogram of saturated hydrocarbon fraction from subtidal sediments at Coal Oil Point. Analysis by J. Scott Warner.

Marine biota

Sampling sites in the Coal Oil Point – Goleta Point area are shown in figure 4. They include a number of offshore locations from which the samples remain incompletely analysed. Direct comparison of data from these studies is impossible because different methods were used in different studies. In spite of this, some trends in biological changes are emerging.

Least information is available about the water column. While numerous studies have measured concentrations of petroleum hydrocarbons in the water column at Coal Oil Point, there have been no attempts to study the free swimming and floating inhabitants. Changes in this portion of the ecosystem therefore remain unknown and open to speculation.

Rocky substrates in this area of the coastline are largely limited to the intertidal area. However, the presence of extensive kelp bed communities indicates that rocks in the shallow water areas are at least periodically exposed for the young kelp plants to become attached to the substrate.

The rocky intertidal areas at Coal Oil Point and at Goleta Point consist of isolated patches of exposed rock. There is considerable sand movement in the area. The importance of this is illustrated by the results of studies following the Santa Barbara oil spill, which indicated that

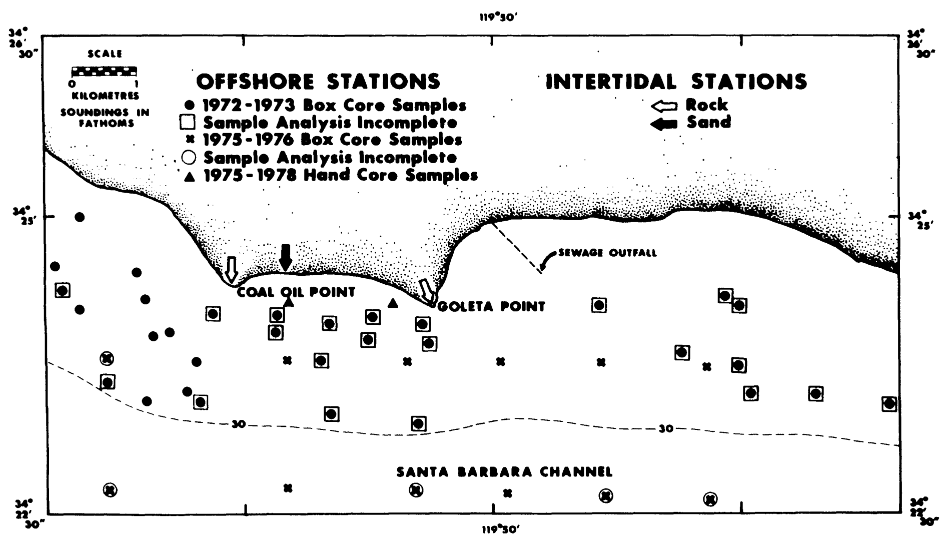

FIGURE 4. Location of sampling sites in the Coal Oil Point – Goleta Point area.

sand movement had a greater impact than the Santa Barbara oil spill on rocky intertidal biota (Cimberg *et al.* 1973; Foster *et al.* 1971; Nicholson 1972; Nicholson & Cimberg 1971). These studies also suggested that the Coal Oil Point and Goleta Point sites were biologically rich in comparison with the control mainland sites, but later studies of mainland and offshore island rocky shore sites suggested that the Coal Oil Point and Goleta Point sites were less rich than offshore island sites (Littler 1978*a*, *b*, *c*, 1979*a*, *b*; O'Brien & Littler 1978). This mainland–island difference is sometimes related to ocean current patterns and at times related to greater human population pressures on mainland sites than on island site (Nicholson & Cimberg 1971). However, in contrast to the mainland shores, the intertidal areas of the offshore islands in southern California are predominantly rocky (Emery 1960). Studies on mainland rocky shores, where the substrate is unstable, indicate that the community composition is limited by this habitat instability (Souza 1979). Littler (1980) also notes that the Coal Oil Point habitat is strongly influenced by sand movements. Therefore, for a number of reasons, data from rocky intertidal island sites are not a good comparison for the Coal Oil Point area in a study to detect effects of natural oil seepage.

Studies on upper intertidal rocky shore communities indicate that when a layer of petroleum (e.g. 1–2 cm thick) covers the substrate, all organisms are smothered (Nicholson & Cimberg 1971). This dry black petroleum substrate has several effects. It increases the substrate

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temperature on sunny days on low tide. This lowers the upper limit in distribution of intertidal species. The upper intertidal community is composed of both barnacles (*Chthamalus* spp.) and short algae (*Enteromorpha* spp.). The blackening of the surface increases the settlement rate of barnacles because cyprids show a preference for black over lighter coloured surfaces. Areas covered with dry black tar therefore have a slightly lower intertidal distribution of these organisms, and larger populations of barnacles in relation to algae, than unoiled surfaces (Straughan 1976*a*). These types of changes can be induced experimentally by the use of black fouling plates in comparison with light coloured fouling plates. *Balanus glandula*, which occurs lower intertidally than the chthamalid zone, readily settled on dry black petroleum (Straughan 1976*a*).

Mussel (*Mytilus californianus*) communities extend from the middle to low intertidal levels and below. Studies of mussel communities from Coal Oil Point from quarterly surveys in 1975–6 revealed that, as at the other sites in the study, there is a certain site specific uniqueness about the Coal Oil Point community, but the data did not reveal anything that could be specifically related to natural oil seepage (Straughan & Kanter 1978). However, when this information was combined with studies from Goleta Point and other mainland and island sites in southern California conducted from 1976 to 1978, Kanter reached the conclusion that 'lower species diversity is associated with the presence of tar' with the exception of Coal Oil Point (Kanter 1978, 1979, 1980). Kanter suggested that some acclimatization to petroleum at Coal Oil Point may account for the actual increase in species numbers at that site. While this may be so, there was a major oceanographic change in southern California in late 1976 (Cayan 1980) that complicates the interpretation of this comparison. In addition, these studies placed little emphasis on intertidal height, which could be a very important factor when combined with an input of petroleum.

Studies conducted on mussel communities from Goleta Point, a site with a lower exposure to natural oil seepage, and a site with an exposure to natural oil seepage as close to zero as practicable, indicated that petroleum was an important factor influencing these communities but that intertidal height was also an important factor (Straughan 1980). Further, as yet unpublished, analysis of these data indicate that the responses of mussel bed faunas to oil seepages differ markedly between the higher and lower intertidal areas of the mussel bed. In the higher mussel bed samples, 5 of the 32 most common species showed a response to petroleum. This included a negative response for *M. californianus* and a positive response for *B. glandula*. In lower mussel bed samples, 26 of the 32 most common species showed a positive response to petroleum but *M. californianus* was generally unresponsive.

Several studies have also been conducted on specific sublethal effects of exposure to petroleum on individual mussel bed species. For example, external presence of black petroleum on the gooseneck barnacle, *Pollicipes polymerus*, is correlated with a reduced brooding rate in this species (Straughan 1971, 1976*b*). However, studies on size and reproduction in *M. californianus* from Coal Oil Point and other sites did not reveal any differences attributable to natural exposure to petroleum seepage (Straughan 1976*b*; 1977*a*).

Kelp bed communities including abalone and sea urchin populations were studied in the Coal Oil Point – Goleta Point area. No structural abnormalities were found among encrusting bryozoans from kelp fronds (Straughan & Lawrence 1975). Studies on the kelp bed fishes and macroplankton (Ebeling *et al.* 1971) and more recent studies on the kelp bed fishes alone (Ebeling *et al.* 1980) did not suggest any population changes related to exposure to natural oil seepage. Population changes in the Coal Oil Point and adjacent kelp beds were related to structural habitat changes.

Population and reproductive studies in the sea urchin (*Strongylocentrotus purpuratus*) and several species of abalone did not reveal any changes correlated with chronic exposure to natural oil seepage. These are benthic grazing species feeding on either attached or drift algae. Relatively low abalone populations at Coal Oil Point are believed to be the result of 'overfishing' (Straughan 1977*b*). Tissue analysis of abalone from Coal Oil Point resulted in the identification of petroleum hydrocarbons in 4 of the 21 animals examined. This illustrates the patchiness of actual exposure to petroleum in the natural oil seep area.

The sandy substrates are very mobile, both intertidally and in shallow subtidal areas. Up to 30 cm of sand may be moved in a single tidal cycle on southern Californian beaches (Straughan 1978*a*, *b*, 1979*a*, 1982). The Coal Oil Point area is no exception even though the generally fine sandy sediments are often thought to indicate little sand movement. The beach rock underlying the sandy beaches is often exposed after storms (e.g. the survey on 20 April 1980). At other times, there is up to 1.25 m of sand covering the rocks. Seventy macrofaunal species were recorded from surveys of the sandy beach sampling site from 1969 to 1978. The actual number of species and organisms changed with the availability of sand.

The sandy beach area studied near Coal Oil Point (figure 4) is the most heavily oiled beach from natural oil seepage in southern California. In one survey in the spring of 1977, 57299 g of tar were collected in a stretch of sandy beach 40 feet (12.1 m) wide and extending from high tide to low tide. However, even in this area there were occasions when no tar was found in the intertidal area.

Analysis of data collected from repeated surveys of seventeen sandy beaches in the Southern California Bight between 1975 and 1978, on a survey by survey basis, indicated that overall biotic changes were more closely correlated with grain size and moisture content of sediments and beach length than with tar (Straughan 1979*c*). There was considerable variability at Coal Oil Point, which is at least partly related to the sediment movement in the area. Further data analyses to relate distribution and abundance of species directly to the abiotic characteristics of their habitats should assist in separating changes due to petroleum from the other environmental changes occurring at this site.

ATP contents varied from 113 to 1274 ng ATP ml^{-1} of sediments taken on quarterly surveys at three intertidal heights (Holm-Hansen 1978). This compares with values of 125–1259 ng ATP ml^{-1} from sandy beaches in southern California away from oil seepage. It also encompasses the range of values recorded for subtidal sediments at Coal Oil Point (Spies *et al.* 1980). This subtidal sampling site is almost directly offshore from the sandy beach.

Meiofaunal samples were collected in conjunction with the intertidal ATP samples (Straughan 1979*b*). The most abundant organisms were nematodes. The distribution and abundance of nematode species changed with intertidal height and depth in the sediments. No harpacticoid copepods were recorded in these samples. This could be related to the grain size of the sediments and may or may not be related to oil seepage.

There have been three major subtidal infaunal studies in the area (figure 4). The box core study in 1975–6 did not sample areas of the natural seepage trends (Fauchald & Jones 1982). These data analyses relate strictly to the biota and do not include abiotic factors. The Coal Oil Point samples were similar to areas sampled on the mainland shelf in the Southern California Bight in species richness and diversity. While Coal Oil Point had similar depth related communities to the other two sampling areas, there was a greater similarity to the Point Dume area than to the Huntington Beach – Laguna area. More individuals were collected at the latter site than at Coal Oil Point. The comparison was complicated by the smaller number of stations sampled at Coal Oil Point than at the other two areas.

The general biotic similarity of benthic infauna to other mainland sites is also noted for the two stations sampled by hand cores. Davis & Spies (1980) note that these stations are quantitatively similar to the *Nothria* spp. – *Tellina* spp. community described for large areas of the shallow Southern California Borderland (Barnard & Hartman 1959; Jones 1969).

Both hand core sampled stations contained petroleum hydrocarbons in the sediments. The 'seep' station contained wet petroleum in the sediments while the 'non-seep' station apparently did not. The publications to date have not shown if data were collected throughout the survey to determine if this difference was consistently maintained (Davis & Spies 1980; Spies & Davis 1979; Spies *et al.* 1980). It is unfortunate that these data were not compared with another control located outside the natural seep area. While this complicates the analysis by including other variations, it is difficult to define changes caused by exposure to natural oil seepage when all samples are within the natural oil seep area.

Hand core samples were also collected at the centre and margins of an oil seep intrusion. These samples showed high bacterial activity in the intrusion area and at times there was surface formation of white mats of the bacterium *Beggiatoa* sp. There were few macroinvertebrates in samples from the intrusion area but numerous nematodes, which increased in numbers from the centre to the margin of the intrusion to form a halo effect.

The third infaunal study was conducted by using box cores in 1972 and 1973. Abiotic variables believed to influence the distribution and abundance of these organisms (e.g. grain size, hydrocarbons in sediments) were measured in each box core sample. However, this was not designed as a community study and was limited to the larger infaunal species by the use of a 2 mm screen. The reasons for the original study design are documented in Straughan (1976*b*). These samples were collected from areas exposed to very high levels of petroleum hydrocarbons in the seepage trends as well as lower levels of petroleum hydrocarbon exposure outside the trends, and from a series of control sites outside the Santa Barbara Channel and heavily urbanized and industrialized areas of the Southern California Bight. While the distant locations of these 'controls' introduced some complicating factors into the data analysis, they do provide non-seep exposure data that were lacking in the hand coring programme. The 1972–3 data did not show any overall trends that could be related to petroleum hydrocarbons in the sediments. In the light of the results from hand core programme, complete reanalysis of these latter box core data, including analysis from the previously unidentified samples, would be of interest to determine if the population response patterns predicted for the smaller forms of the infaunal community can be extended to the larger infaunal species.

Discussion

The data suggest that the impact of natural oil seepage on the distribution and abundance of species fits a curve such as that postulated for organic enrichment (Pearson & Rosenberg 1978) and brine discharges (Mackin 1973) (figure 5*a*). This curve exists through both time and space. Its magnitude and thus ease of detection depends on the initial dosage of oil and the limits of sampling. There is an initial area–time of almost total destruction of benthic organisms, followed by an area–time of stimulation, followed by a gradual return to 'normal' conditions. The area–time scale differs for different organisms.

Events following the deposition of a thick layer of seep oil in the upper intertidal zone provide an example of this relation through time (figure 5*b*). All organisms covered by this layer are killed. The toxic components of the tar are gradually lost and the tar hardens. When the tar is hard, the barnacle population will even recolonize at above the pre-oiled population level. As the tar dries further, it becomes unstable and is removed gradually by wave action. The

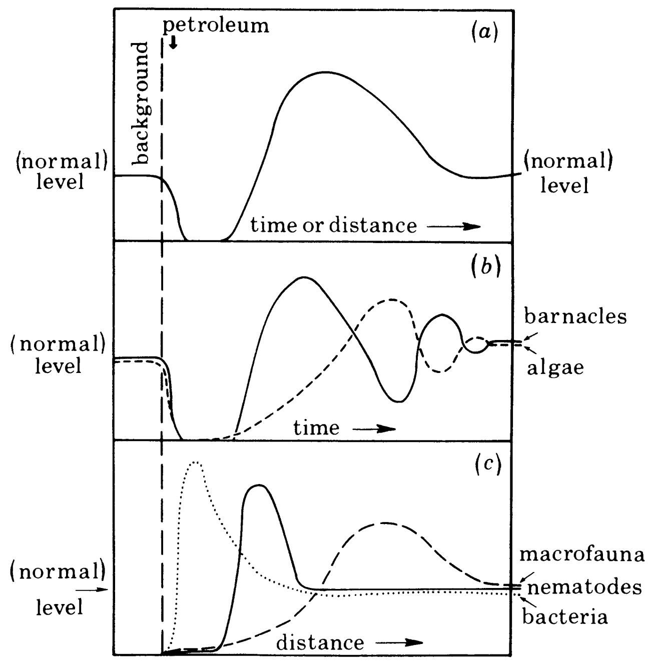

FIGURE 5. Response curves of populations to high levels of exposure to natural seep oil in terms of distance and time: (*a*) the basic type of curve; (*b*) a simple type of interaction on upper intertidal rocks; (*c*) a more complex type of interaction between subtidal benthic fauna.

barnacle population will then gradually return to a pre-oiled equilibrium. This is very simplistic and in the field is complicated by interaction with algal species and seasonal recruitment patterns.

A second example could explain the type of data collected in the detailed shallow water infaunal study from 1975 to 1978. Close to the seep vent, where petroleum hydrocarbon levels are high, there is increased bacterial activity, which decreases with distance and decreasing petroleum hydrocarbons in sediments. A little further from the point of seepage, (*ca.* 0.5 m) there is a 'halo' effect with increased nematode populations, which again then decrease with increasing distance and decreasing petroleum hydrocarbons to normal background levels. A little further away (*ca.* 20 m), there is a peak in macrofaunal populations, which again decreases with increasing distances and decreasing petroleum hydrocarbons to normal background levels. Some of these interactions include food chain interactions that accentuate the successive population peaks (Spies *et al.* 1980).

If such patterns exist, why have they not been recorded in other subtidal studies at Coal Oil Point? Studies conducted in 1975–6 with a box core did not include any of the four major

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seep trends, while studies with box cores in 1972–3, which did include major seep trends, only considered large macroinvertebrates.

These patterns occur over small distances, and the horizontal axis of the curves presented in figure 5 is probably logarithmic. Unless the sampling pattern is appropriate to the scale of pattern change, the change will not be recorded (Kershaw 1973). For example, if the sample block size is equal to a branch on the tree, the data will not show if the leaves form clusters or not. In this instance, the use of a box core (surface area 20 cm × 30 cm), which is then lowered through the water column and cannot be directed to a specific spot as can a diver with a hand core, is something akin to using a branch as a sampling block only to find out that the pattern is in the leaf arrangement on the branch. In the observed instances, the areas of the curve where invertebrate population numbers were low were areas where the petroleum was in a liquid form. Davis & Spies (1980) state, 'it appears that as the level of fresh seep-oil increases, the sediments become less habitable for macrofauna and more conducive to microbes'. The areas of very high oil contamination are very small in relation to the total study area at Coal Oil Point.

The sampling scale is also important for the changes recorded in the barnacle and algal populations in the upper intertidal area. For example, field observations on naturally oiled and unoiled rocks at Goleta Point (referred to as Campus Point) were 2.55 cm^2 (Straughan 1976*a*).

One point that should be noted if these curves are to be extrapolated to the community level is that the distribution of petroleum is patchy in the area of natural seepage. Different patches will therefore be at different stages on the curve. If the sample block size contains several of these patches, it may show an enriched biota in comparison with sample blocks that contain only one type of condition. This hypothesis of patchy removal and varying stages of successional replacements is becoming increasingly popular in general ecological theory (Caswell 1978) and in accounting for the high diversities and patchy distributions of coral reef biotas (Grassle 1973) and subtropical soft-bottom benthos (Stephenson 1980).

Davis & Spies (1980) suggest that fluctuations through time in their data are due to a combination of trophic enrichment of sediments causing increased larval settlement, which in turn attracts and supports larger populations of deposit feeders, and in turn attracts more predators (e.g. sand dabs, halibut and rays), so creating localized disturbances, and these enriched localized disturbances induce large settlements of larval organisms. However, there are parallel population peaks of some species at both sampling stations with wet seep oil in the sediments and those assumed not to have wet seep oil in the sediments. In addition, Spies & Davis do not present any data to show that these changes were not related to variations in abiotic parameters (e.g. changes in hydrocarbon content of sediments, changes on grain size). While sediment instability due to localized disturbances is important to the structure of soft bottom communities, in this instance, it is probably overshadowed by larger sediment movements through oceanic activity (Fischer & Berry (1973) indicate that changes in the surface sediment depth at Coal Oil Point is an important factor in changing rates of oil seepage). Without the abiotic data to show that there were not other limiting factors changing during the study, the importance of localized physical disturbance is questionable. However, if the localized disturbance as hypothesized by Spies & Davis is an important controlling factor, it does not explain the 'apparent enrichment' in biota reported from solid substrate communities.

The other important point emerging from these studies is that the 'impact is greatest' in upper intertidal areas and decreases across the intertidal zone and with increasing water depth. The 'impact is greatest' is defined as meaning that the change due to the presence of oil is the largest and lasts for the longest time. However, this is postulated to be due to a gradation in physical parameters, oceanic forces and bacterial degradation rate from high tide level across the intertidal zone and into deeper waters. At this stage it is unknown if this hypothesis would hold for deep waters off the continental shelf.

One example is the gradation in temperature change caused by the presence of black tar. The surface temperatures of black tar in the upper intertidal zone range over 30 °C depending on the weather conditions (9–40 °C). The surface temperatures of black tar in the lower intertidal zone have a much smaller range of temperature (10–15 °C) depending again on the weather conditions. In a subtidal situation, the tar would remain at sea temperature.

In summary, then, the natural oil seep area at Coal Oil Point is a mosaic of different habitat types upon which is superimposed a mosaic of differences in exposure to natural petroleum seepage in space and time. The natural variations in animal populations and the large-scale natural oceanic variability in the area combine with this variation to produce a very complex system. The mosaic of different types of research programmes conducted in the area then appear to produce conflicting data.

However, when these programmes are considered within the limits imposed on each programme by the aims, sampling methods and data analysis, some overall trends emerge.

1. The effect of high dosage of the seep oil can be described by the types of curves presented in figure 5.

2. Effects are greatest and most prolonged at the top of the intertidal zone and decrease down the beach and with depth to the mainland shelf.

3. The distribution of petroleum is patchy in time and space, causing the effects to be patchy.

4. While some areas may be depauperate, and other areas may actually be trophically enriched, the overall patchiness of this pattern and distribution of intermediate stages may explain the apparent general enrichment over a large area of Coal Oil Point.

5. Few sublethal effects have been recorded and these have generally been very localized.

I thank those who have assisted in the preparation of this paper by assistance on research programmes quoted in the text, financial support for projects and personal support. I am also grateful to Dr G. Jones of the University of Southern California for permission to quote from a document before publication (Fauchald & Jones), and to D. Hadley for preparing the illustrations.

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Discussion

D. H. Dalby (*Department of Pure and Applied Biology, Imperial College, London, U.K.*). Have the Californian sea-floor oil seeps been in progress for, geologically speaking, a long time? This would have bearing on whether or not local populations of the marine benthic fauna might have evolved in equilibrium with this hydrocarbon pollution.

Dale Straughan. Yes the natural oil seeps at Coal Oil Point have been in existence for a long period of time, geologically speaking. However, most of the animals studied in this area have pelagic larval stages so that there has probably been no long-term multi-generation adaptation. The limited tolerance experiments that we have conducted suggest that any increase in tolerance is limited to animals in the immediate seep area.

D. J. Crisp, F.R.S. (*Marine Science Laboratories, Menai Bridge, U.K.*). Could Dr Straughan tell us what would be the scale of the influence of a natural oil seep on the area of enrichment by oil present in demonstrable amounts in the water column, and on the enhancement of bacterial growth on the surrounding seabed?

Dale Straughan. I have discussed this with Dr Spies. He said that the samples showing enhanced bacterial growth were all within 50 cm of the oil seep vent and that the samples showing enriched macro-invertebrates were about 20 m from the oil seep vent. I am afraid I do not have similar information for the water column.

J. M. Baker (*Field Studies Council, Orielton Field Centre, Pembroke, U.K.*). Could Dr Straughan describe in more detail the frequency of oiling of the rocky shore and the sizes of the areas affected each time? How regular or predictable is the oiling of the shore?

Dale Straughan. The oiling of the shore could not be described as either regular or predictable. Some upper intertidal areas always have a layer of dry tar with patchy overlays of oil in various stages of drying. The pieces of tar that actually come ashore vary from very small pieces to pieces up to 60 cm in diameter. At times liquid petroleum also washes ashore. In some instances the whole intertidal area has been covered by wet petroleum in some form, but I have also visited the area when there were no signs of fresh petroleum in the area.

A. J. Southward (*Marine Biological Association, Plymouth, U.K.*). My own view of Goleta point is that it must be one of the most impoverished rocky shores I have seen on the west coast, and I can confirm that sand scour is very severe, as noted by Dr Straughan. However, I wonder if possible long-term effects of the oil seeps could be shown by comparing these Santa Barbara shores with other sand-scoured rocks, such as at Malibu and below Scripps, which are clear of the oil but still within the same faunal province?

Dale Straughan. Goleta Point does appear visually to be very impoverished because the upper surface of the rocks is covered with a layer of black tar. The black body effect of the tar lowers the upper limit of distribution of some of the intertidal species. My own idea is that the impact of this petroleum decreases from high tide to low tide. This is supported by available data.

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Entire intertidal comparisons with sites to the south of the area – but not as far as Scripps – have been conducted, as have some mussel community studies. As I indicated in my paper, the results are somewhat complex due to the various interacting gradients in the area. However, I suspect that a carefully planned upper intertidal comparison alone would show a reduction in biota associated with the Goleta Point area covered with tar.

A. D. McIntyre (*Marine Laboratory, Victoria Road, Aberdeen, U.K.*). The work of Dr Spies suggests that a relatively normal macrobenthic community can exist in some oil seep areas, even where globules of oil can be seen in the sediments. Could Dr Straughan comment on this in view of the well documented adverse effects of low concentrations of oil on marine organisms?

Dale Straughan. I think that the difference between these two sets of observations is due largely to the petroleum involved. Usually, instances where low levels of petroleum have large adverse effects, involve refined products and in general there is a large component containing lighter hydrocarbons.

At Santa Barbara, while some light ends are present in the fresh seep oil, it is generally characterized as being a heavy asphaltic crude.

J. H. Vandermeulen (*Marine Ecology Laboratory, Bedford Institute of Oceanography, Dartmouth, Nova Scotia, Canada*). I should like to add to Dr Straughan's observations some physiological results that were obtained on a cruise through the Scott Inlet seep area on the east coast of Baffin Island. This seep was detected a few years ago by investigators from the Bedford Institute of Oceanography in Canada, and two years ago was the subject of more detailed investigations, including a biological component headed by Dr Ed Gilfillan from the Bowdoin College marine research laboratory in New Brunswick, Maine. In this work, involving field observations on feeding and carbon flow in marine zooplankton, it was noted that feeding in larger *Calanus* copepods taken from the seep area was depressed significantly relative to the same species taken from non-polluted Baffin Bay waters. Of course, it is always difficult to relate directly and unquestionably such observations with the presence of oil, especially in non-controllable field conditions such as a seep area. None the less, the results were so consistent and the feeding inhibition of such magnitude that the conclusion seems inescapable, i.e. that in this instance the zooplankton being swept through the seep area (which is several square kilometres in area) experience a narcotization due to dissolved petroleum hydrocarbons coming up from the bottom seep area.

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