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A review of the toxicity of chemical dispersants

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Abstract

Chemical dispersants are a mixture of various surfactants and solvents. Most dispersants are proprietary, and the complete composition is not often public knowledge. Chemical dispersants used for the cleanup and containment of crude oil toxicity became a major concern after the 2010 Deepwater Horizon oil crisis in the Gulf of Mexico. During the crisis, millions of liters of chemical dispersants (Corexit 9527 and 9500) were used – the largest known application of dispersants in the field. As of February 2011, 38 peer-reviewed articles were available on the toxicity of 35 different chemical dispersants. Nalco, BP, Shell, and Total Special Fluids manufacture a variety of chemical dispersants. Most notably, Nalco manufactures Corexit 9527 and 9500, and 19 miscellaneous dispersants are manufactured by others. Most studies examined the lethality of the dispersants. Several nonlethal end points were considered, including the effect on predator/prey recognition, enzyme activity changes, effects on hatchability, and the threshold for bradycardia. The animals studied included *Daphnia* (small planktonic crustaceans), anemones, corals, crustaceans, starfish, mollusks, fish, birds, and rats. Studies in birds and mammals are distinctly lacking. The variety of chemical dispersants, the variability in test methods, and the lack of distinct species overlap between studies make it difficult to compare and deduce which dispersant is most toxic and which is least. Here, we offer some attempt at comparing Corexit 9527 and 9500 (because these have had the largest field application), but significantly more research is needed before clear conclusions can be drawn.

Keywords

chemical dispersants; marine animal toxicity; oil dispersant toxicity

Introduction

Chemical dispersants are a mixture of surfactants and solvents. Most dispersants are proprietary, and the complete composition is not often public knowledge. Nalco, BP, Shell, and Total Special Fluids are the manufacturers of a variety of chemical dispersants, and 19 miscellaneous dispersants are manufactured by others. Dispersants are used to break down crude oil into smaller particles. The primary objective is to attempt to disperse the crude oil

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throughout the water so that natural processes can break down the oil more quickly, thus keeping the oil from reaching shorelines. The dispersed oil is more available to marine life, however, and little is known about the ecologic impact. The extensive field use of dispersants has not widely been attempted or studied, although Corexit 9527 was used in small quantities in the 1989 Exxon-Valdez oil spill in Alaska. Chemical dispersants were recently thrust into public concern because of their extensive use in the Gulf of Mexico oil crisis. On April 20, 2010, the BP-leased Deepwater Horizon drilling rig exploded, releasing approximately 757 million liters of crude oil into the Gulf of Mexico over an 88-day period. During this crisis, massive quantities of chemical dispersants were used to try to reduce the spread of the crude oil into near-shore waters and onto coastlines. Most notably, Nalco manufactures Corexit 9527 and 9500, the two products used in the Deepwater Horizon spill. The US Environmental Protection Agency (EPA) has posted a full list of the chemical components of Corexit 9527 and 9500 (1).

- 1,2-Propanediol
- Ethanol, 2-butoxy- (not included in the composition of Corexit 9500)
- Butanedioic acid, 2-sulfo-,1,4-bis(2-ethylhexyl) ester, sodium salt (1:1)
- Sorbitan, mono-(9Z)-9-octadecenoate
- Sorbitan, mono-(9Z)-9-octadecenoate, poly(oxy-1,2-ethanediyl) derivatives
- Sorbitan, tri-(9Z)-9-octadecenoate, poly(oxy-1,2-ethanediyl) derivatives
- 2-Propanol, 1-(2-butoxy-1-methylethoxy)-
- Distillates (petroleum), hydrotreated light

This crisis was the first large-scale application of these dispersants, and at least 7.57 million liters were used. Corexit 9527 was used earlier during the spill but was discontinued because it was considered too toxic. Corexit 9527 was used in smaller quantities and was applied via aerial application. Corexit 9500 was administered via deep-water injection and aerial application and was used in higher quantities. As a result of this crisis, the potential toxicity of chemical dispersants to humans and marine species has come into question because whether their application is relatively safe is uncertain. The Material Safety Data Sheet for Corexit 9527 rates this compound a moderate human health risk (2), whereas the human health risk for Corexit 9500 is listed as slight (3).

This review is based on a literature search conducted in February 2011. The literature considered was restricted to peer-reviewed articles that had been published until that point. The literature search sites included, but were not limited to PubMed, Science Direct, and Google Scholar, using the keywords *oil*, *dispersed oil*, *dispersant*, and *toxicity*. The results are presented below, grouped by manufacturer.

For reference, a concentration of 20 ppm of Corexit is the equivalent of one drop in 2.5 L of water. In toxicology, the median lethal dose (LD), LD 50% (LD₅₀), or lethal concentration 50% (LC₅₀) is the dose required to kill half the members of a tested population after a specified test duration. The EC₅₀ is the half-effective concentration or the molarity that produces 50% of the maximal possible effect. The LOEC is the lowest-observable-effect

concentration, and NOEC is the no-observed-effect concentration; the lower the effective concentration, the more toxic the compound. All numeric data for these parameters and experimental details are presented in the tables.

Nalco-manufactured dispersants

Corexit 9500

The first large application of Corexit 9500 was during the BP Deepwater Horizon oil crisis. Studies considered the toxicity of 9500 to marine invertebrates and fish, using the end points of death, fish gill ion regulation, and effects on enzyme activities. The data are presented in Table 1.

Crustaceans

Two studies examined the ability of Corexit 9500 to induce death in crustaceans, specifically a mysid shrimp (*Americamysis bahia*) and a kelp forest mysid (*Holmesimysis costata*). Fuller et al. (4) compared the toxicity of oil, dispersant, and oil plus dispersant to several marine species, including the mysid *A. bahia*. The authors found that continuous exposures to the test media were generally more toxic than declining exposures. Oil media prepared with a chemical dispersant appeared to be equal to or less toxic than the oil test medium alone. Singer et al. (5) compared the toxicity of Corexit 9500 with that of others in the series in kelp forest mysid. The data indicated Corexit 9500 to be of similar toxicity to Corexit 9527 and 9554. Delayed mortality was observed. Only about one third of all recorded mortalities occurred during the first 72 h of the first (32%) and third (31%) tests and during the first 48 h of the second test (34%).

Mollusks

Singer et al. (5) also considered the ability of Corexit 9500 to induce death in mollusks, specifically, red abalone embryos (*Haliotis rufescens*). Corexit 9500, 9527, and 9554 were of similar toxicity.

Fish

Five studies looked at the toxic effects of Corexit 9500 to different fish species: tambaqui (*Colossoma macropomum*), inland silverside (*Menidia beryllina*), sheepshead minnow (*Cyprinodon variegatus*), crimson spotted rainbowfish (*Melanotaenia fluviatilis*), and rockfish (*Sebastes schlegeli*). Duarte et al. (6) reported that exposure to various ratios of Corexit 9500/water had no effect on the gill ion regulation of tambaqui. Fuller et al. (4) considered the ability of Corexit 9500 to induce death in inland silverside. The results showed very little difference between continuous and declining toxicities in this species (see Table 1). When studying the same effects in sheepshead minnow, continuous exposure was more toxic than declining exposure.

Pollino and Holdway (7) studied the ability of Corexit 9500 to induce death in the sensitive early life stages of the crimson spotted rainbowfish in the Australian freshwater environment. Acute exposures resulted in developmental abnormalities at and above 0.5 mg/L total petroleum hydrocarbons (TPH). When assessed alone, Corexit 9500 was found to

be more toxic (14.5 mg/L TPH) than 9527 (20.1 mg/L TPH) for day of hatch larvae, but when mixed with dispersed oil, the result was reversed – toxicity dispersed crude oil's water-accommodated fraction (DCWAF)-9527 (0.74 mg/L TPH) vs. DCWAF-9500 (1.37 mg/L TPH).

Jung et al. (8) reported the ability of Corexit 9500 to alter enzyme activities in rockfish after a 72-h exposure. Concentrations of cytochrome P450 1A (CYP1A) and levels of its catalytic activity ethoxyresorafin *O*-de-ethylase (EROD) in rockfish exposed to WAF at concentrations of 0.1% and 1% were significantly increased by the addition of Corexit 9500 after 48-h exposure. After 72 h of exposure, hydrocarbon metabolites in bile from fish exposed to a WAF/Corexit 9500 mixture were significantly higher compared with fish exposed to WAF alone or with control fish. The results of these experiments implied that the use of oil dispersants will increase the exposure of ovoviviparous fish to hydrocarbons in oil.

Corexit 9527

The first large application of Corexit 9527 was during the Exxon-Valdez spill in Alaska in 1989. The compound was also used during the Deepwater Horizon oil crisis. Studies considered the toxicity of Corexit 9527 to marine invertebrates, fish, birds, and rats, using the end points death, sensitivity, immune responses, gastrointestinal (GI) tract responses, and behavior (Table 2).

Daphnia—One study by Bobra et al. (9) considered the ability of Corexit 9527 to induce death in *Daphnia magna*, a small planktonic crustacean. Bioassays were conducted for dispersants alone, for water-soluble fractions of crude oils obtained at various water/oil ratios, for physical dispersions of crude oils, and for chemical dispersions of crude oils. The results suggested that the dispersed oil particles are the primary sources of toxicity, with the dissolved oil and dispersants contributing relatively little toxicity.

Anemones and coral: Three studies investigated the toxicity of Corexit 9527 to anemones or coral. The species studied included reef corals (*Montastraea franksi*), coral (*Acropora millepora*), and snakelocks anemone (*Anemonia viridis*). Venn et al. (10) examined the gene-expression profiles of P-glycoprotein (or multixenobiotic resistance protein; P-gp), heat shock protein 70 (Hsp70), and heat shock protein 90 (Hsp90) after exposure to the dispersant. Reef corals exposed to Corexit 9527 (in 1 µm filtered seawater) showed a significant increase in P-gp gene expression at 10 and 50 ppm, as well as Hsp70 gene expression at 5, 10, or 50 ppm, indicating a general cellular stress response. Hsp90 gene expression did not change significantly. Corals did not exhibit visible tissue loss. The densities of symbiotic algae in the tissues of the corals did not differ in dispersant treatment groups when compared with controls. The authors noted that the findings provide insight into how corals defend themselves against pollution.

Negri et al. (11) reported that exposure of coral to 10 ppm of Corexit 9527 caused significant inhibition of fertilization, and 5 and 10 ppm of dispersant inhibited larval metamorphosis. The authors noted that dispersed oil was slightly more toxic to fertilization than dispersant alone, suggesting toxicity to that event may be additive. Similarly, crude oil or dispersant

inhibited larval metamorphosis individually, but the toxicity was magnified when larvae were exposed to combinations of both.

Scarlett et al. (12) studied the sublethal effects of 48-h exposures to Corexit 9527 and the ability of species to recover for up to 72 h after exposure. The anemone lethality test (*A. viridis*) was the most sensitive among all species tested, with an LOEC of 20 ppm. The authors reported that those individuals exposed to 20 ppm would not respond to stimuli. Concentrations above 80 ppm caused tissue decomposition in treated anemone; 89% of anemones exposed to 30 ppm did not recover, whereas those exposed to 20 ppm recovered. For all species, Corexit 9527 was found overall to be more toxic than the other dispersant tested, Superdispersant-25.

Crustaceans: Six studies examined the toxicity of Corexit 9527 to various crustacean species, including prawns (*Macrobrachium rosenbergii*), brine shrimp (*Artemia*), copepods (*Pseudocalanus minutus*), mysid, kelp forest mysid, rotifer (*Brachionus plicatilis*), and mud shrimp (*Corophium volutator*).

Scarlett et al. (12) reported the ability of Corexit 9527 to induce death in mud shrimp. At 24 h, individuals were moribund after exposure to 375 or 500 ppm. Those exposed to up to 125 ppm had normal swimming and burrowing, but exposure to more than 175 ppm caused mud shrimp to show signs of stress, and above 175 ppm, the shrimp could not recover. Mud shrimp were more sensitive to Corexit 9527 than to Superdispersant-25. Law (13) studied the effect of Corexit 9527 on the egg hatching rate of *Mac. rosenbergii* (de Man) using an innovated flow-through bioassay technique. The fertilized eggs, when detached from the mother prawn, are able to hatch artificially. The control hatching rate of the eggs of 95.55% $\pm$ 1.74% was reduced drastically with increasing concentrations of Corexit 9527, with no hatchability observed at concentrations above 250 ppm. The recommended safety level of Corexit 9527 for *Mac. rosenbergii* in Malaysian estuarine waters was deemed to be below 40 mg/L.

Wells et al. (14) reported the ability of Corexit 9527 to induce death in adult and larval brine shrimp. The authors conducted six experiments and found the 2-day LC₅₀ to be 52 ppm, with the lowest EC₅₀s ranging from 42 to 72 ppm. The authors did not attempt to combine the experiments to determine an overall LC₅₀ or an overall EC₅₀ and insufficient details were presented for the reader to calculate these numbers. The same group found that Corexit 9527 was more lethal for copepods than for brine shrimp. The results of a physical-chemical partitioning analysis suggested that essentially all the toxic compounds in the dispersant will partition into solution in water after dispersant application to oil spills.

In a comparison of three test methods, George-Ares et al. (15) evaluated the ability of Corexit 9527 to cause death in the 96 h mysid test. Survival observations were recorded at 3, 6, 9, 12, and 24 h to document mortalities from short-term spiked exposures, which are more consistent with field exposure times. At nominal concentrations and exposure times near the upper range of predicted field conditions, mysid mortalities were 5% for all test materials. The estimated LC₅₀s were 27.1 ppm at 96 h and 65.0 ppm at 24 h using the acute mysid IQ

toxicity test. A 1-h LC₅₀ of 34.4 ppm was found using the mysid IQ toxicity test. An EC₅₀ of 4.9 ppm for 15 min was reported for the microtox assay.

Singer et al. (16) investigated the ability of short-term spiked exposure vs. constant exposure to Corexit 9527 to induce death in kelp forest mysid. Test chambers containing sensitive life stages of *H. costata* were inoculated with concentrated dispersant and then allowed to flush with clean, filtered seawater. The dispersant was less toxic under spiked exposure conditions than during constant exposure. Of the four species studied, *Holmesimysis* was the least sensitive in terms of median effect concentration.

Wheelock et al. (17) used a model of San Francisco Bay exposure (where copper levels are approximately 5 µ/L) to examine the effect of multiple stressors on heat shock protein 60 (hsp60) induction in *B. plicatilis* exposed to a Prudhoe Bay crude oil WAF, a Prudhoe Bay crude oil/Corexit 9527 fraction, or Corexit 9527 alone. Rotifers were first exposed to copper (5 µg/L) for 24 h and then to the oil/dispersant preparations for 24 h. Hsp60-specific antibodies and chemiluminescent detection were used to isolate, identify, and measure hsp60 as a percentage of control values. Both oil/dispersant and dispersant alone preparations induced significant levels of hsp60, which were reduced to control levels at high WAF concentrations. Rotifers that had been preexposed to copper maintained elevated levels of hsp60 that did not change significantly upon treatment with WAF at all concentrations.

Mollusks: Six studies considered the toxicity of Corexit 9527 to mollusks. The species considered included mussels (*Mytilus edulis*), bay scallops (*Argopecten irradians*), oyster drill (*Urosalpinx cinerea*), littleneck clam (*Protothaca staminea*), and red abalone embryos.

Two studies measured the toxicity of Corexit 9527 to mussels. Scarlett et al. (12) found mussel lethality to be the least sensitive of all species tested. The results provided no reliable LC₅₀. The authors noted a 2.6% decrease in feeding in treated groups when compared with controls, and the mussels were slow to close upon touch. Mussels were more sensitive to this dispersant than to Superdispersant-25. Hamoutene et al. (18) studied the short-term effect of water-soluble fractions of diesel oil and Corexit 9527 on cellular immune responses in *Mytilus* sp. The authors reported that mussels exposed to Corexit 9527 for 2 days died after being injected with foreign particles (zymosan) to induce inflammation; exposure to 200 ppm for 4 days had no effect on hemocyte (invertebrate phagocyte) cell number or phagocytosis.

Odzie and Garofalo (19) investigated the short-term acute exposure of bay scallops, *Arg. irradians* and two scallop predators, the oyster drill, *U. cinerea*, and the common starfish, *Asterias forbesi*, to oil, dispersant, or oil-dispersant mixtures (Kuwait Crude Oil and Corexit 9527). The results suggested that predators and prey have different lethal susceptibilities. Scallops were most sensitive to dispersant and dispersant mixed with oil and starfish were sensitive only to dispersant, whereas the oyster drill seemed unaffected even though it were exposed to dilutions of identically prepared stock solutions. The scallops were least susceptible during winter months and most susceptible at summer temperatures. Treatment had less effect on predators than on scallops at summer temperatures. Sublethal concentrations of dispersant and oil-dispersant mixtures diminished the behavioral ability of

scallops to recognize drills and starfish. The degree of effect increased with temperature. Predator detection of prey at the same concentrations was more complex. The feeding response or posturing reflex of starfish was significantly slowed by all treatments. In contrast, drills were unaffected in their recognition of scallop effluent in a choice chamber after treatment (see Table 2 for details).

Hartwick et al. (20) carried out field and laboratory experiments to investigate the effects of Alberta crude oil and Corexit 9527 on the larval settlement, survival, siphon activities, and behavior of the littleneck clam (*Pro. staminea*). The dispersant was diluted in sea water 10 or 100 ppm, and littleneck clams were treated twice daily for 5 h for 5 days, followed by a 5-day recovery period to induce death. Larval samples in Petri dishes were exposed to 10 or 100 ppm Corexit 9527 for 5 min, 5 times for 5 days. Corexit 9527 was much more toxic than crude oil, but the highest toxicity was obtained when Corexit 9527 was mixed with crude oil. Singer et al. (16) reported that 5–120 ppm Corexit 9527 induced death in red abalone embryos, with toxicity similar to that of Corexit 9500 and 9554.

Starfish: Ordzie and Garofalo (19) exposed the common starfish (*Ast. forbesi*) to Kuwait Crude Oil, the dispersant Corexit 9527, or to an oil-dispersant mixture (Kuwait Crude Oil and Corexit 9527) for 6 h followed by a 5-day recovery period and found no treatment-related deaths. Starfish exposed to the dispersant were physically stressed, and the feeding response or posturing reflex of starfish was significantly slowed by all treatments.

Fish: Two studies looked at the toxic effects of Corexit 9527 to the crimson-spotted rainbowfish and topsmelt (*Atherinops affinis*). Pollino and Holdway (7) studied the ability of exposure to Corexit 9527 to induce death in sensitive early life stages of the crimson-spotted rainbowfish. Waterborne petroleum hydrocarbons can cross the chorion of embryonic rainbowfish, reducing survival and hatchability. Acute exposures at and above 0.5 mg/L TPH resulted in developmental abnormalities. Corexit 9527 was less toxic than Corexit 9500. Singer et al. (16) performed spiked exposure, continuous flow toxicity tests using the oil dispersant, Corexit 9527, during the early life stages of four California marine species. When compared with three other species, topsmelt was the least sensitive in terms of the NOEC (13.5 vs. 9.7 ppm for red abalone, the most sensitive).

Birds: Two studies considered the toxic effects of Corexit 9527 to hatchability and neurologic behavior in mallards (*Anas platyrhynchos*). When crude oil, petroleum distillate, and chemically dispersed oil were tested for their effects on resistance to bacterial infection and the immune response in waterfowl, Locke et al. (21) noticed that mallards receiving the highest concentration of Corexit 9527 (5.0 mL/kg of a 1:10 dilution in double-distilled water) developed temporary nervous system disorders that included temporary loss of motor coordination and reduced mobility. No mallards died during treatment, and no apparent effect was observed on the liver, kidney, or spleen of the treated groups based on examination for pathogen virulence. Resistance to bacterial challenge (*Pasteurella multocida*) was significantly lowered in mallards receiving 4.0 mL/kg of a 50:1 Bunker C fuel oil/Corexit mixture daily for 28 days. Albers and Gay (22) studied the effect of exposure to Corexit 9527 and crude oil sprayed with Corexit on breeding mallard ducks. Exposure to the dispersant for 48 h did not affect mallard hatchability.

Rats: One study by George et al. (23) examined the toxicity of Corexit 9527 to the intestinal metabolism and microbacteria of Fischer 344 rats. The rats were treated for 5 weeks with oil, dispersant, or oil-dispersant mixture. Body and tissue weights, urine mutagenicity, and the impact on intestinal microflora and three microbial intestinal enzymes linked to bioactivation were determined in the small and large intestines and cecum. Undiluted Corexit 9527 was lethal to rats, and weight changes were observed depending on the dilution, whereas oil alone generally was not toxic. At the end of the study period, body and tissue weights were unaffected at the doses administered. The authors noted that Corexit 9527 was “toxic to *S. typhimurium* strains TA98, TA100, TA1535, TA1537, and TA1538 up to dilutions of 1:1000.” Oil was not mutagenic in strains TA98 and TA100 ($\pm$ S9). None of the treated rats produced urine mutagens detected by TA98 or TA100. Small-intestine levels of azoreductase, β -glucuronidase, and nitroreductase were considerably lower than cecal and large-intestine activities at the same time point. A temporal increase in azoreductase activity occurred in control animals in all tissues examined, and large-intestine (β -glucuronidase activity was elevated in 3-week controls, with no significant changes in cecal β -glucuronidase activity. Oil- or dispersant-treated rats had mixed results with reduced activity at 3 weeks and elevated activity at 5 weeks compared with controls. When the dispersant was combined with oil at 3 weeks, however, the reduction in activity was similar to that of dispersant alone. One-week nitroreductase activity in the small intestine and cecum was unaffected in the three treatment groups, but elevated activity was observed in the large intestines of animals treated with oil or dispersant alone. The effect of the combination dose was not significantly different from the control value. Five weeks of oil treatment eliminated enterobacteria and enterococci from the ceca of treated rats. When oil was administered in combination with dispersant, however, an apparent protective effect was observed on enterococci and on lactose-fermenting and non-lactose-fermenting enterobacteria. The authors suggested that prolonged exposure of mammals to oil, dispersant, or in combination, has an impact on intestinal metabolism, which ultimately could lead to the altered detoxification of oil constituents and coexposed toxicants.

Corexit 7664: Corexit 7664, the first Nalco dispersant used, was water-based and weak and is no longer produced. Five studies reported the effects of Corexit 7664 to 13 marine species: *D. magna*, red abalone larvae, mysid, mussels (*Brachidontes variabilis*), bean clam (*Donax trunculus*), cunner (*Tautoglabrus adspersus*), topsmelt, herring (*Clupea harengus*), pilchard (*Sardina pilchardus*), plaice (*Pleuronectes platessa*), sole (*Solea solea*), lemon sole (*Microstomus kitt*), and haddock (*Melanogrammus aeglefinus*) (Table 3).

Daphnia—Bobra et al. (9) considered the ability of Corexit 7664 alone, water-soluble fractions of crude oils obtained at various water/oil ratios, or physical and chemical dispersions of crude oils to induce death to *D. magna*. The authors concluded that the chemically dispersed oil particles were the primary sources of toxicity, whereas the dissolved oil and Corexit 7664 alone contributed relatively little toxicity.

Crustaceans: Singer et al. (24) reported that the toxicity of Corexit 7664 was less than that of Corexit 9527 in red abalone larvae.

Mollusks: Avolizi and Nuwayhid (25) exposed mussels and bean clams to Corexit diluted in sea water. Fresh mixture was added everyday until an apparent LC₅₀ was reached. Both mussel and bean clam showed interference with the production of byssal thread and an effect on respiration, but the effect was statistically significant only in mussels at 10 mL, causing a 39.2% decrease in respiration, and in bean clams at 5 mL, causing a 59.6% decrease in respiration. The LC₅₀ was not reported as a specific value.

Fish: Singer et al. (24) reported that Corexit 7664 induced death in topsmelt and was more toxic than Corexit 9527. Kiceniuk et al. (26) examined whether hypoxia is involved in the toxicity of detergents. When subjected to hypoxia, fish decrease their heart rate and increase the ventilation volume. Corexit 7664 reduced the bradycardia threshold in cunner, but the heart rate returned to normal after dosing, albeit more slowly than controls.

Wilson (27) studied the ability of several concentrations of Corexit 7664 to induce death in the larvae of herring, pilchard, plaice, sole, lemon sole, and haddock. The larvae of all species showed a similar susceptibility when newly hatched and susceptibility increased throughout the yolk-sac stage. The transition period from yolk reserves to an external food supply was most critical because once larvae had established feeding, resistance increased until metamorphosis. The aromatic content of the solvent was one of the main factors influencing toxicity. The authors found that lowered salinity decreased toxicity slightly.

Other Corexit dispersants

Nalco manufactures a handful of other Corexit products (8666, 8667, 9550, 9554 and 9660) besides Corexit 9527, 9500, and 7664, but these formulations have not had any significant field application. Studies have considered the toxicity of these Corexit products to marine invertebrates and fish. The end points considered were death, respiration, and bradycardia (Table 4). Kiceniuk et al. (26) reported that Corexit 8666 reduced the bradycardia threshold in cunner, but no dose range was given. The heart rate returned to normal after dosing but was slower to return than controls. Bobra et al. (9) found that Corexit 8667 and 9550 were highly toxic and induced death in *D. magna* at very low concentrations.

Singer et al. (28) reported that Corexit 9554 induced death in three marine species: red abalone embryos, topsmelt larvae, and juvenile mysid. Of the three species studied, red abalone was the most sensitive and the mysid was the least sensitive. Delayed mortality was seen with the treated mysid; only 6% of mortalities occurred by 6 h, 57.9% occurred in the first 24 h, and the daily LC₅₀ continually dropped. Bobra et al. (9) found that Corexit 9660 was highly lethal for *D. magna*.

BP-manufactured dispersants

BP 1100X, BP 1100 WD, and BP 1002 are dispersants manufactured by BP. Studies looked at the toxicity to crustaceans, molluscs, starfish, and fish, considering the ability to induce death, the ability to induce bradycardia, and effects on respiration (Table 5).

BP 1100X

Three studies looked at the toxicity of BP 1100X in cunner (*T. adspersus*), hermit crab (*Eupagurus bernhardus*), oysters (*Ostrea edulis*), shrimp (*Crangon crangon*), shore crabs (*Carcinus maenas*), starfish (*A. rubens*), plaice, sole, and periwinkles (*Littorina saxatilis*), mullet (*Mugil*), and hermit crab (*Clibinarius africanus*). Perkins et al. (29) considered the ability of BP 1100X to induce death in hermit crab, shrimp shore crabs, oysters, periwinkles, starfish, plaice, and sole. The results of toxicity tests revealed that this dispersant has very low toxicity with no long-term effects on any species studied; the LD₅₀ ranged from 1000 to >10,000 ppm.

Kiceniuk et al. (26) reported that in exposed cunner fish, BP 1100X caused bradycardia, which returned to normal after exposure. Treatment groups were slower in recovery than control groups. Oyewo (30) studied the death and behavioral effects of BP 1100X to mullet and hermit crab (*Clibinarius africanus*). Of three detergents tested, BP 1100X was the least toxic to the two test organisms at the two test salinities. In mullets, some fingerlings appeared to be stunned and dropped to the bottom of the container (these did not die instantly), opercular movements continued until death. The compound was moderately lethal for mullets, with toxicity decreasing slightly at 17.0 g/L salinity. Oyewo (30) reported that treatment groups of hermit crabs withdrew from their shells (normal behavior around disturbance) and walked around the container continuously. The crabs also clumped together in some midrange concentrations. The author noted that clumping may be normal because it occurred in wild and stock animals. Most animals had their bodies outside the shell at death.

BP 1100WD

Two studies looked at the toxicity of BP 1100 WD in shore crabs, three barnacle species (*Chamaesipho brunnea*, *Cha. columnna*, and *Epopella plicata*), and two bivalves species (*Xenostrobus pulex* and *Perna canaliculus*). The end points considered were the ability to induce death and the effects on heart rate and respiration. Power (31) conducted field studies to evaluate the lethality of BP 1000 WD to three barnacle species (*Cha. brunnea*, *Cha. columnna*, and *Epo. plicata*) and two bivalve species (*X. pulex*, and *Per. canaliculus*) at Anawhata, on the west coast of the North Island of New Zealand. The animals were sprayed on a beach and monitored for 130 days. For all species, no difference in survivorship was found between treatment groups and controls. A rapid decline in numbers in the *Cha. columnna* treatment group leveled off after 2 months. Depledge (32) studied the heart rate and respiration of shore crabs. The animals were allowed up to a 6-week recovery period. The heart and respiration rates, impedance trace height, and cardiac output values increased after exposure to the dispersant. Replacement with clean seawater had no effect on cardiac output. Normal feeding behavior was not resumed during the following 6 weeks of observation.

BP 1002

Two studies looked at the toxicity of BP 1002 in herring, pilchard, plaice, sole, lemon sole, haddock, three barnacle species, and two bivalve species. The end points considered were the ability to induce death, effect on heart rate, and effect on respiration. When compared with controls. Power (31) found no difference in the survival of three barnacle species and two bivalve species 130 days after spraying; in the treatment group, a rapid decline in the

numbers of the barnacle *Cha. columna* leveled off after 2 months. Wilson (27) found that BP 1002 was highly toxic, inducing death in herring, pilchard, plaice, sole, lemon sole, and haddock. Lower salinity decreased the toxicity slightly, specifically for plaice. In younger plaice larvae, temperature increased toxicity.

Shell-manufactured dispersants

Shell SD LTX and Shell SD LT are dispersants manufactured by the Shell Oil Company (30). Studies looked at corals, crustaceans, mollusks, starfish, and fish, using only the end points of death and respiratory rate (Table 6).

Shell SD LTX

Two studies looked at the toxicity of Shell SD LTX in stony coral (*Madracis mirabilis*), three barnacle species (*Cha. brunnea*, *Cha. columna*, and *Epo. plicata*), and two bivalve species (*X. pulex* and *Per. canaliculus*). The end points were death (recorded as LC₅₀) and effect on respiratory rate (reported as RD₅₀).

Elgershuizen and De Kruijf (33) investigated the ability of Shell SD LTX mixed with normal seawater or oil alone to induce death in stony coral. The authors found that mixtures of crude oil and Shell SD LTX in seawater were more toxic than crude oil floating on the surface. The investigators hypothesized that the non-additive effects were related to a higher solubility of the toxic oil fraction in sea water after emulsification by the dispersant. The authors do not recommend the use of this dispersant near coral reefs.

Power (31) sprayed three barnacle and two bivalve species with Shell SD LTX on a beach and monitored the animals for 130 days. No difference in survivorship was found between treatment groups and controls in any species; a rapid decrease in the numbers of the barnacle *Cha. columna* in the treatment groups leveled off after 2 months.

Shell SD LT

Perkins et al. (29) studied death in hermit crab, oysters, shrimp, shore crab, starfish, plaice, sole, and periwinkle. The results indicated that Shell SD LT has very low toxicity and has no long-term effects on any species studied. Oysters and plaice showed no difference between treated and control groups, with no evidence of retarded growth in oysters that were recollected. At concentration of 1000 ppm, plaice showed evidence of paradoxical effects. Periwinkles exposed to 5000 ppm had no mortality during the period studied.

Total Special Fluids-manufactured dispersants

Total Special Fluids produces the dispersants Finasol ESK, Finasol OSR-2, and Finasol OSR-5 (34). Studies looked at fish, crustaceans, and molluscus and lungworms. The end points included death, effects on enzyme activity, and effects on respiration (Table 7).

Finasol ESK

Wilson (27) reported that Finasol ESK induces death in herring, pilchard, plaice, sole, lemon sole, and haddock. The range of 100 h LC₅₀ reported for all species was 4–35 ppm. As with

the other dispersants tested in this study, temperature and salinity had only slight influence on toxicity. A similar slight increase in toxicity with lower salinity was noticed in all other species.

Finasol OSR-2

Two studies by Verriopoulos et al. (35, 36) examined the toxicity of Finasol OSR-2 to brine shrimp. The first study reported that 100% Finasol OSR-2 was highly lethal for brine shrimp (48 h LC_{50} =0.9 vs. 297.8 ppm for oil alone) (35). The oil-dispersant mixture had a pronounced less-than-additive effect. The second study concerned the effects of dilute solutions of crude Tunisian oil and Finasol OSR-2 or a mixture (33) on respiration (36). For oil and Finasol, three test concentrations were prepared from a stock solution diluted immediately (0 h), 48 h, or 96 h before the experiment because the toxicity of oil and Finasol had been previously shown to decrease with time (“age” of stock solution). Both large (8–10 mm length) and medium (6–8 mm) males and females were used. Regardless of time after preparation, all three solutions elicited changes in the respiratory rates of *Artemia*. The magnitude of the respiration changes reflected differences not only among the three toxic solutions but also among the various “ages” of solutions of one toxicant and even among the various groups of experimental animals. The direction (stimulation or suppression) was the same for all and seemed to be concentration-dependent. The lethality of the dispersant was highest at 0 h and lowest at 96 h. The general trend showed a decrease of respiration rate at 0 h up to 48-h LC_{50} concentrations. No statistical differences were found between males and females. Males and females of the higher size class were more sensitive to stress and had more respiratory changes than those of the smaller size class.

Finasol OSR-5

Two different studies examined the toxicity of Finasol OSR-5 to soft-shell clams (*Mya arenaria*), the common cockle (*Cerastoderma edule*), lungworm (*Arenicola marina*), and *Artemia nauplii*. Cotou et al. (37) examined the toxicity of Finasol OSR-5 to the ATPase activities of two naupliar stages of *Art. nauplii* (instar I and II). Mortality was recorded at 6 h in instar I and at 24 h in instar II after exposure to sublethal and lethal concentrations (near to LOEC and NOEC) derived from acute toxicity data. An eight-fold difference noted between the instar stages was instar exposure time-dependent. Newly hatched *Art. nauplii* were exposed to sublethal concentrations of dispersants to measure enzyme activity. The most prominent effects were the respective inhibition and stimulation of Na^+/K^+ -ATPase and Mg^{2+} -ATPase activities, with Mg^{2+} -ATPase activities found higher in all situations. The cause of these effects was related to the surfactants and was directly correlated to concentration of dispersant. Farke et al. (38) found no major effects of Finasol OSR-5 when added alone on the feeding or mortality of lungworm, soft-shell clams, or common cockle.

Miscellaneous manufactured dispersants

A breakdown of studies investigating the toxicity of miscellaneous manufactured dispersants can be found in Table 8.

Actusol

Kiceniuk et al. (26) reported that exposure to Actusol caused bradycardia in cunner fish. As with all other dispersants tested in this study, the heart rate returned to normal after exposure, and treatment groups were slower to recover than control groups.

Atlas and Basol AD6

Wilson (27) considered the ability of various dilutions of Atlas or Basol AD6 to induce death in herring, pilchard, plaice, sole, lemon sole, and haddock. For both solvents, the LC₅₀ range was highly toxic. The susceptibility, which was similar for larvae of all species when newly hatched, increased throughout the yolk-sac stage. Salinity affected the toxicity of dispersant.

Biosolve

Otitolaju (39) evaluated the toxicities of a Nigerian brand of crude oil (Forcados Light), a newly approved dispersant for use in Nigerian ecosystems (Biosolve), and their mixtures, based on ratios 9:1, 6:1, and 4:1 (v/v), against the juvenile stage of prawn, *Macrobrachium vollehovenii*, in laboratory bioassays. Crude oil was found to be about six times more toxic than the dispersant when acting alone, whereas effects of the crude oil/dispersant mixtures varied, depending largely upon the proportion of addition of the mixture components. The interactions between mixtures of crude oil and dispersant at the test ratios of 9:1 and 4:1 were found to conform with the model of synergism, whereas those based on the 6:1 ratio conformed with the model of antagonism, based on the concentration-addition model. The mixtures prepared based on ratios 9:1 and 6:1 were less toxic than crude oil when acting singly against *Mac. vollehovenii*, whereas the mixture prepared based on ratio 4:1 showed similar toxicity with crude oil when acting alone.

Conco-K

Oyewo (30) studied the toxic effects of Conco-K to mullet and hermit crab (*Cli. africanus*). The animals were exposed to dispersant, and death and behavioral effects were investigated. Most animals lost balance and fingerlings dropped dead to the bottom of the container, with no spinal flexure “arrest”. A decrease in salinity increased toxicity in mullets and hermit crabs. Treated hermit crabs withdrew from their shells and walked around the container continuously. The crabs also clumped together at some midrange concentrations. Most animals had their bodies outside the shell at death.

Cleaner Crystal Simple Green

Vosyliene et al. (40) considered the toxicity of Cleaner Crystal Simple Green, used for the cleanup of the oil spill in the Baltic Sea near Lithuania in 2001, to adult (4-day duration) rainbow trout (*Oncorhynchus mykiss*) and on yolk-sac larvae (25-day duration). The Simple Green solution alone did not affect the survival of larvae or adult fish, and no significant changes were determined in respiratory parameters. The most expressed alterations were a decrease in the average body mass of larvae and in the hematologic indices of adult fish at the end of the tests. Simple Green combined with oil induced an increase in larval mortality as approximately 46% of individuals died. No mortality was recorded in adult fish exposed

to the combination, but a significant decrease in the leukocyte count of adult fish was noted. The average heart rate of larvae was significantly decreased. Marked changes were also found in respiratory parameters. The authors suggested that when Simple Green is mixed with crude oil in water, an up to fourfold increase in the concentration of petroleum hydrocarbons in the mixture could explain the augmentation of the adverse impact.

D-tar

Wilson (27) examined the ability of D-tar to induce death in herring, pilchard, plaice, sole, lemon sole, and haddock. The dispersant was highly toxic for all species. As before in this series, salinity affected the toxicity of dispersant.

Duosol

Kiceniuk et al. (26) reported that exposure to Duosol caused bradycardia in cunner fish. The results were the same as for other dispersants tested in this report.

Foremost

Oyewo (30) studied the death and behavioral effects of Foremost to mullet and to hermit crab (*Cli. africanus*). Normal spinal swimming spinal flexure was arrested, fingerlings assumed the shape of the letter S, and they swam sluggishly until death. The treated hermit crabs withdrew from their shells and walked around the container continuously. The crabs also clumped together in some midrange concentrations. The bodies of most animals were outside their shells at death.

Hiclean II

Jung et al. (8) studied the response of the ovoviparous rockfish, *S. schlegeli*, to hydrocarbons in the WAF of crude oil in the presence or absence of Hiclean II. The concentrations of CYP1A and EROD in rockfish exposed to WAF of crude oil (0.1% and 1%) were significantly increased in WAF that was chemically enhanced with 0.1% or 0.01% Hiclean II dispersant. After 72 h exposure, the hydrocarbon metabolites in bile from fish exposed to WAF in the presence of Hiclean II were significantly higher compared with fish exposed to WAF alone or control fish. After 72 h exposure of 0.1% Hiclean II alone, the authors reported the rockfish had no detectable changes to CYP1A, EROD, or acetylcholinesterase (AChE) when compared with controls.

Houghtoslov

Wilson (27) examined the ability of various concentrations of Houghtoslov to induce death in herring, pilchard, plaice, sole, lemon sole, and haddock. The dispersant was highly toxic with an LC₅₀ range of 4–35 ppm; salinity affected the toxicity of dispersant.

Nokomis 3

Singer et al. (41) compared the effects of oil dispersants on the early life stages of topsmelt (*Atherinops affinis*) and kelp (*Macrocystis pyrifera*). Median effect concentration data showed *Atherinops* tests to be more sensitive to the dispersant Nokomis 3 than *Macrocystis* tests. *Holmesimysis* tests were seen to be least sensitive to Nokomis 3. In another study by

Singer et al. (42), Nokomis 3 was more lethal for red abalone embryos than for kelp forest mysid. The authors reported that the immediate effect of surfactant exposure in mysids was asphyxiation due to disruption of the respiratory membranes.

Oilspere 43

Kiceniuk et al. (26) reported bradycardia in cunner fished exposed to Oilspere 43, which returned to normal after exposure. Treatment groups were slower in recovery than control groups.

Penetone 861

Wilson (27) reported that Penetone 861 was lethal for herring, pilchard, plaice, sole, lemon sole, and haddock. The range of LC₅₀ was 4–35 ppm and was affected by salinity.

Slik-A-Way

Singer et al. (41, 42) found that Slik-A-Way induced death in topsmelt, kelp forest mysid, and red abalones embryos. Red abalone embryos were most sensitive, followed by mysid and topsmelt.

Slix

Wilson (27) considered the ability of different dilutions of Slix to induce death in herring, pilchard, plaice, sole, lemon sole, and haddock. The dispersant was highly toxic for all species and was affected by salinity.

Su-Gee 2

Kiceniuk et al. (26) reported that Su-Gee 2 caused bradycardia in cunner fish, which returned to normal after exposure. The treatment groups were slower in recovery than control groups.

Superdispersant-25

Scarlett et al. (12) investigated the exposure to Superdispersant-25 in mud shrimp, mussels, and snakelocks anemone. At 18 h, mud shrimp exposed to >175 ppm showed stress. Individuals exposed to 175 ppm had normal swimming and burrowing behavior and survived during recovery. Death occurred at 375 and 500 ppm. Mussels had decreased feeding rates and were slow to close upon touch. For anemone, 55% were insensitive to stimuli at LC₅₀ of 20 ppm, and above 80 ppm, tissue decomposed. All anemones exposed to 30 ppm recovered and responded to stimuli.

Synperonic OSD 20

Kiceniuk et al. (26) noted bradycardia in cunner fish exposed to Synperonic OSD 20. The heart rate returned to normal after exposure, but treatment groups were slower in recovery than control groups.

Summary

Peer-reviewed published studies have been conducted in animal groups ranging from zooplankton to rats. The toxicity of dispersants varies, depending on the dispersant and species. Some studies suggest that dispersants are highly toxic, whereas others suggest that they can be mildly toxic (Tables 1–8). The distinct lack of data on the toxicity of dispersants to large predatory fish, marine mammals, marine birds, and humans is noteworthy.

The variety of chemical dispersants, variability in test methods, and lack of species overlap among dispersant studies make it difficult to compare and determine which dispersant is most toxic and which is least. We offer some attempt at synthesis here for the two chemical dispersants that have seen the largest applications in the field (Corexit 9527 and 9500), but significantly more research is needed before clear conclusions can be drawn. Both chemicals were used in the 2010 Gulf of Mexico oil crisis, and the total administered amount of chemical dispersants was at least 7.57 million liters.

Considering invertebrates, the lowest LC₅₀ reported for Corexit 9527 was 14 ppm [48-h exposure in *D. magna* (9)]. For invertebrates treated with Corexit 9500, the lowest LC₅₀ reported was 18 ppm [96-h exposure in mysid (4)]. Thus, ignoring the exposure time differences, the data suggest that Corexit 9527 may be somewhat more lethal to invertebrates. For nonlethal effects, tissue decomposition, gene-expression changes, and physically stressed animals were end points considered. The lowest NOEC, for nonlethal effects, for Corexit 9527 was 3.3 ppm [96 h exposure looking at death in kelp forest mysid (16)], whereas for Corexit 9500, the lowest NOEC was 9.7 ppm [48 h exposure when studying death in red abalone embryos (5)]. The data also suggest that Corexit 9527 may be more toxic than Corexit 9500, when considering nonlethal end points.

Considering fish, the lowest LC₅₀ reported for Corexit 9527 was 20.1 ppm [96 h exposure in crimson-spotted rainbowfish (7)]; for Corexit 9500, the lowest LC₅₀ was 14.5 ppm [96 h exposure in crimson-spotted rainbowfish (7)]. Thus, ignoring the exposure time differences, the data suggest that the lethality of Corexit 9500 to fish could be greater than Corexit 9527. For nonlethal effects, gill ion regulation and enzyme activity changes were the end points considered. The lowest NOEC, for nonlethal effects for Corexit 9527 was 13.5 ppm [96 h constant exposure in topsmelt studying death (17)], whereas no NOEC was reported for Corexit 9500. The data suggest that Corexit 9500 could be more toxic than Corexit 9527 if nonlethal end points are considered.

Birds and mammals were studied only after exposure to Corexit 9527 (21–23), with no mortality data provided. Considering birds, Corexit 9527 had no effect on hatchability in mallards but did cause temporary motor coordination loss and temporary nervous system disorder (21, 22). In mammals, Corexit 9527 was lethal to rats (no amount was provided). At diluted concentrations (1:20, 1:10 Corexit/peanut oil) some slight change occurred in enzyme activities in the gastrointestinal tract indicating stress (23). Thus, considering nonlethal end points, Corexit 9527 appears to be more toxic to rats than birds. Considering all the points above, Corexit 9527 appears to be more toxic to fish than rats. Overall,

invertebrates appear to be the most sensitive to Corexit 9527, followed by fish and then rats, with birds being the least sensitive.

Because only three animal species overlapped, however, reaching a definite answer as to which organisms Corexit is more toxic is difficult, and even more challenging is to compare all dispersants. A critical need exists for more comparative studies with the same groups of different species, using different dispersants, and particularly with emphasis on Corexit 9527 and 9500 because these two have become the most extensively used.

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References

1. US Environmental Protection Agency (EPA). EPA response to BP spill in the Gulf of Mexico Dispersants. Monitoring and assessment of dispersants used in the BP response [website]. Last updated 19 July 2010. Washington, DC: US Environmental Protection Agency Available at: <http://www.epa.gov/bpspill/dispersants-qanda.html#chemicals>. Accessed 08 September 2011.
2. Nalco. Corexit® EC9527A safety data sheet. Naperville, IL: Nalco Available at: http://www.deepwaterhorizonresponse.com/posted/2931/Corexit_EC9527A_MSDS.539295.pdf. Accessed 11 May 2010.
3. Nalco. Corexit® 9500 Material Safety Data Sheet, Naperville, IL: Nalco Available: http://www.deepwaterhorizonresponse.com/posted/2931/Corexit_EC9500A_MSDS.539287.pdf. Accessed 11 May 2010.
4. Fuller C Bonner J, Page C, Ernest A. McDonald T, et al. Comparative toxicity of oil, dispersant, and oil plus dispersant to several marine species. *Environ Toxicol Chem* 2004;23: 2941–9. [PubMed: 15648769]
5. Singer MM, George S, Jacobson S, Lee I, Weetman LL, et al. Comparison of acute aquatic effects of the oil dispersant Corexit 9500 with those of other Corexit series dispersants. *Ecotoxicol Environ Saf* 1996;35:183–9. [PubMed: 8950541]
6. Duarte RM, Honda RT, Val AL. Acute effects of chemically dispersed crude oil on gill ion regulation, plasma ion levels and haematological parameters in tambaqui (*Colossoma macropomum*). *Aquat Toxicol* 2010;97:134–41. [PubMed: 20097436]
7. Pollino CA, Holdway DA. Toxicity testing of crude oil and related compounds using early life stages of the crimson-spotted rainbowfish (*Melanotaenia fluviatilis*). *Ecotoxicol Environ Saf* 2002;52:180–9. [PubMed: 12297077]
8. Jung JH, Yim UH, Han GM, Shim WJ. Biochemical changes in rockfish, *Sebastes schlegeli*, exposed to dispersed crude oil. *Comp Biochem Physiol C Toxicol Pharmacol* 2009;150: 218–23. [PubMed: 19410657]
9. Bobra AM, Shiu WY, Mackay D, Goodman RH. Acute toxicity of dispersed fresh and weathered crude oil and dispersants to *Daphnia magna*. *Chemosphere* 1989;19:1199–222.
10. Venn AA, Quinn J, Jones R, Bodnar A. P-glycoprotein (multixenobiotic resistance) and heat shock protein gene expression in the reef coral *Montastraea franksi* in response to environmental toxicants. *Aquat Toxicol* 2009;93:188–95. [PubMed: 19501419]
11. Negri AP, Hey ward AJ. Inhibition of fertilization and larval metamorphosis of the coral *Acropora millepora* (Ehrenberg, 1834) by petroleum products. *Mar Pollut Bull* 2000;41:420–7.

12. Scarlett A, Galloway TS, Canty M, Smith EL, Nilsson J, et al. Comparative toxicity of two oil dispersants, Superdispersant-25 and Corexit 9527, to a range of coastal species. *Environ Toxicol Chem* 2005;24:1219–27. [PubMed: 16111003]
13. Law AT. Toxicity study of the oil dispersant Corexit 9527 on *Macrobrachium rosenbergii* (de Man) egg hatchability by using a flow-through bioassay technique. *Environ Pollut* 1995;88:41–3. [PubMed: 15091567]
14. Wells PG, Abernethy S, Mackay D. Study of oil-water partitioning of a chemical dispersant using an acute bioassay with marine crustaceans. *Chemosphere* 1982;11:1071–86.
15. George-Ares A, Clark JR, Biddinger GR, Hinman ML. Comparison of test methods and early toxicity characterization for five dispersants. *Ecotoxicol Environ Saf* 1999;42:138–42. [PubMed: 10051362]
16. Singer MM, Smalheer DL, Tjeerdema RS, Martin M. Effects of spiked exposure to an oil dispersant on the early life stages of four marine species. *Environ Toxicol Chem* 1991;10:1367–74.
17. Wheelock CE, Wolfe MF, Olsen H, Tjeerdema RS, Sowby ML. Hsp60-induced tolerance in the rotifer *Brachionus plicatilis* exposed to multiple environmental contaminants. *Arch Environ Contam Toxicol* 1999;36:2811–7.
18. Hamoutene D, Payne JF, Rahimtula A, Lee K. Effect of water soluble fractions of diesel and an oil spill dispersant (Corexit 9527) on immune responses in mussels. *Bull Environ Contam Toxicol* 2004;72:1260–7. [PubMed: 15362458]
19. Ordzie CJ, Garofalo GC. Lethal and sublethal effects of short term acute doses of Kuwait Crude Oil and a dispersant Corexit 9527 on bay scallops, *Argopecten irradians* (Lamarck) and two predators at different temperatures. *Mar Environ Res* 1981;5:195–210.
20. Hartwick ED, Wu RS, Parker DB. Effects of a crude oil and an oil dispersant (Corexit 9527) on populations of the littleneck clam (*Protothaca staminea*). *Mar Environ Res* 1982;6:291–306.
21. Rocke TE, Yuill TM, Hinsdill RD. Oil and related toxicant effects on mallard immune defenses. *Environ Res* 1984;33:343–52. [PubMed: 6714187]
22. Albers PH, Gay ML. Effects of a chemical dispersant and crude oil on breeding ducks. *Bull Environ Contam Toxicol* 1982;29:404–11. [PubMed: 7171850]
23. George SE, Nelson GM, Kohan MJ, Warren SH, Eischen BT, et al. Oral treatment of Fischer 344 rats with weathered crude oil and a dispersant influences intestinal metabolism and microbiota. *J Toxicol Environ Health Part A* 2001;63:297–316. [PubMed: 11437062]
24. Singer MM, George S, Jacobson S, Lee I, Tjeerdema RS, et al. Comparative toxicity of Corexit 7664 to the early life stages of four marine species. *Arch Environ Contam Toxicol* 1994;27:130–6.
25. Avolizi RJ, Nuwayhid M. Effects of crude oil and dispersants on bivalves. *Mar Pollut Bull* 1974;5:149–53.
26. Kiceniuk JW, Penrose WR, Squires WR. Oil spill dispersants cause bradycardia in a marine fish. *Mar Pollut Bull* 1978;9:42–5.
27. Wilson KW. Acute toxicity of oil dispersants to marine fish larvae. *Mar Biol* 1977;40:65–74.
28. Singer MM, George S, Jacobson S, Lee I, Weetman LL, et al. Acute toxicity of the oil dispersant Corexit 9554 to marine organisms. *Ecotoxicol Environ Saf* 1995;32:81–6. [PubMed: 8565881]
29. Perkins EJ, Gribbon E, Logan JW. Oil dispersant toxicity. *Mar Pollut Bull* 1973;4:90–3.
30. Oyewo EO. The acute toxicity of three oil dispersants. *Environ Pollut* 1986;41:23–31.
31. Power FM. Long-term effects of oil dispersants on intertidal benthic invertebrates. *Oil Petrochem Pollut* 1982;1:97–108.
32. Depledge MH. Changes in cardiac activity, oxygen uptake and perfusion in *Carcinus Maenas* (L.) exposed to crude oil and dispersant. *Comp Biochem Physiol Part C Toxicol Pharmacol* 1984;78:461–6.
33. Elgershuizen JH, De Kruijf HA. Toxicity of crude oils and a dispersant to the stony coral *Madracis mirabilis*. *Mar Pollut Bull* 1976;7:22–5.
34. Total Special fluids. Total fluids marine dispersants: Finasol OSR product range. Available at: http://www.totalspecialfluids.com/lub/sf.nsf/V_S_OPM/CE0FA89C21DCDA99C12573E10033E68F?OpenDocument/.

35. Verriopoulos G, Moraitou-Apostolopoulou M, Million E. Combined toxicity of four toxicants (Cu, Cr, Oil, oil dispersant) to *Artemia salina*. *Bull Environ Contam Toxicol* 1987;38:483–90. [PubMed: 3814873]
36. Verriopoulos G, Moraitou-Apostolopoulou M, Xatzispirou A. Evaluation of metabolic responses of *Artemia salina* to oil and oil dispersant as a potential indicator of toxicant stress. *Bull Environ Contam Toxicol* 1986;36:444–51. [PubMed: 3955258]
37. Cotou E, Castritsi-Catharios I, Moraitou-Apostolopoulou M. Surfactant-based oil dispersant toxicity to developing nauplii of *Artemia*: Effects on ATPase enzymatic system. *Chemosphere* 2001;42:959–64. [PubMed: 11272919]
38. Farke H, Wonneberger K, Gunkel W, Dahlmann G. Effects of oil and a dispersant on intertidal organisms in field experiments with a mesocosm, the Bremerhaven Caisson. *Mar Environ Res* 1985;15:97–114.
39. Otitoloju AA. Crude oil plus dispersant: always a boon or bane? *Ecotoxicol Environ Saf* 2005;60:198–202. [PubMed: 15546636]
40. Vosyliene MZ, Kazlauskienė N, Jokšas K. Toxic effects of crude oil combined with oil cleaner simple green on yolk-sac larvae and adult rainbow trout *Oncorhynchus mykiss*. *Environ Sci Pollut Res Int* 2005;12:136–9. [PubMed: 15986996]
41. Singer MM, George S, Jacobson S, Lee I, Tjeerdema RS, et al. Comparative effects of oil dispersants to the early life stages of topsmelt (*Atherinops affinis*) and kelp (*Macrocystis pyrifera*). *Environ Toxicol Chem* 1994;13:649–55.
42. Singer MM, George S, Benner D, Jacobson S, Tjeerdema RS, et al. Comparative toxicity of two oil dispersants to the early life stages of two marine species. *Environ Toxicol Chem* 1993;12:1855–63.

Table 1

Toxicity of Corexit 9500 to crustaceans, mollusks, and fish.

Dose	Time, h	Species	End point	Summary of effects	References
18–900 ppm	96	Mysid (<i>A. bakia</i>)	Death	Continuous LC ₅₀ =32 ppm, declining LC ₅₀ =900 ppm Continuous NOEC=18 ppm, declining NOEC=900 ppm	(4)
25–500 ppm	96	Kelp forest mysid (<i>H. costata</i>)	Death	NOEC=142.3 ppm, LC ₅₀ =158.0 ppm	(5)
2–100 ppm	48	Red abalone embryos (<i>Hal. rufescens</i>)	Death	NOEC=9.7 ppm, estimated EC ₅₀ =12.8–19.7 ppm	(5)
1:1200 or 1:1000 (Corexit/ water)	6	Tambaqui (<i>C. macropomum</i>)	Gill ion regulation	No effect	(6)
50–76 ppm	96	Inland silverside (<i>M. beryllina</i>)	Death	Continuous LC ₅₀ =79 ppm, declining LC ₅₀ =76 ppm Continuous NOEC=50 ppm, declining NOEC=42 ppm.	(4)
107–670 ppm	96	Sheepshead minnow (<i>Cyp. variegatus</i>)	Death	Continuous LC ₅₀ =180 ppm, declining LC ₅₀ =670 ppm Continuous NOEC=107 ppm, declining NOEC=305 ppm	(4)
0, 1, 3.2, 10, 32, or 100 ppm	96	Crimson spotted rainbowfish (<i>Mel. fluviatilis</i>)	Death	LC ₅₀ at 72 h=34.7 ppm LC ₅₀ at 96 h=14.5 ppm	(7)
0.1%	72	Rockfish (<i>S. schlegelii</i>)	CYP1A catalytic activity; EROD, brain AChE	Dispersant alone: no detectable CYP1A activity, no significant effects of EROD or AChE levels WAF+dispersant: 48 h exposure – CYP1A and EROD significantly increased 72 h exposure – CYP1A and EROD significantly increased in 0.1% and 0.01% chemically enhanced WAF (Corexit 9500 and Hitean II dispersant)	(8)

Table 2

Toxicity of Corexit 125210 to *Daphnia*, anemones, and coral, crustaceans, mollusks, starfish, fish, birds, and rats.

Dose	Time, h	Species	End point	Summary of effects	References
34–163 ppm at 5°C or 9.0–24.6 ppm at 20°C	48	<i>D. magna</i>	Death	LC ₅₀ at 5°C=75 ppm LC ₅₀ at 20°C=14 ppm	(9)
1, 5, 10, or 50 ppm in 1 µm filtered seawater	4 or 8	Reef coral (<i>Mon. franksi</i>)	P-gp, Hsp70, and Hsp90 gene expression	8 h - P-gp gene expression increased at 10 and 50 ppm Hsp70 increased after 8 h at 5, 10, or 50 ppm Hsp90 not significantly differentially express after 4 or 8 h	(10)
0.01%, 0.01%, 0.1%, 1%, or 10% of 1%	24	Coral (<i>Acr. millepora</i>)	Reproduction and growth	10 ppm - significant inhibition of fertilization Between 5 and 10 ppm - inhibited metamorphosis	(11)
0, 10, 20, 40, 80, or 160 ppm	48	Snakelock anemone (<i>Arte, viridis</i>)	Death	Individuals highly sensitive, 100% of individuals at 20 ppm were insensitive to stimuli, EC ₅₀ =15 ppm (interpolated from data only, not derived from model), NOEC=10 ppm, LOEC=15 ppm	(12)
50–500 ppm in 12 g/L salinity brackish water	12 mL/h of solution added for a total duration of 12 days	Prawn (<i>Mac. rosenbergii</i>)	Effects on hatchability	Estimated hatchability: EC ₅₀ =80.4±5.5 ppm, EC ₉₅ =193.5±39.9 ppm, no hatchability at >250 ppm	(13)
200 mL in water dilution	2–4 days	Adult and larvae brine shrimp (<i>Artemia</i>)	Death	1 and 2 day LC ₅₀ and EC ₅₀ lower at 20°C and higher at day 1, 2 day LC ₅₀ at 20°C=52 ppm (6 bioassays), lowest 2 day EC _{50s} = 42–72 ppm at 20°C	(14)
200 mL in water dilution	2–4 days	Copepod (<i>P. minutus</i>)	Death	2-day LC ₅₀ =35.5 ppm, 4 day LC ₅₀ =24.8 ppm (8 bioassays)	(14)
6.25, 12.5, 25, 50, or 100 ppm	24 or 96	Mysid (<i>Mysidopsis bahia</i>)	Mysid acute toxicity	96 h LC ₅₀ =27.1 ppm; 24 h LC ₅₀ =65.0 ppm	(15)
6.25, 12.5, 25, 50, or 100 ppm	1		Mysid IQ toxicity test	1 h. LC ₅₀ =34.4 ppm	
12.5, 25, 50, or 100 ppm	15 min		Microtox	15 min EC ₅₀ - 4.9 ppm	
5–500 ppm	96	Kelp forest mysid (<i>H. costata</i>)	Death	Spiked exposure: NOEC=20.5 ppm, LC ₅₀ =140.1 ppm Constant exposure: NOEC=3.3 ppm, LC ₅₀ =6.2, ppm	(16)
0.78%–5%	24	Rotifer (<i>B. plicatilis</i>)	Changes in Hsp60 gene expression	Four to five-fold increase over controls in percentage of Hsp60	(17)
0, 50, 125, 175, 213, 250, 375, or 500 ppm	48	Mud shrimp (<i>Cor. volutator</i>)	Death	LC ₅₀ = 159 ppm; NOEC=125 ppm >17.5 ppm - no recovery	(12)
0, 80, 130, 200, 250, or 320 ppm	48	Mussels (<i>Myt. edulis</i>)	Death	Significant mortality at 250 ppm NOEC=200 ppm LOEC=250 ppm	(12)
200–500 ppm	4 days	Mussels (<i>Myt. edulis</i>)	Effect on hemocyte cells and phagocytosis	No effect at 200 ppm on hemocyte cell number or phagocytosis	(18)
0%–100% of stock at 2°C, 10°C, and 20°C	6 5 day recovery	Bay scallops (<i>Arg. ir radians</i>)	Death and predator/prey recognition	When temperature increased survivorship decreased, LD ₅₀ not listed; dispersant caused no effect on swimming clap index; see text for recognition details	(19)

Dose	Time, h	Species	End point	Summary of effects	References
0%–100% of stock at 2°C, 10°C, and 20°C	6 5 day recovery	Oyster drill (<i>V. cinerea</i>)	Death and predator/prey recognition	No treatment-related deaths during treatment at 20°C, no effect on scallop recognition	(19)
10 or 100 ppm	5 5 day recovery (see text for details)	Littleneck clam (<i>Pro. staminea</i>)	Death	No mortality at 10 ppm for small clams, the LT ₅₀ for large and small clams treated with 100 ppm was 2–3 days	(20)
5–120 ppm	48	Red abalone embryos (<i>Hal. rufescens</i>)	Death	Spiked exposure NOEC=6.6 ppm; EC ₅₀ = 15.9 ppm Constant exposure NOEC=1.1 ppm; EC ₅₀ =1.6 ppm	(16)
0%–100% of stock at 2°C, 10°C, and 20°C	6 5 day recovery period	Starfish (<i>Ast. forbesi</i>)	Physical responses	No treatment-related deaths	(19)
0, 6.3, 12.5, 25, 50, or 100 ppm	24–96	Crimson-spotted rainbowfish (<i>Mel. fluviatilis</i>)	Death	24 h LC ₅₀ =64.3 ppm 48 h LC ₅₀ =61.2 ppm 72 h LC ₅₀ =47.3 ppm 96 h LC ₅₀ =20.1 ppm	(7)
5–500 ppm	96	Topsmelt (<i>Aik. affinis</i>)	Death	Spiked exposure: NOEC range=57.0 ppm, LC ₅₀ =83.0 ppm Constant exposure: NOEC=13.5 ppm, LC ₅₀ =30.7 ppm	(16)
1:10 Corexit/water	Gavage exposure for 28 days	Male mallards (<i>Ana. platyrhynchos</i>)	Immune system	5.0 mL/kg caused a temporary nervous system disorder	(21)
10 mL of 9527/m ² of water surface	48	Mallard (<i>Ana. platyrhynchos</i>)	Effect on hatchability	No significant effect	(22)
1:2, 1:5, 1:10, or 1:20 Corexit/peanut oil	4 days	Fischer 344 rats	Body/tissue weights, urine mutagenicity: effect on intestinal microflora and microbial intestinal enzymes	No urine mutagens detected by TA98 or TA100, Corexit 9527 (1:1000) toxic in vitro. In vivo: concentrated 9527 lethal to rats, no effect on body or tissue weight 1 or 3 weeks. Large- intestine nitroreductase elevated (334.2±63.1 µg 3,4 dichloroaniline/g tissue/h), β-glucuronidase reduced (84.8±5.4 µg <i>p</i> -nitrophenol/g tissue/h) Small-intestine enzymes not affected 5 weeks. Small-intestine and cecal azoreductase decreased (0.17±0.02 µg <i>N,N</i> -dimethyl- <i>p</i> -phenylenediamine/g tissue/h). Large-intestine β-glucuronidase increased (99.3±12.2 µg <i>p</i> -nitrophenol/g tissue/h). Reduced lactosefermenting enterobacteria in the ceca. Obligate anaerobic Gram-negative rods (VK), lactobacilli (Rogosa), and total anaerobes (blood agar) unaffected	(23)

Table 3

Toxicity of Corexit 7664 to *Daphnia*, crustaceans, mollusks, and fish.

Dose	Treatment length, h	Species	End point	Summary of effects	References
231–316 ppm at 5°C, or 26.9–288 ppm at 20°C	48	<i>D. magna</i>	Death	LC ₅₀ at 5°C=270 ppm, LC ₅₀ at 20°C=88 ppm	(9)
5–250 ppm	48	Red abalone larval (<i>Hal. rufescens</i>)	Death	EC ₅₀ estimated to be between 0.55 and 0.92 ppm, NOEC=0.4 ppm	(24)
5–250 ppm	96	Mysid (<i>H. costata</i>)	Death	LC ₅₀ =34.24 ppm, NOEC=40.6 ppm	(24)
0, 0.1, 1, 2.5, 5, or 10 mL/L Corexit/sea water	Fresh mixture added daily until LC ₅₀ reached	Mussel (<i>Bra. variabilis</i>) Bean clam (<i>Don. trunculus</i>)	Effect on respiration	Interference with the production of byssal thread, caused a significant decrease in respiration at 10 mL, in mussels of 39.2% and at 5 mL in bean clams of 59.6%, LC ₅₀ value not reported as a number	(25)
5–250 ppm	96	Topsmelt (<i>Ath. affinis</i>)	Death	LC ₅₀ =3.51 ppm, NOEC=6.96 ppm	(24)
None given	10 min	Cunner (<i>T. adspersus</i>)	Effects on bradycardia threshold	Bradycardia threshold=8.1±10.8 ppm	(26)
0.5, 1, 2.5, 5, 10, 25, 50, or 100 ppm	100	Herring (<i>Clu. harengus</i>), pilchard (<i>Sar. pilchardus</i>), plaice (<i>Ple. platessa</i>), sole (<i>Sol. solea</i>), lemon sole (<i>Mic. kitt</i>), daddock (<i>Mel. aeglefinus</i>)	Death	No individual 100 h LC ₅₀ reported for each species, LC ₅₀ listed as 400 ppm	(27)

Table 4

Toxicity of various corexit to *Daphnia*, crustaceans, mollusks, and fish.

Chemical and dose	Treatment length, h	Species	End point	Summary of effects	References
Corexit 8666 None given	10 min	Cunner (<i>T. adspersus</i>)	Effects on bradycardia threshold	Bradycardia threshold=900±311 ppm	(26)
Corexit 8667 0.75–12 ppm at 5°C or 0.001–0.81 ppm at 20°C	48	<i>D. magna</i>	Death	LC ₅₀ at 5°C=3 ppm, LC ₅₀ at 20°C=0.03 ppm	(9)
Corexit 9550 2.0–12.2 ppm at 5°C or 0.19–1.3 ppm at 20°C	48	<i>D. magna</i>	Death	LC ₅₀ at 5°C=4.9 ppm, LC ₅₀ at 20°C=0.5 ppm	(9)
Corexit 9554 3–48 ppm	48	Red abalone embryos (<i>Hal. rufescens</i>)	Death	NOEC ranged from 6.9 ppm EC ₅₀ estimated to be between 8.0 and 10.3 ppm	(28)
Corexit 9554 50–300 ppm	48	Juvenile mysid (<i>H. costata</i>)	Death	NOEC=125.5 ppm, LC ₅₀ =162.1 ppm	(28)
Corexit 9554 50–300 ppm	48	Topsmelt larvae (<i>Ath. affinis</i>)	Death	NOEC=148.1 ppm, LC ₅₀ =159.2 ppm, very little delayed mortality	(28)
Corexit 9660 2.0–10.6 ppm. at 5°C or 0.06–2.7 ppm at 20°C	48	<i>D. magna</i>	Death	LC ₅₀ at 5°C=4.6 ppm, LC ₅₀ at 20°C=0.4 ppm	(9)

Table 5

Toxicity of BP-manufactured dispersants to crustaceans, mollusks, starfish, and fish.

Chemical and dose	Treatment length, h	Species	End point	Summary of effects	References
BP UOOX None given	24	Hermit crab (<i>E. bernhardus</i>)	Death	48 h LC ₅₀ >10,000 ppm	(29)
	Animals released to shore for 5 day recovery	Shrimp (<i>Cra. crangon</i>)		48 h LC ₅₀ >1000 ppm (100% mortality)	
		Shore crab (<i>Car. maenas</i>)		48 h LC ₅₀ =20,000 ppm	
		Oyster (<i>O. edulis</i>)		48 h LC ₅₀ =2500 ppm, no difference between controls and treated group	
		Periwinkle (<i>L. saxatilis</i>)		No mortality in the 5 day period, exposed to 5000 ppm	
		Starfish (<i>Art. rubens</i>)		48 h LC ₅₀ =3000–6000 ppm	
	24	Plaice (<i>Ple. platessa</i>)		48 h LC ₅₀ =7100 ppm, no difference between controls and treated group; at 1000 ppm, evidence of paradoxical effects	
	5 day recovery			No 48 h LC ₅₀	
	24 Animals released to shore for 5 day recovery	Sole (<i>Sol. solea</i>)			
	10 min	Cunner (<i>T. adspersus</i>)	Bradycardia threshold	Bradycardia thresh.hold=78±23.8 ppm	(26)
BP 1100 X Not given (fresh test media added every 24 h)	24, 48, or 96	Mullet (<i>Mugil</i>)	Death	At 33.5 g/L salinity, 24 h LC ₅₀ of 153.4 µL/L, a 48 h LC ₅₀ of 152.5 µL/L, and a 96 h LC ₅₀ of 151.0 µL/L; salinity at 17.0 g/L decreased toxicity to 155.4 µL/L 24 h LC ₅₀ , 153.7 µL/L 48 h LC ₅₀ , and 152.2 µL/L 96 h LC ₅₀ .	(30)
BP 1100 X Not given	24	Hermit crab (<i>Ch. affcanus</i>)	Behavioral effects and death	24 h LC ₅₀ > 30,000 µL/L at 33.5 g/L	(30)
BP 1100 WD Animals sprayed on a beach in New Zealand	Monitored for 130 days	<i>Cha. brunnea</i> <i>Cha. columna</i>	Death	No major difference between survivorship of treated and controls Rapid decline in numbers, which leveled off after 2 months; little mortality after	(31)
		<i>Epo. plicata</i> <i>X. pulex</i>		No major difference between survivorship of treated and controls	
		<i>Per. canaliculus</i>		No major difference between survivorship of treated and controls	
BP 1100 WD 10% diluted in seawater	24 h Followed by a recovery period of up to 6 weeks	Shore crabs (<i>Car. maenas</i>)	Heart and respiration rate	Initial heart rate=104.6±2.8 b/min; after 1.5 min, increased to 121±3.0 b/min, initial respiratory rate=43.0±2.8 µL/g/min; after 15 min, increased to 50±2.5 b µL/g/min; impedance trace height increased for 15–60 min; after 24 h, dropped below pretreatment values; cardiac output values increased by 25%–40% within 15 min; decreased to initial level after 24 h	(32)
BP 1002 1:10 dilution Sprayed to a beach in New Zealand	Animals monitored for 143 days	<i>Cha. brunnea</i>	Death	No major difference between treated and controls, most sensitive barnacle	(31)

Chemical and dose	Treatment length, h	Species	End point	Summary of effects	References
		<i>Cha. columna</i>		No major difference between treated and controls, least sensitive barnacle	
		<i>Epo. plicata</i>		No major difference between treated and controls	
		<i>X. pulex</i>		Caused significant mortality, reached 10% mortality in 2 months	
		<i>Per. canaliculus</i>		Caused significant mortality, reached 12% mortality in 2 months	
BP 1002	100	Herring (<i>Clu. harengus</i>), pilchard (<i>Sar. pilchardus</i>), plaice (<i>Ple. platessa</i>), sole (<i>Sol. solea</i>), lemon sole (<i>Mic. Kitt</i>), haddock (<i>Mer. aeglefinus</i>)	Death	No individual 100 h LC ₅₀ reported for individual species, range=4–35 ppm, lower salinity decreased toxicity slightly, specifically in 100 h LC ₅₀ for plaice: 8.6 ppm at 34‰ to 10.7 ppm at 14‰ salinity	(27)
0.5, 1, 2.5, 5, 10, 25, 50, or 100 ppm					

Table 6

Toxicity of Shell--manufactured dispersants to coral, crustaceans, mollusks, starfish, and fish.

Chemical and dose	Treatment length, h	Species	End point	Summary of effects	References
Shell SD LTX 10, 50, 100, 500, 1000, 5000, or 10,000 ppm	24, then 24 h exposure to normal sea water	Stony coral (<i>Mad. mirabilis</i>)	Death, respiratory effects	Crude oil on surface of water LD ₅₀ =10 ⁵ ppm; RD ₅₀ =38,550 ppm; mixed dispersant with water LD ₅₀ =700 ppm; RD ₅₀ =162 ppm.	(33)
Shell SD LTX Sprayed to a beach in New Zealand	Animals monitored for 130 days	<i>Cha. brunnea</i> <i>Cha. columna</i> <i>Epo. plicata</i> <i>X. pullex</i> <i>Per. canaliculus</i>	Death	No major difference between treated and controls	(31)
Shell SD LT None given 20°C	48 5 day recovery	Shrimp (<i>Cr. crangon</i>)	Death	48 h LC ₅₀ > 1000 ppm (55% mortality)	(29)
		Shore crab (<i>Car. maenas</i>)		48 h LC ₅₀ =20,000 ppm	(29)
		Hermit crab (<i>E. bernhardus</i>)		48 h LC ₅₀ > 10,000 ppm, no delayed mortality	(29)
		Oyster (<i>O. edulis</i>)		48 h LC ₅₀ > 10,000 ppm, no difference between controls and treated group	(29)
		Periwinkle (<i>L. saxatilis</i>)		No mortality in the 5 day period, exposed to 5000 ppm	(29)
	48 Released to shore for 5 day recovery	Starfish (<i>Ast. rubens</i>)		48 h LC ₅₀ > 6000 ppm	(29)
		Plaice (<i>Ple. platessa</i>)		48 h LC ₅₀ > 10,000 ppm, no difference between controls and treated group; at concentration of 1000 ppm, evidence of paradoxical effects	(29)
		Sole (<i>Sol. solea</i>)		48 h LC ₅₀ > 10,000 ppm	(29)

Table 7

Toxicity of total special Fluids-manufactured dispersants to coral, crustaceans, mollusks, starfish, and fish.

Chemical and dose	Treatment length, h	Species	End point	Summary of effects	References
Finasol ESK 0.5, 1, 2.5, 5, 10, 25, 50, or 100 ppm	100	Herring (<i>Clu. harengus</i>), pilchard (<i>Sar. pilchardus</i>), plaice (<i>Ple. platessa</i>), sole (<i>Sol. solea</i>), lemon sole (<i>Mic. kilt</i>), haddock (<i>Met. aeglefinus</i>)	Death	No individual 100 h LC ₅₀ reported for each species, range=4–35 ppm, salinity changes increased toxicity slightly when salinity was lower, specifically in 100 h LC ₅₀ for plaice: 16.4 ppm at salinity of 34‰–20.6 ppm at 14‰ salinity	(27)
Finasol OSR-2 100%	48	Brine shrimp (<i>Artemia salina</i>)	Death	LC ₅₀ =0.90 ppm	(35)
Finasol OSR-2 0.5, 1, 2.0, 30 ppm (solutions prepared at 0.48, or 96 h before treatment)	Not given	Brine shrimp (<i>Anemia salina</i>)	Effects on respiration, death	0 and 48 h solution decreased respiration below control, 96 h solution did not; 48 h LC ₅₀ for 0, 48, and 96 h solution=1, 10, and 20 ppm, respectively	(36)
Finasol OSR-5 Adults: 10, 20, 30, 40, 50, 60, 70, 80, 90, 100, 200, 300, 400, 500, 600 ppm Newly hatched; 5 or 20 ppm	Not given	<i>Art. nauplii</i>	6-h observations for mortality in instar I; 24-h observations for mortality in instar II; ATPase activity	6 h LC ₅₀ =414.25; 24 h LC ₅₀ =51.13 ppm, LOEC at 6 h=100 ppm, at 24 h LOEC=20 ppm, 24 h NOEC=10 ppm 5 and 20 ppm Na ⁺ /K ⁺ -ATPase activities were inhibited and were statistically significant (40.41% at 5 ppm to 66.12% at 20 ppm for instar I, and from 3.08% at 5 ppm to 67.47% at 20 ppm for instar II); total ATPase and Mg ²⁺ -ATPase activities stimulated in both stages and statistically significant (19.2%–28.22% for instar I and from 7.49%–59.40% for instar II compared with controls)	(37)
Finasol OSR-5 Not given	None given	Lugworm (<i>Are. marina</i>)	Death	No effect	(38)
Finasol OSR-5 None given	None given	Common cockle (<i>Cer. edule</i>)	Effect of feeding		(38)
Finasol OSR-5 None given	None given	Soft-shell clams (<i>Mya arenaria</i>)	Effect of feeding		(38)

Table 8

Toxicity of various manufactured dispersants to different marine species.

Chemical and dose	Treatment length, h	Species	End point	Summary of effects	References
Actusol Not given	10 min	Cunner (<i>T. adspersus</i>)	Effects on bradycardia threshold	Bradycardia threshold=1.6±1.08 ppm.	(26)
Atlas 0.5, 1, 2.5, 5, 10, 25, 50, or 100 ppm Basol AD6 100-h exposure to 0.5, 1, 2.5, 5, 10, 25, 50, or 100 ppm	100	Herring (<i>Clu. harengus</i>), pilchard (<i>Sar. pilchardus</i>), plaice (<i>Ple. platessa</i>), sole (<i>Sol. solea</i>), lemon sole (<i>Mic. kittl</i>), haddock (<i>Mel. aeglefinus</i>)	Death	No 100 h LC ₅₀ reported for individual species; range LC ₅₀ =4–35 ppm	(27)
Biosolve 0.4, 1.2, 1.6, 1.8, 2.0, 4.0, 5.0, 7.0 ppm	24–96	Prawn (<i>Mac. volienhovenii</i>)	Death	24 h LC ₅₀ =2.6 ppm; LC ₉₅ =5.5 ppm 48 h LC ₅₀ =3.2 ppm; LC ₉₅ =5.2 ppm 72 h LC ₅₀ =2.2 ppm; LC ₉₅ =4.7 ppm 96 h LC ₅₀ =1.9 ppm; LC ₉₅ =3.4 ppm	(39)
Conco K Not given (fresh test media added every 24 h), concentration not given	24, 48, or 96	Mullet (<i>Mugil</i>)	Death	At 33.5 g/L salinity LC ₅₀ =5.4 µL/L for 24 h, 48 h LC ₅₀ =5.9 µL/L, 96 h LC ₅₀ =4.6 µL/L; salinity at 17.0 g/L increased toxicity to 6.75 µL/L 24 h LC ₅₀ , 5.9 µL/L 48 h LC ₅₀ , and 5.6 µL/L 96 h LC ₅₀	(30)
Cleaner CRYSTAL Simple Green Adult; to 0.5 ppm SG in 1 L of water Yolk-sac larvae; 0.5 ppm of SG in 1 L of water	Adult: 4 days On yolk-sac larvae: 25 days	Hermit crab (<i>Cli. africanus</i>) Rainbow trout (<i>Onc. mykiss</i>)	Effects on body mass, heart rate, and blood	24, 48, and 96 h LC ₅₀ of 9200, 6500, and >2000 µL/L at 33.5 g/L salinity; toxicity increased to 17,400, 10,200, and >3200 g/L at 17.0 g/L salinity No effect on survival of adult or larvae; a significant decrease in average body mass for larvae from 124.0±4.2 to 113.1±4.7 mg; no changes in heart rate or gill ventilation frequency, RBC, or hemoglobin; WBC significantly decreased in adults from 22.8±3.4×10 ³ mm ³ at day 1 to 12.1±1.2×10 ³ mm ³ at 4 day exposure; hematocrit level decreased in adults from 0.51±0.02 1/L at day 1 to 0.39±0.07 1/L at 4 day exposure	(30) (40)
D-tar 0.5, 1, 2.5, 5, 10, 2.5, 50, or 100 ppm	1000	Herring (<i>Clu. harengus</i>), pilchard (<i>Sar. pilchardus</i>), plaice (<i>Ple. platessa</i>), sole (<i>Sol. solea</i>), lemon sole (<i>Mic. kittl</i>), haddock (<i>Mel. aeglefinus</i>)	Death	No 100 h LC ₅₀ reported for individual species, range=4–35 ppm, lowered salinity decreased toxicity slightly	(27)
Duosol Not given Foremost Not given (fresh test media added every 2.4 h)	10 min 24, 48, or 96	Cunner (<i>T. adspersus</i>) Mullet (<i>Mugil</i>)	Bradycardia Death	Bradycardia threshold=12±7.0 ppm 33.5 g/L salinity - 54.3 µL/L 24 h LC ₅₀ , 52.7 µL/L 48 h LC ₅₀ , and 52 µL/L 96 h LC ₅₀ 17.0 g/L salinity - increased toxicity in mullets to 56.6 µL/L 24 h LC ₅₀ , 55.8 µL/L 48 h LC ₅₀ , and 52.6 µL/L 96 h LC ₅₀	(26) (30)

Chemical and dose	Treatment length, h	Species	End point	Summary of effects	References
		Hermit crab (<i>Chi. africans</i>)		33.5 g/L salinity - 24,48, and 96 h LC ₅₀ of 19,400, 17,050, and 16,700 µL/L, respectively 17.0 g/L salinity - toxicity decreased to 17,300, 17,050, and 16,400 µL/L, respectively	(30)
Hiclean II 0.1%	72	Rockfish (<i>S. schlegeli</i>)	Effects on CYP1A, EROD, and brain AChE	Dispersant alone: No detectable CYP1A activity; no significant effects of EROD or AChE levels of dispersant treated groups when compared with control After 72 h exposure, CYP1A levels and EROD activity significantly increased in 0.1% and 0.01% chemically enhanced WAF (Corexit 9500 and Hiclean II dispersant)	(8)
Houghtoslov 0.5, 1, 2.5, 5, 10, 2.5, 50, or 100 ppma	100	Herring (<i>Clu. harengus</i>), pilchard (<i>Sar. pilchardus</i>), plaice (<i>Ple. platessa</i>), sole (<i>Sol. solea</i>), lemon sole (<i>Mic. kin</i>), haddock (<i>Mel. aeglefinus</i>)	Death	No 100 h LC ₅₀ reported for individual species, range=4–35 ppm	(27)
Nokomis 3 20–50 ppm	96	Topsmelt (<i>Ath. affinis</i>)	Death	NOEC=52.3 ppm, LC ₅₀ =48.2 ppm	(41)
Nokomis 3 60–220 ppm	96	Kelp forest mysid (<i>H. costata</i>)	Death	NOEC=87.6 ppm, LC ₅₀ =119.9 ppm	(42)
Nokomis 3 5 ppm	48	Red abalone (<i>Hal. rufescens</i>)	Death	NOEC=10.8 ppm, EC ₅₀ estimated to be between 21.0 and 24.0 ppm	(42)
Oilspere 43 Not given	10 min	Cunner (<i>T. adspersus</i>)	Bradycardia	Bradycardia threshold=81±35.1 ppm	(26)
Penetone 861 0.5, 1, 2.5, 5, 10, 25, 50, or 100 ppm	100	Herring (<i>Clu. harengus</i>), pilchard (<i>Sar. pilchardus</i>), plaice (<i>Ple. platessa</i>), sole (<i>Sol. solea</i>), lemon sole (<i>Mic. kin</i>), haddock (<i>Mel. aeglefinus</i>)	Death	No 100 h LC ₅₀ reported for individual species, range=4–35 ppm, lowered salinity decreased toxicity slightly	(27)
Silk-A-Way 20–50 ppm	96	Topsmelt (<i>Ath. affinis</i>)	Death	NOEC=42.2 ppm, LC ₅₀ =43.7 ppm	(41)
Silk-A-Way 3–48 ppm	96	Kelp forest mysid (<i>H. costata</i>)	Death	NOEC=24.7 ppm, LC ₅₀ =31.3 ppm	(42)
Silk-A-Way 3–48 ppm	48	Red abalone (<i>Hal. rufescens</i>)	Death	NOEC=10.4 ppm, EC ₅₀ estimated to be between 16.8 and 23.9 ppm	(42)
Slix 100-h exposure to 0.5, 1, 2.5, 5, 10, 25, 50, or 100 ppm		Herring (<i>Clu. harengus</i>), pilchard (<i>Sar. pilchardus</i>), plaice (<i>Ple. platessa</i>), sole (<i>Sol. solea</i>), lemon sole (<i>Mic. kin</i>), haddock (<i>Mel. aeglefinus</i>)	Death	No 100 h LC ₅₀ reported for individual species, range=4–35 ppm	(27)
Su-Gee 2 Not given	10 min	Cunner (<i>T. adspersus</i>)	Bradycardia	Bradycardia threshold=77±23.8 ppm	(26)

Chemical and dose	Treatment length, h	Species	End point	Summary of effects	References
Superdispersant-25 0, 50, 125, 175, 213, 250, 375, or 500 ppm	48	Mud shrimp (<i>Cor. volutator</i>)	Death	At 24 h, individuals were seen moribund only at exposures to 375 and 500 ppm, NOEC=125 ppm, LOEC=175 ppm	(12)
Superdispersant-25 0, 80, 130, 200, 250, or 320 ppm	48	Mussels (<i>Myt. edulis</i>)	Death	No reliable LC ₅₀ , significant mortality at 250 ppm, NEOC=200 ppm and LOEC=250 ppm	(12)
Superdispersant-25 0, 10, 20, 40, 80, or 160 ppm	48	Snakelock anemone (<i>Ane. viridis</i>)	Death	LC ₅₀ =20 ppm (interpolated from data only, not derived from model). NOEC=10 ppm, LOEC=20 ppm	(12)
Synperonic OSD 20 Not given	10 min	Cunner (<i>T. adspersus</i>)	Bradycardia	Bradycardia threshold=9.2±5.41 ppm	(26)