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Edible-Oil Pollution on Fanning Island[1]

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ABSTRACT: In August 1975 the M.V. *Lindenbank* went aground on Fanning Atoll and dumped 17,797 metric tons of cargo onto a pristine coral reef. Nearly 10,000 tons of the cargo were vegetable oils and edible-oil raw materials such as copra. Although no toxic substances were dumped into the water, the effects of these oily substances were similar to those occurring after a petroleum oil spill. Fishes, crustaceans, and mollusks were killed and an excessive growth of *Enteromorpha* and *Ulva* occurred. The animal kill was most likely attributable to asphyxiation and clogging of the digestive tract, while the algal growth was most likely attributable to the elimination of algal competitors, increased fertilization from the pollution and ship, and reduced grazing pressure. Oil may have suppressed certain algal species while stimulating others. Complete recovery of the original coralline algal community proceeded in sequence from *Enteromorpha* to *Ulva* to *Cladophora-Lyngbya* to *Hypnea-Caulerpa* to *Jania-Gelidium*. The climax community became evident 11 months after the original spill.

DURING THE NIGHT of 17 August 1975, the 148.7 m long general cargo ship M.V. *Lindenbank* (Andrew Weir and Co. Ltd., Glasgow) drifted onto the reef at Fanning Island (Figure 1). On the following day, a small tug boat attempted to assist the *Lindenbank*, but the ship remained stationary; 4 days later, large southerly swells drove the southwesterly exposed ship farther onto the reef and hindered rescue operations. Three U.S. Navy tugs arrived on 25 August and were unable to free the ship. It was during this time that the crew lightened the vessel by jettisoning most of its cargo, primarily copra (dried coconut meat), palm oil, coconut oil, and cocoa beans. The effect of this material on the reef community was profound and provided a rare opportunity to observe the effects of nontoxic oily products on an isolated tropical coastline.

Although this appears to be the first report of a massive nontoxic oil spill in the marine environment, comparisons can be made between this spill and toxic crude oil spills in relation to the changes they cause in the environment. Fish kills and green algal growth have been cited (Bellamy et al. 1967; Foster, Charters, and Neushul 1971; Foster, Neushul, and Zingmark 1971; Holme 1969; Holmes 1969; Nelson-Smith 1971; North et al. 1964; Smith 1968) as the result of toxins in oil, detergents, excessive rainfall, and other factors, whereas the *Lindenbank* oil spill contained no toxins and occurred in such a way that meteorological factors could be eliminated as causes.

LOCATION

Fanning Atoll (3°50′ N, 159°20′ W) lies approximately 1500 km south of Honolulu, Hawaii, in the central Pacific (Figure 2). It consists of an almost continuous ring of land enclosing a lagoon that communicates with the ocean through one main pass at English Harbor on the west side and two other minor passes, one to the north and one to the east. Surrounding the atoll is a shallow reef flat

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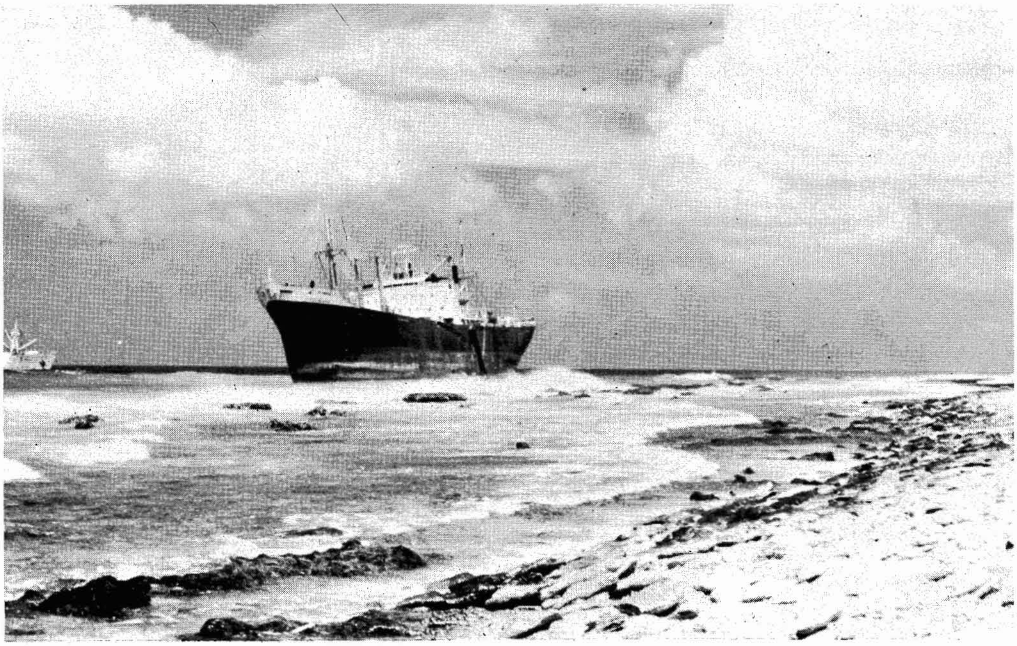

FIGURE 1. M.V. *Lindenbank* irreversibly lodged on the western rim of Fanning Island.

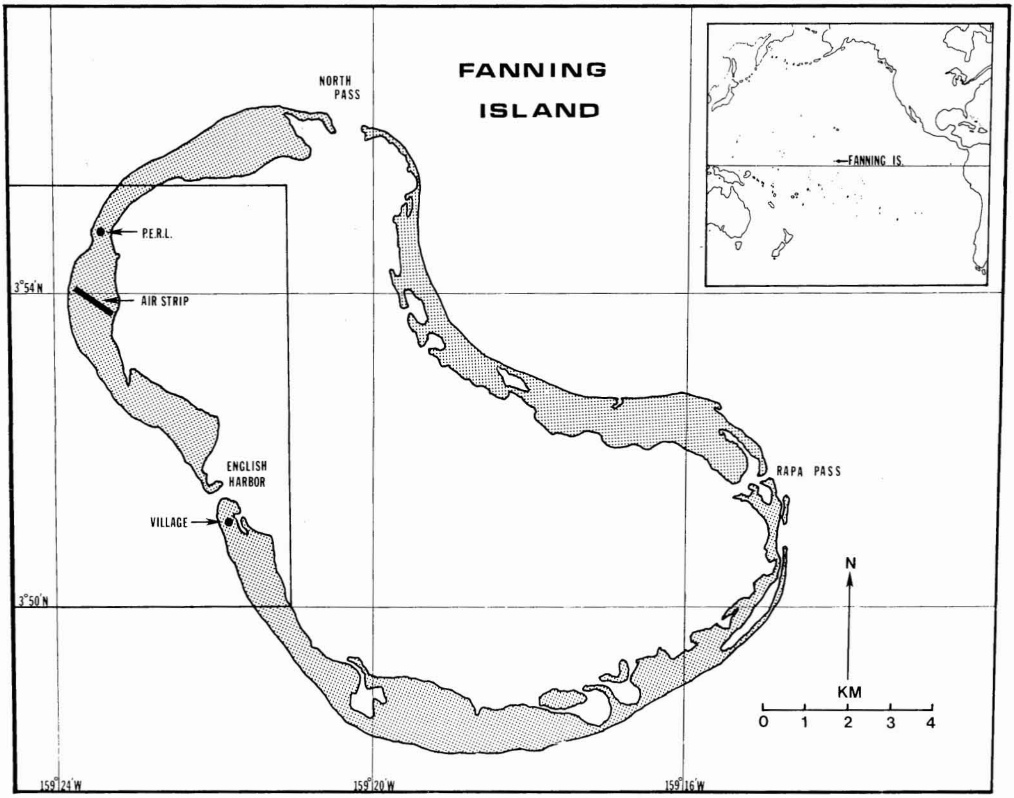

FIGURE 2. Fanning Island, Line Islands, lying about 1500 km south of Honolulu, Hawaii.

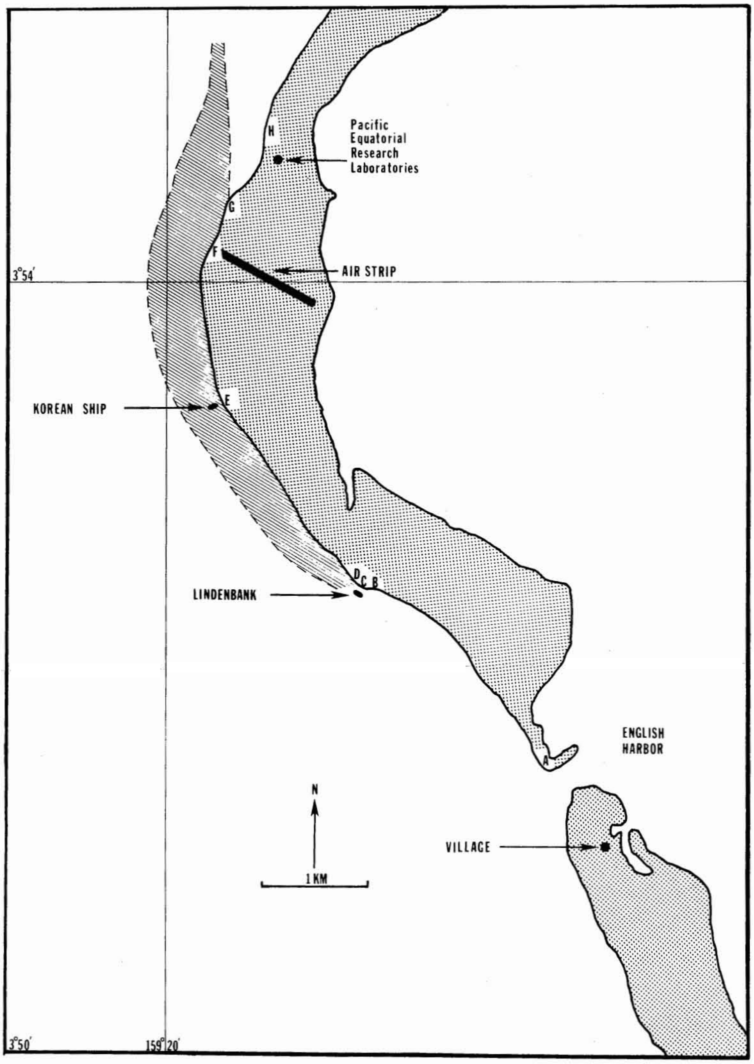

FIGURE 3. The western rim of Fanning Island; the sampling sites are marked *A–H* and the area shaded with fine lines represents the oil slick.

that extends about 100 to 200 m offshore, beyond which the depth increases abruptly to 25 to 30 m.

The reef flat upon which the *Lindenbank* foundered is made up of scattered coralline algal heads, often 1.0 m in diameter and partially exposed at low tide. The oil spill affected only the area north of the *Lindenbank* on this leeward shore (Figure 3). The shoreline in this vicinity consists of a 2.0-m high coral rubble rampart (Kay 1970) made up of loosely piled flat coral rocks and extends from English Harbor to the Pacific Equatorial Research Laboratories (PERL), a distance of 12 km. At PERL there is a sandy beach, while further north the shoreline changes to beach rock and coral rubble.

Previous phycological and zoological studies (Chave 1970, Chave and Kay 1972) did not include the specific site of the shipwreck, although observations from the air in 1972 by the senior author and unpublished photographs of the atoll show that the reef where the *Lindenbank* was stranded had been

TABLE 1

TYPES OF DATA GATHERED AT VARIOUS LOCATIONS DURING OCTOBER 1975 AND JULY 1976

LOCATIONS ALONG SHORE	COPRA AND COCOA BEANS		SUSPENDED SEDIMENT		SHORE TRANSECT, 100 m		REEF TRANSECT, 50 m	
	1975	1976	1975	1976	1975	1976	1975	1976
A	+	+	+	−	+	+	+	−
B	+	+	+	+	+	+	+	−
C	−	−	−	−	−	−	+	−
D	+	+	+	+	+	+	+	−
E	+	+	+	+	+	+	+	−
F	−	−	−	−	+	+	−	−
G	+	+	+	+	+	+	−	−
H	+	+	+	+	+	+	+	−

pink to red, indicating the dominance of coralline and foliose red algae at that time.

MATERIALS AND METHODS

A four-part approach was used to conduct this study: (1) interviews with persons who witnessed the events, (2) reconnaissance from an airplane and from shore, (3) selection of transect sites, and (4) quantitative assessments. In addition, the senior author conducted a brief follow-up study in July 1976. Eight days were available for the study, 1–8 October 1975, plus 2 days the following year.

Interviews were held with the following persons: Harold Cropp, plantation manager at Fanning Island; Bill Frew, plantation manager at Washington Island; Martin Vitousek, Director of PERL; Kam Chou, caretaker-scientific assistant of PERL; and the five remaining crew members aboard the *Lindenbank*.

Reconnaissance consisted of aerial observations and photography as well as evaluation of the incident from shore. We walked the entire distance from English Harbor through the affected area and beyond to PERL.

Eight sites were selected for study and given letter designations (Figure 3). Five of these sites (*C*–*G*) were in affected areas, while three (*A*, *B*, *H*) had not been touched by the pollution and therefore served as controls. Data gathered at each of these sites (Table 1) included the amounts of copra and cocoa beans, their distribution along the shore, amounts of noncalcareous organic matter suspended in the water, numbers and species of dead organisms washed onto the shore, and underwater observations.

Suspended sediment was sampled from the water with a 40-μ mesh Turtox 73–465, 15.2-cm diameter plankton net. The net was pulled through the water at each site, 50 m offshore for 5 min. The sediment was later suspended in 10 percent HCl to dissolve the calcium carbonate, filtered, dried, and weighed. A small subsample was taken before filtering for microscopic examination.

At seven locations on shore, all species of dead organisms were listed, counted, or weighed along 100-m transects.

Underwater surveys were made along a premarked 50-m transect line anchored at the summit of the coral rampart and extended out onto the reef. Algal species were determined and percentages of cover were obtained by counting the number of points out of 16 that intersected the location of various algal thalli under a grid in a 40 × 40 cm frame. Only the most abundant algae were recorded, species were noted, and specimens were preserved in formalin for identification at a later time. Fishes were censused by recording the numbers of species and individuals observed in ten successive

TABLE 2

CARGO JETTISONED BY THE M.V. *Lindenbank* DURING INITIAL SALVAGE OPERATIONS 28 AUGUST 1975

SUBSTANCE	METRIC TONS
Coconut oil	1,000
Copra	5,497
Cocoa beans	500
Palm oil	2,500
Total vegetable matter	9,497
Miscellaneous cargo	8,300
Total cargo jettisoned	17,797

quadrats, each 5 × 1 m, along one side of the transect line.

Strong surf action in July 1976 prevented the laying of the reef transect, but samples of algae growing on the reef were taken and relative abundance noted.

RESULTS

Distribution of Pollution

Over half of the cargo jettisoned was edible vegetable matter. Out of a total of 17,797 metric tons of jettisoned cargo, 9497 metric tons were edible materials, while the remainder consisted of burlap bags, ropes, lumber, cow hides, empty 55-gal drums, and ship's furniture (Table 2). Coconut oil was dumped during 25–27 August and formed a 10-cm thick layer on shore that persisted for several weeks. On 28 August, the majority of copra was dumped overboard, much of which washed ashore as far north as PERL. A week later, large quantities of copra drifted ashore at Washington Island, 150 km northwest of Fanning Island (Bill Frew, personal communication). At no time, however, was lubricating or fuel oil spilled, nor was any detected during the October investigation. Most of the ship's No. 10 diesel fuel was taken to Honolulu, Hawaii, and none was spilled.

Aerial observations and photographs were used to estimate the position and extent of an oil slick that extended 0.5 km from shore and approximately 6.0 km to the north of the ship. At PERL, the slick deflected from shore and became narrower as it diffused out to sea (Figure 3). None of the copra or oil spread to the south due to prevailing currents.

Almost all the copra and cocoa beans were washed ashore north of the *Lindenbank* and were partially degraded by the surf, the grinding action of the rubble, land crabs (*Cardisoma carnifex*), and other organisms. Oil released from the copra covered the rocks as a slippery, colorless film.

Copra and cocoa beans were found in a nearly unbroken line 4.5 km long from the ship's stern (site *D*) to site *G* (Table 3, Figure 4). Copra along this line increased from 21.8 kg/m at site *D* to 61.0 kg/m at site *G* (Figure 5). No copra was found on the beach at PERL or to the north. It is estimated that in October 1975 there were about 203.0 metric tons (45.1 kg/m average over 4.5 km), or 3.7 percent of the ship's copra cargo, remaining along the shore. There were also

TABLE 3

QUANTITIES OF POLLUTION MATERIALS ON SHORE AND SUSPENDED IN THE WATER

MATERIALS	YEAR	ENGLISH HARBOR, *A*	*Lindenbank* BOW, *B*	*Lindenbank* STERN, *D*	KOREAN SHIP, *E*	COCOA BAGS, *G*	PILL BOX, *H*
Cocoa bean bags	1975	0	0	0	0	633	0
Copra (kg/100 m)	1975	0	0	2,180	5,250	6,080	0
	1976	0	0	0	3,470	0	0
Cocoa beans (kg/100 m)	1975	0	0	0	71	118	0
	1976	0	0	0	5	0	0
Total sediment (g)	1975	0.88	0.95	0.61	3.04	5.14	0.20
	1976	—	5.68	—	7.33	5.74	2.07
Organic sediment (g)	1975	0.01	0.05	0.24	1.68	4.63	0.02
	1976	—	0.21	—	2.45	0.23	0.06

FIGURE 4. A nearly unbroken line of copra, cocoa beans, and other cargo extended along the shore north of the *Lindenbank*.

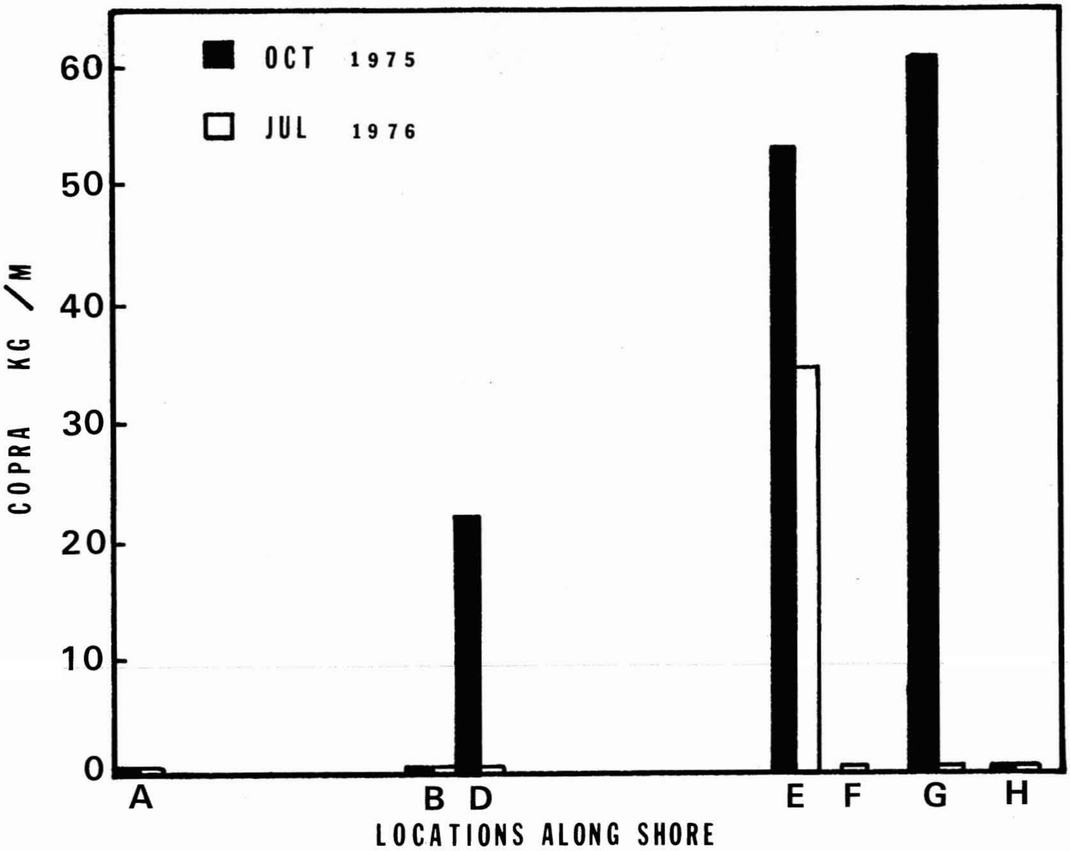

FIGURE 5. The histograms represent copra deposited along the western shore of Fanning Island and are spaced relative to the actual distance between locations.

about 4.3 metric tons (0.95 kg/m over 4.5 km) of soaked cocoa beans, or about 1.0 ton of dry beans, less than 1 percent the amount jettisoned. Therefore, 5,294 metric tons of copra and 499 metric tons of cocoa beans were washed out to sea.

The most noticeable effect of the copra on the reef was the reduction of water clarity in comparison to control sites (Table 4). Examination of the sediment collected from the water revealed that particles of copra made the water milky and turbid. These samples also showed that the greatest amounts of suspended material were adjacent to the greatest amounts of copra along shore (Figure 6). Furthermore, two dips with the sampling net 2.0 m from shore yielded 4.0 g copra sediment, while only 1.68 g were collected after 5 min at 50 m. Ground copra was being washed out onto the reef from shore continuously, but especially at high tide.

Organisms Washed Ashore

At site *A* and progressing to site *H*, there was a change in the algal species in the drift. At site *A*, there was no drift (Table 5), while at sites *B* and *D*, clumps of *Jania natalensis-Gelidium pulchellum* were found. These turf pieces were present only near the ship's stern and were apparently carried to shore by a current that was sweeping them from the reef at site *B* to site *C*. The sparse algal drift to the north consisted of *Turbinaria ornata* at site *E* and *Hypnea pannosa* at site *H*.

At site *A* and progressing to site *H*, there was a change in the animal species in the drift. There were no animal remains observed

TABLE 4

DESCRIPTION OF EACH TRANSECT AREA, OCTOBER 1975

TRANSECT DESIGNATION	NAME OF LOCATION	SHORE TYPE	COPRA LITTER	COCOA BEANS	WATER CLARITY	DOMINANT ALGAE	GENERAL REMARKS
A	English Harbor	Rubble	–	–	Clear	Corallines pink	Many loose rocks were on the reef and live *Pocillopora* was common.
B	*Lindenbank* bow	Rubble	–	–	Clear	Corallines pink	Large coral heads, loose rocks, and ship ropes were present.
C	*Lindenbank* midship	Rubble and sand	–	–	Moderately clear	*Jania* and *Cladophora*	Large coral heads were present in water deeper than at *B* or *D*.
D	*Lindenbank* stern	Rubble	+	+	Milky	Chlorophyta, dark green	Large coral heads were on the reef. Cowries, cans, barrels, and boards were cast ashore.
E	Korean ship	Rubble	+	+	Milky	*Cladophora*, light green	Large coral heads were on the reef. Dead fish and crabs were mixed with decaying copra on shore.
F	Air strip	Rubble	+	+	Milky	*Cladophora*, light green	Few large coral heads were on the widening reef flat. Many dead fish were mixed with decaying copra on shore.
G	Cocoa bags	Rubble	+	+	Milky	*Hypnea*, *Caulerpa*	Few large coral heads were scattered on a wide reef flat. Many dead fish were mixed with copra, ropes, and burlap bags on shore.
H	Pill box	Rubble and sand	–	–	Clear	*Hypnea*, blue-greens	No large coral heads were present on an extensive reef flat. *Tripneustes* tests were abundant on shore.

NOTE: + denotes the presence of the pollutant,
– denotes its absence.

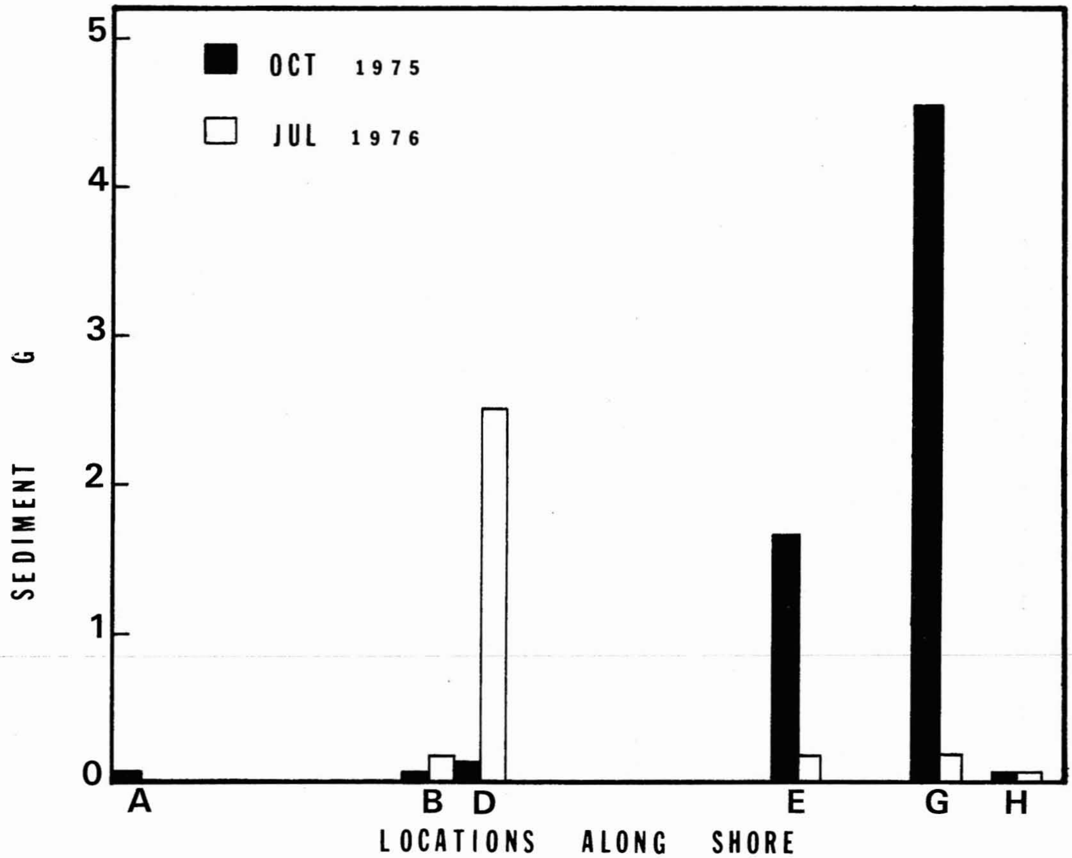

FIGURE 6. The histograms represent the amounts of organic sediment sampled from the water covering the reef flat and are spaced relative to the actual distance between locations.

at site *A*. But at site *D*, 65 gastropod shells of *Cypraea* spp. were washed ashore—nearly four times the amount collected at site *B* (Table 5, Figure 7). The shells at site *D* were empty and had a glossy appearance, while those at site *B* were heavily abraded. Seven species of crustacea and three species of fishes were found at sites *E*, *F*, and *G*, and the numbers of individual remains at these sites increased directly with the increase in copra along the shore. For example, 5 crustacean remains were found at *E*, 77 at *F*, and 241 at *G*.

The Reef Community

More algal species occurred on the reef south of the *Lindenbank* than to the north, and a transition from a coralline-dominated reef in the control area to one dominated entirely by green algae in the affected area occurred in a distance of only 150 m (Table 4, Figure 5). At sites *A* and *B*, coralline algae were abundant; at midship (site *C*), *Cladophora trichotoma*, *Porolithon onkodes*, *Gelidium pulchellum*, and *Dictyota friabilis* were present; while at site *D*, *Enteromorpha lingulata* was the only alga present and covered 78 percent of the reef substratum (Table 6). At site *E*, 80 percent of the reef was covered with *C. trichotoma* and *Lyngbya majuscula* tufts. The reef at *H*, however, was dominated by *Schizothrix calcicola*, *Microcoleus lyngbyaceus*, *P. onkodes*. and *Hypnea pannosa*, which were also present during earlier investigations at that site.

TABLE 5

DEAD ORGANISMS ALONG SEPARATE 100-m SEGMENTS OF SHORE

ORGANISMS	*A*	*B*	*D*	*E*	*F*	*G*	*H*
Algal drift (g), 1975							
Jania natalensis turf	0	39.0	225.0	0	0	0	0
Hypnea pannosa	0	0	0	0	0	0	140.0
Turbinaria ornata	0	0	0	276.0	0	0	0
Algal drift (g), 1976							
Hypnea pannosa	0	0	0	87.5	11.1	74.0	186.0
Turbinaria ornata	0	0	0	283.0	5.5	0	0
Ulva fasciata	0	0	2.0	0.6	1.1	0	0
Fishes							
Muraenid eels	0	0	0	7	2	36	0
Myripristis sp.	0	0	0	0	0	1	0
Epinephelus sp.	0	0	0	0	0	1	0
Crustaceans, 1975							
Charybdis erythrodactyla	0	0	0	1	5	2	0
Carpilius convexus	0	0	0	0	5	1	0
Carpilius maculatus	0	0	0	0	5	5	0
Zosimus anaeus	0	0	0	0	7	10	0
Daira perlata	0	0	0	3	50	201	0
Etisus dentatus	0	0	0	0	2	1	0
Panulirus penicillatus	0	0	0	1	3	1	0
Mollusks*, 1975							
Cypraea spp.	0	16	65	1	0	0	0
Conus spp.	0	9	12	0	0	0	0
Turbo argyrostomus	0	5	17	1	0	0	0
Other mollusks	0	0	12	2	0	0	0
Mollusks, 1976							
Cypraea caputserpentis	0	0	0	0	0	2	0
Cypraea depressa	0	0	0	0	0	2	0
Echinoderms							
Echinothrix sp.	0	0	0	0	2	2	0
Echinometra sp.	0	0	0	0	0	1	1
Holothuria atra	0	0	0	0	0	1	1
Total algae (g), 1975	0	39	225	276	0	0	140
Total algae (g), 1976	0	0	2	371	17.7	74	186
Total animal counts, 1975	0	30	106	16	81	263	2

* *Cypraea caputserpentis*, *C. depressa*, *C. helvola*, *Conus catus*, *C. chaldaeus*, and *C. tulipa* were combined under their respective genera, while other mollusks include *Astraea calcar*, *Bursa granularis*, *Drupa morum*, *Latrus iris*, *L. amplustris*, *Mitra ferruginea*, *M. stictica*, and *Nassa serta* (identified by A. Kay).

More species of fishes and greater numbers of individuals occurred on the reef south of the *Lindenbank* than to the north. From two to four times more fish species and five to ten times more individuals were found along transects at sites *A*, *B*, and *C* than at sites *D* and *E*. The surgeonfish, *Acanthurus triostegus*, was the only fish encountered along every transect, with the greatest numbers at site *C* and fewest at sites *D* and *E*. The reef at *H* also had more individual fishes than the affected areas.

Results, 1976

In July 1976, 11 months after the oil spill, all sites were reexamined for copra and cocoa beans (Table 3). At site *E*, 34.7 kg/m of copra and 48.4 g/m of cocoa beans were still present under 0.5 m of coral rubble (Figure 6). The copra was gelatinous, red, and full of *Hermetia illucens* maggots (determined by Dick Tsuda). At sites *F* and *G*, only fragments of the dark-brown nucellus of copra and cocoa beans were found. Near the ship, however,

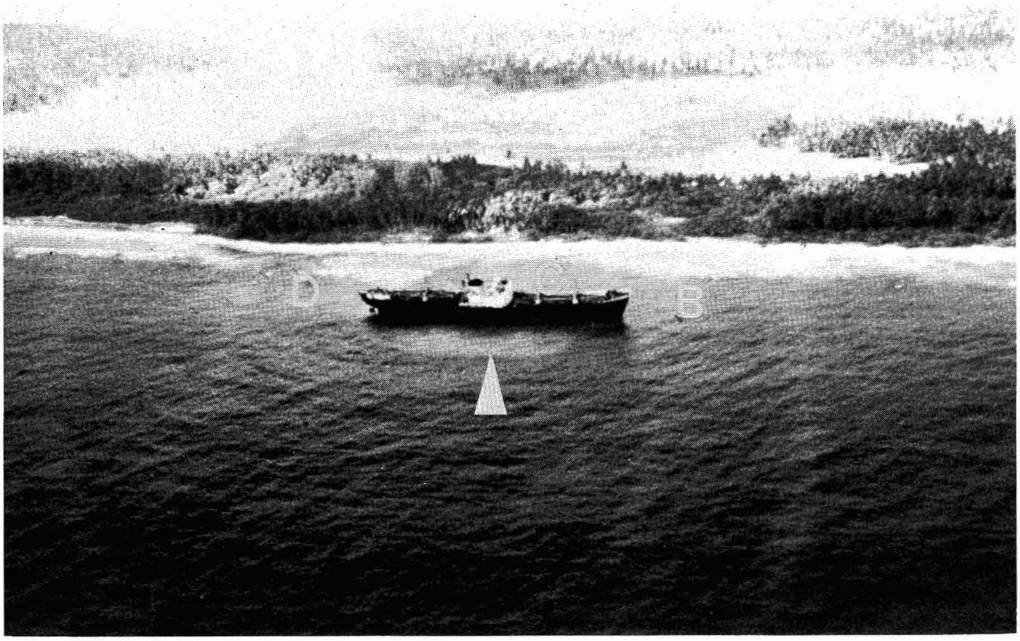

FIGURE 7. The *Lindenbank* resting aground on Fanning Island. Three sampling sites are located: *B* is the control area, *C* is midship, and *D* is in the affected area. The arrow points to a white patch of newly crushed coral on the reef edge.

pieces of fresh copra and cocoa beans were found in the water. These were released from the ship through two holes 5 to 7 m in diameter in the seaward hull; these had formed by surf action during 1976. Sediment from site *D* contained fly pupa cases, fragments of *Ulva fasciata*, copra, and petroleum-covered particles. A brown scum on the water near the ship and oil on the rocks near shore was caused by lubricating oil emanating from the engine room of the ship. This oil was affecting the reef both to the south and to the north of the ship for about 0.5 km in each direction.

There was no drastic change in the color of the reef from pink at site *B* to dark green at site *D* in 1976. Neither was the ship fringed by *Enteromorpha* at the waterline. Instead, the reef at site *B* and the ship were colonized heavily by a dense mat of *Lyngbya majuscula*, *L. mucicola*, and *Calothrix confervicola* (Desikachary 1959). The only red alga in the surf was *Gelidiella bornetii* (Table 6), and site *C* had filled in with sand. Site *D*, however, was covered almost entirely by *Ulva fasciata*. The reef at sites *E* to *G* was dominated by *Hypnea pannosa* and *Caulerpa racemosa*, with large areas of *Jania natalensis* and *J. capillacea* growing adjacent to and beneath the *Hypnea*. Site *H* had remained essentially the same as in 1975.

DISCUSSION

The *Lindenbank* edible-oil spill on Fanning Island provided a unique situation which, in some respects, resembled a planned experiment. For instance, immediately adjacent to the affected reef was a control area, an identical portion of reef untouched by the pollution. This meant that both the affected area and the control were subject to the same natural phenomena, such as excessive rainfall, high or low surf, low tides, fertilizer seepage from estuaries, and changes in reef physiography that may, in some cases, also affect the reef community. The changes in the

TABLE 6

LIVING ORGANISMS ALONG SEPARATE 50-m UNDERWATER TRANSECTS

ORGANISMS AND SUBSTRATA	*A*	*B*	*C*	*D*	*E*	*H*
Algae and substrata						
Cyanophyta	—	—	—	—	73	131
Porolithon onkodes	68	35	10	—	—	22
Gelidium pulchellum	56	63	23	—	—	—
Gelidiella bornetii	17	25	—	—	—	—
Jania natalensis	—	19	—	—	—	—
Laurencia surculigera	1	—	—	—	—	—
Enteromorpha lingulata	—	—	—	124	—	—
Cladophora trichotoma	—	—	53	—	55	—
Avrainvillea lacerata	2	—	—	—	—	—
Caulerpa racemosa	1	—	—	—	2	—
Dictyosphaeria versluysii	1	—	—	—	—	—
Dictyota friabilis	—	—	26	—	—	—
Total species present	7	4	4	1	3	2
Living coral	9	—	—	—	—	—
Rock	4	16	34	32	29	3
Sand	1	2	14	4	1	4
Fishes living on the reef						
Gymnothorax pictus	—	1	—	—	—	—
Lutjanus fulvus	—	—	1	—	—	—
Caranx sp.	—	—	—	1	—	—
Chaetodon auriga	1	—	—	—	2	—
Chaetodon lunula	—	—	—	—	1	—
Abudefduf sordidus	3	1	2	2	1	—
Stegastes albofasciatus	20	—	—	—	—	—
Stegastes aureus	—	—	5	—	—	—
Stegastes nigricans	—	—	—	—	—	2
Glyphidodontops glaucus	28	—	—	—	—	41
Plectroglyphidodon dickii	1	—	—	—	—	—
Plectroglyphidodon imparipennis	4	1	6	—	—	—
Plectroglyphidodon phoenixensis	—	2	6	—	—	—
Mullet	50*	—	—	—	—	—
Gomphosus varius	1	—	—	—	—	—
Halichoeres centriquadrus	3	4	—	—	—	—
Halichoeres margaritaceus	—	19	8	—	—	1
Labroides dimidiatus	1	—	—	—	—	1
Thalassoma purpureum	—	2	3	2	—	—
Thalassoma amblycephalus	7	—	3	—	—	5
Stethojulis bandanensis	2	—	—	—	—	—
Parrotfish	—	—	2	—	—	—
Cirripectes (2 spp.)	23	—	4	—	—	—
Istiblennius sp.	19	12	—	10	—	—
Ctenochaetus striatus	2	—	—	—	—	—
Acanthurus achilles	—	2	1	—	—	—
Acanthurus lineatus	2	—	—	—	—	—
Acanthurus triostegus	25	50*	100*	5	7	11
Acanthurus xanthopterus	—	2	—	—	—	—
Rhineacanthus aculeatus	1	—	—	—	—	—
Rhineacanthus rectangulus	1	—	—	—	—	—
Canthigaster amboinensis	—	—	2	—	—	—
Total fishes present	20	11	13	5	4	7
Total individuals present	194	96	143	20	11	68

NOTE: Each number represents the sum of grid intersection points in ten samples.
* Approximate counts.

reef community were therefore directly related to the pollution materials and the presence of the ship.

An unusually lush growth of green algae after a petroleum oil spill is a well-documented event, although the causes of the phenomenon remain unknown. *Enteromorpha* completely covered the rocks after the Torrey Canyon oil spill (Bellamy et al. 1967, Holme 1969, Nelson-Smith 1971, Smith 1968, Tendron 1969), and *Enteromorpha intestinalis* covered unoiled but affected rocks along the shore at Santa Barbara (Foster, Charters, and Neushul 1971). We also observed a similar greening effect in the present study.

A green alga overgrowth after an oil spill is often attributed to reduced grazing pressure (Bellamy et al. 1967, Holme 1969, North et al. 1964, Smith 1968, Tendron 1969) caused, presumably, by the death of grazers killed by toxins in either the oil or the detergents used to clean up the oil (Dicks 1973, Nelson-Smith 1968). Fish and other grazers may graze selectively (Bryan 1975, Randall 1961) and may have the ability to eliminate *Enteromorpha* from a tropical reef (Tsuda and Bryan 1973), but this appears to be only part of the cause.

A comparison between the control area (site *B*) and the areas affected by the oils and copra (sites *D*, *E*, *F*, and *G*) has shown that there were far fewer fishes in the polluted waters. Kam Chou suggested the fish may have moved elsewhere to avoid the pollution, as was also suggested by Tendron (1969) and North et al. (1964). It is possible that *Acanthurus triostegus*, absent from site *D*, may have moved 60 m to site *C*, which was not affected by oil. This could account for the unusually high numbers of this species at site *C*. Many other nonterritorial fishes may have swum away from the affected areas also.

More obvious than pollution avoidance by fishes was the fish kill that accompanied the pollution events. Observations by Mr. Chou, along with our underwater and shore data, clearly indicate that a massive kill of fishes and other animals occurred, primarily because of the pollution. Dead crustaceans and fishes were cast ashore simultaneously with the oils and copra. In addition, dead crustacea and fishes were found only in areas where the copra and cocoa beans were found (Tables 3, 5). The organic oily substances released by the *Lindenbank* had an obvious adverse effect on the reef crustacea and fishes, but we were unable to determine the causes of animal death since only mummified remains of eels, skeletal elements of fishes, and exoskeletons of invertebrates remained.

Death of animal life during petroleum oil spills has been attributed to asphyxiation (Atlas and Bartha 1973, Boesch et al. 1974), uptake of toxins through the gills (Parker and Menzel 1974), clogging of the digestive tract (Tendron 1969), or poisoning by ingestion (Parker and Menzel 1974). Since no toxins were in the oils spilled at Fanning Atoll (Bradley 1956, Kirschenbauer 1960, Leung et al. 1972), unless traces of estrogen (Stob 1966), caffeine, and theobromine (Blood and Rudolph 1966) have some unknown profound effect on fish, the fishes and invertebrates in the polluted areas were probably killed by either asphyxiation or clogging of the digestive tract. The former was probably the case, although we do not have data to substantiate this hypothesis.

Death of *Cypraea* spp. near the stern of the *Lindenbank* was probably not due to pollution. When the ship was driven onto the reef by storm waves, its hull destroyed a 150-m wide section of the reef edge (Figure 7). This destroyed much of the cowrie habitat (Burgess 1970), and probably caused the shells to be cast ashore at site *D* (Table 5) and not at sites *E* and *G* where the greatest pollution occurred (Figures 5, 6).

The growth of green algae at sites *D* and *E* may have been allowed by the weakening or elimination of the competitive dominant *Gelidium-Jania* community. Reduced vigor (Bellamy et al. 1967) of competing algae or an alga's elimination due to excessive weight (Nelson-Smith 1971) may allow other algae to become predominant. Entrapped sand in the *Gelidium-Jania* turf (DeWreede and Doty 1970) plus the additional weight of the oils may have caused the coralline turf to be torn from the rocks. The result would open space for a pioneer species such as *Entero-*

morpha (Nelson-Smith 1971). However, the elimination of grazers and competing algae does not account for the abundance and large thallus size of green algae on the reef.

Ulva and *Enteromorpha* not only appear after an oil spill, but are often present in far greater quantities than one would expect. Reduced grazing pressure did not explain the unprecedented growth of ulvoids after the Torrey Canyon oil spill (Smith 1968), and some authors (Kauss and Hutchinson 1975, Nelson-Smith 1971) are of the opinion that *Ulva* and *Enteromorpha* may even be stimulated by the presence of oil. Perhaps the pollution at Fanning Island acted both as a stimulant and as a fertilizer for these algae.

Although palm and coconut oils lack nitrogen, sulfur, phosphorus, and other inorganic elements (Bradley 1956, Leung et al. 1972) that may fertilize, copra and cocoa beans do contain some phosphorus and protein nitrogen that could be released upon degradation. In conjunction with these fertilizers, iron and trace metals derived from the ship hulls may be present and these may also have stimulated green algal growth. Iron deficiency often limits algal growth on nonigneous islands (Doty 1954) and *Enteromorpha* was found to grow much larger near a small sewage outfall by PERL than at other locations at Fanning Island (DeWreede and Doty 1970). Although the degradation of vegetable oils requires nitrate (Smith 1974), the copra and cocoa beans may have supplied nitrogenous and phosphorus elements, while the *Lindenbank* and Korean ship hulls may have provided necessary metallic elements.

Algal Succession

Eleven months after the oil spill, the original dense cover of *Enteromorpha* near the ship had changed to *Ulva fasciata*; the *Cladophora-Lyngbya* community at site *E* had been replaced by *Hypnea-Caulerpa*, and this latter association was in the process of being replaced by a *Gelidium-Jania* turf, which would be the normal climax community for this reef. It appears that recovery of the original coralline algal community would be complete within 2 years after the pollution event. Such a succession in conjunction with the decline in pollution has led us to conclude that oil may repress certain algal species while stimulating the growth of green algae and that grazing may be of secondary importance.

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