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THE BIOLOGICAL AND ECOLOGICAL EFFECTS OF OIL POLLUTION IN TROPICAL WATERS

An Annotated Bibliography

Office of International & Environmental Programs
Smithsonian Institution

Appendix C

Annotated Bibliography on the Biological and Ecological Effects of Oil Pollution in Tropical Waters

Christopher P. Onuf

This bibliography does not pretend to be complete nor does it include unpublished surveys recently carried out in Indonesia on oil pollution effects.

C. P. Onuf
Santa Barbara
California
July, 1973

Citations in the annotated bibliography include oil pol-
plution in colder, high latitude waters as well as tropical waters. Those which are specific to warm tropical waters are listed below.

Tropical Regions in General

Anonymous, 1971

Birkeland et al., 1973

Burns and Teal, 1973

Cabrera, 1971

Cerame-Vivas, 1969

Connell, 1970, 1971

Diaz-Piferrer, 1964

Glude, 1968

Gooding, 1971

Grant, 1970

Johannes et al., 1972

Lewis, 1971

Pearce and Ogren, 1968, 1969

Puerto Rico University, 1968

Rutzler and Sterrer, 1970

Spooner, 1970

Spencer and Spooner, 1968

Straughan, 1970

Wohlschlag and Cameron, 1967

Gulf of Mexico

Alpine Geophysical Associates, 1971

Anonymous, 1970

Arlington, 1970

Bechtel and Copeland, 1970

Bleakley, 1969

Copeland, 1965, 1966, 1967

Crowder, 1971

Environmental Protection Agency, 1972

Glasgow, 1971

Gowanloch, 1935

Kloth and Wohlschlag, 1972

Lund, 1957

Macklin and Hopkins, 1961

Macklin and Sparks, 1961

Petty, 1970

St. Amant, 1970

Spears, 1971

Steed and Copeland, 1967

Allen, H. 1971. Effects of petroleum fractions on the early development of a sea urchin. Marine Pollution Bulletin 2(9):138-140.

The soluble extracts of the oils used were prepared by vigorously shaking 25 ml. of the oil with 500 ml. of sea water in a separatory funnel. The water was then drawn off leaving almost the original volume of oil behind. Oils had virtually no effect on fertilization. In general, the more highly refined products were less harmful to cleavage and development. The author's reservation about the study is her use of one of the most sensitive organisms known. Trials consisted of observations on 100 individuals replicated 3 times.

Alpine Geophysical Associates. 1971. Oil pollution incident: Platform Charlie, main pass block 41 field, Louisiana. Water Pollution Control Research Series 15080 FTU 05/71. Washington, D.C.: U.S. Government Printing Office.

No adverse biological effects can obviously be attributed to the wild well. Most of the report that deals with biological aspects consists of cataloguing the biological resources of the Mississippi delta, conjecturing about possible consequences such as blooms of noxious dinoflagellate due to nutrient enrichment by the oil and conversion to toxic products upon biodegradation, and listing the fortuitous circumstances which minimized the effects on organisms and fisheries: of important organisms, only shrimp were present in the region at the time of the spill and it was not the season for catching them.

Anderson, E.K., L.G. Jones, and C.T. Mitchell. 1969. Evaluation of ecological effects of liberated oil in the Santa Barbara Channel. Report to Western Oil and Gas Association. 54 pp.

[Two page summary of the Tamipco Maru spill.]

Anonymous. 1970a. Few blowouts reported in Gulf. Offshore 30(3):28.

Of 7800 wells drilled in the Gulf of Mexico since 1956, there have been only 26 blowouts. Only 2 spilled much before the big 1970 blowout and fire.

[This is probably the best evidence for predicting the probabilities of blowouts in other exploitation of continental shelves.]

Anonymous. 1970b. Effect of slicks on fish life is studied with roller device. National Fisherman 51(2), Sec. B:23.

The "roller device" is only used in collecting oil films from the surface of water. No mention is made of the biological experiments that are conducted with the oil that is collected this way.

Anonymous. 1971a. Cuba tackles pollution. Marine Pollution Bulletin 2(3):36.

The grounding of the Oriental Challenger is barely mentioned. An unspecified amount of high octane aviation fuel was pumped into the sea. "Temporary losses of fauna were reported, but in subsequent routine sampling no more dead organisms were found."

Anonymous. 1971b. A harmless oil dispersant. Marine Pollution Bulletin 2(2):22.

Dr. S.A. Broom, University of Washington, tested the effect of concentrations between $5x10^2$ and 10^5 ppm of Corexit 7664, alone and mixed with oil (Kuwait crude), on the photosynthetic and degradative capacities of microflora in beach sand. "There was no significant breakdown of chlorophyll... and the uptake of radioactive carbon remained fairly steady throughout. Oxygen uptake was increased in all cases... but with oil alone was greatest. The lesser uptake in the presence of Corexit was probably due not to toxicity but to the rapid removal of oil, the substrate of the microflora."

Anonymous. 1971c. Oil company not guilty of fish kill. Clean Air and Water News 3(22):336-337.

Arlington, R. 1970. Corpus Christi Bay: a case history of oil and a clean seaport. Offshore 30(6):28-34.

Deals only with administration of oil production and cleaning up policies, which so far has been quite successful.

Baker, J.M. 1973. Biological effects of refinery effluents. In Conference on Prevention and Control of Oil Spills, 13-15 March 1973, pp. 715-724. Amer. Petrol. Inst., Washington, D.C.

The major factor determining the extent of damage caused by refinery effluents is how fast they are dispersed in receiving waters. Where dilution is rapid, no effects are apparent. Where receiving waters are not rapidly renewed, damage is severe and may extend to many acres.

[Data on the characteristics of the effluents add to the usefulness of the review. It is important to note that much besides hydrocarbons is present in the effluents and will contribute to damage. The conclusion that saltmarshes and mudflats are the most vulnerable environments seems justified.]

Bardach, J.E., F. Masaru, and A. Holl. 1965. Detergent effects on the chemical senses of the fish Ictalurus natalis (Le Suer). Science 148(3677):1605-1607.

Detergents caused damage to chemoreceptors of yellow bullheads at concentrations as low as 0.5 ppm. Electrophysiological studies showed impaired function sooner than histological examination. At 1 ppm for 28 days, experimental animals exhibited heightened activity compared to controls, also did not respond to the introduction of food pellets whereas controls did. When returned to clean water, fish returned to normal activity patterns but even after six weeks did not respond to food pellets dropped further away than 12 cm. whereas controls did up to 50 cm.

[Irreversible sensory impairment which interfered with feeding occurred at 1 ppm of detergents. Death occurred at 10 ppm.]

Bechtel, T.J., and B.J. Copeland. 1970. Fish species diversity indices as indicators of pollution in Galveston Bay, Texas. Contr. Marine Science, University of Texas 15:103-132.

The biggest contribution of wastes to Galveston Bay is petrochemical industrial effluents into the Houston Ship Canal. Trawls were made in each of four seasons at 27 stations in bay waters and Shannon-Weaver diversities were calculated for all catches. Apparently diversity increases as the wastes are diluted. Increased dominance of anchovies, Anchoa mitchilli, are indicative of deteriorating water quality, as is a decline in the number of large fish.

[The data are not convincing. Correlating diversity with salinity accounts for more of the variance than does dilution of wastes. Comparisons of diversities in different bays are inferred to agree with expectations based on the relationship between pollution and diversity but no account is taken of possible salinity differences.]

Birkeland, C., A.A. Reimer, and J.R. Young. 1973. Effects of oil on tropical shore natural communities in Panama. Smithsonian Institution. Prepared for the Federal Water Quality Administration, Environmental Protection Agency. Washington, D.C. 217 pp.

(Authors' Abstract and Summary Conclusions). The effects of oil pollution on tropical intertidal marine communities were tested by precisely controlled experiments utilizing tarry Bunker C and volatile marine diesel oils. Field experiments were performed on a Caribbean intertidal reef flat community, a Pacific rocky shore community, settling plates in both oceans, mangrove trees sprayed with oil on the leaves and/or stilt roots and on coral growth. Major conclusions from these experiments were:

(1) Although appearing to be in good health after one day in the field following 2.5 hours of exposure to Bunker C oil, the mean growth increments of the hermatypic coral Porites furcata were significantly smaller than those of the controls during the following 61 days. Growth rates provide an indicator of the presence of unobserved physiological stress or damage and a quantitative index of the cost of repair.

(2) The mean growth of Porites furcata heads used as controls did not differ significantly while the mean growth of P. furcata heads subjected to Bunker C differed significantly among themselves. An individual variation in susceptibility to oil pollution is implied.

(3) The mean growth increments of control and experimental coral heads varied significantly in the field over 3 meter distances at the same depth and during time periods of the same length but two months apart. Location and time of year each had a greater effect than 2.5 hours exposure to Bunker C oil so very precise controls are required for pollution experiments.

(4) An increased percent surface coverage of algae was found on settling plates coated with Bunker C oil and in aquaria previously containing some Bunker C oil. After spraying with Bunker C oil, quadrats in the Caribbean intertidal contained more species of algae. The favorable effect of Bunker C on algae may be partially responsible for the increase in algae after tarry oil spills. This effect could be augmented by the failure of herbivore populations to recover as quickly as algae from oil spill destruction.

(5) Unlike Bunker C, the volatile marine diesel oil had a clear toxic effect on fouling communities. Dry weight measurements of production showed that plates coated with marine diesel had a significantly lower biomass of fouling organisms than did the control plates. Surface coverage measurements showed less space occupied by algae and animals on settling plates coated with marine diesel than on control plates.

(6) The spraying of leaves of mangrove trees (Rhizophora mangle) with the volatile fuel oil marine diesel was correlated with reduced leaf coverage or no growth of the trees during the following year. Coating the stilt roots with tarry Bunker C was of less definite effect. This may explain why the most obvious mortality among mangrove trees following the wreck of the SS Witwater was in a band along the windward edge of the forest facing the sea from the other side of a causeway. As Rützler and Sterrer (1970) noted, "high winds caused a spray of mixed seawater and oil to cover mangrove trees...to a height of 2 m above mean tide level" and that the oil had "...already killed many of these plants."

Birkeland, C., A.A. Reimer, and J.R. Young. 1973. (continued).

(Authors' Abstract and Summary Conclusions continued.)

(7) The quadrats on the Caribbean intertidal at Galeta were subjected to 8.6 times the concentration of oil as the coast off West Falmouth, Mass. The West Falmouth oil spill was accompanied by a 94 percent mortality while the animal communities at Galeta underwent no perceptable change. The factor responsible for the difference in mortality was probably the size of area involved. The isolated square meter quadrats were supplied with unaffected plankton and nutrients as the surrounding water washed across.

Baseline surveys were conducted on both the Caribbean and Pacific coasts of Panama. Different zones along the same transect in the Caribbean intertidal were found to differ in magnitude of fluctuations, predictability of change and spatial heterogeneity as measured by patterns of surface coverage on the primary substratum. Changes in structure of macro-invertebrate communities along the Caribbean transect were compared with patterns of temporal variation from data collected for over 500 identified species in 108 samples including a total of over 50,000 specimens. Recruitment to benthic communities was investigated with settling plates. The Caribbean was found to be seasonal in species occurrence while the Pacific was seasonal in productivity.

Bleakley, W.B. 1969. Shell production complex efficient, controls pollution. Oil and Gas Journal 67(36):65-69.

The water pumped back into the Gulf contains 30 ppm oil. Mackin and Hopkins (1961, p. 76) found a high of 226 ppm in 60 determinations of 23 bleedwaters. Their average value was 35 ppm. They cite values from other work varying from 3 to 931 ppm.

Blumer, M., G. Souza, and J. Sass. 1970. Hydrocarbon pollution of edible shellfish by an oil spill. Marine Biology 5(3):195-202.

Gas chromatography was used to determine the fate of No. 2 fuel oil spilled at West Falmouth, Massachusetts. Four months later it was still detectable in sediments. Oysters *Crassostrea virginica* and scallops *Aeguipecten irradians*

picked up an oily taste and exhibited chromatograms similar to those of the fuel oil. The alterations in composition of oil in the sediments and in the shellfish consisted primarily in the reduction of low boiling fractions. The sediments showed a greater decrease in normal alkanes than branched ones, probably due to preferential degradation by bacteria.

[Incorporation of oil into sediments preserves it.]

Blumer, M., H.L. Sanders, J.F. Grassle, and G.R. Hampson. 1971. A small oil spill. Environment 13(2):2-12.

95% of animals captured in trawling immediately after the spill were dead. Fish, shellfish, worms, crabs and other crustaceans were affected. Eight months after the incident the oil had spread to an area ten times that originally affected, reaching the deepest part of the bay. At that time amounts of oil in the sediments 2 1/2 miles from the wreck site increased ten-fold and areas which had been recovering at the periphery suffered mortality again. 500 acres of saltmarsh were contaminated and shellfishing was stopped for two years because of tainting. The second year, prohibitions on shellfisheries actually had to be imposed on areas not affected the first year. Reproduction of polluted mussels was virtually eliminated. Oil penetrated marsh sediments at least to a depth of 2 feet. Apparently the death of organisms in the sediments accelerated erosion. The sediments were then spread to new areas by waves and currents where they caused more mortality.

[The analysis of samples for oil as well as organisms makes this a valuable study. The generally greater damage reported for this spill than others probably owes to the combination of it occurring during a storm in shallow water over a soft bottom in semi-enclosed conditions, No. 2 fuel oil with a high proportion of aromatics being particularly toxic, and the workers looking in the right place. The findings which are important in considering potential dangers of future spills are the persistence of toxic oil in sediments, the importance in shallow water of turbulence and fine sediments in rapidly depositing oil in sediments before the dissipation of toxic fractions occurs, and the spread of damage long after an incident by movements of the sediments. In addition, the long closure of shellfishing might occur elsewhere under conditions where contaminated sediments may get suspended long after a spill.]

Burns, K.A., and J.M. Teal. 1973. Hydrocarbons in the pelagic *Sargassum* community. *Deep-Sea Res.* 20:207-211.

Sargassum contain several hydrocarbons which they seem to synthesize but in addition, they contain on the average as much which is due to pollution by petroleum. The animals do not seem to synthesize hydrocarbons, but generally contain larger concentrations of petroleum hydrocarbons than do the seaweeds. There is no evidence of food-chain magnification among the animals analyzed.

[This seems to be the only study reporting concentrations of petroleum hydrocarbons from different trophic levels. If carcinogenic hydrocarbons behave as those fractions studied here, they will not accumulate in fisheries products.]

Cabrera, J. 1971. Survival of the oyster *Crassostrea virginica* (Gmelin) in the laboratory under the effects of oil drilling fluids spilled in the Laguna de Tamiahua, Mexico. *Gulf Research Reports* 3(2):197-213.

No evidence is given that there actually was any mortality of oysters due to spilling 970.12 m^3 of drilling fluid into the lagoon. The whole fluid did cause mortality at concentrations of 1000-2000 ppm and 200-500 ppm, but not at 80-120 ppm in laboratory experiments. In tests of separate components of the drilling fluid, mortality was also demonstrated but it was noted that oxidation states in the used fluid were different than for the pure substances tested. Furthermore diesel oil comprised 64.7% of the commercial fraction of the drilling fluid, yet it was not tested alone.

[No useful conclusions are possible without knowing if the original spill actually did cause damage and without the major constituent of the fluid being tested (e.g., the constituent that most likely would be presumed dangerous.) No mention is made if tainting occurred. IMCO (1973) also reviews this report.]

California Water Quality Control Board. 1964. Fuel oils. In *An investigation of the effects of discharged wastes on kelp*, pp. 63-67. Sacramento.

[See annotations for North *et. al.* (1965), who review this work.]

Cerame-Vivas, M.J. 1969. Wreck of the Ocean Eagle. Sea Frontiers 15(4):224-231.

This is a journalistic report on the oil spill at San Juan, Puerto Rico. The only items on biological effects were: "Some of the detergents being used in San Juan harbor were lethal to all species observed in concentrations of one part per thousand." and that the absorbent which seemed most effective (Ekoperl 33) did not seem to be toxic.

Clark, R.B. 1972. Ecology of oil pollution. Marine Pollution Bulletin 3(4):63-64.

[A useful general evaluation of oil pollution studies.]

Connell, D.W. 1970. Protecting the Great Barrier Reef. Marine Pollution Bulletin 1(4):51-52.

[Note about proposed drilling.]

_____. 1971. Kerosene-like tainting in Australian mullet. Marine Pollution Bulletin 2(12):188-189.

The taint has led to condemnation of mullet catches in Moreton Bay, Queensland. Gas chromatography has shown that the tainting is due to a combination of n-alkanes and that chromatograms of sediment samples from the Brisbane River near a petroleum storage facility, and a sewerage outfall, and commercial kerosene all have very similar patterns. Concentrations ranged from traces to 5 ppm in the sediments. Other workers have shown that mullet become tainted in water containing 5 ppm kerosene and that detergents promote the acquisition of tainting substances.

[Tainting may be the most important biological effect of oil pollution that is definitely provable in the field.]

Copeland, B.J. 1965. Industrial pollution in marine ecosystems. In Commission Internationale pour l'Exploration Scientifique de la Mer Mediterranée, Pollutions Marines par les Micro-organismes et les Produits Petroliers. Symposium de Monaco, Avril, 1964, pp. 79-88. Paris.

[Same publication as "Copeland. 1966." (see below).]

_____. 1966. Effects of industrial wastes on the marine environment. J. Water Pollution Control Fed. 38:1000-1010.

By retaining petrochemical effluents in holding ponds (refineries, petrochemical plants) their adverse effects on the marine environment can be virtually eliminated before release into coastal waters. Fresh wastes are toxic and greatly reduce community metabolism (respiration plus photosynthesis). By 30 days holding time, metabolism is greatly stimulated. In addition, there has been a progressive change from respiration dominating to photosynthesis dominating, and finally to balance between the two.

[Probably the same pattern will occur with distance from an effluent source as dilution, aging, and growth of decomposer and plankton populations modify the wastes.

The importance of this paper is that it points out how wastes can be very simply handled to reduce their harm to coastal waters. One chemical plant in South Texas can process its effluents at 12¢/1000 gal. It would take 100 plants of similar size discharging into the same bay to equal the value of fisheries there. This seems to be a strong argument where waste disposal and other functions of receiving waters are in conflict to clean up the wastes first.]

_____. 1967. Biological and physiological basis of indicator communities. In Pollution and Marine Ecology, eds. T.A. Olson, and F.J. Burgess, pp. 285-288. New York: Interscience.

The number of zooplankton species per 1000 animals counted increased from 5 at the source of petrochemical industrial wastes to 19 at a distance of 20 miles.

[No indication is given of composition and quantity of wastes nor of what happens along control transects, where the study was done, or what else might be changing besides concentration of petrochemical wastes.]

Cowell, E.B. 1971. The ecological effects of oil pollution on littoral communities. Elesevier Publ. Co., New York. 250 pp.

(Author's Abstract). Milford Haven is the largest oil port in Great Britain. As of 1969, it handled 40 million tons of oil per year; by 1980, the load will probably be 80 million tons. In the first ten years of the port's existence, there were only four serious spills. These were the only incidents which led to obvious fouling of the shore. The other 400 plus incidents of pollution were treated before they reached shore. The number of pollutions per 100 vessels has generally declined during the period, with the last three years having the lowest rates.

Saltmarshes. The field studies of the spills which affected areas of saltmarsh indicate that recovery is rapid. Although the emergent vegetation is killed, new growth of the same shoots generally occurs. Field experiments consisting of spraying fresh Kuwait crude oil on marsh vegetation (4.51 applied by a sprayer to a 5m x 2m plot), indicate that recovery from one, two and four monthly sprayings is good, but eight and twelve monthly sprayings lead to more lasting damage, killing almost all of the vegetation and exposing mud. Annuals with shallow roots and little or no food reserves die upon one oiling. The dominant grasses are intermediate, responding well to as many as four applications of oil, some perennials usually with a rosette habit and large food reserves (e.g., tap roots) survive eight and twelve oilings. Cover by *Agrostis stolonifera* and *Oenanthe lachenalii* increased as a result of oiling. The season of the application had some effects. Summer spraying harmed annuals (*Salicornis spp.* and *Suaeda maritima*). Oiling, when flower buds are developing, markedly reduces flowering of the important grasses. Oiling of seed during winter may reduce germination in the spring. Possibly oil does more damage in hot, sunny weather. The die off of a *Spartina* marsh near the effluents of an oil refinery was probably due to frequent covering by thin films of oil since temperature, pH, sulfide concentrations and soil aeration did not seem to exceed the tolerances of the plants. Dying vegetation

Cowell, E.B. 1971. (continued).

(Author's Abstract continued.)

was seen to be covered by a light film of oil. The height of the dead marsh was lower than the healthy marsh surrounding, probably due to both increased erosion and the absence of decomposition of dead vegetation. Death due to phenols in the water or residual petroleum products in the soil are unlikely because plants survived and grew in soil and water taken from the vicinity of the effluent. The soil contained 6% diethyl ether extractable petroleum products. Perhaps damage by oil is enhanced by the up to 12°C increase in temperature caused in parts of the marsh by the refinery effluent. Cleaning treatments did not improve recovery of marsh but did not seem to retard it either (burning, treating with BP 1002 and cutting). Untreated oil adheres to marsh vegetation whereas it will lift off when treated with emulsifiers, only to be deposited elsewhere.

Points from discussions. Figures on the extent of oil pollution at Milford Haven presented in the October, 1969, Oceanus, are 50 times to 100 times too great. Also damage to saltmarshes similar to that of the West Falmouth spill is probably unusual because of its composition: 42% aromatics. The amount of oil deposited has an effect. The use of fresh Kuwait crude oil probably accentuates the damage which was observed in the field experiments compared to what would occur in a spill. Even 1/2 hour of weathering on the surface of the water before beaching would appreciably diminish the proportion of volatiles. In the burning experiments, five seconds was enough to make the oil on vegetation unlightable. It was necessary to use the sprayer as a flame thrower to do the burning treatment at all. D.S. Ranwell (Nature Conservancy) made the observation that the ability of saltmarshes to trap oil and their resilience to the damage make them valuable buffers in the vicinity of fisheries. The concern for fisheries centered upon intertidal shellfish beds, flat shallow sandy areas where young flatfish feed and grow and areas important to shrimp fishing.

The marsh grasses *Puccinellia maritima* and *Festuca rubra* when treated with oil showed greater increases in shoot length and dry weight than when untreated. Reasons considered for the stimulation were increased moisture retention

of soils, nutrients released from other oil killed organisms, growth regulating compounds in the oil, nutrients released from the oil itself, and increased nitrogen fixation. The last definitely did occur, nutrients released from dead organisms may have contributed in some cases but no macrofauna were obvious in the experimental turves, the growth regulator implicated in other research, naphthenic acid, did not have an effect and the other possibilities did not produce observable effects. Consequently nitrogen fixation is regarded as the most likely explanation of the observed stimulation. Fresh crude oil is more toxic than atmospheric residue which stimulates growth. Toxicity increases in the series paraffins, naphthenics, and olefin-aromatics. Within each series toxicity decreases with increasing molecular weight. Toxicity increases: hexane-hexene-cyclohexane-cyclohexene-benzene-toluene-xylene-trimethylbenzene. Exposure to air and sunlight of some highly purified oils increases toxicity by oxidizing part to acids and peroxides. Low viscosity equals high toxicity. The effect of oil applied at night when stomata are closed is small. The same emulsion is lethal when sprayed in the light. Very sunny or hot weather increases phytotoxicity of oils applied to terrestrial vegetation. Fresh Kuwait crude oil harms marsh vegetation whereas weathered stimulates it. All emulsifiers tested killed marsh grasses when applied undiluted but had no lasting detrimental effects when diluted to 10%, even when the same amount of emulsifier was applied. Since emulsifiers must be applied undiluted to be effective on oil, they ought not to be used in cleaning saltmarshes. Emulsifiers that arrive on shore from cleaning operations in open water, however, probably will do no lasting harm because they will be diluted sufficiently before reaching shore.

The rocky shore. Monitoring of the shore transects including 22 that were originally set up before industrialization of Milford Haven indicate that pollution has not led to distinguishable changes in the flora and fauna of the rocky shores. Changes of most species abundances were ranges to be expected of natural communities. The distinct increase in *Balanus balanoides* and decrease in *Chthamalus stellatus* almost certainly owes to a cooling trend of the last ten years compared to the ten years preceding. Probably the same cause accounts for the decline of the topshell *Monodonta lineata*. No explanation is offered for the decline of *Littorina saxatilis*.

Cowell, E.B. 1971. (continued).

(Author's Abstract continued.)

Field experiments. "Conclusions," p. 128, seem an adequate evaluation: "Two main conclusions may be drawn from the experiments. First, experimental oiling of the rocky shore did not damage the fauna and flora, except where the application of thick atmospheric residue brought about physical dislodgement of periwinkles and topshells. Secondly, the application of emulsifier caused substantial mortalities amongst many species, but its most damaging consequences stemmed from the development of an algal forest following the destruction of limpets and mussels. The ultimate effects of emulsifier treatment were, therefore, much greater than is apparent from an assessment of mortalities alone."

Laboratory experiments on organisms of the rocky shore. There are distinct seasonal variations in the responses of *Thais*, *Monodonta*, and perhaps *Gibbula*, to emulsifier BP 1002. Generally the limpet *Patella vulgata* seems to be the most susceptible of all shore animals to emulsifiers followed by *Mytilus edulis*. BP 1100 seems to be about two orders of magnitude less toxic than BP 1002. For most shore animals the higher the mortality also the longer for survivors to recover from effects of the emulsifiers. This effect is likely to have important ecological consequences for shores which are cleaned since even if the grazers survive, most will be washed out of the treated area. (They retract into their shells when exposed to the emulsifier and do not remain attached). The case histories of recovery from oil spills seem best explained by the dosages of emulsifiers used: untreated areas show no effects, moderate use of emulsifiers reduces populations of sensitive organisms which permits luxuriant growth of green seaweeds but animal populations are soon restored, and heavy use of emulsifiers which reduces many animal populations permits luxuriant growth of algae, which in turn ingibit re-establishment of animal populations.

[The rocky shore studies are not so convincing as the marsh studies because what happens in control areas is never explicitly presented. Green flushes do occur naturally, so their occurrence in areas of pollution is not necessarily caused by the pollution, nor is it clear that the fates of natural as opposed to pollution produced green flushes differ because of the activities of grazers. Laboratory assays of emulsifier toxicity were performed on

50 animals, but were never replicated. How much of the seasonal variation is actually block effects is not certain.]

Comparative toxicity of crude oils. See "Conclusions," p. 180. Figure 4 suggests that a 16°C toxicity is correlated with the content of aromatics and total distillate to 149°C but this relationship does not hold so well at 26°C and may even be opposite at 3°C.

Fresh crude oil is more toxic for all the shore animals tested than is atmospheric residue. *Littorina littorea* suffered 70-80% mortality when gasoline is poured on it but the length of exposure did not alter damage. Kerosene and crude oil were about comparable, increasing from about 10% mortality for 30 minutes exposure to 60-70% mortality for six hours exposure. Diesel fuel and two kinds of fuel oils had virtually no effect. Aeration of fresh crude oil for up to 24 hours did not diminish its toxicity. Some species are vulnerable to the physical effect of smothering: 100% mortality in two days for *Littorina obtusata*, in six days for *Thais lapillus*, but only 6% in five days for *Littorina littorea*. Conclusions include: only lighter fractions, which rapidly disperse are toxic, persistent fractions are not toxic.

In the vicinity of an outfall from a refinery receiving as much as 1000 million gallons of 20-25 ppm oil in a year, the shore was not barren. The fauna seemed normal beyond 50 yards, favored algae take over near the outfall. Lab experiments with the starfish *Asterias rubens* in 200 ppm oil showed diminished feeding on *Mytilus edulis* in eight weeks and death for most in 14 weeks. Similar conditions did not seem to affect *Carcinus maenas*.

On a 5m x 5m area of mudflat, there were 990 lugworm casts. The day after spraying with BP 1002, there were none while no change was seen in a control plot. Excavation three days later yielded no worms.

[The conclusion that heavy fractions are not toxic is contradicted by the effects of the fuel oil of the West Falmouth spill, Allen's (1971) assays of toxicities for sea urchin larvae and North, Neushul and Clendenning's (1965) experiments with the fuel oils and diesel oils on kelps. The chronic effects seem to be as localized as those described by Mackin and Hopkins (1961) for oysters near bleedwater effluents. The general conclusion of the symposium seems justified that oil is one of the least harmful pollutants of the sea.]

Crowder, B.E. 1971. Oil and fishing are compatible, says Crowder. National Fisherman 51(11):22-23.

Increasing production of commercial fisheries has accompanied the increased production of oil from offshore waters in Louisiana. The drilling rigs are responsible for a large and successful sportfishing industry. The article includes the text of a speech by Crowder, an Esso executive.

Deshimaru, O. 1971. Studies on the pollution of fish meat by mineral oils. Bulletin of the Japanese Society of Scientific Fisheries 37(4):297-306. (Japanese, English summary.)

Crude oil at 50 ppm caused tainting of yellow tail Seriola quinqueradiata in five days, 10 ppm in 13 days. Fish tasting or smelling of oil had gas chromatograms almost identical to the crude oil tested.

Dennis, J.V. 1959. Oil pollution survey of the United States Atlantic coast with special reference to Southeast Florida coast conditions. American Petroleum Institute, Division of Transportation. Washington, D.C. 87 pp.

This report presents data on the amount and kind of oil deposits occurring on Miami beaches each day for one year. Much more cursory observations are made of conditions at other locations along the Atlantic coast. The amount of oil reaching beaches at Miami was related to time of year, currents, and prevailing winds. The only biological effects mentioned were on bird life.

[The report is not useful for evaluation of ecological effects. It may provide some useful information on chronic dosage, but probably is outdated.]

Diaz-Piferrer, M. 1964. Effects of an oil spill on the shore of Guánica, Puerto Rico. Deep-Sea Research 11(5):855-856.

On the night of 16 July 1962, the Italian tanker Argea Prima ran aground on the reefs off Guayanilla Harbour on the south shore of Puerto Rico. Unable to obtain assistance, the captain decided to pump about 10,000 tons of crude oil into the sea coincident with the incoming tide to set the vessel afloat. The oil was blown ashore and transported by currents along the beaches as far as the bay at Boquerón on the west coast of the

island. Offshore coral reefs to the west also received a blanket of thick oil.

The first part of the shore affected was Guánica. The littoral zone at Guánica was characterized by a particularly rich and varied marine flora.

Having studied this area carefully, the author was able to note extensive damage caused by the oil. The most important physical damage was the heavy erosion of the beaches from the combined action of waves and oil. An estimated 3000 m^3 of sand disappeared from Tamarindo beach in less than a week. The sand tended to form small spherical masses with the oil. Some of these globules, consisting of small particles of shell and fine sand enclosed in oil (about 50% by mass of oil), were nearly afloat. Denser globules 20% or less of oil contained larger particles of sand, gravel and shell; these remained on the bottom but tended to move seaward.

The oil striking mangrove swamps settled among the roots, and where the amount of oil was great, this habitat was virtually destroyed.

There was a tremendous mortality of marine organisms along the shore. Adult and juvenile lobsters, crabs, sea urchins, star fishes, sea cucumbers, gastropods such as king helmets and queen conchs, octopuses, squids, a variety of fishes, particularly clupeoids, and sea turtles were found dead. It was noted that sea birds were absent from the area. The marine vegetation was seriously affected, especially the plants living in intertidal and sub-littoral zones. Large rocky areas were completely denuded of algae. Marine phanerogams, particularly Thalassia, were badly affected.

Economic damage was also extensive. The loss of entire beaches and large deposits of tarry oil seriously handicapped beach hotels and resorts as well as private individuals with beach cottages. This also directly affects local business dependent on tourists. The fishermen of Guánica had their gear damaged and there was an obvious depletion of the fisheries.

The oil-soaked sand was still evident on the bottom in several feet of water four months later. In October, 1962, algae began to repopulate the rocks and pools of the intertidal zone, almost entirely Myxophyceae.

[This is a valuable study, if the actual report and subsequent observations are available.]

Easley, C.T. 1970. Spill effects claimed grossly exaggerated. Oil and Gas Journal 68(18):69.

[Excerpt from a speech which consisted only of unsupported opinion concerning the potential dangers of oil prospecting on the Great Barrier Reef. The claim was made that 80% of oil spilled at sea evaporates in a short time and bacteria break down the rest. The lack of damage to the reef after the sinking of so many ships in the Coral Sea is cited as indicative that oil prospecting and production will not cause damage.]

Environmental Protection Agency. Office of Water Programs. 1972. Studies and investigations of the fate and effect of the Shell Oil spill, Platform B, Block 26, South Timbalier Bay (December 1, 1970 - November 30, 1971). EPA, Washington, D.C.

The patterns in the distributions of hydrocarbons and organisms in the sediments along transects radiating from the drilling platform are very erratic. There is no relationship between the number of species and hydrocarbons in the sediments, but there is a weak inverse correlation between numerical abundance of the invertebrate fauna and the concentration of hydrocarbons.

[The study was poorly conceived and conducted making it impossible to draw any firm conclusions. No controls were incorporated into the study. There is no indication of expected variability in benthic fauna in the vicinity of drilling platforms under normal conditions. Maxima in diversity and abundance occurred two or three miles from the rig along each of the transects and in most cases achieved lower values at greater distances from the rig than at the closest stations (one mile away from the rig). Contamination by oil was very patchy. Mortality, if important, was very localized and did not affect the number of species.]

Floodgate, G.D. 1972. Microbial degradation of oil. Marine Pollution Bulletin 3(3):41-43.

Bacterial degradation of hydrocarbons is very dependent on the conditions of culturing. Because optimum conditions are not often likely to coincide with the spilling of oil, it is suggested that the breakdown will usually take much longer than in laboratory tests and often will not reach completion. Oil degradation rates under varying conditions in the United Kingdom are tabulated below. It should be noted that seawater temperatures around the U.K. vary from about $2^{o}C$ to $16^{o}C$. The inorganic nitrogen concentration varies from <1 to around 500 μg N l^{-1}.

Floodgate, G. D. 1972.

Oil Degradation Rates

Bacteria involved	Kind of oil	Experimental conditions	Summary of results	Reference
Garden soil aerobes of several genera	Hydrocarbon mixtures in common use	Batch culture. Mineral salts media. Several temperatures between 20°C and 37°C.	0.4-0.75 g m^{-2} d^{-1} of some materials measured at 28°C.	Sohngen, N.L. (1913) Zentralbl. Bakt. Parasitkde. Ab. II:37,595.
Soil aerobes	Emba crude and lubricating oils	Batch culture. Nitrate or ammonia in mineral salts media. 23°C.	1.2 g m^{-2} d^{-1} for crude oil (45% of added oil), 0.4 g m^{-2} d^{-1} for lubricating oil.	Trusson, V.O., and Shapiro, S.L. (1934) Mikrobiologiya 3:79.
Enriched culture consisting predominantly of a marine Pseudomonas	Clear refined mineral oils	Probably batch culture 25°C aged sea water plus 0.5% KNO_3.	The oxidation of the mineral oil was indicated by O_2 uptake, CO_2 output and bacterial growth. The Q_{10} is given as about 3.0 for temperatures between 0 and 40°C. The average amount of oil degraded at 25°C is given as 1.2 x 10^{-10} mg per day bacterial cell. Hence it is calculated that if the oil is uniformly distributed in the water and the population is constant at 8 x 10^6 organisms ml^{-1} then the rate of oil degradation will be about 350 g m^{-3} yr^{-1} at 25°C and about 36.6 g m^{-3} yr^{-1} at 5°C.	ZoBell, C.E. (1964) Advances in Water Poll. Res., 3:85. This paper also appears in Air and Water Poll., (1960), 7:173.

Floodgate, G.D. 1972. (continued).

Bacteria involved	Kind of oil	Experimental conditions	Summary of results	Reference
Mixed culture of oil oxidizing bacteria	American crudes	Batch culture, aerated by shaking. 25°C sea water medium reinforced with 0.01% $(NH_4)_2HPO_4$. About 1 g placed in 100 ml medium. Oil dispersed on ignited asbestos.	Between 17.8% and 98.8% by weight of oil removed in 30 days. Average around 45%.	ZoBell, C.E., and Prokop, J.V. (1966). Z. allg. Mikrobiol. 6:143.
Natural sea water population	Crudes and several refined products	Batch culture. 18°C sea water medium reinforced with NH_4Cl and phosphates	The influence of various physical and chemical factors on oil degradation is illustrated. The presence of nitrogen and phosphate was shown to increase markedly the breakdown of diesel oil in 8 weeks. The presence of easily degraded material "spared" the oil. The effect of temperature is also shown.	Gunkel, W. (1967) Helgolander wiss. Meeresunters., 15:210.
Natural marine populations	"Atmospheric residue" of Kuwait oil	Sea water percolated through columns of beach sand (median grain size 250) with natural meio and micro fauna. Sands were lightly or heavily oiled. 10°C.	Oxygen uptake used as indication of degradation. Using a "B.O.D." value of 5.0, the author calculates a loss of oil from 0.09 g oil m^{-2} d^{-1} to 0.04 g oil m^{-2} d^{-1} depending upon dosing. These rates applied for several months and accounted for 10% of the oil. Preliminary gas chromatograms	Johnston, R. (1960) J. mar. biol. Ass. UK, 50:925.

Floodgate, G.D. 1972. (continued).

Bacteria involved	Kind of oil	Experimental conditions	Summary of results	Reference
Natural marine..... continued.			suggested the main loss of the alkane fraction. The remaining 90% decayed "immeasurably slowly."	
Selected mixed cultures of oil oxidizing organisms	Louisiana crude	Shaken flasks with sea water enriched with inorganic nitrogen, phosphates and yeast extract. Approx. 70 mg. oil added to 200 ml medium, 20°C and 30°C. Also simulated field studies of large tanks (900 l). Sea water enriched with $(NH_4)SO_4$. 500-100 ml of crude added. Temperature ambient 8-15°C. Seeded with oil oxidizing bacterial.	Initial oxidation attributed to breakdown of n-alkanes smaller than C_{18}. The initial rate was followed by a decrease and then another increase. Up to approx 50% of the crude was lost. No evidence of utilization of aromatics was found. In the large tanks the bacteria accelerated the loss of oil and changed its physical character.	Kator, H., Oppenheimer, C.H., and Miget, R.J. (1971). Prevention and control of oil spills. American Petroleum Institute Conference, 1971, pp. 287.

George, J.D. 1970. Sub-lethal effects on living organisms. Marine Pollution Bulletin 1(7):107-109.

A fuel oil spill at Southampton had no discernible effect on the polychaetes Cirratulus cirrata (Muller) or Cirriformia tentacula (Montagu), but where treated with the detergent "Essolvene" mortality occurred. Laboratory experiments demonstrated that animals which survived exposure to emulsifiers failed to develop gonads.

[This study is valuable because the site affected was already under intensive study. Consequently it was possible to ascertain that growth and reproduction were normal in addition to no lethal effects.]

Gilet, R. 1960. Water pollution in Marseilles and its relation with flora and fauna. In International Conference on Waste Disposal in the Marine Environment, 1st, Berkeley, 1959, ed. E.A. Pearson, pp. 39-59. New York: Pergamon Press.

Light oil slicks are common though not continuous occurrences throughout Marseilles Harbor. There is almost no tidal fluctuation. Nothing grows in the splash zone which is covered with oil. Below the surface, life is varied and exceedingly abundant, probably because of the organic enrichment by sewage discharges.

Gilfillan, E.S. 1973. Effects of seawater extracts of crude oil on carbon budgets in two species of mussels. In Conference on Prevention and Control of Oil Spills, 13-15 March 1973, pp. 691-695. American Petrol. Inst., Washington, D.C.

The extract was prepared by shaking 90 ml. of a blend of Mid-Continent Sweet crudes (Mobil) with 900 ml. of seawater at one stroke per second for 96 hours. The hexane extractable hydrocarbons dissolved in the water amounted to 12 ppm. 0, 1, 10, 50% solutions of extract and a 100 ppm emulsion were used at salinities of 31, 21, and 11 $^{o}/oo$. The mussels Mytilus edulis and Modiolus demissus were acclimated for 48 hours to each treatment and replicated five times. Salinity alone considerably depressed feeding rate. Oil at normal salinity depressed net carbon balance above 1% and progressively more so at higher concentrations. Effects of oil and

lowered salinity were not directly additive because oil stimulated feedings as well as respiration up to and including the 10% treatment for Mytilus. Apparently the diatom used as food was not acceptable to Modiolus, so conclusions are impossible about it.

[There is a clearcut stimulation of respiration by oil at the intermediate salinity and the combined effects of oil and salinity lead to a more severe depression of net carbon balance than either alone. The author's conclusion that this would lead to less available energy for growth and reproduction seems reasonable. As usual, the problem is how the results may be extended to field conditions. Except in the vicinity of continuous oily discharges it is unlikely that mussel populations will be exposed to the concentrations tested. Recovery when returned to clean water was not studied. If there are residual effects, it is much more likely that the observed physiological changes will be reflected in growth and reproduction than if the depression of net carbon balance holds only when exposed to the stresses.]

Gilmore, G.A., D.D. Smith, A.H. Rice, E.H. Shenton, and W.H. Moser. 1970. Systems study of oil spill cleanup procedures, In Analysis of Oil Spills and Control Materials, Vol. I. American Petroleum Institute. New York.

[The biological information is so sketchy as to be useless; however, the compilation of statistics on the conditions during which 36 major spills occurred is valuable.]

Glasgow, L.L. 1971. Louisiana fisheries resources pollution problems and recommended solutions. In Pollution Control and the Marine Industry, the Proceedings of the Conference sponsored by the International Association for Pollution Control, held at Rivergate, New Orleans, Louisiana, 1-3 April 1971, ed. J.S. Ives, pp. 15.1-15.6.

[A speech about potential dangers of pollution to the coastal environment. There is no information on biological effects of oil pollution.]

Glude, J.B. 1968. Observations of the effect of oil from the tanker Ocean Eagle and oil control operations on the fisheries of San Juan, Puerto Rico. U.S. Bureau of Commercial Fisheries. Seattle. 42 pp.

200-250 barrels of dispersant were applied, less than half inside the harbor. Talc, trade name "Mistrom Vapor," helped to coagulate the oil which then could be raked or scooped into containers and removed. Since it floats and is insoluble, the material probably did not damage aquatic species. Biological damage noted is the same as that reported by Pearce and Ogren (1968 and 1969), except that in addition an estimated 100 dead anchovies were seen in oil slicks. The absorbent Ekoperl (volcanic ash treated with silicone to enhance absorbing and prevent sinking) appeared to be moderately effective in absorbing patches of oil and did not seem to damage fish populations.

Gooding, R.M. 1971. Oil pollution from the tanker R.C. Stoner. Special Scientific Report--Fisheries No. 636. Washington, D.C.: U.S. Government Printing Office.

The tanker was carrying mainly military and commercial jet aviation fuels. The spill occurred at Wake Island. Apparently all the mortality had already occurred before the survey began. An estimated 2500 kilograms of fish were washed up on shore, more could have been lost seaward. Of fish >15 cm squirrel fishes (Holocentridae), surgeon fishes (Acanthuridae), parrot fishes (Scaridae) and groupers (Serranidae) composed the bulk of the kill and of the survivors as well. The most abundant dead invertebrates were Turbo sp. (gastropods), Tripneustes sp. (sea urchins), some beach crabs and cowries. Hermit crabs were abundant alive and did not occur among the dead. Diving surveys showed fish to be very abundant off the reef slope and perhaps unexpectedly rare on the reef flat. The reef flat is usually depauperate and stormy weather may have contributed to this condition. Probably the spill would have caused more damage if it had entered the lagoon and been trapped. Presumably the invertebrates of the reef flat were hit hard and will be slow to come back. Sharks seemed to be less cautious than usual. Typhoon Sarah removed almost all traces of the spill.

Gordon, D.C., Jr., and N.J. Prouse. 1973. The effects of three different oils on marine phytoplankton photosynthesis. Submitted to: Marine Biology, 2 April 1973.

Rates of photosynthesis of phytoplankton samples collected from the Bedford Basin, Nova Scotia, and the northwest Atlantic between Halifax and Bermuda were measured using a radiocarbon method while being exposed to concentrations of Venezuelan crude oil, No. 2 and No. 6 fuel oil up to 200 ppb. Up to ~20 ppb there is stimulation of photosynthesis, above that it is depressed. No. 2 fuel oil inhibited photosynthesis by 50% at 200 ppb, the others by about 20%. Even at 50 ppb inhibition was >25% and >10% respectively. Ambient concentrations in the Bedford Basin range from 0.5 to 60 ppb with a mean around 20 ppb. The open sea averaged a few ppb. The maximum observed 25 cm. below a 2 day old slick of crude oil was 800 ppb.

[This is the best study that I have seen of effects on phytoplankton because it uses natural phytoplankton communities and levels of contamination which are low enough to occur in coastal and oceanic waters. Their conclusion seems justified that levels of pollution in inshore waters may be sufficient to inhibit photosynthesis slightly but may even stimulate photosynthesis in oceanic waters.]

Gowanloch, J.N. 1935. Pollution by oil in relation to oysters. American Fisheries Society, Transactions 65:293-296.

Observations. Oyster beds in the vicinity of oil wells tapping salt domes suffered such high mortality as to make them economically unfeasible operations, whereas they had been good producers before the drilling.

Field experiments. Oysters were transplanted from healthy beds to areas outside the zone of the alleged pollution and to a bed that had suffered high mortality. In three months, mortality for the control transplant (outside polluted areas) was 9% and 46% inside.

Laboratory experiments. Treatment water pumped from above a healthy bed passed through a layer of crude oil, then baffles so that there was no direct contact between the oysters and the oil. Three similar experiments were run for 109, 60, and 22 days at different times of the year. Mortality of treatments averaged 4 times greater than controls.

Gowanloch, J.N. 1935. (continued).

[The design of the research seemed excellent, but only bits and pieces got reported. I do not know that the reported results for the field experiments were representative or the only ones suggestive that pollution by oil might be important. Also high mortality of transplants to a bed which had suffered high mortality could result from a communicable disease rather than pollution. The laboratory results indicate a difference, but the concentration of oil might have been unlikely to occur under field conditions (3ppm). The experiments were of long duration, applicable to cases of chronic pollution rather than a spill. Finally and possibly very important, high levels of mortality in the oiled water occurred much sooner in the high temperatures of summer. This phenomenon could have important consequences in evaluating the probable effects of oil in tropical waters.]

Graham, R.J., and T.C. Dorris. 1968. Long-term toxicity bioassay of oil refinery effluents. Water Research 2:643-663.

Untreated refinery wastes when diluted to subacute concentrations were no more harmful upon 32 days of exposure than they were in routine 96 hour tests. Effluents taken from different parts in a series of holding ponds caused little mortality even at full strength during routine 96 hour tests, but caused significant mortality in 16 and 32 day tests. Also, the "condition" (weight x 100,000 ÷ length^3) of the fathead minnows exposed to wastes was worse than that of control animals.

[This is a valuable study because it relates routine toxicity test to long-term effects including condition of animals as well as mortality. Although a freshwater fish was used, it is likely that the results will apply to marine organisms as well. The difference in behavior of high toxicity effluents diluted to subacute levels and full strength treated effluents which are also subacute is probably due to the fact that the processes which reduce toxicity in holding ponds do not operate on all the harmful substance. Heavy metals, for instance, may still be present in sufficient amounts to cause long-term damage.]

Grant, E.M. 1970. Notes on an experiment upon the effects of crude oil on live corals. Fisheries Notes. N.S. (1):1-3.

The experiment consisted of placing two turban corals (Favia speciosa) which were 6-inches in diameter in each of 3-15 gallon tanks and adding three pints of Moonie crude oil to two tanks. In one tank the water level was altered by siphoning to expose the corals to the oil layer for five minutes each day. Some of the oil dissolved because the water immediately became uniformly discolored. All corals survived five days, then a further 16 days with the oil layer removed. A soft coral (Xenia sp.) 1-inch in diameter died in two days.

Greze, V.N. 1970. Conservation in the Black Sea. New Scientist 48(724):180-181.

Oil products released from ships sometimes exceed several grams per liter in Black Sea ports. 10^{-4} to 10^{-5} ml/l of oil products have pronounced toxic effects on developing spawn of the plaice-kalkan.

[The report is a review which touches only lightly on oil. The author mentions the work of Mironov, some of which I have looked at.]

Horn, M.H., J.M. Teal, and R.H. Backus. 1970. Petroleum lumps on the surface of the sea. Science 168:245-246.

Tar balls occurred in 75% of 734 neuston hauls made in the Mediterranean and Atlantic from Gibraltar to the Azores. As much as .5 ml/m^2 was found. An isopod Idotea metallica and a gooseneck barnacle Lepas pectinata were commonly associated with the lumps. Stomach contents of the epipelagic fish Scomberesox saurus included tar.

[Although harmful fractions of petroleum are still present within the tar lumps, they probably do not constitute a serious hazard to marine life because an impervious layer encloses them. It is impossible to ascertain if the tar lumps have caused any change in the composition of the neuston because study of the neuston is so recent that the petroleum pollution has always been present. It is not known whether ingested tar gets into tissues. Burns and Teal (1973) suggest that the gills are probably the important route by which hydrocarbons are incorporated into animals.]

Hurst, J.W., Jr. 1955. Oil pollution of shellfish. Maine Department of Sea and Shore Fisheries. 1 p.

Tainting of clams occurred near a fuel depot at Searsport even though there was no visible evidence of oil pollution. 30% of clams tested tasted oily. After a spill at Wiscasset all clams were tainted, but they were not common in the several miles of contaminated beach. In another spill, 58% of the clams were tainted two weeks after the incident; 37% were still tainted after three weeks, but not afterwards. Fishermen suffered an economic loss because buyers refused all clams from this region for several weeks.

IMCO. 1973. The environmental and financial consequences of oil pollution from ships, Appendix 3. Report of Study No. VI submitted by the United Kingdom to Intergovernmental Maritime Consultative Organization.

[This is a very thorough and valuable review. Generally, I concur with their evaluations. I differ from their point of view in regard to baseline studies. Pollution incidents have proved to be so local that almost never is a valid baseline available, nor is it even reasonable to plan for the future. In general, I think that simultaneous controls are more practical and useful.]

Jacobson, S.M., and D.B. Boylan. 1973. Seawater soluble fraction of kerosene: effect on chemotaxis in a marine snail, Nassarius obsoletus. Nature 241:213-215.

Using kerosene extracts prepared in different ways, concentrations of 1 ppb in one experiment and 4 ppb in the other significantly reduced the number of snails responding to oyster or scallop extracts. Three months after a spill at Chedabucto Bay, Nova Scotia, 10-90 ppb of dissolved Bunker C oil were found at stations up to 20 miles away. Naphthalenes, the major component in kerosene seawater extracts have been reported around 1 ppb in the Charles River Basin, Boston.

[The demonstrated effects could be important since similar concentrations do occur in the field. It would have been more useful to have acclimated snails to the kerosene extract first, since in time the snails might be able to distinguish between the food cue and the kerosene inhibitor.]

Jeffries, H.P. 1972. A stress syndrome in the hard clam, Mercenaria mercenaria. Journal of Invert. Pathol. 20: 242-251.

Clams from a polluted part of Narragansett Bay do not get larger than 11 cm. whereas they frequently exceed 12 cm. in cleaner parts of the bay. During the summer mortality of adults is 1% per day (polluted). Young clams are abundant there but must be recruited from breeding populations in cleaner parts of the bay. Polluted animals differ in many biochemical characteristics from clean ones, but in the same way as animals stressed by normal environmental variation such as temperature. The difference is in degree, the pollution adding on to the normal burden of environmental stress. The cause of the pollution stress is the accumulation of a tar-like substance in epithelial then renal tissue which persists at least a year in animals transplanted to clean water. Presumably the tar-like irritant is derived from petroleum products and hydrocarbons from other pollutants. There is also a high incidence of infection by a polychaete parasite in polluted animals.

[The study was conducted in a very heavily polluted estuary receiving large quantities of domestic and industrial wastes. The clam beds have been closed to exploitation for many years. The point which generalizes is that normal environmental stress and pollution interact additively to reduce size of individuals and populations of adults of a commercially important species even where it is not eliminated.]

Johannes, R.E., J. Maragos, and S.L. Coles. 1972. Oil damages corals exposed to air. Marine Pollution Bulletin 3(2):29-30.

Lewis' (1971) study of the effects of oil and dispersants on corals can be objected to because he did not permit evaporation of volatiles which would be likely to occur under natural conditions. Nevertheless, particularly in the Pacific, corals are occasionally exposed to air. In combination with oil, damage might result. 22 species of coral were tested in floating racks which partially exposed part of each coral to air. A .6 mm layer of oil overlay the water. Waves agitated the racks and splashed water and oil on the exposed portion for 1 1/2 hours. Thereafter, the racks were placed in 2 m of water and the subsequent histories

Johannes, R.E., J. Maragos, and S.L. Coles. 1972. (continued).

of the corals followed for a month. No colonies were killed outright, but portions of most kinds to which oil adhered after being fully immersed in water died and macroscopic algae grew on the exposed skeletons. Branching forms suffered more damage than massive kinds.

[The conditions for the contact of oil and corals in air do not occur frequently nor are whole colonies likely to succumb even when they do occur. Probably corals themselves are not particularly vulnerable to oil. (The oil was Santa Maria crude oil, 12% kerosene distillate, 20% aromatics.)]

Kanter, R., D. Straughan, and W.N. Jessee. 1971. Effects of exposure to oil on Mytilus californianus from different localities. In Conference on Prevention and Control of Oil Spills, 15-17 June 1971. Am. Petr. Inst., Washington, D.C.

Mussels collected from different localities differed in their abilities to survive in seawater covered with layers of crude oil. Those collected in the vicinity of a natural seep did best in all treatments but animals collected from two non-seep areas differed considerably in their tolerances. Even without mixing, the thicker the oil layer the greater the mortality.

[Doses were huge, ranging from 1:10 to 1:1000 oil to water. The results are suggestive that the mussels from near a natural seep are more tolerant to oil because of prior selection, but the drastic differences between non-seep regions at all but the 1:10 treatment suggest that other factors are important and the conclusion is by no means certain that natural seep animals are more tolerant to oil because of long-term exposure to oil.]

Kasymov, A.G. 1970. Industry and productivity of the Caspian Sea. Marine Pollution Bulletin 1:100-103.

Concentrations of many pollutants in the region of Baku greatly exceed the maximum permissible concentrations; however, the author singles out petroleum and the petroleum industry as being the major contributors. Petroleum

concentrations mentioned: 27 ppm, 46 ppm, 143 ppm, and 146 ppm. Productivity at all trophic levels is diminishing rapidly, including commercial catches: in 35 years catches have decreased from 300 million kg (excluding herring which was not fished then) to 110 million kg (including 100 million kg of herring).

[Hydroelectric projects on the two big rivers feeding the sea, decreasing sea level and other sources of pollution certainly contribute to the degradation of the sea, but the concentrations of petroleum are so high that Kasymov's assertion that oil is responsible seems justified. The reported concentrations exceed those for other regions (Torrey Canyon surveys, Sweden, Finland and the Baltic Sea as reported in IMCO (1973)) by orders of magnitude, suggesting that the values must be very local maxima. It is unlikely that other areas would be so vulnerable unless they are also completely enclosed and also subject to the uncontrolled emissions of a very large petrochemical industry.]

Kloth, T.C., and D.E. Wohlschlag. 1972. Size related metabolic responses of the pinfish Lagodon rhoinboides to salinity variations and sublethal petrochemical pollution. Contr. Marine Science, University of Texas 16:125-137.

At 20°C in unpolluted water there is no effect of varying salinity between 20 and 45 ppt on metabolic rate (oxygen consumption per hour per kilogram). When the same variation of salinity is imposed on the fish in "sublethal pollution" by petrochemical wastes, there were very marked alterations in metabolic rate: greatest depression at the lowest salinity, increasing with increasing salinity such that it actually exceeded unpolluted metabolic rate for big pinfish at the maximum salinity.

[The simultaneous operation of different kinds of stress magnify effects on metabolism. Under field conditions where temperature is not held at the optimum as it was in these experiments, alterations of metabolism might be more extreme. The shortcomings of the research are that there is no indication how extensive similar or greater levels of pollution may be in coastal waters, acclimation to polluted water was brief (two days), it is only conjecture that the alterations of metabolic rate will manifest themselves in slower growth, increased age at maturity, reduced mating populations and other populational consequences.]

König, D. 1968. Biologische Auswirkung des Abwassers einer Ol-Raffinerie in einem Vorlandgebeit an der Nordsee. Helgolander Wissenschaftliche Meeresuntersuchungen 17:321-334.

(Author's Abstract). Biological effects of the waste water of an oil refinery in a silting area at the North Sea. The knowledge of the effects of oil refinery water wastes on the area of discharge is important for general ecological reasons, as well as for water resources policies and water laws. The amount of mineral oils and of phenols in the purified waste water is, in the present case, tolerable; but the content of these matters concentrates in the mud of the ditches; it exceeds the initial values about 100 times or more (in addition to the amount of oils and fats present in mud organisms). As a consequence, the composition of plant and animal communities of the mud area has changed: Cyanophyceae are now predominant and the usual representatives of the macrofauna have decreased in number or disappeared altogether, except Nereis diversicolor, a rather euryplastic species which occurs nearly everywhere. Further controls are necessary in order to ascertain whether these biological consequences of the wastes disposed remain restricted to the area of little ditches in the immediate neighborhood of the outlets or whether they may affect also animals and plants of mud flat areas farther away.

[It is very important that oil accumulated to over 100 times its original concentration in the mud.]

Korringa, P. 1968. Biological consequences of marine pollution with special reference to the North Sea fisheries. Helgolander Wissenschaftliche Meeresuntersuchungen 17(1-4): 135-136.

[Shelton (1970) makes the points in greater detail. Korringa adds the observation on the psychological effects of an oil spill on potential fish buyers: "The fish sales on the Parisian market dropped to about half their normal value in the period the "Torrey Canyon" was in the news, irrespective of the quality of the fish offered for sale."]

Kuhnhold, W.W. 1971. The influence of crude oils on fish fry. In FAO Technical Conference on Marine Pollution and Its Effects on Living Resources and Fishing, 9-18 December 1970. FAO Rome. p. 157.

Seawater extracts of Venezuelan crude and Iran crude killed cod eggs down to 100 ppm while Libyan crude caused no mortality. Mechanical dispersions were at least an order of magnitude more harmful to day old herring larvae than extracts from the same amount of oil. Corexit alone had to exceed 100 ppm to cause harm. Aging diminished the effect of mechanical emulsions but not of emulsions with Corexit.

[Emulsions whether mechanical or chemical in origin are more harmful than soluble extracts. In addition the chemical emulsion stays harmful longer. Corexit is an excellent dispersant compared to other common ones because of its low toxicity, but it still increases the biological damage of oil by facilitating the formation of emulsions and retarding their loss of toxicity. Both are good reasons not to use dispersants in nursery areas.]

Lalou, C. 1965. Concentration des benzo-3,4 pyrenes par les holothuries de la region de Villefranche et d'Antibes. In Commission Internationale pour l'Exploration Scientifique de la Mer Mediterranée. Pollutions Marines par les Micro-organismes et les Produits Petroliers. Symposium de Monaco, Avril, 1964, pp. 363-365. Paris.

Differences in the concentration of benzo-3,4 pyrenes by sea cucumbers probably are due to the very patchy nature of pollution by this substance (varying from 1 to 175 mg/100g dry weight in sediments collected from different stations). These results are contrasted with the 100-to-300 fold enrichments of some radioactive isotopes in the viscera of the sea cucumbers. These substances are uniformly distributed. Differences for the hydrocarbon between what is in the animal and what is in the neighboring sediments also owes to patchiness of distribution.

[Benzo-3,4 pyrenes are known to be carcinogenic; however, I have no idea if the concentrations found in the sediments or in the sea cucumbers approach dangerous levels. Definitely the holothurians incorporate the substance into their tissue (maximum so far observed - 1 ppm), but there is no evidence of a food chain magnification.]

Lewis, J.B. 1971. Effect of crude oil and an oil spill dispersant on reef corals. Marine Pollution Bulletin 2(4):59-62.

In one experiment, small coral colonies were exposed to concentrations of 0, 10, 50, 100, 200, 500 and 1000 ppm of Corexit. In the other, Barbados crude oil was used at the same range of concentrations. Tests were replicated 20 times in 350 ml finger bowls sealed by glass plates with stopcock grease. The effects of the pollutants were rated by behavior and exposure of septal filaments. The corals used were all common Caribbean forms: Porites porites (Pallas), Agaricia agaricites (L.), Favia fragum (Esper), and Madracis asperula (Milne-Edwards and Haime). All were sensitive to both crude oil and Corexit upon 24 hours exposure, more sensitive to the latter. The branching types were more affected than the encrusting. Both pollutants had harmful effects at 100 and 500 ppm and recovery was not complete (24 hours exposure then 24 hours to recover).

[Sealing the finger bowls prevented evaporation of the volatile fraction of the oil. I do not know if that is a reasonable treatment for tests in the tropics where such evaporation is going to occur rapidly in the event of spills. Also there certainly should have been a dispersant mixed with oil treatment.]

Lund, E.J. 1957. Effect of bleedwater, "soluble fraction" and crude oil on the oyster. Texas University, Institute of Marine Science Publications 4:328-341.

The author used rate of clearing of turbid water and rate of formation of castings as the best measures of the effects of various kinds of oil pollutants on oysters. He also repeated Galtsoff's (1935) pumping rate experiment. The threshold of sensitivity to bleedwater (salinity 120.4°/oo) on clearing rate lies between 3% and 6% whereas for pumping rate 10% or more is required. "Soluble fraction" by counter current extraction had no discernible effect even at the highest concentration used (12%). Flowing water making non-turbulent contact with a layer of crude oil produced no effects in a closed system as judged by clearing rate nor in an open system (water pumped from the Gulf continuously for 11 days) as judged by the volume of castings produced. No adverse effects were observed for the test animals in the month after the experiments.

[The experiments were controlled and in most cases repeated; however, in some cases interpretation is difficult. All the clearing experiments lasted one day or less and the castings experiment was 11 days. Perhaps deleterious effects would be expressed at lower concentrations after longer exposure. There is no indication of what the concentration of hydrocarbons is in the soluble fraction. This objection is probably not important because the concentration is likely to be much greater than what could occur under natural conditions. Non-turbulence at the oil-water interface may be a problem. Winds must produce white caps in the Gulf some of the time. Emulsions would result.]

Mackin, J.G., and S.H. Hopkins. 1961. Studies on oyster mortality in relation to natural environments and to oil fields in Louisiana. Texas University, Institute of Marine Science Publications 7:1-131.

(Authors' Abstract). Field and laboratory studies and examination of historical records were made in the tidal waters of Louisiana to determine the possible role of operations of oil companies on mortality of commercial oysters, *Crassostrea virginica*. Periods of disastrously high mortality were found in past records, both before and after the beginning of oil operations in the area. According to official figures, 1940-1947 as a whole was a period of good production, but there was a decline in 1944-1947 due mainly to a sharp drop in St. Bernard Parish, outside the area of major oil operations.

Field studies showed that oysters had a consistently high mortality rate throughout the warmer half of the year in the study area, and that mortality rate increased with salinity increase within this area. There was no such correlation with proximity of oil fields.

Chemical studies revealed measurable quantities (0.001 to 0.010 percent dry weight) of unsaponifiable carbon tetrachloride extractives, called "hydrocarbons" by some chemists, in all mud samples tested, including many from locations where no pollution seemed possible. In some cases the quantity of such materials was correlated with the amount of plant debris in samples, and it was found that unsaponifiable material could be extracted by carbon tetrachloride directly

Mackin, J.G., and S.H. Hopkins. 1961. (continued).

(Authors' Abstract continued.)

from plants in areas distant from any source of petroleum. Within oil fields, the amounts of unsaponifiable carbon tetrachloride extractives were highest (up to 5.8 percent) in mud samples taken near bleedwater outlets and other known centers of pollution, and were correlated with high (up to 0.00578 percent) "pentane and heavier hydrocarbons" as measured independently by a commercial laboratory. Water samples showed minute quantities (approximately 1 ppm) of substances identifiable by routine analysis as "hydrocarbons" to be very widely distributed in Louisiana bay waters. These substances showed highest concentrations (up to 226 ppm) in oil field bleedwater and were still high (up to 7.6 ppm) in bay or bayou waters near the point of discharge, but decreased rapidly with distance from the source "Hydrocarbon" content of mud and water was no higher in areas of high oyster mortality than in areas of low mortality. Calculations showed that bleedwater alone could not significantly increase the hydrocarbon content of mud or water on the commercial oyster beds where mortality occurred even if none were destroyed. Bacteriological studies showed that crude oil and its fractions were rapidly destroyed by bacteria living in Louisiana bay muds. Accidental oil spillages were found to cause enough oily taste to make nearby oysters unpalatable for periods ranging from several days to several weeks, but did not kill any oysters on commercial beds. In one case, however, a few intertidal oysters were killed by smothering.

Laboratory experiments showed that bleedwater, crude oil, water extracts of emulsions of crude oil, and the principal constituent of drilling mud (barium sulphate) had no effect on survival of oysters over periods of several months, when the concentrations tested were far above the maximum that could be maintained on an oyster bed. Quebracho, another constituent of drilling mud, caused some increase in mortality when used in concentrations much higher than could occur on an oyster bed. In physiological experiments, bleedwater and water extracts of crude oil slowed water pumping and filtering rates of oysters when used at concentrations much higher than could be expected in oyster-growing waters, but these effects were temporary and reversible.

In field experiments, spraying oysters repeatedly with crude oil and keeping them under a surface layer of crude oil did

not affect survival or growth over a period of months. In other field experiments oysters were kept for months at various distances from bleedwater outlets, underwater natural gas discharges, and other sources of pollution. A discharge of 6600 barrels of bleedwater per day at Lake Barre increased mortality of oysters as far as 50 to 75 feet from the point of discharge, and apparently caused decrease of shell growth and glycogen storage in oysters as far as 150 feet away, but had no detectable effect at greater distances. Field experiments at Dog Lake, Caillou Island, Lake Pelto, and Bay Sainte Elaine oil fields did not show any adverse effect of bleedwater, natural gas, or small oil spillages upon the setting, survival, growth, or fattening of oysters. High explosives used for seismographic exploration in the manner prescribed by Louisiana law did not injure oysters either immediately or over a period of months.

It was concluded that oil production factors of the kinds tested could not be responsible for the oyster mortalities spread throughout the large area where damage was claimed. The widespread mortalities that did occur during the study period were correlated with high temperature and high salinity, but not with proximity to oil operations. (End of authors' abstract.)

[This is a superb study. It is very thoroughly documented and deals with a great variety of aspects. The background information on natural levels of hydrocarbons in sediments from many areas where oil prospecting and production had never occurred, from other areas where the probability was high that no oil pollution had ever occurred, and from areas of oyster production, both which had suffered high mortality and which were healthy is invaluable for comparative purposes. The variety of treatments in both laboratory and field experiments included all stages of the oysters from settlement to old age, covered all seasons, included long term trials (over a year in some cases), considered growth as well as mortality and short term physiological responses, in one case involved a complete facsimile of commercial oyster production on areas exceeding one acre, tested components of drilling muds and even the effects of explosions under condition used for seismic prospecting, etc. All experiments had controls.

The report also evaluates Gowanloch (the same study, but appearing in different sources as I have reported on) and

Mackin, J.G., and S.H. Hopkins. 1961. (continued).

Galtsoff (1935). For three of Gowanloch's transplants, no oysters were recovered because of the deterioration of the racks. The last one not reported yielded only 17 oysters at the end of the study, none of which were dead. It was from a "polluted" location. Also the areas he selected for treatments and controls were different in ways besides oil pollution. Repeats of Gowanloch's crude oil experiments did not confirm his results. Galtsoff's results of adverse effects on diatom cultures were for such high concentrations of bleedwater and crude oil that they could not possibly apply to conditions in the field in Louisiana. Owen (1955) got enhanced growth of mixed cultures of diatoms the more oil he added, apparently contradicting Galtsoff.

The only mortality that could definitely be attributed to the oil spills observed in this study were approximately a dozen oysters apparently smothered in the intertidal zone. Where the few oysters had died so did some mussels, Brachidontes recurvus. No other plants or animals seemed to be affected. "Polydora, Cliona, Membranipora, Thais, Eurypanopeus, Callinectes, Balanus gobies and a few toadfish were found associated with the oysters. Algal growths were unaffected. In the marsh, there were thousands of Littorina, Uca, and a few Sesarma, which did not move out of the oily area. Goby eggs were particularly numerous attached to the oyster shells, especially in boxes." (Boxes are the still attached valves of dead oysters.) The only clearly detrimental effect of oil on oysters (except in the immediate vicinity of bleedwater effluents) seems to be tainting which was observed to last from a few days up to a few months.

Summer water temperatures usually range from 27°C to 32°C. Small bayous which drain from exposed mudflats may reach temperatures up to 40°C, so this work definitely is pertinent to the warm water tropics.]

Mackin, J.G., and A.K. Sparks. 1961. Study of the effects on oysters of crude oil loss from a wild well. Texas University, Institute of Marine Science Publications 7:230-261.

An oil well was out of control and on fire for two weeks. Most of the volatiles probably were burned away. It is

impossible to estimate how much oil was spilled; however, it was enough to leave a heavy oil slick a week after the spill was stopped, which extended as much as three miles from the source. Two weeks after the spill, oil was still obvious in the vicinity of the well but not elsewhere. Three months was the last time at which visual evidence of oil could be stirred from the bottom. Transplants from the most heavily affected area were moved to four polluted and two unpolluted areas. Oysters from a distant unpolluted bed were introduced to within 25 feet of one of the two transplants to an unpolluted area. Mortality, cause of mortality, growth, new settlement and size attained by the new set were all followed at all stations. Observations of the associated fauna were made each month. The study lasted from February to September. No differences that could be attributed to oil were found. In fact mortality was normal and growth was particularly good for the study as a whole by comparison to other studies which have been done in the Gulf. Most mortality was due to the fungus Dermocystidium marinum. There was no synergistic effect between the disease and oil.

[The data that they present on dry weight of flesh per volume of shell capacity suggest that control areas may be slightly better.]

Mallet, L. 1965. Pollution par les hydrocarbures en parliculier du type benzo-3,4 pyrenes des rivages Mediterraneens Francais et plus specialement de la Baie de Villefranche. In Commission Internationale pour l'Exploration Scientifique de la Mer Mediterranée, Pollutions Marines par les Microorganismes et les Produits Petroliers. Symposium de Monaco, Avril, 1964, pp. 325-330. Paris.

Concentrations of the carcinogenic substance benzo-3,4 pyrene are variable in the south of France but reach high levels in some places at the mouth of the Rhone (up to 96.6 μg/100 g dry weight of sediment), and at Villefrance 500, maybe 1800 μg/100 g. For a sample separated into components: plant fibers, 150 μg/100 g; black mud, 400. Variation with depth in the sediment: 180-500 in top 33 cm, 37-73 in the next 30 cm and 2.6 and 1.6 at 100 cm and 200 cm.

Mallet, L., and J. Sardou. 1965. Recherche de la presence de l'hydrocarbure benzo-3,4 pyrene dans le milieu planctonique de la region de la Baie de Villefranche. In Commission Internationale pour l'Exploration Scientifique de la Mer Mediterranée, Pollutions Marines par les Micro-organismes et les Produits Petroliers. Symposium de Monaco, Avril, 1964, pp. 331-334. Paris.

Benzo-3,4 pyrene ranged from 0-40 μ/100 g of sample in planktonic samples. Transport is believed to be through the air rather than by interaction with sediments. Definitely some of the hydrocarbon is incorporated in the tissues of the organisms since saponification greatly increases yields.

[There is no analysis by taxa or trophic level and no indication of concentration in the water.]

Mann, H. 1965. Effects on the flavour of fishes by oils and phenols. In Commission Internationale pour l'Exploration Scientifique de la Mer Mediterranée. Pollutions Marines par les Micro-organismes et les Produits Petroliers. Symposium de Monaco, Avril, 1964, pp. 371-374. Paris.

Chlorine compounds of phenol tainted carps at 0.015 and 0.06 ppm (0- and p-chloride phenol), if exposed for long periods, 0.001 0-chloride phenol will taint eels and oysters. Eels kept in the water of Hamburg harbor became tainted. Two weeks were required to dissipate it. Ingestion of tainted food imparted foul taste to fish. Presence of detergents increased incorporation of phenols by fish. Phenols are incorporated above ambient concentrations in some organs of carps (gills and livers). Fish tainted by 6 ppm oil from refinery wastewater lose taint in three weeks in clean water, but also lose 20% of their weight. Phenol concentrations were measured after the fish were in the water (16°C) three days.

Water of aquarium	Phenol in the fish
5 ppm Phenol	3,5 mg/kg
5 ppm Phenol + 0,5 ppm Dodecyl-benzolsulfonat	6,0 mg/kg

Water of aquarium	Phenol in the fish
5 ppm Phenol + 1,0 ppm Dodecyl-benzolsulfonat	7,0 mg/kg
5 ppm Phenol + 2,0 ppm Dodecyl-benzolsulfonat	6,5 mg/kg

McAuliffe, C. 1966. Solubility in water of paraffin, cyclo-paraffin, olefin, acetylene, cyclo-olefin and aromatic hydrocarbons. J. Phys. Chem. 70:1267-1275.

(Author's Abstract). The solubilities in water at room temperature of 65 hydrocarbons have been measured using a gas-liquid partition chromatographic technique. For each homologous series of hydrocarbons, the logarithm of the solubility in water is a linear function of the hydrocarbon molar volume. Branching increases water solubility for paraffin, olefin, and acetylene hydrocarbons. The increased solubilities due to branching apparently are not due to a structural feature of the molecules, but to the higher vapor pressure of the branched-chain hydrocarbons compared with the corresponding paraffin or olefin hydrocarbon. The "structure" of water is such that, for the same hydrocarbon vapor pressure, approximately the same weight of a C_2 through C_9 paraffin hydrocarbon dissolves in water. For a given carbon number, ring formation increases water solubility. Increasing unsaturation of the hydrocarbon molecule, chain or ring, increases solubility of the hydrocarbon in water.

[Experiments with terrestrial organisms indicate that aromatic compounds are most toxic. McAuliffe's work shows that aromatic compounds are most soluble in water. In order to do harm to a marine organism, a substance must be toxic when it comes in contact with the organism, but perhaps more importantly, mechanisms must exist to bring about that contact. The combination of inherent high toxicity and high solubility make aromatic compounds doubly dangerous. High solubility is associated with high volatility as well. Both features mean that rapid dissipation will occur, suggesting that harmful effects will be local. Balancing off toxicity and rapidity of dissipation, it is still likely that low-boiling aromatics are the most harmful fraction of petroleum.]

Mironov, O.G. 1967. Effects of low concentrations of oil and petroleum products on the development of the eggs of the Black Sea flatfish. Voprosy Ikhtiolgil 7(3):577-580.

[Article is printed in Russian. Judging from the tables, concentrations ranged from 10^{-1} to 10^{-5} ml/liter of petroleum product. Effects ceased to be striking at 10^{-4}. 10^{-2} caused 100% mortality in three days for all types of petroleum products tested. Probably tests were conducted with 20-30 eggs in 180 ml.]

_____. 1968. Hydrocarbon pollution of the sea and its influence on marine organisms. Helgolander Wissenschaftliche Meeresuntersuchungen 17:335-339.

The hyponeuston (organisms of the top 0-5 cm of the sea) includes the early stages of many pelagic and benthic organisms which are generally more sensitive to oil pollution than adults. For instance, pre-larvae of plaice in 10^{-4} to 10^{-5} mg/l of crude oil and diesel oil experienced 40-100% mortality.

[Recruitment of marine fish seldom is limited by the number of eggs available, and young stages usually suffer very high mortality. Nevertheless, the reported concentration is low enough to occur at least locally in the sea. If spawn are concentrated in such a locality, fisheries might suffer.]

_____. 1969a. Development of some Black Sea fishes in polluted waters. Journal of Ichthyology 9(6):919-922.

Concentrations of 1-100 ppm of petroleum, solar oil and black oil all had adverse effects on early developmental stages of the Black Sea anchovy, Engraulis enchrasicholus ponticus Alex.; the Black Sea scorpion fish, Scorpaena porcus L.; and the sea parrot Crenilabrus tinca L. Solar oil was most harmful to the first and second species whereas black oil was for the third.

[There is no indication of the composition of the oils.]

_____. 1969b. Effects of oil pollution on some representatives of the Black Sea zooplankton. Zoologischeski Zhurnal 48(7): 980-984.

(The article is printed in Russian. English abstract follows.) "The effect of Malgobek oil, mineral oil and black oil at concentrations from 0.1 to 0.001 ml/l upon adult forms of Acartia clausi Giesbr., Paracalanus parvus Claus., Penillia avirostris Dana, Centropages ponticus Karav., Oithona nana Giesbr. as well as on larval forms of A. clausi and O. nana has been studied. Planktonic organisms were found to be sensitive to the presence of oil in the seawater which accelerated their death already at the concentration of 0.001 ml/l. At the concentration of 0.1 ml/l all organisms died within the first day."

_____. 1970a. The effect of oil pollution on flora and fauna of the Black Sea. In FAO Technical Conference on Marine Pollution and its Effects on Living Resources and Fishing, 9-18 December 1970. FAO, Rome.

Of eleven phytoplankton species tested, nine required 100 to 1000 ppm to kill 100%, but one died completely at 0.1 ppm. At 1 ppm five species of zooplankton had 42-95% greater mortality in 100 hours than controls. There was little difference in sensitivity comparing oil, "mazout" (bunker oil?) and diesel oil. Molluscs varied in sensitivity but most withstood 1000 ppm for 10-15 days. Crustaceans were also variable, Diogenes pugilator succumbing in 10 ppm, others withstanding 1000 ppm. The worm Nereis diversicolor was sensitive to 1000 ppm mixed in sediments. Fish eggs were destroyed at 0.1 - 1 ppm, fish larvae at 10-100 ppm while adults survived 250 ppm. Some plankton showed adverse effects to 5, 30, and 60 minute exposure to 1000 ppm.

[There are internal inconsistencies in the data presented. The experimental designs are not described so that interpretation is difficult. Probably internal comparisons are reliable: larval stages may be orders of magnitude more sensitive than adults. Most phytoplankton are resistant but a few are sensitive so that oil pollution is likely to cause a change in species composition. Short-term exposure to high concentrations can have delayed effects.]

_____. 1970b. Microorganisms growing in oil and oil products in western and central regions of the Mediterranean Sea. Revue Internationale d'Oceanographie Medicale 17:79-85.

28 of 54 water samples taken from different parts of the Mediterranean west of Greece contained bacteria capable of growth on diesel oil or crude oil. The greatest number of samples indicating the growth of microorganisms in oil were taken in regions of visible oil pollution. Some isolates lost the ability to grow on oil when kept on a common agar medium. Microorganisms capable of using hydrocarbons grew better on peptones. This suggests that the bacteria will utilize more accessible sources of carbon first, thus lessening the effectiveness of self-purification, especially when domestic sewage is present.

Mironov, O.G., and L.A. Lanskaya. 1967. Growth of diatoms in seawater polluted by petroleum products. In Biology and distribution of plankton of the southern seas, Moscow, USSR Academy of Sciences, pp. 31-34.

(Article is printed in Russian.) Two kinds of petroleum products were tested. Dytilium brightwelli and Coscinodiscus granii were sensitive down to the lowest concentration tested (.001 ml/l). Melosira moniliformis, Grammatophora marina and Chaetoceros curvisetus only showed effects at or above .1 ml/l.

Mitchell, C.T., E.K. Anderson, L.G. Jones, and W.J. North. 1970. What oil does to ecology. Water Pollution Control Federation Journal 42(5):812-818.

[Two page summary of the Tampico Maru spill.]

Moore, S.F., R.L. Dwyer, and A.M. Katz. 1973. A preliminary assessment of the environmental vulnerability of Machias Bay, Maine, to supertankers. Department of Civil Engineering, Massachusetts Institute of Technology. Report No. 162.

This report includes a tabulated review of many reports on toxicities of oils to marine organisms. In addition it attempts to incorporate projections of the area and extent of damage to the coast by different sized spills different distances from shore at different seasons.

[This is the most useful compilation of toxicity data that I have seen. No attempt is made to judge the reliability of the sources, but the general remarks and conclusions seem reasonable.]

Morris, B.F. 1971. Petroleum: tar quantities floating in the northwestern Atlantic taken with a new quantitative neuston net. Science 173:430-432.

Estimates of concentrations of tar in surface waters are 20 mg/m^2 for the Mediterranean and 1 mg/m^2 for the North Atlantic.

[The calculations based on assumed half-lives of tar lumps and proportion of spilled oil which becomes tar lumps are so conjectural as to be of little value. It is not known whether the contamination of surface waters is presently an equilibrium situation nor is any mention made whether a relationship exists between amount of tar and amount of dissolved or dispersed hydrocarbons, which might be more influential on marine life.]

Nelson-Smith, A. 1972. Oil pollution and marine ecology. London: Elek Science. 260 pp.

[This book is a useful review covering physical and chemical attributes of spilled oil as well as ecological and economic consequences. It suffers by not attempting to provide a critical evaluation of the material cited. So many sources are covered (25 pages of bibliography) that the net result may be a fair presentation of the field, even accepting without remark many dubious results.]

Nemoto, T. 1971. La pesca en el Lago de Maracaibo. Informe Technico No. 24. Caracas.

[Not seen. Cited in IMCO (1973). Apparently the oil industry has not had an adverse effect on the fishery.]

Nicholson, N.L., and R.L. Cimberg. 1971. The Santa Barbara oil spills of 1969: a post-spill survey of the rocky intertidal. Biological and Oceanographical Survey of the Santa Barbara Channel Oil Spill, 1969-1970, ed. D. Straughan, pp. 325-400.

Plants and animals were sampled along intertidal transects at many stations along the coast of Southern California, both in areas affected by the spill and others well away from it. No damage clearly attributable to the spill was evident; however, a drastic decline in the variety of algae was noted along transects that had been sampled by Dawson ten years before. Coal Oil Point had less variety of organisms than other areas which were not so close to active offshore natural seeps.

[Sampling along line transects is not at all suitable for determining the variety of plants and animals which inhabit a particular locality. It is not clear that Dawson's survey was done in this way. More importantly it yields a gross misrepresentation of conditions at Coal Oil Point. Contrary to their conclusion that it has a less varied assemblage of organisms due to chronic exposure to oil from a natural seep, it is locally regarded as the richest bit of rocky intertidal. Furthermore, the majority of invertebrates on their list which they did not encounter during their 12 samplings, I have found during casual examination of the area. Finally, several of the organisms that they list are sand dwellers. Why should they be included in surveys of the rocky intertidal? This is a poor study and the conclusion that the fauna and flora of Coal Oil Point is less varied than non-seep areas is unwarranted.]

North, W.J. 1967. Tampico: a study of destruction and restoration. Sea Frontiers 13(4):212-217.

[The article from Pollutions Marines par les Micro-organismes et les Produits Petroliers is a much more detailed presentation of this material.]

North, W.J., M. Neushul, and K.A. Clendenning. 1965. Successive biological changes observed in a marine cove exposed to a large spillage of mineral oil. In Commission Internationale pour l'Exploration Scientifique de la Mer Mediterranée. Pollutions Marines par les Micro-organismes et les Produits Petroliers. Symposium de Monaco, Avril, 1964, pp. 335-354. Paris.

The Tampico Maru ran aground across the mouth of a small cove off the Pacific Coast of Baja California. It released 59,000 barrels of dark diesel oil (80% heavy distillate and 20% residual fuel oil); 1/3 upon stranding, the remainder over a period of months. The spill affected 1000 m of coast. Only the 100 m x 100 m cove was studied. The only animals to survive were a sea anemone (Anthopleura xanthogrammica and/or elegantissima) and the periwinkle (Littorina planaxis) which probably escaped contact with the oil by being so high on the shore. The most abundant dead animals cast up on the beach were abalones, lobsters, sea urchins, pismo clams, mussels and sea stars. Intertidally the algae were destroyed, subtidally they were greatly reduced, as indicated by the number of forms not seen until three years later. The kelp Macrocystis pyrifera became extremely abundant shortly after the accident, probably because the important herbivores were eliminated and the wreck acted as a breakwater. Even after the ship broke up and heavy surf tore out most of the big individuals, many more juveniles were present than is typical of undisturbed areas. As well as the absence of herbivores, the absence of filterfeeders may contribute to the great success of young stages. Gradually the cove has been repopulated by a wide variety of plants and animals in abundance; however, the major herbivores are still absent or present in reduced numbers. The algal community is probably different from what it would have been without the oil because of the very large influence which the present dominant Macrocystis wields by shading and completely modifying the structure of the area. (There is much epiphytism.) The influence extends to the animals as well.

Lab experiments were performed on the toxicities of diesel oil and fuel oil emulsions and surface films to sea urchins and kelp. 0.1% emulsions were the highest concentrations that were stable. The lowest concentration used (0.01%) reduced photosynthetic capacity in three days and eliminated it in seven days. Boiler fuel was much more toxic than diesel oil. Even short exposures to oil had large effects several days later: three hours exposure to .1% boiler fuel eliminated photosynthesis after four days in fresh seawater; twelve hours were required for diesel oil. Sea urchins retract their tube feet within 20 minutes when exposed to .1% diesel oil. They recovered immediately when returned to fresh sea water after minutes exposure and recovered overnight after one hour exposure. Probably mortality was due to being washed ashore after retracting tube feet.

North, W.J., M. Neushul, and K.A. Clendenning. 1965. (continued).

[Two or three years were required to restore a rich and varied community; however, even after seven years it is qualitatively different from what it had been. There is a problem ascertaining how much the long term differences are attributable to the wreck. First, there was no thorough survey prior to the wreck and second, there was no control study. It is essential to know what is happening simultaneously in similar undisturbed areas to be able to interpret the progression of species records which they obtained. Nevertheless, the conclusions seem justified and the long-term consequences of the selective elimination of one trophic level may apply in other cases as well.]

Nuzzi, R. 1973. Effects of water soluble extracts of oil on phytoplankton. In Conference on Prevention and Control of Oil Spills, 13-15 March 1973, pp. 809-913. American Petroleum Institute, Washington, D.C.

Cultures of *Phaeodactylum tricornutum*, *Skeletonema costatum* *Chlorella* sp., and *Chlamydononas* sp. and a natural sample of seawater were exposed to water soluble fractions of No. 2 and No. 6 fuel oils and outboard motor oil prepared by agitating 1% oil in growth medium or filtered seawater for one hour, then letting it separate in a separatory funnel for 24 hours. Fuel oil No. 6 and outboard motor oil had little effect whereas fuel oil No. 2 extracts retarded growth for all except *Chlamydononas* at 50% extract. Fuel oil No. 6 had no obvious effect on the natural sample, outboard motor oil stimulated growth of most things identified, and fuel oil No. 2 slowed growth of everything.

[Adverse effects are clearly demonstrated for fuel oil No. 2 extracts under the culture conditions used. Probably its toxicity is due to its relatively high proportion of soluble compounds (0.053% compared to 0.005% for No. 6). If this figure is reliable, the concentration of hydrocarbons in the extract is 5 ppm and gross effects are apparent at or below 2.5 ppm. The most serious obstacle in applying this result to field conditions is that the culture vessels were sealed. Presumably evaporation and diffusion might limit the duration and volume of exposure to similar concentrations.]

Pearce, J.B., and L. Ogren. 1968. Observations on the effects of oil from the tanker Ocean Eagle on marine organisms of San Juan Bay and vicinity. 21 pp.

5.7 million gallons of Venezuelan crude oil were being carried by the Ocean Eagle of which an estimated 1.2 million gallons spilled. The oil extended along fifteen miles of coast after four days (March 3-7, 1968); ten to twelve foot waves and moderate northerly winds prevailed. The oil spill had little observable effect on the ichthyofauna or on benthic organisms in spite of the fact that conditions permitted large scale vertical mixing. These findings were based on three trawl and two dredge samples. There was no evidence of oil in the sediments. There were observable effects in the intertidal zone, most pronounced on sessile and sedentary forms. High littoral and supralittoral zones were most affected. Xanthid and grapsoid crabs were oiled and dead. Uca did not seem so susceptible but may have died in their burrows. The authors suggest that many species were affected in the mangrove swamp because of the heavy coverage by oil but note that comparative studies with unaffected areas are required. (Neither were actually done.) On rocky areas barnacles were killed but motile forms such as Nerita, chitons and pagurids found protection under rocks or in tidepools. One observer noted a thousand dead sea urchins.

The effect of the oil spill on fisheries seemed to be small, perhaps partly attributable to being the slack season. Also shellfishing is not well developed. It is suggested that the small amount of damage may have been due to the very limited use of detergents.

_____. 1969. Observations on the effect of oil from the tanker Ocean Eagle on marine organisms of San Juan Bay and vicinity. II. Observations one year after the catastrophe. 16 pp.

Three million gallons were estimated to have been released. Observations one year after the spill did not indicate that major changes in or deterioration of the marine environment had taken place. No evaluations were made of smaller benthic and planktonic species. It is inferred that they could not have been seriously affected or it would have been reflected in the macrofauna. A local observer stated that 300 pelicans died, but the local commercial fishery suffered no obvious loss.

Petty, C.E. 1970. Louisiana's omnipresent offshore operations. Our Sun 35(3):3-11.

There is no evidence of damage to the shrimp fishery by oil. Concentrations in seawater of as little as 1 ppm of oil can be concentrated to several hundred ppm by oysters in two weeks; 10-15 ppm will affect taste. Erosion and alteration of hydrological conditions are the other important consequences of oil industry activities.

Puerto Rico University, Department of Marine Sciences. 1968. Ocean Eagle oil spill. U.S. Office of Naval Research, Cerame-Vivas, M.J. 14 pp.

Damage was complete to littoral species along five miles of coast in the vicinity of the entrance to San Juan Harbor. Limpets and chitons were probably killed by detergents or oil-detergent emulsions or were swept off oiled surfaces. Four months later "Intertidal aquatic life was well recovered from the conditions present in the harbor shortly after the oil spill; i.e., March 3-9, 1968, and there was no evidence of oil or oil residues in these intertidal areas." Small populations of several grazing gastropods were found but sea urchins seemed to be absent. Ulva was abundant in some places. Recovery "has been very excellent, but not quite complete."

Toxicity tests indicated that all detergents examined were harmful to fish and invertebrates (Polycomplex A-11, Janoslor 60, Hemco #2 and Muratti). 100 ppm killed everything in 24 hours, usually much sooner. Adverse effects at lower concentrations may have been lethal by the usual 48 or 96 hour criterion for tests. 34 dead fish were seen during a two hour cruise along the shore. Another time, an estimated 100,000 sardina Opisthonema oglinum were seen 95% of which bore abnormal lesions.

[The toxicity tests are useless for comparative purposes, not being conducted under standard conditions and, at least for the invertebrates, involving only one urchin at each concentration (three species of sea urchins were the only invertebrates tested). The reports of the initial surveys are not at all informative and do not always agree with the reports by Pearce and Ogren. The survey four months later is impossible to evaluate except to say that the oil itself was no longer evident and that some organisms were present.]

Rice, S.D. 1973. Toxicity and avoidance tests with Prudhoe Bay oil and pink salmon fry. In Conference on Prevention and Control of Oil Spills, 13-15 March 1973, pp. 667-670. American Petroleum Institute, Washington, D.C.

Bigger fry are more susceptible to oil pollution than small but also they show an avoidance response at much lower concentrations. Big fry avoided 1.6 ppm oil but did not respond to .75 ppm. Their TL_m was 110 ppm at that time.

[As well as size, season and water temperature were different. The author's speculation that pollution well below lethal levels could have adverse effects by altering migration routes seems reasonable. He cites a study that just that did happen to Atlantic salmon in response to zinc pollution.]

Rosenthal, H., and W. Gunkel. 1967. Effects of crude oil-emulsifier mixtures on marine fish fry and their food animals. Helgolander Wissenschaftliche Meeresuntersuchungen 16(4):315-320. (German, English summary.)

Mixtures of the emulsifier "Moltoclar" and Irak crude oil at 1:4 were lethal down to 2.5 - 5.0 ppm emulsifier. Sublethal damage was clear down to 0.5 ppm in two days' time. Crude oil alone did damage the fry (Clupea harengus L. and Agonus cataphractys L.).

Rützler, K., and W. Sterrer. 1970. Oil pollution: damage observed in tropical communities along the Atlantic seaboard of Panama. Bioscience 20(4):222-224.

Approximately 20,000 barrels of diesel and Bunker C oil were released in December, 1968. Some of it came ashore in the vicinity of the Smithsonian Tropical Research Institute at Galeta Island. The authors made their observations two months after the spill. Along stretches of rocky shore many plants in the supralittoral zone were killed. Spray and high tidepools were still covered by as much as 2 cm of oil and were devoid of life. They assumed damage to gastropod and barnacle populations but the tar crusts were being repopulated "by the usual variety of intertidal organisms." The coral reef did not seem to be harmed. Sandy beaches looked clean but contained oil beneath the surface

Rützler, K., and W. Sterrer. 1970. (continued).

at least to a depth of 30 cm. One analysis showed that 121.9 g wet weight of sand contained 31.8 g of water and 6.2 g of oil. No interstitial copepods could be found. Ciliates were abundant, presumably feeding on bacteria which were decomposing the oil. The authors suggest that there was dramatic reduction of the meiofauna population due to the oil. An area of mangroves was thickly covered with oil. Many seedlings had died. It was too early to judge damage to adult trees but probably the black mangrove Avicennia would suffer because of covering of their pneumatophores with oil. "A strong reduction of the fiddler crab population (Uca sp.) could be observed in comparison to other mangrove areas." 100 cm mud samples contained up to 21.4 g of oil. The algal community of red mangrove roots were practically eliminated as were oysters (Crassostrea sp.), mussels (Brachidontes sp.), barnacles (Balanus sp.), sponges, tunicates and bryozoans. It is suggested that damage to the mangrove habitat would affect fish and crustaceans of economic importance. The authors observed dead and dying young sea turtles (Carretta sp.).

[The authors do document the persistence of massive doses of oil in sediments two months after the fouling originally occurred. The direct observations of mortality in the mangroves is convincing; however, based on the information that the authors present, there is no reason to accept the conclusions about interstitial fauna which depend upon comparisons with samples from North Carolina and Florida. Since Sterrer works with meiofauna ordinarily, his impression probably is valid, but not on the basis of what he presents. It is impossible to evaluate their supposition of damage to economically important crustacea and fish which depend at some stage upon mangrove swamps. Nowhere do they mention mortality to fish, nor whether they were absent from the area during their observations. I doubt that any of the species that they listed as suffering high mortality figured importantly in the nutrition of economically important organisms.]

St. Amant, L.S. 1970. Biological effects of petroleum exploration and production in coastal Louisiana. In Santa Barbara Oil Symposium, held at the University of California, Santa Barbara, 16-18 December 1970, pp. 335-355.

Production of Louisiana fisheries has increased simultaneously with the increasing activity in Louisiana oil fields. So far, at least, reduction of stocks due to oil is not interfering

noticeably with commercially important groups, if it is occurring at all. Oysters, shrimps and menhaden make up the bulk of catches valued at about $150 million each year. Most work has been done with oysters. The consensus is that oil is not directly responsible for oyster mortality; however, in many indirect ways the oil industry has been detrimental to oyster production. Directly assessable factors are loss of suitable grounds to oil production activities, increased silting and, most important, tainting. The important source of tainting is drilling muds that have been treated with kerosene for deep drilling. The kerosene being adsorbed to particles sinks to the bottom and gets filtered out by oysters. A less tangible impact of oil production may be the incursion of high salinity water further inland because of all the channels which have been dredged. Oil may not have caused the high mortalities of the 1940's, but it might have been responsible for the increased salinity which did. The only reason that high production has been maintained is that the whole system of planting and cultivation has been changed to avoid serious losses to the fungus disease which thrives in high salinity. Shrimp catches have not declined because of oil but the changed salinity regime probably caused the switch from 95% white shrimp (Penaeus sertiferus) and 5% brown shrimp (Penaeus aztecus) in catches to 50% each which has occurred in the last 30 years. Oil platforms and submerged spoils from drillings are navigational hazards and reduce the area in which trawling operations may be conducted. Seismic testing does not kill many fish but can make the bottom unsuitable for trawling if detonated too near the bottom. Regulations now make this danger rare.

[I think that this is an excellent overview with a much broader perspective than Mackin's work. Unfortunately the broader problems do not lend themselves to the direct tests that make Mackin's work so impressive. For instance, implicating the dredging and canal digging which went along with drilling 30,000 to 40,000 wells in altering the salinity of the inshore region is eminently reasonable but not provable. The really valuable contribution of this report lies in bringing up the factors which Mackin failed to consider and putting a very different emphasis on other factors. Mackin did not discuss the accelerated erosion which accompanies canal digging and the large scale disturbance to the swamp caused by moving big equipment from place to place for prospecting and putting in new wells. Also Mackin tested components of drilling mud as possible causes of oyster mortality but did not mention their use with kerosene and the concomitant danger of tainting. Although oil is not a direct source of mortality, it probably does have serious adverse effects on Louisiana fisheries.]

Shelton, R.G.J. 1970. The effect of oil spills on fisheries. In Coastal Water Pollution. Pollution of the Sea by Oil Spills. Colloqium held in NATO Headquarters, 2-6 November 1970, pp. 10.1-10.8. Brussels.

The damage to fisheries caused by oil depends upon the composition of the oil, where the spill occurs and how it is treated. In the open sea, even treatment with the most toxic dispersants did little recognizable damage. Over fishing grounds sinking is inadmissable, not because it is likely to kill fish, but because it will certainly cause tainting and foul gear. This is particularly true for dry powders which produce big globs. Beam trawling for flatfish and shrimp is susceptible to contamination by any kind of sinking. Also, bottom currents as slow as 1/2 knot will move the oil out of the area where it was sunk. Even if the fish are not tainted before catching, they will be after cooking if even small lumps of oil accompany them or if the fishermen handling them have oil on their hands and clothes. Any kind of treatment is not advisable in bays and estuaries with fisheries.

[The report seems to be a balanced evaluation. Oil by itself is not particularly harmful but sinking it or treating with detergents may make it so. Tainting is the most serious danger. The author mentioned the possibility of food chain concentration analogous to DDT but indicated that so far there is no evidence that it occurs in the sea.]

Simpson, A.C. 1968. Torrey Canyon disaster and fisheries. Fisheries Laboratory, Burnham-on-Crouch, Essex. Laboratory Leaflet (New Series)No. 18. Great Britain. 43 pp.

Although 120,000 tons of crude oil were spilled and 2.5 million gallons of emulsifiers were applied, little damage to fisheries could be detected. This is attributed to the lack of intertidal fisheries in Cornwall and the removal to deeper water of susceptible forms because it was winter. Even during the periods when emulsifiers were being applied in largest quantities to beaches, concentrations of detergents 100 yards beyond the low water mark were no more than 0.15 ppm. The 15 measurements reported from 100 - 600 yards from shore and surface to bottom ranged from 0.01 ppm to 0.15 ppm with bottom samples being about half those on the surface. Several diving surveys showed few dead of commercially important

species: isolated individuals of crabs, lobsters, sea urchins and young fish. Only in shallow water close to areas of application did the abundances of fish seem lower than normal. Some tainting of lobsters and crabs occurred among commercial catches. Fishermen were advised to move storage pots to deep water. Catches of no commercial species were abnormal in quantity or quality.

[Damage would have been much greater at a different season or if oil had reached estuaries where oysters and mussels are cultured. The conclusion that benthic forms are safe is generally borne out by catch results but is contradicted by the observation during one diving survey of a thick layer of oil overlain by sand in 25 feet of water. Tainting is the greatest danger both of the animals by their own activities and by contamination of gear. Direct damage may be minor but the indirect increases in operating costs due to temporary restriction of fishing from the closest or best grounds, premature termination of trawling when slicks are encountered and cleaning up gear may add up to serious levels. The report only deals with commercial forms; however, it is mentioned that damage to intertidal organisms was very extensive. Simpson suggests that exposure of nursery areas would have large effects because eggs and larvae of many important species are at the surface. This could conceivably lead to the elimination of a whole year's class.]

Spears, R.W. 1971. An evaluation of the effects of oil, oilfield brine and oil removing compounds. In American Institute of Mining, Metallurgical and Petroleum Engineers, AIME Environmental Quality Conference, 7-9 June 1971, pp. 199-216. Washington, D.C.

Laboratory tests on the toxicity of the listed components were performed on pinfish, brown shrimp and blue crabs and these results used to interpret field studies on contamination of the environment and the abundance of commercially important kinds in one contaminated stream compared to five streams that were relatively free of human disturbance. The contaminated stream received 30,000 barrels of oil brine per day; 16.0 mg/l of oil reached the bay. The productivity of uncontaminated streams was 4-30 times greater for shrimp, 2-25 times greater for blue crabs, 5-16 times greater for game fish, and 1.4-11 times greater for forage fish than in the polluted stream.

Spears, R.W. 1971. (continued).

[The comparisons among streams are convincing that oil production activities are reducing the abundances of important species; however, there is no way to judge if the effects extend into the bay. Also it is not clear if any of the indices of environmental harm derived from the 48 hour median tolerant limit are valid.]

Spooner, M.F. 1970. Oil spill in Tarut Bay, Saudi Arabia. Marine Pollution Bulletin 1(11):166-167.

At least 100,000 barrels of Arabian light crude oil were spilled into the bay. Corexit 7664 was used to disperse some slicks which were being carried out into the Persian Gulf. Otherwise dispersants were not used. Natural emulsions were produced at the edge of slicks with concentrations of 50 ppm. Oxygen in the water seemed to be adequate for biodegradation. The trawling fishery for shrimp did not seem to be adversely affected. There was no evidence of oil in the guts. Fish were not tainted. Weirs were contaminated with brown oily mousse, catches declined presumably because the fish and shrimp avoided them. A storm cleaned them up and catches returned to normal. In the area affected by heavy slicks most of the intertidal fauna was killed with exception of the gastropod Cerithium. Dead included crabs, bivalves, and limpets. Numerous dead fish were washed up on the shore. On mud, some mat crabs were killed but others survived. Swimming crabs and shrimp from fish traps had shed limbs and were obviously sick. The mud of the mangrove swamps was usually free of oil. Some plants were losing all their leaves but many survived. After three months most areas looked clean. Algae were growing in one area, presumably because of depletion of grazers. Crabs had not yet reinvaded one area where they had been killed off.

[This is a superficial account but nevertheless valuable for considering Indonesian problems. The whole bay is shallow (less than one fathom), the habitats around it are common to Indonesia (mangroves, mudflats, sand and coral), the fisheries are probably quite similar. I don't know if the oil is similar. My impression is that more important than destruction of life may be the damaging of fishing gear, particularly weirs.]

Spooner, M.F., and G.M. Spooner. 1968. Problems of oil spills at sea as illustrated by the stranding of the General Colocotronis on Eleuthera, Bahamas, March 7, 1968. West of England Steam Ship Owners Protection and Indemnity Association. London. 22 pp.

Most of the oil was successfully off-loaded. Detergents and dispersants were used sparingly and apparently did not harm marine life. Oil which reached the shore only did so near the ship. Coral rock and coral sand are porous and absorb oil. Attempts at cleaning are probably futile. Chitons and limpets graze upon the patches of oil thus cleaning the rocks without apparent harm to themselves. "Rough and preliminary" experiments on the toxicity of dispersants indicate that Enjay 7664 does not do damage even at the high concentrations of 1000 and 100 ppm. In ascending order of toxicity above Enjay 7664 are Polycomplex A (also a water base solubilizer) Magnus and Drew. Animals tested were:

26	small reef pool fish (Abudefcluf saxitilis)
250	small gastropods (zebra nerites) - Activity levels gave clear results.
50	spider crabs and other crabs - These proved unexpectedly resistant.
20	sea urchins - fairly sensitive.
72	tiny bivalves - sensitive but not satisfactory material.
10	chitons - tough and slow.

"Full details of methods and results have been submitted to interested biologists and chemists."

[It is impossible to determine whether the toxicity tests were of dispersants alone or dispersants plus oil. For the most part the report consists of administrative recommendations.]

Stander, G.H., and J.A.V. Venter. 1968. Oil pollution in South Africa. In International Conference of Oil Pollution of the Sea, Rome, 1968. Report of proceeding (London?), pp. 251-258.

In the Esso Essen incident millions of sand-hoppers (Talorchestia sp.) were killed. Fresh periwinkle (Oxystele sp.) and limpet (Patella sp.) shells suggested appreciable mortality in some areas but many survived. Subtidally there

Stander, G.H., and J.A.V. Venter. 1968. (continued).

was no evidence of damage. "Three planktological surveys in the area where the oil was originally released revealed no unusual conditions which could be attributed to oil pollution. A marked plankton mortality which was observed and affected mainly cold-water forms, e.g., Centropages brachiatus, Ctenocalanus vanus, Paracalanus parvus, Paracalanus crassirostris, could be explained by the intense interaction between warm water of Angulhas Current origin and cold Benguela Current water."

Steed, D.L., and B.J. Copeland. 1967. Metabolic responses of some estuarine organisms to an industrial effluent. Contr. Marine Science, University of Texas 12:143-159.

The average concentration of oil in the effluent was 15.9 ppm; however, sulfates, sulfides, phenols and suspended solids were all present in higher concentrations. Estuarine fishes Cyprinodon variegatus, Lagodon rhomboides and Micropogon undulatus and shrimps Penaeus duorarum and P. aztecus were exposed to dilutions of 1-8% effluent in unpolluted bay water (Port Aransas, Texas). Most concentrations tested were below TLM_{48} for the species. The authors conclude that low concentrations depress metabolic rate but as concentrations approach TLM_{48} metabolic rate exceeds normal. In one long-term experiment (six days) at 1/2 TLM_{48} for C. variegatus, there was initially a depression in metabolic rate compared to controls maintained in clean water, followed by an increase at the termination of the trial. These results are used to suggest long-term effects in nature: slower growth, lower fecundity, shorter life-span all contributing to declining populations. This coupled with reduced success in interspecific contact may lead to replacement by less valuable forms.

[Probably the other components of the effluent are more harmful toxicants than the oil; nevertheless, it certainly is relevant to consider the effluent as a whole since oil refining is a very common intrusion in the coastal environment. Short-comings are that no information is given on how far from the effluent source the tested dilutions would be achieved, the concentrations tested really were not much less than TLM_{48}, the data for the three fish do not support the generality of the low level metabolic depression, near TLM_{48} metabolic stimulation claimed by the authors (the pattern is only clear for Cyprinodon variegatus), test

animals were given only three to four hours to acclimate The discussion is relevant and interesting but probably is not justified on the basis of the data presented.]

Straughan, D. 1970. Redressing the balance on the reef. Marine Pollution Bulletin 1(6):86-87.

Living corals are not likely to come in direct contact with oil. Also they are slimy and probably oil will not stick. Possible dangers are the soluble fractions of the oil and reduction in the penetration of light. Intertidally oil would probably stick to the dead coral and coral rubble. Even if volatile fractions evaporated, the danger of smothering would remain. The intertidal mudflats especially in areas of mangroves could be seriously affected because the vegetation would retain the oil. Also oil can penetrate into crab holes. In the absence of dispersants oil will not penetrate muds but will float off with each high tide. Coral sands tend to absorb oil. It is difficult to predict if the oil would wash off easily.

[This is conjecture which seems reasonable but is unsupported by data.]

Tagatz, M.F. 1961. Reduced oxygen tolerance and toxicity of petroleum products to juvenile American shad. Chesapeake Science 2:65-71.

No shad died in 42 hours exposure to 1.8-2.9 ppm oxygen nor to 68 mg/l gasoline and 84 mg/l diesel fuel oil. In combination, however, all fish died in one hour for gasoline and five hours for diesel fuel oil.

[In coastal waters which receive other kinds of wastes, it may be extremely important that synergistic interactions exist between low oxygen and petroleum wastes, since that is where both circumstances are most likely to occur. It would be valuable to know how much lower concentrations of petroleum products would have to be not to cause damage. The nominal concentrations are undoubtedly higher than the fish actually experience because the oil was applied to the surface and solution was accomplished only by the circulation of water at one gallon per minute dripped through the oil layer.]

Tarzwell, C.M. 1971. Toxicity of oil and oil dispersant mixtures to aquatic life. In Water Pollution by Oil, ed. P. Hepple, pp. 263-272. Institute of Petroleum. London.

There is a 700-fold difference in toxicities of different emulsifiers. Mixing with oil increases the least toxic emulsifiers by up to 60-fold but does not increase the effect of the most toxic emulsifiers much at all. Emulsifying oil in water by physical means alone greatly increases its toxicity. The rest of the report consists of very brief reviews of other studies.

Tegelberg, H. 1971. Razor clam mortality at Pacific and Copalis Beaches, March, 1964. Department of Fisheries. Management and Research Division. (Olympia). Washington. 21 pp.

A conservative estimate of mortality was 300,000 due to the spilling of gasoline, diesel fuel and furnace oil on the beach. Areas 1/2 mile distant from the site of the grounding showed declines of 37% and 50% since the fall of the previous year. The former was partly due to commercial fishing but not the latter. The rest was believed mainly due to petroleum. There was no indication of long-term damage. As well as the direct loss of revenue from death of clams, the closure of the commercial season and temporary closure of sport fishing led to further loss to fishermen and tourism.

Wells, P.G. 1972. Influence of Venezuelan crude oil on lobster larvae. Marine Pollution Bulletin 3(7):105-106.

"Emulsions of crude oil are lethal to larvae of the American lobster at concentrations of 100 ppm and appear to have sublethal effects down to 1 ppm."

[The author points out that the preparation of the emulsion might be so different from those produced under natural conditions that the toxicity might be increased. The point stands that adverse effects on a commercially important crustacean were expressed at low concentrations. Probably the lethal level of 100 ppm would not be attained over large areas simultaneously and whether lower doses would effect recruitment, even if destroying a large proportion of larvae, is debatable.]

Wilhm, J.L., and T.C. Dorris. 1968. Biological parameters for water quality criteria. Bioscience 18:477-481.

Species diversity is a sensitive indicator of pollution. In streams receiving oil field brines, diversity decreased below an effluent outfall, then progressively increased further downstream. In oil refinery effluent holding ponds, the diversity of insects increased from the pond receiving the wastes to the last one in the series. Reanalysis of Reish and Winter (1954) using species diversity revealed that areas near oil fields that they judged not to show evidence of damage had around half the diversity of nearby areas. (Reish, D.J., and H.A. Winter, 1954 . The ecology of Alamitos Bay, California, with special reference to pollution. California Fish Game 40:105-121.).

[Changes in relative abundances of species may be the important consequence of pollution, which may not be shown by only counting number of species or overall biomass. The reservation about the technique must be that the areas compared are indeed similar except for the pollution. This may not have been true for some of the examples used. The adequacy of controls is of utmost importance.]

Wilson, K.W. 1970. The toxicity of oil spill dispersants to the embryos and larvae of some marine fish. In FAO Technical Conference on Marine Pollution and its Effects on Living Resources and Fishing, 9-18 December 1970. FAO, Rome.

Corexit is very low in toxicity. Emulsifiers in kerosene base solvents are somewhat less harmful than in aromatic hydrocarbon solvents but are still orders of magnitude more harmful than Corexit. The tolerance of various fish larvae to BP 1002 (aromatic hydrocarbon solvent) ran: herring > lemon sole > pilchard > sole > haddock with plaice being most tolerant to 10 ppm but between pilchard and sole at 100 ppm. Larvae were most sensitive between hatching and first feeding and much more sensitive than advanced embryos. Exposure to as little as 2.5 ppm BP 1002 as eggs for 96 hours or as larvae for 48 hours lowered the proportion metamorphosing; 10 ppm virtually eliminated development as far as metamorphosis. Larvae which survived to metamorphose after exposure to 7.5 ppm were not different in appearance from controls. 0.5 ppm altered the behavior of herring larvae.

Wilson, K.W. 1970. (continued).

[This seems to be a well executed and useful piece of work. The concentrations used are probably too high to be applicable to field conditions but the information on relative tolerances of kinds of larvae and stages of development can be applied. The delayed effects of exposure to high concentrations for a brief period may be realistic and suggest that direct spraying where larvae occur would do damage even if dissipation is rapid.]

Wohlschlag, D.E., and J.N. Cameron. 1967. Assessment of a low level stress on the respiratory metabolism of the pinfish (Lagodon rhomboides). Contr. Marine Science, University of Texas 12:160-171.

Waters from the Corpus Christi turning basin are mainly polluted by petrochemical wastes. The concentration is not known. Undiluted water killed 5-10% of the fish in five days. The experiments were run with half diluted and clean seawater at 10°, 15°, 20°, 25°, and 30°C and acclimated for three days. Oxygen consumption of the fish when resting and when moving at 10 m/min. were then measured. Big fish were more sensitive to the pollutants than small and the effect was accentuated at the temperature extremes.

[The study does demonstrate that sublethal effects of a mainly petrochemical waste may have important ecological consequences. The depressed metabolism in polluted waters probably would lead to reduced growth, reproduction and perhaps life span. More important may be the synergistic interaction of different kinds of stresses operating simultaneously. The difficulties in applying the study to the problem of oil pollution are that other contaminants were present and that the concentrations are not known.]

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