SUMMARY MANUSCRIPT FOR EFFECTS OF OIL ON WILDLIFE CONFERENCE

NET ENVIRONMENTAL BENEFIT ANALYSIS (NEBA) OF DISPERSED OIL VERSUS NON-DISPERSED OIL ON COASTAL ECOSYSTEMS & WILDLIFE UTILIZING DATA DERIVED FROM THE 20-YEAR TROPICS STUDY

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Introduction

It is axiomatic that the best approach to oil spill response is prevention. This axiom applies as well to the effects of oil after a spill, as plans and response strategies and methods under consideration will determine the extent to which responders can prevent (or minimize) spilled oil from impacting sensitive ecosystems and wildlife. Advocates of the use of dispersants have traditionally viewed the application of dispersants as a means of minimizing environmental damage through the construct of Net Environmental Benefit Analysis (NEBA), trading off lower value resources in favor of those identified as higher value.

This paper draws on empirical data and observations collected over 20 years of the Tropical Oil Pollution Investigations in Coastal Systems (TROPICS) field study in Bahia de Almirante, Panama. The study began in November 1984, when non-treated and dispersed Alaska North Slope (ANS) crude oil were intentionally released into two separate sites representative of mangrove, seagrass and coral ecosystems. Data on the relative physical presence and biological effects of non-treated and dispersed oil in these ecosystems (as well as a third reference site) were acquired and analyzed over various periods (30 days, 20 months, and 3, 10, 17, 18 and 20 years). The short and long-term physical and biological effects of non-treated and dispersed oil are summarized in numerous reports and proceedings (e.g., RPI 1987, Dodge et al. 1995, Ward et al. 2003, and Baca et al. 2005). The primary goal of this study is to examine the Net Environmental Benefit Analysis (NEBA) for the use or non-use of dispersants in nearshore tropical ecosystems.

Twenty year observations and mangrove substrate core samples reveal the continued presence of oil and diminished mangrove repopulation, as well as substrate erosion, at the non-treated oil site. There was no oil detected and no long-term impacts observed at the dispersed oil and reference sites (Baca et al). Associated coral reef and seagrass communities were also more adversely effected in the long-term than at the non-dispersed crude oil site. The observed difference in the presence of oil and its long-term effects can be attributed to well-known and understood mechanisms associated with the use of dispersant:

1. The surfactant in dispersants facilitates the formation of stabilized oil droplets that do not as readily adhere as non-dispersed oil to impacted surfaces, such as non-organic and organic substrate, mangrove roots, seagrass blades, sediments, rocks, etc. This allowed the dispersed oil to be flushed from the study site with diurnal tidal floods. The resident time of oil and consequent exposure time of flora and fauna to the oil at the dispersed oil site was therefore significantly shorter than at the non-dispersed oil site. At the non-treated oil site, oil adhered to mangrove roots and became trapped in subsurface crab holes up to 30 cm into the mangrove substrate. Evidence of oil oozing from the substrate could be visually observed 17 and 18 years after the intentional release of oil. The persistence of the non-dispersed oil represents longer exposure time for flora and fauna at the non-treated oil site.
2. At the dispersed oil site, the mixing of the dispersed oil droplets in the water column presented an overall lower concentration of total hydrocarbon exposure to the flora and fauna due to physical dilution. At the non-treated oil site, aside from soluble fragments, the non-dispersed crude oil that impacted flora and fauna was at full concentration. This oil coated mangrove roots at high tide and mangrove substrate and some seagrass at low tide.

TROPICS Methodology & Results

It is important to remember that this spill was a worst case scenario, releasing 4.5-6 barrels of oil into a 900m^2, shallow ecosystem. Dispersed crude oil was pre-mixed with Corexit® 9527 in drums and 4.5 barrels of this mix were released by multiple hoses into a boomed, 900m^2 site on November 28-29, 1984. A total of 6 barrels of crude oil were likewise applied via multiple hoses to a very similar boomed site on December 1-2, 1984. Chemical analyses of water, sediment, and organism tissues began with pre-spill baseline studies and was ongoing for 20 months after the spills.

In the spring of 2004 mangrove sediment samples at the non-dispersed site showed a petroleum hydrocarbon high of 22ppm; however, this number was much reduced in fall samples. A summary of fall chemistry results is given in Table 1. The 20-year results for the fall samples were provided by NOAA from the laboratory at LSU. Samples were collected at various depths (0-17 cm) in the mangrove substrate and results were separated into alkanes and aromatics. Total petroleum hydrocarbon (TPH) is a combination of the two. Data were highly variable due to the patchiness of the oil distribution. Importantly for year 20, aromatics represented only 1.5% of total hydrocarbons. Hydrocarbons were at insignificant levels at all three sites by the end of the 20th year from the date of the spills.

Table 1. Total Petroleum Hydrocarbons (TPH) from Sediment Collections at the TROPICS Sites.

Sample Dates	Non-Treated ppm	Dispersed Oil ppm	Reference Site ppm
Pre-dosing (11/84)	1.44±0.51	2.04±0.53	0.97±0.39
1 Year (12/85)	552±713	125±66	Not Analyzed
10 Years (94-95)	19.4±27.5	30.8±36.9	4.1±1.0
20 Years (9/04)	2.00±0.93	1.04±0.14	1.57±0.24

A summary of mangrove results is given in Table 2. Much more data on tree parameters were collected but tree and seedling counts were indicative of the overall trends in effects. Mangroves suffered a serious and unexpected die-off by year 10. At the end of the first phase of the study, researchers assumed that mortalities had stabilized and the sites were essentially ignored for 7 years during which time mortality increased at the non-treated oil site from 17% to 46%. This mortality resulted in a large void and erosional depression in the center of site. This void became a magnet for seedlings to establish, and in the 20th year these seedlings had grown large enough to be classified as trees (i.e., >2 meters tall), effectively re-populating the site. Today they form a dense thicket in the center of the mangrove section of the non-treated oil site. However, in the last five or so years a second mangrove die-off began occurring offsite north of the non-treated oil site and appears to be spreading to that portion of the island. An offsite area similar in size to the original die-off zone now exists north of the site. In stark contrast to non-treated oil results, tree counts and condition at the dispersed oil site remained constant, although seedlings experienced a reduction which rebounded in 20 years. The Reference Site experienced a 24% reduction in trees and a 31% increase in seedlings by year 20.

Table 2. Summary of mangrove counts between treatments. Numbers represent percent of original population; original population size is given in brackets. Notable effects were detected at the non-treated oil site: significant declines in trees and increases in seedlings (later to become trees) were seen by year 10.

Sample Dates	Parameter	Non-Treated	Dispersed Oil	Reference Site
Pre-dose (84)	Mature Trees	100 (149)	100 (72)	100 (108)
	Seedlings	100 (13)	100 (33)	100 (26)
1 Year (85)	Mature Trees	83	100	100
	Seedlings	100	100	100
10 Years (94)	Mature Trees	54	97	100
	Seedlings	685	58	81
20 Years (04)	Mature Trees	98	94	76
	Seedlings	838	100	112

A summary of seagrass results is given in Table 3. Turtle grass, *Thalassia testudinum* was the only species encountered at the sites. At the start of the study turtle grass occupied dense, wide beds seaward of the mangrove zone. By the end of the 20-year study seagrass had virtually disappeared from the non-treated oil site, being replaced by finger coral, *Porites porites*. Seagrass density increased after one year but also continued to decrease after that. However, the reference site also experienced decreases during that time.

Table 3. Summary of seagrass results during the first 20 years of the TROPICS project. Numbers represent percent of original measures; original population size (per m^2) and growth rates (cm/da) are given in brackets.

Sample Dates	Parameter	Non-Treated	Dispersed Oil	Reference Site
Pre-dose (84)	Density	100 (356)	100 (423)	100 (379)
	Growth rate	100 (0.49)	100	100
1 Year (85)	Density	105	135	113
	Growth rate	90	111	115
10 Years (94)	Density	73	83	86
	Growth rate	111	106	107
20 Years (04)	Density	38	66	113
	Growth rate	89	111	87

A summary of coral results is given in Table 4. Only coral cover is presented because this provides a good representation of overall trends. As shown, percent coral cover increased across all sites, significantly at the non-treated oil site. This increase was due to the increase of *Porites porites* into the seagrass bed at the non-treated oil site whereas coral cover increased primarily on the reef edge at the dispersed oil site. Further investigations were conducted on the spread of *Porites* coral into the seagrass bed at the non-treated oil site as reported in Ward et al. (2003). A study of other locations on the treatment island revealed that no other location existed where 30m of intertidal seagrass bed was so densely populated by *Porites*.

Table 4. Summary of coral cover results during the first 18 years of the TROPICS project. Numbers represent percent of original measures; original percent cover data are given in brackets.

Sample Dates	Parameter	Non-Treated	Dispersed Oil	Reference Site
Pre-dose (84)	Total Coral Cover	100 (27.6)	100 (21.6)	100 (15.3)
1 Year (85)	Total Coral Cover	84	75	92
10 Years (94)	Total Coral Cover	129	124	84
18 Years (02)	Total Coral Cover	244	211	110

Dispersant Mechanisms

Spilled crude oil degrades in a typical fashion through a series of physical and chemical steps, depending on type and composition of the spilled oil, weather conditions, evaporation, photo-oxidation, sediment characteristics, and biodegradation (Munoz et al. 1997). In general the lightest hydrocarbons degrade quickest, and among compound classes alkanes degrade quickest followed by naphthenes and lastly aromatics (Andrett et al. 1997). Dispersants generally enhance these processes when applied correctly, although some preferential degradation occurs (Lindstrom and Braddock 2002). Dispersants in the laboratory have produced a 50-fold increase in solubilized hydrocarbons in the water column (Baca and Getter 1984). Dispersant at the TROPICS site was pre-mixed in drumss containing crude oil prior to release throughout the water column. The dispersant was observed to form a cloud of the oft-reported discreet, stabilized droplets that do not adhere as readily as non-dispersed oil to surfaces such as organic substrate, roots, sands, rocks, etc. They penetrated the substrate but were more easily removed and degraded. They also mimicked food particle sizes and thus were ingested by invertebrates which in turn suffered high mortality. However, the short-term loss of invertebrates was compensated for by rapid re-colonization. Importantly, the ecological home for these organisms, the mangrove and seagrass ecosystem remained intact at the dispersed oil site. Being filter-feeding invertebrates, the corals also suffered short-term impacts, but then rebounded to high coral cover.

Application for other Habitats and Wildlife

The study and the dispersant mechanisms have application to other climate zones, ecological communities and their attendant flora and fauna. In fact, due to a large number of sensitivities, it is unlikely that field studies would ever be envisioned that intentionally oil higher order fauna, such as seabirds and marine mammals. Therefore, interpolation from this and other existing studies, while imperfect, may be the only limited scientific inputs available for NEBA for decision-making for the use of dispersants. For example, In the 1997 “San Jorge” spill in Uruguay, dispersants were used to prevent the impact of approximately 2,000 tonnes of spilled Canadon Seco crude oil on an extensive population (200,000-300,000) of sea lions at Isla de Lobos Wildlife Reserve. A number of new born sea lions were oiled by the spill and at least 200 of these may have died as a direct result of the spill. There is neither no clear figures on the number of sea lions that died as a direct result of the spill nor the number that may have been saved by the use of dispersants.

The TROPICS sites were habitats for a variety of wildlife which feed on the invertebrates and juvenile fish that dwell among the protective mangrove roots. Additonally, , including numerous wading birds, diving birds, and waterfowl. Migratory songbirds were also common. These organisms are not permanently affected by short-term food base loss, but they are affected by loss of tropical ecosystems. The dispersant mechanism observed at the TROPICS site and elsewhere has application in other marine environments for preventing/minimizing the impact of oil spills on seabirds and marine mammals, including reduced adherence of dispersed oil on feathers, fur, and nesting areas and beaches.

NEBA and Conclusions

The goal of this paper is to use these data to determine a Net Environmental Benefit Analysis (NEBA) for the use or non-use of dispersants in nearshore tropical ecosystems. The first step is to define mangrove, seagrass and coral habitat parameters, as follows:

Habitat (Refer back to Tables 1-4)	Component	Parameters available	Parameters used herein
Sediment	Hydrocarbons	1	TPH
Mangrove	Trees Seedlings	14	# Live # Live
Seagrass	Seagrass Seagrass	4	Density Growth
Coral	Coral	4	% Cover

Next, an assessment can be made of whether the 10-year data indicate a positive or negative benefit for dispersant use. A resulting summary is as follows:

Habitat (Refer back to Tables 1-4)	Parameter	NEB?
Sediment	Hydrocarbons	No
Mangrove	# Live Trees Seedlings	Yes No
Seagrass	Density Growth	Yes Yes
Coral	% Cover	Yes

Hydrocarbon levels were still high at the dispersed oil site so the NEB was negative. Clearly, the benefit for mangroves at the dispersed oil site is positive, although seedlings suffered a decline but returned later. The NEBA is moderately positive for seagrass and corals also, and coral cover increased over reference in both treatments.

Ultimately 20-year data would be evaluated as follows:

Habitat (Refer back to Tables 1-4)	Parameter	NEB?
Sediment	Hydrocarbons	Yes

Mangrove (7)	# Live	Yes
	Seedlings	Yes
Seagrass (3)	Density	?
	Growth	Yes
Coral (4)	% Cover	?

In this case dispersed oil was beneficial for hydrocarbon content over the long term. Likewise the benefit of dispersant use to mangroves is clearly shown. Seagrass density continued to decline such that further studies or additional parameters should be looked at for a final NEBA. However, seagrass density was still nearly twice as high at the dispersed oil site than at the non-treated oil site and seagrass growth rates have remained higher than baseline at the dispersed oil site. Likewise for corals further studies or additional parameters should be looked at for a NEBA although the increase in corals at the dispersed site did not result in an invasion of the seagrass bed nor was it as high as at the non-treated oil site.

Weighting of Resources

The NEBA analysis did not weigh any of the resources studied over others in the same community. Such a weighting would be relative sensitivity, ability to recover, place in the food chain or role in the ecosystem, and ability to repopulate. Relative value and weighting of respective resources at risk.

The yes/no answers should attempt to use quantitative, statistically validated data for proper assignation. Also, when more parameters are added for a NEBA then the value of each parameter can be taken into account to fine tune the answers. Overall, nearshore dispersant use at the TROPICS site continues to show benefits for mangroves, and to a lesser but positive extent, for seagrass.

The TROPICS sites continue to be active locations for research as many questions remain unanswered, such as:

- What are the causes of the takeover of the non-dispersed oil site by finger coral?
- What is the extent of offsite contamination and damages at the non-dispersed oil site?
- Will the emerging forest on the non-dispersed oil site become productive and permanent?
- When will the decline of seagrasses at both treatment sites stabilize?
- What is happening to the invertebrate fauna at the treatment sites in the twelve years since they were last surveyed?

Scientific Design Issues

There is a lack of publications on this study in peer-reviewed literature, primarily due to the fact that the study sites were non-replicated. Hurlbert published on the error of pseudoreplication in 1984 and this started a reaction where all non-replicated studies, regardless of scale, were disdained. Also followed were back-and-forth arguments about the value of large-scale, non-replicated studies (Oksanen 2001 and others). During the early years of planning the TROPICS study (1982-1983) it was determined that large, controlled-spill sites (>900m^2) were advantageous over laboratory or microcosm studies. Smaller, replicated studies had been performed but these were criticized for not representing real world conditions, a criticism still levied today (e.g., Schindler 1998). In addition, finding a location where one can intentionally release crude oil and/or dispersed oil on a large site containing mangroves, seagrass and coral is nearly impossible (even 20 years ago), and replication of these large spills was out of the question. Research such as the TROPICS experiment needed to be done because oil spill studies continue to rely on post-hoc data with little or no pre-spill information. There remains a need for adequate pre-spill, baseline data as well as pre-measured and metered dosing, to accurately determine the fate and effects of oil spills and to evaluate treatments options. Opportunities exist for research at the Reference Site, especially since replicate reference sites exist on that island for future use.

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