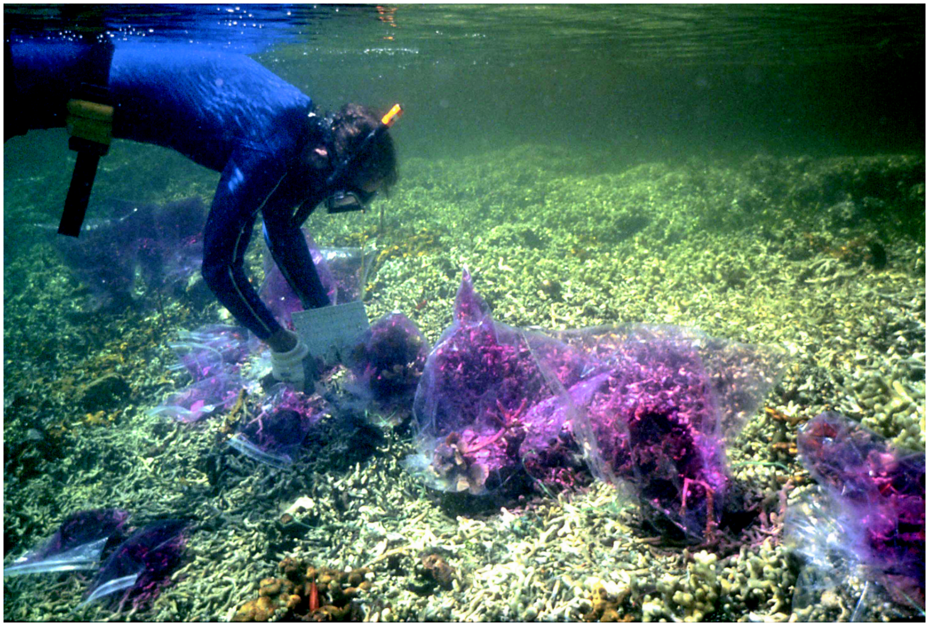

Diver studying coral growth as part of TROPICS study (Research Planning Inc.)

CHAPTER 3. OIL TOXICITY TO CORALS

Key points

- Spill impacts vary in severity with the specific conditions at a given spill, including oil type and quantity, species composition, and the nature of oil exposure.
- Oil can kill corals, depending on species and exposure.
- Longer exposure to lower levels of oil may kill corals as well as shorter exposure to higher concentrations.
- Chronic oil toxicity impedes coral reproduction, growth, behavior, and development.
- The time of year when a spill happens is critical, since coral reproduction and early life stages are particularly sensitive to oil.
- Branching corals are more sensitive to oil impacts than are massive or plate-like corals.
- Laboratory toxicity studies should mimic actual spill conditions to the extent possible.

Introduction

Evaluation of oil toxicity is not an easy task, since each spill presents a unique set of physical, chemical, and biological conditions. The term "oil" includes substances that are chemically very different, ranging from highly toxic and volatile refined products, to less acutely toxic but long-lived, heavier fuel oils. Different species and life stages within a species have varying sensitivities and thus may respond very differently to oil exposure.

Exposure pathways

How corals are exposed to oil bears directly on how serious the impact will be. There are three primary modes of exposure for coral reefs in oil spills. In some areas (especially the Indo-Pacific), direct contact is possible when surface oil is deposited on intertidal corals. Presuming that some portion of spilled oil will enter the water column either as a dissolved fraction or suspended in small aggregations, this potential pathway must be considered in most cases. Subsurface oil is a possibility in some spills, particularly if the spilled product is heavy, with a density approaching or exceeding that of seawater, and if conditions permit oil to mix with sediment material to further increase density.

Evaluation of risk based on exposure pathway is a complex calculus that is highly spill-dependent. Relevant questions that feed into the determination are linked to the considerations above and include:

- Are corals in the affected area intertidal?
- Does this spilled oil have a component of lighter, more water-soluble material?
- Will sea conditions mix oil on the surface into the water column?
- Is there a heavier component to the oil that raises the possibility of a density increase through weathering and association with sediment that could take the oil to the bottom?

Areas with intertidal corals could be considered at greatest risk in a spill because of the increased potential for direct contact with a relatively fresh oil slick. Regardless of differences in susceptibility by species or physical form, direct oil contact is most likely to result in acute impact because in this kind of exposure scenario the oil is fresher, with a greater proportion of lighter aromatic hydrocarbons, and the slicks are relatively heavy aggregations of spilled oil.

Water column exposure

Coral exposure via the water column can be a serious route under some circumstances. Because much of the constituent material in oil has a relatively low solubility in water, in general coral may be protected from exposure by overlying waters. However, if rough seas and a lighter, more soluble product are involved, subtidal corals may experience harmful exposure when oil mixes into the water column. The absolute levels of exposure would be expected to be much lower than those encountered by direct contact with intertidal slicks, since only a small fraction of the total oil can be placed into the water column either in solution or physically suspended. However, the components of the oil mix most likely to enter the water column are those generally considered to be most acutely toxic. Corals may therefore be exposed to "clouds" of naturally dispersed oil driven into the water column under turbulent conditions, with impacts dependent on exposure concentrations and length of exposure.

Heavy fuel oil exposure

Heavier fuel oils contain fewer of the light fractions identified with acute toxicity than do refined and crude oils (although these bunker type oils are sometimes "cut" with lighter materials to facilitate loading and transfer). If they remain on the water surface, spills of heavier fuel oils are less of a concern from a reef perspective, but more of a concern for protection of other habitats like mangrove forests where they can strand and persist for long periods of time. However, the heavy oils can also weather or mix with sediment material and increase in density to the point where they may actually sink—which provides a direct route of exposure to subtidal corals. Although acute toxicity characteristics of heavy fuel oils may be lower, the potential for significant physical effects from smothering is greatly increased.

Laboratory studies

Concentrations and exposure

Although many laboratory studies of oil toxicity to coral can be found in the literature, interpreting results from a spill response perspective is complicated by the experimental methods used. Many laboratory studies on the effects of oil on corals have limited applicability to real-life oil spill scenarios because of the way corals were exposed during the experiments, or how oil exposure was quantified. Many early studies on oil toxicity to coral relied on severe, direct exposure methods that were difficult to extrapolate to spill conditions. In addition, few studies actually quantified the exposure concentrations to corals, relying instead on a calculated, or nominal, value derived simply from the amount of oil mixed with a volume of water. Because only a fraction of the oil mixes directly into the water, the true toxicity levels can be assumed to be much lower than reported. This makes it difficult to compare studies or extrapolate data to real-life conditions.

During actual oil spills, oil concentrations do not remain constant, but vary over time. Oil is most concentrated at the very beginning of a spill when the product is consolidated in one location and relatively unweathered. As the spill spreads laterally and weathering processes begin, oil concentrations rapidly decline. These changing exposure levels can be simulated in experiments by reducing oil levels after a specified amount of time. Studies focusing on dispersed oil impacts use pulse exposures with flow-through systems, in which concentrations dissipate with time. When trying to estimate real-life exposures, it is important to carefully evaluate the methods used when applying data from laboratory studies.

Field studies

Field studies offer the best opportunity to understand the effects of oil spills under realistic conditions, but are uncommon in a coral reef habitat. One of the best examples is the 1986 Bahía Las Minas crude oil spill in Panama. This extensive series of studies documented both short-term mortality to corals and long-term, sublethal impacts to reproduction and growth lasting 5 years or longer. Guzmán et al. compared cover of common coral species at six reefs before 1985 and 3 months after 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. Coral colony size and diversity also decreased significantly with increased oiling. (See case studies for more detail.)

The 1984 TROPICS effort, sponsored by the American Petroleum Institute, was the most carefully designed and monitored attempt to perform a large-scale field experiment with corals and oil. Intended to provide a degree of realism within a more controlled setting than an actual spill, TROPICS examined short- and long-term effects of oil and dispersed oil to mangroves, seagrass, and coral reefs. Of these habitat types, coral reefs were least affected by exposure to oil alone, showing minimal short-term (0-20 months) and no long-term (10 years) effect to corals in an intentionally oiled zone. Mangroves were the most severely impacted, even 10 years after oiling.

Acute effects

A review of laboratory and field studies on acute effects of oil to corals can be confusing, since different studies appear to show contradictory results. Widespread coral mortalities following actual spills have been reported only infrequently, even when associated reef-dwelling organisms have perished. It may be that acute toxicity is not the best indicator of oil impact, and that adverse effects to the coral would be manifested over the longer term.

Oil exposure can kill coral, however, on varying time frames. Early studies of acute oil toxicity to coral used severe exposure conditions, such as directly coating coral with oil or submerging coral in marine diesel for 30 minutes. It is surprising that any of the test corals survived at all. Sometimes, a colony was not killed outright after a "dunking" in pure product, but later showed a steady decline in condition over a long period (>100 days) before dying.

A recent study by Harrison, using methods more comparable to spill conditions, found that low-level exposures almost completely disintegrated coral tissues after 48 hours. While they had selected a coral species known for its sensitivity to stress (*A. formosa*), these results suggest that longer exposure (4-48 hrs) to low concentrations of oil may be more toxic than shorter exposures at higher concentrations.

Differences in tolerance by coral species may be an important consideration but physical form may be more significant. Branching corals appear to be among the most susceptible whereas massive corals are more tolerant of oil exposure in laboratory studies. Bahía Las Minas field investigations noted that nearly all branching corals were killed in oiled reef areas. Thus, researchers could conduct longer-term studies only on massive species of coral.

The old notion that coral reefs do not suffer acute toxicity effects from oil floating over them is probably incorrect. Certainly, direct coating increases the severity of impact, but oil concentrations attainable during a spill may also kill some species.

Chronic effects

Chronic effects of oil exposure have been consistently noted in corals and, ultimately, can kill the entire colony. Chronic impacts include histological, biochemical, behavioral, reproductive, and developmental effects (see Table 3.1). Field studies of chronically polluted areas and manipulative studies in which corals are artificially exposed to oil show that some coral species tolerate oil better than other species. In contrast to acute toxicity studies, nearly all researchers studying chronic effects have documented sublethal changes in exposed corals. Advances in technology now allow the detection of effects at cellular and genetic levels.

Sublethal oil exposure affects many normal biological functions, including reproduction and recruitment, which may have the greatest potential to adversely impact coral survival. A host of studies show that oil reduces coral fertility, decreases reproductive success, and inhibits early life stage development. A spill occurring at just the wrong time in a given area, at the peak of reproductive activity, could cause immediate and long-lasting harm to the communities of corals themselves. For example, several species of the coral *Montastre* in Florida spawn during August and September. This would be a time when these communities would be at greater risk for reproductive impacts (see Table 1.1).

Oil also impairs two fundamental bioenergetic components for the entire coral reef community: primary production by the zooxanthellae symbionts in coral, and energy transfer via coral mucus. While some studies indicate that these effects are transient and that corals can recover from them in the absence of oil, circumstances of individual spills will dictate whether these would be of concern to responders and resource managers.

Bioaccumulation

Oil quickly and readily bioaccumulates in coral tissues and is slow to depurate. This may be linked to the high lipid content of the tissues. Uptake into the symbiotic zooxanthellae also occurs. Researchers have found that petroleum hydrocarbons are deposited into the calcareous exoskeleton of corals, which introduces the possibility of using coral skeletons as historical records of hydrocarbon contamination in an area. Bahía Las Minas field studies indicated that corals took up hydrocarbons from the water column, as opposed to sediments.

Associated reef organisms

In addition to corals themselves, oil may also adversely affect the associated fish, invertebrates, and plants in the coral reef community. Turtles and marine mammals may be seasonal inhabitants of the reef, and may be susceptible to direct oil exposure since they must surface regularly to breathe. Broad generalizations on oil toxicity are not very helpful for such a diverse group of species, life histories, and life stages. Though the scientific literature on oil toxicity to coral reef fish is limited, one can assume that they would show similar ranges in sensitivity to oil as would fish from temperate areas. Likewise, toxicity information on invertebrate groups could be generally inferred from data collected on related organisms from other habitats.

Table 3.1. Stress responses shown by corals exposed to oil and oil fractions (updated from Fucik et al. 1984).

Response	References
Tissue death	**Johannes et al. (1972); Reimer (1975); Neff and Anderson (1981); Wyers et al. (1986)**
Impaired feeding response	**Reimer (1975); Lewis (1971); Wyers et al. (1986)**
Impaired polyp retraction	**Elgershuizen and de Kruijf (1976); Neff and Anderson (1981); Knap et al. (1983); Wyers et al. (1986)**
Impaired sediment clearance ability	**Bak and Elgershuizen (1976)**
Increased mucus production	**Peters et al. (1981); Wyers et al. (1986); Harrison et al. (1990)**
Change in calcification rate	**Birkeland et al. (1976); Neff and Anderson (1981); Dodge et al. (1984); Guzmán et al. (1991, 1994)**
Gonad damage	**Rinkevich and Loya (1979b); Peters et al. (1981)**
Premature extrusion of planulae	**Loya and Rinkevich (1979); Cohen et al. (1977)**
Larval death	**Rinkevich and Loya (1977)**
Impaired larval settlement	**Rinkevich and Loya (1977); Te (1991); Kushmaro et al. (1996); Epstein et al. (2000)**
Expulsion of zooxanthellae	**Birkeland et al. (1976); Neff and Anderson (1981); Peters et al. (1981)**
Change in zooxanthellae primary production	**Neff and Anderson (1981); Cook and Knap (1983); Rinkevich and Loya (1983)**
Muscle atrophy	**Peters et al. (1981)**

Fish in open waters are thought to be able to avoid oil, although fish kills have been documented at several spills in shallow coral reef habitats (see the *Morris J. Berman* and Wake Island case studies). Since many coral reef fish have small home ranges and are residents of the reef, it follows that they would be at higher risk from oil exposure than non-resident, more widely ranging fish.

Some groups of invertebrates are known to be very sensitive to oil, including many crustaceans. As with coral reef fish, there are a number of documented incidents where invertebrates were killed after an oil spill. Some invertebrates, such as bivalves and snails, may not be acutely impacted by oil, but may accumulate oil components such as polynuclear aromatic hydrocarbons (PAH) in their tissues. Species sensitivity varies greatly. Generally, early life stages are more sensitive than adult organisms, though there are exceptions. Consulting local experts and the broader toxicity literature is in order to assess oil toxicity to specific organisms in the reef community.

Also of concern are concentrations of fish and invertebrate larvae, which often are found within the upper water column where they may come in contact with oil products. Marine larval organisms may be more susceptible to oil toxicity given their surface-to-volume ratio and limited ability to steer clear of a spill. Larvae and other plankton serve as major food sources for a variety of coral reef organisms (including corals themselves). Larvae thus may serve as a mechanism for ingestion of oil products by reef organisms that otherwise would not come in contact with surface spills.

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