CHAPTER 6. CORAL CASE STUDIES

Introduction

By studying past oil spills in coral reef environments, we get a good idea of some of the complexities and variability of these types of incidents. We have searched for case studies of oil spills impacting coral reefs that were well documented both during the incident and response, and also were re-visited after the spill to determine long-term outcomes. Unfortunately, many incidents are poorly documented, especially those dating back several decades. We describe several case studies representing oil spills from the Pacific, Caribbean, and Arabian regions. Some events caused devastating, long-lasting impacts, while others appeared to have caused little long-term impact to corals. Some spills, such as the *Ocean Eagle* and *Morris J. Berman*, did not impact coral because the oil did not reach areas rich in coral. However, these incidents illustrate many of the other response limitations that may be present on tropical island incidents, such as limited availability of salvage and response equipment and limited storage capacity for collected oil. The Rose Atoll incident illustrates an unfortunate but not uncommon type of spill, especially in the Pacific—a freighter or fishing vessel runs aground in bad weather on a remote atoll. Response options are almost nonexistent, and salvage vessels must travel for several days to weeks to reach the site. The ship often breaks up before the salvor can reach the scene, spilling cargo and fuel and causing repeated physical damage as wind and waves toss the wreck about on sensitive coral structures.

For several spills that were not well documented, and where limited follow-up research was conducted after the spill, we often do not know whether corals were impacted or for how long (e.g., *R.C. Stoner* and *Zoe Colocotronis*). At the time, these response efforts and associated studies focused on oiled beaches and shorelines that represented a valuable economic resource, while paying less attention to offshore, underwater habitats. Our most extensively documented case study is that of Bahía las Minas, Panama where several biological habitats were studied intensively, and followed for many years after the spill. Bahía las Minas provides an excellent example of the tradeoffs that are encountered in many tropical environments between different nearshore habitats, such as mangroves, and subtidal seagrass beds or coral reefs and how these respond differently to oil contamination.

We have included descriptions of two field experiments that, while not representing actual oil spills, do provide good information on oil spill impacts in a controlled, non-laboratory setting. Lastly, several restoration case studies give current examples of how reefs that have been physically damaged from ship groundings can be given a boost towards eventual recovery by the developing technologies of reef restoration.

Spill case studies

R.C. Stoner, Wake Island/September 1967

On September 6, 1967, the tanker *R.C. Stoner* grounded 200 m southwest of the harbor entrance at Wake Island. Wake Island consists of three islets forming an atoll enclosing a shallow lagoon. The tanker was fully loaded with over 6 million gallons of refined fuel oil, including 5.7 million gallons of aviation fuels; 168,000 gallons of diesel oil; and 138,600 gallons of Bunker C. There was an immediate release of fuel after the grounding, believed to be primarily aviation fuel. On the following day, a "considerable quantity" of Bunker C was also observed, and gasoline vapor odor was detected through September 8.

The heavy cargo load and rough seas hampered efforts to refloat the vessel, and on September 8 the stern of the ship broke off. An estimated 600,000 gallons of the mixed fuels covered the surface of a small boat harbor, up to 20 cm thick. The strong southwest winds concentrated the spilled oil in that harbor and along the southwestern coast of Wake Island.

Response

Oil recovered from the small boat harbor by pumps and skimmers was moved into pits near the shore and burned each evening; over 100,000 gallons were disposed of in this fashion. The oil was blocked from entering the central lagoon area of the Wake Island group by an earthen causeway.

Impacts

Large numbers of dead fish were stranded along the southwestern shoreline. The Federal Aviation Administration (FAA) cleared the area closest to the spill of dead fish. In addition to the massive fish kill (approximately 1,360 kg collected), dead turbine (*sic*) molluscs, sea urchins, and a few beach crabs were also reported. About 2.4 km of shoreline beyond the FAA-cleaned zone was also oil-contaminated; another 900 kg of dead fish were present but not removed. Other dead invertebrates included cowries, nudibranches, and grapsoid crabs.

In this assessment, corals in the area were mentioned only in passing, and apparently were not surveyed either formally or informally for impact. Discussion of corals was completely in the context of the associated fish communities. Given the mixture and quantities of fuel spilled, and the massive mortalities manifested in fish and reef-associated invertebrates, there almost certainly was an impact to the coral animals themselves. Gooding did note that, on a survey conducted 11 days after the grounding (after a typhoon had passed through the area), the only remaining visible impact in the inner harbor was black oil impregnated in coral. He stated that only cursory observations were made on reef invertebrates and, given external challenges to impact assessment described in the account (typhoons, tropical storm, harassment by black-tipped sharks, skin irritation to divers from exposure to fuels in water), effects to coral was presumably not included in survey objectives.

For further reading

Gooding, R.M. 1971. Oil pollution on Wake Island from the tanker *R.C. Stoner*. Special Scientific Report--Fisheries No. 636. Seattle: NOAA/National Marine Fisheries Service. 12 pp.

Ocean Eagle spill, Puerto Rico / March 1968

Morris J. Berman, Puerto Rico / January 1994

These two spills are grouped together primarily because they had similar locations, along the northern shoreline of Puerto Rico; and both reported a lack of impacts to coral reefs. The two considerations are linked. The northern coast of Puerto Rico has many large hotels and recreational beaches, but few coral reef areas. The circumstances of the two spills were otherwise rather different. The *Ocean Eagle* grounded on March 3, 1968 in San Juan Harbor, after which it broke in two and spilled 83,400 bbl of Venezuelan light crude oil. The *Morris J. Berman* was a barge laden primarily with a No. 6 fuel oil that drifted ashore about 300 meters off Escambron Beach after its towing cable parted on January 7, 1994.

Response

At the *Ocean Eagle*, chemical treatments then called an "emulsifier" were spread on thick oil on the water surface. These treatments were described as effective, apparently functioning similarly to dispersants. The *Berman* barge was eventually pulled off its grounding site and scuttled in deeper waters offshore. Shoreline cleanup was extensive, and included manual cleanup and washing. Submerged oil mats were collected by divers.

Impacts

Impacts of concern, as noted above, were similar for both incidents. Nearly all of the large tourist hotels and beaches in San Juan are concentrated along the north-central shoreline of Puerto Rico, where much of the oil in both incidents came ashore. Although many of these recreational areas were heavily impacted, sensitive natural resources such as coral reefs and mangroves that would be a major concern elsewhere in Puerto Rico are not found in abundance here. Widespread mortalities, primarily among fish and benthic invertebrates, were noted during both the *Ocean Eagle* and the *Morris J. Berman* spills; however, except for a small number of soft corals at the *Berman* grounding site, there is no mention of adverse effects to corals. This should not be construed as the absence for potential effect, but rather as a semi-fortuitous consequence of spill location and circumstance.

For further reading

Cerame-Vivas, M.T. 1968. The wreck of the *Ocean Eagle*. *Sea Frontiers 15*:222-231.

NOAA. 1992. Oil spill case histories 1967-1991, Summaries of significant U.S. and international spills. Report No. HMRAD 92-11. Seattle: NOAA/Hazardous Materials Response and Assessment Division.

NOAA. 1995. Barge *Morris J. Berman* spill, NOAA's scientific response. HAZMAT Report 95-10. Seattle: NOAA/Hazardous Materials Response and Assessment Division. 63 pp.

SS Witwater spill, Panama / December 1968

On December 13, 1968, the 35,000-barrel tanker *SS Witwater* broke apart on the Caribbean coast of Panama and released around 20,000 barrels of Bunker C and marine diesel oil. The spill occurred within three miles of the then-new Smithsonian Tropical Research Institute laboratory at Galeta Point.

Response

Response methods included pumping and in-situ burning of oil that collected in a small bay. Little documentation is available about how the burning was conducted, though it appears to have been without booms, and was considered successful in removing some oil and in limiting environmental impacts.

Environmental impacts

A follow-up study conducted 2 months after the spill found that coral reefs were the least affected of all the communities studied, and no ill effects to corals (mainly *Porites furcata*, *P. asteroides*, *Siderastrea radians*, and *Millepora complanata* (a hydrocoral)), were observed. Since the reefs are subtidal, they had no direct contact with the oil, and a higher-than-normal low tide caused by high winds may have protected coral from impacts. The incident highlighted the dearth of baseline information on Caribbean intertidal reef flat communities. A substantial effort was invested by the Smithsonian lab to compile those data, which were then used to provide background information for experimental tests of effects of oil, reported in Birkeland et al. (1976).

Black and red mangroves were more severely impacted, with visible sediment contamination, oil coating on roots and pneumatophores, and die-off of seedlings. Sandy shorelines had heavily oiled subsurface sediments, to depths of 30 cm.

For further reading

Birkeland, C., A.A. Reimer, and J.R. Young. 1976. Survey of marine communities in Panama and experiments with oil. EPA Report EPA-60013-76-028. Narragansett: U.S. Environmental Protection Agency. 177 pp.

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

Zoe Colocotronis / March 1973

On March 18, 1973 the tanker *Zoe Colocotronis* intentionally dumped 37,000 barrels of Venezuelan crude oil in order to lighter the vessel from the reef on which it grounded. Oil was carried ashore to beaches near Cabo Rojo in Bahía Sucia, Puerto Rico and into several areas containing mangrove forests.

Response

Response efforts included booming, digging sumps, and pumping collected oil into tank trucks. The U.S. Coast Guard Atlantic Strike Team helped with beach cleanup.

Impacts

Oil impacts killed approximately 2.5 acres of mangrove forest, including red and black mangroves. Numerous dead invertebrates washed ashore, including sea cucumbers, conchs, prawns, sea urchins, and polychaetes. *Thalassia* seagrass beds offshore were heavily impacted with oil and sediments were contaminated. Impacted *Thalassia* beds suffered die off and subsequent erosion, followed by recolonization after approximately one year.

Oil could well have impacted the numerous coral reefs near the spill site. Most of the attention seems to have been focused on the shoreline and nearshore subtidal impacts, including seagrass and mangroves. To our knowledge, no one looked at potential oil impacts to coral reefs.

For further reading

Nadeau, R. J., and E.T. Bergquist. 1977. Effects of the March 18, 1973 oil spill near Cabo Rojo, Puerto Rico on tropical marine communities. In *Proceedings of the 1977 International Oil Spill Conference, New Orleans*, March 8-10, pp. 535-538.

Page, D. S., D.W. Mayo, J.F. Cooley, E. Sorenson, E.S. Gilfillan , and S. A. Hanson. 1979. Hydrocarbon distribution and weathering at a tropical oil spill site. In *Proceedings of the 1979 International Oil Spill Conference*, Los Angeles, March 19-22, 1979, pp. 709-712.

T/V Garbis spill, Florida Keys / July 1975

On July 18, 1975, the tanker *Garbis* spilled 1,500 to 3,000 bbls of crude oil into the waters approximately 26 miles south-southwest of the Marquesas Keys, Florida. The oil was blown ashore along a 30-mile stretch of the Florida Keys, east of Key West. The only published description of this spill and its impacts are found in Chan (1977), although the 1976 M.S. thesis of that author at the University of Miami further detailed effects and recovery. The source of the spill, the *Garbis*, was identified after the publication of both documents.

Environmental impacts

In addition to documenting early impacts, Chan established a series of sites to be monitored over a year following the spill. Since no pre-spill information was available, effect and recovery were judged through comparison with unoiled, biologically similar locations.

Several habitats were impacted, including killing of echinoderms, pearl oysters, and oiled red and black mangroves. However, a notable lack of spill effect was found in coral reef areas. Reefs were surveyed by divers immediately following the spill, and subsequently in August and November 1975 and January 1976. Chan attributed this lack of impact to the fact that the reefs were completely submerged during the spill and to calm seas that minimized water column contact with the oil.

For further reading

Chan, E.I. 1977. Oil pollution and tropical littoral communities: Biological effects of the 1975 Florida Keys oil spill. In *Proceedings of the 1977 International Oil Spill Conference*, New Orleans, March 8-10, pp. 539-542.

Bahía Las Minas, Panama / April 1986

On April 27, 1986, about 240,000 barrels of medium weight crude oil (70 percent Venezuelan crude, 30 percent Mexican Isthmus crude) spilled from a ruptured storage tank at a petroleum refinery at Bahía Las Minas, on the central Caribbean coast of Panama. Of this amount, an estimated 60,000-100,000 barrels spilled into the waters of Bahía Las Minas. This was the largest recorded spill into a sheltered coastal habitat in the tropical Americas. The spill was located close to the Galeta Marine Laboratory of the Smithsonian Tropical Research Institute, and extensively studied.

Response

Six days after the release began, 137 bbls of Corexit 9527 chemical dispersants were applied in one bay and along the northern breakwater at the mouth of the Panama Canal. The dispersants appeared to be ineffective due to the weathered state of the oil and the calm seas. Researchers later concluded that this limited use of dispersant chemicals could not explain the widespread subtidal biological impacts reported.

Impacts

The area where this spill occurred was not pristine before the 1986 incident. Nevertheless, the incident was shown to have widespread lethal and sublethal impacts in all environments examined, including the coral reefs and reef flats. In coral reefs, the cover, size, and diversity of live corals decreased substantially on oiled reefs after the spill. Sublethal impacts included decreased growth, reproduction, and recruitment.

Follow-up studies reported an extensive mortality of both intertidal reef flat corals (*Porites spp*.) and subtidal reef corals (*Diploria clivosa*, *Porites astreoides*, and *Siderastrea siderea*) that was attributed to the spill. *S. siderea* was particularly vulnerable, with patches of recent coral death disproportionately common on heavily oiled reefs one year after the spill.

A longer-term follow-up study found higher percentages of recently injured corals at heavily oiled reefs. However, there were peaks immediately after the spill and also during another period spanning 3-5 years post-spill. The latter impacts were attributed to a series of diesel fuel spills at the electrical generation plant in Bahía Las Minas.

Coral growth studies in four native species after the spill initially found reductions in growth for *P. astreoides, D. strigosa, M. annularis*, and no effect in *S. siderea*. The lowest annual mean growth rates were measured for 1986, the year of the spill. *S. siderea* and *P. astreoides* grew more slowly during the first three years after the spill than they had before. At heavily oiled reefs, growth after the spill declined significantly for *S. siderea* but not for *P. astreoides*.

Guzmán et al. (1991) compared cover of common coral species at six reefs before (1985) and after (3 months post) the oil spill at Bahía Las Minas. At one heavily oiled reef, total coral cover decreased by 76 percent in the 0.5-3 m depth range and by 56 percent in the >3-6 m range. Cover decreased less at moderately oiled reefs and either increased or did not change at the unoiled reference reefs. The branching species *Acropora palmata* nearly disappeared at the heavily oiled site, but increased by 38 percent at the unoiled reefs. This same survey found average colony size and diversity decreased significantly with increased oiling.

For further reading

Guzmán, H.M. and I. Holst. 1993. Effects of chronic oil-sediment pollution on the reproduction of the Caribbean reef coral *Siderastrea siderea*. *Marine Pollution Bulletin 26*:276-282.

Jackson, J., J. Cubit, B. Keller, V. Batista, K. Burns, H. Caffey, R. Caldwell, S. Garrity, C. Getter, C. Gonzalez, H. Guzmán, K. Kaufmann, A. Knap, S. Levings, M. Marshall, R. Steger, R. Thompson, and

E. Weil. 1989. Ecological effects of a major oil spill on Panamanian coastal marine communities. *Science 243*:37-44.

Keller, B.D. and J.B.C. Jackson, eds. 1993. Long-term Assessment of the Oil Spill at Bahía Las Minas, Panama, Synthesis Report, Volume 1: Executive Summary. OCS Study MMS 93-0047. New Orleans: U.S. Department of the Interior, Minerals Management Service, Gulf of Mexico Outer Continental Shelf Region. 129 pp.

Gulf War Spill, Arabian Gulf / January 1991

During the waning days of the Gulf War in 1991, oil was deliberately discharged by the Iraqi military. This resulted in the largest oil spill in history, an estimated 6.3 million barrels. Between 19 and 28 January 1991, oil was released from two major sources: three Iraqi tankers anchored in the Kuwaiti port of Mina Al-Ahmadi, and the Mina Al-Ahmadi Sea Island terminal area.

Impacts

Given the magnitude of this release and the previous coral reef impacts noted at other tropical spills, there were dire expectations of severe impacts to nearshore and offshore reefs in Kuwait and Saudi Arabia. However, to date the extent of coral reef damage directly attributable to the Gulf War spill has been remarkably minor. Surveys of nearshore and offshore reefs conducted in 1992 included a reef at Qit'at Urayfijan that was very likely covered by oil released from at least one tanker and the Mina Al Ahmadi terminal. While the reef is never exposed to the atmosphere, crude oil was assumed to have flowed over it for days. This reef was clearly impacted, mostly in shallower water, with coral death in large colonies of *Platygyra* as well as in most of the *Porites*. New growth, however, was observed in nearly all dead portions of coral.

In contrast, conditions at Getty Reef, close to a visibly oiled beach and directly downstream from known release points, showed no evidence of recent coral kills or even stress among *Porites*, *Platygyra, Cyphastrea, Leptastrea, Psammocora, Favia*, and *Favites*, and the associated fish community was especially robust. Other environmental impacts from the war, such as reduced water temperature and lowered ambient light from oil fire smoke, may have obscured actual effects of oil on coral.

Vogt (1995) established six 50-m study transects nearshore and offshore the Saudi Arabian shoreline to document effects and recovery from the spill. On the basis of video recordings made along these transects between 1992 and 1994, Vogt concluded that live coral cover had significantly increased and that the corals offshore from Saudi Arabia had survived the largest spill on record "remarkably unscathed."

For further reading

Reynolds, R.M. 1993. Physical oceanography of the Gulf, Strait of Hormuz, and the Gulf of Oman—Results from the Mt. Mitchell expedition. *Marine Pollution Bulletin 27*:35-59.

Vogt, H.P. 1995. Coral reefs in Saudi Arabia: 3.5 years after the Gulf War oil spill. *Coral Reefs 14*:271-273.

Rose Atoll National Wildlife Refuge, American Samoa / October 1993

On October 14, 1993, the Taiwanese fishing vessel *Jin Shiang Fa* ran aground on the southwestern side of Rose Atoll, a remote coral reef in eastern American Samoa. The grounding resulted in the spillage of 100,000 gallons of diesel fuel and 500 gallons of lube oil and 2,500 pounds of ammonia onto the reef.

Rose Atoll is a National Wildlife Refuge that supports giant clams and a special reef composed of coralline algae. The atoll is inhabited by green sea and hawksbill turtles and was considered one of the most remote and pristine coral reefs in the world. It is a unique coral habitat in Samoa, in that crustose coralline algae (identified as primarily *Hydrolithon onkodes* and *H. craspedium*) dominate instead of hermatypic corals. Common reef-building corals include *Favia, Acropora, Porites, Montipora, Astreopora, Montastrea*, and *Pocillopora*.

Response

Because of its remote location, and safety concerns, response options at Rose Atoll were very limited. A salvor was underway (from Singapore) but the grounded ship broke up in heavy seas before the salvor arrived. Most of the larger pieces of wreckage and debris were removed, but the stern and associated debris were left in place. A post-spill analysis by a U.S. Coast Guard responder on scene early in the incident suggests that one option (not pursued at the time) could have been an intentional release of oil when wind and currents were favorable to carry the oil away from the atoll into deeper waters. Instead, when the tanker did break up under storm conditions, winds were onshore, and most of the oil came directly onto the reef and into the lagoon.

Impacts

All of the petroleum products and ammonia were released into the marine environment, over a period estimated as six weeks. Oil was reportedly forced down onto the reef structure by wave action, as was oily debris from the wreck.

Although the injury to the corals from the grounding was judged to be "moderate to high," it was not possible to ascertain causal factors in a more specific way. Several possibilities for injury pathways were identified:

- Fuel and other contaminant toxicity;
- Mechanical damage from the grounding and subsequent debris impacts;
- Anoxia due to mortalities in the reef community;
- Smothering and scouring from sediments created by the wreck;
- Competition from opportunistic algae and cyanobacteria;
- Bleaching from direct and indirect impacts of the incident.

Surveys conducted in the weeks following the grounding indicated that the reefs at Rose Atoll had sustained substantial injuries from the physical impact of the vessel and the contaminant releases. The grounding caused major physical damage to the reef framework, gouging large grooves into the atoll and grinding reef into rubble, both during the initial grounding and subsequently as the ship rocked back and forth with the movement of ocean swells. Calcareous sediments generated from the grounding formed large berms, smothering and scouring thousands of square meters of adjacent reef. The vessel eventually broke up within a few weeks after the grounding, before a salvage operation could take place.

The wreckage covered an estimated 9,000 square meters of reef flat. A large amount of ship-related debris was also released onto the reef and spread over an estimated area of 175,000 square meters. The movement of this debris is believed to have further injured coral reef organisms and associated biota through abrasion, breakage, entanglement, smothering, and burial. Additionally, observations indicate the large volume of decomposing dead marine organisms and organic ship debris created a widespread zone of anoxia at the wreck site, which persisted for several months after the grounding and killed some of the surviving sedentary reef organisms in the area

While the physical effects of the grounding were obvious and long-term, the authors contend that the most widespread and severe injuries to the atoll were from the release of diesel fuel. A massive die-off of coralline algae and many reef-dwelling invertebrates was observed after the release, blue-green algae blooms were recorded where they are typically not found, and the structure of algal communities had shifted substantially. Four years after the grounding, the affected areas remained visibly impacted—particularly with respect to cover of coralline algae—and Green et al. Cast some doubt as to whether Rose Atoll would ever return to its former pristine condition.

Resource management agencies recommended the removal of the remaining pieces of the wreck, but recommended against more invasive restoration, such as reconstruction of coral framework or coral transplantation as employed in Florida coral restoration efforts. Concerns regarding use of these techniques at Rose Atoll involve potential introduction of pathogens, alien species, or genotypes to this otherwise relatively isolated reef ecosystem. Natural recolonization of the affected areas by native biota has been deemed the preferred restoration alternative. It has been estimated that the impacted area of Rose Atoll reef will take several more years or perhaps decades to recover.

For further reading

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Maragos, J.E. 1994. Reef and coral observations on the impact of the grounding of the longliner *Jin Shiang Fa* at Rose Atoll, American Samoa. Honolulu: U.S. Fish and Wildlife Service, Pacific Island Office. 27 pp.

Field Experiment Case Studies

Tropical Oil Pollution Investigation in Coastal Systems (TROPICS), Panama

December 1984; September-November 1994

In 1984, the American Petroleum Institute (API) sponsored a multi-year experiment in which a representative tropical system (comprised of mangrove, seagrasses, and coral) was exposed to oil and chemically dispersed oil. The experimental design simulated a severe, but realistic, scenario of two large spills of crude oil in nearshore waters. The original experiment and its findings were detailed in Ballou et al. (1987). The original research team revisited the site in 1994, and collected follow-up data.

Although both efforts encompassed oil and chemically dispersed oil effects studies in mangrove, seagrass, and coral systems, we discuss only oil impacts to corals here.

Treatment

Experimental sites were selected on the Caribbean coast of Panama, with the nearshore half of each site occupied by mangrove forest, fronted by a subtidal seagrass bed and a coral reef. Water depth over seagrass averaged about 0.5 m and over coral reef, 0.63 m. Coral reefs were dominated by *Porites porites* and *Agaricia tennifolia*. Each of the three sites was treated with oil, dispersed oil, or remained as an untreated reference. The oiled site was treated with 953 liters of Prudhoe Bay crude oil (the amount of oil that would strand from a 100- to 1000-bbl spill) that was released onto a boomed area of the water surface and allowed to remain for about two days. Tides and winds distributed the oil over the study area, and after the exposure period free-floating oil was removed with sorbents.

Monitoring

Chemical and biological monitoring continued for two years. Chemical monitoring, conducted hourly for the first 24 hours, confirmed that sediments and biota were exposed to rising and then rapidly declining dispersed and undispersed oil. For coral reefs, detailed transects were conducted to measure abundance of epibiota living on the reef surface. Four measurements were taken: total organisms, total animals, corals, and total plants. Growth rates of four coral species (*P. porites, A. tennufolia, Montastrea annularis*, and *Acropora cervicornis*) were also measured.

Impacts

The only statistically significant effect documented over the first 20 months at the oiled site was a decrease in coral cover. No significant changes in growth rates of four targeted corals were noted. Ten years later, neither coral cover nor coral growth showed oil impacts. The authors contrasted the finding of no impact from oiling alone to that described by Guzmán et al. (1991) at Bahía Las Minas, where significant effects of oil alone were found in several of the same species studied at TROPICS. Dodge et al. implied that these differences may have been due to the size of the spill at Bahía Las Minas and continued chronic exposure.

For further reading

Ballou, T.G., R.E. Dodge, S.C. Hess, A.H. Knap, and T.D. Sleeter. 1987. *Effects of a Dispersed and Undispersed Crude Oil on Mangroves, Seagrasses, and Corals*. API Publication No. 4460. Washington, D.C.: American Petroleum Institute, Health and Environmental Sciences Department. 198 pp.

Dodge, R.E., B.J. Baca, A.H. Knap, S.C. Snedaker and T.D. Sleeter. 1995. The effects of oil and chemically dispersed oil in tropical ecosystems: 10 years of monitoring experimental sites. MSRC Technical Report Series 95-014. Washington, D.C.: Marine Spill Response Corporation, 93 pp.

Arabian Gulf field experiment/Field dates unknown, reported 1989

This large-scale field experiment conducted on Jurayd Island, off the coast of Saudi Arabia, tested responses of corals to dispersed oil under realistic spill conditions. The design included exposure to crude oil only (Arabian light) among its four exposure scenarios, at exposures of 24 hrs and 120 hrs. Study plots were established over existing coral reefs that were comprised mostly of *Acropora spp.* (more than 95 percent), with scattered colonies of *Platygyra sp., Goniopora sp.*, and *Porites sp*. The plots measured 2 m by 2 m, located over approximately 1-m depth at low tide, and anchored in place.

Treatment

The stated intent of the experiment was to simulate conditions of a typical Arabian Gulf oil spill and not to overwhelm the corals with "extraordinary and catastrophic stresses." As such, oil was added to test plots to produce a slick of 0.25 mm in thickness, a total of 14 liters in the 24-hr. oil-only treatment; and 0.10 mm and 5.63 liters in the 120-hr. experiment. Water concentrations of hydrocarbons were measured by infrared methods, and no water column elevations were detected in the oil-only plots.

Monitoring

The oil-only plots were visually inspected at the end of the 24-hr and 120-hr exposures, and they appeared normal. These areas were monitored for one year, and no extraordinary changes occurred relative to the unoiled plots (seasonal changes in degree of bleaching, however, were noted across all monitored plots). While dispersed oil appeared to delay the recovery from seasonal bleaching, this was not observed in the oil-only plots.

Growth rates, expressed as skeletal extension along branch axes, showed no correlation to treatment in the 24-hr exposure. There was some indication that growth rates were depressed with 120-hr exposure, but LeGore et al. cautioned that these were not definitive. In summary, after one year of monitoring coral showed no visible effects after exposure to surface oil for 24 hours and for 120 hours. The authors concluded that healthy reef corals can tolerate brief (1 to 5-day) exposures to floating oil with no observable effect. They did note the potential for seasonal susceptibility to exposure in this region in the wintertime when low water temperatures stress corals.

For further reading

LeGore, S., D.S. Marszalek, L.J. Danek, M.S. Tomlinson, J.E. Hofmann and J.E. Cuddebak. 1989. Effect of chemically dispersed oil on Arabian Gulf corals: A field experiment. In *Proceedings of the 1989 International Oil Spill Conference, San Antonio*, February 13-16, 1989, pp. 375 - 381.

Restoration Case Studies

M/V Wellwood Grounding, Key Largo/August 1994

On August 4, 1984, the *M/V Wellwood*, a 400-foot freighter, ran aground on Molasses Reef in the Key Largo National Marine Sanctuary, causing massive destruction to living corals and underlying reef framework. Subsequent surveys indicated that the grounding fractured 644 square meters of underlying reef framework, with a 1,282-square meter area losing 70 to 100 percent of its live coral cover. Limestone rubble and fine sediment mobilized after the grounding posed further risk of reef injury and delayed recovery.

Restoration

Small-scale pilot studies conducted at the grounding tested the feasibility of stabilizing fractured reef framework, transplanting hard and soft corals into the major damage area, and rebuilding reef topography. Grouting with quick-setting underwater cement restabilized a selected area of fractured reef framework. Loose sand, gravel, and attached algal epiphytes were removed from the site so that the cement could bond properly.

A test coral transplantation plot was established in an area with only moderate fracture damage to the reef framework. In preparation, loose sediment, rock debris, and attached dead soft coral skeletons were removed from the area, but attached dead hard corals were left in place. Representative hard and soft corals from a nearby reef were transplanted to the pilot site. Corals were secured into holes in the reef framework with quicksetting underwater cement, as was used in framework repair.

Recovery

Transplanted hard corals survived, but soft corals were killed at high rates from heavy ocean swells generated by Hurricane Kate in late 1985. Observations indicated soft corals were twisted off at the holdfast base. High mortality of gorgonian corals was observed in areas surrounding the grounding site following the hurricane, some of which may have been caused by debris from the site.

Following the pilot studies, areas flattened by the hull of the ship were partially reconstructed. Divers and airlift bags moved sections of dislodged reef framework and intact head corals back into damaged areas and cemented them permanently into the reef framework. Observations to date suggest that a limited number of gorgonian corals have recruited to cement surfaces, but the material does not sufficiently mimic natural reef rock to warrant its general use.

For further reading

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M/V Alec Owen Maitland* and *M/V Elpis, Florida Keys/Fall 1989

On October 25, 1989, the 155-foot *M/V Alec Owen Maitland* ran aground on shallow coral reef in the Florida Keys National Marine Sanctuary. More than 1,600 square meters of formerly pristine coral reef dominated by fire coral and gorgonians were totally or partially destroyed by the time the vessel was removed from the grounding site. On November 11, 1989, the 143-meter freighter *M/V Elpis* also ran aground nearby in the sanctuary. The ship's propellers caused two large craters. The grinding of the ship's hull against the reef created a large rubble field.

Restoration

Following these incidents, efforts were made to repair damaged coral reef resources through structural and biological restoration at 3-4 m depth. At the *M/V Alec Owen Maitland* grounding site, 40 specially designed pre-cast concrete reef modules or slabs, called "Reef Replicating Units," were placed in blowholes created by the ship. The reef replicating units, which weighed nearly ten tons each, had upper surfaces textured to somewhat resemble those of living reefs and were intended to provide a hard surface for larvae of coral and other stationary reef organisms, such as sponges, to settle and grow.

Blowholes created by the grounding of the *M/V Elpis* at 10 m depth were filled to grade with rock and rubble from berms adjacent to the craters. The rock and rubble was covered with large limestone quarry boulders and voids were filled with sand transported by barge to the site. The objective was to recreate a stable foundation to facilitate recruitment of coral colonies. Following structural stabilization of the reef framework, debris was removed from the site.

Structural restoration at both grounding sites was completed in 1995, and biological restoration efforts were commenced in 1996. The biological restoration efforts were intended to enhance or "jump-start" natural biological recovery processes at the sites. This included transplantation of hard and soft corals, as well as sponges and sea fans, onto the hard surfaces of the concrete reef-replicating units at the *Maitland* grounding site and onto the limestone boulders at the *Elpis* site.

Monitoring

A monitoring program to assess the health and recovery of the areas affected by the groundings before, during, and after restoration has been in place since 1993. The program includes monitoring for structural integrity, survival, and growth rates of transplanted organisms, and recruitment of new coral colonies and fish populations. Initial monitoring results indicate that the reef framework has been restored, although it will take several years to determine whether the reef organisms will continue to survive and successfully repopulate these areas.

Columbus Iselin, Florida Keys/August 1994

On August 11, 1994 the University of Miami's 170-foot research vessel *Columbus Iselin* ran aground on a coral reef off Looe Key, in the Florida Keys National Marine Sanctuary. No damage to coral or other resources was reported as a result of the diesel fuel released. However, the coral reef framework was seriously damaged by the grounding and subsequent salvage operations. Before restoration was started, Hurricanes Georges and Irene and the Groundhog Day storm increased the area of initial injury by displacing reef rock destabilized by the grounding.

Restoration

In order to prevent further damage from loose, dead coral rubble created by the impact of the vessel, NOAA conducted an extensive rubble removal project in the summer after the grounding. Several tons of rubble and ship debris were removed and barged away.

Four coral reef spurs damaged in the grounding were physically reconstructed in the summer of 1999. Using cranes, several layers of five-ton quarried limestone boulders were lowered into the grounding excavation from the deck of a barge. These boulders were held in place by a matrix of composite rebar and tremie concrete. A special, non-separating, underwater concrete was then pumped into the filled excavations. Special fiberglass reinforcing rod and stainless steel anchor rods anchored in the boulders provided additional linkage between the concrete and the boulders. Each spur surface was then dressed with smaller limestone boulders to minimize the concrete surface.

Before pumping in the concrete, divers scrubbed biofouling from the limestone boulders to enhance concrete adhesion. Various-sized limestone rocks and small boulders were placed on the surface of the poured concrete to mimic natural reef outcroppings and to provide more suitable habitat for recruitment of corals and other reef biota. Finally, adult coral colonies were transplanted and embedded into the restored reef framework. This was the first successful structural restoration of a spur and groove reef. The success of this restoration effort indicated that quarried limestone boulders and pumped concrete are suitable materials for rebuilding reef framework. It also supported the conclusion that coral transplanting is an effective technique to help speed recovery of coral communities.

For further reference

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Fortuna Reefer, Puerto Rico/July 1997

The 325-foot container ship *Fortuna Reefer* ran aground on July 24, 1997 on fringing coral reef off the west coast of Mona Island (Isla de Mona) in Puerto Rico. Mona Island is a pristine natural reserve. The remoteness of the grounding site hampered salvage efforts and the vessel remained aground for eight days. Though the vessel never released oil to the environment, the grounding and subsequent salvage activities damaged the reefs substantially. Much of the damage was attributed to tow and anchor lines.

Restoration

An expedited settlement for natural resource damage, pursued under the Oil Pollution Act of 1990, enabled NOAA and other state and Federal resource agencies to initiate an emergency restoration in September 1997 that was completed within a two-and-a-half month period after the grounding. The objectives of the emergency restoration were to quickly reestablish the physical structure of the coral reef community and to reduce coral mortality.

The 6.8-acre grounding site was dominated by a well-established reef of branching elkhorn coral, *Acropora palmata*, at a depth ranging between 3 and 9 m. Restoration consisted of immobilizing loose branches of elkhorn coral by securing them to the reef buttress and to existing elkhorn coral framework using stainless steel wire and nails. Several stabilization methods were tested. Due to the density and hardness of the reef structure, the method selected consisted of drilling holes into the reef, driving nails into the holes, and wiring corals to the reef. Stainless steel materials were used to minimize corrosion and increase the longevity of the repair effort. Other materials tested, such as plastic tie wraps, did not perform as well in the wave surge. The timely removal of injured coral from sand areas prevented them from being smothered and also minimized abrasion damage to broken coral pieces from swell and wave motion. Upon completion, 1,857 coral fragments had been stabilized.

Monitoring

Monitoring stations were established to track the success of the restoration effort. Monitoring will include tracking survival of transplants and success of the transplant materials and techniques employed.

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Table 6.1 Summary of Case Studies and Oil Impacts

Spills

Name	Spill Location	Spill Response	Impacts
R.C. Stoner **September 1967**	**Wake Island**	**Ca. 6 million gallons of refined fuel oil Oil pumped into pits and burned**	**Fish kill Crustaceans Invertebrates (Coral unknown)**
Ocean Eagle **March 1968**	**Northeast Puerto Rico (few coral reefs)**	**83,400 bbls Venezuelan crude Chemical "emulsifier" spread on oil**	**Fish Benthos No coral effects**
Morris J. Berman **January 1994**	**Northeast Puerto Rico (few coral reefs)**	**Ca. 800,000 gallons No. 6 fuel oil Skimming and lightering Extensive shoreline cleanup**	**Fish Benthos No coral effects**
S.S. Witwater **December 1968**	**Caribbean coast of Panama (subtidal reefs)**	**20,000 bbls Bunker C and diesel oil Oil pumped and burned in-situ**	**No coral effects Mangroves Sandy shorelines**
Zoe Colocotronis **March 1973**	**Reef off Puerto Rico**	**37,000 bbls Venezuelan crude Booming, digging sumps, pumping into trucks**	**2.5 acres mangrove forests Invertebrates Seagrasses (Coral unknown)**
T/V *Garbis* July 1975	**Florida Keys (submerged coral reefs)**	**1,500-3,000 bbls crude oil**	**No coral effects Echinoderms Black oysters Mangroves**
Bahía Las Minas April 1986	**Caribbean coast of Panama**	**60,000-1000,000 bbls Venezuelan crude oil Chemical dispersants (Corexit 9527)**	**Widespread lethal, sub-lethal effects to coral and other environments**
Gulf War Oil Spill January 1991	**Arabian Gulf**	**6.3 million bbls crude oil**	**Minor coral damage**
Rose Atoll National Wildlife Refuge October 1993	**American Samoa**	**100,000 gallons of diesel fuel 500 gallons of lube oil 2,500 pounds of ammonia No response: oil spilled onto the reef**	**Moderate to high coral injury Massive die-off of coralline algae and many reef-dwelling invertebrates Impacts still visible 4 years later**

Table 6.1 Summary of Case Studies and Oil Impacts, cont'd.

Field Experiments

Name	Spill Location	Experiment	Impacts/Conclusions
TROPICS December 1984 Sept.-Nov. 1994	**Panama**	**Exposure of representative tropical system (mangrove, seagrasses, and coral) to oil and chemically dispersed oil.**	**Decrease in coral cover**
Arabian Gulf	**Jurayd Island, Saudi Arabia**	**Tested responses of corals to dispersed oil under realistic spill conditions**	**Conclusion: healthy reef corals can tolerate brief (1-5 day) exposures to floating oil with no observable effect.**

Restoration Case Studies

Name	Spill Location	Restoration	Impacts/Conclusions
M/V *Wellwood Grounding* August 1984	**Molasses Reef Key Largo National Marine Sanctuary**	**Grouted fractured reef with underwater cement Transplanted corals**	**Transplanted hard corals survived (soft corals killed by hurricane)**
M/V *Alec Owen Maitland* October 1989 M/V *Elpis* November 1989	**Florida Keys National Marine Sanctuary**	**Structural and biological reef restoration with concrete "reef replicating units" Transplanted corals, sponges, sea fans**	**Monitored since 1993; initial results indicate successful restoration**
***Columbus Iselin* August 1994**	**Looe Key Florida Keys National Marine Sanctuary**	**Four coral reef spurs rebuilt Adult coral colonies embedded in restored reef**	**Coral transplanting is an effective technique to help speed recovery of coral communities**
***Fortuna Reefer* July 1997**	**Isla de Mona Puerto Rico**	**1,857 coral fragments transplanted and stabilized**	**Emergency restoration to quickly reestablish the physical structure of the coral reef community and to reduce coral mortality.**