NET ENVIRONMENTAL BENEFIT ANALYSIS (NEBA) OF DISPERSED OIL ON NEARSHORE TROPICAL ECOSYSTEMS DERIVED FROM THE 20 YEAR "TROPICS" FIELD STUDY[1]

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ABSTRACT

In November 1984, non-treated Prudhoe Bay crude oil and dispersed Prudhoe Bay crude oil were intentionally released into two separate sites, representative of nearshore mangrove, seagrass and coral ecosystems, as part of the ***TR****opical* ***O****il* ***P****ollution* ***I****nvestigations in* ***C****oastal* ***S****ystems (TROPICS) field study in Bahia de Almirante, Panama. Data on the relative effects of non-treated crude oil and dispersed crude oil on these ecosystems (compared to a reference site) were acquired and analyzed over various periods (30 days, 3 months, and 2.6, 10, 17, 18, and 20 years).*

In the short term, the oil caused mortality to invertebrate fauna, seagrass beds, and corals at both sites. At the non-treated crude oil site, there was also significant mortality to the mangrove forest. 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 crude oil site. No oil was detected and no long-term impacts were observed at the dispersed crude oil and reference sites. These results provide baseline scientific data for developing a Net Environmental Benefit Analysis (NEBA) of dispersant use in nearshore tropical systems.

This paper is a review of TROPICS data and its application to NEBA preparation. Data and NEBA from the 20-year TROPICS study clearly show that the use of dispersant in the nearshore environment is a sound strategy for both minimizing environmental damage to tropical ecosystems and for providing the best opportunity for recovery and repopulation in this environment. Results of this work should be applicable to similar tropical ecosystems.

INTRODUCTION

In 1984, the TROPICS field study was conducted on the Caribbean coast of Panama to study the relative effects of non-treated crude oil and dispersed crude oil on tropical ecosystems (mangrove, seagrass, and coral). Over twenty years ago, the experiment was designed "to allow examination of possible trade-offs of impacts between intertidal and subtidal tropical ecosystems and to establish whether the application of dispersants to spilled oil in nearshore tropical areas is an ecologically safe means of minimizing damages to these habitats" (Getter et al., 1985). Baseline parameters were collected prior to intentional release of oil. A total of 960 liters (6 barrels) of non-treated Prudhoe Bay crude oil was released onto the surface of the non-treated crude site. A total of 720 liters (4.5 barrels) of pre-mixed, dispersed crude oil was released into the water column of the dispersed crude oil site. The short-term and long-term effects were then monitored. Target hydrocarbon levels were 1 liter per square meter on the surface at the non-treated crude oil site and 50ppm dissolved hydrocarbons in the water column at the dispersed crude oil site. Both target levels were exceeded by the above releases (RPI, 1987). Studies of the sites continued for 2.6 years (RPI, 1987; Ballou et al., 1989), at which time the sites were left, assuming all effects had run their course. However, when researchers revisited the sites in 1993, they found that effects were still occurring (Dodge et al., 1995). Since then a number of site revisits have been conducted, significantly adding data for assessment of dispersant use or non-use (reviewed in Ward et al., 2003). After 20 years, sediments at the non-treated crude oil site still emit a visible sheen, and chemical analyses have confirmed the presence of petroleum hydrocarbon contamination at this site. At this site, mature mangrove trees are still dying, although surviving recruits are maturing to repopulate vacant areas left by die-offs. The non-treated crude oil elicited few short-term effects in sub-tidal invertebrate communities. However, long-term coral invasion of the seagrass bed was observed (Ward, 2003).

A summary of main studies is shown in Table 1. Data from these studies are available in published reports, numerous conference proceedings, and original team member notes, in order to conduct an assessment of dispersant use or non-use.

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Table 1. Summary of TROPICS Studies and Activities.

DATE	ACTIVITY
February 1984	Screening of Research Sites
March 1984	Pre-spill Baseline Studies
November 1984	Pre-spill Baseline Studies
November 28-30, 1984	Dispersed Oil Spill
December 1-3, 1984	Crude Oil Spill
December 1984	Post-spill Studies
March 1985	Post-spill Studies
June 1985	Post-spill Studies
December 1985	Post-spill Studies
July 1986	Post-spill Studies
December 1993	Site Reconnaissance
September 1994	Long-term, Post-spill Studies
November 1994	Long-term, Post-spill Studies
June 2001	Site Reconnaissance
November 2001	Long-term, Post-spill Studies
June 2002	Long-term, Post-spill Studies
April 2004	Site Reconnaissance
August 2004	Site Reconnaissance

METHODS

Using TROPICS data derived from the above activities, the NEBA for dispersant use detailed herein was completed using summary data from four assessment periods for each habitat and component:

- 1984 Pre-spill baseline
- 1986 Short-term post-spill
- 1994 10-year Long-term post spill
- 2002 18-year Long-term post spill
- 2004 20-year Long-term revisit

Short-term and long-term data were then compared over time, between sites, and within habitat components. Short-term data reflect acute, but different environmental impacts at the non-treated crude oil and dispersed crude oil sites, but it was believed more important to consider the use of dispersants in a long-term context. Therefore, only comparisons between 1984 and long-term studies are used herein for NEBA production.

The NEBA was conducted from two perspectives: biological, for the impacts on the ecosystem, and physical, for the presence of hydrocarbons in the substrate and the erosion of the substrate itself. Biological procedures involved dividing main habitats into habitat components, and each component was further divided into parameters measured in the field and published in reports (unless otherwise noted). To further quantify and compare habitat impacts, all parameters considered were assigned a Parameter Importance Level (PIL). Coverage parameters, such as number of trees in the mangrove forest, seagrass cover in the seagrass bed, and coral cover in the coral reef, were assigned a top PIL of “1”. As an exception, tree numbers were based on single counts over entire sites, and therefore no replicates exist for statistical testing. Also, because seagrass percent cover was not obtained in the first ten years of studies, seagrass density was used as the primary parameter. Coral (and all reef organisms) cover data were obtained from the M.S. research of Greg A. Ward (2003). A summary of final comparative parameters is as follows:

- PIL 1 = most important parameters, primarily main organism coverage
- PIL 2 = parameters which are secondary in importance, but which represent a majority of field measures, and
- PIL 3 = parameters which are not directly important to the habitat, are usually transient, and which have been shown to have little correlation, or reverse correlation (e.g., growth enhancement), to treatments.

Statistical significance of parameter values ($p<0.05$), as compared to pre-spill and reference site, was used to determine if a Net Environmental Benefit (NEB) existed. A NEB was believed to exist if all PIL 1 values, and a majority of PIL 2 values, were significantly different for the non-treated crude oil site and the dispersed crude oil site, and/or the reference site. For a given parameter, if the dispersed crude oil site and/or reference site fared significantly better than the non-treated crude oil site, the NEB was “yes”; if not, the NEB was “no”. Comparing 1984 with 1994 gives the results shown in Table 2. No standard errors or degree of significance results are given in the table; parameter measures and significance reporting were obtained directly from published reports (RPI, 1987; Ballou et al., 1989; Dodge et al., 1995; Ward et al., 2003). In Table 2: * = reported significant differences at $p<0.05$; **PIL = Parameter Importance Level; NEB = Net Environmental Benefit (yes/no?); NM = significance based only on comparison to reference site because no measure was taken at the treatment site.

Any Parameter Importance Level (PIL) which showed a significant environmental benefit from dispersants, especially when supported by secondary parameters (PIL 2), was considered as providing a Net Environmental Benefit (NEB). Comparing the 1984 and 1994 data, the use of dispersant for mangroves is supported by PIL 1 (tree number parameter), and 60% of PIL 2. Mean height showed no significant difference and leaf production showed significant reductions in both the non-treated crude oil and dispersed crude oil sites. As anticipated, no PI L 3 parameters supported the use of dispersants.

For seagrasses, significant differences were detected in shoot density although all sites showed decreased densities over the 10 years. All other parameters were PIL 3, and none of these showed advantages or disadvantages of using dispersant. The results indicated a Net Environmental Benefit (NEB) for using dispersants over seagrasses.

Coral results showed no long-term, clear advantages or disadvantages for dispersant use when analyzed using data from 10 years after the original release of oil. Significant increases in flora and total organism cover at the dispersed crude oil site were not considered since the reference site also experienced increases.

The second example applicable to the NEBA is a comparison of the most recent (17, 18, and 20 years) detailed surveys with 1984 and the recent reference site. Although data was collected in 2004, the larger data set is for 2002 (mangrove data from 2001), and comparisons for relevant dates are given in Table 3. Parameters have been removed which were not measured in 2001/2002 (* = reported significant differences at $p<0.05$; **PIL = Parameter Importance Level; NEB = Net Environmental Benefit (yes/no?); NM = significance based only on comparison to reference site because no measure was taken at the treatment site).

For mangroves, only PIL 2 parameters indicated a positive NEB for dispersant use. However, the number of trees at the non-treated crude oil site was artificially high. At this site, almost half of the trees died and were replaced by seedlings which became trees (> 2m) over time. The replacement of dead trees by young seedlings at the non-treated crude oil site resulted in a return of tree numbers but a significant lowering of all PIL 2 parameters, for example, trunk diameter, height, and canopy cover. If original trees are counted and growing seedlings ignored, the total count is reduced to less than 50%. For these reasons, and when compared

Table 2. NEBA 1984 compared with 1994

Habitat	Component	Parameter	**PIL	Crude 1984	Crude 1994	Disp 1984	Disp 1994	Ref 1984	Ref 1994	NEB?
Mangrove	Trees	Number Living	1	149	80	72	70	108	108	YES
	Trees	Mean Trunk Diameter (cm)	2	5.3	*6.9	8.9	9.4	7.5	9.0	YES
	Trees	Mean Height (m)	2	4.4	5.0	5.0	4.9	4.4	4.7	NO
	Trees	Open Canopy (LAI#)	2	2.7	*3.9	3.1	3.6	2.4	2.6	YES
	Trees	Canopy Density (%)	2	NM	*38.1	NM	44.1	NM	56.1	YES
	Trees	Leaf Production (#/mo)	2	0.64	0.47*	0.67	0.40*	0.78	0.73	NO
	Trees	Leaf L/W Ratios	3	2.21	2.16	2.19	2.16	2.37	2.24	NO
	Trees	Mean % Herbivory	3	NM	24.0	NM	18.4	NM	20.1	NO
	Trees	Mean Lenticels/cm^2	3	0.44	0.61	0.37	0.52	0.42	0.52	NO
	Mangrove sediment	Hydrocarbons (mg/l)	3	0.9	19.4	0.6	*30.8	0.6	1.1	NO
	Seedlings	Number Living	3	13	*89	33	19	26	21	NO
	Tree Snails	Mean #/tree	3	297	*879	766	*690	445	927	NO
	Tree Oysters	Mean #/m root	3	53	*184	48	83	61	64	NO
	Cup Oysters	Mean #/m root	3	16	*77	33	58	23	35	NO
Seagrass	Seagrass	Mean Shoot Density (#/m^2)	2	841.7	*440.0	816.7	516.0	666.7	452.0	YES
	Seagrass	Mean Growth (cm/da)	3	0.48	0.53	0.38	0.48	0.46	0.58	NO
	Seagrass	Mean Leaf Area (cm^2)	3	22.2	17.6	24.4	18.6	27.6	20.4	NO
	Urchins	Mean #/line intercept	3	1.93	1.69	1.53	0.57	0.77	1.00	NO
Coral	Corals	Total Cover (%)	1	30.5	35.6	33.5	26.9	21.3	12.8	NO
	Fauna	Total Cover (%)	3	50.3	50.8	50.3	49.3	49.3	48.5	NO
	Flora	Total Cover (%)	3	7.0	18.5	3.8	*26.9	19.3	34.5	NO
	Organisms	Total Cover (%)	3	57.3	69.3	54.0	*76.1	68.5	83.0	NO

Table 3. NEBA: 1984 Compared with 2001, 2002 (17 and 18 year).

Habitats (1984/2001)	Component	Parameter	**PIL	Crude 1984	Crude 2001	Disp 1984	Disp 2001	Ref 1984	Ref 2001	NEB?
Mangrove	Trees	Number Living	1	149	141	72	60	108	85	NO
	Trees	Mean Trunk Diameter (cm)	2	5.3	*2.3	8.9	10.2	7.5	9.0	YES
	Trees	Mean Height (m)	2	4.4	*3.1	5.0	5.4	4.4	4.3	YES
	Trees	Open Canopy (LAI #)	2	2.7	*2.3	3.1	5.0	2.4	3.6	YES
	Trees	Leaf L/W Ratios	3	2.21	2.38	2.19	2.08	2.37	2.14	NO
	Trees	Mean % Herbivory	3	NM	12.6	NM	*22.3	NM	10.2	NO
	Seedlings	Number Living	3	13	*75	33	*13	26	21	NO
Habitats (1984/2002)	Component	Parameter	**PIL	Oiled 1984	Oiled 2002	Disp 1984	Disp 2002	Ref 1984	Ref 2002	NEB?
Seagrass	Seagrass	Mean Shoot Density (#/m^2)	2	841.7	*228.0	816.7	*412.0	666.7	593.3	YES
	Seagrass	Mean Growth (cm/da)	3	0.48	0.43	0.38	*0.47	0.46	0.40	NO
	Seagrass	Mean Leaf Area (cm^2)	3	22.2	*28.5	24.4	20.2	27.6	17.4	YES
Coral	Corals	Total Cover (%)	1	30.5	*67.5	33.5	45.5	21.3	16.8	YES
	Fauna	Total Cover (%)	3	50.3	*79.5	50.3	53.3	49.3	37.3	YES
	Flora	Total Cover (%)	3	7.0	6.0	3.8	31.0	19.3	42.0	NO
	Organisms	Total Cover (%)	3	57.3	85.5	54.0	84.3	68.5	79.3	NO

to the striking results seen in year 10, the use of dispersant is again considered to have NEB.

For seagrasses, during a period when all seagrass densities were low, shoot density was highest at the dispersed crude oil site. Density was significantly lower at the non-treated crude oil and dispersed crude oil sites than at the reference site but the non-treated crude oil site was also significantly low when compared to the 1984 data. This supports the NEB being positive for dispersant use (i.e., the better option). All other parameters were inconclusive.

Similarly, coral cover data was significant for the drop at the dispersed crude oil site cover versus the reference site, but not for the large increase at the non-treated crude oil site (result of variability according to Ward, 2003). However, when the sites were compared to 1984, only the non-treated crude oil site was significant. This follows recent work at the sites by Ward (2003) wherein significant cover by *Porites* coral occurred at the non-treated crude oil site. This increase is reflected in the fauna cover which was significant at the non-treated crude oil site for all combinations tested. Because of the much higher than background (reference) increase in coral coverage at the non-treated crude oil site, a situation not seen previously or elsewhere in the vicinity of the sites, and which resulted in seagrass bed reduction (Ward, 2003), the NEB for use of dispersants in the vicinity of shallow, nearshore corals is supported.

DISCUSSION AND CONCLUSIONS

In general, the NEBA conducted using almost 20 years of data indicated a Net Environmental Benefit (NEB) for dispersant use in tropical habitats. For mangroves, assigning the highest priority to tree counts, albeit a parameter without replications, provided the most striking example of effects at the non-treated crude oil site. Other parameters statistically support the NEBA conclusions. Recent work by Niklas et al. (2003) and Enquist and Niklas (2001) links tree number with stem diameter, biomass, basal area, and other parameters to study disturbances, and this linkage may help improve comparisons of these forested sites in the future.

For seagrasses and corals, long-term results were also positive for dispersant use, but a number of parameters were inconclusive. A refinement of this quantitative NEBA method, such as listing actual significance results and variability, or deriving a NEBA Index from the data, may be necessary to resolve these inconsistencies.

Recent (2004) field observations (unpublished) support the Net Environmental Benefit (NEB) of dispersant use, including the findings that:

- Oil contamination remains at the non-treated crude oil spill site but is non-detectable at the dispersed crude oil and reference sites,
- Oil contamination originating from the non-treated crude oil site is spreading outside of the site and into adjacent parts of the island,
- *Porites* corals have overrun the seagrass bed at the non-treated crude oil site, a situation which occurs nowhere on the island nor at the dispersed crude oil or reference sites, and
- Erosion and sediment re-distribution have apparently occurred at the non-treated crude oil site, but not at the dispersed crude oil and reference sites.

These observations, combined with the statistical comparisons given previously, underline the importance of considering dispersant use in nearshore tropical systems. The physical approach to NEBA included observation of oil sheen emanating from substrate of the non-treated crude oil site even after 20 years. This was not observed at the dispersed crude oil and reference sites. These observations were followed up by comprehensive core sampling and chemical analysis for the presence of hydrocarbon in 2004 (20 years). These data are not yet available for inclusion in this paper. Additionally, substrate erosion and deposition was observed at the non-treated crude oil site. Monuments were installed at all sites in 2004 for use in future studies.

In conclusion, the more one studies and observes the long-term impacts of the TROPICS study oil spill, versus short-term impacts, the more support there is for the Net Environmental Benefit (NEB) of the nearshore use of dispersants in tropical ecosystems. Environmental effects from the release continue for 20 or more years, as some oil has become trapped in the substrate. We postulate that "stabilized" oil droplets initially formed by the surfactant in the dispersant, although having penetrated the organic substrate of the mangrove forest, did not adhere and were subsequently flushed clear of the mangroves during tidal fluctuations. Dispersed crude oil did not become trapped in the substrate and consequently allowed for repopulation and recovery. However, non-treated crude oil that penetrated the mangroves forest's substrate, adhered to and became trapped in the substrate, despite tidal flushings over 20 years. This oil was only released when pressure of an individual's weight was applied, thereby releasing a visible sheen. It is believed that this trapped oil in the organic substrate is responsible for the long-term effects observed at the non-treated crude oil site. Further studies at the TROPICS sites are needed to monitor the long-term impacts and recovery.

BIOGRAPHY

Dr. Bart Baca is a marine biologist with almost 25 years of experience in oil spill research. He has responded to many large and historic spills and he has published numerous articles on fate and effects.

ACKNOWLEDGMENTS

The authors gratefully acknowledge the assistance of Research Planning, Inc.

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