References and Notes

1. P. Ashton, *Biol. J. Linn. Soc.* **1**, 155 (1969).
2. G. L. Stebbins, *Flowering Plants: Evolution above the Species Level* (Harvard Univ. Press, Cambridge, Mass., 1974).
3. B. S. Simpson and J. Haffer, *Annu. Rev. Ecol. Syst.* **9**, 497 (1978).
4. J. S. Beard, *J. Ecol.* **33**, 1 (1945); J. Wyatt-Smith, *Malayan Forester* **17**, 5 (1954); L. J. Webb, *Aust. J. Bot.* **6**, 220 (1958).
5. T. C. Whitmore, *Change with Time and the Role of Cyclones in Tropical Rain Forest on Kolombangara, Solomon Islands* (Commonwealth Forestry Institute, Oxford, England, 1974).
6. J. H. Connell, *Science* **199**, 1302 (1978); M. Huston, *Am. Nat.* **113**, 81 (1979).
7. S. P. Hubbell, *Science* **203**, 1299 (1979).
8. Data from the National Geophysical and Solar-Terrestrial Data Center, Environmental Data Service, National Oceanic and Atmospheric Administration, Washington, D.C.
9. We observed landslides along 45 km of the coast from Jaqué to the Colombian border and 10 km inland in the Rio Jaqué valley. Observations further inland were not feasible at the time and Landsat photographs are unavailable for the region after the quakes: damage may be more extensive.
10. We distinguished a highly damaged central zone (160 km^2), less damaged peripheral areas (193 km^2), and river plains and mangroves with few slides (97 km^2). Mean percent of denuded ground in eight sections (1 by 3 km) of an aerial photograph (Fig. 2) from the central zone was 20 ± 6.2 [standard deviation (S.D.)]; the percent of the two least damaged, adjacent sections, used as an estimate for the less damaged peripheral areas, was 11 ± 2.4 (S.D.).
11. E. O. Wilson and E. O. Willis, in *Ecology and Evolution of Communities*, M. L. Cody and J. M. Diamond, Eds. (Harvard Univ. Press, Cambridge, Mass., 1975), pp. 522–534.
12. The most abundant [*Trema micrantha* (L.) Blume] and five most abundant species included 66 and 91 percent, respectively, of 539 individuals in 18 species in a transect 30 m^2 on a 2-ha slide in Panama, 8 months after the quakes.
13. Calculated over a square degree of latitude and longitude (≈12,000 km^2). A cut-off point of 6.0 on the Richter scale was used by Brooks (*15*) and was maintained in the analysis of the Panama data.
14. From or calculated from data in D. S. Simonett, in *Landform Studies from Australia and New Guinea*, J. N. Jennings and J. A. Mabbutt, Eds. (Australian National Univ. Press, Canberra, 1967), pp. 64–84.
15. J. Brooks, unpublished report, cited in Simonett (*14*).
16. Distribution of seismic zones from B. Gutenburg and C. F. Richter, *Seismicity of the Earth* (Princeton Univ. Press, Princeton, N.J., 1954). Distribution of tropical rain forests from the following maps: A. W. Küchler, *Vegetation of the World* (Rand McNally, Chicago, Ill., undated); figure 2 in (*17*); and figure 1.1 in (*18*).
17. P. W. Richards, *The Tropical Rain Forest* (Cambridge Univ. Press, Cambridge, England, 1952).
18. T. C. Whitmore, *Tropical Rain Forests of the Far East* (Clarendon Press, Oxford, 1975).
19. Mean and maximum height of *T. micrantha* were 94 ± 6.8 [standard error (S.E.)] cm (N = 152) and 4.5 m, respectively; individuals in less disturbed areas ranged up to at least 6 m. Growth was 65 ± 5.7 (S.E.) cm (N = 152) from 8 to 20 months after the quake.
20. Percent cover, visually estimated through a transparent grid, was 2 percent after 8 months and 23 percent after 20 months on the upper two-thirds of the slide, and 19 and 43 percent on the lower third.
21. G. S. Hartshorn, in *Tropical Trees as Living Systems*, P. B. Tomlinson and M. H. Zimmermann, Eds. (Cambridge Univ. Press, Cambridge, England, 1978), pp. 617–638; N. Brokaw, unpublished data.
22. R. B. Foster, personal communication.
23. H. L. Crutcher and F. T. Quinlan, *Atlantic Tropical Cyclone Strike Probabilities* (Naval Weather Service Command, Washington, D.C., 1971); H. L. Crutcher and L. R. Hoxit, *Southwest Pacific and Australian Area Tropical Cyclone Strike Probabilities* (Naval Weather Service Command, Washington, D.C., 1974).
24. C. F. Bennett, *Human Influences on the Zoogeography of Panama* (Univ. of California Press, Berkeley, 1968).
25. K. J. White, presidential address to the Papua New Guinea Scientific Society, 26 March 1975 (T.C. Whitmore, personal communication).
26. T. T. Veblen and D. H. Ashton, *Vegatatio* **36**, 149 (1978).

27. We thank R. Foster, R. Lawton, E. Leigh, A. S. Rand, A. P. Smith, J. Teeri, two anonymous reviewers, and others for comments and discussion; G. Angehr, J. Bryan, L. Cruz, N. Franks, D. Glanz, W. Glanz, R. Lawton, and G. VanVliet for field assistance; H. Janos for figure assistance; R. Steward and J. Steward for bringing the landslides to our attention; and the Smithsonian Tropical Research Institute (STRI), especially I. Rubinoff and A. S. Rand. Funds for the Panamanian expeditions were provided by STRI and, for operation of the R.V. *Stenella*, by the George Becker Fund of the Smithsonian Institution (SI). Supported by an NSF graduate fellowship and the Hutchinson Fund of the University of Chicago (to N.C.G.), by an SI postdoctoral fellowship (to D.P.J.), and by the Coulter and Hutchinson Funds (University of Chicago) and STRI (to N.B.).

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Observation of a Subsurface Oil-Rich Layer in the Open Ocean

Abstract. *A layer of water at a depth of 200 meters containing 3 to 12 milligrams per liter of oil was found during February and March 1978 over a distance of 800 nautical miles in the southwest North Atlantic and the eastern Caribbean. The geochemistry and carbon-14 activity of the oil shows it to be a weathered crude, probably from a submarine seep. Although the dimensions of the oily layer were not determined, conservative estimates indicate that more than 1 megaton could have been present.*

During February and March 1978, on a cruise investigating the chemistry of the subtropical underwater (*1*), we found an extended layer of unusually oil-rich water about 200 m below the surface of the southwestern North Atlantic Ocean and the eastern Caribbean Sea (Fig. 1). At stations 11 to 24, a transect of 800 nautical miles, hexane extracts of seawater obtained from depths of 150 to 250 m yielded 3 to 12 mg of weathered oil per liter (average of 6 mg per liter). Extracts of samples from both above and below the oily layer at stations 11 to 24 and from all depths at stations 26 to 38 had hydrocarbon concentrations (micrograms per liter) and distributions typical of the open ocean (*2*). Because the sampling at each station was centered about the subtropical underwater, the discovery of the oily layer was serendipitous.

Water was collected in a 90-liter polyvinyl chloride drop-top sampler and transferred into 20-liter glass bottles through steel tubing. Forty liters of each sample was batch-extracted with hexane within 1 hour of collection. The extracts were concentrated by means of a vacuum within 1 hour of collection, esterified with boron trifluoride-methanol reagent,

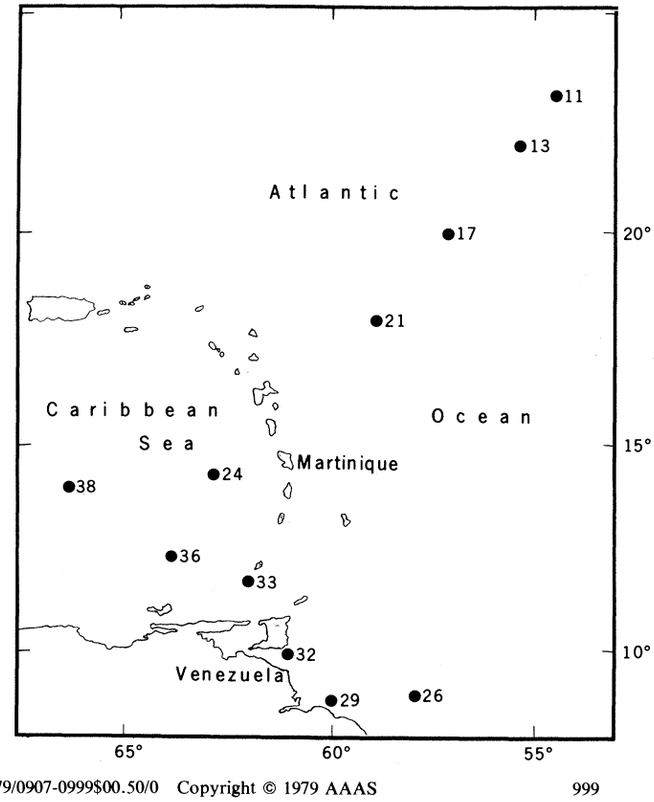

Fig. 1. Sampling stations of NOAA *Researcher* cruise R-78-1. The oily layer was found at stations 11 (12.6 mg, 200 m), 13 (5.8 mg, 200 m), 17 (9.6 mg, 270 m), 21 (3.2 mg, 145 m), and 24 (2.8 mg, 150 m and 5.7 mg, 200 m).

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Table 1. Percentage of fatty acid distributions.

Station	Depth (m)	14:0*	15 br	15:0	16:1	16:0	17 br	17:0	18:1	18:0	20:1	20:0	22:0	24:0
11	56	10	1.7	3.0	6.5	33.6	2.9	1.5	13.6	15.4	0.5	0.8	0.8	0.8
11	200	0.2	0.0	0.0	0.0	32.1	0.4	0.0	33.2	13.6	1.0	5.0	0.8	2.9
17	130	6.2	2.0	3.0	9.6	26.8	1.9	2.3	4.3	10.3	0.6	0.6	0.1	0.2
17	270	0.0	0.0	0.0	0.0	28.1	0.3	0.0	31.1	12.7	0.9	6.1	0.3	5.1

*In this nomenclature, 14:0 is a 14-carbon straight-chain acid with no pi bonds, 16:1 has one pi bond, and br indicates branching as determined by the GC retention index and mass spectral analysis.

and fractionated (*3*). The paraffinic and aromatic hydrocarbons, fatty acid methyl esters, and silated sterol fractions were analyzed at sea by gas chromatography (GC) on 30 m by 0.25 mm wall-coated, open tubular glass capillary columns coated with either SE-30 silicone oil or Dexsil 300. During the cruise, all likely sources of extraneous contamination, such as the ship's fuel, lubricants and hydraulic fluid, the water sampler, and other associated hardware, were extracted, fractionated, and analyzed by GC. None of these extracts resembled those from the oily layer. Procedural blanks, run at regular intervals during the cruise, did not resemble the subsurface oil.

The fractionated oil consisted of 60 to 70 percent hydrocarbons, 5 to 10 percent fatty acids, and 4 to 8 percent sterols and fatty alcohols. The GC of the paraffin fraction showed a narrow-range (C_{16} to C_{26}) symmetrical, unresolved complex multiplet (*4*) centered at n-C_{20} with only traces of n-alkanes evident. Such symmetrical distributions are usually not observed in pelagic tars (*5*). The pristane to phytane ratio varies from 0.9 at station 24 to 1.2 at station 11. The C_{18} to phytane ratio of 0.3, the C_{22} to background ratio of 0.2, and the absence of alkanes above C_{25} indicate a biochemically weathered oil that has not undergone evaporative weathering (*6*). Comparison of these ratios with those from sunken tar weathering studies (*7*) indicates that the subsurface oil was weathered for 1 to 2 years when we found it. The infrared and mass spectra indicate only normal, saturated, cyclic and branched hydrocarbons in fraction 1 (*3*). Gravimetric and GC calculated weights agree within 10 percent. The aromatic fraction was analyzed by computer-assisted GC and mass spectrometry. In addition to abundant ions due to alkylated naphthalenes, anthracenes, and phenanthrenes, mass fragmentograms of mass to charge ratios of 184, 198, and 212 revealed the presence of dibenzothiophenes. Dibenzothiophenes are not biosynthesized and are known only in fossil fuels.

The nonhydrocarbon fractions in the extracted oil were distinct from those extracted from samples outside the oily layer and must have a different source. Table 1 shows the fatty acid distribution at two typical stations above and in the oily layers. The shallower samples had distributions similar to those observed by others in open-ocean waters (*8*). In contrast, the distribution of acids associated with the oil is biased toward the longer chain lengths, and $C_{18:1}$ accounts for one-third of the total acids.

The sterol distribution of open-ocean water has been studied by Gagosian (*9*). In the present study, analyses of water outside the oily layer agree with his work and indicate that cholesterol is the dominant sterol at a concentration of about 1 μg per liter. In contrast, the dominant sterol in the oil was β-sitosterol or clionasterol (*9*) at a concentration of more than 300 μg per liter; cholesterol was only a minor component at 5 μg per liter.

Because of its quantity, quality, and observed distribution, we believe this oil layer results from a natural seep. This is supported by the absence of natural ^{14}C activity in the sample from station 11, which thus has an apparent age of >22,000 years before present. The total amount of oil entering the sea from natural seeps is unknown. On the basis of limited data from known seeps and conservative extrapolations, Wilson *et al.* (*10*) estimated that between 0.2×10^6 and 6.0×10^6 tons of oil per year enter the oceans from seeps. Blumer (*11*) argued that such estimates were too high. The currently used estimate of 0.6×10^6 ton/year reported in a workshop of the National Academy of Sciences (*12*) is obviously a compromise figure.

The breadth and thickness of the oily layer reported here is not known, but integrating over a conservative estimate of its dimensions, that is, 800 nautical miles long, 1 nautical mile wide, and 100 m thick, results in a total of more than 1 megaton.

Accurate assessment of the quantity, frequency, and duration of subsurface oil seeps is beyond present resources or technology. Similar discharges of crude oil may occur elsewhere and would pass undetected except by chance. The quantity of the oil described here may have been greater than the total estimated oil entering the sea annually (*12*). An attempt was made, on another cruise in January 1979 to determine the width of the oily layer. Sampling was done between 10° and 21° north latitude on a course of 130°. This cruise crossed the 1978 track near Martinique. Gravimetric and GC analyses of detailed profiles from seven stations revealed no trace of the oil found 11 months before.

We believe the most likely source of the oily layer is a seep located on the Venezuelan shelf at a depth of about 200 m. This is an area where offshore seeps have been reported. Such oil could be carried north at depth, probably in a dispersed state, by the Guyana and Antilles currents until entrained by midwater easterly flows into the southern Sargasso Sea as discussed by Reid (*13*). In fact, observations of subsurface oil east of the Antilles represent independent evidence supporting physical indications of a mid-depth easterly return of water into the subtropical North Atlantic (*13*).

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References and Notes

1. L. V. Worthington, *On the North Atlantic Circulation* (Johns Hopkins Press, Baltimore, 1976), chap. 14.
2. R. A. Brown and H. L. Huffman, Jr., *Science* **191**, 847 (1976).
3. The fractionation is adapted from J. W. Farrington and B. W. Tripp, *Geochim. Cosmochim. Acta* **41**, 1627 (1977). A portion of the oil not exceeding 5 mg was chromatographed on 3 cm of alumina (5 percent deactivated with H_2O) over 3 cm of silica (5 percent deactivated with H_2O) in a disposable Pasteur pipette. Eight fractions (F) were eluted with 1.5 ml of each of the following: hexane, 10 percent benzene-hexane, 20 percent benzene-hexane, 50 percent benzene-hexane, benzene, 5 percent methanol-benzene, 10 percent methanol-benzene, and 20 percent methanol-benzene. Saturated hydrocarbons were in F-1, aromatics were in F-2 and F-3. Fatty acid methyl esters were in F-4 and F-5. Sterols were in F-7 and F-8.
4. J. W. Farrington and B. W. Tripp, in *Marine Chemistry in the Coastal Environment*, T. M. Church, Ed. (ACS Symposium Series No. 18, American Chemical Society, Washington, D.C., 1975), pp. 267–284.
5. J. N. Butler, B. F. Morris, J. Sass, "Pelagic tar from Bermuda and the Sargasso Sea," *Bermuda Biol. Stn. Res. Spec. Publ. No. 10* (1973), appendix 3.

6. M. Blumer, M. Ehrhardt, J. H. Jones, *Deep-Sea Res.* **20**, 239 (1973).
7. A. Zsolnay, *ibid.* **25**, 1245 (1978).
8. P. M. Williams, *J. Fish. Res. Board Can.* **22**, 1107 (1965).
9. R. B. Gagosian, *Geochim. Cosmochim. Acta* **39**, 1443 (1975).
10. R. D. Wilson, P. H. Monaghan, A. Osanik, L. C. Price, M. A. Rogers, *Science* **184**, 857 (1974).
11. M. Blumer, *ibid.* **176**, 1257 (1972).
12. *Petroleum in the Marine Environment* (National Academy of Sciences, Washington, D.C., 1975).
13. J. L. Reid, *J. Geophys. Res.* **83**, 5063 (1978).

14. We thank J. Farrington and N. Frew for the mass spectral analyses and M. Ehrhardt, J. Farrington, and W. Sackett for valuable discussions. The ^{14}C activity was run by E. Drüffel, La Jolla Radiocarbon Laboratory (University of California, San Diego) through the courtesy of P. M. Williams under NSF grant No. EAR76-226-23. The officers and crew of the National Oceanic and Atmospheric Administration (NOAA) ship *Researcher* made the sampling both possible and enjoyable.

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Oxidant Effects on Californian Coastal Sage Scrub

Abstract. *Causes for the reduced cover of native species of coastal sage scrub in certain southern Californian sites were sought among 43 habitat variables. The mean annual concentration of oxidants (which averaged 18 parts per 100 million on the 11 most polluted sites) is statistically indicated as the most likely causal factor. Sites of high oxidant levels in the region are also characterized by declining species richness and equitability.*

Southern California experiences the highest mean annual concentrations of photochemical oxidants in the United States. In 1976, for example, the federal standard for oxidants [8 parts per hundred million (pphm)] was exceeded on 206 days in the South Coast air basin (*1*). While the effect of these oxidants on montane conifer vegetation (*2*) and crop species (*3*) grown in the region has been investigated in some detail, information is lacking on the effect of oxidants and other air pollutants on the predominant native shrubland vegetation of the region: chaparral and coastal sage scrub. I report here suggestive evidence that regional oxidant levels are causing a deterioration of the natural structure of sage scrub communities in the most polluted portions of their range.

Coastal sage scrub dominants (such as species of *Salvia*, *Eriogonum*, and *Encelia*) are drought-deciduous, mesophyllic, shallow-rooted, and typically 0.5 to 2.0 m tall. By contrast, the dominant shrubs of the chaparral are evergreen, sclerophyllous, deep-rooted, and typically 1 to 3 m tall. Coastal sage scrub occupies lower elevations (generally below 500 to 900 m) on the coastal and interior sides of the coast ranges, from San Francisco to El Rosario (Baja California). The chaparral occupies upper elevations of the coastal mountains, extending into the North Coast ranges, east to central Arizona, and south into Baja California (*4*).

In 1977–1978 I sampled 67 sites of coastal sage scrub throughout its range. I recorded foliar cover of all plant species along four 25-m line transects within a sample plot 25 m on a side, and recorded the presence of any additional species within the plot which did not intercept the transect. This sample intensity was shown to be adequate for 99 percent replicability in chaparral vegetation (*5*). In addition, for each site I obtained information on 43 habitat variables concerning community structure, topographic position, substrate, climate, fire and grazing history, and mean annual air pollution concentrations (*6*). No sampled site had burned less than 7 years previously, and past or present grazing intensity at the sites was such that the present shrub cover was not noticeably affected. Sites were embedded within areas supporting comparable vegetation, extending at least an additional 25 m on all sides.

Data for eight air pollutants monitored in a network in southern California were obtained from the California Air Resources Board and the South Coast Air Quality Management District. Annual mean concentrations of each pollutant were calculated for as many years as data were available [mean ± standard deviation (S.D.) = 7 ± 4 years; range 1963 to 1977] at each monitoring station. The mean concentration of the air pollutant at the sampling site was estimated by averaging values from nearby monitoring stations and adjusting the values by distance from the site by using the formula of Oshima (*7*). No station was used if it was (i) more than 30 km from the site, except for six coastal sites where prevailing wind conditions made the use of closer inland stations inappropriate; (ii) separated from the site by a topographic barrier greater than 1000 m in elevation and 5 km in length;

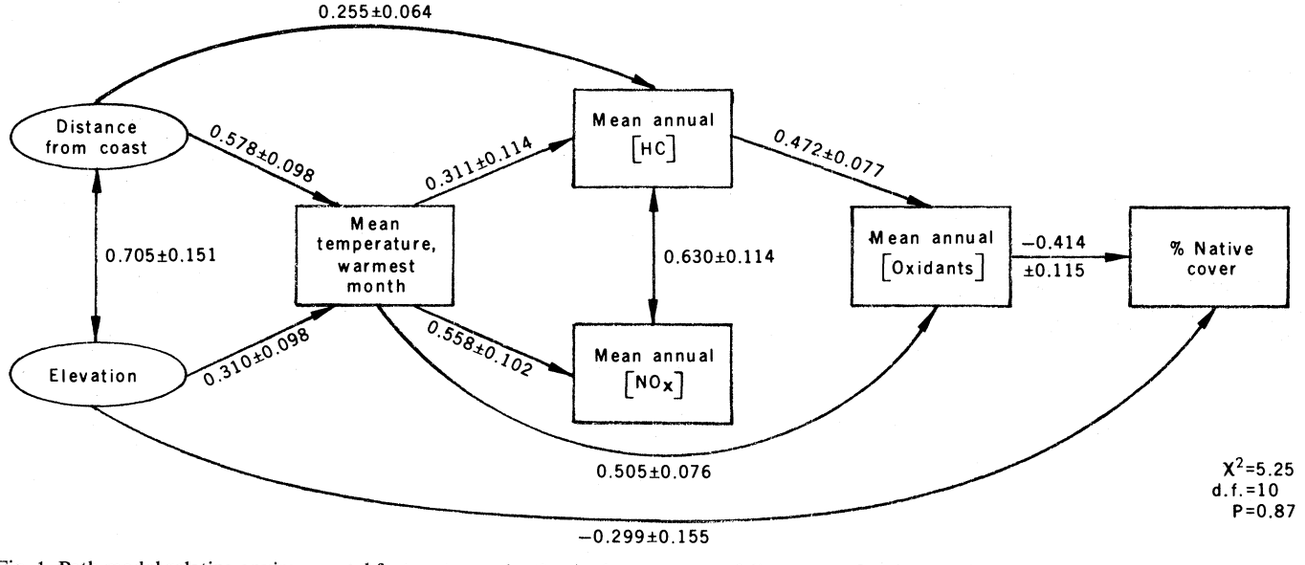

Fig. 1. Path model relating environmental factors to a reduction in the percentage foliar cover of native species of coastal sage scrub in 67 sites in California and Baja California. Single-headed arrows are causal paths (numbers are path coefficients ± standard errors); double-headed arrows indicate correlations; *HC* indicates total hydrocarbons; NO_x indicates oxides of nitrogen.

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