PN-ABG-5-2
7.103

logged
86-69

FINAL REPORT

~~U.S. A.I.D~~
PROJECT #936-5542

SPECIFIC SUPPORT GRANT

DPE-5542-G-SS-7076-00

Project Office Science & Technology/Sci
Obligation #7361422

1359 SW 22 Terrace
Miami, FL 33145

RESEARCH ON THE TOXICITY OF OIL SPILL CLEANUP

INVESTIGATORS
SCIENTIFIC PARTICIPATION

Anitra Thorhaug, Ph.D., C.E.P.
Florida International Univ.

Howard Teas, Ph.D.
University of Miami

Beverly Miller, M.S.
IMERU (Local PVO)
(UNEP, Reg Coord Center)

Valerie Gordon, M.S.
IMERU (local PVO)

George Sidrak, Ph.D.
Univ. of West Indies

Karl Aiken, M.S.
Dept of Zoology
Univ. of West Indies

JAMAICAN
GOVERNMENT

OFFICE OF DISASTER PREPAREDNESS

Barbara Carby, Ph.D.

Franklin McDonald, M.S.
Office of Disaster Preparedness

Richard Reese
National Housing Trust

Mike Rodriguez
Jamaica Coast Guard

John McFarlane
Port Authority of Jamaica

MINISTRY OF PLANNING & DEVELOPMENT
NRCD

Marcel Anderson, Ph.D.
Director NRCD
and staff

JUL 12

cc: BUSTIO + CD

. EXECUTIVE SUMMARY

I. INTRODUCTION

II. SIGNIFICANT GOALS ACCOMPLISHED
- A. Training
- B. Scientific Results
  - 1. Laboratory testing
  - 2. Field testing
- C. Management Goal
- D. Outreach of Information

V. PROJECT OUTPUTS AND ACTIVITIES
- A. Project Productivity
- B. Training
  - 1. Hazardous Substance Conference in Kingston
  - 2. Hands on lab training
  - 3. Production of Oil Spill Sensitivity map
  - 4. Spill scenario
- C. Scientific Presentations
  - 1. International Oil Spill Conference
  - 2. Australian Oil Spill Conference
  - 3. U.N.D.R.O. Workshop
  - 4. U.N.E.P. Regional Caribbean Workshop
  - 5. Coral Reef Symposium
  - 6. Botanical Society
  - 7. E.P.A. Dispersant Workshop
  - 8. A.ST.M. Conference on Ecological use of Dispersants
  - 9. Mombasa, Kenya "Mangrove related ecosystems"
  - 10. National Geographic
  - 11. Television
  - 12. Information to interested users
  - 13. World Bank Presentation
- D. Scientific Publications
  - 1. Proceedings International Oil Spill - 1989 & 1991
  - 2. U.N.E.P. - Siren
  - 3. A.S.T.M. - Dispersants Ecological Effect
  - 4. Marine Pollution Bulletin or Science Laboratory Tests
  - 5. U.N.D.R.O. Newsletter
  - 6. "Oil Spills in Subtropical and Tropical Coastlines"
- E. Public Service Information

. SCIENTIFIC ANALYSIS CONTENT
- A. Methodology of Hazardous Substance Test: A Goal Accomplished by Itself
- B. Results
  - 1. Corals
  - 2. Seagrass
  - 3. Mangrove
  - 4. Fisheries
- C. Oil Spill Command Map [Sensitivity Map]

I. PROBLEMS ENCOUNTERED IN FULFILLING OBJECTIVES

VII. POLITICAL ANALYSIS

VIII. SIGNIFICANCE

IX. IMPACT, RELEVANCE, TECHNOLOGY TRANSFER

X. LIST OF ACTIVITIES AND DATES

XI. RECOMMENDATIONS FOR FURTHER ACTION

XII. ADDITIONAL FUNDS
- A. Greater Caribbean Energy and Environment Foundation
- B. Mobil Oil Foundation
- C. U.S. EPA
- D. BOSTID
- E. Jamaican Government
- F. International Oceanographic Committee
- D. Florida International University

XIII. SUMMARY

APPENDICES

I. SCIENTIFIC PAPERS PRODUCED
- A. Proceedings International Oil Spill Conference 1989,1985 & 1991
- B. CRC Book "Tropical Marine Pollution", Oil spills in the Tropics and Subtropics
- C. A.S.T.M. Conference " Dispersed Oil Effects on the Tropical Nearshore Ecosystems". Oil Dispersant: New Ecological Approach.
- D. Comparative Dispersant Tolerances of Critical Tropical Organisms.
- E. International Coral Reef Symposium, 1988, Townsville, Australia
- F. Proceedings of Mombasa Kenya Conference on Mangroves and related Ecosystems
- G. Mar. Poll. Bull, 1985/87
- H. Editorials, *Washington Post* and *Miami Herald*

II. THE EFFECT OF THE KUWAIT WAR ON MARINE AND COASTAL RESOURCES IN THE ROPME REGION

III. DATA OIL SPILL DISPERSANT USE MAP
- A. Graphs of Seagrass
- B. Graphs of Corals

I. EXECUTIVE SUMMARY

A program to strengthen the capacity of the Jamaican Office of Disaster Preparedness and National Response Team to deal with oil spills has been completed. Jamaica is on five major petroleum shipping routes. Annually, hundreds of millions of barrels of petroleum transit within miles of the coast. A series of accidents in the shipping lanes has increased the awareness of possible catastrophic spills on Jamaican shores. The program trained 55 persons in a hazardous substance workshop 20 persons from the government and the University in "hands-on" details of hazardous substance testing, the National Response Team and the Jamaican Oil Spill Committee in toxicity of various dispersant products and in the potential applications of non-toxic dispersants for Jamaica. The program helped the Jamaican government, especially the strengthened ODP make the transition from "reactive" environmental management to "anticipatory" environmental management. The development of ODP and other Jamaican agencies affected other nations who were eager to follow the Jamaican pattern.

The basic scientific program had 9 sections for which important new scientific data was obtained:

1) Coral laboratory testing - carried out at Discovery Bay Marine Station with FIU (Florida International University), ODP, NRCD and the University of the West Indies (UWI). Results published in 4 articles.

2) Seagrass toxicity testing - carried out at IMERU labs in Kingston with FIU, NRCD (Natural Resource Conservation Department of Jamaican Government) and UWI personnel. Results published in 4 articles.

3) Fish testing at Port Royal and Discovery Bay with UWI and FIU personnel. Results published in 2 articles.

4) Mangrove lab testing carried out at the UWI Botany Department greenhouses.

5) Technology transfer for hazardous and toxic substance testing methodology to Jamaican government and University workers. Hazardous waste management workshop by P.I., January 1988.

6) Presentation and discussions with Jamaican Oil Spill Committee and National Response Team to incorporate the data into their procedures for oil spills. Spring 1990.

7) Constructing an ecological map of important matrix coastal organisms known as "sensitivity map. Spring 1990.

8) Field Testing: 1) monitoring of mangrove and seagrass training (completed), 2) toxicant application, 3) mangrove/seagrass/coral field testing for least toxic dispersant to be done near airport

in Palisados (not completed).

9) Presentation of the data to the International Community of scientists and spill response personnel on a series of international meetings in the Caribbean and elsewhere.

The Development aspect had the following aims:

1) To strengthen the response capability of ODP to deal with hazardous substance spills (especially oil) and emergency handling of toxic substances. ODP is the coordinating agency for hazardous material response in the Jamaican government.

2) To relate this information to the needs of the Jamaican Oil Spill Response Team who had originally formulated the questions of applications of dispersants to oil spills.

3) To help the other LAC countries by ODP sharing this information through UNDRO, UNEP's Oil Spill Contingency Planning Committee, the National Response Team, the regional response coordinator (sent by USAID), etc.

All these development goals were reached and surpassed expectations.

The research was shared by Jamaican delegates to UNEP, UNDRO and Caribbean Regional Seas Oil Spill Committee as well as the regional IMO representative (Matt Dillon) as rapidly as it was generated. Indeed, during the Kuwait war, we continually faxed upon request to the Middle East (Saudi Arabia, Bahrain, etc.) and to UN agencies much of the yet unpublished information. Evidently, during the Kuwait War Oil Spill, Saudi Arabia sent out a request for information about dispersants to UNEP, FAO and certain petroleum companies. Our data was simultaneously faxed to them by FAO, UNEP and the Mobil Oil Company. In fact, both Mobil Oil and the United States Coast Guard hand carried the entire set of data and Teas' earlier data to Saudi Arabia during the spill. Evidently, two other sources sent our data to Bahrain and Qatar at this same time. The Canadian government's effort to predict the impact of the spill on Qatar and Bahrain with a spill simulation model included our data in their impact model.

The proof that this was cutting edge information was in the number of nations and scientific agencies who requested and used the information. The immediate and global information transfer by fax requests, by international agencies and by invitation of many governments shows that a "usefulness" and "development" potential from the scientific standpoint exists beyond original expectations.

The disaster of a large oil spill could seriously impede the rapid and important tourism development in Jamaica and other 2nd and 3rd World nations, decimate coral reefs for a century, and decimate seagrass

nurseries for fisheries and mangrove forests for decades. Preparedness has long been the solution sought by the Jamaican Office of Disaster Preparedness. There are only 4 ways of handling an oil spill: 1) Mechanical clean-up, 2) Dispersants, 3) Beach clean-up, and 4) Do nothing (oil goes where it will). Recognizing that in the U.S. mechanical treatments for clean-up are only effective 15% of the time (Siva, 1989) - a fact long apparent to ODP and that oil on Jamaican beaches could be extremely debilitating in terms of foreign exchange, ODP long ago decided that Jamaica needed as full an arsenal as possible for at-sea clean-up techniques. The missing link in their tools was to ascertain whether any of the current dispersant products for handling oil spills at sea would be of low toxicity to the Jamaican coral, fish, seagrasses and mangrove should a portion of the at-sea clean-up activity come to shore.

Then came the scientific information during our project (from one of our investigators) that the way to protect mangroves from being killed by oil was to first disperse them (Teas & Duerr, 1987). This left the nearshore spill question, "Are there dispersants which will not kill corals, fish and seagrasses but which will save the mangroves?"

These two issues, offshore large-scale oil spill protection and nearshore protection, led us in the same direction: To test a wide variety of dispersant products to see if any were low toxicity.

The appropriate mode of testing of tropical organisms to hazardous substances had been established previously by Thorhaug and by Teas. Application of information, technology transfer to Jamaican Government workers and scientists and hands-on training were the methods used for this project.

In terms of scientific success, the laboratory testing programs and map construction for corals, mangroves and seagrass and the supplement provided by the USAID Jamaica for fish was completely carried out with highly interesting results:

1) This was the first time in the world an array of dispersant projects has been systematically toxicity tested over an array of important tropical organisms and a range of concentrations and times.

2) The organisms tested all basically ranked the dispersed oil products similar in toxicity ranking. There were low, medium and high toxicity dispersed oil products at concentrations which had been used in Jamaica.

3) The coral, fish and seagrasses were 20 to 100 times less sensitive to death by oil toxicity than were mangroves (However, mangroves frequently encounter far higher levels in a spill).

4) The three low toxicity products had been ranked by oil chemists for efficiency and two were fairly effective.

5) The time of exposure was important. Fish could generally not tolerate more than six hours' exposure of any compound at high concentration.

6) A sensitivity map on which to plot spills was made for the first time for Jamaica.

7) The results showed the IMO guidelines now being adopted by many developing nations for lack of a better international standard to not use dispersants nearshore may indeed be incorrect and damaging to resources since mechanical clean-up only works 15% of the time in developed countries. These results and the mangrove results show a role for non-toxic dispersants in reducing impact of oil spills on nearshore tropical systems. A "non-toxic" dispersant may be the choice of nearshore clean-up. IMO has recognized this and has asked Dr. Thorhaug to reverse this policy.

8) All this led to the Oil Spill Response Team drafting and agreeing on a non-toxic dispersant use policy, which was submitted to the government.

II. INTRODUCTION

Jamaica sits on the path of five oil shipping routes. Jamaican oil spills frequently have not been able to be controlled by mechanical means. Near-miss catastrophes could be environmental disasters. Ecological resources lost could have been saved if dispersants were available for use.

Two major goals were to be met by this project:

A. Transfer of the process of creating standards for toxicity by testing tropical coastal organisms. The national standards for release of hazardous substances was done by training and purchasing and leaving equipment.

B. Scientific tests by which the critical matrix organisms of the Caribbean and Jamaica may be tested establish tolerance limits to the selected hazardous substance ("dispersants"). Products were categorized high and low toxicity. Concentration limits for dispersants were set.

1. Considerable time and effort were spent doing extensive laboratory tests. Tests were carried out after U.S. counterparts conducted training. Jamaican participants from ODP, NRCD and the University of the West Indies carried out much of the work. Three seagrasses, three corals (species as recommended by the chief Jamaican coral expert, Dr. Woodley), three mangroves and three fish species (recommended and collaborated by UWI professor Karl Aiken) were tested. This was the first time anywhere in the world this array of dispersants had been tested on corals or mangroves.
2. The seagrass, coral and mangrove were monitored after exposure to hazardous substances. These techniques, measurements and statistics were taught to the Jamaican workers who can use the monitoring techniques on sublethal effects of other pollutants and hazardous substances in field and laboratory.
3. Field testing (although delayed by Hurricane Gilbert and elections and finally not approved) set up and prepared to monitor for mangroves and seagrass. This gave ODP, NRCD and UWI the techniques of monitoring after a spill.
4. The planning tool of a "sensitivity" resource map where scenarios for oil spills could be run or a real spill could be plotted. Dispersant guidelines were constructed. The meetings were held with concerned parties as to "if, when and where" dispersants might be used as a second line of defense if the mechanical means failed (about 85% failure rate of mechanical in U.S. - Siva, 1991)
5. A dispersant policy was discussed by a sub-committee of the Jamaica Oil Spill Committee. This sub-committee took the Bonn agreement to study the dispersant policies of other nations. It proposed its own policy for Jamaica to keep oil from impacting living resources.

6. Meetings were held to review oil spill contingency plans of other nations.
7. Through UNEP (Regional technical Meeting in Kingston, January, 1990, by B. Miller, Dr. Anderson, Gardner & Thorhaug), UNDRO (newsletter and conferences, McDonald & Carby), IMO Caribbean representative (Matt Dillon), 1991 International Oil Spill Meetings 1989 & 1991 (Thorhaug & Carby), International Coral Reef Symposium (Thorhaug. 1989), Australian International Oil Spill Meeting (Thorhaug, 1988), ONSED prep meeting on women and development world-wide, scientific journal articles, and through IMO, UNEP, IOC and FAO, the information was transferred to the Caribbean and other developing subtropical and tropical nations. During the Persian Gulf crisis a great many parties requested the information: U.N. agencies (IMO, IOC, UNEP, FAO, World Bank, ONSED); U.S. (Coast Guard, EPA); Governments of Saudi Arabia and Bahrain.
   In addition, the U.S. public wished explanations. Voice of America had 3 interviews, TV-12 and a public information to school children (Dial-a-Teacher).
8. The United Nations has requested the services of Dr. Anitra Thorhaug with respect to the Persian Gulf Clean Up. The UN has been in constant communication with the Kuwait spill. The trip included Oman, Iran, U.A.E., Qatar, and Saudi Arabia. Considerable attention was paid to our dispersed data during the early days of the Kuwait spill by FAO, UNEP, IOC and the Saudi government and clean-up people.
9. The UNDP is raising $2.7 billion for clean-up and restoration of the Persian Gulf based on this report of Dr. Thorhaug.
10. Other nations are now in serious proposal stages to repeat this: a) Egypt, b) Saudi Arabia, c) the United Arab Emirates

III. THE SIGNIFICANT GOALS ACCOMPLISHED

A. Training of Government, Industry, University in hazardous substance toxicity.

1. Theoretical Training

A one week course taught by a joint faculty of Office of Disaster Preparedness, Natural Resource Conservation Department, Florida International University and Dr. Howard Teas, University of Miami. Participants included five government agencies (ODP, Agriculture, Fisheries, Testing & Standards), university students and industry (oil industry). The lectures included hazardous substance management, toxicity testing methods, procedures, statistics and standards setting to be used for tesding tropical matrix organisms (See Appendix A). Field work for monitoring mangroves and seagrasses was included. Hazardous substance toxicity testing training was specifically denoted for tropical organisms. Use of dispersants as the "model" substance for hazardous substance testing was emphasized. Sixty students were well trained.

2. Practical Training

a. Group Toxicity Training

Training: The course included hands on field and laboratory training for two days for twenty students. Mangroves (Teas), corals and seagrasses were emphasized.

b. Special coral toxicity training

The actual testing of corals was used as a training. Participants included NRCD, ODP and UWI coral reef experts. It occurred at the Discovery Bay site of UWI by Dr. A. Thorhaug. The techniques of hazardous substance application, acute and chronic stress, physiological reactions of matrix organisms, dosage concentration effects and time of exposure.

c. Seagrass laboratory toxicity testing

The group included NRCD, ODP, UWI, PVO and UNEP personnel. The training was in Kingston. All above (b) parameters were instituted. Mrs. Beverly Miller was leader of toxicity testing along with Dr. Thorhaug.

d. Fish laboratory toxicity

The training was carried out at UWI with UWI and NRCD personnel. Dr. Karl Aiken was the Jamaican counterpart with Dr. A. Thorhaug and students from UWI.

e. Field monitoring. Mangrove and seagrass toxicity monitoring were set up in the field and taught.

B. Scientific Results Accomplished

1. Seagrass Toxicity

Laboratory results have already been published in good part in Proceeding 1989 & 1991 Oil Spill Symposium Proceedings, UNEP's Siren and the attached manuscript to Marine Pollution Bulletin and Science (Appendices ____) and Dr.

Thorhaug's 2 review chapters in "CRC Handbook Tropical Marine Pollution", 1991 and "Ecological Aspects of Dispersed Oil", 1989 ASTM (M. Flarety, ed.). Results proved the original theory. Seagrass show definite differences between dispersed oil products. High toxicity products include Conco K, Wonder-O (local), Kemarine (local), V-25, Petrogreen, Corexit 9527 ADD. Medium to low toxicity were Finasol, Corexit 9550, Jansolv, Clean Cold, Elastosol (a solidifier). This is the first synoptic study on the ecological effect of any solidifier. Variations between species were: Thalassia testudinum, more tolerant; Halodule wrightii, less tolerant; Syringodium filiforme, least tolerant but close to Halodule.

2. Coral toxicity

Three species chosen by Dr. J. Woodly, coral reef expert for Jamaica, represented the structural reef-building coral (Montastrea annularis), crest of reef - most likely to be impacted in an off-shore oil spill, (Acropora palmata) and estuarine and back-reef coral (Porietes porietes). The results were published in Proceeding 1989 Oil Spill Conference, UNEP Siren and the attached manuscript to Bulletin Marine Pollution. Results showed definite toxicity differences between species in the same ranked order, as above references for seagrass [II. B.1.] The results showed Acropora palmata (crest of reef) far more sensitive than Montastrea annularis and least sensitive is Porietes porietes.

3. Mangrove toxicity

Special emphasis on the mangrove toxicity was needed. Results for "pot" experiments of red mangroves from Jamaica and Florida (7 of each of 12 dispersants) showed no mortality and no statistical significance from specimens exposed to 125 ppm dispersants in oil (1:10) for 12 hours. Higher concentrations were attempted when Dr. Teas' survey of real spill situations concentrations of oil in mangroves showed up to 500 to 10,000 ppm of oil on mangroves around the world. The higher concentrations for 24 hours 1250 ppm showed mortality of species as a function of dispersants. In general, toxicity to dispersed oil products ranked in a similar pattern to seagrasses.

4. Field tests on mangroves

The fields tests on mangroves initiated by Dr. Teas at Turkey Point in 1983-5 showed that mangroves were killed by oil alone, but that dispersed oil with Corexit 9527 on mangroves saved mangroves. Field experiments using Cold Clean, Corexit 9550 and Finasol OSR-7 were set up in the airport lagoon area of Palasadoes, Kingston. Workers were trained to measure the mangrove parameters, which are the same monitoring after many pollutants. No oil or dispersed oil were administered. The field venue was changed to Miami. The mangrove field testing was set up at Turkey Point, then changed to FIU North campus and set up.

5. Field tests on seagrasses were set up at the airport on Palasadoes, Kingston, Jamaica and Jamaican workers were trained in monitoring the effects of pollution on seagrasses. No oil or dispersed oil was administered. The field site was changed to Turkey Point, then to Florida International University, North Campus. Preparations for monitoring seagrass were made at both those sites.
6. The first comprehensive map of Jamaica's coastline with important matrix organisms (corals, mangroves, seagrasses, fish) and fishing, beaches, fishing grounds, tourist beaches, harbors and ports was constructed. This has already aided in exercises for oil spill clean-up. It will help in spills and contingency planning for spills.
7. Solidifier tests. The group tested the effect of a second type of oil spill clean-up tool - the solidifier "Elastosol". This is the first synoptic ecological testing on this category of clean-up tools. The tool had extremely low toxicity which means it has great promise in extremely sensitive areas such as coral reefs.

C. Development Goals Accomplished

Development goals met were that the Oil Spill Committee discussed formulating a "non-toxic" dispersant policy which had not been previously available. This policy could then be drafted. Thorhaug brought a collection of European and North American policies. These were studied by a subcommittee of the Oil Spill Committee for the drafting of the Jamaican policy.

Second, the entire set of new data was presented to the Oil Spill Committee with scenarios of real "near-misses" of disastrous Jamaican oil spills which showed that the potential was present to cause large coral reef and fish nurseries death and destruction. The same "near-catastrophic" spill, if dispersed at its point of origin would have left the Jamaican coast unharmed. The committee has done a series of contingency planning exercises with the data from this project already.

Third, through the UNDRO, IMO (Caribbean representatives), UNEP (Oil Spill Contingency Planning Committee), and FAO, a great many nations now have and are using the data who were not previously. Jamaica ODP directly functioned in the development of other Caribbean, African and Pacific nations. Antigua, Puerto Rico, Virgin Islands, other islands of the Lesser Antilles, Guatemala, Panama, Venezuela, Egypt, Ecuador, and due to Bostid support for A. Thorhaug to Kenya, the African nations were able to obtain material (Kenya, Tanzania, Ghana, Nigeria,Guinea Bissau, Somalia and Sri Lanka). They formed a committee to ask IMO to change the policy to use dispersants nearshore.

Beyond the external development, there was inter-ministry development. The various agencies of the Jamaican government had various viewpoints on the issue of oil-spill clean-up during the project. A series of debates between levels within ministries and among ministries were spawned by this project. The complacent reliance on mechanical means of clean-up which was only effective in a small percentage of cases and could not be effective in a large or catastrophic spill was examined for the first time by fisheries and NRCD on a serious level. The debates were health growth processes for the addressing technically and politically of why the protection from large spills was important. Few ministries which participated in oil spill clean-up were left at the same level of technical knowledge. A lot of learning about recent advances in spill clean-up occurred. Particularly interesting was the fact that evidently certain groups stock-piling petroleum had been using dispersants for clean-up of small spills for some time although dispersants were not allowed. It was acknowledged by all that frequent small to medium sized spills had to be controlled and that some were more successfully handled than others with the existing mechanical equipment. The failure of mechanical equipment frequently caused beach clean up. Most of the Jamaican shoreline is sensitive ecologically, particularly the north coast and estuaries on the south coast. There are only four options: mechanical clean-up (needs immediate action, large amount of expensive equipment and is 15% effective), beach clean-up,

"do-nothing-let-oil-go" and dispersants. There were large differences in opinion about the risk to ecology and tourism caused by the petroleum tankers and other ship traffic, stored petroleum, future potential plans for potentially refining petroleum. Anticipatory environmental management, since it prepares to avert a future disaster, always generates these arguments. As the world faces larger and larger oil spills each year of the project, some reality of what a massive spill could do occurred for the participants. ODP felt a detailed risk analysis could show the real threat. The situation that six spills occur per year and that a major spill (as a series of "near-misses" have already shown) could find Jamaica without the equipment and protection was motivating the Oil Spill Committee to find alternate solutions to the clean-up and other sectors. The fact that chemicals would be used to combat the petroleum was evidently an issue with other groups. The establishment of non-toxicity of certain dispersants at levels 10 times higher than use in Jamaica to indigenous organisms were of value in this set of internal arguments. This same set of discussions is happening in many Caribbean, LAC, African and Asian nations now.

The accomplishments that remain in Jamaica are the following:
1) The ability and equipment to test other toxic substances
2) The expertise to test toxic substances
3) The hazardous waste management training framework which is now being utilized in government and private sectors, especially ODP
4) Increased ability to handle large scale or small scale oil spills
5) An increased awareness of risk of spills in government, Oil Spill Committee and university circles
6) A leadership role for Jamaica in regional oil-spill and scientific testing capabilities.

The production and uses of our information far exceeded our original estimates due to the obvious need of a series of groups for the information. The level to which this project was able to influence the development of "anticipatory" environmental management of toxic substance spills throughout the developing and developed subtropics and tropics was beyond any anticipated goals.

1) International Organizations requesting our data:
International Maritime Organization - Oil Spill Branch; United Nations Disaster Relief Organization, UN Food & Agriculture Organization - Fisheries branch, UNESCO, United Nations Environment Program, World Bank, UN Development Program, UNEP Regional Seas.

2) National Governments requesting data:
Antigua, Venezuela, Ecuador, Netherland Antilles, other islands of the Antilles through regional IMO and UNEP Regional Seas program, Belize, Costa Rica, Cuba, Trinidad, Kenya, Somalia, Nigeria, Egypt, Israel, Saudi Arabia, Qatar, UAE, Oman, Iran, Turkey, Guinea Bissau, Canada, Mexico, Islands in Pacific, Australia, Indonesia, Malaysia, Brunei, India, Pakistan, Mozambique, Sri Lanka, Thailand, Caribbean and LAC nations

through UNDRO and UNEP regional seas.

3) Scientific contributions which published data:
   a) ASTM book on "Ecological Effects of Dispersants". Chapter by A. Thorhaug, 1989. "Tropical Oil Spill"
   b) CRC book "Pollution in Tropical Systems" chapter by A. Thorhaug "Tropical and subtropical oil spills".
   c) Presentations at International Meetings of Coral Reef, Mangrove, Oil Spill, Kuwait War in Australia (1987, 1988), Kenya (1990), International Oil Spill (1989, 1991) on Dispersants, Mar. Pill. Bull (1991).

4) Public Media for Service
   TV - Miami - 16 presentations
   Radio - 7 presentations (Voice of America)
   2 editorials [Washington Post, Miami Herald, El Nuevo Herald]
   CNN has requested all data for a special they are doing.

5) Coordination with spill coordinators:
   a) In Caribbean through IMO in Puerto Rico for Caribbean region and UNEP Oil Spill Committee
   b) In Persian Gulf Kuwait war crisis clean-up
   c) In Region IV. Training session (GOM and Coast Guard)
   d) In Florida drill of US Coast Guard
   e) In Environment Canada review of ecological toxicological literature
   f) IMO has asked Thorhaug to review its Oil Spill Guidelines with respect to mangroves, corals, and sensitive tropical areas.

IV. PROJECT OUTPUTS AND ACTIVITIES

A. Project Productivity

The productivity of the project far exceeded the anticipated outputs. The major goal was to set up the process for testing hazardous substances on local critical organisms, train workers, create a sensitivity map, obtain useable results and allow ODP to be able to use the results for crisis management. All of these goals were accomplished. The greater productivity was a combination of the high level of interaction of the project personnel with the international communities of emergency response and environmental protection. Through UNDRO and UNEP the project had built up networks. Through their delivery of talks about the project data and design, a great many nations approached individuals on the projects for further information, assistance, advice, reprints, and even direct consultation.

Two portions of the final project appeared important to ODP add. 1) The creation of a sensitivity map on which ODP could predict the impact of oil spills on Jamaica's ecosystems and 2) The testing of fish toxicities to dispersants. The USAID in Kingston very kindly provided us with a subsidiary grant by which we could carry out this work. This also was completed in spring of 1990 and presented by the ODP to the Oil Spill Committee and at scientific meetings.

The one experimental step was not completed: field training. The Jamaican training portion of the field testing was done in January 1988 and in the summer of 1989, but the testing of dispersant products was not allowed. We had complete permits in 1989, had chosen and marked sites behind the airport in a lagoon scheduled for construction in a few years for a runway, had purchased equipment and trained personnel to carry out the field monitoring when the newly elected government NRCD board wished to review the permit. The NRCD board had been involved in site selection originally. After 9 months of review, they withdrew the permit. The ODP, USAID, and FIU decided to move the site to Miami where all permits were in place and past mangrove-dispersant field testing had occurred. The permits were reviewed by county, state and federal government. These plus insurance requirements were given to the owners of the land, the Florida Power and Light Company(FP&L). After 6 months of considerations, FP&L withdrew the former "lease" due to liability considerations under the new hazardous waste laws of the county and the state. The site was moved to FIU Bay Vista campus. After receiving affirmation of permits from FIU, State and County, the federal government said this might take up to 2 years to get the permit.

B. Training

1. Hazardous Waste Management Conference
   This training was over and above originally mandated.
2. Training for toxicity testing
   This training was fully executed as proposal outline.

C. Scientific Presentations

1. International Oil Spill Conference; February 1989 and 1991, San Antonio, Texas and San Diego, California. Biannual conference by U.S. E.P.A., U.S. Coast Guard and Petroleum Industry. The Jamaican data presented to large audience by Carby and Thorhaug. A lot of comment of favorable nature including U.S. E.P.A. (John Riley) and U.S. Coast Guard (La Vache, regional heads, Corbett), and foreign governments. Dr. Carby, ODP, presented 1991 paper.
2. Australian International Oil Spill Conference
   A. Thorhaug invited by Australian government to international meeting on oil spill clean-up. She delivered two lectures. One on mangrove/seagrasses and the second on coral to representatives of sixteen nations in Indo-Pacific and International Association of Environmental Managers from the Petroleum Industry.
3. United Nations Disaster Preparedness Conference
   Dr. McDonald, Mr. McFarlane and Dr. Carby helped organize this meeting of Disaster Experts. Dr. Thorhaug spoke on how to organize country oil spill sensitivity and command maps in the Caribbean including dispersant use information.
4. United Nations Environment Program
   Regional Seas Caribbean Technical Experts. Poster session organized by Beverly Miller including Dr. Anderson and Dr. Thorhaug. The UNEP Regional Seas has now instituted a project on setting testing methods for effluents and hazardous substances.
5. Coral Reef Symposium
   At the 1988 Coral Reef Symposium, Dr. A. Thorhaug presented oil spills and use of dispersants on seagrass and corals. Townsville, Australia, 1988.
6. Botanical Society of America
   A presentation of seagrass and dispersed oil was given to the Society in summer, 1988.
7. Environmental Protection Agency held a regional workshop for regional experts with state oil spill command personnel, EPA and Coast Guard. Dr. A. Thorhaug was one of several speakers in this two day workshop in Atlanta. She spoke on use of various dispersants on corals, seagrass and mangroves.
8. American Society for Testing and Materials
   Conference on Ecological Effects of Dispersants. Dr. A. Thorhaug was an invited speaker on Effects on Tropical Organisms. Williamsburg, 1987. Sponsored by US EPA, Coast Guard, ASTM and API.
9. State of Florida workshop on Dispersants - Presentation of knowledge to date.

D. Public Service [in addition to proposal requirement]
During the course of this experimental program, the information was called for and used.

1. In Jamaica (Coast Guard, ODP and NRCD) during various spills and for companies, including Petroleum companies, wishing to have toxicity information for stock-piling dispersants.
2. Nations inquiring from ODP, UNDRO or NRCD as to results (Egypt, Israel, Kenya, Guinea-Bissau, Venezuela, Ecuador, Mexico, Antigua, Bahrain, Saudi Arabia, Kuwait)
3. During Valdez, Exxon inquired as to "least" toxic dispersant.
4. During Rhode Island spill, Senator Pell's office called to ascertain results for dispersant use.
5. Egyptian Government and Institute of Oceanography and Fisheries has requested results (presented December, 1989, 1990 and 1991 to them). These were used in several spills. Exxon and Shell in Egypt have asked for results.
6. Israeli government, during December, 1989, large scale spill, requested information.
7. Meeting with Moroccan environmental experts during January, 1990, spill.
8. During GOM Florida proceedings on drilling, Congressman Dante Fascell, Congressman William Lehman and Senators Robert Graham and Connie Mack requested data.
9. Ex-Governor Martinez (Florida) and Governor Chiles have consistently asked for and kept abreast of data. Three meetings for protection of Florida's coastlines and formulation of dispersant plans invited Drs. Thorhaug and Teas. A group of Florida faculty members have been meeting with Florida decision-makers (Department of Environmental Regulation and Department of Natural Resources) to consider each bay and each area to decide whether dispersants will be used and, if so, which ones and whether to stockpile them.
10. Request 1989 to Dr. Thorhaug to visit Arabian Gulf nations on results of studies in Gulf Wide Symposium. [International Oceanographic Commission, UNESCO]
11. Request by IMO for data to examine the policy of non-use of dispersants near-shore.
12. International Petroleum Environmental Cooperative Association (IPEICA) has asked Thorhaug to write a booklet on oil spill and seagrasses.
13. Report on Oil Spill in Gulf, correct clean-up activity, correct mitigative measures: mangroves, seagrasses, corals, shorelines.
14. Use of our dispersant and oil data in Gulf of Mexico Oil Spill Trajectory Microcomputer Impact Assessment program [All Gulf of Mexico states].
15. Request from World Bank for data.

16. Television

A program for which the videotape is available was aired on public television with Dr. Thorhaug and Coast Guard Commander of Southeast U.S. (video sent to RTSC). 14 TV appearances and radio (Voice of America) occurred during the "Persian Gulf Crisis." CNN has requested data for a special.

V. SCIENTIFIC CONTENT ANALYSIS

A. Methodology of Test: A Goal Accomplished by Itself

The testing methodology in laboratory and field studies was transferred to ODP and NRCD and can assist in testing a wide variety of hazardous substances in the future. The teams included NRCD staff, ODP, private sector (IMERU) and UWI faculty and staff. The methodology is based on EPA and IMO methodologies. This was worked out for DOE and EPA testing in 1968-1972 for power plant and other standard tests.

B. Results - Summary of conclusions from data

1. The ranking of dispersants for toxicity was carried out on a variety of species and yet found to be relatively the same. The high toxicity products, medium toxicity and relatively low toxicity. There were large differences between species within a group to some medium toxicity products at higher concentration levels. These differences frequently disappeared at lower concentration levels.
   This was the first time a wide variety of dispersants had been tested on tropical critical matrix organisms.
2. For the first time anywhere in the tropical world, a scheme to use dispersants as a second line of defense (if mechanical means fail) was made for a developing country. This will protect it against its own spills and foreign tankers spilling near the island nation.
3. Data on dispersability as a function of temperature and oil type was experimentally worked out for the first time. Previous work did not include 25°C to 32°C.
4. The usefulness of the data was continually put into the format for use of oil spill command personnel, not only scientific format. This is the first time that a developing nation without its own oil has had such a detailed map and one outlining potential dispersant use.
5. Ecologically, the ranking of groups of critical matrix organisms sensitivity to spills were clear since this was the first time the equivalent work was done on corals, mangroves, seagrasses and fish. Fish and corals were the most sensitive to dispersed oil. The response of coral was almost as rapid to the highly toxic substances. Seagrass response occurred several days later. Mangrove response was in weeks. Not only the time factor of response, but the absolute response to the chemicals showed fish and corals more sensitive, seagrass somewhat less and mangroves more tolerant of dispersed oil at a concentration. This is unlike certain other pollutants where corals and seagrass are far more sensitive than the fish.

C. Scientific Results - Details of Data and Methodology

The following papers have the results embodied in them and have been presented to various scientific audiences 1) Scientists, 2) Oil Spill decision makers, 3) Policy Makers, 4) Citizens. All the published papers and chapters for books have had extensive press reviews. For brevity, the abstracts are given herein and the body of the papers are in the appendices.

VI. PROBLEMS ENCOUNTERED

A. Hurricane

A one in a hundred year hurricane occurred in September 1988 which was a major responsibility for the Office of Disaster Preparedness. For many months a major portion of ODP's energy went to solve problems of homelessness, flooding and damages caused by the hurricane. A substantial delay occurred. An extension was requested and granted by U.S. A.I.D. The coral Acropora was thought to be too sensitive and damaged after the hurricane for further experiments.

B. Elections

In winter, 1989, general elections wer2Deputye called immediately after the hurricane clean-up. The last elections had been in the early 1980's. It appeared wise to await the new government for the resumption of field testing. All of this was discussed with the PSTC, Jamaica AID and ODP in detail.

C. NRCD Board Permit Delay

In May, 1989, having waited six weeks for new Ministers and Directors to be provided by newly elected government, ODP had a meeting of the various groups (including UWI, ODP, NRCD staff) who met and agreed upon a site for mangrove experiments and a field test time frame. The site was behind the "old airport" and was scheduled for construction into the plans for remodelling the present airport in the 1990's. In late June, 1989, Dr. Aldridge, Vice Chairman of NRCD board, asked ODP, Coast Guard, FIU, IMERU, and NRCD staff to meet. He said that NRCD board had not yet issued the field permit. The fact previous permission (with the 1982-1989 government) had been obtained did not matter. The committee took nine months to deliberate. The urgency of a decision was impressed on them by Dr. Carby and ODP director. A meeting to express the need for such information was called by FIU/ODP. A committee was convened by ODP including ODP, Coast Guard, Jamaica Defense Force (McFarlane), FIU and UWI participants. The ODP group felt a negative decision would be forthcoming and wanted Dr. Thorhaug to explore other alternatives to field testing. A Florida field test was explored. The permits already were in place in the closed cooling canal of Turkey Point. We proceeded.

D. Turkey Point Delay

All permits at state, county and federal level were renewed and given along with insurance to Florida Power and Light. A series of 4 conferences with Teas and Thorhaug were held. After 6 months, it was said that the liability risks under the new hazardous substance laws (county, EPA, state, federal) were too great to permit this activity.

E. Florida International University site. EPA delay.
After a thorough search for a site which had all the needed ecological and logistic parameters and could be made available, we chose FIU's shoreline campus. Permission was first gotten from FIU to avoid the above problem of FP&L. When the permission was sent to EPA, Atlanta, they sent it to Toxic Substances, Washington. The final word from EPA Washington was that it probably would take 10 months to 2 years to obtain permission at FIU.

The PSTC office preferred not extending the contract for an indefinite time since other parts of the program were carried out well enough to complete the report and terminate with the greater majority of scientific items done, surpassing the goal level.

VII. POLITICAL ANALYSIS

The regulations of industrial accidents are difficult enough on the shore where the accident is caused by private or public industry. The oceanic accidents of oil spills are particularly complex because the ships may have no relationship to the nation receiving the spill. The key is to have policies regulating and implementing clean-up of the accident which keeps the resource impact to a minimum.

Accidents by foreign flagship carriers who are not in Jamaican waters, but whose spilled oil comes into the shore, are more complex. The Government of Jamaica localized a series of accidents (Table ___) not adequately cleaned up by their carefully-formed contingency plans for mechanical equipment. No policy or regulations applied to industry or ships in terms of use of near-shore dispersants since conventional wisdom (IMO) held that dispersants should not be used near-shore (Table ___). This statement of IMO was largely based on temperate water data (Torrey Canyon Spill, Santa Barbara Spill) and for an older generation of dispersant products (containing more kerosene and heavy metals). We tested a series of products on critical indigenous tropical organisms to see if the IMO statement extrapolated from temperate zone and other dispersants was scientifically valid. It was not. IMO will be changing its policy to fit our data. Many developing nations simply adopt IMO policy in place of their capability to change their own policies.

Testing was carried out in such a manner to be a teaching and institutionalization of the techniques for establishing standards for toxicity. This allowed other future substances as they were created or imported in Jamaica's future to be tested.

Clear cut results of laboratory testing showed some dispersant products even 10 times more concentrated than they would be used during oil spills to be non-toxic to selected Jamaican critical matrix organisms.

The use of data is critically important. 1.) The data can be used for setting Jamaican government "approved" list of dispersants. 2.) The data can be the basis of dispersant regulation and policy. This has already occurred.

The map for use of dispersants was formulated as a group activity between participants in this grant and the Oil Spill Planning Committee. The new policy on dispersants was given in a public proposal meeting to the Oil Spill Command personnel at oil and industrial sites around the nation by ODP and the Oil Spill Committee.

The proposed drafting of a dispersant policy is to be a joint activity between members of the Oil Spill Committee, government regulatory agencies and the private sector.

VIII. SIGNIFICANCE

For the first time the details of toxicity of tropical organisms to a wide variety of dispersant products which are internationally marketed, and several local products were tested on the critical near-shore tropical organisms for the coastal food webs, corals, mangroves and seagrasses. Jamaica once more became a world leader for blending technology with tropical environment. In addition, due to the special interest of the Jamaican government and U.N. Caribbean Action Plan, commercial fish species were tested. The results showed some products relatively toxic to corals and seagrass, such as Conco K, OFD 609, Kemarine (manufactured in Jamaica), Corexit 9527 (which was stockpiled in Jamaica) and Wonder O. There were low toxicity products also (Finasol OSR7, Cold Clean, Corexit 9550, Elastosol).

Mangroves can be protected from incoming oil by booming or by dispersing oil prior to it hitting the mangroves. Dispersants were found which could not be toxic to seagrasses, corals or fish, yet save mangroves.

The hazardous substance testing procedure for critical tropical organisms was taught to the Jamaican NRC, ODP, Fisheries Department and other agencies convened by NRCD. Theoretical aspects of hazardous substance testing were taught as well as hands-on aspects of testing to ODP. NRCD, UWI and IMERU. This is the first time to our knowledge that a developing nation has been able to test for hazardous substance standards. This process can be used for a great many other hazardous substances which may accidentally or on purpose be released into the Jamaican environment.

A new work procedure for the island of Jamaica for use of dispersants in the case that mechanical means would fail or be inadequate was devised by ODP, Coast Guard, FIU, the Oil Spill Committee, certain professors and other concerned parties.

The data on dispersed oil toxicity came in a timely fashion so that the new contingency plans for all facilities using large amounts of oil could use this information.

The strengthening of ODP as a center for the most recent oil spill clean-up and other hazardous substance emergency response which is relative to developing nations in the tropics and subtropics has occurred. ODP clearly emerged as a leader in developing emergency response information for Caribbean nations. The Jamaican ODP is leading the Caribbean from "reactive" environmental management to "anticipatory" environmental management. This may be the most important significance of the project.

IX. IMPACT, RELEVANCE, TECHNOLOGY TRANSFER

Usefulness

The usefulness of the scientific data has already been demonstrated by the Oil Spill Committee's turning the data into policy for oil spills dispersant use. The decision to stockpile the less toxic dispersants was made and implemented. The usefulness was also seen in ODP finding its data sought by many foreign countries in a series of recent spills including the Kuwait War, Hawaii, Morocco, Egypt, Israel, and the east coast of the U.S.. It was also seen as many nations sought the data for contingency planning.

The sensitivity map and contingency planning portion of the project was useful to stockpiling and analyzing vulnerable points of Jamaican spills (from the sensitivity map left at ODP headquarters). Exercises and drills have been carried out using the map.

The results are that the dispersant tool in the arsenal of oil combatting activities of the ODP is now workable for Jamaica. The results have also been passed to many other nations. and they are also using them.

Impact

The difference the project has made is that the local dispersant products all were very toxic to the Jamaican corals., fish, and seagrass and cannot be used in near-shore spills. They had been used previously without permits. The stockpiled products also were toxic. These will not be used within many miles of the shore nor in land clean-up. Opportunities for larger scale trials now are occurring in real spills around the Caribbean and will occur in Jamaica since there are an average of 6 spills per year.

The dispersant tool which is for rapid response to oil heading toward sensitive shorelines may be the only viable choice which can be rationally made based on data by the ODP and the Oil Spill Committee. The non-toxic dispersants can and will be stockpiled and the data on critical matrix organisms and fish can give a real database to the decision makers rather than fear, rumor or speculation as the motivation for use or non-use. Clearly, others in the tropics and the subtropics have been waiting for this data since requests for data have been numerous. The data that oil entering mangroves must be dispersed is 180° different from the procedure previously used.

Technology Transfer

Now the capacity for ODP in its role as hazardous substance coordinator is its ability to test other hazardous substances on its own important organisms. Products manufactured in Jamaica or imported wherein no toxicity testing has been done for organisms like Jamaican corals, seagrasses, fish, etc. can be tested. We recommend this for herbicides used in agriculture, mining products, cleaning fluids for power plants, and other substances entering rivers and estuaries. Equipment and technical expertise are residual with ODP, NRCD and UWI as well as the capacity to judge data produced.

Increased Capability

The increased scientific capabilities include: 1) the ODP's ability to model oil spills on the sensitivity map. Other types of hazardous substance spills may also be modelled and response measures thought through on this map. We have urged transforming it to the computerized natural disaster maps at ODP. 2) ODP's collaborative ability with NRCD and with the University of the West Indies was strengthened so that further production of hazardous waste and products data can be facilitated. 3) ODP leadership role with UNEP Regional Seas Oil Spill.

X. LIST OF ACTIVITIES AND DATES

A. Training Activities

1. Hazardous Waste Training Workshop and Dispersant, Kingston, NRCD, Thorhaug, Anderson, Reese, Oerke, Teas, 1988
2. Dispersant laboratory and field training, Seagrass toxicity, Kingston, Thorhaug, January, 1988
3. Coral dispersant training, February, April, July, Discovery Bay, 1988
4. Statistics, January, 1988 (Dr. M. Anderson), Fall, 1988 (Dr. A. Thorhaug)
5. Mangrove monitoring, January, 1988, (Prof. Howard Teas)
6. Mangrove toxicity experiments (Teas) July, 1988, field and May, 1988, lab

B. Experiments

1. Seagrass lab toxicity [Miller, Gordon, Thorhaug, NRCD staff], January, 1988 to October, 1988
2. Coral lab toxicity, January, 1988 to January, 1989 [Hurricane interruption, Anderson, Gardiner, NRCD staff, Thorhaug, Oerke]
3. Mangrove lab toxicity, Spring, 1989, Fall and Winter, 1989-1990 [Teas, Sidrak, Thorhaug]
4. Mangrove and Seagrass field toxicity, Winter, 1989 [Teas, Sidrak, students, Thorhaug]
5. Fish Toxicity Data, 1989-1990 [Aiken, Thorhaug, Gayle, Walker]
6. Sensitivity Map, Winter-Spring, 1990 [Gordon, Rodriguez, Woodley, Thorhaug, Chow, Sidrak, ODP staff]

C. Public Service and Information Activities

1. United Nations Disaster Relief Organization Mapping Symposium, November, 1987; presentation and written paper
2. Australian Oil Spill Meeting, Fall, 1987, presentation
3. American Society for Testing and Materials, Fall, 1987; presentation; 1988, written paper
4. Globescope meeting 1988. Sun Valley, Idaho - Fall 1987
5. International Coral Reef Symposium, 1988. Townsville.
6. International Oil Spill Proceedings, San Antonio, presentation and written paper
7. United Nations Regional Planning Workshop, Jamaica, 1990; presentation and written paper (UNEP)
8. International Mangrove Symposium, Mombasa, Kenya, 1990
9. International Oil Spill Symposium, Carby, 1991
10. Antigua Contingency Plan - Oil Spill, Rodriguez, 1990
11. Kuwait Ward Oil Spill Clean-up, Thorhaug, 1991

D. Command Map for Oil Clean-up, January, 1990 - July, 1990

1. Carby, Rodriquez select Gordon to assemble map.
2. Map portions assembled.
3. Rodriquez, Thorhaug, Gordon make final map.

4. Presentation to Oil Spill Committee and NAtional Response Team.

E. Status of portions of Project

1. Laboratory testing. Lab work completed. Final data in process of final compilation.
   3 preliminary publications:
   a) 1989 Oil Spill Proceedings
   b) 1989 Coral Reef Symposium
   c) 1991 Oil Spill Proceedings
2. Policy for oil spills. The Jamaican ODP is still working on draft. When completed, an approved list of dispersants can be compiled, with guidelines for use of on-scene-commanders during a spill.
3. Oil Spill Coastal Resources Map (Sensitivity Map). Large command map is completely prepared and is being used by ODP and Oil Spill Committee for training spills and preparedness. Has been presented at International Oil Spill Conference by Carby.
4. Field Testing. All U.S. permits in hand since June 1990. The Florida Power & Light Company decided against our permit on their Turkey Point facility. We have set up test plots on FIU property. Some seagrass, many mangrove are present on a canal behind the campus.
5. Information Transmittal
   A series of steps to transmit information to others listed under project outputs has been undertaken.

XI. RECOMMENDATIONS FOR FURTHER ACTION

A. The Jamaica ODP needs to continue to update toxicity tests on new dispersant products (about 2 per year come on the market).

B. A dynamic model which could simulate all the potential spill types which Jamaica might have and at various amounts of spilled oil would be a useful planning tool. Jamaica does possess computer map of certain disaster information. This could form the basis for the dynamic map. A resource base program for Jamaica also exists. The dynamic model of the Gulf of Mexico also can quantitatively assess the difference between dispersed oil spill and non-dispersed oil. This would be a valuable planning tool for large spills in the Caribbean beyond the scope of this project.

C. The range of hazardous substances, including agrochemicals, major industrial releases into aqueous environment and potential substances spilled into water should be tested. Spill clean-up of large quantities of any of these potentially toxic substances could follow the same format, but different technical solutions other than those for dispersants would apply.

D. These were acute toxicity tests although specimens of corals, seagrass and mangrove were observed over time. Chronic toxicity tests at low concentrations should be studied on reproduction and growth of matrix organisms versus the dispersed oil products chosen to be stockpiled by Jamaica.

E. A risk analysis of shipping of petroleum, stockpiling of petroleum and of ships and planes carrying fuel should be carried out.

F. Effectiveness testing of the low toxicity versus oils transported (Mexican, Venezuelan, Kuwaiti, Nigerian crudes), stockpiled, fuel oil for ships (Bunker C) at high temperatures (20°-35°C) should be run.

G. Testing of dispersants on local indigenous organisms elsewhere. Countries wishing to repeat work: Egypt, Israel, Qatar, UAE, Indonesia, Australia, Venezuela.

H. Beach oil clean-up compounds should be tested by same methods on seagrass, fish, corals and mangroves.

XII. ADDITIONAL FUNDS

A. Greater Caribbean Energy & Environment Foundation (PVO status) participated through the labor and administration of several members, staff and sponsors, such as Fitzgerald Booker, Andrew Oerke and Nina Birnbach. Equipment of the Foundation and office space for Thorhaug was also used as the primary office throughout the project, as well as laboratory space. Four trips for Thorhaug presenting data for this audience were paid by Greater Caribbean.

1. Australian Oil Spill Conference; Sydney, 1987
2. International Oil Spill Conference; San Antonio, 1988
3. International Coral Reef Symposium; Townsend, Australia, 1987 [Oerke and Thorhaug]
4. International Symposium on Ecological Aspects of Dispersant Use, American Society for Testing and Materials, 1987, Williamsburg, Virginia

B. Mobil Oil Foundation contributed funds to the Greater Caribbean Energy & Environment Foundation. This paid part of Thorhaug and Aiken's salaries to examine fish-dispersant toxicity. One grant sent Thorhaug to the Australian Oil Spill Conference, Sydney, 1988. One grant sent Thorhaug to the Coral Reef Symposium in Townsville, 1989, the ASTM Conference on Dispersants in 1988 and to the International Oil Spill Symposium, 1989.

C. U.S. E.P.A. arranged a regional response meeting, had a section on dispersants where they invited Dr. Thorhaug to deliver an hour and a half lecture on tropical oil spills and dispersants. This was paid for by E.P.A.

D. BOSTID of the National Academy of Sciences paid for Dr. Thorhaug to give a paper on this project at an Indian Ocean Conference on Mangroves and their related Ecosystems.

E. The government of Jamaica and the government of Antigua sponsored Mike Rodriguez to set up contingency spill plans for Antigua.

F. The International Oceanographic Committee of UNESCO and UNEP sent Thorhaug to the Arabian (Persian) Gulf to do the assessment for clean-up of the Gulf.

XIII. SUMMARY

During the project's lifetime (1987-1988), the U.S. National Academy of Sciences convened a panel on the use of dispersants for oil spill clean-up.

In their conclusion they stressed the pressing need to test dispersants for toxicity to near-shore organisms so that the discussion could be based on sound data as to when, how and where to use dispersants near-shore.

DISPERSED OIL EFFECTS ON TROPICAL HABITATS: PRELIMINARY LABORATORY RESULTS OF DISPERSED OIL TESTING ON JAMAICA CORALS AND SEAGRASS

Anitra Thorhaug
Florida International University
P.O. Box 490559
Miami, Florida 33149

John McFarlane and Barbara Carby
Office of Disaster Preparedness
10 Camp Road
Kingston, Jamaica

Franklin McDonald
Pan American Disaster Preparedness Organization
St. Johns, Antigua

Marcel Anderson
Natural Resource Conservation Department
59½ Molynes Road
Kingston, Jamaica

Beverly Miller
UNEP, Caribbean Regional Office
Kingston, Jamaica

Valerie Gordon
IMERU
Kingston, Jamaica

Peter Gayle
University of West Indies
Discovery Bay, Jamaica

ABSTRACT: *The island of Jamaica experiences six small- to medium-sized oil spills per year. Major ports for petroleum entry are close to mangrove, seagrass and coral resources.*

Mangrove and coral habitats form important nurseries for fish and shrimp populations. The coral reefs and white sand beaches of the north and west coasts are the basis of the tourism industry, which generates $406 million U.S. dollars per year, and accounts for 55 percent of the island's foreign exchange earnings. Thus, protecting these resources from the effects of spilled oil is of priority to the government. Mechanical means are clearly not the solution in a variety of spills. Also, no maps exist to guide the on-scene coordinator (OSC) in oil spill management.

To initiate a study of dispersed oil and formulate a command map, habitat-dispersed oil toxicity testing on three species of seagrasses, three indicator species of coral, and three mangroves has been conducted in Jamaica. Ten dispersants and their dispersed oil toxicity in these habitats will be ranked. In general, the coral toxicity parallels the seagrass response to the dispersants. Responses of the coral to intermediate-toxicity dispersants differed widely. Black, white, and red mangroves also were tested. This is the first time comprehensive among-dispersant and among-species dispersant testing has been carried out in the tropics.

The Jamaican coastline has surrounding barrier reefs, which are particularly pronounced on the north coast. Between reef and shoreline, seagrasses frequently cover large areas and are important for erosion control and as highly productive fisheries nurseries. The Jamaican shoreline has substantial mangrove forests in many areas. Tourism and fisheries depend on these critical coastal habitat resources.

Contingency planning for oil spills in major oil ports has been undertaken. Many more nearshore spills have occurred than offshore spills. Until the present, no nearshore oil spills led to the use of dispersants as a primary cleanup method. The questions of toxicity of various dispersants to important habitat organisms and which dispersant product to use have repeatedly arisen.

This project was aimed at producing information on which rational contingency planning could be based, so that when mechanical cleanup methods have reached their limits, an alternative method is available. It was found that cases of rapid tidal flow conditions, high wave energy conditions, entry of oil into very shallow water (where ships cannot be used), and in very widely spread spills were beyond the capacity of mechanical equipment. The problems of nearshore cleanup in Jamaica have frequently included one or more of these variables. The laboratory and field testing were designed to provide answers for a command map for oil spill cleanup contingency planning for the nearshore coastline, including the use of dispersant as a well-thought-out alternative.

Prior experience will be briefly summarized. A more extensive summary is found in Thorhaug.[7,8] Mangroves are killed by oil spills, as seen in massive spills in all major ocean basins. Oil dispersal cuts down on mortality appreciably, as seen in the Florida[5] and Panama field experiments[1] and the eastward Panama spill.[2] The principle at present appears to be to disperse the oil before it enters the mangroves

We are then left with the problem that either heading to the shoreline or out to sea, the dispersed oil will pass over seagrass and corals. The data on dispersed oil on corals gathered by Le Gore et al.[4] and Knap et al.[3] all showed no effects from Corexit 9527, used in concentrations to 50 ppm, tested on the corals *Diploria strigosa, Agaricia sp, Porites porites,* and several Red Sea corals. Knap has recommended dispersant use to the Bermuda government. The seagrasses in the subtropical Atlantic have been tested more consistently for the range of dispersant products registered with the U.S. Environmental Protection Agency Tables from Thorhaug and Marcus[9] summarize this data

There are no data even for the one dispersant previously tested, Corexit 9527, on the major reef-building coral in Jamaica. The biological goal of the present study was to select species indicative of major coral communities and test a range of dispersants against them.

29

Methods

The specimens were selected to represent major critical habitat organisms on the barrier reef and the reef crest, and in mid-range and nearshore or estuarine coral communities. The specimens were chosen with help from University of West Indies (UWI) and Natural Resource Conservation Department (NRCD) experts.

Sever specimens for each testing variable set were taken, from outer Kingston Harbor near the Palisadoes and Gallows Point for seagrasses, and from the middle north coast for corals. Only very healthy specimens were used.

After collection and acclimation, specimens were exposed to the test substance in 100,000 mL of fresh sea water in 50 gallon glass tanks. Static conditions with vigorous bubbling occurred for the incubation period. Specimens had test substance plus incubation water removed and replaced with fresh running sea water (the seagrass did not have running sea water). The oil was aged 24 h before it was administered. The dispersant was poured into the oiled sea water with vigorous stirring by a paddle for 1 min, representative of energy of application. Exposure (incubation) periods were 6 and 10 h. Measurements of health and growth were made prior to application of the test substance, after, and at two- to three-day intervals thereafter (10 days for seagrasses and 14 days for corals). The health of corals was rated on a graduated scale previously outlined, with 100 percent alive and colorful graded at 10 and deal equal to one. Five equals 50 percent bleached or discolored, or 50 percent spotted.

Gradation of seagrass health and blade growth followed established procedures and included a scale of health. The growth measurements were made on 2-to-4 cm young blades, one on each of seven shoots. Mortality counts were made on all 700 blades per tank. The statistics were student Newman-Keuls analysis of variables.

The preliminary results of our first sets of experiments are recorded in results below. Ongoing results are still being carried out on major concentration and time periods. Field experiments will follow.

Results

The results to date can be synthesized between corals and seagrasses. There are large differences in the toxicity of dispersed oil products to the corals and to the seagrasses. The relative ranking of toxicity falls about the same way for both corals and seagrasses. There is a very toxic group of products, a medium-toxic group, and a low-toxicity group.

The different species of corals and seagrasses can have widely varying responses to specific dispersant products, although generally the tolerance ranking from toxic to non-toxic was in the same order from species to species.

Seagrasses. The differences between the dominant Jamaican seagrasses' tolerances to dispersed oil products in Venezuelan middle weight oil can be clearly seen in Table 1. Here the toxicities clump around high mortality, 80 to 100 percent mortality (at high concentrations); medium-toxicity products at around 50 percent; and low-toxicity products such as Finsol, Cold Clean, and Elastosol. The intermediate-toxicity Corexit 9550 appears far less toxic to seagrasses than Corexit 9527.

Generally, *Thalassia*, found in unpolluted offshore areas, is more tolerant than *Halodule*, which is found in intertidal areas and polluted areas (this was also seen in subtropical work). (*Syringodium filiforme* is now being tested. It is the most sensitive to dispersed oil products, but in the same tolerance range of *Halodule wrightii*.)

These are preliminary laboratory studies. More concentrations and time periods are being tested.

The results from tests of bunker crude oil, the most dominant oil in nearshore Jamaican spills, were analyzed. Generally, the toxicities were higher than with normal oil.

Corals. This is the first time comparative data on the effects of dispersant products on corals have been reported. There was a clear ranking of toxicity: very toxic, medium, and low-toxicity products (Table 2). The low-toxicity products appear to have the same level on all three species and included Finasol and Cold Clean.

The products Conco, OFCD609, Corexit 9527, Keramine, and ADP 7 were toxic. Corexit 9550 was appreciably different in toxicity than these former products; yet, its effects are appreciably different than Finasol or Cold Clean for *Porietes porietes*. The decreasing concentrations and times of exposure clearly made a difference in the medium toxicity levels, less difference in high toxicity levels, and less difference in high-toxicity products.

Table 3 shows the effects of high concentrations of dispersed oil with crude oil. The effect can be compared to Table 2 with Venezuelan crude.

In terms of coral reef sensitivity, the top of the forereef dominant *Acropora palmata* was far more sensitive to pollutants than was the nearshore and shallow water *Porites porites* (found throughout reef flats and in south shore estuaries, as well as back reefs) or the dominant reef-building coral *Montastrea annularis*

This is the first time major differences in tolerances to dispersed oil products between coral species have been established. Prior studies tacitly assumed "corals" as a group either had a tolerant or non-tolerant response to "dispersants" as a generic term. This is incorrect. *Acropora palmata*, the reef crest dominant, is far more sensitive than either of the shallow water dominant products of the reef-building coral *Montastrea annularis*.

Table 1. Relative toxicities of selected Jamaican seagrasses to a variety of dispersant products

Dispersant product	Dispersability ratio[1]	Cost[2]	Mortality 125 mL; 6h[3] Thal	Hal	75 mL; 6h Thal	Hal	12.5 mL; 6h Thal	Hal	Syr.
Conco	0.580	0.59	100	82	48	70	17	35	16
OFC D609	0.007	0.08	70	63	25	70	20	25	—
Corexit 9527	0.009	0.11	89	93	42	72	10	22	11
Keramine	—	—	63	68	42	68	17	28	—
ADP 7	—	—	50	46	18	68	21	30	0
Corexit 9550	—	—	40	46	15	20	7	7	0
Jansolv	—	—	0	5	0	7	0	0	0
Elastosol[4]	NA	—	15	46	10	11	8	10	—
Cold Clean	—	—	0	0	0	2	0	0	0
Finasol	0.038	0.28	0	3	0	5	0	0	3
Oil only	0	NA	30	28	10	16	10	12	2
Control	0	0	11	9	7	5	0	5	0

1. Dispersability is the ratio of dispersant to oil required to disperse 90 percent of the oil (U.S. EPA, 1984).
2. Cost is the relative effective cost of sufficient dispersant to disperse 90 percent of 1 gal of oil under the conditions of the Mackay apparatus.
3. Concentations in 100,000 cc of sea water are 10:1 of oil to dispersant product.
4. A surface active agent, not an emulsifier: It does function as an oil spill cleanup compound for shallow waters and discrete small spills, so we included it in these first tropical habitat toxicity tests

30

Table 2. Results of dispersant toxicity tests, using Venezuelan crude oil, on 3 important species of Jamaican habitat corals

Dispersant product	Dispersability ratio[1]	Cost[2]	Mortality 125 mL; 10 h[3] Por.por	Mont.an	Ac.pl.	125 mL; 6 h Por.por	Mont.an	Ac.pl.	75 mL; 10 h Por.por.	Mont.an.
Conco	0.580	0.59	100	100	100	100	100	100	100	100
OFC D609	0.007	0.08	100	100	100	100	100	100	ND	ND
Corexit 9527	0.009	0.11	72	100	100	90	86	100	88	76
Keramine	—	—	100	100	100	90	57	100	ND	ND
ADP 7	—	—	100	100	100	90	72	100	ND	ND
Corexit 9550	—	—	43	0	100	64	14	100	0	12
Jansolv	—	—	87	72	ND	ND	ND	ND	ND	ND
Elastosol[4]	NA	—	ND	ND	ND	ND	ND	ND	ND	ND
Cold Clean	—	—	0	17	ND	ND	ND	ND	ND	ND
Finasol	0.038	0.28	0	0	ND	ND	ND	ND	0	0
Oil only	0	NA	52	52	ND	52	52	100	12	0
Control	0	0	0	0	0	0	0	29	0	0

1. Dispersability is the ratio of dispersant to oil required to disperse 90 percent of the oil (U.S. EPA, 1984)
2. Cost is the relative effective cost of sufficient dispersant to disperse 90 percent of 1 gal of oil under the conditions of the Mackay apparatus.
3. Concentrations in 100,000 cc of sea water were 10:1 of oil to dispersant product.
4. See note 4, Table 1.

Discussion

Contingency planning should require that the details of the option to use dispersants be as meticulously worked out as the mechanical cleanup option. This has not generally been the case. Little time or energy has gone into the dispersal option, and very little planning has been undertaken after that command decision point in the nearshore tropics.

We now see that in shallow tropical shorelines where there have been major oil spill disasters involving massive mangrove and coral mortality and reduced fisheries harvests, only two investigators (Chan and Diaz-Piferrera) investigated carefully enough to document seagrass mortality. The small-scale field experiments[1,6] indicate that mangroves are not adversely affected by use of the dispersant Corexit 9527 in concentrations to 50 ppm. The mortality of oil mangroves is substantially greater than dispersed-oil mangroves if the dispersant is applied first, before the oil enters the mangrove intertidal area. Apply dispersant after the oil has already entered the mangrove-intertidal area and mortality is similar to oil alone in effect.[5]

The problem is that in order to save the mangroves, oil must be dispersed before it reaches them. This means that in most tropical and subtropical areas the dispersed oil wedge must flow across either (or both) seagrass meadows or corals, both of which are generally more sensitive to substances than mangroves.

Thus, the search for "non-toxic" or very low toxicity dispersant products is so that portions of the critical habitat of the nearshore tropical ecosystem do not have to be traded off for other portions.

Each nation should know which dispersants are acceptable for use on their habitats. The United Kingdom now has such a list for its habitats. This depends on specific toxicities of critical habitat organisms, important fisheries species, and other organisms of importance. The Jamaica model may suffice for other coastal Caribbean nations.

Nations should end the debates on whether to use dispersants near shore and begin scientific examinations of which ones and in what concentrations, and education of all users of dispersal techniques, since dispersants easily can be wrongly applied.

Legal language and contingency planning should delete generic use of "dispersants" and use an "acceptable" list of non-toxic dispersant products.

Where tradeoffs are being made with major habitats, the level of information on the habitats should be as equal as possible. Prior to ongoing studies, we have much more data about dispersant product toxicity for fish and seagrasses than for corals or mangroves. We

Table 3. Coral mortality data for tests with dispersants and bunker oil

Dispersant product	Dispersability ratio[1]	Cost[2]	Mortality 125 mL; 6h[3] Por.por	Mont.an	A.pl.
Conco	0.580	0.59	100	100	100
OFC D609	0.007	0.08	100	100	100
Corexit 9527	0.009	0.11	86	88	100
Kemarine	—	—	88	56	100
ADP 7	—	—	88	74	100
Corexit 9550	—	—	88	12	100
Jansolv	—	—	ND	ND	ND
Elastosol[4]	NA	—	24	0	14
Cold Clean	—	—	ND	ND	ND
Finasol	0.038	0.28	ND	ND	ND
Oil only	0	NA	28	12	100
Control	0	0	0	12	0

1. Dispersability is the ratio of dispersant to oil required to disperse 90 percent of the oil (U.S. EPA, 1984).
2. Cost is the relative effective cost of effective dispersant to disperse 90 percent of 1 gal of oil under the conditions of the Mackay apparatus.
3. Concentration in 100,000 cc of seawater were 10:1 of oil to dispersant product
4. See note 4, Table 1.

31

continue laboratory and field tests of dispersants' effects on seagrass, mangroves and corals.

The IMO guidelines for the use of dispersants in nearshore tropical waters do not work in many nations because management plans call for mechanical means that are inadequate when spills are very spatially extensive, when boundary conditions of high energy are passed (strong currents, high wave action, high wind), when the mechanical response to too slow or equipment must be transported to very distant areas, or when the oil is in very shallow areas. In many tropical nations, beaches, mangroves, corals, and fisheries are of substantial economic or recreational importance. Better plans must be made to deal effectively and safely with various sizes of nearshore tropical spills, of which only a portion are being handled effectively by mechanical cleanup at present. This report is the preliminary stage of such an effort in a developing nation.

Acknowledgments

The authors wish to gratefully acknowledge the support of the U.S. AID Science and Technology, Office of Science Advisor, as the source of a PST grant for this work. The Jamaican Office of Disaster Preparedness (ODP), the Natural Resource Conservation Department (NRCD) and Florida International University also contributed to the project.

Individuals whose work helped the studies are Gregory Fitzroy, Anthony McKensie, and Dr. Lee of the NRCD; and the staff at ODP.

Dr. Jeremy Woodley is warmly thanked for selecting coral species and participating in the lab set-up for coral. Dr. Karl Aiken and Dr. George Sidrak of the University of West Indies are gratefully acknowledged for advice on general aspects of Jamaican nearshore ecology. Minister Anthony Johnson, of the Jamaican Department of Agriculture has been most supportive throughout, as has the minister of public works, and Prime Minister Edward Seaga. U.S. AID Disaster Preparedness, members of AID's Latin American and Caribbean staff, Dr. Donald Marzalek, Dr. Alfonso Botello, the IOC and UNAM are acknowledged. Audley Chin is thanked for laboratory help in seagrass tests.

References

1. Ballou, Thomas G., Steven C. Hess, Charles D. Getter, et al., 1987. Final results of the API tropics oil spill and dispersant use experiments in Panama. *Proceedings of the 1987 Oil Spill Conference*, American Petroleum Institute, Washington, D.C., pp634
2. Cubit, John D., et al., 1987. An oil spill affecting coral reefs and mangroves on the Caribbean coast of Panama. *Proceedings of the 1987 Oil Spill Conference*, American Petroleum Institute, Washington, D.C., pp401
3. Knap, A. H., S. C. Wyers, R. E. Dodge, T. D. Sleeter, H. R. Frith, S. R. Smith, and C. B. Cook, 1985. The effects of chemically and physically dispersed oil on the brain coral *Diploria strigosa*. *Proceedings of the 1985 Oil Spill Conference*, American Petroleum Institute, Washington, D.C., pp547-551
4. Le Gore, R. S., D. S. Marszalek, J. E. Hofmann, and J. E. Cuddeback, 1983. A Field Experiment to Assess the Impact of Chemically Dispersed Oil on Arabian Gulf Corals. SPE 11444. Society of Petroleum Engineers, pp51-60
5. Teas, H., 1986. Mangrove ecosystems and recent research into the effects of dispersed and non-dispersed oil. *International Petroleum Environmental Conservation Association (IPIECA) Symposium on Oil Spills Research in Tropical Environments and Contingency Planning in the Wider Caribbean*, Caracas, Venezuela
6. Teas, Howard J., and Erik O. Duerr, 1987. Effects of South Louisiana crude oil and dispersants on *Rhizophora* mangroves. *Proceedings of the 1987 Oil Spill Conference*, American Petroleum Institute, Washington, D.C., pp633
7. Thorhaug, Anitra, 1987. Effects of oil spills on mangroves and seagrasses systems. *Proceedings of the 1987 Oil Spill Conference*, National Oil Spill Conference, Melbourne, Australia
8. Thorhaug, Anitra, 1988. Dispersants on tropical nearshore ecosystems. *in* Dispersants: New Ecological Approaches Through the 90's. ASTM STP 1018. Baltimore, Maryland
9. Thorhaug, Anitra, and Jeffrey H. Marcus, 1987. Preliminary mortality effects of seven dispersants on subtropical/tropical seagrasses. *Proceedings of the 1987 Oil Spill Conference*, American Petroleum Institute, Washington, D.C., pp223

DISPERSANT USE FOR TROPICAL NEARSHORE WATERS: JAMAICA

Anitra Thorhaug
Florida International University
555 NE 15th St., PH-H
Miami, Florida 33132

Barbara Carby and Richard Reese
Office of Disaster Preparedness
12 Old Camp Road
Kingston, Jamaica

George Sidrak
Botany Department
University of the West Indies
Kingston, Jamaica

Marcel Anderson
Natural Resource Conservation Dept.
59½ Molynes Road
Kingston 10, Jamaica

Karl Aiken and Wendy Walker
Zoology Department
University of the West Indies
Kingston, Jamaica

Mike Rodriquez
Coast Guard
Jamaican Defense Department
Kingston, Jamaica

Howard J. Teas
University of Miami
Coral Gables, Florida 33124

Beverly Miller and Valerie Gordon
IMERU
Kingston, Jamaica

Franklin McDonald
UNDRO, Antigua

John McFarlane
Jamaican Defense Department
Kingston, Jamaica

ABSTRACT: *Jamaica's shoreline is at the intersection of five major petroleum tanker shipping routes, and is a cargo transshipment point for the Caribbean. The natural coastline resources are valuable economically, with two-thirds of exchange dollars coming through tourism associated with beaches, clear waters, coral reefs, and nearshore fishing. The most thorough examination of the feasibility of using dispersants ever carried out in a developing nation has been undertaken. Dispersant toxicity of various species of critical matrix organisms has been carried out with an array of 12 dispersants. Corals, fish, seagrasses, and mangroves were tested. Toxic dispersants and three very low toxicity compounds were identified at concentrations ten times those likely to occur and ten times longer exposures. Thus, a safety factor was built in. A sensitivity map of the coastline was constructed. Simulations of "near-miss" tanker accidents were done manually with disperse and non-disperse options. A policy study of European and North American dispersant use was undertaken by the Office of Disaster Preparedness, the Coast Guard and the Oil Spill Committee. A draft policy was prepared for nontoxic dispersant use. The recommendations for use of nontoxic dispersants—with primarily coral reef and fish sensitivity as paramount concerns—are Cold Clean, Corexit 9550 and Finasol OSR7. Several European nations also have approved lists with Corexit 9550 (or allied products) and Finasol OSR-7. A computer simulation of all potential occurrences is the future goal.*

Jamaica sits at the intersection of major tanker routes (1) from Panama to the northeast U.S. (Alaskan oil), (2) from Venezuela to various nations, (3) from Mexico going south to the Caribbean nations, (4) from the Middle East, and (5) from Nigeria and West Africa to the Caribbean and North America. In addition, Jamaica is a substantial transshipment center, where thousands of ships per year offload cargo from North America, Europe, and South America, destined for Caribbean ports. On the north coast, a large cruise ship industry provides dockage and support facilities for the very large cruise ships bringing passengers to enjoy the island's attractions. Jamaica also has extensive petroleum bunkering facilities that support power plants, the bauxite industry, airlines, ships and the petroleum industry.

The Jamaican economy was announced in 1990 by the Ministry o tourism to be 67 percent based on tourist revenue for foreign exchange dollars. Tourism employs hundreds of thousands of persons. Most o the tourism is based on coastal hotels with their natural facilities o beaches, clear waters, and coral reefs.

The prevailing winds are onshore, the prevailing currents are alongshore. The island has extensive coral reefs on the north shore and mangroves and seagrasses on the south shore. Fishing is an impor tant local employment source. Jamaica's unemployment rate is high

Thus, conditions are set for maximum loss to Jamaica if accidenta vessel oil spills or bunkering spills occur.

Mechanical cleanup equipment has been in use since the 1980s. Ar average of six spills per year have occurred of 10,000 gallons and above Several large spills have had extensive natural resource impacts, par tially because the mechanical cleanup equipment is difficult to deploy Due to the difficulty of reaching the shoreline in many areas such as the very shallow and sensitive waters near the coast and in bays and estuaries, and the difficulty of moving equipment by road (especially from the south coast to the north coast over the mountains), portions o the coastline are hard to protect mechanically. Spills in the areas are better managed with the use of dispersants.

The rate of response to spills has been highly variable and dependent on the speed of reporting the spill, the distance of the spill from equipment and manpower, the degree of spill preparedness and responsibility of the spilling party, including whether they were cleaning up the spill or asking the government to handle it, and the size of the spill. To date, no spill over 25,000 gallons has occurred There have been several near misses of large, loaded oil tankers almost hitting reefs.

Several very large oil spills have occurred in less-developed nations, such as Indonesia, Panama, Nigeria, and Egypt, and all have been beyond the capabilities of mechanical methods to clean up. The resulting "beach" clean-up in mangroves and on corals has been very damaging to these resources, but not catastrophic to the economies of the

nations because the spills were not in recreational areas. All the nations were on tanker routes; the spills were associated with tanker accidents. Many nations in the Caribbean do not have extensive non-utilized coastal resource areas as do the above-mentioned nations.

Jamaica dispersant study

The use of dispersants has been considered for many spills, but the threat of potential toxicity to nearshore organisms prevented this. Thus, a program has been initiated to determine the feasibility of the use of dispersants in Jamaica, when mechanical equipment would not suffice.

Methods

Toxicity studies

Laboratory investigations. Standardized procedures used by the U.S. Environmental Protection Agency (EPA) and various agencies (FAO, UNESCO, UNEP) for testing tropical matrix organisms were employed so that standardized results could be produced. The hope was to compare results with FAO's fish efforts in 2 tropical nations (not yet available) and U.S. EPA temperate results, along with UNEP European dispersed-oil toxicity data.

Selection of critical matrix organisms for tropical shorelines was a choice based on (1) importance to the food web, (2) rate and difficulty of replacement once decimated, (3) shoreline stabilization characteristics, and (4) usefulness to the nation (fisheries, tourism). Local experts, such as Jeremy Woodley, director of the Discovery Bay Marine Laboratory and preeminent Jamaican coral reef expert, were asked to choose indicator species for the project.

Standardization among techniques for various groups was attempted so that the results of each group could be compared. Thus, the standardized portion will be explained first.

Laboratory conditions. The procedure was described in detail by Thorhaug and Marcus.[1] Fifty-gallon glass aquaria were used in out-of-door conditions (such as fluctuating light, temperatures, and running water) and, except for the mangroves and seagrasses, were protected from rain and wind. Temperatures ranged from 26° to 30° Centigrade, with fluctuation of 1° C ± 0.5° C. Seawater ranged from 30% to 33% (except for mangroves). In seagrasses, three inches of beach sand was at the bottom. Coral and fish tanks were bare. For seagrasses, a minimum of 15 blade groups of each species was placed in each tank (1 tank per treatment); for fishes, 7 of each species. Great care was taken in transport and holding conditions for the coral and mangrove specimens. Time for equilibration of specimens was allowed. 100,000 cc of seawater were placed in each treatment.

Laboratory procedures. Oil-only was a treatment in each set. Time for weathering of oil was 24 hours at 28° C in shallow plastic pans. The control tank was handled exactly the same as treatments. The dispersant was applied to oil floating on the tank surface with 1 minute of vigorous stirring. The dispersed oil formed a brown cloud of free-floating material, visually homogeneous throughout the tank (dependent somewhat on concentration and dispersant). The coral, seagrasses, and fish were not touching the oil floating on the top; the mangroves were in contact on the bark. All specimens were in contact with the dispersant mousse.

For each specie's experiment, three concentrations (12.5 ppm, 75 ppm, and 125 ppm dispersed oil—1:10 dispersant to oil) were used. The exposure times were 1 to 96 hours for fish, 6 and 10 hours for corals and seagrasses, 10 hours for mangroves. The treatment was immediately removed, and the water cleaned and changed.

The specimens were incubated up to 14 days (coral, seagrass), and 9 months (mangroves) The observation period included daily or bi-weekly readings of health. Seagrasses had young green blades tagged and numbered. These were graded for discoloration, spotting, wilting and other morbidity symptoms. Corals were graded by bleaching, spotting, browning, wilted polyps, extruded polyps, and mucous secretion. Fish were graded by behavior modifications, spotting and color change, movement patterns, and breathing rates. Mangroves were graded by leaf drop, twig drop, root death and discoloration, leaf coloration, leaf spots, and leaf wilt. These symptoms of mortality and illness were made quantitative by experts and organisms were graded. The tables showing the results are not of health but of mortality.

Sensitivity map. There had been several compilations of information of coastal resources: the Jamaican Atlas, the Jamaican Profile, and the Jamaican geological survey maps. All of these sources plus personal observations, and information from the authors and other experts have been used to compose the sensitivity map. The base map was one previously selected by NCRD on which other emergency preparedness information was associated and available to scale. The generalized winds and currents were from data provided by the Coast Guard. The map was compiled under ODP direction.

Oil spill scenarios from near-misses and high risk areas could be simulated on the map to train and prepare the Oil Spill Committee.

Dispersant policy. The dispersant policies of a number of countries, including France, Britain, Denmark, Sweden, Belgium, Canada, and the United States were studied by the ODP, Coast Guard, and the Oil Spill Committee. A meeting of the Oil Spill Committee was convened to hear the findings of the dispersed oil toxicity data, to review coastal resources, to review the sensitivity map with spill scenarios, and to discuss the potential for dispersant use. A subcommittee including the Natural Resource Conservation Committee, Fisheries Department, Coast Guard, ODP, and oil companies was convened. They began to draft a dispersant policy which was presented to the Oil Spill Committee. The draft was then circulated, refined, and re-discussed at the second meeting of the Oil Spill Committee.

Results

Toxicity studies

Laboratory experiments. Critical coastal organisms were the ones chosen to test. There were 3 species of mangroves, 3 species of corals, 3 species of seagrass, and 3 species of fish tested versus a wide array of dispersants, which represented the various types of compounds and levels of refinement for biological toxicity. The toxicity was defined for 125 ppm dispersed oil, as well as 75 ppm and 12.5 ppm. Thus, we bracketed the potentially high end of concentration toxicity. Manufacturers usually state 2 to 50 ppm concentrations of dispersants should be used. The time periods of exposure were 6 to 10 hours for seagrass and corals, 1 to 72 hours for fish, and 10 hours for mangroves. The time of exposure for organisms to oil spills, as stated by the National Academy of Sciences, is 1–3 hours. Thus, the experiment shown below is "worst case" exposure, which is the longest time with the highest dosage. Lower concentrations and shorter times would, for several of the middle and low toxicity compounds, result in less mortality. The safety factor of the worst case has been shown by the U.S. EPA and other regulatory agencies

The results show a relative ranking of dispersants, from very toxic to low toxicity, with the plants and animals generally responding about the same in toxicity ranking to a dispersant. Corals and fish were more sensitive than seagrasses.

General results. Table 1 shows the results as a mean response of fish, corals, and seagrass at 12.5 ppm dispersed oil for exposure of 6 hours for various dispersant compounds. Table 2 shows various mangrove species at 1250 ppm dispersed oil versus toxicity for a 10-hour exposure time.

Clearly, the more toxic compounds include Conco K, Corexit 9527, OFC D609, LTX, Kemarine, Wonder O, and V-25.

The medium toxic compounds include Jansolv (except to fish) and ADP-7 (except to fish, when it is highly toxic).

The low toxicity compounds include Corexit 9550, Cold Clean 500, and Finasol OSR7 to all organisms tested.

There were differences, not only between groups of organisms, but also between species of seagrass, corals, and fish. These data will be described in detail (Thorhaug, et al., in preparation). As concentrations decreased, the toxic effects of those in the low toxicity groups and medium groups decreased to around 5 percent and 20 percent respectively of 125 ppm for 12 5 ppm dispersed oil.

Mangrove results. The results of mangroves at 1,250 ppm can be seen in Table 2.

The mangroves showed no response to the dispersed oil at 125 ppm or 12 5 ppm. There was no leaf drop and no mortality of any plant.

Table 1. General results

The mean mortality of 3 Jamaican fish species, 3 Jamaican seagrasses, and 3 Jamaican coral species (at 6-hour exposure of 125 ppm dispersed oil for the seagrasses and coral; and at 3-hour exposure of 125 ppm dispersed oil for the fish; $\bar{x}$ is the mean of 3 species toxicity)

	Fish[1]				Seagrasses[2]				Coral[3]			
	1	2	3	$\bar{x}$	1	2	3	$\bar{x}$	1	2	3	$\bar{x}$
A. Conco	100	100	100	100	100	82	100	94	100	100	100	100
B. OFC D609	40	100	100	80	70	63	—	67	100	100	100	100
C. Corexit 9527	40	100	100	100	89	93	—	91	72	100	100	91
D. V-25	100	100	100	100	nd	nd	nd	nd	100	100	100	100
E. Wonder-O	100	100	100	nd	100	100	100	100	100	100	100	100
F. Kemarine	nd	nd	nd	100	63	68	—	66	100	100	100	100
G. ADP-7	100	100	100	100	50	46	—	48	100	100	100	100
H. Jansolv	100	100	100	100	0	0	0	0	0	0	73	24
I. LTX	100	100	100	20	nd	nd	nd	nd	nd	nd	nd	nd
J. Corexit 9550	0	60	0	47	40	46	nd	43	43	0	100	47
K. Cold Clean	0	60	80	7	0	0	0	0	0	0	21	7
L. Finasol	0	0	20	0	0	0	0	0	0	0	11	4
M. Oil	0	0	0	0	30	28	30	29	52	52	58	54
N. Control	0	0	0		11	9	10	10	0	0	0	0

1. Fish no. 1, *Holocentrus rufus;* Fish no. 2, *Acanthurus sp.;* Fish no. 3, *Haemulon sp.*
2. Seagrass no. 1, *Thalassia testudinum;* Seagrass no. 2, *Halodule wrightii;* Seagrass no. 3, *Syringodium filliforme*
3. Coral no. 1, *Porietes porietes;* Coral no. 2, *Montastrea annularis;* Coral no. 3, *Acropora palmata*

Thus, these experiments used concentrations 10 to 100 times higher than for the other species. (Note that the Teas's and other measurements of oil slick in stands of mangroves are substantially higher—up to 10 liters of oil per m—than the open ocean oil slicks: 0.03 mm or 50 ppm oil.) The 12,500 ppm oil shows that there was a difference in toxicity response among the dispersed oils on all three species. The least toxic were Finasol OSR7, Cold Clean 500, Jansolv, Corexit 9550, ADP-7, and Wonder-O. The most toxic were Conco, Corexit 9527, ADP (petroleum), and V-25. Intermediate dispersed oil effects were seen in Corexit 9527. There were statistically significant differences between the control response and V-25, OFC D609, and Wonder-O for red mangroves; and the control and Conco, Corexit 9527, ADP-7, Jansolv, and Wonder-O for white mangroves. The lower concentration of 1,250 ppm also shows strong differences between the toxicity responses in very similar order of toxicity to higher concentration. The difference among the responses of species was frequently marked. The white mangrove was the most sensitive to oil and dispersed oil, with black mangrove the most tolerant. The effect of oil alone was considerable for the white mangroves.

Sensitivity map. From the standpoint of the Oil Spill Committee's efforts to protect it, the coastline of Jamaica is a fragile coast with abundances of natural resources throughout.

Most of the north coast has living coral reefs clearly marked on the continental shelf edge, the reefs of which extend around back frequently into the bays. These reefs are extensive around the western coast also. The tourist hotels are closely associated with the reefs, from Nigril in the west and extending past Port Antonio in the east. Almost all the bays and inlets on the north coast have important tourist facilities. Most major tourist hotels include beach and ocean facilities as an important part of their package. The exchange money brought in by this economic sector means that these beaches and reefs have a high priority for protection. Spill scenarios from the heavy tanker routes at the east end and off the north shore show that the risk is high. Ships entering harbors for bauxite (Ocho Rios, Discovery Bay), cruise ships (Port Antonio, Ocho Rios, Montego Bay), and cargo ships (Port Antonio, Ocho Rios, Montego Bay) cause nearshore risk almost immediately on top of the reefs. There are corals on the continental shelf southeast of Kingston.

Mangroves frequently line the shores of embayments on the north, east, and west coasts; heavy mangrove forests are found between Hunt's Bay and Alligator Point on the South coast. Seagrass is found on the north coast in large quantities between the outer reef and the shoreline, including bays and inlets. Seagrass is found in larger areas in south coast bays and on the continental shelf of the south coast. Fish nurseries are highly associated with seagrasses, adult fish with coral reefs, and other species with the fishing banks found offshore. Fishing beaches for launching fishing boats are also found throughout the island.

Bunkering areas for petroleum are intense in Kingston Harbor. These areas are found in Old Harbor on the south coast, and at bauxite-loading facilities and ports throughout the rest of the island.

The currents close to the shore run generally east to west. Tidal flows occur into and out of the bays. Winds are strongly onshore for at least part of each day.

Dispersant policy. The dispersant policies which appeared most suited for the Jamaican systems were carefully examined, and elements were derived from the experiences of these nations. Incorporating necessary Jamaican elements resulted in the Oil Spill Committee's producing a policy which will be presented at the 1991 meeting. The Swedish and Belgian policies provided part of the model for the Jamaican dispersant policy. The U.S. policy was not utilized, since it did not provide clear "recommended" and "non-recommended" dispersants.

Table 2. Mangrove results[1]

Dispersants	*Rhizophora* red	*Avicennia* black	*Laguncularia* white
Conco K	28.6	14.3	80
OFC D609	42.9	14.3	25
Corexit 9527	71.4	0	40
Corexit 9550	0	0	20
Wonder-O	42.9	14.3	50
ADP-7	28.6	28.6	50
Jansolv	14.3	0	60
Cold Clean	28.6	14.3	20
Finasol	0	14.3	40
V-25	71.4	14.3	40
LTX	nd	nd	nd
Oil-only	14.3	28.6	40
Control	0	14.3	14.3

1. The mortality percent of Jamaican mangroves exposed for 10 hours at 1,250 ppm dispersed oil

Discussion and summary

In order to complete an arsenal of tools which could be available to Jamaica during large-to-massive spills, the toxicity of dispersants to Jamaican critical habitats has been investigated. The concept of dispersant use policy was also investigated, with conclusions by the Oil Spill

Committee. The data about dispersants, the sensitivity map, and policy considerations have shown several new facts as follows.

1. There is an array of dispersants toxic to Jamaican corals, fish, mangroves, and seagrasses which Jamaica does not wish used close to shore. These include Conco K, Corexit 9527, V-25, Wonder-O, Kemarine, and OFC D609.

2. There are three dispersants which appeared to perform effectively and to be nontoxic to all our species at critical matrix concentrations 10 times above potential use levels and for time periods 10 times longer than potential exposure levels. In particular, the sensitive corals and fish were not killed in substantial numbers by them over 10 hours. Cold Clean-500, Finasol-OSR7, and Corexit 9550 were acceptable to the Oil Spill Committee. This constitutes the present Jamaican-accepted non-toxic dispersant list. These experiments were carried out by combined groups from the Natural Resource Conservation Department, University of the West Indies, and Florida International University, and were examined by ODP.

3. In the east Jamaican coast shipping lanes, there have occurred simulations of spills from a ship involved in a "near-miss" on the reefs. It would not have been possible to mechanically contain any sizeable spill at this position. If the vessel would have spilled half or more of its petroleum cargo, and if the spill had not been treated, the north coast beaches, reefs, mangroves, and fishes of at least two-thirds of our north coast, as well as to Kingston on the south coast, could have been heavily oiled. If the oil had been dispersed, the damage at the east end of the island would have been minimal and none of the other coasts, fish or reefs would have been oiled.

4. The constructed sensitivity map shows important coastal resources throughout the coastline of Jamaica with along-shore currents and onshore winds during a portion of each day. There are few places where a large oil spill would not cause appreciable damage.

5. The potential for a spill to occur beyond the three mile limit and to begin to drift toward Jamaica's coastal zone is fairly great. If the possibility that the spill would enter the nearshore area occurred, the recommendation might include use of dispersants.

6. The need for a coherent dispersant policy, which would be useful to command officers, became clear. The Oil Spill Committee has drafted this policy; legislative adoption still remains.

7. Individual contingency plans, for each major facility where oil enters or is stored, are now being updated with the dispersant alternative in mind, if a mechanical cleanup is inoperative or not correct.

8. The three non-toxic dispersants should be noted with respect to effectiveness. We have not been able to obtain effectiveness data at 25° C and 30° C from vendors or the literature—the relevant temperature range for tropical spills. Effectiveness data is predominantly for 5° C and 15° C. The compounds we recommend should be tested at 32‰ and 20° C, 25° C, and 30° C.

Our aim is the education and training of the personnel of the Oil Spill committee and the continuing updating of information to this group. Simulations of other types of spills around the various shipping lanes and ports are underway to increase preparedness efforts. Detailed training for several levels of command and cleanup personnel on the use of dispersants will occur in the near future. Computer simulations of oil spills versus dispersed spills are one of the goals of the Office of Disaster Preparedness.

Conclusions

Non-toxic dispersants provide another oil spill response tool. The ability to use them when mechanical means have failed or would be inadequate provides further protection for the Jamaican coastline.

Acknowledgments

The U.S. Agency for International Development, Office of Science Advisors (especially Drs. Minner and Daly) is gratefully acknowledged as the primary source of funding for this study. The authors would also like to thank the Latin American Caribbean Office for program supervision (especially Drs. James Hester and John Wilson). Very helpful was the Jamaican/U.S. AID Office (especially Charles Matthews). The U.S. AID Office of Disaster Relief (Dr. Oliver Davidson) is thanked for helpful suggestions throughout. The Government of Jamaica, Office of Disaster Preparedness, and the Ministry of Construction were highly instrumental in this project. NRCD personnel who carried out coral and seagrass studies are thanked.

Also thanked is Florida International University for its matching contribution and its administrative support. The Mobil Oil Foundation is thanked for matching funds for seagrass and fish in the dispersed-oil testing. We are grateful to dispersant manufacturers and vendors who donated dispersants. Wendy Walker from UWI and the NRCD personnel are thanked for laboratory technical work. We thank participants in the sensitivity mapping: Dr. Woodley, who volunteered a map of corals of a section of the coast; fisheries experts Moo Young and Karl Aiken; Barbara Chow and Elizabeth Ross for mangrove maps from their NRCD projects; and Anitra Thorhaug, George Sidrak, Peter Gayle, and Margaret Greenway for their seagrass observations.

Reference

1. Thorhaug, Anitra and Jeffry Marcus, 1985. Effects of dispersant and oil on subtropical and tropical seagrasses. *Proceedings of the 1985 Oil Spill Conference*, American Petroleum Institute, Washington, D.C., pp 497–501

Bibliography

Brundtland, G. H., 1988. Our Common Future. Oxford Press, Oxford, England, p 154

National Research Council, Committee on Effectiveness of Oil Spill Dispersants, 1989. Using Oil Spill Dispersant on the Sea. National Academy Press, Washington, D.C., p 310

Schroeder, P., 1978. The Effect of Temperature on Seagrass *Thalassia* in Guyarilla Bay, Puerto Rico. Ph.D. dissertation. University of Miami, Coral Gables, Florida, 201 pp

Teas, H. and E. Duerr, 1987. Oil and Dispersed-Oil Effect on Mangroves. University of Miami, Coral Gables, Florida, 18(3), pp 121–124.

Thorhaug, Anitra, 1988. Dispersant effects on tropical ecosystems. *in* Oil Dispersants: New Ecological Approaches, M. Flaerety, ed., American Society for Testing and Materials (ASTM), Philadelphia, Pennsylvania, pp 245–268.

Thorhaug, Anitra, Franklin McDonald, Beverly Miller, John McFarlane, Barbara Carby, Marcel Anderson, Valerie Gordon, and Peter Gayle, 1989. Dispersed oil effects on tropical habitats: preliminary laboratory results of dispersed oil testing on Jamaica corals and seagrass. *Proceedings of the 1989 Oil Spill Conference*, American Petroleum Institute, Washington, D.C., pp 455–458

Thorhaug, Anitra, M. A. Roessler, and D. Segar, 1973. Impact of a power plant on a subtropical estuarine environment. *Marine Pollution Bulletin*, n7, pp 166–169

Trudel, B. K., R. C. Belore, B. J. Jessiman, and S. L. Ross, 1989. A microcomputer-based spill impact assessment system for untreated and chemically dispersed oil spills in the U.S. Gulf of Mexico. *Proceedings of the 1989 Oil Spill Conference*, American Petroleum Institute, Washington, D.C., pp 533–538

EFFECTS OF DISPERSANT AND OIL ON SUBTROPICAL AND TROPICAL SEAGRASSES

Anitra Thorhaug and Jeffry Marcus
Greater Caribbean Energy and Environmental Foundation, Inc.
1121 Crandon Boulevard
Miami, Florida 33149

ABSTRACT: *Preliminary experiments, using the subtropical/tropical coastal and estuarine seagrasses* Thalassia testudinum, Halodule wrightii, *and* Syringodium filiforme, *were carried out to examine the effects of dispersants. Experiments exposed seagrasses* in vitro *to concentrations of Louisiana crude oil ranging from 7.5 to 500 milliliters (mL) in 10^4 mL seawater at exposure times of 5 to 100 hours (seagrass not in contact with oil slick). In other experiments, the seagrasses were exposed to the dispersant Corexit 9527, which was combined with the oil in a ratio of 1 part dispersant to 10 parts oil with dispersant concentrations ranging from 0.75 to 50 mL in 10^4 mL seawater (dispersant plus oil forming a cloud of the substance in contact with seagrasses).*

The oil or oil with dispersant treatment was removed from the seagrasses after the designated exposure periods. Thereafter, the seagrasses were monitored for 14 days. Blade length was measured as a factor of growth. Thalassia *showed the greatest tolerance to dispersant plus oil of the three species tested. It was not substantially affected by any oil concentration alone; however, when exposed to oil and dispersant, growth significantly decreased with concentrations of 125 mL oil and 12.5 mL dispersant in 10^4 mL seawater at longer periods of exposure (100 hours), and also at much decreased exposure times (5 hours) for 500 mL oil and 50 mL dispersant in 10^4 mL sea water.* Syringodium *and* Halodule *were generally less tolerant than* Thalassia, *particularly to oil. For example, at 75 mL oil/10^4 mL sea water and an exposure of 100 hours, growth decreased significantly and mortality increased to 53 percent. Growth and mortality of* Syringodium *and* Halodule *were further affected by the addition of dispersant.*

Seagrasses are one of the most important coastal and estuarine organisms in the Gulf of Mexico, Florida, and Greater Caribbean, functioning as a major fisheries nursery habitat, food and shelter for more than 300 fish and 350 invertebrate species. Being distributed from the low tide line outward to the reefs, they are frequently forced to absorb whatever coastal pollutant eliminations and accidents occur. Once they are decimated, it has been shown that decades frequently are required before seagrass recolonization is complete.

Oil effects on tropical and subtropical seagrasses have been documented in Bahia Sucia, Puerto Rico[1] to have killed *Thalassia* and eroded sediments in March 1973. In 1976, renewed seagrass growth was observed. In July 1975, a small volume of oil was spilled near Marquesa Key, Florida, for which Chan[1] observed no direct damage to seagrasses. Diaz-Piferrer[4] found a decline in *Thalassia* beds when 10,000 tons of oil were released at Guanica, Puerto Rico. Dispersants were not used at any of the above-mentioned spills. A review of the effects of spills on temperate seagrass beds is found in Cairns and Buikema.[5]

One laboratory study on the effects of oil plus dispersants on subtropical and tropical seagrasses has been published. Baca and Getter[1] used Prudhoe Bay crude oil and Corexit 9527 on *Thalassia testudinum*. Between 0.38 and 17.7 mL of dispersed oil turned the blades of *Thalassia* from 60 percent green to 30 percent green, an increase to 70 percent brown.

In summary, clear toxicity levels of oil spills on tropical seagrasses have been seen. No lower lethal limits for subtropical seagrasses exist from field or laboratory studies, although 0.38 mL of dispersed oil was not lethal to *Thalassia*.

Dispersant use

IMO/UNEP Guidelines on Oil Spill Dispersant Application and Environmental Considerations[6] instructs in section 6.2:

A number of different habitats will be discussed with some general remarks as to possible application of oil spill chemicals. These remarks are generalized statements which require caution in their interpretation, as the ecosystems of the same type of habitat may vary considerably with their geographical location. Ecologists or marine biologists should be consulted as to the best way of handling the oil once it enters the inshore area.

With rare exceptions dispersant application onshore is followed by transference of oil and dispersant to the sea, either by tidal action or hosing with seawater. The impact of this on the near-shore ecosystems has to be balanced against the advantage that may be gained onshore. It should be realized that the biota onshore are not exposed to a low concentration dispersion, but to direct contact with oil and dispersant together, or to dispersant alone, in places where spraying takes place and accidentally misses the oil patch. Therefore, toxicity tests with chemically dispersed oil would not be sufficient. Special tests should be carried out in which the organisms are in direct contact with the dispersant.

Various types of coastal environment and recommended clean-up methods are described in the IMO Manual on Oil Pollution, Section IV, Chapter 6 (IMO 1980). Generally, each country will have several shoreline types which vary in their sensitivity to undispersed oil, dispersed oil and dispersant alone. Guidance is given below on use of dispersants inshore and near-shore:

1. habitats where dispersant spraying generally should not take place are the most sensitive of marine environments, including coral reefs, salt marshes, mangrove swamps, estuaries, tidal flats and lagoons with poor water exchange. When oil enters these environments, it may be best to restrict clean-up activities (including mechanical clean-up) to those methods which do not add to the damage caused by the oil. These areas should receive highest priority for protection before the oil arrives. . . .
3. habitats where spraying can take place on advice of experts and with caution include low energy sand, gravel and shingle beaches and sheltered rocky shores. Because of the low wave energy characteristics of such locations oil may remain for some time. Dispersants may aid in removing oil on the approaching tide.

In deciding how best to deal with an oil spill, the possible fate and effects of chemically dispersed oil will have to be compared with those of the naturally dispersing slick. The effects can be short-term

and or long term. They include physical smothering as well as toxic effects. The biological effects of an oil spill might be assessed by trained marine biologists, using acceptable methods. It should be stressed that knowledge about the pre-spill situation is desirable and should be considered in contingency planning.

Presently the potential use of dispersants near seagrass beds is under discussion for situations such as: when seagrass beds are deeper than 10 meters (m), where floating oil is likely to ground on intertidal seagrasses, when impacts to seagrass beds have been weighed against impacts to onshore habitats if grass beds are between 10 m and intertidal depths, or in shallow lagoons or areas of restricted flushing, dispersants are being considered[1] for use on seagrass beds as an option to protect shoreline environments. Particularly in developing nations (most of which are located in the tropics) with oil spill problems, these questions are now being incorporated into oil spill contingency plans.

Thus, in the case of future oil spills, dispersants may be considered in the proximity of coastal or even estuarine seagrass populations. The data on which to make decisions for use of dispersants in subtropical and tropical seagrass areas are not available. Questions that arise are: at what concentrations dispersants can safely be applied without effecting specific seagrasses; which seagrasses can tolerate what levels of dispersants plus oil and for what time periods, and how sensitive are subtropical and tropical seagrasses to dispersants versus shoreline species such as mangroves.

If the onshore habitat is a mangrove forest or salt marsh, the question arises as to how to make a decision on the potential lethality of dispersed oil versus non-dispersed oil to the sublittoral habitat versus the shoreline habitat. It should be kept in mind that mangroves usually are more resistant to pollutants than are seagrasses. If lethal limits for oil or oil plus dispersants are not known for seagrasses, the trade-off between onshore and offshore protection becomes a difficult decision. The only quantitative data presently available (*i.e.*, without concentration effect data) would be the areal extent of shorelines versus seagrasses to be affected, or the potential cost benefit ratio of decimating and then restoring one or the other. Not only do decision makers in the United States need this information, but so do those in many developing nations who frequently do not have sufficient research budgets to obtain their own data.

Statement of the problem

The question then is, what are the lethal and LD_{50} (lethal dosage for 50 percent of the population) concentrations of oil plus dispersant for major subtropical and tropical seagrasses. The following is the first report of our ongoing investigation designed to explore this question. The results may be used only with the caveat that laboratory results often yield toxicity limits for only a single stress. Field studies of concentration limits and times are needed to correlate laboratory studies.

Methods

The three major subtropical tropical nearshore seagrasses *Thalassia testudinum*, *Halodule wrightii*, and *Syringodium filiforme* were each exposed to a wide range of oil and oil plus dispersant (10:1) concentrations in 50 gallon aquaria situated outdoors in Key Biscayne, Florida. Three inches of quartz sand sediment per tank was obtained from naturally-occurring grass beds. Seagrasses were transplanted into the aquaria with apical meristems, several shoot groups, roots, and six inches of rhizome in the same manner which has proven successful in prior laboratory studies and large restoration projects. A minimum of 15 blade groups of each species was placed in each aquarium. The time between harvesting the seagrasses, transporting them in standard ice chests, and planting was usually one hour but never exceeded four hours. Each aquarium was filled with 100,000 cm³ of sea water [salinity concentration 28–32 parts per thousand (‰)] collected from Biscayne Bay near a major ocean inlet. The aquaria were aerated and protected from rain by a transparent plastic covering. The temperature of the water ranged from 38 to 31 °C with a daily fluctuation of 1 °C. The seagrasses were illuminated by natural sunlight. Experiments reported here were carried out from March to September 1984.

The seagrasses were acclimatized to the aquaria for a minimum of 48 hours prior to each experiment. Each aquarium was designated for treatments by random sampling techniques. Each experiment included the following treatments: the effect of oil, the effect of oil combined with dispersant (10:1), or control, the condition and growth of seagrasses growing in an aquarium with no exposure to oil or dispersant.

Oil was weathered by exposing it to sunlight and air at approximately 29 °C for 24 hours prior to each experiment in a 1 cm layer in a shallow plastic pan. Oil and oil plus dispersant treatments were applied to test tanks by decanting from the weathering vessel. Oil plus dispersant was vigorously stirred into the test tank with a paddle for 10 minutes. Both treatments were incubated with bubbling by aerators during the experiments and holding periods after the experiments. The oil alone treatment formed a slick on the sea water surface. The dispersant plus oil treatment formed a brown cloud of free-floating material (visually homogeneous throughout the tank without a surface slick). The dispersant plus oil did not appear to be accumulating interfacially. In the oil alone treatment tanks, the seagrass blades were not directly touching oil; in the oil plus dispersant tanks, the blades were continuously exposed to the test substances.

In each experiment a specific concentration of Louisiana crude oil was placed in one aquarium designated to test the effects of oil on the seagrasses; the concentrations of oil tested were 7.5, 75, 125, and 500 mL in 100,000 cm³ of sea water. Corexit 9527 dispersant was mixed in a ratio of 10 parts oil to one part dispersant in a second aquarium (recommended dosage of 10:1 or 20:1 by Corexit distributors, Exxon Chemicals).

Immediately after the designated exposure time, the water and test substances were removed from the aquaria. The aquaria were thoroughly cleaned; the contaminated water was immediately replaced with clean ocean water.

The seagrasses were then carefully observed for the following 14 days. During this time 15 of the most healthy blades of each species were chosen in each tank and tagged. Young green blades were selected which had no discoloration or signs of stress. They were measured on an average of six times during the 14 day period to the nearest ± 0.1 cm. The blades were measured from the base of the blade at the sediment surface to the end of the growing tip. During each measurement the blades were examined for browning, yellowing, and spotting, all evidences of physiological stress. A blade was considered moribund if it had totally lost its content of chlorophyll a and turned brown.

Results

Growth rates. When plotted on arithmetic scales, the relationship between Y (mean length increase; cm) and X (time in days) was curvilinear, especially in the case of the faster growing blades on the 14 day experimental period (Figure 1a). The increase in blade length values was therefore converted into logarithms (log 1) and from these the geometric mean length increases were calculated and plotted (semi-log plot) against time. A linear relationship was established (Figure 1b).

Values for b were estimated by linear regression analyses of usually n = 6 determinations on each blade increase (cm) over a 14 day period using the relationship

$$\ln L = \ln a + b t$$

Where L = the length increase (cm)
a = a constant
b = the slope
t = the experimental period of growth (14 days)

All the growth rates are expressed as specific growth, G: percent per day, obtained from $G = b(100)$. G was calculated for each individual. The mean specific growth rate $G \pm 95$ percent confidence limit was then determined for 15 blades of each species in each tank.

Effect of oil and oil plus dispersants on *Thalassia*. *Thalassia testudinum* was not affected by oil alone in tested concentrations ranging between 7.5 and 500 mL in 10 mL seawater (Table 1). There were no significant differences ($P > 0.05$) between growth in the controls and growth in the tanks that were exposed to oil concentrations as follows: [illegible]

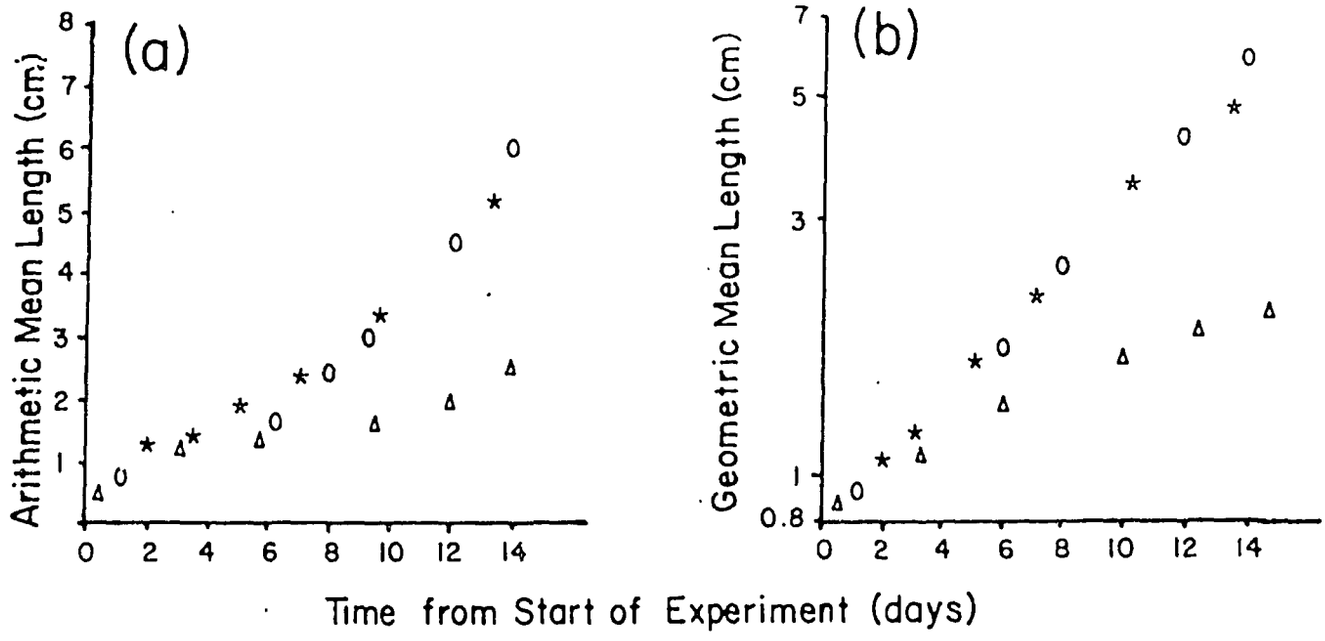


Figure 1. Increase in growth of subtropical tropical seagrasses plotted on (a) arithmetic and (b) semi-logarithmic scales—0 represents mean increase of 15 blades of *Thalassia testudinum* exposed to 75 ppm oil for 10 hours; * represents the mean increase of 13 blades of *Syringodium filiforme* exposed to 75 ppm oil for 10 hours; Δ represents the mean increase of 15 blades of *Halodule wrightii* exposed to 1,250 ppm oil for 100 hours.

500 mL, 5 hours—all in 10^4 mL seawater. Growth rates of *Thalassia* ranged from $\bar{G}$ = 3.78 percent per day when exposed to 125 mL in 10^4 mL sea water for 100 hours to 4.85 percent per day when exposed to 7.5 mL in 10^4 mL sea water for 10 hours. Mortality of *Thalassia* remained low (below 13 percent) in both control and dosage tanks (Table 1). It should be noted that *Thalassia* blades did not touch the oil slick on the sea water in these experiments.

The effects of oil plus dispersant could be divided into two categories. Lower concentrations of oil combined with dispersant (ranging from dispersant concentrations of 0.75 mL for 10 hours to 7.5 mL in 10^4 mL seawater for 100 hours) did not significantly affect ($P > 0.05$) the growth rates or survival of *Thalassia* (see Table 1). However, higher concentrations or greater exposure time severely stressed *Thalassia*. In tanks with 125 mL oil (12.5 mL dispersant) for 100 hours, and 500 mL oil (50 mL dispersant) for 5 hours, all in 10^4 mL sea water, mean specific growth rates of *Thalassia* were reduced to 2.59 percent per day and 2.45 percent per day respectively, both significantly lower ($P < 0.05$) than in tanks without the dispersant. Mortality also increased to 40 and 47 percent in these cases (see Table 1), very close to LD.

Effect of oil and dispersant on *Halodule* and *Syringodium*. The effects of oil plus dispersant on *Halodule* and *Syringodium* also could be divided into two categories. *Halodule* and *Syringodium* responded identically to oil and dispersants, and differently from *Thalassia*.

Table 1. Mean specific growth rates, $\bar{G}$ (percent length increase per day) with 95 percent confidence limits and percent mortality in *Thalassia testudinum* after exposure to varying concentrations of Louisiana crude oil and Corexit dispersant for 14 days at 28–31° C—*n* is the number of healthy green blades measured (±0.5 cm); *CV* is the coefficient of variation in growth rate (*CV*, percent); mortality was determined by 100 percent browning of individual leaves; * denotes the control for each experimental trial.

Trial No.	Concentration in 10^4 mL seawater: Oil	Concentration in 10^4 mL seawater: Dispersant	Exposure time (h)	$\bar{G}$	*n*	*CV*	Mortality at 14 days (percent)
1	7.5	0.75	10	4.81 ± 0.55	15	18	7
	7.5	0	10	4.85 ± 0.37	15	24	0
	* 0	0	10	4.96 ± 0.45	15	17	0
2	75	7.5	5	4.37 ± 0.63	15	21	7
	75	0	5	4.41 ± 0.84	15	31	7
	* 0	0	5	4.44 ± 0.41	15	18	0
3	75	7.5	100	3.98 ± 0.55	15	24	20
	75	0	100	4.53 ± 0.62	15	20	7
	* 0	0	100	4.75 ± 0.35	15	10	0
4	125	12.5	100	2.59 ± 0.44	15	51	40
	125	0	100	3.78 ± 0.75	15	26	13
	* 0	0	100	3.44 ± 0.33	15	17	0
5	500	50	5	2.45 ± 0.35	15	65	47
	500	0	5	4.10 ± 0.55	15	14	0
	* 0	0	5	3.95 ± 0.66	15	17	0

BEST AVAILABLE COPY

Table 2. Mean specific growth rates, $\bar{G}$ (percent length increase per day) with 95 percent confidence limits and percent mortality in *Halodule wrightii* after exposure to varying concentrations of Louisiana crude oil and Corexit dispersant for 14 days at 28–31° C—*n* is the number of healthy green blades measured (±0.5 cm); *CV* is the coefficient of variation in growth rate (*CV*, percent); mortality was determined by 100 percent browning of individual leaves; * denotes the control for each experimental trial.

Trial No.	Concentration in 10^4 mL seawater: Oil	Dispersant	Exposure time (h)	$\bar{G}$	*n*	*CV*	Mortality at 14 days (percent)
1	7.5	0.75	10	3.81 ± 0.88	15	21	7
	7.5	0	10	3.72 ± 0.37	15	13	7
	* 0	0	10	3.95 ± 0.44	15	18	0
2	75	7.5	5	3.14 ± 0.54	15	11	20
	75	0	5	3.65 ± 0.37	15	17	7
	* 0	0	5	3.78 ± 0.25	15	19	7
3	75	7.5	100	1.85 ± 0.44	15	74	73
	75	0	100	2.22 ± 0.37	15	65	47
	* 0	0	100	3.84 ± 0.71	15	12	0
4	125	12.5	100	0.75 ± 0.35	15	94	100
	125	0	100	1.41 ± 0.44	15	83	80
	* 0	0	100	3.75 ± 0.78	15	21	7
5	500	50	5	0.69 ± 0.48	15	89	100
	500	0	5	3.88 ± 0.25	15	14	7
	* 0	0	5	3.95 ± 0.44	15	18	0

Table 3. Mean specific growth rates, $\bar{G}$ (percent length increase per day) with 95 percent confidence limits and percent mortality in *Syringodium filiforme* after exposure to varying concentrations of Louisiana crude oil and Corexit dispersant for 14 days at 28–31° C—*n* is the number of healthy green blades measured (±0.5 cm); *CV* is the coefficient of variation in growth rate (*CV*, percent); mortality was determined by 100 percent browning of individual leaves; * denotes the control for each experimental trial.

Trial No.	Concentration in 10^4 mL seawater: Oil	Dispersant	Exposure time (h)	$\bar{G}$	*n*	*CV*	Mortality at 14 days (percent)
1	7.5	0.75	10	3.57 ± 0.43	13	7	8
	7.5	0	10	3.65 ± 0.37	13	12	15
	* 0	0	10	3.81 ± 0.54	13	9	0
2	75	7.5	5	3.24 ± 0.24	15	14	27
	75	0	5	3.58 ± 0.15	15	19	7
	* 0	0	5	3.10 ± 0.33	15	21	33
3	75	7.5	100	0.91 ± 0.45	15	94	80
	75	0	100	1.13 ± 0.65	15	87	53
	* 0	0	100	3.47 ± 0.51	15	14	7
4	125	12.5	100	0.64 ± 0.38	15	91	100
	125	0	100	0.85 ± 0.66	15	84	87
	* 0	0	100	3.51 ± 0.71	15	7	13
5	500	50	5	0.45 ± 0.32	15	96	100
	500	0	5	3.44 ± 0.58	15	14	13
	* 0	0	5	3.59 ± 0.61	15	8	0

There were no significant differences between *Halodule* and *Syringodium* in the mean specific growth rates ($P > 0.05$) or mortality when these species were exposed to varying concentrations of oil or oil combined with dispersant (Tables 2 and 3).

Halodule and *Syringodium* were not affected when exposed to oil concentrations ranging from 7.5 mL to 500 mL in 10^4 mL sea water for short durations of 5 or 10 hours, however, mean specific growth rates were significantly lowered ($P < 0.05$) in both species with longer exposure periods. When *Halodule* was exposed to oil concentrations of 75 and 125 mL in 10^4 mL sea water for 100 hours, the growth rates were reduced to $\bar{G}$ = 2.22 and 1.41 percent per day respectively and mortality rose to 47 and 80 percent (Table 2). Similar reactions occurred to *Syringodium* exposed to oil concentrations of 75 and 125 mL in 10^4 mL sea water for 100 hours (Table 3). It should be noted that the blades of the seagrasses did not touch the seawater slick in these experiments.

Dispersants plus oil did not effect *Halodule* or *Syringodium* at low concentrations (0.75 or 7.5 mL in 10^4 mL sea water) for short exposure periods (5 to 10 hours). However, these species were significantly less tolerant ($P < 0.05$) to higher concentrations and greater exposure times of oil mixed with dispersants than was *Thalassia*. At a dispersant concentration of 7.5 mL in 10^4 mL sea water for an exposure period

BEST AVAILABLE COPY

of 100 hours, the mean specific growth rates for *Halodule* and *Syringodium* fell to $\bar{G}$ = 1.85 and 0.91 percent per day, respectively, while mortality increased to 73 and 80 percent. *Thalassia* when exposed to the same concentrations of oil with dispersant for the same time period, had a growth rate of $\bar{G}$ = 3.98 percent per day and 20 percent mortality. The growth rates for *Halodule* and *Syringodium* were even lower when the concentration of dispersant was increased to 12.5 mL for 100 hours. $\bar{G}$ = 1.41 percent per day for *Halodule* and 0.85 percent per day for *Syringodium*, mortality for both species reached 100 percent by the end of the 14 day observation period.

Higher concentrations of dispersant mixed with oil also directly affected *Syringodium* and *Halodule* even at lower exposure times. At 5 hour exposure and 50 mL dispersant, the growth rates were further reduced to $\bar{G}$ = 0.69 percent per day for *Halodule* and 0.45 percent per day for *Syringodium*. Mortality reached 100 percent in 14 days. *Thalassia* was also affected ($\bar{G}$ = 2.45 percent per day) but to a lesser degree, and mortality did not exceed 50 percent.

The Louisiana crude oil used had the following profile: unweathered, aliphatic/aromatic 7.7/0.2; weathered, 7.4/0.2 ratio as determined by proton nmr in deuterated chloroform (Eugene Man, personal communication).

Discussion

In these initial laboratory experiments ranging from relatively low to high dispersant concentrations, clearly *Thalassia testudinum* was more resistant to Louisiana crude oil plus the dispersant Corexit 9527 than *Halodule wrightii* or *Syringodium filiforme*. *Halodule* and *Syringodium* had responses similar to one another. In these experiments LD_{50} for *Thalassia* appears to be near a concentration of 12.5 mL in 10^4 mL sea water for 100 hours, or 50 mL for 5 hours in 10^4 mL sea water. LD_{50} for *Halodule* and *Syringodium* with dispersant concentrations of 7.5 mL in 10^4 mL sea water occurs somewhere between five and 100 hours. More exact toxicity limits need to be defined by further experimentation.

It should be kept in mind that laboratory experimentation with only one stress (all other conditions optimum) frequently yields more optimal LD_{50} than field conditions where multiple stress factors often cause synergistic effects, thus lowering the LD_{50}. It would be prudent to test the limits found after further laboratory experiments *in situ*. Also, synergistic effects between sublethal ranges of oil plus dispersant combined with other important ecological factors (such as light, temperature, and salinity) need testing.

In terms of use of these preliminary data for guidelines, the following are offered:

- Subtropical and tropical sea grasses are more sensitive to oil plus dispersants than is shoreline vegetation (e.g., mangroves, compare to Teas, *et al.*[10]).
- *Thalassia* is more resistant for short time periods (5 hours) to dispersants than *Syringodium* or *Halodule*. Thus it is important to know the extent of *Syringodium* or *Halodule* habitats in acreage that might be affected in a coastal or estuarine region before a decision to use dispersants is made. We currently have no ability to extrapolate this for the different species inhabiting the other subtropical and tropical ocean basins of the world.
- Further laboratory and basic field testing is clearly necessary to define sublethal concentrations, ranges and times.

Acknowledgments

The authors gratefully acknowledge the support of the Mobil Oil Foundation. We thank Gordon P. Lindblom for supplying us with Corexit 9527, Edward Gilfillan for helpful discussions, and Howard Teas for many helpful discussions, and a supply of Louisiana crude oil. Our thanks also are due to Fitzgerald Booker who was instrumental in the experimental design and setup, and to Bartow Duhart who measured the seagrasses.

References

1. Baca, B. J. and C. D. Getter, 1982. The toxicity of chemically dispersed oil on the seagrass, *Thalassia testudinum*, using static and flow-through bioassays. *in* Dispersants: Five Years of Research, Abstracts. American Society for Testing and Materials, Philadelphia, Pennsylvania. 30pp.
2. Cairns, J., Jr. and A. L. Buikema, Jr., 1984. Restoration and Management of Marine Ecosystems Impacted by Oil. Butterworth Publishing Co.
3. Chan, E. T., 1977. Oil pollution and tropical littoral communities. Biological effects of the 1975 Florida Keys oil spill. *Proceedings of the 1977 Oil Spill Conference*, American Petroleum Institute, Washington, D.C., pp539–542.
4. Diaz-Piferrer, M., 1971. The effects of oil on the shore of Guanica, Puerto Rico. *Deep Sea Research*, v11, pp855–856.
5. IMO UNEP, 1982. Guidelines on Oil Spill Dispersant Application and Environmental Considerations. International Maritime Organization, London. 43pp.
6. Lopez, J. M., 1978. Ecological consequences of petroleum spillage in Puerto Rico. *Proceedings of the Conference on Assessment of Ecological Impacts of Oil Spills*, American Petroleum Institute, Washington, D.C., pp894–903.
7. Marcus, J. H. and A. Thorhaug, 1981. Lethal and Sublethal Effects on Seagrass Seedlings, *Thalassia testudinum*, Created by Light, Salinity and Temperature. Publication 160, Botanical Society of America, p51.
8. Mather, K., 1965. Statistical Analysis in Biology. Methuen and Company, Ltd., London. 267pp.
9. Nadeau, R. J. and E. T. Bergquist, 1977. Effects of the March 18, 1973 oil spill near Cabo Rojo, Puerto Rico on tropical marine communities. *Proceedings of the 1977 Oil Spill Conference*, American Petroleum Institute, Washington, D.C., pp535–539.
10. Teas, H. J., E. Duerr, and R. Wilcox, 1985. Effects of oil and dispersant on Rhizophora mangroves. *Proceedings of the 1985 Oil Spill Conference*, American Petroleum Institute, Washington, D.C.
11. Thorhaug, A., in press. Large scale seagrass restoration in a damaged estuary: Test plot program. *Marine Pollution Bulletin*.

BEST AVAILABLE COPY

ELASTOSOL, an oil spill control agent: Toxicity effects on tropical and subtropical seagrass, corals, fish and mangroves.

Anitra Thorhaug
Florida International Univ
1359 SW 22 Terrace
Miami, FL 33145

Barbara Carby/Richard Reese
Offc of Disaster Prepared.
12 Old Camp Road
Kingston, Jamaica

George Sidrak
Botany Department
Univ West Indies
Kingston, Jamaica

Marcel Anderson
Natural Resource
Conservation Department
59 1/2 Molynes Road
Kingston 10, Jamaica

Karl Aiken/Wendy Walker
Zoology Department
Univ West Indies
Kingston, Jamaica

Mike Rodriquez
Coast Guard
Jamaican Defense Dep
Kingston, Jamaica

Dr. Howard Teas
Biology Departmet
Univ of Miami
Coral Gables, FL 33124

Beverly Miller
Valerie Gordon
IMERU
Kingston, Jamaica

Franklin McDonald
UNDRO, Antigua

John McFarlane
Jamaican Defense Dept
Kingston, Jamaica

The toxicity of other than dispersant oil spill control agents (solidifiers, gels, sorbent and bioremediation agents) for cleaning oil spills has received very little attention (NRC, 1989; Thorhaug, 1991; IMO, 1991). This is the beginning of an attempt to give the same attention to the toxicity of these products to critical tropical/subtropical matrix organisms and fisheries species.

The product elastosol contains polyisobuylene and an oleophilic surfactant. Although it is proprietary, it has undergone chemical analysis and field testing (Fingas, 1989; Bobras, 1987a&b, 1988a&b; Fingas and Tennyson, 1988; Laun and Hingmann, 1988). A wide variety of crude oils became elasticized within 15 minutes more-or-less after elastosol treatment. These were retained in solidified condition up to 30 days with viscoelastic properties maintained over this time period. The properties appear to be that slicks are prevented from spreading and can be picked up by skimmers efficiently. With sensitive ecosystems, the major use of elastosol clearly will be relatively small confined spills probably at ports, marinas, oil refineries or in bays or estuaries. Thus, the tolerance of critical habitat organisms to elastosol is important.

METHODS:

Toxicity studies

Laboratory investigations. Standardized procedures used by the U.S. Environmental Protection Agency (EPA) and various agencies (FAO, UNESCO, UNEP) for testing tropical matrix organisms were employed so that standardized test results could be produced. The hope was to compare results with temperate results, along with UNEP European dispersed-oil toxicity data.

Selection of critical matrix organisms for tropical shorelines was a choice based on (1) importance to the food web, (2) rate and difficulty of replacement once decimated, (3) shoreline stabilization characteristics, and (4) usefulness to the nation (fisheries, tourism). Local experts such as Jeremy Woodley, director of the Discovery Bay Marine Laboratory and preeminent Jamaican coral reef expert, were asked to choose indicator species for the project.

Standardization among techniques for various groups was attempted so that the results of each group could be compared. Thus, the standardized portion will be explained first.

Laboratory conditions. The procedure was described in detail by Thorhaug and Marcus (1985). Fifty-gallon glass aquaria were used in out-of-door conditions (such as fluctuating light, temperatures, and running water) and, except for the mangroves and seagrasses, were protected from rain and wind. Temperatures ranged from 26° to 30°C, with fluctuation of 1°C ± 0.5°C. Seawater ranged from 30% to 33% (except for the mangroves). In seagrasses, three inches of beach sand was at the bottom. Corals tanks were bare. For seagrasses, a minimum of 15 blade groups of each species was placed in each tank (1 tank per treatment). Great care was taken in transport and holding conditions for the coral and mangrove specimens. Time for equilibration of specimens was allowed. 100,000 cc of seawater was placed in each treatment.

Laboratory procedures. Oil-only was a treatment in each set. Time for weathering of oil was 24 hours at 28°C in shallow plastic pans. The control tank was handled exactly the same as treatments. The dispersant was applied to oil floating on the tank surface with 1 minute of vigorous stirring. The dispersed oil formed a brown cloud of free-floating material, visually homogeneous throughout the tank (depended somewhat on concentration and dispersant). The coral and seagrasses were not touching the oil floating on the top; the mangroves were in contact on the bark. All specimens were in contact with the dispersant mousse.

The application of elastosol was 12.5 ppm oil, 75 ppm oil and 125 ppm oil with ____ mg (1 package) of elastosol. The exposure times were 6 and 10 hours for corals and seagrasses, 10 hours for mangroves. The treatment was immediately removed, and the water cleaned and changed in all treatments.

The specimens were incubated up to 14 days (coral, seagrass) and 9 months (mangroves). The observation period included daily or bi-weekly readings of health. Seagrasses had young green blades tagged and numbered. These were graded for discoloration, spotting, wilting and other morbidly symptoms. Corals were graded by bleaching, spotting, browning, wilted polyps, extruded polyps, and mucous secretion. Mangroves were graded by leaf drop, twig drop, root death and discoloration, leaf coloration, leaf spots, and leaf wilt. These symptoms of mortality and illness were made quantitative by experts and organisms were graded. The tables showing the results are not of heath but of mortality.

RESULTS:

Morphologically, the results of elastosol included the observation that the oil flowing on the surface of the tanks within a few minutes of treatment with elastosol congealed into long lines. There appeared to be no film on the glass sides of the aquaria or on the water. The mixture of elastosol and oil was complete.

There were a series of biological and morphological observations.

1) The corals continued with their polyp feeding patterns with the elastosol-oil mixture in the tank. This was an extraordinary result compared to the other compounds used in the test which were a variety of dispersed-oil products. Color and vigor of the polyps of all species was retained.
2) The elastosol had no apparent effect on seagrass or mangrove vigor or color.

The quantitative data for the various concentrations and various oils show that the oil plus the elastosol at concentrations of 125 ppm were appreciably less toxic than oil alone for corals and seagrasses. Mangroves had no effect from elastosol. Oil alone did not affect mangroves at these concentrations. Corals were the most sensitive to oil. The response of decreased toxicity by application of elastosol is seen dramatically at 125 ppm oil in corals where the control had a higher mortality than the oil plus the elastosol. The mangroves were far more tolerant of oil, plus oil and clean-up product of any kind than were seagrasses or corals.

CONCLUSIONS:

The herder or solidifier Elastosol does not appear to have marked toxic effects on the tropical/subtropical matrix organisms studied, even at high concentrations. Oil alone at the higher concentrations does have a toxic effect on seagrasses and corals. The results of dispersants at these same concentrations were highly toxic on the seagrasses, corals and mangroves for many of the products tested.

The elastosol in all tests was the least toxic of a series of oil spill clean-up formulations. The toxicity of oil alone was definitely greater than the elastosol treatments in almost all the concentrations tested.

The difficulty of application of elastosol would indicate use for a smaller spill such as a harbor or estuarine spills. The fact of very low toxicity corals would make this extremely well-adapted to spills near or over coral reefs. It may also be very helpful to control oil when spills are within mangrove swamps. Certainly, spills which cannot be mechanically handled or chemically dispersed may warrant the expense and application methods for elastosol.

Literature cited

Thorhaug, Anitra and Jeffrey Marcus, 1985. Effects of dispersant and oil on subtropical and tropical seagrasses. *Proceedings of the 1985 Oil Spill Conference*, American Petroleum Institute, Washington, D.C. pp 497-501.

National Research Council, Committee on Effectiveness of Oil Spill Dispersants, 1989. Using Oil Spill Dispersant on the Sea. National Academy Press, Washington, D.C., p 310.

Fingas, 1989.

Bobras, 1987a.

Bobras, 1987b.

Bobras, 1988a.

Bobras, 1988b.

Fingas & Tennyson, 1988.

Laun and Higmann, 1988.

Anitra Thorhaug[1]

Dispersed Oil Effects on Tropical Nearshore Ecosystems

REFERENCE: Thorhaug, A., "**Dispersed Oil Effects on Tropical Nearshore Ecosystems,**" in *Oil Dispersants: New Ecological Approaches, ASTM STP 1018*, L. Michael Flaherty, Ed., American Society for Testing and Materials, Philadelphia, 1989, pp. 257–273

ABSTRACT: Tropical and subtropical critical habitats are generally more fragile and slower to recover than temperate ones in which the environmental standards and guidelines are made. Fisheries nurseries are found immediately adjacent to shore in seagrass in the tropics, unlike temperate zones where fisheries are most frequently offshore and much of the adult fish catch is in this coastal region (the exceptions are a few highly migrating fish such as tuna). Studies have dealt with oil effects on corals and mangroves; fewer have dealt with seagrass. Very few studies have looked at dispersed oil on any of these habitats. The single dispersant used for mangroves and corals and the primary dispersant in seagrass studies was Corexit 9527, which showed no mortality on subtropical and tropical habitat species between 1 to 50 ppm (1:20 dispersant-to-oil dilution) for short (4 to 6 h) time periods. Higher concentrations of dispersed oil tested on seagrasses showed ranked sensitivity. Other dispersants have *only* been tested on seagrasses. Ranked sensitivity from nontoxic to very toxic appeared as in animal testing. The time of exposure and concentration of dispersants are important to increasing toxicity effects. Four species of corals were tested to Corexit 9527 1 to 50 ppm. Little difference in response was yet apparent. For mangroves, only the Western Atlantic red mangrove has been reported for the single dispersant Corexit 9527. (This manuscript was prepared in June 1987 when some ongoing experimental mangrove data were not yet published.) The Indo-Pacific basin critical habitat species and Arabian Red Sea species need similar testing for "safe limits." Field testing of various dispersants is necessary. Regulators and planners must stop using the generic "dispersants" in oil spill contingency planning and name a nontoxic substance tested in their ecosystems since some dispersants are toxic and others are not. We must establish a network to disseminate recent work.

KEY WORDS: dispersed oil, dispersants, tropical, subtropical critical habitats, mangroves, corals, seagrasses, oil pollution, oil spill, contingency planning, toxicity testing, tropical coastal ecosystems, fisheries

How Tropical Ecosystems Differ from Temperate Ecosystems

Fragility or Resiliency of Ecosystems

A system of rating the "survival" ability of ecosystems through natural and ecological disaster has been done by Cairns [*1*], whose recovery index (RI) compares resiliency, stability, elasticity, inertia, and vulnerability of ecosystems to irreversible damage. Thorhaug [*2*] has rated tropical ecosystems versus temperate, subtropical, and arctic ecosystems on this scale, which Cairns did not do (Table 1).

[1] President, Greater Caribbean Energy and Environment Foundation, P.O. Box 490559, Key Biscayne, FL 33149, research professor, Department of Civil Engineering, Florida International University, Tamiami Campus, Miami, FL 33199, and president, Applied Marine Ecological Services, Inc., P.O. Box 490559, Miami, FL 33149

46

TABLE 1—*Comparative coastal and estuarine habitat recovery ratings on Cairns (1980) scale*

	Temperate	Subtropic	Tropic	Arctic
1 Elasticity	medium	medium	low	low
existence of epicenters				
disseminule transport	high	medium	low	high
habitat conditions	high	medium	low	high
water quality	high-med.	medium	low	high
regional management	high	high	low	high
2 Inertia	high	medium	low	medium
organisms	medium	medium	high	high
viability in stable ecosystems	high	medium	medium	medium
redundancy	medium	medium	high	low
mixing capacity	high	medium	low	high
proximity to threshold	high	medium	low	low
regional management	high	high	low	high
3 Vulnerability to irreversible damage	high	medium	low	low
4 Resiliency	high	medium	low	low
overall recovery index	high	medium	low	medium

It can be seen that tropical nearshore ecosystems are low on the recovery index as a result of (1) lack of elasticity and resilience once perturbed, (2) vulnerability to ecosystem irreversible damage with pollutant stress, and (3) inertial factors (proximity to critical thresholds when polluted and low regional management capacities; that is, most third-world countries with much less capacity for managing ecosystems lie in the tropics, which are close to their critical pollution limits, while few first-world countries are situated in the tropics).

To give a specific example, a coral reef takes 10 to 50 years to recover naturally from disasters; mangroves, 20 to 50 years; seagrasses, 6 to 50 years. These recovery rates are all dependent on species and extent of impact. These are dependent on the extent of the damage, water and physical conditions, proximity of disseminule epicenters (islands are longest to recover), closeness to limit of range, high or low energy system, and several other factors.

Several investigators [2–4] have called the tropics "on the brink of disaster" because they are close to the critical threshold (LD_{50} or LD_{100} which is the lethal dosage at which 50% or 100% of the population being tested will die, respectively).

Fisheries

Much of the fisheries nurseries for the several thousand species fished in the tropics (with the exception of tuna and a few other strictly pelagic commercial species) are found very near to shore in seagrass beds, mangroves, and coral reefs. The adult stages may be captured out to sea, but the juveniles and eggs need these nursery habitats to complete their live stages. The temperate ecosystems have many fewer species and more abundance of these species. Spawning and juvenile habitat frequently occurs in open ocean, so that the estuaries and coastal areas lose a portion of their importance to the food web.

The fragility of tropical fisheries may be based on the reasons stated: that the tropics are

47

already at the high radiation, high temperature end of line. This "multiple-stresses" organisms so that additional stresses easily push them over the "brink of disaster." The reasons may be far more complex. Moore [3] theorizes that the reason there are so many more species in the tropics is that the radiation level, temperature level, and light are all higher and these cause genetic breakage and speciation. Examples of tropical ecosystems succumbing to pollutants of lower levels than their functional analogues in temperate ecosystems are abundant such as heated waste effects [5] and dredge and fill effects [6].

Toxicity Testing Standards for the Tropics

Because of the fact that most first-world nations are in the temperate zone, most of the environmental protection agencies that have research and development money for standard testing are in the temperate zone, thus the test organisms have been mostly temperate species for pollutant standards. An example is the U.S. Environmental Protection Agency (EPA). Almost all the designated test animals are temperate. Standards were set after elaborate testing in the laboratory and field for elimination of heated wastes. These standards were invalid when taken to tropical parts of the United States such as Miami, Key West, Puerto Rico, Hawaii, Guam, and Samoa. New standards had to be set up with tropical organisms. Rarely, if ever, have tropical organisms been used as standards in North America, Europe, or Japan.

In my opinion, the standardization tests for toxicity of a substance discharged into the environment must be redone using tropical organisms to set tropical standards such as the following outlines.

Critical tropical organisms that are vulnerable to pollution and affect the food chain are the estuarine and coastal matrix organisms. These important matrix organisms are coral reefs, mangrove, and seagrass species. In a few tropical locations, macroalgae *(Halimeda, Caulerpa, Laurencia)* or marshes might be included. When these are removed, hundreds to thousands of species have no habitat or nursery and thus are effectively removed from the area, even though they could survive the water quality characteristics.

The temperate zone has a plankton-driven food web in coastal areas, which sometimes dominates even in nearshore or estuarine areas. The tropics have benthically driven systems. The difference in recovery rate of a plankton system is days versus years for tropical food webs (at least two orders of magnitude longer).

Tropical Environmental Management, Standards, and Guidelines

Environmental management in the third world is basically 15 years old, being initiated with the United Nations Stockholm Conference on the Environment in 1972. Many developing nations set up environmental protection agencies in response to the mandates on valuable natural resources being decimated by the thoughtless management set forth at this conference.

The natural progression was to set up a large management agency. Then guidelines or standards and laws or policies to enforce sound environmental management were sought. Frequently the nation examined the set of laws, regulations, and policies from first-world nations. They were impressed with the thoroughness of first-world regulations. These standards were translated into the laws, regulations, policies, and legal frameworks used in that nation. For instance, in the Philippines, much of the environmental law (after Stockholm) appeared during a period of martial law, so it was decreed by Presidential Proclamation as a new set of laws. It bears a strange resemblance to U.S. EPA regulations, laws, and policies. Egypt had a very extensive set of environmental laws, but no agency to manage it

until the early 1980s. However, no enforcement funds, personnel, or policies were appropriated for the laws, making enforcement impossible.

Several items must be appreciated about tropical environmental management. In first-world countries, fairly strict laws, which are well enforced, are now operant. In first-world territories, protectorates, and second-world nations, such as Venezuela, Israel, and Middle East nations, this is also occurring. In third-world nations, which form the bulk of the tropical area, good policies and laws and an organizational structure frequently exist. Often low economic budgets, understaffing, lack of advanced professional training for staff, and other political constraints such as little veto power over the government's own environmentally impacting projects (roads, power plants, and other infrastructures) cause less than optimum resource management.

There is no place this phenomenon is so evident as in oil spills in the third world. Oil spills are frequently well planned for on paper. The process of implementation is entirely different. There, lack of enforcement, personnel, funds, and equipment are manifest. Frequently valuable natural resources are impacted during spills.

The first-world guidelines frequently are meant to protect offshore fisheries such as found in temperate areas and the more capital intensive first-world fishing fleets. The fisheries are nearshore in tropical and artesanal nations, and employment is an important element of fisheries. Present oil spill contingency plans are not calculated to protect the complex nearshore sets of critical habitats. *Offshore* spills are the assumed basis for most sets of guidelines for cleanup now in practice in tropical nations. When spills come close to shore, the trade-off, use of dispersant to protect the resources, while not impacting on others, is not understood or implemented. Spills in harbors or at terminals are particularly repetitive in some nations. Therefore, we see large losses of resources in one tropical spill after another: Nigeria, Panama, Puerto Rico, Jamaica, Bahrain, Indonesia, Egypt, and so forth.

Results

Comparative Dispersant Effects on Tropical Habitats

Tables 2, 3, and 4 show dispersant effects available from the literature. Seagrasses, mangroves, and corals are shown separately to compare dispersant effects within each critical habitat group. Unfortunately, scientists and government workers in the tropics do not publish material at the same rate as the first world, so there may be dispersed oil spills with unpublished results (I would appreciate receiving synopses from the authors of these). For instance, the Philippine Coast Guard was funded by the United Nations for a large dispersant toxicity testing program, but results were not published nor are they available. (Fish were the major test organisms.)

In general, there is more detailed data in laboratory experiments about seagrass than others. There is more field testing on corals. A wider range of dispersants have been tested on seagrasses than on mangroves or corals. More real-life spills have been documented on mangroves than seagrasses or corals.

The clearest point is that all reported testing, with one exception, has been in the Greater Caribbean, and we know nothing of other basins.

Importance of Seagrasses, Mangroves, and Corals to the Tropical World

Seagrasses are found from the tropics to the arctic and therefore differ from mangroves and corals, which are almost strictly tropical and found generally in subtropics close to the tropics (mangroves go to Anclote on the West Florida coast and Daytona Beach on the

East Florida coast). Seagrasses are a very critical habitat to tropical systems, forming a chief fisheries nursery for hundreds of commercial species. Seagrasses cover at least 1 million km^2 [7]. They are distributed from the high tide marsh in estuaries to the coastal areas in continental shelves. There are about 50 species worldwide.

Mangroves are found throughout the world's tropics, especially in low energy areas such as estuaries, lagoons, and river deltas. Throughout the world's tropics 500 000 km^2 are found [8]. There are about 50 species worldwide. The detritus adds appreciably to the productivity. The trees form a major intertidal and upland coastal habitat for hundreds of species.

Coral reefs are well known to be important structural elements to a coastline's integrity and to be habitats for a wide array of important species for fisheries and ecology. Reefs are chiefly coastal, tropical and in some seas are rarely found in estuaries. Reefs can be found on coastlines from the intertidal zone to the edge of the continental shelf. Of the world's tropics 600 000 km^2 contain corals. They are found in all tropical ocean basins. There are hundreds of species.

Because of the predominance of drilling on continental shelves, reefs and seagrasses are in danger of spills from most drilling sites. In Mexico and some Middle East nations, drilling is in and around mangrove areas. Tanker spills most frequently affect reefs, and secondarily affect seagrasses. Port, harbor, terminal, pipeline, and other "facility based" spills most frequently affect mangroves and seagrasses.

The Tethys Seas of ancient geological times had a worldwide tropical zone which connected through either Mexico or Central America and the Suez area. Species were similar. The uplift of the Central American area cut circulation and further speciation continued, making very different groups in the Red Sea, Indo-Pacific, and wider Caribbean. There are presently very different species of corals, mangroves, and seagrasses in each ocean basin with almost no overlap between the Atlantic and Pacific.

Differences of Toxicity Effects Between Species

Seagrasses—Tropical and Subtropical—In the Atlantic, the seagrass *Thalassia testudinum* is the most tolerant to high concentrations of oil and dispersed oil [9–12]. The least tolerant is *Syringodium filiforme*. *Halodule wrightii* sensitivity usually was similar, but it was slightly more tolerant to oil alone than was *Syringodium filiforme*. These sensitivity rankings were amazingly constant between concentrations, oil, and dispersant type. We have no data yet on the Indo-Pacific species, but would generally expect cogenetors to behave similarly based on comparative pollutant Atlantic versus Pacific work [13] (Figs. 1 through 4).

Mangroves—It should be pointed out that the tolerance to salt of the various 50 species of trees lumped as "mangroves" does not indicate similar physiology between species. Probably mangroves may be more dissimilar in toxicity response than seagrasses.

The only mangrove that has been dispersant tested for oil toxicity in experimental sites (canals) is the red mangrove *Rhizophora mangle* [14,15]. Several field situations give results for red mangroves [15–17]. Clearly, research on interspecific differences to dispersed oils of various types is called for.

Field results reported from the Atlantic would indicate *Rhizophora mangle* has a higher tolerance than the other species. The final results of the Panama experiment, only reported in abstract form at the time of writing [18], will no doubt resolve some comparative Caribbean tolerances. Other parts of the world beyond the Caribbean are yet to be tested for dispersed oil effects on various mangrove species. An ongoing project in Jamaica (Thorhaug, Teas, and McDonald) may answer questions for the Caribbean.

TABLE 2—*Tropical and subtropical dispersed oil and oil effects on seagrasses.*

Location	Author and Date	Type	Dispersant Used and Dilution	Conc. of Dispersant	Amount of Spill	Date	Resource Affected	Impact	Dispersant Effect
	Baca and Getter (1984) [22]	lab. outdoors	Corexit 9527	50-ppm oil 1:20 24 h	50 ppm oil lab.	1984	*Thalassia estudinum*	LD_{50} 12- and 96-h bioassays oil & dispersed oil	oil with dispersant has lower toxicity than without dispersant
Miami, FL	Thorhaug and Marcus (1985) [9]	lab. outdoors	Corexit 9527 1:20	La. crude Murban	lab.	1983–1984	Thalassia Halodule Syringudium	LD_{50} vs. time and conc.	at medium conc. high high at 5 to 100 h
Miami, FL	Thorhaug and Marcus (1985) [9]	lab. outdoors	Corexit 9527 1:20	La. crude Murban	...	...			
Miami, FL	Thorhaug and Marcus (1987) [11]	lab. outdoors	ARco D-609 1:10	La. crude Murban	...	...	Thalassia Halodule Syringudium	LD_{50} 5 h 100 h	low to medium low to medium low to medium at 75 and 125 mL
Miami, FL	Thorhaug and Marcus (1987) [12]	lab. outdoors	Conco K (K) 1:10	La. crude Murban	...	...	Thalassia Halodule Syringudium	LD_{50} at 5 & 100 h	medium to high high high

Panama	Getter (1986) [16]	field	Corexit 9527	50 ppm at 24 h	exp. Prudhoe Bay crude	1985	Thalassia testudinum	none to Thalassia	no effect on Thalassia
Miami, FL	Thorhaug and Marcus (1987) [11]	lab. outdoors	Corexit 9550	125- and 75-mL oil 1:20 disp. in 100 000 cm^3	La. crude exper.	1986	Thalassia Halodule Syringudium	100 h	low medium low to medium
Miami, FL	Thorhaug and Marcus (1987) [11]	lab. outdoors	OFC-D-607	SW La. crude 75- and 125-mL oil La. crude	La. crude exper.	1986	Thalassia Halodule Syringudium	100 h	low low medium
Miami, FL	Thorhaug and Marcus (1987) [12]	lab. outdoors	Cold Clean 500	La. crude 75 and 125 mL in 100 000 cm^3 SW	...	1986	Thalassia Halodule Syringudium	LD_{50} 100 h	low low to medium low
Miami, FL	Thorhaug and Marcus (1985) [9]	lab.	Finsol OSP-7	La. crude 75 and 125 mL in 100 000 cm^3 SW	...	1986	Thalassia Halodule Syringudium	LD_{50} 100 h	med.-low low low-med./low

TABLE 3—*Dispersed oil and oil effects on corals.*

Location	Author and Date	Type	Dispersant Used and Dilution	Conc of Dispersant	Amount of Spill	Date	Resource Affected	Impact	Dispersant Effect
Bermuda	Knap et al (1985, 1986, 1987) [*19*]	field and lab.	Corexit 9527 BP 1100 WD	1:20 1:10	Arabian light crude	1981–1986	corals	6 to 24 h after, 1 to 50 ppm on *Diploria strigosa*	No effect to brief exposures when oil dispersed 20-ppm polychaetes, bivalves crustacea intolerant
Arabian Gulf	Le Gore et al. (1983) [*20*]	field exper.	Corexit 9527 20:1		Arabian light crude	1980	corals	No impact immed. Some death after 6 mo. during winter cold	Unclear after 9 mo whether dispersant had effect or not
Panama	Getter and Ballou (1987) [*23*]	field exper.	Corexit 9527	50 ppm 20:1	Prudhoe Bay crude	1985	corals, seagrasses, mangroves	no coral death at 24-h exposure	No death on corals with dispersant.
Panama	Cubit et al. (1987) [*17*]	spill	Corexit 9527	20:1	50 000 med. wt. crude	1986	corals, seagrasses, mangroves	coral death	Reports intertidal reefs extensive mortality, subtidal to 2-m mortality

TABLE 4—*Dispersed oil and oil effects on mangroves.*

Location	Author and Date	Type	Dispersant Used and Dilution	Type of Oil	Amount of Spill	Date	Resource Affected	Impact	Dispersant Effect
Panama	Getter (1986) [16]	field	Corexit 9527 24 h 1:20	50-ppm Prudhoe Bay crude	exp.	1984	mangroves	defoliation death	Dispersed oil before it reached mangroves
Turkey Pt Biscayne Bay, Fl.	Teas et al. (1987) [15]	field	Corexit 9527 1:20	La. crude	exp.		*R. mangle*		
Coast on Caribbean side of Panama	Cubit et al. (1987) [17]	accidental	Corexit 9527, approx. 21 600 L 1:20	med. wt. crude	55 000 to 60 000	27 April 1986	*R. mangle*	defoliation death	
Coast on Caribbean side of Panama	Getter and Ballou (1987) [23]	exper.	Corexit 9527 1:20	Prudhoe Bay crude	exp.	1985	*R. mangle*	28% trees defoliated	no defoliation at sites with dispersant
South Florida	Teas (1986) [14]	field	Corexit 9527 1:20	50 ppm	exp.	1982–1986	*R. mangle*		
Panama	Teas et al. (1987) [15]	field spill	Corexit 9527 1:20	med. wt. crude	. . .	fall, 1986	mangroves	observed mangrove death	if dispersed before oil on mangroves less mortality

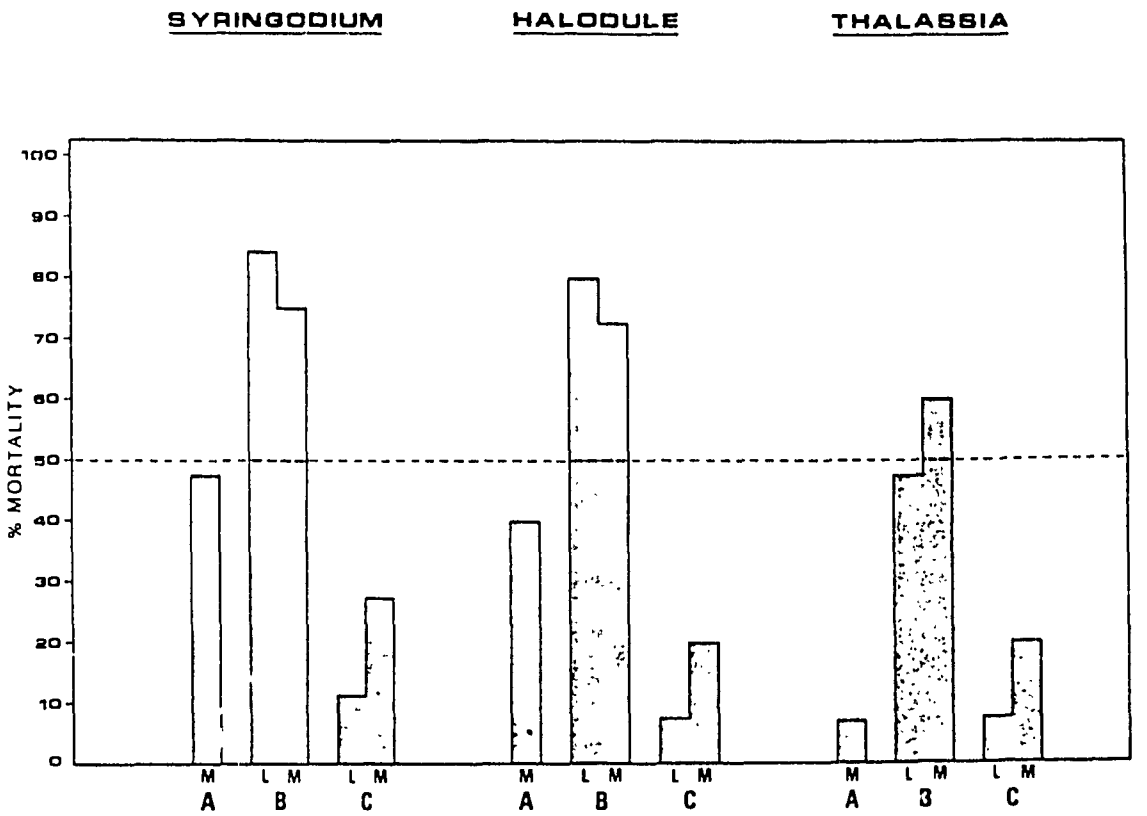


FIG. 1—*Time of exposure (5 h) of three subtropical and tropical seagrasses versus mortality.*

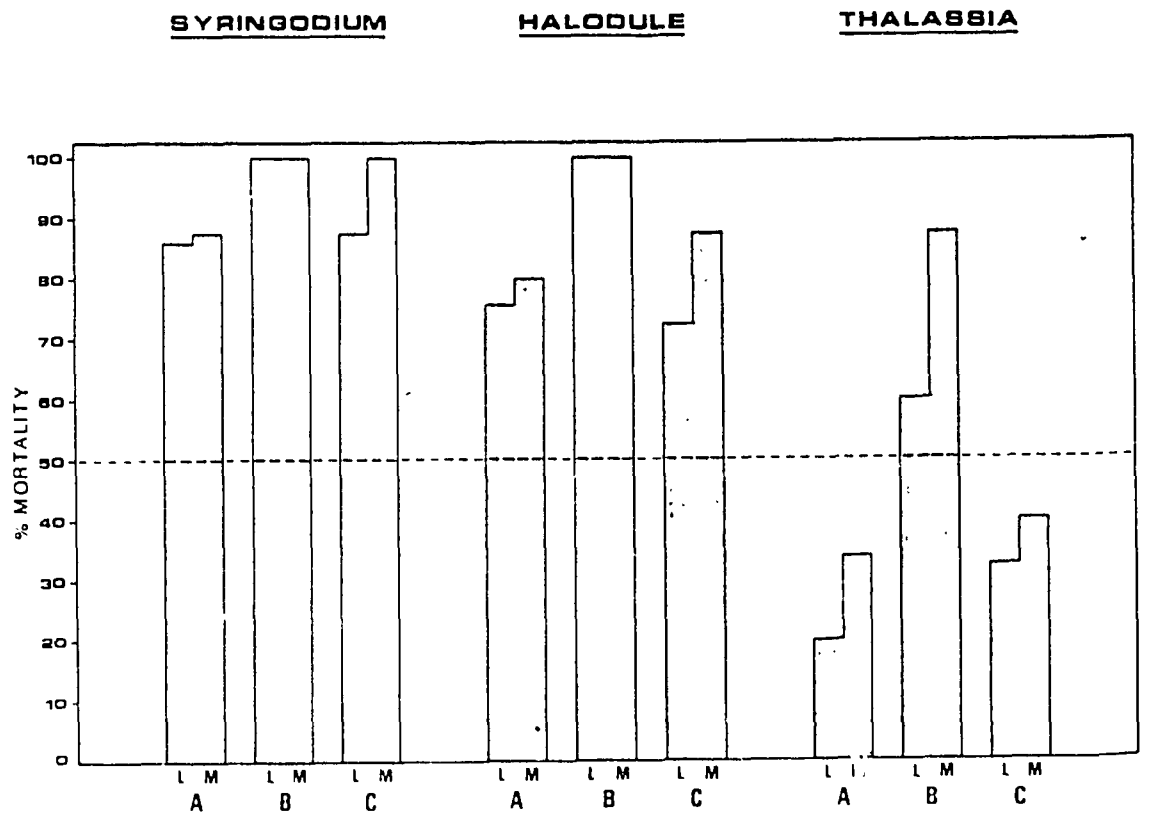


FIG. 2—*Time of exposure (100 h) of three species of subtropical and tropical seagrasses versus mortality.*

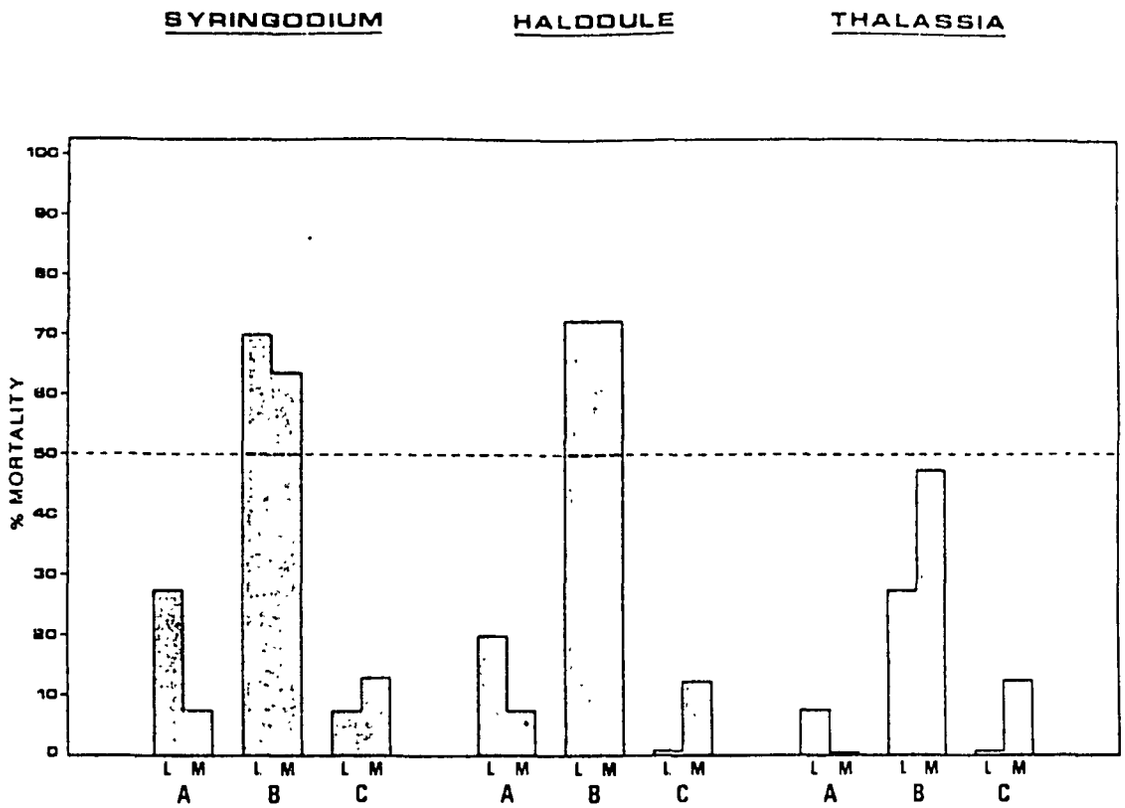


FIG. 3—*Dispersant type versus mortality.*

Corals—Several coral species have had dispersed oil spilled on them. Knap [*19*] mentions several *Acropora* species. Although several sets of field experiments have been carried out which used various corals [*16,19,20*], there was not a particular attempt to increase concentration until toxicity differences appeared to occur. Thus, there is not, at present from the publications, a hierarchy of sensitivities. My theory, based on toxicities of other substances, is that there may be various sensitivities among coral species[2] if experiments are carefully defined.

Differences Between Concentrations

Seagrasses—Large toxicity tolerance differences appeared as increased concentration-raised percent mortality for a species. In each case seen in Figs. 2 and 3, a general range occurred where some species are less than 50% and others (*Syringodium* and *Halodule*) are greater. Time of exposure also influences these sets of curves (Figs. 1 and 2). Statistically significant differences occurred between species at higher concentrations. These ranges are at least an order of magnitude above advised usage levels for dispersants, but useful for small and less controlled spills in bays and harbors in which greater than instructed dispersant concentrations may be used.

Mangroves—No comparative studies between concentrations of dispersants for mangroves could be found. The existing studies used different concentrations between authors, but too many variables occurred to make a comparison.

[2] Note added in final edit. Jamaica experiments are showing specific differences

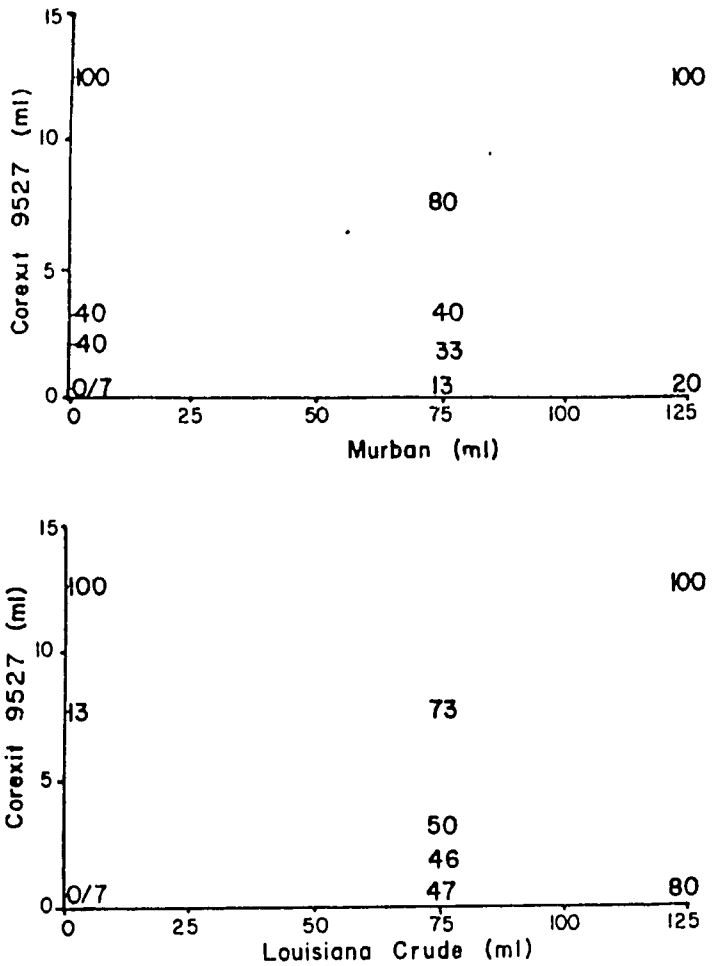


FIG. 4—*Oil type versus mortality for* Halodule wrightii *exposed for 100 h.*

Corals—There was some experimental work by Knap and colleagues [*19*] using concentrations in the range 1 to 50 ppm. The higher concentrations showed sublethal effects of behavioral treatment (tissue contraction, tentacle retraction, and localized tissue rupture); lower concentrations did not show such effects.

Differences Between Dispersants

The EPA toxicity tables indicate large differences among the 20 dispersant products listed with the U.S. Environmental Protection Agency. A biological indicator organism test was done by a scientific group using a temperate Pacific estuarine species. Indeed, large toxicity differences highly correlated with the EPA information were found [*21*].

Seagrasses—A set of laboratory experiments using three seagrasses and seven dispersants as dispersed oil was run [*7*]. The seagrasses responded generally in the same relative tolerance order to each of the dispersants. Dispersants could be clumped into three groups: low toxicity, medium, and high. Finasol OSR-7 was least toxic; Cold Clean 500, Conco K (K), Jansolv 60, OFC-D-609 were most toxic; and Corexit 9550 and 9527 fall in between. The difference between dispersants was much greater than differences between species (Fig. 3 and Table 5). This seagrass ranking of dispersed, toxicity oil correlated well with temperate animal toxicity data [*21*].

51

TABLE 5—*The effects of seven dispersants on three subtropical, tropical seagrasses* [12].

Dosage Oil, mL	Dispersants	*Thalassia testudinum* $\overline{G}$ ± 95% C.L.[a]	CV%[b]	% Mortality	*Halodule wrightii* $\overline{G}$ ± 95% C.L.	CV%	% Mortality	*Syringodium filiforme* $\overline{G}$ ± 95% C.L.	CV%	% Mortality
0	...	4.51 ± 0.22	18	0	4.20 ± 0.31	24	7	3.98 ± 0.25	28	7
75	Finasol OSR-7	4.22 ± 0.55	48	0	3.64 ± 0.35	15	7	3.41 ± 0.26	28	7
125	Finasol OSR-7	4.11 ± 0.41	37	7	3.52 ± 0.29	21	10	3.11 ± 0.61	35	10
75	Jansolv-60	3.98 ± 0.31	51	10	2.25 ± 0.61	64	41	3.05 ± 0.41	299	12
125	Jansolv-60	3.76 ± 0.24	18	18	2.11 ± 0.37	41	57	2.86 ± 0.35	22	25
75	Cold Clean 500	3.54 ± 0.11	9	16	3.31 ± 0.28	36	21	3.25 ± 0.25	18	18
125	Cold Clean 500	2.95 ± 0.37	21	26	3.22 ± 0.66	45	27	2.80 ± 0.54	28	30
75	Corexit 9550	3.35 ± 0.31	28	22	2.05 ± 0.45	31	58	1.97 ± 0.35	17	63
125	Corexit 9550	2.78 ± 0.41	35	37	1.69 ± 0.55	65	88	1.49 ± 0.45	41	84
75	Corexit 9527	3.28 ± 0.41	31	26	1.84 ± 0.41	60	76	1.39 ± 0.37	25	84
125	Corexit 9527	2.60 ± 0.33	28	40	0.66 ± 0.21	31	100	0.51 ± 0.45	37	100
75	OFC-D-609	3.10 ± 0.27	24	35	1.66 ± 0.31	24	73	1.42 ± 0.38	46	86
125	OFC-D-609	2.73 ± 0.45	38	51	0.54 ± 0.31	38	100	0.44 ± 0.39	29	100
75	Conco K(K)	2.10 ± 0.41	49	65	0.76 ± 0.75	61	97	0.59 ± 0.35	37	98
125	Conco K(K)	1.74 ± 0.35	37	88	0.45 ± 0.25	28	100	0.41 ± 0.68	52	100

[a] $\overline{G}$ = mean specific growth rate (% length increase/day) and C.L. = confidence limit.
[b] CV = coefficient of variation.

58

Mangroves—The mangrove studies, both field and experimental, carried out to date have all been with a single dispersant, Corexit 9527. There is no indication of the effect of other dispersants. Since dispersed oil is far better for mangroves than oil alone, it may result that a variety of dispersants are appropriate. These experiments are now ongoing with red, white, and black mangroves [*13*].

The major finding from experimental studies with Corexit 9527 is that dispersant-treated oil does not cause mass mortality whereas nondispersant treated oil (that is, no dispersant) can cause mass mortality, perhaps by cutting off oxygen from the prop roots [*14*].

Corals—Most field experiments as well as laboratory tests have dealt with one dispersant product, Corexit 9527. One study [*19*] tested 9527 (1:20 dilution) and BP 1100 WD (1:10 dilution) and found no statistical difference in the ranges 1 to 50 ppm with 6- to 24-h exposure with light Arabian crude oil.

Differences Between Oil Types

In general, both fresh oil versus "aged oil" and various weights of oil might have a difference in toxicity on habitat organisms. To date, no comprehensive program on any of the three critical habitat types has been carried out using various "ages" and types of petroleum products (Tables 2, 3, and 4).

Seagrasses—Oils and ages used were the following: light Middle Eastern crude, aged for 24 h in sunlight and air, and Louisiana crude, treated in the same manner. Both were tested on three seagrass species. No statistically significant difference between oils was seen. The more toxic "newly spilled" oil was not tested (Fig. 4).

Mangroves—Prudhoe Bay crude and Louisiana crude have been used for mangrove results. No differences have been pointed out by authors [*13–16*] or are apparent from results.

Corals—"Aged" Arabian light crude and Prudhoe Bay have been tested on corals. The authors [*16,19,20*] do not point out any differences between them, nor are they apparent from results.

Differences in Times of Exposure

There are several times of exposure that are relevant to tropical coastal oil spills: (1) very short times (1 to 2 h) where a parcel of dispersed or oiled water might flow over a habitat; (2) 6 to 12 h, where a tidal cycle could wash a dispersed or oiled water parcel onto a habitat, especially in an estuary; and (3) longer times where oil might sit in an estuary. The traditional EPA standard of 96 h (near 100 h), not designed for oil spills but for toxicity tests in general, is relevant to this.

Seagrasses—Three tropical Atlantic seagrasses have been tested for time of exposure response to Corexit 9527. Figures 1 and 2 show this result. Clearly, the longer exposure times have a greater toxicity effect, especially at higher concentrations of dispersant and oil.

Mangroves—Mangroves appear not to have had systematic experiments on time of exposure to dispersed oil.

Corals—Corals were exposed from 6 to 24 h to dispersed oil in a continuous flow experiment [*19*]. No toxicity appeared within this time frame. Field experiments were 24 h [*16*] and 6 h [*20*].

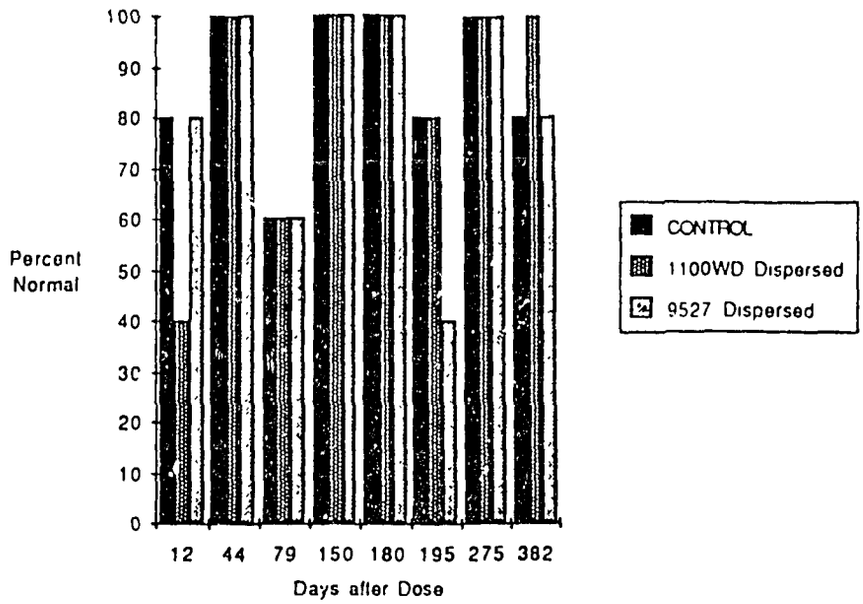


FIG. 5—*Seasonal effect of two dispersed oils on corals* [1].

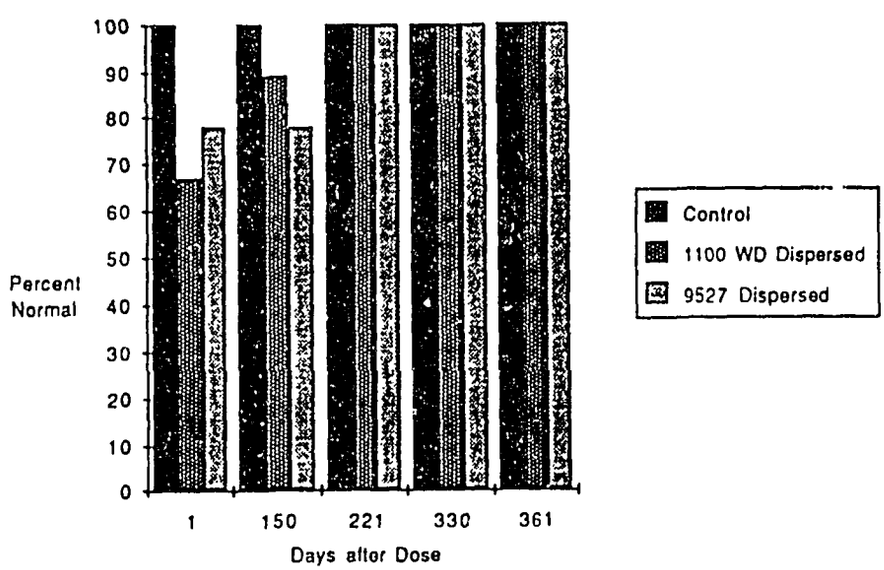


FIG. 6—*Seasonal effect of two dispersed oils* [1].

Seasonal Effects

Seagrasses—Tests were run throughout the year in subtropics. No differences were found.

Mangroves—No data for mangroves.

Corals—Seasonal differences in response to BP 1100 WD were seen in winter. No differences to Corexit 9527 were seen in winter (Figs. 5 and 6).

Conclusions

Management Principles for Use of Dispersants on Tropical Habitats

1. It is now apparent that certain selected dispersants at concentrations recommended by the manufacturer can be used under various sets of emergency conditions for oil spills

which frequently occur in the world's tropics: (*a*) estuarine spills where or when mechanical means are inadequate to control oil from impacting one or more type of habitat, especially mangroves; (*b*) nearshore coastal spills where environmental conditions are rapidly transporting spills toward one or more critical habitats; and (*c*) weather conditions when mechanical cleanup is ineffective and there is a danger of impacting corals, mangroves, or seagrasses.

2. All parties must stop using the generic term "dispersants" within the oil spill cleanup plans. Specific tested and nontoxic dispersants must be named or an approved list made as Britain does for spills on each habitat type with their upper concentration limits for use described.

3. Further laboratory tests must be done by nations in tropical areas to test their commonly used and stockpiled dispersants for toxicity effects on their critical habitat organisms such as various species of corals, mangroves, seagrasses, and marshes. It is unrealistic to imagine small third-world nations will find this a priority. Regional multilateral and industrial funding agencies should undertake this.

4. A network of rapid information dissemination to industry, environmental management, and government spill cleanup managers should be organized so that whatever information is derived can be disseminated.

5. Resource maps which must include the *exact* species of mangrove, seagrass, or corals should be included in oil spill contingency plans. Since the toxicity effects differ by more than an order of magnitude between species, present "lumping" resource maps (that is, "seagrasses") are inadequate. As an example, the U.S. Department of Interior is spending a large amount of money for seagrass maps without specifying the species. By integrating the resource maps into planning oil spill cleanup in a manner as Venezuela has, updated information can easily be incorporated into plans on a yearly basis.

Acknowledgments

The author wishes to acknowledge Mobil Oil Foundation for a three-year grant to test dispersants on seagrasses. Mr. Stu Horn, Dr. Hildrew, and Dr. McCullough of Mobil were most helpful in establishing guidelines for tests relevant to industry. L. Michael Flaherty of U.S. EPA toxic substances (ret.) is thanked for helpful discussions about differences among dispersants. Captain Charles Corbett and U.S. Coast Guard oil spill cleanup personnel in Washington, Miami, and Puerto Rico are thanked for discussions on cleanup problems. A variety of members of International Petroleum Industry Environmental Conservation Association (IPEICA) and American Petroleum Institute (API) are thanked, especially Dr. Duane Levine of Exxon, for discussions of the oil industries' problems. Members of the United Nations Environmental Programme office such as Dr. Tolba, Dr. Keskes, and in other offices Dr. Noel Brown (North American Liaison office) and the Caribbean Action Plan, especially Franklin McDonald, Jamaica; Mrs. Beverly Miller, Natural Resources Conservation Department, Jamaica; Venezuelan environmental staff; Mrs. Veronica Villavicencio, Philippines; and Dr. Kassas, Egypt are thanked. Dr. Howard Teas is especially thanked as mentor, particularly during the preliminary stages of oil being a new pollutant to us. Dr. Jeffrey Marcus was fully involved in all laboratory experiments on seagrasses. Fitzgerald Booker in year experiments.

References

[1] Cairns, J., Jr., Ed., *The Recovery Process in Damaged Ecosystems*, Ann Arbor Science, Ann Arbor, 1980

[2] Thorhaug, A., in *Micronesia*, Vol. 12, No. 1, 1976, pp. 49–65.
[3] Moore, S. F., in *Technology Review*, 1976, pp. 61–67.
[4] Thorhaug, A., Roessler, M., and Segar, D., in *Marine Pollution Bulletin*, Vol. 7, No. 11, 1973, pp. 166–169.
[5] Thorhaug, A., in *Ambio*, Vol. 10, No. 6, 1981, pp. 295–298.
[6] Thorhaug, A. and Marcus, J., in *Proceedings: 4th International Coral Reef Symposium*, Vol. 2, University of Manila, Philippines, 1982, pp. 14–20.
[7] Thorhaug, A., in *Oil Spills Research in Tropical Environments and Contingency Planning in the Wider Caribbean*, International Petroleum Industry Environmental Conservation Association, Venezuela, Jan. 1986.
[8] Kapetsky, J. M., "FAO Report of the 11th Session of the Advisory Committee on Marine Resources Research," Supplement, FAO Fisheries Report 358, 1985.
[9] Thorhaug, A. and Marcus, J., in *Proceedings, 1985 Oil Spill Conference*, American Petroleum Institute, Washington, DC, April 1985, pp. 497–501.
[10] Thorhaug, A., Marcus, J., and Booker, F., in *Marine Pollution Bulletin*, Vol. 17, 1986, pp. 357–361.
[11] Thorhaug, A. and Marcus J., in *Proceedings, 1987 Oil Spill Conference*, American Petroleum Institute Publication 4452, 1987, pp. 223–224.
[12] Thorhaug, A. and Marcus, J., in *Marine Pollution Bulletin*, Vol. 18, No. 3, 1987, pp. 124–126.
[13] Thorhaug, A., Teas, H., and McDonald, F., in *American Journal of Botany*, 1988.
[14] Teas, H., in *Oil Spills Research in Tropical Environments and Contingency Planning in the Wider Caribbean*, International Petroleum Industry Environmental Conservation Association, Venezuela, Jan. 1986, pp. 17–23.
[15] Teas, H., Duerr, E. O., and Wilcox, J. R., in *Proceedings, 1987 Oil Spill Conference*, American Petroleum Institute Publication 4452, 1987, p. 633.
[16] Getter, C. D., in *Oil Spills Research in Tropical Environments and Contingency Planning in the Wider Caribbean*, International Petroleum Industry Environmental Conservation Association, Venezuela, Jan. 1986, pp. 29–35.
[17] Cubit, et al., in *Proceedings, 1987 Oil Spill Conference*, American Petroleum Institute Publication 4452, 1987, pp. 401–406.
[18] Cubit, J. D. et al., "El Valor de los Manglares y Arrecifes en la Costa de Colon," in *Agonia de la Naturaleza*, Impetex, S.A., Panama, Rep. de Panama, pp. 183–199.
[19] Knap, A. H., et al., in *Proceedings, 1987 Oil Spill Conference*, American Petroleum Institute Publication 4452, 1987.
[20] Le Gore, R. S., Marszalek, D. S., Hofmann, J. E., and Cuddeback, J. E., "A Field Experiment to Assess the Impact of Chemically Dispersed Oil on Arabian Gulf Corals," SPE 11444, Society of Petroleum Engineers, 1983, pp. 51–60.
[21] Anderson, J. W., McQuerry, D. L., and Kiessere, S. L., in *Environmental Science and Technology*, Vol. 19, No. 5, 1985, pp. 454–457.
[22] Baca, B. J. and Getter, C. D., "Toxicity of Oil and Chemically Dispersed Oil to the Seagrass *Thalassia testudinum*," in *Oil Spill Chemical Dispersants: Research, Experience, and Recommendations, ASTM STP 840*, T. E. Allen, Ed., American Society for Testing and Materials, Philadelphia, 1984, pp. 314–323.
[23] Getter, C. D. and Ballou, T. G., in *Proceedings, 1987 Oil Spill Conference*, American Petroleum Institute Publication 4452, 1987.

Spill Clean-up in the Tropics:

Jamaica, as model for developing and developed nations.

Professor Anitra Thorhaug, Department of Biological Sciences, Florida International University, Miami, Florida.

Dr. Marcel Anderson, Director, NRCD, Kingston, Jamaica.

Ms. Beverly Miller, UNEP Caribbean Office, Kingston, Jamaica.

Major R. Reese, Director, Office of Disaster Preparedness.

Dr. Barbara Carly, Science Director, ODP, Kingston, Jamaica.

Captain Mike Rodriguez, Jamaica Coast Guard.

Dr. Franklin McDonald, UN Disaster Preparedness Office, St. Johns, Antigua.

Commander John McFarlane, Jamaica Armed Forces.

Professor Howard Teas, University of Miami, Coral Gables, Florida.

Ms. Valerie Gordon, IMERU,

Professor George Sidrak, University of West Indies, Department of Botany.

Professor Karl Aiken, University of West Indies, Department of Zoology.

Should we use dispersants to clean up nearshore spills when mechanical means fail? How does a small nation with limited mechanical equipment deal with a Valdez or Torrez-Canyon-type spill? With dispersants? Is it only good fortune that the catastrophic spills have been in first-world nations or oil-producing nations (Nigeria, Indonesia)? Should small nations on tanker routes consider dispersant plans for catastrophic spills? What would a rational and scientifically based dispersant policy be in a tropical developing nation? Is there a "best" dispersant to recommend for stockpiling? These were the questions repeatedly asked when we began.

On the one hand, IMO states dispersants should not be used near to shore". This is not based on tropical data. On the other hand, there are recent pieces of data by Teas and Duerr (1987), Ballou et al. (1989), indicating that mangroves can be saved from death if the dispersant Corexit 9527 is used on the oil <u>prior</u> to the time the oil hits the mangroves.

A large spill next to shore due to a pipeline break in 1984, which covered mangroves, killed acres of seagrasses, covered a beach and affected a fisheries nursery, convinced Franklin McDonald, Mike Rodriguez John McFarlane, and Richard Reese that dispersants could have been very useful when mechanical means could not be deployed due to shallowness of many nearshore areas and late alert from the spilling source. "Is there a non-toxic dispersant?", they asked Professor Anitra Thorhaug, who was testing a variety of dispersants on Florida seagrass. She brought Professor Howard Teas, who was testing Corexit 9527 on

mangroves, into the team. A project was born when U.S. Agency for International Development expressed a keen interest and granted funding. The goal was to clearly answer "Is there any dispersant product non-toxic enough to use on oil spills where mechanical means fail to work in Jamaica?" We knew local industries were using dispersants but not reporting it. Jamaica, being between Haiti and Cuba, in the northern chain of large Caribbean islands, has more than 200 miles of coast-line. There are 3 to 6 oil spills per year which are sizeable. There are many more small spills. The north coast is highly dependent on tourism for two thirds of exchange dollars in the economy. Tourism is based on natural resources, use of coral reefs, clear water, sand beaches. The south coast has large bays, where industry is sited, nurseries for fishermen and a lot of fishing activity. Most of the population lives on the south coast, and recreational facilities are there for citizens. Industry is largely sited on the south coast.

Critical habitat organisms that acted as matrix to a wide variety of species and took decades to restore themselves were our first target. We began our project by laboratory testing of the three critical habitat organisms: corals, seagrass, and mangroves. We then are moving to field studies and dispersant command map for Jamaica.

The coral studies of dispersed-oil effects were carried out on three indicator species selected from many potential species. The indicators were chosen by Dr. Jeremy Woodly, Director of Discovery Bay Marine Laboratory, and Jamaican coral reef expert. Back reef, where most spills occurred, were represented by

15

Porietes porietes, a finger coral. The predominant reef building coral was Monastrea annularis. The crest of reef coral indicator was Acropora palmata. Seven specimens of each were exposed to oil plus each dispersant for 6 and 10 hours (1/2 and 1 tidal cycle). The team was Dr. Thorhaug plus Natural Conservation Department of Jamaica, Dr. Anderson, Director, Lloyd Ardiner, team leader, and Peter Gayle, UWI. The laboratory was Discovery Bay. Results showed Conco K, ADP 7, OFC D609, Kemarine and Corexit 9527 to be quite toxic at both time periods, with two oils (light Venezuelan crude and Bunker C) and concentrations from 125 ppm dispersant to 12.5 ppm dispersant Corexit 9550 and Jansolv were 0-55% lethal on Porietes porietes and Montastrea annularis and far more toxic to the species Acropora at 125 ppm than at 75 ppm and 12.5 ppm (more realistic levels for applications and encounter of Acropora to the dispersant). Low toxicity products were Finasol OSR-7, Cold Clean, and "herder" Elastosol. Oil alone was 50% or more toxic to all three species at 125 ppm.

Seagrasses had toxicity which ranked in the same order to the same dispersant as did the coral. Three species were tested, Thalassia testudinum, turtle grass, a primary fisheries nurseries species, Halodule wrightii, shoal grass, found intertidally and also where impact had altered areas and Syringodium filiforme, offshore seagrass. (Previously Thorhaug and Marcus, 1987, have tested these three species, Syringodium had very similar tolerance to dispersed oil products as Halodule.) The site was a Kingston laboratory. The experiment team included Beverly Miller

66

(UNEP), Valerie Gordon (IMERU), NRCD staff, and Professor Anitra Thorhaug. Result showed Kemarine, Conco K, OFC D609, Corexit 9527 to be of high toxicity to all seagrasses. Corexit 9550 and ADP-7 were intermediate. Jansolv, Cold Clean, Finasol OSR-7 and Elastosol were of low toxicity.

We have done the same concentrations on year old mangroves taken directly from field to lab and incubated with sand and slow release fertilizer. At 1250 ppm oil and 125 ppm dispersant for 12 hours there was no statistically significant leaf drop among the various dispersed-oil types from controls. No mortality occurred. According to Howard Teas' survey of concentrations of oil on large-scale mangrove kills throughout the world, 5 to 10 liter per meter square is common in lethal oil spills. Thus, we will increase dosages on future yearling mangrove experiments.

The most important result to date is that clearly there are major differences in dispersant toxicities to corals and seagrasses between products. There are some products which have markedly less effect than oil alone and can be recommended for nearshore spills in Jamaica, dependent on field testing.

Fish toxicity studies to these same dispersed oils are now under way, with Dr. Karl Aiken and Dr. Thorhaug as co-investigators. The methods are the same as for corals and the dispersants are also the same. Results recorded twice daily over 96 hours. Fish were killed within an hour by Corexit 9527, Conco K, Kemarine. The lowest toxicity to sea bream were Finasol OSR-7, Elastosol, and Corexit 9550.

Thus, we have found to date the following:

1. The dispersant capable of saving mangroves of heavy oil

61

spills come ashore [Corexit 9527] is not advisable for use on corals, seagrass, and the commercial fish species tested. This dispersant is the corium only stock-piled one. Other dispersants could be used on coral, seagrass and fish.

2. The corals, seagrass and fish generally appear to have similar ranking of toxicity to the dispersants. The year old mangroves at similar concentrations were unaffected by the dispersants. There were one or two exceptions between groups. Individual species had varying sensitivities to the dispersants.

3. Our data indicates, especially when taken with data for field experiments in Miami and Panama, that certain dispersants may be used in case of mechanical equipment failure for nearshore clean-up.

4. The ongoing research needs field testing of these experiments prior to formulating the Jamaican dispersant use policy.

5. Suggestions to major stockpilers of Corexit 9527 have already been made as to less toxic products.

We will continue to present field and dispersant-use methodologies to Siren for use by other nations.

Acknowledgments:

The authors are extremely gratef l for the funding by U.S. AID Science and Technology Office, and AID Jamaica. The Jamaican government cooperation, . especially Office of Disaster Preparedness (Ministry of Local Government), Natural Resource Conservation Department (Ministry of Planning), Coast Guard (Jamaica Defense Department), and others, have been extremely helpful. The Mobil Oil grant to Dr.'s Thorhaug and Teas has been helpful in underlying Florida date and the fish toxicity data. UWI faculty Dr. Jeremy Woodly, director of Discovery Bay Marine Station, Professor George Sidrak, Chairman of Botany, and Dr. Kark Aiken, Zoology, are to be thanked heartily for their hands-on help in experimental phases.

Chapter 4

OIL SPILLS IN THE TROPICS AND SUBTROPICS

Anitra Thorhaug

TABLE OF CONTENTS

I. Introduction .....
- A. Decision-Making Realities for Environmental Scientists and Environmental Managers .....
- B. Cleanup Methods .....
- C. Types of Biologically Important Oil Spills in the Tropics .....
- D. Computer Models for Decision-Makers regarding Oil Spills and Dispersed-Oil Impact on Species .....
- E. Costs .....

II. Results .....
- A. Comparative Toxicity of Oil Alone on Various Tropical Ecosystems .....
  1. Mangroves .....
  2. Corals .....
  3. Fish .....
  4. Seagrasses .....
  5. Comparison .....
- B. Comparative Dispersed-Oil Effects on Various Groups of Tropical Organisms .....
- C. Differences of Dispersed-Oil Toxicity Effects Among Various Dispersants .....
  1. Seagrasses .....
  2. Mangroves .....
  3. Corals .....
  4. Fish .....
  5. Comparative Dispersant Effects on Tropical Matrix Species .....
- D. Differences of Dispersed-Oil Toxicity Effects Among Species within Phyla .....
  1. Seagrasses .....
  2. Mangroves .....
  3. Corals .....
  4. Fish .....
  5. Invertebrates .....
- E. Differences among Concentrations of Dispersed Oil .....
  1. Seagrasses .....
  2. Mangroves .....
  3. Corals .....
  4. Fish .....
- F. Differences between Oil Types .....
  1. Seagrasses .....
  2. Mangroves .....

100 T

3. Corals .....
G. Differences in Times of Exposure .....
1. Seagrasses .....
2. Mangroves .....
H. Seasonal Effects .....
1. Seagrasses .....
2. Mangroves .....
3. Corals .....
I. Temperature of Spill .....
J. Mitigation after Oil Spills .....
K. Methods of Managing Spills .....
1. Mechanical Cleanup .....
2. Shoreline and Reef Cleanup .....
3. Other Techniques .....
4. Dispersant Cleanup .....
L. Dispersability of Oil .....

III. Recommendations .....
A. Policy .....
B. Preparedness .....
C. Stockpiling Correct Equipment .....
D. Dependence on Others' Equipment .....

IV. Discussion .....
A. Management Principles for Use of Dispersants in Tropical Habitats .....

Acknowledgments .....

References .....

I. INTRODUCTION

This chapter will review major impacts of oil spills in the tropics and the techniques for managing those oil spills, including recent dispersed-oil data. It will also include cost and policy issues, as well as recommendations. The information is meant to bring the reader to a more comprehensive view of a subject frequently treated in most books as individual case studies, which are of very limited value. Predictive use of data for decision-makers and implementors is essential. Thus, a synoptic understanding is important.

Much of the tropics lies in the third world. The petroleum industry has production and shipping ports throughout the subtropical and tropical world: the Red Sea, Arabian (Persian) Gulf, Indonesia and Brunei, Venezuela, Ecuador, Mexico, Nigeria, Angola, and the Gulf of Mexico. A map of major shipping lanes (from the Middle East, Nigeria, Indonesia, Mexico, and Venezuela) by the International Maritime Organization (IMO) shows that many tropical nations, which themselves do not produce oil, are on major shipping routes between producers and consumers. (Bilging brings 7.2 million bbl of oil into the environment per year.) All of the East and West African and Caribbean nations fall on major oil tanker routes, as do Pakistan, India, Sri Lanka, and Southeast Asian countries. Other nations, such as South Pacific nations, must realize that all ships carry petroleum. Local oil depots, refineries, and ports and harbors have higher accident rates than do petroleum transport ships.

Yearly input of petroleum hydrocarbons, from transportation sources, includes the following totals: 126 million gal from accidents, 300 million gal from bilging; 320 million gal from municipal wastes; 12 million gal from offshore production.[1] Bilging and accidents are chiefly on tanker routes.

This chapter will deal mainly with the 126 million gal spilled from accidents and 12 million gal from offshore production. A large amount of the 300 million gal from bilging — if reported and treated rapidly enough — can also be handled in the same manner. Municipal wastes are a question of storm water runoff and hazardous materials disposal, and must be treated seperately. We do not address that issue here.

A. DECISION-MAKING REALITIES FOR ENVIRONMENTAL SCIENTISTS AND ENVIRONMENTAL MANAGERS

Oil spills present a different problem to the environmental manager and to the environmental scientist than do most pollution sources. The spill is already an ongoing fact. An unfortunate accident has occurred which no one wanted, no one chose. The sole problem for the environmentalist is, "Which strategy would be the most realistic to minimize environmental impact?" There are few choices, none ideal. To do nothing may result in a great catastrophe. The management process is something like a forest fire, without any good biological results at the conclusion. Also, there will be a great many players intensely involved in oil spills, including those from the military, the petroleum industry, and politicians.

B. CLEANUP METHODS

Despite more than 50 years of research, there are only four major methods of cleaning spills: (1) mechanical cleanup, (2) shoreline cleanup, (3) no spill control and (4) dispersants.

Mechanical cleanup had 20 years during which it was the only acceptable or preferred method. A great deal is known about its limits. Much environmental damage has been done because it was the accepted method. It works in small discrete spills quickly reported and responded to, near the site of the equipment where an experienced team can immediately surround the spill and where the seas and winds are fairly calm. Frequently mechanical cleanup fails. For a developing nation it is seen as advanced technology which is expensive to prepare for and difficult to perform well. At the end of the cleanup, there is the question

of land disposal of the used oil. The situations under which mechanical cleanup is not likely to work are the following:

1. When seas are rough; tide currents or winds are high.
2. When the site is distant from the equipment; the time to surround the spill is critical to calculate ahead of time.
3. The shallow areas or sensitive bottom types can be damaged during deployment, since the boats must maneuver.
4. The boom must be in good working order; breakages have been known (Panama), and then the cleanup results can be very difficult; therefore a backup position is always necessary. Secondary spills are common.
5. It is rare in a large spill (50,000 gal or more) that all the oil is mechanically contained. A second choice frequently must be made for the noncontained remaining oil.

The environmentalist must face the fact that the "mechanical option" is likely to result in much unmanaged oil. It is far easier and safer to make the decision to cleanup by mechanical means than it is to implement this decision, particularly in second- and third-world nations. The final problem is disposal of waste oil which must enter as a part of the "mechanical decision". Many countries do not have places to dispose of waste oil.

The choice of shoreline cleanup has several environmental hazards, if the shoreline surface — in contact with the oil — has coral or vegetation, mangroves, marshes, algae, and animals. Intertidal flats, especially coral reefs within 2 ft of low tide, are frequently the tropical shorelines in which that oil strands. Mangroves are definitely killed by oil when the oil hits their roots. Corals are definitely killed by oil. Animals are killed by oil. Thus, living shorelines, which concentrate large amounts of oil, are not good places for oil to strand. Beaches can be scraped to remove oil. This is costly, and it also can lead to beach erosion. Cleanup on a coral reef or in mangroves can cause harm.

The "do nothing" decision is usually best when oil is headed out to the deep sea and/or when the spill is in the deep sea and not coming to shore. It is the worst decision nearshore, when coral reefs and/or mangrove swamps are going to be affected. Frequently, "do nothing" is what occurs due to bad preparations and lack of adequate decision-making ahead of time. Hundreds of miles of mangroves around the world have been damaged, due to this decision (Indonesia, Nigeria, Puerto Rico, as examples). The dispersant decision is discussed in this chapter in detail, as well as recent work in the 1980s on dispersants which had not previously been analyzed in great detail. Dispersant solution was shelved for 20 years. The problem was that the older generations of dispersants, as exemplified by Torrey Canyon, were highly toxic. Thus, two decades have passed during which time the dispersant option has not been used in large-scale tropical field situations, although in the Temperate Zone alone, the author can name 50 examples of dispersant use in the last 5 years with no negative effects. This lack has provided large numbers of mechanical cleanup, beach cleanup, and "do nothing" examples. Many of these have been highly resource damaging. The dispersant option for temperate and arctic organisms has been discussed by the U.S. National Academy of Science,[41] and they seemed to agree that dispersants are a viable option. They emphasize the need for tropical information and quote some of the older tropical work included here.

Dispersants have the ability to flow with the tides and currents, whereas normal oil flows with wind vectors. Usually the oil alone ends up, in good part, stranded onshore, whereas dispersed oil tends to be carried out to sea.

The other options are, at this point, mostly theoretical, i.e., not tested and not known to be either effective or nontoxic, except under specific conditions.

1. Flaring is rarely done because it needs a certain thickness of oil and needs to be away from the vessel for safety factors.

2. Sinking compounds coat or smother organisms, can re-release oil, and blobs of oiled compounds in the environment, which must be dealt with. Obviously, they are very bad for infauna.
3. The gels are not yet commercially on the same order of magnitude with sorbant pads or dispersants and are practically out of the question, due to cost. Some have low toxicity.
4. The bacterial-activated compounds have not been tested, to our knowledge, in large scale on mangrove forests, coral reefs, or in seagrass beds. Their work on beaches, rocks, and the deep sea looks promising, but expensive. If developing nations must clean up the spills themselves, cost is of the essence frequently.
5. Other new products continually come on the market, and one must keep up to date on these products.

No doubt 5 years from now, the subject will have dramatically advanced. It is necessary to keep up with research in this field.

C. TYPES OF BIOLOGICALLY IMPORTANT OIL SPILLS IN THE TROPICS

Another important set of factors to remember is the types of spills and the priority to biological protection. There are offshore spills which can be from moving vessels or from fixed points. If the spill moves offshore or out to sea, the biological protection priority is fairly low. If it is moving toward land, it is high. The second case is coastal shoreline spills. This case usually needs biological protection, especially with onshore winds and sensitive shorelines (mangroves, corals, seagrass, etc.).

The third case is in an estuary. This type of spill almost always needs much protection. The unfortunate part of the estuarine type is that there is seldom much time between the spilling and the resource being hit. The time to mobilize mechanical cleanup crews and boats can be 4 to 6 h. Oil from a port or harbor collision can be in the mangroves in 1/2 h. The realities of the cleanup operation and its timing should be clearly understood by the biologist. If the mechanical cleanup tools are available, but there is no chance of their protecting the estuarine mangroves before 6 h to mobilize crew, obtain boom from storage, and put the boom in place (the fairly simple projection of the winds pushing the rapidly leaking oil from a barge that has collided with an object midestuary predicts 40,000 gal in the mangroves in 1.5 h), the biologist would be highly irresponsible to stick with the high risk of mechanical equipment not adequate in timing for protection. The management Plan B (nontoxic dispersant sprayed right away on the leading edge) should be called into immediate action, because unless that operation is mobilized, the mangroves will be killed as the tide goes low.

The key here is clearly and realistically seeing the options and risks, then generating predecisions so that the command person does not need to struggle through a postdecision, as in the Exxon Valdez incident. The command person will have enough difficulty implementing the plan, whatever it is, even if a predecision has been made.

A quantitative picture, rather than a qualitative picture, of the exact dimension and trajectory of the spill is of greatest help to all concerned.

D. COMPUTER MODELS FOR DECISION-MAKERS REGARDING OIL SPILLS AND DISPERSED-OIL IMPACT ON SPECIES

One of the best uses of concentration mortality data for species has been seen in the simulations of oil spills and dispersed oil spills. Much of the above-mentioned data have been used in a Gulf of Mexico simulation by Ross et al.[2] for the U.S. Gulf Coast. The field experiments done on spill trajectories and dispersed oil trajectories, along with currents, winds, tides, and chemical data, are programmed into a geographic information system with

104T

40-1

extensive spatial analytic capabilities. The environmental regulators in the Gulf States chose 90 species, including important commerical fish and invertebrates, critical habitat organisms (corals, seagrass, mangroves, marshes), endangered species, and a few others. The algorithms assessed for resource-specific impact linking oil or dispersed-oil concentrations to organism tolerance can compute mortality from the spill point as the spill is diluted in time and space. The readout is a map with spill trajectory over time as concentration dilutes. The impact on all resources and location of impact is calculated and read out specifically such as "percent mangrove mortality". The program is run a second time with the same oil source and spill volume, but dispersed. The mortality is again computed, readout, and this time compared with "oil alone". Frequently, there are large resource impact differences between the two spills. The quantitative visualization of the potential impact over time, space, and important species can wipe away "fuzzy thinking" and allow detailed predecisions about whole sets of spill scenarios. Many biological managers would be better off to have a visual image of spill trajectory over time and concentration.

I recommend this technology for predeterminatica of operational techniques with all parties concerned with studying the options and making decisions.

Up to now, no tropical nation has this capability. South Florida is the only tropical region that has this.

E. COSTS

Cost accounting must consider short-term cleanup costs and long-term resource value costs. When all options are available and it is the taxpayers or citizens of the area who will bear the expense of cleanup (Bahrain's catastrophic spill, for example), then cost becomes a major factor to be taken into consideration. Long-term as well as direct costs must be considered. If the cost will be borne by the insurance company of the spiller or by the spiller, then the manager must deal with these parties.

There is the hidden cost of taking away the oil removed from beach cleanup and disposing of it properly. If the developing nation has no appropriate oil dump so the oil will not enter into the ecosystem through storm runoff from dumps, then the shoreline cleanup option must be reappraised due to risk from the ultimate dumping point of oil. The Jamaican government now faces a fisherman's legal action for such a strategy.

The cost to the ecosystem of tens of miles of dead mangroves which could take 25 years to reestablish the forest properties for primary productivity, fish nurseries, etc. is a large amount of money. A coral reef is worth more than $200,000/ha, according to United Nations Environment Program (UNEP). Tourism loss where a spill covers a tourist beach would be a direct cost to take into account.

The socioeconomic costs of disruption of the lives and diet of communities dependent on artesanal fisheries, especially children and pregnant women, is another hidden cost. The direct loss of tourist industry revenue for exchange dollars should be carefully thought out during plans for oil-spill contingencies in areas such as the Caribbean, East Africa, and Pacific nations. (See Reference 26 for a full explanation of environmental cost accounting.)

II. RESULTS

A. COMPARATIVE TOXICITY OF OIL ALONE ON VARIOUS TROPICAL ECOSYSTEMS

1. Mangroves

There has been a wide array of mangrove oil spills reported to kill mangroves in Nigeria, Indonesia (on several occasions), Panama,[6] Kenya, Puerto Rico,[8] and other areas. Several oil spills which did not sink into the root systems, but only oiled the bark of mangroves at high tide, were reported not to kill the mangroves.[24, 42, 43] A mesoscale field experiment

6
6501
6645

with mature red mangroves in the Caribbean[13] indicates that dispersed oil Corexit 9527 does not kill the red mangrove, even at high concentrations, but oil alone at that same concentration kills the red mangrove *Rhizophora mangle*. If the dispersant was placed on the mangrove after the oil reached the roots, the mangrove died as if no dispersant had been added, but oil alone had spilled. The field experiments of Getter et al.,[9] Ballou et al.,[2] and Cubit et al.[21] on red mangroves in Panama reestablished that dispersed oil (Corexit 9527) does not kill mangroves.

Our experiments[3] in the laboratory with very young (6 months to 1 1/2 years) red, black, and white mangroves showed that the oil concentration between 1 and 125 ppm had no effect on red and very little on black and white mangroves. The higher concentrations (1250 and 12,500 ppm) did have effects on black and white mangroves (Tables 1 and 2).

2. Corals

The coral, *Diploria strigosa*, in laboratory and field conditions, has been shown by Knap et al.[4, 5] to have been affected by oil alone. Oil spills in Egypt,[36] in Indonesia, in Curacao,[7] and in Panama[6] showed a series of species of corals in various oceans to be sensitive to oil.

Emerged coral reefs are clearly more vulnerable to oil than those submerged. Bak[7] has shown oil effect down to 125 ft on high energy coastlines in Curacao (Table 3).

3. Fish

Fish have been extensively tested in temperate and subarctic waters, but tropical oil tests and reports are far less available.[1] Several large tropical oil spills enumerate fish and invertebrate kills such as Puerto Rico[A, 8] and Indonesia and Singapore government reports.

The data in Thorhaug, et al.[3] show four important tropical commercial fish to be very sensitive to oil spills. Frequently, fish are far less sensitive to pollutants than tropical seagrass and corals, but this is not apparent in these data (Table 4).

4. Seagrasses

Tropical and subtropical seagrasses have been tested between 12.5 and 125 ppm oil. The results show that lethal concentrations are greater for *Thalassia testudinum* and less for *Halodule* and *Syringodium*. The type of oil was important to the toxic effect on seagrasses (Figure 2). In field situations, real spill results have been far less accurate for seagrass than any other critical habitats (Tables 5, 6, and 7).

5. Comparison

When the three sets of dominant matrix organisms were tested using the same relative methods and the same oil at the same location, the mangroves were approximately 100 times more tolerant than the seagrasses. The seagrasses were somewhat more tolerant than the corals at high concentrations of oil (Tables 5 and 6). (These experiments used oil at 10 times the concentration expected in a normal open water spill and 6 to 10 times longer exposure time). The tropical commercial fish had tolerances similar to corals.

Now, why do we have so many reports of mangrove deaths if this is so? First, the oil grows in concentration along a shoreline, which acts as a sorbant. Mangroves have been found by Teas et al.[13] in the field and in the literature to have oil levels 5 to 10 l/m^2. Second, oil spreads from the source where it could be 0.3 mm thick to a thinner and thinner film. Thus, the corals and seagrass, unless in very shallow water, would never experience more than 50 ppm oil whereas mangroves might experience orders of magnitude higher, especially in the holes in the sediment, where oil might accumulate near root structures of mangroves.

TABLE 1
Dispersed Oil and Oil Effects on Mangroves

Location	Type	Dispersant used & dilution	Type of oil	Amount of spill	Date	Resource affected	Impact	Dispersant effect	Ref.
Panama	Field	Corexit 9527, 24 h, 1:20	50 ppm Prudhoe Bay crude	Exp.*	1984	Mangroves	Defoliation, death	Dispersed oil before it reached mangroves	9
Coast on Caribbean side of Panama	Accidental	Corexit 9527, ca. 21,000 l, 1:20	Medium weight crude	55,000—60,000	Apr 27, 1986	*R. mangle*	Defoliation, death		21
Coast on Caribbean side of Panama	Experimental	Corexit 9527, 1:20	Prudhoe Bay crude	Exp.	1985	*R. mangle*	28% trees defoliated	No defoliation at sites with dispersant	9
South Florida Turkey Pt., Biscayne Bay, FL	Field	Corexit 9527, 1:20	50 ppm LA Crude concentrated	Exp.	1982—1986	*R. mangle*			13
Panama	Field spill	Corexit 9527, 1:20	Medium weight crude		Fall, 1986	Mangroves *R. mangle*	Observed mangrove death	If dispersed before oil on mangroves, less mortality	34
Jamaica	Lab	11 dispersants	Venezuelan	Exp.	1988—1989	*Rhizophora* *Avicennia* *Laguncularia*	Defoliations, death of root	Various at 1250 ppm not low	3

* Exp. = experimental.

Revised 1/27/89

TABLE 2
The Mortality Percent of Jamaican Mangroves Exposed for 10 h at 1250 ppm Dispersed Oil

Dispersants	Rhizophora (red) (%)	Avicennia (black) (%)	Laguncularia (white) (%)
Conco K	28.6	14.3	80
OPC D609	42.9	14.3	25
Corexit 9527	71.4	0	40
Corexit 9550	0	0	20
Wonder-O	42.9	14.3	50
ADP-7	28.6	28.6	50
Jasco Iv	14.3	0	60
Cold Clean	28.6	14.3	20
Finasol	0	14.3	40
V-25	71.4	14.3	40
LTX	nd	nd	nd
Oil only	14.3	28.6	40
Control	0	14.3	14.3

From Thorhaug, A., Carby, B., Reese, R., Rodriguez, M., McFarlane, J., Teas, H., Sidnak, G., Anderson, M., Aitken, R., McDonald, F., Miller, B., Gordon, V., and Geyla, P., in *Proc. 1991 Oil Spill Conf.*, American Petroleum Institute, Washington, D.C., 1991.)

B. COMPARATIVE DISPERSED OIL EFFECTS ON VARIOUS GROUPS OF TROPICAL ORGANISMS

Tables 1-4 show dispersant effects available from the literature. Seagrasses, mangrove, and corals are shown separately to compare dispersant effects within each critical habitat group (Table 8, A and B). Unfortunately, scientists and government workers in the tropics do not publish material at the same rate as those in the first world, so there may be dispersed oil spills with unpublished results. For instance, the Philippine Coast Guard was funded for a large dispersant toxicity testing program, but results were not published nor are they available (fish were the major test organism).

In general, there are more detailed data in laboratory experiments about seagrass than others: Fish data are abundant from temperate zones, but sparsely available in the tropics. There is more field testing on corals than mangroves, seagrasses, or tropical fish. A wider range of dispersants has been tested on seagrasses than on mangroves or corals. More real-life spills have been documented on mangroves than seagrasses or corals.

C. DIFFERENCES OF DISPERSED-OIL TOXICITY EFFECTS AMONG VARIOUS DISPERSANTS

The U.S. Environmental Protection Agency (EPA) toxicity tables indicate large differences between the 20 dispersant products listed with the agency. A biological indicator organism test was done by a scientific group using a temperate Pacific estuarine species. Indeed, large differences highly correlated with the EPA information were found.[10] Countries in temperate zones have found differences between their organisms.

1. Seagrasses

A set of laboratory experiments using three subtropically grown (but distributed throughout subtropics and tropics) seagrasses and seven dispersants was run.[11, 12] The seagrasses responded generally in the same relative tolerance order to each of the dispersants. Dispersants could be clumped into three groups: low, medium, and high toxicity. Finasol OSR-7 was

TABLE 3
Dispersed Oil and Oil Effects on Corals

Location	Type	Dispersant used & dilution	Conc. of Dispersant	Amount of spill	Date	Resource affected	Impact	Dispersant effect	Ref
Bermuda	Field & lab	Corexit 9527 BP 1100 WD	1:20 1:10	Arabian light crude	1981—1986	Corals	6—24 h after, 1—50 ppm on *Diploria strigosa*	No effect to brief exposures; when oil dispersed 20 ppm polychaetes, bivalves crustacea intolerant unclear after 9 mo. whether dispersant had effect or not	4,5
Arabian Gulf	Field	Corexit 9527 20:1		Arabian light crude experiment	1980	Corals	No impact immediately, some death after 6 mo. during winter cold		28
Panama	Field	Corexit 9527	50 ppm 20:1	Prudhoe Bay crude experiment	1985	Corals, seagrasses mangroves	No coral death at 24 h exposure	No death of corals with dispersant	9
Panama	Spill	Corexit 9527	20:1	50,000 med. wt. crude	1986	Corals, seagrasses mangroves	Coral death	Reports intertidal reefs extensive mortality, subtidal to 2 m mortality	12
Jamaica	Lab	10 dispersants	1:10	Venezuela light	1988—1989	Corals	Various	3 nontoxic, 5 highly toxic	3

Revised 1/27/89

TABLE 4
Jamaican Coral Mortality and Seagrass Mortality, Dispersed Oil and Oil at Various Concentrations and Times

	125 ml, 6 h			75 ml, 10 h	
	Por.por.	Mont.an.	Ac.pl.	Por.por.	Mont.an.
Conco	100	100	100	100	100
OFC D609	100	100	100	91	91
Corexit 9527	90	86	100	88	76
Kemarine	90	57	100	85	90
ADP 7	90	72	100	85	90
Corexit 9550	64	14	100	0	12
Jansolv	0	0	50	0	0
Elastosol	15	0	4	0	0
Cold Clean	15	0	15	8	0
Finasol	8	0	15	0	0
Oil only	52	52	100	12	0
Control	0	0	29	0	0

Note: Por. por. = *Porites porites*; Mont. an = *Montastrea annularis*; Ac. pl. = *Acropora palmata*.

From Thorhaug, A., McDonald, F., Miller, B., McPherson, J., Carby, B., Anderson, M., Gordon, V., and Gayle, P., in *Proc. Int. Oil Spill Conf.*, American Petroleum Institute, Washington, D.C., 1989, 455.

least toxic; Conco K and OFC-D-609 were most toxic; Corexit 9550, Jansolv 60 had medium toxicity; Cold Clean 500 and Corexit 9550 had low toxicity. The differences between dispersants was much greater than differences between species (Figures 1, 3 and Tables 5-7). This correlated well with animal toxicity data.[10]

The differences between dispersants was also determined on tropical seagrasses. The ranking was precisely the same as the subtropical seagrasses from Florida. The locally made products V-25, Kemarine (Jamaica), Wonder-O (Jamaica) were all very toxic, especially at higher concentrations.[19]

2. Mangroves

A series of comparative mangrove seedling experiments were performed by Thorhaug et al.[3] These showed that at concentrations of 12.5 and 125 ppm, typical of open ocean spills, that no difference between dispersants or between dispersants and oil or dispersants and control appear. All are healthy. The next group of experiments showed that at 1250 ppm and 12,500 ppm, large differences in effect between dispersants occurred. Corexit 9527, Conco K, V-25, ADP7 were highly toxic. Jansolv, Cold Clean, Corexit 9550, and Finasol OSR-7 were far less toxic. The others fell in between (Tables 1 and 2).

3. Corals

Most field experiments as well as laboratory tests, have dealt with one dispersant product, Corexit 9527. One study tested Exxon 9527 (1:20 dilution) and BP 1100 WD (1:10 dilution) and found no statistical difference in the ranges 1 to 50 ppm, 6 to 24-h exposure with light Arabian crude oil.[5] A second studied LTX and found 162 ppm LC50 for *Madracis mirabilus* on Indo-Pacific species.[14]

Knap et al.[5,6] discussed differences between coral toxicity and BP 1100 WD vs. Corexit 9527. There seemed little difference in response.

Thorhaug et al.[3,19] have investigated three major reef species from the Central Caribbean reef crest *(Acropora palmata)*, reef face *(Montastrea annularis)*, and reef back *(Porites*

TABLE 5
Tropical and Subtropical Seagrass Dispersant Oil and Oil Effects on Seagrasses

Location	Type	Dispersant used & dilution	Type & Conc. of dispersed oil	Amount of spill	Date	Resource affected	Impact	Dispersant effect	Ref
	Lab out doors	Corexit 9527 1:20	50 ppm oil, 1:20, 24 h	50 ppm oil, lab	1984	*Thalassia testudinum*	LD_{50} 12 & 96 hr bioassays, oil & dispersed oil	Oil with dispersant has lower toxicity than without dispersant	
Miami, FL	Lab out doors	Corexit 9527, 1:20	LA crude, Murban	Lab	1983—1984	*Thalassia, Halodule, Syringodium*	LD_{50} vs. time & conc. at 5 to 100 h	At medium conc. High High	11
Miami, FL	Lab. out doors	Arco D-609, 1:10	LA crude, Murban	Lab		*Thalassia, Halodule, Syringodium*	LD_{50} 5 h 100 h	Low to medium Low to medium Low to medium at 75 & 125 ml	12
Miami, FL	Lab. out doors	Conco K (K), 1:10	LA crude, Murban	Lab		*Thalassia, Halodule, Syringodium*	LD_{50} at 5 & 100 h	Medium to high High High	12
Panama	Field	Corexit 9527	Prudhoe Bay crude, 50 ppm @ 24 h	Lab	1985	*T. testudinum*	None to *Thalassia*	No effect on Thalassia	20
Miami, FL	Lab out doors	Corexit 9550 1:20	LA crude 125 & 75 ml oil 1:20 disp. in 100,000 cc SW	Lab	1966	*Thalassia, Halodule, Syringodium*	LD_{50} at 100 h	Low Medium Low to medium	12
Miami, FL	Lab out doors	OFC-D-607 1:10	LA crude 75 &	Lab	1986	*Thalassia, Halodule,*	LD_{50} at 100 h	Low Low	12

Revised 1/27/89

			125 ml oil LA crude			*Syringodium*		Medium		
Miami, FL	Lab out doors	Cold Clean 500 1:10	LA crude 75 & 125 ml in 100,000 cc SW	Lab	1986	*Thalassia, Halodule, Syringodium*	LD_{50} 100 h	Low Low to medium Low	12	
Miami, FL	Lab	Finsol OSP-7 1:10	LA crude 75 & 125 ml in 100,000 cc SW	Lab	1986	*Thalassia, Halodule, Syringodium*	LD_{50} 100 hr	Medium Low Low to medium low	12	

From Thorhaug *et al.* lab 10 dispersants Venezuelan lab 1988-89 Thal, Syr., Hal LD_{50} 3 low, 3 mod., 4 high.

Revised 1 27 89

TABLE 6

A comparison of the effect of Murban oil vs. Louisiana Crude plus Conco K(K) dispersant on *Thalassia*, *Halodule*, and *Syringodium* at a variety of exposure times and volumes in 160 liters seawater

Dosage (ppm)	Volume of dispersant (ml)	Exposure (hr)	Dispersant/oil	*Thalassia testudinum*				*Halodule wrightii*				*Syringodium filiforme*			
				n	G 95% C.L.	CV%	% mortality	n	G 95% C.L.	CV%	% mortality	n	G 95% C.L.	CV%	% mortality
Murban oil															
75.0	7.5	5	1/10	15	3.80 ± 0.21	42	13	15	3.34 ± 0.21	34	13	15	3.25 ± 0.61	31	13
75.0	7.5	100	1/10	15	2.78 ± 0.33	61	40	15	1.11 ± 0.25	29	87	15	1.35 ± 0.38	25	100
125.0	12.5	5	1/10	15	3.21 ± 0.46	38	20	15	3.04 ± 0.61	58	20	15	3.15 ± 0.43	61	27
125.0	12.5	100	1/10	15	1.21 ± 0.65	29	73	15	0.68 ± 0.21	30	100	15	0.93 ± 0.25	44	100
0	0	100	—	15	4.15 ± 0.21	18	0	15	4.51 ± 0.65	24	0	15	4.15 ± 0.31	25	0
Louisiana crude															
75.0	7.5	5	1/10	15	4.21 ± 0.11	28	0	15	3.74 ± 0.23	32	0	15	3.55 ± 0.28	24	7
75.0	7.5	100	1/10	15	3.10 ± 0.61	41	33	15	1.98 ± 0.23	41	73	15	1.65 ± 0.88	45	87
125.0	12.5	5	1/10	15	3.98 ± 0.25	13	7	15	3.25 ± 0.45	35	7	15	3.10 ± 0.36	31	13
125.0	12.5	100	1/10	15	2.51 ± 0.41	37	40	15	1.66 ± 0.41	48	100	15	1.05 ± 0.47	52	100
0	0	100	—	15	4.25 ± 0.21	21	0	15	4.10 ± 0.21	21	0	15	3.99 ± 0.24	21	7

Note: Mean specific growth rates (G % p d, 95% confidence limits, and coefficient of variation in growth rates (CV%) are given on number of blades measured (n) for each species of seagrass.

From Thorhaug, A. and Marcus, J., in *Proc. Oil Spill Conf.*, American Petroleum Institute, Publ. 4452, Washington, D.C., 1987, 223.

Revised 1/27/89

1187

TABLE 7
Seagrasses in Jamaica vs. Toxicity

Dispersant product	Dispersability ratio[a]	Cost[b]	Mortality 125 ml; 6 h *Thal*	125 ml; 6 h *Hal*	75 ml; 6 h *Thal*	75 ml; 6 h *Hal*	12.5 ml; 6 h *Thal*	12.5 ml; 6 h *Hal*
Conco	0.580	0.39	100	82	48	70	17	35
OFC D609	0.007	0.08	70	63	25	70	20	25
Corexit 9527	0.009	0.11	89	93	42	72	10	22
Kemarine	—	—	63	68	42	68	17	28
ADP 7	—	—	50	46	18	68	21	30
Corexit 9550	0.009	0.11	40	46	15	20	7	7
Jansolv	—	—	0	0	0	0	0	0
Flactosol	—	—	15	46	10	11	8	10
Cold Clean	—	—	0	10	0	8	0	5
Finasol	0.038	0.28	0	8	0	0	0	0
Oil only	0	0	30	28	10	16	10	12
Control	0	0	11	9	7	5	0	5

[a] Dispersability is the ratio of dispersant to oil required to disperse 90% of the oil.[44]
[b] Cost is the relative effective cost of sufficient dispersant to disperse 90% of 1 gal of oil under the conditions of the Mackay apparatus.
[c] Concentrations in 100,000 cc of seawater were 10:1 of oil to dispersant product.

From Thorhaug, A., Carby, B., Reese R., Rodriguez, M., McFarlane, J., Tess, H., Sidrak, G., Anderson, M., Alton, R., McDonald, F., Miller, B., Gordon, V., and Gayle, P., in *Proc. 1991 Oil Spill Conf.*, American Petroleum Institute, Washington, D.C., in press.

porites). They were all very sensitive to Conco K, Corexit 9527, V-25, ADP7, and Wonder-O (local product). The low toxicity comparisons were Cold Clean, Finasol OSR-7, Corexit 9550, and Jansolv, in that order. Other dispersants fell in between (Table 4, Figure 2).

4. Fish

Laboratory tests[3] of dispersants on four species of tropical commercial fish showed Conco K, Kemarine, V-25, Wonder-O, ADP-7, and Jansolv to be very toxic. Cold Clean, OFC D609 were least toxic. Fish were *Holocentrus rufus*, *Acanthuris spp.*, *Haemulon spp.*, and *Archosargus rhonboddales*. Some subtropical Gulf of Mexico species have been investigated by Shuba and Heikamp[16] (two shrimp, blue crab, oyster, and redfish) and temperate fish and invertebrates by Anderson *et al.*[10] and by McAuliffe[15] showing clear differences between dispersant toxicities. Cold Clean and Corexit 7664 (a fourth-generation dispersant) were of low toxicity to temperate species. Of high toxicity were Corexit 9527, OSP-20 (Table 8).

5. Comparative Dispersant Effects On Tropical Matrix Species

Recently, there has been a comparison of important tropical species to the same or similar subtropical species using the same methods and involving the same investigators.[19,29,45] The tropical and subtropical species and phyla had the same ranking in sensitivity to dispersed oils. That is, the species behaved the same, whether subtropical or tropical, to the toxicity level of the dispersed oil. The quantitative levels of sensitivity were approximately the same to a given oil or dispersed oil. Tolerance levels were the following: mangroves > seagrasses > fish > corals.

114T

52-1X

TABLE 8A
The Mean Mortality of 3 Jamaican Fish Species, 3 Jamaican Seagrasses and 3 Jamaican Coral Species

	Fish[a]				Seagrasses[b]				Coral[c]			
	1	2	3	$\bar{X}$	1	2	3	$\bar{X}$	1	2	3	$\bar{X}$
Conco	100	100	100	100	100	82	100	94	100	100	100	100
OFC D609	40	100	100	80	70	63	nd[d]	67	100	100	100	100
Corexit 9527	40	100	100	80	89	93	nd	91	72	100	100	91
V-25	100	100	100	100	nd	nd	nd	nd	100	100	100	100
Wonder-O	100	100	100	100	100	100	100	100	100	100	100	100
Kemsorine	nd	nd	nd	nd	63	68	nd	66	100	100	100	100
ADP-7	100	100	100	100	50	46	nd	48	100	100	100	100
Jensolv	100	100	100	100	0	0	0	0	0	0	73	24
LTX	100	100	100	100	nd	nd	nd	nd	nd	nd	nd	nd
Corexit 9550	0	60	0	20	40	46	nd	43	43	0	100	47
Cold Clean	0	60	80	47	0	0	0	0	0	0	21	7
Finasol	0	0	20	7	0	0	0	0	0	0	11	4
Oil	0	0	0	0	30	28	30	29	52	52	58	54
Control	0	0	0	0	11	9	10	10	0	0	0	0

Note: At 6-h exposure of 125 ppm dispersed oil for the seagrasses and coral; at 3-h exposure of 125 ppm dispersed oil for the fish. $\bar{X}$ is mean of toxicity of three species.

[a] Fish 1, *Holocentrus rufus*; fish 2, *Acanthurus sp.*; fish 3, *Haemulon sp.*
[b] Seagrass 1, *Thalassia testudinum*; seagrass 2, *Halodule wrightii*; seagrass 3, *Syringodium filiforme*.
[c] Coral 1, *Porites porites*; coral 2, *Montastrea annularis*; coral 3, *Acropora palmata*.
[d] nd = no data.

From Thorhaug, A., Carby, B., Reese, R., Rodriguez, M., McFarlane, J., Teas, H., Sidrak, G., Anderson, M., Aiken, R., McDonald, F., Miller, B., Gordon, V., and Gayle, P., in *Proc. 1991 Oil Spill Conf.*, American Petroleum Institute, Washington, D.C., 1991, 142.

1.1

D. DIFFERENCES OF DISPERSED-OIL TOXICITY EFFECTS AMONG SPECIES WITHIN PHYLA

1. Seagrasses

In the subtropical Atlantic, the seagrass *Thalassia testudium* is the most tolerant to high concentrations of oil and dispersed oil.[12, 13, 17] The least tolerant is *Syringodium filiforme*. *Halodule wrightii* usually is similar, but slightly more tolerant to oil than *Syringodium filiforme*. These differences are amazingly constant between concentrations, oil, and dispersant type. We have no data yet on the Indo-Pacific species, but would generally expect cogenetors to behave similarly based on comparative Atlantic-Pacific work.[18] (See Figures 1-4.)

The tropical species investigated by Thorhaug et al.[19] had the same order of sensitivity ranking as subtropical species determined by Thorhaug and Cruz.[18] It may be interesting to note from a large range of field experiments in the Philippines (central in distribution of Indo-Pacific species) that the sensitivity from most sensitive to least sensitive ranked *Syringodium* fairly sensitive, whereas *Halodule* was tolerant of most substances.[18] In the Indo-Pacific, one would expect *Enhalus* and *Thalassia* to be the most tolerant, and *Syringodium* and *Thallasodendron* least tolerant.

2. Mangroves

Mangroves *(Rhizophora mangle)* were dispersant tested in experimental mesoscale setups by Teas et al.[13] Field situations consistently have given similar results for red mangroves.[2, 9, 21] Experiments by Thorhaug et al.[3] showed that the red mangrove *(Rhizophora mangle)*

TABLE 8B

Survival (%) and Growth (Shoots m^{-2}) of Five Species of Seagrass Tested Vs. Pollutant Type in Philippine Test Plots

Pollutant	*Enhalus*		*Thalassia*		*Halodule*		*Syringodium*		*Cymodocea*	
	Sprigs	Seeds	Sprigs	Plugs	Sprigs	Plugs	Sprigs	Plugs	Sprigs	Plugs
Dredge & fill										
Marinduque	78 (1.9)	80 (2.7)	78 (2.4)	38 (4.3)	36 (16.5)	80 (40)	30 (6.1)	28 (3.8)	20 (6.7)	38 (8.9)
Manila Bay	60 (2.64)	62 (2.22)	80 (1.8)	78 (9.2)	18 (5.4)	82 (12.3)	n.p.	n.p.	20 (2.3)	50 (8.2)
Urban Outfall										
Manila Bay	38 (1.8)	n.p.	0	0	0	0	n.p.	n.p.	0	0
Mine tailings										
Marinduque										
East (high energy)	68 (2.3)	8 (1.0)	n.p.	40 (2.6)	16 (11.8)	32 (42)	n.p.	n.p.	40 (1.5)	52 (3.1)
West (low energy)	80 (1 3)	60 (1.2)	84 (2.4)	100 (14.4)	84 (43.5)	96 (60.8)	24 (14.3)	44 (5.2)	4 (1.0)	60 (4.4)
Chemical factory										
(Phosphate fertilizer)	0	0	0	0	4 (3.5)	0	0	0	0	0
Power plant										
Bataan	60 (16.2)	n.p.	52 (12.2)	28 (3.7)	24 (2.2)	24 (35)	0	0	60 (3.7)	60 (4.3)
High current										
Tip of Marinduque	4 (2)	n.p.	n.p.	0 (0)	n.p.	0 (0)	n.p.	n.p.	n.p.	n.p.

Note: Number without parenthesis is survival %. The number in parenthesis is number of shoots per square millimeter. n.p. = not planted.

Thorhaug, A. and Cruz, R., in *Restoring the Earth*, Berger, A., Ed., Elsevier, Amsterdam, 1989, 21.

Revised 1/27/89

53-1

115

116T

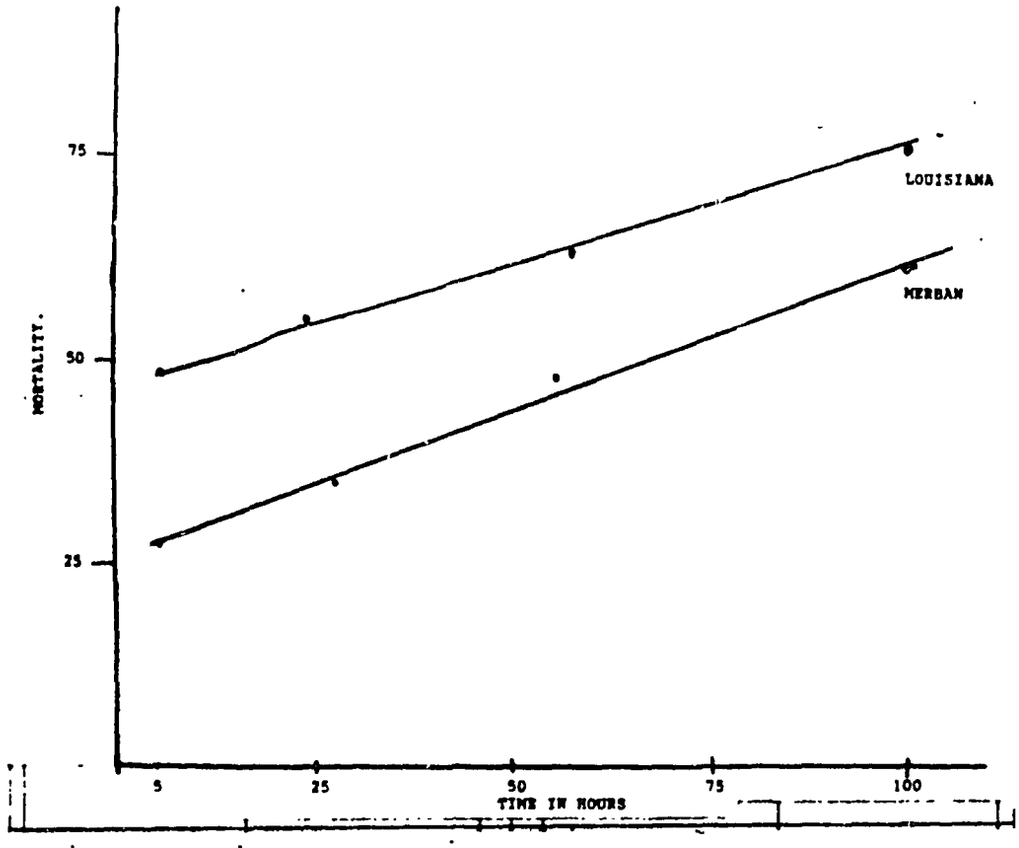


FIGURE 1. Laboratory experiment: time vs. mortality of subtropical *Thalassia testudinum* and Thalassia seagrass.

was far more tolerant than the black *(Avicennia niger)* and black more tolerant than white *(Lagungularia sp.)* to oil and dispersed oil. This was done over four orders of magnitude of concentration, the red and black with 25 dispersants, the red vs. white with 13 dispersants (Table 2).

Field results from the Atlantic would indicate *Rhizophora mangle* had higher tolerance than the other two species. Other parts of the world are yet to be tested.

3. Corals

Several coral species have been employed in dispersant experiments. LeGore et al.[22] mention several *Acropora* species. Although several sets of field experiments have been carried out which utilized various corals, there was no particular attempt to increase concentration until toxicity differences appeared to occur. Thus, at present there is not an established hierarchy of tolerance.

The experiments of oil alone in Bermuda (at the far upper edge of corals anywhere in the Atlantic) done by Knap et al.[4] *in situ* and in laboratory experiments showed a fairly high level of control conditions and excellent chemistry. The species used were *Diplora strigosa*, brain coral, dominant to Bermuda reefs.

The work of Ballou et al.[2] later reported by Cubit et al.[21] from the Caribbean (Panama) did not seem to indicate differences between the ubiquitous *Porites porites* (transplants to site) and *Agaricia sp.* found in back reef (also transplanted to site). Both of these species are estuarine, as well as reef.

In the report of LeGore et al.[22] in the Arabian Gulf on several *Acropora* species, the corals were exposed for 1 to 5 d. Differences between species were not noted.

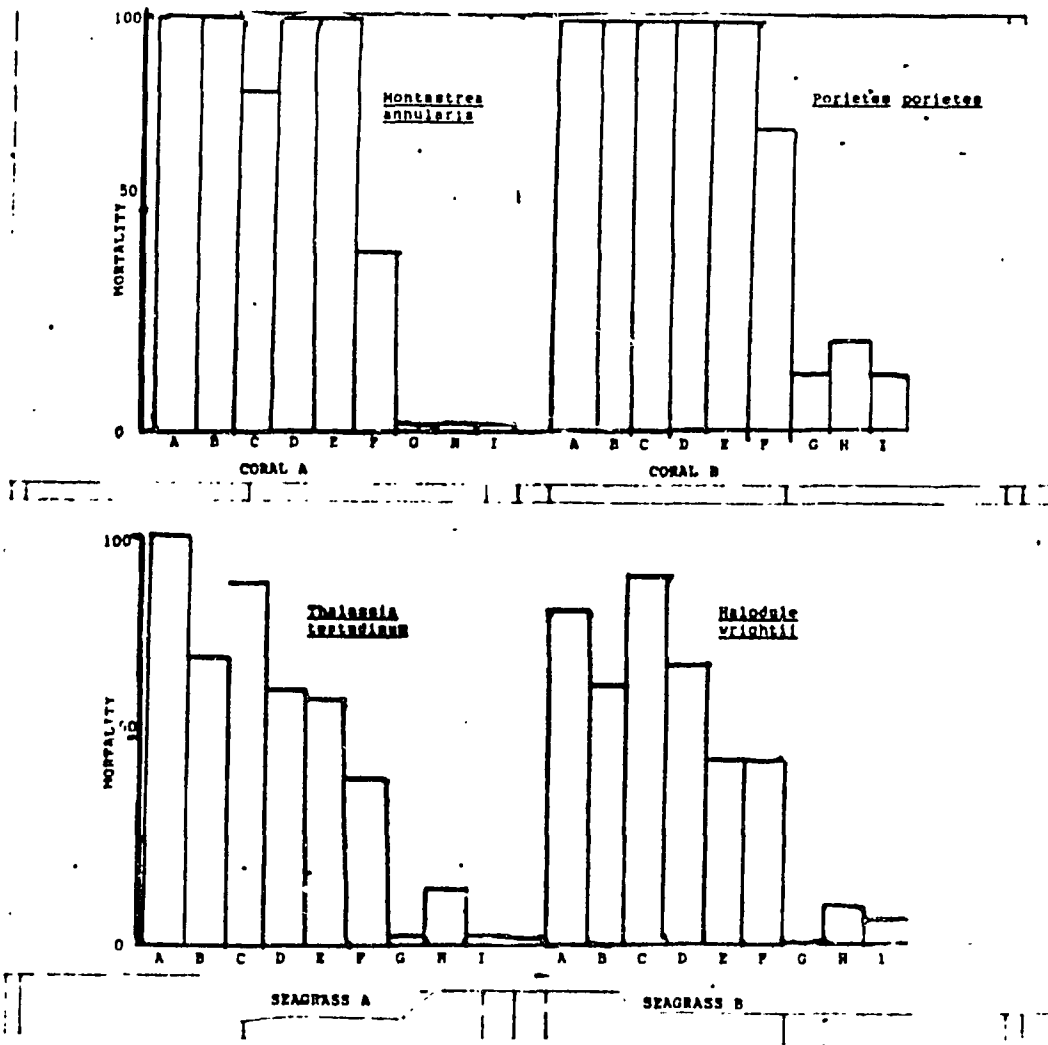


FIGURE 2. Laboratory results of nine types of dispersed oil with two seagrasses, and two coral species. (From Thorhaug, A., Carby, B., Reese, R., Rodriguez, M., McFarlane, J., Tees, H., Sidrak, G., Anderson, M., Aiken, R., McDonald, F., Miller, B., Gordon, V., and Gayle, P., in *Proc. 1991 Oil Spill Conf.*, American Petroleum Institute, Washington, D.C., 1991, 142.)

The work of Thorhaug et al.[19] shows strong differences between species. *Porites porites* was, by far, the most tolerant of all substances, and *Acropora palmata* (crest of reef) was by far the most sensitive to all substances. The reef-building *Montastrea annularis* was in the middle, but closer to *Porites* in responses to changes than to *Acropora*. The tolerance to other substances or changes of *Porites* is great while *Acropora* is sensitive to changes and substances (Table 6).

4. Fish

There were differences in tolerance to dispersant and concentration in the work of Aiken et al. (See Reference 9.) The fish were ranked: squirrel fish *(Holocentrus rufus)* > grunts *(Haemulon sp.)* > sea bream *(Archosargus rhonboddales)* > doctor fish *(Acanthurus sp.)* for tolerance. Not a great deal has been done with tropical commercial fish and tolerances to pollution (Table 8).

5. Invertebrates

For the more than 100 tests of various invertebrates vs. dispersed oil, a few in the Gulf

118T

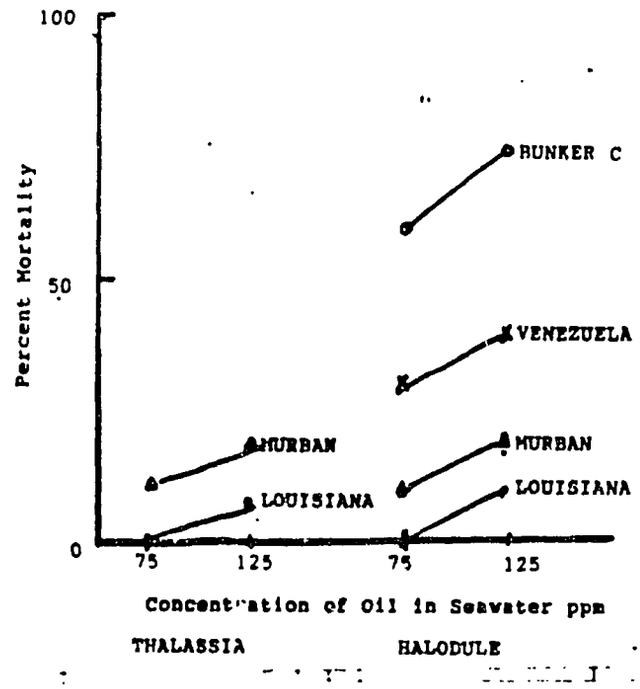


FIGURE 3. Oil type vs. mortality.

of Mexico[16] temperate zone are relevant to subtropical and tropical species. Early shrimp and crab stages appear relatively sensitive, but less so than corals, as evaluated by the National Research Council.[1]

E. DIFFERENCES AMONG CONCENTRATIONS OF DISPERSED OIL

Obviously, high concentrations of organic materials are more toxic than low concentrations.

1. Seagrasses

Large toxicity tolerance differences appeared as increased concentrations of oil dispersants raised percent mortality for a species. In each case seen in Tables 6 and 7, a general concentration range exists where some species show less than 50% mortality and others *(Syringodium* and *Halodule)* are greater. Time of exposure also influences these sets of curves (Figure 1). Statistically significant differences occurred between species at higher concentrations. These ranges are at least an order of magnitude above advised usage levels for dispersants. The differences hold for subtropical and tropical seagrasses of the same species, as evaluated by Thorhaug.[3]

2. Mangroves

Our studies[3] showed that mangroves do not respond to the levels of concentration that fish corals and seagrasses do, that is, 12.5 to 125 ppm. No differences between controls, oil, or concentrations existed. Thus, we attempted higher concentrations (one and two orders of magnitude greater) to obtain differences showing the red mangrove *(Rhizophora mangle)* most resistant to oil and dispersed oil, the white *(Laguncularia)* the least tolerant, black *(Avicennia niger)* medium tolerant. One should keep in mind the high concentrations found by the scientists who measured buildup of oil in mangroves (Open ocean concentrations would be 1 to 50 ppm). Reports of liters of oil per square meter are not uncommon in mangrove spills. The time of exposure for mangroves at an interface of oil is often longer than organisms found further seaward or in the ocean itself.

3. Corals

There is experimental work by Knap and colleagues[4, 5] using concentrations in the range 1 to 50 ppm. The higher concentrations showed sublethal effect of behavioral treatment (tissue contraction, tentacle retraction, and localized tissue rupture); lower concentrations did not show behavior effects.

The work by Thorhaug et al.[3, 19] shows oil only has some effect on *Acropora palmata* at 12.5 ppm, far greater effect (100% mortality) at ten times the level (i.e., 125 ppm). *Porites porites* and *Montastrea annularis* go from 1 and 12% death, respectively, at 75 ppm oil to 100% at 125 ppm oil. The Pacific species *Madricis mirabilus* has LC_{50} of 162 ppm to Shell LTX.[14] BP and Corexit 9527 showed no mortality in the concentration range 1 to 20 ppm on *Diploria strigosa*.[5] Corexit 9527 was not lethal in mesoscale field experiments at 50 ppm on *Porites porites* and *Agaricia sp.*[21] The work of Thorhaug et al.[19] shows different responses due to concentrations. At 125 ppm, many coral have a very toxic response to all but four dispersants. At 12.5 ppm, there was a wide variety of responses ranging from 0 to 50% mortality for 6-h exposure. Corals tested were *Porites porites, Montastrea annularis,* and *Acropora palmata.* The mortality differences between concentrations were seen for all species.

4. Fish

Four tropical fish were tested by Thorhaug, Aiken, Walker et al. (See Reference 9). They all were very concentration sensitive, the doctor fish *Acanthurus sp.* being the most sensitive and the squirrel fish *Holocentrus rufus* the least. At 12.5 ppm, they were not as affected for short exposure times (1 to 3 h, which the National Academy of Sciences[1] has as the time period a fish would encounter an oil spill).

F. DIFFERENCES BETWEEN OIL TYPES

In general, fresh oil vs. "aged oil" and various weights might make a difference in toxicity. To date, no comprehensive program on any of the three critical habitat types has been carried out using various ages and types of petroleum products.

1. Seagrasses

Figure 3 shows the effect of different oils on seagrass toxicity.

2. Mangroves

Prudhoe Bay crude, Louisiana crude, and Venezuelan middle weight has been used for mangrove results. No differences have been pointed out by authors or are apparent from results.

3. Corals

Arabian light crude, Prudhoe Bay, and Venezuelan middle weight have been tested on corals. The authors do not point out any differences nor are they apparent from results.

G. DIFFERENCES IN TIMES OF EXPOSURE

There are several times of exposure which are relevant to tropical coastal oil spills: (1) very short times (1 to 2 h) where a parcel of dispersed or oiled water might flow over a habitat; (2) 6 to 12 h, where a tidal cycle could wash an oiled parcel onto a habitat, especially in an estuary; and (3) longer times where oil might sit in an estuary or be trapped behind a reef or strand in a mangrove swamp. The EPA standard of 96 h (nearly 100) is relevant to this; however, this standard has been applied mostly to fish, which are the least likely to have to tolerate 96 hours of exposure in the same way that plants or corals would.

120T

1. Seagrasses

Three subtropical and tropical Atlantic seagrasses have been tested for time of exposure response to various dispersed oils. Figure 1 and Tables 6 and 7 show these results. Clearly, the longer exposure times have a greater toxic effect, especially at higher concentrations of dispersant and oil.

2. Mangroves

Mangroves appear not to have had systematic experiments on time of exposure to dispersed oil. Thorhaug et al.[3] used 12 h (Table 2).

3. Corals

Corals were exposed from 6 to 24 h to dispersed oil in a continuous flow experiment.[4] No toxicity appeared within this time frame. Field experiments were 24 h[20] and 6 h.[22]

H. SEASONAL EFFECTS

1. Seagrasses

Tests were run throughout the year in the subtropics. No differences were found.

2. Mangroves

There are no data for mangroves.

3. Corals

Seasonal differences in response to BP 1100 WD were seen in winter.[4] Differences of corals exposed to Corexit 9527 treatments vs. controls were seen in winter in the Arabian Gulf.[22] Both the above studies are at the furthest limit of corals in the respective ocean basin.

I. TEMPERATURE OF SPILL

In general, the warmer the temperature, the more toxic the compound's effect for physiological processes. The temperate and arctic-work has corroborated this. However, there is a small window of temperatures available for tropical organisms: 25 to 30°C are the continental shelf temperatures for tropical organisms. The estuarine temperatures can reach 34°C and fall to 20°C in shallow waters, but these are diurnal variations with low tides and flush back to the central temperatures within hours.

The work of Thorhaug et al.[3, 17] was carried out at the 25 to 30°C temperature range, Knap et al.[4] at 22 to 28°C, Cubit et al.[21] at 27°C, and Teas et al.[13] in the 25 to 30°C range.

J. MITIGATION AFTER OIL SPILLS

There have been three notably successful sets of attempts to mitigate after oil spills. Two were in temperate areas on marshes and the third on mangroves in the tropics. The tropical one is handled in detail.

What we see from all three sets of authors is the following: (1) the physical-chemical conditions of the sediment are altered by the spill, even after extensive cleaning (in the French case); (2) recurrences of the spilled oil may occur if oil is not all cleaned up, (3) some species and some elevations produce better results than others. The higher or lower above the tidal zone, the better the result.

In the case of Teas et al.[34] the sediment of the mangroves was noted as altered. The first attempt to restore mangroves after the spill produced a low survival rate of planted red mangrove propagules *(Rhizophora mangle)*. The second attempt several months after the spill was more successful with intermediate survival. The third attempt, many months after the spill, was the one which the authors recommend. Plants higher in elevations survived better than lower, an example of the system restoring itself.

The attempt in France to replant marsh by Seneca[35] was very well executed and was differentially successful. The upper elevation plants survived better than lower elevation plants. One portion of the problem was that the oil came back with tides which recirculated it after plantings had been done. A great deal of steam and other rock cleaning was done which evidently resulted in oil being carried out to sea and then back in some time later. Some of the lower tidal levels were not restored. The higher portion could be restored.

Some careful studies have been done on temperate marshes after mesocosm spills in Great Britain.[33] The studies showed restoration of marshes after heavy oiling was possible, but not a simple endeavor.

Seagrass, corals, and fish stocks have not been attempted to be restored after oil spills. Techniques for restoring these under a variety of other impacts have been successful in Atlantic and Pacific Basins.[18,28-30]

K. METHODS OF MANAGING SPILLS

1. Mechanical Cleanup

These methods include booms to contain oil, skimmers, and sorbants. The performance of any of these methods so as to have low biological damage is dependent on the speed of transporting them to the site and having them operational in time to function on the spilled oil. Physical conditions at the site frequently make this option nonviable: (1) current must be less than 1 kn; (2) wind should be less than 6 kn; (3) wave action must be very low, less than the freeboard of the barrier; (4) the nature of the oil slick itself. The stress on the boom is appreciable, and the booms frequently break, demanding a second strategy be employed. Skimmers decrease their recovery rate at decreasing thickness of oil. Below 1 mm, the rate is almost negligible.

The distance the spill site is from the stockpile of sufficient mechanical equipment and the time for deployment are major factors as to whether "mechanical" will be an adequate combat tool. In many cases, even "optimal" time of setup of mechanical equipment precludes use of mechanical as an option. Estuarine spills are a chief example of this. There is almost no time (minutes) between a port spill and mangroves in many areas. In shallow, ecologically sensitive habitats, it is a particular problem to setup a boom. Mechanical cleanup is a far more highly skilled technology, dependent on speed, accuracy, maintenance of equipment, and logistic coordination. The author has many reports of failed attempts to contain oil in less-developed countries and developed nations. Mechanical cleanup frequently fails due to operator errors or inability. In the U.S. only 15% of mechanical cleanup occurs, leaving 85% uncleaned.

If the mechanically retained oil cannot be recovered, then the waste oil must be taken ashore and disposed of correctly. This author has made a survey. Most nations in Central America, South America, the Caribbean, and East or West Africa do not have any central disposal sites for waste oil.

Mechanical cleanup costs $700 to $7000 per barrel[38, 39] (Tables 9 and 10).

2. Shoreline and Reef Cleanup

If the winds are onshore at points during the life of the spill and if proximity to shore is small, some of the oil will land on shore. If mangroves are hit by the spill, they will die (unless it is a high tide and the oil is carried out before the tide goes low).

Coral reefs may also be a site of shoreline circulation, which at high oil concentration will kill corals.

Beach cleanup includes removing sand which can lead to accelerated erosion. In a tourist-oriented location, beach cleaning is not appropriate.

Hard surfaces, such as rocks, can be sandblasted or steam cleaned This reinjects oil into the water for further stranding and must be done along with mechanical barriers.

These shoreline methods are all expensive (see Tables 9 and 10).

122T

TABLE 9
Costs of Oil Spill Cleanup Techniques

Type	Cost per barrel	Ref.
Mechanical	$65—5000	38
Dispersant	$15—65	38
Shoreline	$650—7000	39
Gels	Above $7000	39

TABLE 10
Short-Term Oil Spill Cleanup and Indirect Long-Term Costs

	Capitalization costs	Direct costs	Indirect waste removal	Indirect environmental costs	Socioeconomic costs
Mechanical	High	$1.50—0.60/gal	$2/gal		None if successful, high if not successful
Beach cleanup	Low	$8—17/gal	$4/gal	Very high in productive ecosystems (mangroves, reefs)	High if tourism is involved or if mangroves/coral die; low if rock or sand not used
No action	0	0	0	About $100,000/acre if mangroves, seagrasses corals are killed	Very high if fisheries or tourism is affected or if mangroves or corals die
Dispersant	Medium to low	$0.06—0.30/gal	0	None if nontoxic dispersants used, some if toxic dispersants used	Low

3. Other Techniques

If the slick is thick enough and human life and property are not at risk, flaring may be possible. Substantial air pollution results. Ixtoc in Mexico used flaring.

Gels are still in experimental stages or very expensive. No known tropical field testing has been done.

Bottom sinking agents: seagrasses, corals and meiofauna are notably unable to deal with these substances and can be smothered. Sinking agents can releak oil.

Bacterial agents are still very expensive although the 1990 MegaBorg spill in open waters far off Galveston, TX used them. Bacterial agents may be better for remediation.

The field is fast moving. Keeping abreast of technology is critical.

4. Dispersant Cleanup

The real spills for which dispersants have been used are far less in the tropics than in the temperate zone. However, in the many reports of use of dispersant, a report of the dispersed oil killing a population of any organisms could not be found. There were reports where one portion of a spill was not dispersed while another was, the nondispersed portion causing harm.

The Ixtoc and Yum spills, both drilling rig blowout spills, offer an interesting comparison. The Ixtoc spill was the largest spill in the tropics with the largest amount of dispersants

used up to that time. Jernalov and Linden[32] reported that no statistical difference in total fish landing occurred after the spill started flowing from the year before. The Yum spill which flowed from approximately the same area on the northern shelf of the Yucatan for only 4 months compared with Ixtoc (more than 1 year). The volume of flow was approximately the same. The UNEP regional headquarters in Mexico and the fisheries report about 50% reduction in fish catch in Yum. No dispersant was used in Yum.

The reports on the Panama Texaco spill where the dispersant Corexit 9527 was used are difficult to separate out due to legal procedures which inhibit information. However, there are reports that a portion of the spill which occurred in the mangroves did get dispersed by the dispersant airplane of the Clean Caribbean Cooperative, which sprayed dispersant on a sizable portion of the spill. There are also reports of nondispersed portions of the spill being carried by winds into mangroves, killing them. Some controversy remains as to exactly where the dispersed oil on the leading edge was.

The reports of other spills in Belize, Jamaica, and Egypt, which were dispersed without fish or mangrove kills, have been reported to international governments.

The preliminary data analysis[1] has not revealed any tropical "Torrey Canyon", where large-scale dispersants were used to the detriment of the environment. This is an important setting in which to place the laboratory and mesoscale data.

L. DISPERSABILITY OF OIL

One important point for a commander of an oil spill is the effectiveness of whatever technique he is going to use on the oil cleanup. The problem at present is that the effectiveness of the dispersants have not been tested at higher temperatures relevant to tropical seas and estuaries, that is, from 22 to 35°C. Most data are from 1 to 15°C; some data go to 20°C. Certain dispersant manufacturers claim they are presently testing at higher temperatures and salinities.

Effectiveness of emulsions are strongly affected by temperature, and, in general, the warmer the temperature, the greater the immiscibility.

Effectiveness is also a function of salinity. There are no effectiveness tests for the very salty waters in the Red Sea, Gulf of Arabia, or Gulf of Aquaba, for example. Some dispersants are effective over a larger range of salinities than others (Corexit 9550). There are very few tests for low salinity or brackish water situations.

Various oils are differently dispersed. Generally, the heavier the oil, the more difficult to disperse; the lighter the oil, the easier.

We must now have results of studies of major oils from major shipping routes vs. the more-toxic dispersants at high temperatures to understand their effectiveness and efficiency. We must have the effectiveness from 0 to 40 0/00 salinity at higher temperatures.

III. RECOMMENDATIONS

A. POLICY

The policies most useful are those which allow the commander of the oil spill to predetermine implementation during pre-oil spill planning sessions, finding the least resource-damaging option, and comparing the spill with the predetermined model to implement it immediately at the time of spill. Unless the spill is far offshore, time is of the essence for the spill commander to do his best for a good result. Any delay whatsoever may be to the detriment of the very resource the environmentalist wishes to protect.

Nations and states should have oil-spill policies which allow them to use cost-accounting recovery for their damaged coastal resources. This means the nation should carry out "pricing" of coral reefs, mangroves, and sustainable fisheries.

The 1980 IMO policy about mangroves was cautious when formalized, but is out of

124T

date because it would cause mangrove death directly by not having dispersed oil as it entered the mangroves.

The Bonn Agreement may be a good policy entry point for developing nations without a present policy. The central focus of these European policies are the "least impact".

B. PREPAREDNESS

Successful management of oil spills has preparedness of all parties as the key. Any and all decisions which can be made ahead of time should be. All decisions in which resources are the highest priority should be made ahead of time. As much experience and coordination as possible should be made as in preplanning. The luxury of offshore spills, like the 1989 Morocco spill (of over 1 million gal) which took days to come ashore, are few. Most spills (55%) take place within several miles of shore. In Florida, a spill can move 60 mi in 24 h. Thus, most spills near shore take only hours to hit living resources which might be irreparably damaged.

C. STOCKPILING CORRECT EQUIPMENT

When the spill occurs, either the equipment of choice is there or difficult arrangements to get it flown in must be made. For some African countries, it is easier to get it flown in from Europe than from a neighbor.

If dispersants will be useful, be sure the nontoxic ones are stockpiled in your area so the temptation to use the toxic ones will not occur. This must be done ahead of time.

D. DEPENDENCE ON OTHERS' EQUIPMENT

The problem with not having adequate equipment is that the neighbors' equipment may not work. In regions with many small nations (East and West Africa, Caribbean, Pacific Islands), the expenditure for protecting the nation from a major spill is always seen as a trade-off from some other project. The regional center now being founded by UNEP is one alternative.

IV. DISCUSSION

A. MANAGEMENT PRINCIPLES FOR USE OF DISPERSANTS IN TROPICAL HABITATS

It is now apparent that nontoxic dispersants at concentrations recommended by the manufacturer can be used under various sets of emergency conditions for oil spills which frequently occur in the tropics as they are being used by the Bonn Agreement nations: (1) estuarine spills where or when mechanical means are inadequate to control oil from impacting one or more types of habitat, especially mangroves; (2) nearshore coastal spills where environmental conditions are rapidly transporting spill toward one or more critical habitats; (3) in weather conditions when mechanical cleanup is ineffective and there is a danger of impacting corals, mangroves, or seagrasses.

All parties must stop using the generic term "dispersants" within the oil spill cleanup plans. Specific tested and *non-toxic* dispersants must be named for spills on each habitat type with the upper concentration limits for use described.

Further laboratory tests must be done by nations in tropical areas to test their commonly used and stockpiled dispersants for toxic effects on their critical habitat organisms such as various species of corals, mangroves, seagrasses, and marshes. It is unrealistic to imagine small third-world nations will find this a priority. Regional multinational and industrial funds should be found to do this. It must be done according to international or accepted standards.

A network of rapid information dissemination to industry, environmental management, government spill cleanup managers should be organized so that whatever information is derived can be disseminated.

Resource maps which must include the *exact* species of mangrove, seagrass, or corals should be included in oil-spill contingency plans. Since the toxic effects differ by more than an order of magnitude between species, present "lumping" resource maps are inadequate. Dominant species must be available on sensitivity maps.

ACKNOWLEDGMENTS

The Office of Science Advisor, U.S. Agency for International Development (AID) has generously supported research on toxicity limits to oil and various dispersants. The Jamaica Mission of U.S. AID also supported the project as did the Office of Disaster Preparedness, the Government of Jamaica, and Florida International University. The author wishes to acknowledge Mobil Oil Foundation for a grant to test dispersants on seagrasses, corals, and fish. Mr. S. Horne, Dr. J. Hildrew, and Dr. Marum of Mobil were most helpful in establishing guidelines for testing relevant to industry. M. Flaherty of the U.S. EPA (ret.) is thanked for helpful discussions about differences among dispersants. Captain Charles Corbett and the U.S. Coast Guard oil spill (cleanup) staff in Washington, D.C., Miami, and in Puerto Rico Matt Dillon are thanked for discussions on cleanup problems.

A variety of members of IPEICA and APS members are thanked for the industry viewpoint. Members of the United Nations Environmental Programme office such as Dr. Tolba, Dr. Keakes, Arthur Dahl, Macrum Gerges, and other offices (Dr. Noel Brown, North American office), especially Franklin McDonald, United Nations Disaster Relief Organization, Mrs. Beverly Miller, and Salvino Breaenio, Dr. S. Lizarraga of UNEP are also thanked. Natural Resources Conservation Department, Jamaica, Venezuelan environmental staff, Mrs. Veronica Villavicencio, Philippines, Drs. Badawi and Esaway, Prof. M. Kassas, Egypt.

Dr. Howard Teas is especially thanked as mentor on oil spill and physiology, particularly during the preliminary stages of our experiment. Dr. Jeffrey Marcus and Dr. Fitz Booker were involved in early years of laboratory experiments on seagrasses, and Dr. Jeffrey Marcus is co-author of much of the subtropical seagrass results quoted here. Barbara Carby, John McFarlane, Richard Reese from the Jamaica Office of Disaster Preparedness, Mike Rodriquez from Jamaica Defense Department Coast Guard, Marcel Anderson and staff, NRCD, Beverly Miller and Valerie Gordon, IMERU, Prof. George Sidrak, Dr. Karl Aiken, and Peter Gayle and Wendy Walker, UWI, were all involved in phases of the Jamaica data and model project. The Oil Spill Committee of Jamaica is thanked for its input as is the Jamaican Coast Guard. Investigators and cleanup regulators around the world have contributed experiences and ideas to this document. Dr. G. Kollenberg and Dr. Ibe of IOC (UNESCO) for sending me to the Persian Gulf to report on the oil spill.

REFERENCES

1. National Research Council, *Using Oil Spill Dispersants on the Sea*, National Academy Press, Washington, D.C., 1989.
2. Ballou, T. G., Dodge, R., Hess, S., and Knap, A., Tropical oil pollution investigations in coastal systems (tropics): the effects of untreated and chemically dispersed Prudoe Bay crude oil on mangroves, seagrasses, and corals in Panama, in *Oil Dispersants: New Ecological Approaches*, Flaherty, L. M., Ed., ASTM, Philadelphia, 1989, 229.
3. Thorhaug, A., Carby, B., Reese, R., Rodriguez, M., McFarlane, J., Teas, H., Sidrak, G., Anderson, M., Aiken, R., McDonald, F., Miller, B., Gordon, V., and Gayle, P., Dispersant use for tropical nearshore waters: Jamaica, in *Proc. 1991 Oil Spill Conf., American Petroleum Institute*, Washington, D.C., 1991, 142.

126T

4. Knap, A. H., Wyers, S. C., Dodge, R. E., Sleeter, T. D., Frith, H. R., Smith, S. R., and Cook, C. B., The effects of chemically and physically dispersed oil on the brain coral *Diploria strigosa* (Dana) — A summary review, in Proc. Oil Spill Conf., American Petroleum Institute, Washington, D.C., 1985, 547.
5. Knap, A. H. et al., Oil spills research in tropical environments and contingency planning in the wider Caribbean, International Petroleum Industry Environmental Conservation Association, 1986, Venezuela, 1985, 24.
6. Jackson, J. B. C., Cubit, J. D., Keller, B. D., Batista, V., Burns, K., Caffey, H. M., Caldwell, R. L., Garrity, S. D., Getter, C. D., Gonzalez, C., Guzman, H. M., Kaufmann, K. W., Knap, A. H., Marshall, J., Steger, R., Tompson, R. C., and Weil, E. Ecological effects of a major oil spill on Panamanian coastal marine communities, *Science*, 1989.
7. Beck R., Effects of oil on coral reefs, in West Indies Island Mar. Lab. Proc., 1981, 31.
8. Lugo, A., Teas, A. H., and Lewis, R., Effect of oil on mangroves and restoration, in *Restoration and Management of Marine Ecosystems Impacted by Oil*, Cairns, J. and Buikema, A., eds., Butterworths, New York, chapt 5, 1984.
9. Getter, C. D., Baltos, T. G., Ilem, S. C., Knap, A., Dodge, R., and Sleeter, R., Final results of the API tropics oil spill and dispersant use experiments in Panama, in Proc. Oil Spill Conf., American Petroleum Institute, 1987, 634.
10. Anderson, J. W., McQesarry, D. L., and Kleinore, S. L., Laboratory evaluation of chemical dispersants for use on oil spills at sea, *Environ. Sci. Technol.*, 19(5), 454, 1985.
11. Thorhaug, A. and Marcus, J., Effects of dispersant and oil on tropical and subtropical seagrasses, in Proc. Oil Spill Conf., American Petroleum Institute, 1985, 497.
12. Thorhaug, A. and Marcus, J., Effects of dispersant and oil on subtropical and tropical seagrasses, in *Proc. Oil Spill Conf.*, American Petroleum Institute Publ. 4452, Washington, D.C., 1987, 223.
13. Teas, H., Dunn, E. O., and Wilson, J. R., Effects of dispersed and non-dispersed oil on the red mangrove, *Mar. Pollut. Bull.*, 18(3), 122, 1985.
14. Elgershuizen, J. H. W. B. and deKruijf, H. A. M., Toxicity of crude oils and a dispersant to the stoney coral *Madrepora microbilis*, *Mar. Pollut. Bull.*, 7(2), 22, 1976.
15. McAuliffe, C. D., Organism exposure to volatile soluble hydrocarbons from crude oil spills — a field and laboratory comparison, in *Proc. Oil Spill Conf., Washington, D.C.*, American Petroleum Institute, 1987, 275.
16. Shaba, R. J. and Heinemann, A. J., Toxicity test on biological species indigenous to the Gulf of Mexico, in *Proc. Oil Spill Conf.*, American Petroleum Institute, Washington, D.C., 1989, 249.
17. Thorhaug, A. and Marcus, J., Effect of seven dispersants on three subtropical seagrasses, *Mar. Pollut. Bull.*, 18(3), 124, 1987.
18. Thorhaug, A. and Cruz, R., Restoration of Pacific seagrasses, in *Restoring the Earth*, Berger, A., Ed., Elsevier, Amsterdam, 1989, 21.
19. Thorhaug, A., McDonald, F., Miller, B., McFarlane, J., Carby, B., Anderson, M., Gordon, V., and Gayle, P., Dispersed oil effects on tropical habitats, in *Proc. Int. Oil Spill Conf.*, American Petroleum Institute, Washington, D.C., 1989, 455.
20. Getter, C. D., Oil spills research in tropical environments and contingency planning in the wider Caribbean, in Proc. Int. Petroleum Industry Environmental Conservation Association, Venezuela, 1986, 29.
21. Cubit, J. D., Getter, C. D., Jackson, J. B. C., Garrety, S. D., Caffey, A. M., Thompson, R. C., Weil, E., and Marshall, M. J., An oil spill affecting coral reefs and mangroves on the Caribbean coast of Panama, in *Proc. Oil Spill Conf.*, American Petroleum Institute, Washington, D.C., 1987, 401.
22. LeGore, R. S., Marszalek, D. S., Hoffman, J. E., and Cuddeback, J. E., A field experiment to assess the impact of chemically dispersed oil on Arabian Gulf corals, SPE 11444, Society of Petroleum Engineers, 1982, 51.
23. IMO/UNEP Guidelines on Oil Spill Dispersant Application and Environmental Consideration, International Maritime Organization, London, 1982.
24. Chan, E. T., Oil pollution and tropical littoral communities, Biological effects of the 1975 Fla. Keys Oil Spill, in *Proc. Oil Spill Conf.*, American Petroleum Institute, Washington, D.C., 1977, 539.
26. Daly, H. E. and Cobb, J. B., *For the Common Good*, Beacon Press, Boston, 1989.
27. Thorhaug, A., Dispersant effects on tropical ecosystems, in *Oil Dispersants: New Ecological Approaches*, Flaherty, M., Ed., ASTM, Philadelphia, 1988, pp 249-265.
28. Thorhaug, A. and Cruz, R., Restoration of Philippine seagrass, in Proc. LSD Philippines Conf. on Seagrass, 1987, 20.
29. Thorhaug, A., Miller, P., Cruz, and Gayle, P., Comparison of Seagrass Restoration from Atlantic and Indo-Pacific Tropics, in Proc. Int. Ecological Conf., 1986, 312.
30. Grigg, R., Restoration of coral reefs after lava flows, report to University of Hawaii, *Mar. Sci.*, 22pp., 1981.
31. Hudson, H. and Diaz, R., Damage survey and restoration of M/U Wellwood, in Proc. 6th Int. Coral Reef Symp., Vol. 2, 1988, pp 231-236.

32. Jernelov, N. and Linden, O. E., IXTOC, *Ambio*, 10(6), 299, 1981.
33. Baker, J. and Goodman, K. S., A preliminary ecological survey of coastline, British Petroleum International, London, 1982.
34. Tens, H., Lindsay, A. H., Elias, L. L., Morales, R. A., DeDiego, M. E., and Baber, J. M., Mangrove restoration after the 1986 refineries Panama oil spill, in Proc. 1989 Oil Spill Conf., American Petroleum Institute, Washington, D.C., 1989, 427.
35. Seneca, A. E., Restoration of marshes after the Amoco Cadiz oil spill, in Proc. Int. Bot. Soc. Congr., Vancouver, 1980.
36. Hanna, R. G. and Ormond, R. F., Oil pollution, urchins, erosion, and coral reef deterrents in the Egyptian Red Sea, *Iraqi J. Mar. Sci.*, 1(1), 35, 1982.
37. Belt, R. P. M., The effect of chronic oil pollution on a Caribbean coral reef, *Mar. Pollut. Bull.*, 18(10), 534, 1987.
38. Lindsay, A. H., Economic evaluation of dispersants to combat oil spills, in *Oil Dispersants, New Ecological Approaches*, 1018, Flaherty, M., Ed., ASTM STP Philadelphia, 1989, 41.
39. White, L. C. and Nichols, L. A., The cost of spills, in Proc. Oil Spill Conf., Washington, D.C., American Petroleum Institute, 1983, 541.
40. United Nations Environment Program Latin American Office, 1987, personal communication.
41. Baker, et al., 1990.
42. Curry, personal communication.
43. Tens, personal communication.
44. U.S. Environmental Protection Agency, 1984.
45. Thorhaug, A., Tropical and subtropical thermal pollution, *Thalassia Yugoslavia*, 20(2), 103, 1986.

24
6581

PROCEEDINGS OF THE SIXTH INTERNATIONAL CORAL REEF SYMPOSIUM

TOWNSVILLE, AUSTRALIA

8th - 12th August 1988

VOLUME 2:

CONTRIBUTED PAPERS

(Mini Symposium 1 to 10/14)

Edited by J.H. Choat, D. Barnes, M.A. Borowitzka, J.C. Coll, P.J. Davies, P. Flood, B.G. Hatcher, D. Hopley, P.A. Hutchings, D. Kinsey, G.R. Orme, M. Pichon, P.F. Sale, P. Sammarco, C.C. Wallace, C. Wilkinson, E. Wolanski and O. Bellwood

Published by the 6th International Coral Reef Symposium Executive Committee

99

Proceedings of the 6th International Coral Reef Symposium, Australia, 1988, Vol. 2

DISPERSED OIL EFFECTS ON MANGROVES, SEAGRASSES, AND CORALS IN THE WIDER CARIBBEAN

A. THORHAUG
Florida International University
P.O. Box 490559, Miami, FL USA 33149

ABSTRACT

Most oil spill clean-up plans in the wider Caribbean indicate that dispersants should not be used. This is in error for coastal and estuarine spills. There have been a series of studies, which will be reviewed, both for field and laboratory on toxicity effects of dispersants on critical habitat matrix organisms in the Caribbean basins. Red mangroves and several coral species were seen to not have toxic effects from Corexit 9527 within the 1-50 ppm range. The Rhizophora mangle experiments by Teas indicated better survival when Corexit was used, than oil alone. Laboratory results for seagrasses on seven dispersants showed lows, medium, and high toxicities not dependent on oil type. These results indicated an "acceptable" list of dispersants as the British have is necessary for the wider Caribbean matrix-species preservation during spills where dispersants will be used. Three major wider Caribbean seagrasses have differing toxicity responses, dependent on the dispersant, but in the same ranking: Thalassia more tolerant than Halodule, more tolerant than Syringodium. Coral results in Bermuda and Panama by Knap et al. (1985) for Diploria strigosa and Porites porites with Agaricia sp. indicate that the dispersant Corexit 9527 is not toxic (1-50 ppm). Ongoing studies in Jamaica are discussed for coral and seagrasses.

INTRODUCTION

Most of the shorelines containing mangroves and corals are in the developing world. Oil spill clean-up in these countries has been adopted from measures from temperate climates where less sensitive habitat species occur on shorelines.

After dispersants were used with a negative result in the Torry Canyon Spill, dispersants were banned from use by most nations. Two developments occurred: 1) many manufacturers made a far less toxic dispersant; 2) many spills were not able to be controlled by mechanical means because these were too large, too fast in arriving at the shore, or too difficult to contain in booms (high seas, high winds, fast tides), or a different spatial configuration for boom development. Recent work on mangroves (in field and laboratory) shows that mangroves are statistically more able to survive oiling if dispersant is added prior to the time the oil approaches the mangroves (Teas et al., 1987).

The work done to date on corals included intensive studies of the effects of the dispersant Corexit 9527 and a BP product on the coral Diploria strigosa in Bermuda (the northern-most site of Atlantic corals) by Knap and associates. Their conclusion was to recommend use of dispersants to the government of Bermuda. Le Gore et al. (1983) studied Corexit 9527 on several Arabian Gulf corals and found no toxicity. In Panama, field tests showed no toxicity of Corexit 9527 on Porites porites, Avicennia niger and Thalassia testudium (Getter et al., 1987, Knap et al., 1985), although a real life oil spill showed large areas of decimation (Cubit et al., 1987).

Mangroves have been shown to be decimated in a series of oil spills in all continents. Seagrasses have been less well documented, but definite damage as an effect of oil spills have been shown (review by Thorhaug, in prep).

METHODS

The specimens were selected to represent major critical habitat organisms in the front seaward edge of community, in mid-depth range and in near-shore or estuarine areas. The specimens were chosen with help from U.W.I. and NRCD experts.

Seven individual specimens for each variable testing set were taken from outer Kingston Harbor for seagrasses and from the middle north coast or the proximity of Discovery Bay for seagrasses. Only very healthy specimens were used.

After collection and acclimation, specimens were exposed to the test substance in 100,000 mL fresh seawater in 50 gallon glass tanks. Static conditions with vigorous bubbling occurred for the incubation period. Specimens had test substance plus incubation water removed replaced with fresh running seawater. The oil was aged 24 hours prior to administration. The dispersant was poured into the oiled seawater and vigorously mixed by a paddle for one minute. Measurement of incubation exposure and growth were made prior to administration of test substance, after and at 2 to 3 d intervals thereafter (10 d seagrass and 14 d corals). 125 ml oil with 12.5 ml dispersant or 75 ml oil with 7.5 ml dispersant were used. Measurements were made from May to September. Health of corals was described on a graduated scale previously discussed by Thorhaug and Marcus (1982) with 100% alive and colorful as 10 and 1 equals to dead, bleached. Five to 50% bleached, discolored or spotted. 10 = 100% alive and colorful, 5 = 50% bleached, discolored or spotted and 1 = 100% dead, bleached.

Seagrass gradation of health and blade growth included a scale previously outlined in Thorhaug and Marcus (1982). The growth measurements were made on a 2-4 cm young blade, one on each of seven shoots. Counts of mortality made on all 700 blades per tank. The statistics wese Student-Newman-Keuls analysis of variances. The preliminary results of our first sets of experiments are recorded in results. Ongoing results are still being analyzed.

RESULTS

The results to date are preliminary. Final results will be forthcoming in one year. The results of the laboratory testing can be separated into two sets of data, although general results have begun to emerge which can be synthesized. The general result, not ever recorded until now, shows that the toxicity of various dispersant products was very similar in order of ranking between species of both corals and seagrass: three

100

levels of toxicities were apparent at high concentrations: high toxicity (80 to 100% mortality); medium toxicity (45 to 75% mortality) and low toxicity (0 to 30% mortality). The same dispersant products fall into the same rank-order for all species tested and for corals and seagrasses.

Coral Data

Table 1 shows two high concentrations of dispersed oil for 10 hour exposure (which time period is relevant to about the time a tidal cycle would have the dispersed oil exposure to corals).

Corals show a definite order of increasing tolerance to the dispersant products. Conco K (K), OFC D609, Corexit 9527, Kemarine, ADP 7 (Petrogreen) and Janosolv are among those most toxic to all three species. Corexit 9550 falls into an intermediate range. The lesser toxicity includes Elastosol, Cold Clean, Finasol. These latter mortalities were 25% and less. We are continuing to test dispersant products in Jamaica.

Seagrass

The preliminary laboratory toxicity testing seen in Table 2 shows that Jamaican seagrasses were very sensitive to the following dispersants: Conco K(K), ADP 7 and OFC D609 and Corexit 9527.

The seagrass tolerated Elastosol, Cold Clean and Finasol far better. With ADP 7 and Corexit 9550 being intermediate toxicity. Bunker crude oil was more toxic than was Venezuelan middle light crude.

DISCUSSION

Management Principles for Use of Dispersant on Tropical Habitats

For the first time a series of major dispersants marketed around the world were laboratory tested and compared in toxicity on dominant corals and seagrasses in the Greater Caribbean. These tests showed some products of low toxicity, which even 2 orders of magnitude above recommended use were not toxic to corals or seagrasses. On the other hand, some products were quite toxic to both seagrass and corals and should not be used near these resources. The order of ranking of toxicity of products was approximately the same between corals and seagrasses.

It is now apparent that some dispersants at concentrations recommended by the manufacturer can be used under various sets of emergency conditions for oil spills which frequently occur in the world's tropics: a) estuarine spills where or when mechanical means are inadequate to control oil from impacting one or more type of habitat, especially mangroves, b) nearshore coastal spills where environmental conditions are rapidly transporting spill toward one or more critical habitat, c) weather conditions when mechanical clean-up is ineffective and there is a danger of impacting corals, mangroves or seagrasses. (It should be noted that our present information from literature shows mangroves appear to be affected "physically" by oil. When oil remains in the sediment, it appears to smother the mangroves by cutting off oxygen to the lenticels in the subsediment. If only the above ground portion is oiled, no mortality occurs. If the oil is dispersed prior to arriving into the mangroves, the mangroves do not experience massive mortality [Teas et al., 1987]).

Thus, it is important to find low toxicity products as dispersants for coral and seagrass.

All parties must stop using the generic term "dispersants" within the oil spill clean-up plans. Specific tested and non-toxic dispersants must be named for spills on each habitat type with their upper concentration limits for use described.

Further laboratory tests must be done by nations in tropical areas to test their commonly used and stockpiled dispersants for toxicity effects on their critical habitat organism such as various species of corals, mangroves, seagrasses and marshes. It is unrealistic to imagine small third world nations will find this a priority. Regional multinational and industrial funds should undertake this.

A network of rapid information dissemination to industry, environmental management, government spill clean-up managers should be organized so that whatever information is derived can be disseminated.

Resource maps which must include the exact species of mangrove, seagrass or corals should be included in oil spill contingency plans. Since the toxicity effects differ by more than order of magnitude between species, present "lumping" resource maps (ie. "seagrasses) are inadequate. By integrating the resource maps into planning oil spill clean-up in a manner as Venezuela has, updated information can easily be incorporated into plans on a yearly basis.

ACKNOWLEDGEMENTS

The author wish to acknowledge U.S. Agency for International Development, PSTC Grant, Jamaica OPD and NRCD and Florida International University. Appreciation for experimental help from NRCD staff especially Fitzroy Gregory, and Anthony McKenzie with corals and to University of West Indies faculty who helped plan the concept, Dr. George Sidrak, Dr. Karl Aiken and especially Dr. Jeremy Woodley. M. Flaherty of USEPA (ret.) is thanked for helpful discussions about differences among dispersants. Captain Charles Corbett and U.S. Coast Guard oil spill (clean-up) staff in Washington, Miami, and Puerto Rico are thanked for discussions on clean-up problems. A variety of members of IPEICA and API are thanked, especially Dr. Duane Levine of Exxon, for discussions of the oil industries' problems. Members of the United Nations Environmental Programme office such as Dr. Tolba, Dr. Keskes and other offices (Dr. Noel Brown, North American Liaison office) and Caribbean Action Plan. Dr. Howard Teas is especially thanked as a mentor on oil spill and physiology particularly during the preliminary stages of our experiment.

REFERENCES

Cubit, J.D., Getter, C.D., Jackson, J.B.C., Garrity, S.D., Caffey, H.M., Thompson, R.C., Weil, E. & Marshall, M.J., 1987. An oil spill affecting coral reefs and mangroves on the Caribbean coast of Panama. In: Proceedings of 1987 Spill Conference, Amer. Petrol. Inst., Washington D.C., pp. 401-106.

Getter, C.D., Ballou, T.C., Hess, S.C., Knap, A., Dodge, R. & Sleeter, T., 1987. Final results of the API tropics oil spill and dispersant use experiments in Panama. In: Proceedings of 1987 Oil Spill Conference, Amer. Petrol. Inst., Washington D.C., pp. 634.

Knap, A.H., Wyers, S.C., Dodge, R.E., Sleeter, T.D., Frith, H.R., Smith, S.R. & Cook, C.B., 1985. The effects of chemically and physically dispersed oil on the brain coral Diploria strigosa (Dana) - a summary review. In: Proceedings of 1985 Oil Spill Conference, Amer. Petrol. Inst., Washington D.C., pp. 547-551.

Le Gore, R.S., Marszalek, D.S., Hofmann, J.E., & Cuddeback, J.E., 1983. A field experiment to assess the impact of chemically dispersed oil on Arabian Gulf corals. Soc. of Petr. Eng., SPE 114444: 51-60.

Teas, H.J., Duerr, E.O. & Wilcox, J.R., 1987. Effects of South Louisiana crude oil and dispersants on Rhizophora mangroves. In: Proceedings of 1987 Oil Spill Conference. pp. 633.

Thorhaug, A. & Marcus, J. 1982. Pacific versus Atlantic responses of the subtropical hermatypic coral Porites sp. to temperature and salinity effects. In: Proceedings of the 4th International Coral Reef Symposium, Manila, Philippines. 2: 14-20.

Table 1. Percentage mortality of selected Jamaican major habitat corals vs. Dispersant type of dispersed Venezuelan light oil.

Dispersant Type	Porites porites 125 mL. 10 Hrs.	Porites porites 75 mL. 10 Hrs.	Montastrea annularis 125 mL. 10 Hrs.	Montastrea annularis 75 mL. 10 Hrs.	Acropora palmata 125 mL. 10 Hrs.	Acropora palmata 75 mL. 10 Hrs.
Conco	100	100	100	100	100	
OFC D609	100	88	100	ND	100	
Corexit 9527	72	88	100	76	100	
Kemarine	100	100	100	88	100	
ADP 7	100	ND	100	ND	100	
Corexit 9550	43	0	0	12	100	
Jansolv	87	72	72	52	ND	
Elastosol	0	0	0	0	0	
Cold Clean	0	ND	17	ND	ND	
Finasol	0	0	0	0	20	
Oil only	52	12	52	0	90	
Control	0	0	0	0	0	

Table 2. Percentage mortality of selected Jamaican major habitat seagrasses vs. Dispersant type of dispersed Venezuelan light oil.

Dispersant Type	Thalassia 125 mL. 6 Hrs.	Thalassia 75 mL. 10 Hrs.	Halodule 125 mL. 6 Hrs.	Halodule 75 mL. 10 Hrs.
Conco	100	57	82	90
OFC D609	70	35	63	82
Corexit 9527	89	32	93	72
Kemarine	63	48	68	68
ADP 7	50	22	46	90
Corexit 9550	40	20	46	31
Jansolv	0	0	0	3
Elastosol	15	11	46	13
Cold Clean	0	0	0	0
Finasol	0	0	0	4
Oil only	30	11	28	13
Control	11	10	9	11

International Symposium on

THE ECOLOGY OF MANGROVE AND RELATED ECOSYSTEMS

24 - 30 September, 1990

Mombasa, KENYA

Organised by

the Department of Zoology, University of Nairobi

In collaboration with Kenya Marine and Fisheries Research Institute
and RECOSCIX - WIO Regional Dispatch Centre

With sponsorship of:
African Biosciences Network
US - National Research Council
Commission of the European Communities
Australian Intern. Development Assistance
The Netherlands Ministry of Agriculture, Nature Management and Fisheries
UNEP - Forestry Department
UNESCO - ROSTA
Third World Academy of Sciences

EFFECTS OF VARIOUS DISPERSANTS ON TROPICAL ORGANISMS:
Corals, Mangroves, Seagrass, Tropical Commerical Fish in Jamaica

Anitra Thorhaug, Richard Reese, Howard Teas, Barbara Carby, Mike Rodriguez, Marcel Anderson, George Sidrak, Beverly Miller, Valerie Gordon, Karl Aiken, Peter Gayle

For the first time anywhere in the world's tropics (in Jamaica, under the direction of the Office of Disaster Preparedness) a series of dispersant products were screened to determine toxicity on the most important tropical matrix organisms. The laboratory test procedures used were standardized tropical toxicity test methods from U.S. and U.N. sources. 100,000 ml seawater with specimens collected and transported under optimal conditions were taken to out-of-door facilities, controls and oil only were run. The corals selected were reef crest, Acropora palmata, back-reef and estuarine, Porietes porietes, and reef-building, Monstastrea annularis. The mangroves were black (Avicinnia niger) red (Rhizophora mangle) and white (Laguncularia). The seagrasses were turtle grass (Thalassia testudinum), shoal grass (Halodule wrightii) and manatee grass (Syringodium filiforme). The fish were important to Jamaican nearshore fisheries, doctor fish (Acanthurus) grunts (Haemulon), squirrel fish (Holocentrus rufus) and sea bream (Archosagus rhonbodales). Concentration levels of dispersant were 12.5 ppm to 125 ppm (only mangroves were tested at higher concentrations). The sensitivity index, which occurred, was fish and corals more sensitive than seagrass which was more sensitive than mangroves. Ranking of dispersed oil products was generally similar between biological groups in terms of toxicity. High, medium and low toxicity dispersant products were found in the 13 tested dispersant products on all groups (8 additional products on mangroves). Field tests consisted of toxicity testing on in situ intertidal mangroves with seagrass and coral seaward of the mangroves. Three of the least toxic dispersants, Cold Clean, Finasol OSR-7 and Corexit 9550 (the least toxic products), were field tested for the first time.

For those oil spills when mechanical means are not adequate and non-treatment would result in substantial environmental damage, a set of tropical policies for "within 3 mile" dispersant use were developed. The dispersant use policy, when mechanical means fail or are inadequate, was formulated by the Jamaican Oil Spill Committee and will be presented in brief.

Thanks to U.S. A.I.D. for major support, also to the Government of Jamaica, Mobil Oil Foundation, Florida International University and Greater Caribbean Energy and Environment Foundation.

Oil and Dispersed Oil on Subtropical and Tropical Seagrasses in Laboratory Studies

ANITRA THORHAUG, JEFFRY MARCUS and FITZGERALD BOOKER
Greater Caribbean Energy and Environment Foundation, 1121 Crandon Blvd. E-1005, Key Biscayne, FL 33149, USA

This is the first study of a range of concentrations of dispersed oil on several species of seagrasses dominant throughout the Atlantic subtropical Greater Caribbean basin. Out-of-door laboratory tanks included 100 l. natural seawater apical meristem and short groupx, rhizome and tissue of each species (15 specimens per treatment). Treatments included dispersed oil, oil alone, dispersant alone, and control. Times of exposure ranged from 5 to 100 h. Concentrations of dispersants ranged from 7.5 to 50 ml in 100 l. seawater. Louisiana crude and Murban oils were tested. Results showed *Halodule wrightii* and *Syringodium filiforme* had an LD_{50} at 75 ml dispersed oil in 100 l. seawater for 100 h exposure, whereas *Thalassia* was more tolerant with an LD_{50} at 125 ml in 100 l. seawater for 100 h. Dispersant alone had a significant effect on *Halodule* and *Syringodium*, but not on *Thalassia*. Louisiana crude oil had a slightly lesser effect than Murban. Difference between seagrass species was greater than between oils.

This is the first study on the effects of a range of concentrations of dispersed oil on several species of seagrass. The seagrasses chosen for investigations are the primary components of the seagrass community within the region of the Greater Caribbean Basin (defined by UNEP as including the Gulf of Mexico, Bahamas and South Florida). Guidelines governing the use of dispersants in the US coastal waters have recommended use of dispersants offshore after mechanical clean-up means have been exhausted. Dispersants have not been recommended within several miles of a shore and not within bays, estuaries and lagoons. Caution has been used as a strategy to conserve natural resources with the caveat that no data on seagrass tolerance to dispersed oil were available.

PROOFS SHOULD BE RETURNED
TO PROF. R.B. CLARK
MARINE LAB. ENCLOSED

Due to the rapidity with which dispersants could theoretically be administered to a spill, their cost-effectiveness, and their rapid transportability to distant locations where an oil spill might occur, more information on their toxicity to living coastal resources is clearly necessary for rational decison making at the time of such a spill, and wise resource use in preserving seagrass beds. Seagrasses in subtropical and tropical regions form a large part of the fisheries nurseries and play an important role in nearshore coastal ecosystems. Depending upon the tropical ocean basin, from 300 to 500 species of invertebrates are found associated with seagrasses and about the same number of fish species. In terms of extent of area, the seagrass is usually the major ecosystem between the mangrove shoreline and the coral reef. In many areas seagrass forms a large biomass. In the Gulf of Mexico, Caribbean basin, east Florida and the Bahamas, three seagrasses form the major members of seagrass habitats: *Thalassia testudinum*, *Halodule wrightii* and *Syringodium filiforme*.

The impact of oil spills on tropical and subtropical seagrass beds have been summarized by Zieman *et al.* (1984) and Thorhaug & Marcus (1985). The effects of dispersants on seagrass beds have not been reported with oil spills on seagrass beds except for one preliminary laboratory test where 17.7 ml dispersed oil turned 70% of the *Thalassia* blades tested brown (Baca & Getter, 1982).

The purpose of the present study was to test the responses of the three major Greater Caribbean species of seagrasses in the laboratory to various concentrations of dispersed oil. The results need field testing at a series of critical concentrations and times prior to guideline recommendations. An equivalent set of tests, in terms of methodology, dispersant type and oil type, is being carried out on the temperate seagrass *Zostera* (Page & Gilfilin, personal communication).

Methods

Collecting

Each test specimen had apical meristematic tissue, 19 cm of rhizome, and several short blade groups. They were collected from nearshore bay waters (Biscayne Bay) and transported to test tanks located within 6 km of the collecting site. Fifteen specimens of each species were placed in each tank. Acclimation time was 48 h prior to the experiments.

% Mortality vs. Dispersed Oil

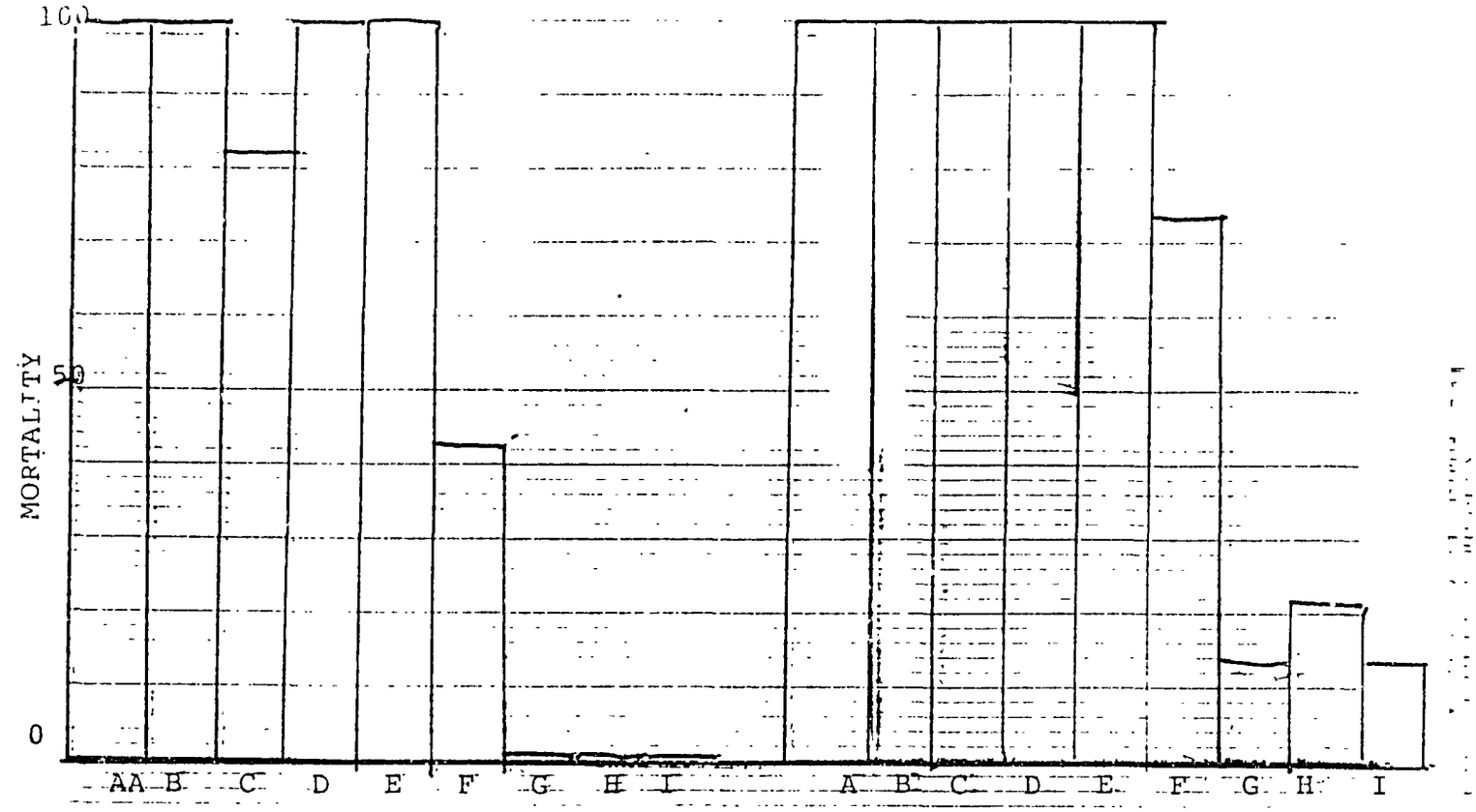
Venezuelan light; 125 mL; 6 hr

Dispersant	Thal	Hal
Conco	100	82
OFC D609	70	63
Corexit 9527	89	93
Kemarine	63	68
[illegible] 7	50	46
Corexit 9550	40	46
Jansolv	ND	ND
Elastosol	15	46
Cold Clean	ND	ND
Finasol	ND	ND
Oil only	30	28
Control	11	9

Table 2, continued.

	Mortality				
	125mL;6h			75mL;10h	
	Por.por	Mont.an	Ac.pl.	Por.por.	Mont.an.
Conco	100	100	100	100	100
OFC D609	100	100	100	91	91
Corexit 9527	90	86	100	88	76
Kemarine	90	57	100	85	90
ADP 7	90	72	100	85	90
Corexit 9550	64	14	100	0	12
Jansolv	0	0	50	0	0
Elastosol	15	0	4	0	0
Cold Clean	15	0	15	8	0
Finasol	8	0	15	0	0
Oil only	52	52	100	12	0
Control	0	0	29	0	0

DISPERSED OIL TYPES VERSUS MORTALITY



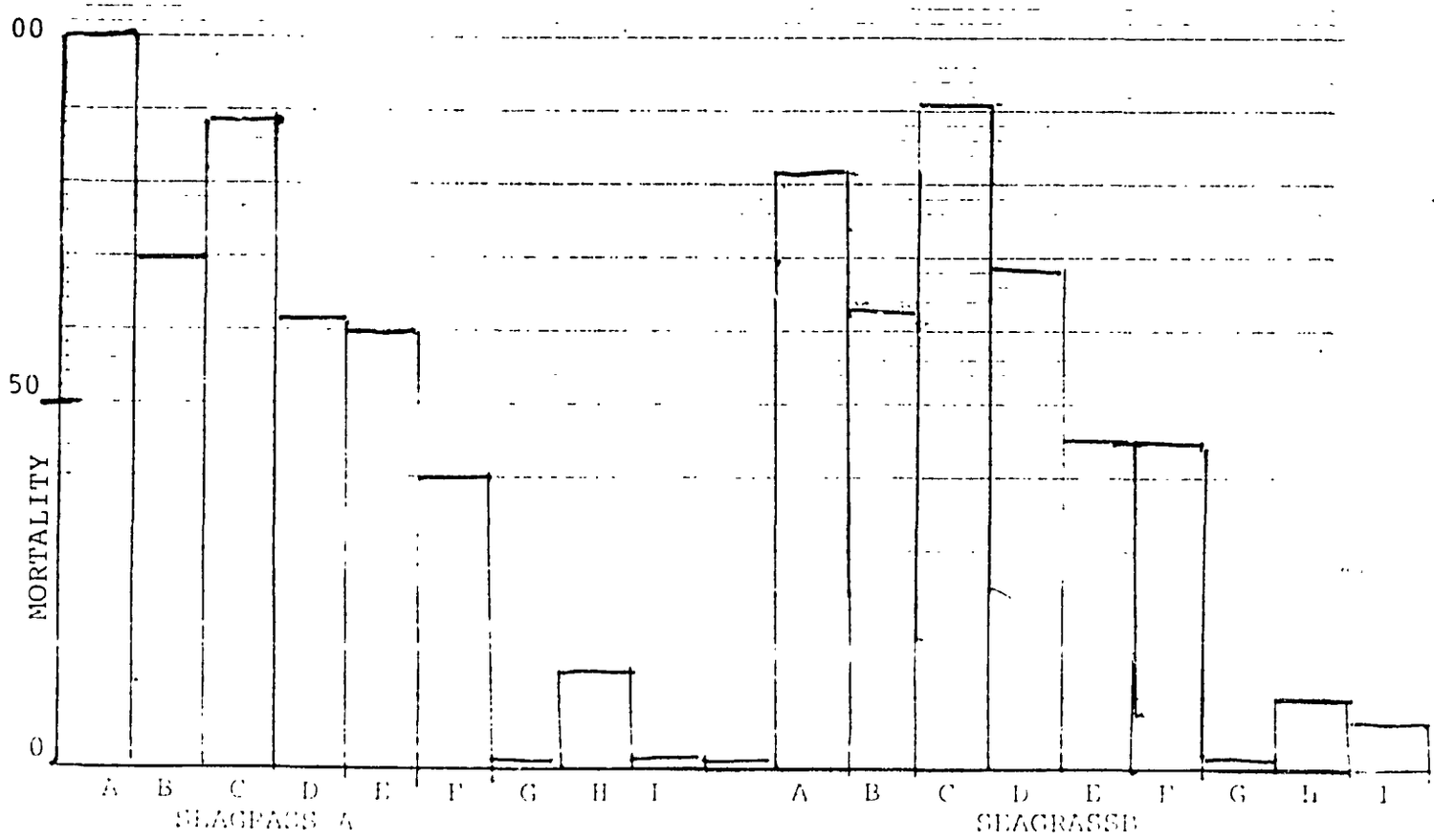


Table 2. Coral results for Venezuelan crude oil and 3 species of Jamaican important habitat corals.

Dispersant Product	Dispersability Ratio (1)	Cost (2)	Mortality 125mL:10h (3)		
			Por.por	Mont.an	Ac.pl.
Conco	0.580	0.59	100	100	100
OFC D609	0.007	0.08	100	100	100
Corexit 9527	0.009	0.11	72	100	100
Keramine	-	-	100	100	100
ADF 7	-	-	100	100	100
Corexit 9550	-	-	43	0	100
Jansolv	-	-	0	0	73
Elastosol	-	-	0	0	15
Cold Clean	-	-	0	0	21
Finasol	0.038	0.28	0	0	11
Oil only	-	-	52	52	58
Control	-	-	0	0	0

---

(1) Dispersability is the ratio or dispersant to oil required to disperse 90% of the oil (U.S. EPA, 1984)

(2) Cost is the relative effective cost of sufficient dispersant to disperse 90% of 1 gal of oil under the conditions of the Mackay apparatus.

(3) Concentrations in 100,000 cc of seawater were 10:1 of oil to dispersant product.

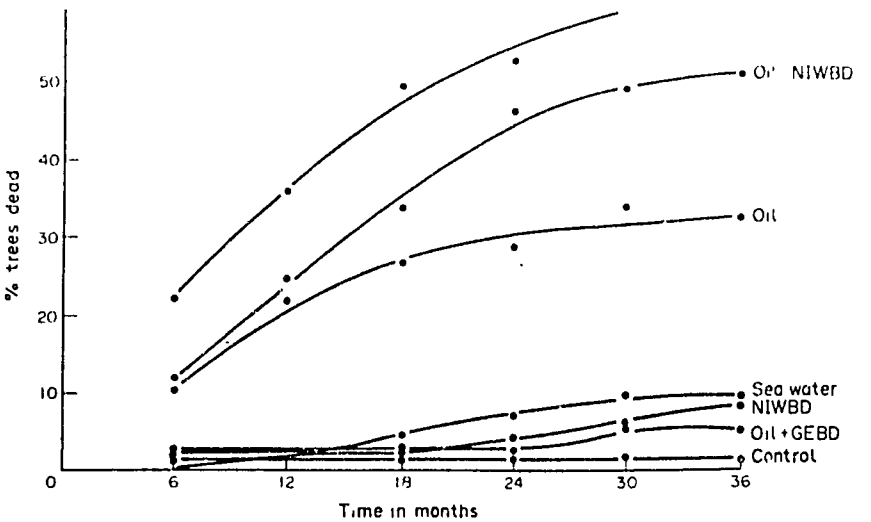


Fig. 2 Mangrove mortality at 6 month intervals for experimental treatments.

The authors wish to express their thanks to the Florida Power & Light Co. for permission to carry out the experiment on their property; Earl Baker of Florida Power & Light Co. for logistic support of field operations; Gerald P. Canevari for the loan of the gasoline-powered pump used for spray treatments; Daniel Cary for assistance with statistical analyses; Exxon Chemical Company and Texaco, Inc. for materials; the American Petroleum Institute (API) for financial support of the investigations; the API Task Force members (Stuart Horn, Gerald P. Canevari, June Lindstedt-Siva, C. Bruce Koons, Albert Lasday, Clayton McAuliffe and James Marum) for advice and field assistance; Donald Casey and Jack R. Gould, API staff, for advice and administrative support; and Michael de Groot, Carlos Manalich, George Concepcion, Clorinda Robles, and Marie Morgan for technical assistance.

Canevari, G. P. (1979). Restoration of oiled shorelines by proper use of chemical dispersants. Proceedings of 1979 Oil Spill Conference, pp. 443–446. American Petroleum Institute, Washington, D.C.

Chapman, V. J. (1970). Mangrove phytosociology. *Tropical Ecology* **11**, 1–19.

Lewis, R. R. (1983). Impact of oil spills on mangrove forests. In *Tasks for Vegetation Science* (H. J. Teas, ed.), pp. 171–183. Dr. W. Junk Publishers, The Hague.

Teas, H. J. (1979). Silviculture with saline water. In *The Biosaline Concept* (A. Hollaender, ed.), pp. 117–161. Plenum Publishing Corporation, New York.

Marine Pollution Bulletin, Vol 18, No 3, pp 124–126, 1987
Printed in Great Britain

0025-326X/87 $3.00+0.00
© 1987 Pergamon Journals Ltd.

Oil Spill Clean-up:

The effect of Three Dispersants on Three Subtropical/Tropical Seagrasses

A. THORHAUG* and J. MARCUS
Florida International University, Tamiami Campus, Miami FL 33199, USA
*On leave to United Nations Food and Agriculture Organization

Three seagrasses found throughout the Greater Caribbean tropical/subtropical region as major critical habitat organisms were tested in the laboratory for toxicity limits to three dispersants commonly stockpiled in the region. At concentrations in the recommended dosage level, that is, below 1 ml dispersant with 10 ml oil in 100 000 ml seawater, even for 100 h no large mortality occurred (15–18 barrels per acre as calculated by Exxon, 1985). At an order of magnitude higher, especially for longer time periods, the more sensitive seagrasses *Syringodium filiforme* and then *Halodule wrightii* succumbed. The dispersants had widely differing effects, with Corexit 9527 and Arcochem D609 having far less toxic effect than Conco K(K) at the same exposure time and concentration. There was comparatively little difference between effects of oils (Louisiana crude versus Murban). Types and brands of dispersants should be referred to specifically in oil spill contingency plans since such widely varying ecological toxicity occurs among various dispersants. Use of the word 'dispersant' as a policy tool should be used with caution, realizing that dispersants vary widely in toxicity effects. Further testing of seagrasses in other ocean basins and those dispersants to be used there is highly recommended.

The question of how various dispersants effect various critical organisms in the tropics and subtropics has not yet been addressed. In the temperate zone, the environmental management departments of many first world governments have asked industry to perform specific toxicity tests of their dispersant product on temperate animals to register or list the dispersant. For example, a temperate fish and a temperate shrimp were used by US Environmental Protection Agency. From the testing of dispersant toxicity under standard conditions on these organisms, Anderson *et al.* (1985) have proved very different toxicity effects of different dispersants.

The question remains: Are the tropical/subtropical critical habitat organism toxicity limits the same as temperate organisms to various dispersants, or different?

Seagrass is a major coastal and estuarine habitat in the subtropics and tropics. It has been seen to be sensitive to a variety of man's impacts (Thorhaug *et al.*, 1973, 1985; Thorhaug, 1981 in press; Thorhaug and Marcus, 1985). When seagrass is removed by a pollutant, the animal community and fisheries nursery associated with it disappear (Roessler *et al.*, 1975), and when it is restored, the animals recolonize (McLaughlin *et al.*, 1983).

Tropical and subtropical critical habitat seagrasses have been shown to differ in their response to a single dispersant (Corexit 9527) (Thorhaug *et al.*, 1986). *Thalassia testudinum* (turtle grass) is far more resistant to Corexit 9527 than *Halodule wrightii* (shoal grass) or *Syringodium filiforme* (manatee grass) over time and concentration.

Methods

The methods duplicate those described by Thorhaug *et al.* (1986). In summary, out-of-door aquaria with sand and 100 000 ml natural seawater were planted with 15 healthy sprigs each of three species (*Thalassia testudinum, Halodule wrightii,* and *Syringodium filiforme*). Treatments included dispersed oil, oil only, dispersant only, and control. Variables included: Concentration of dispersed oil, time of exposure, type of oil, and type of dispersant. Oil was weathered in shallow pans exposed to sunlight for 24 h prior to experimentation. Dispersants were vigorously mixed with oil at time 0. Bubbling throughout the experiment kept dispersed oil in a 'mousse' phase. After treatment, oil was thoroughly removed and tank cleaned; specimens were measured for 14 days for mortality, sublethal effects, and growth of 15 new blades of each species.

Statistical analysis of data is described in detail in Thorhaug & Marcus (1985). Mortality at a series of concentrations was calculated to LD_{50}. Regression analysis from growth data was plotted. T-tests for statistically significant differences between treatments (at 5% and 1% levels) were performed.

Results

Results of dispersed oil mortality can be seen in Figs 1–3. Fig. 1 shows the percentage mortality at 5 h for 7.5 ml dispersant with 7.5 ml oil in 100 000 ml seawater for three seagrasses. Only Conco K(K) dispersant produces mortalities near LD_{50} of the population in all three seagrasses. The other two dispersants show low percentage of population mortalities. Fig. 2 shows the same concentration of dispersed oil as above, but for the longer period of 100 h (which conforms to US EPA test criteria of 96 h for LD_{50} standard tests). Herein all dispersants have high mortalities for *Syringodium filiforme* and *Halodule wrightii*, but only Conco K(K) has greater

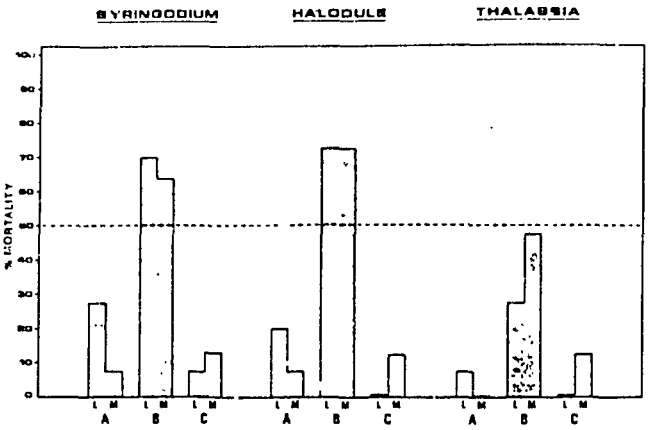


Fig. 1 % mortality of *Syringodium, Halodule,* and *Thalassia* (n = 15) exposed for 5 h to 75 ml of Louisiana Crude oil (L) or Murban oil (M) mixed with 7.5 ml of one of the following dispersants: A. Corexit 9527; B. Conco K(K); C. Arcochem D609 in 100 l. seawater.

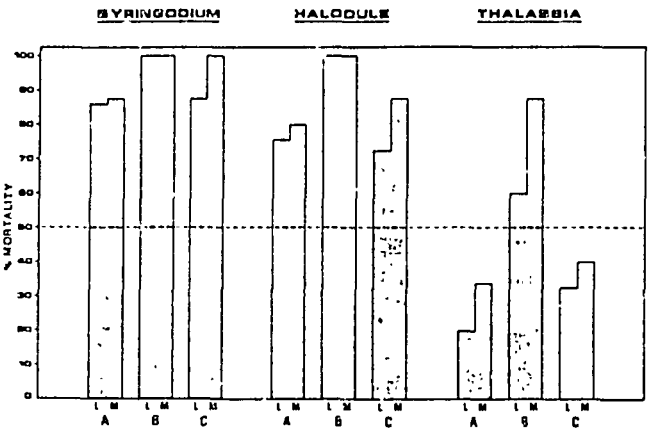


Fig. 2 % mortality of *Syringodium, Halodule,* and *Thalassia* (n = 15) exposed for 100 h to 75 ml of Louisiana Crude oil (L) or Murban oil (M) mixed with 7.5 ml of one of the following dispersants: A. Corexit 9527; B. Conco K(K); C. Arcochem D609 in 100 l. seawater.

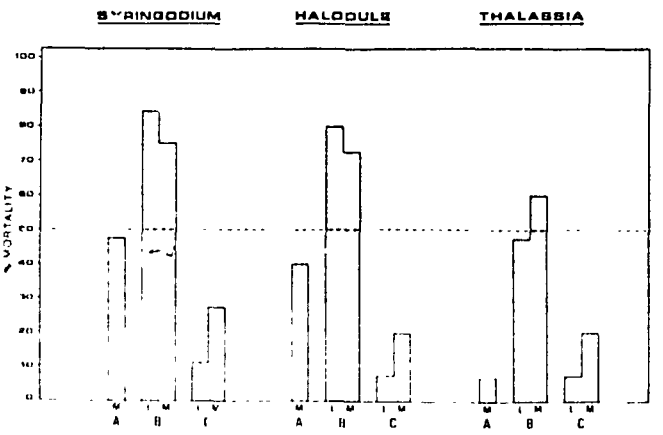


Fig. 3 % mortality of *Syringodium, Halodule,* and *Thalassia* (n = 15) exposed for 5 h to 12.5 ml of Louisiana Crude oil (L) or Murban oil (M) mixed with 12.5 ml of one of the following dispersants: A. Corexit 9527; B. Conco K(K); C. Arcochem D609 in 100 l. seawater.

difference in lethal dosages for various species appears in this figure.

Fig. 3 shows 12.5 ml dispersant in 125 ml oil for 5 h. Here the LD_{50} level is approached by Corexit 9527 for all species of seagrass, and is surpassed by Conco K(K) for all species of seagrass, but is not effectively reached by Arcochem D609 for any species. This shows the largest difference between dispersants of any test concentration/time.

Conclusions

The seagrasses reacted very differently to the dispersant Corexit 9527 versus Conco K(K). Significant differences at 5 h for several concentrations were found between the two dispersants. The third dispersant tested, Arcochem D609, behaved much like Corexit 9527 in terms of effect on survival and growth. The relative ratio of toxicity between the three seagrasses stayed fairly constant between dispersants and between concentration–time exposures with *Syringodium* being the most sensitive, *Halodule* slightly less, but similar in sensitivity to *Syringodium*, and *Thalassia* generally far more hardy to dispersants. These data correlate well with those of Anderson *et al.* (1985), who found relative toxicities of these three dispersants (plus others) on the temperate mysid shrimp *Mysidopsis bahia* (LD_{50} for Corexit 9527 = 31.9 ppm; for Arcochem D609 = 29.0 ppm; for Conco K(K) = 3.5 ppm).

Since there is such a large difference between toxicity of the various dispersants it is best not to discuss 'dispersants' as a lumped group. Clearly some dispersants are far less toxic than others, and are therefore safe to use on nearshore tropical/subtropical seagrass ecosystems. All the other tropical investigations to date (Le Gore *et al.*, 1983; Knap *et al.*, 1985; Getter, 1986; Teas, 1986) have used Corexit 9527. One unpublished study by the Philippine Coast Guard sponsored by FAO/GESAMP looked at a series of dispersants used in the Philippines on the milkfish *Talapia*. They found large differences between dispersants using LD_{50} measurements.

Note that very little effect was seen between Louisiana crude oil versus Murban oil (a Middle East product) compared to differences between dispersant products.

The concentrations of dispersants found lethal in these laboratory studies to 50% of the population of the most sensitive seagrass is an order of magnitude above what is recommended for field use; for the least sensitive seagrass and least toxic dispersant, two orders of magnitude. Field testing is strongly recommended prior to use at a spill for 'safe guidelines' on all the various seagrasses. None of the subtropical seagrasses, which are generally more sensitive to other types of pollutants (Thorhaug *et al.*, 1978), have been field tested. One tropical seagrass, *Thalassia testudinum*, the most hardy to oil pollution was field tested in Panama at 5 ppm Corexit 9527 dispersant and 50 ppm oil for 24 h with no ill effects (Getter, 1986) which would be predicted by our study. All the tropical dispersant studies refer studies.

In conclusion, when three dispersants in relatively wide usage were laboratory tested on three subtropical/tropical seagrasses, low concentrations which follow instructions for use of dispersants (15–18 barrels per acre calculated by Exxon, 1985) or 0.75 ml dispersant and 7.5 ml oil in 100 000 ml seawater, were not toxic to any seagrasses for any dispersant. At an order of magnitude higher concentration, especially at longer time periods (100 h), differential effects occurred. Corexit 9527 and Arcochem D609 were found far less toxic than Conco K(K). Results showed *Syringodium filiforme* and *Halodule wrightii* less tolerant to dispersed oil and oil than *Thalassia testudinum*.

The authors gratefully acknowledge the support of Mobil Oil Foundation. Also thanked are discussions with Michael Flaherty, US EPA and US Coast Guard decision makers. The authors and Mobil Oil Foundation do not represent endorsement of registered trademark names of dispersants, referenced for reader convenience. We gratefully acknowledge IPIECA support and the combined Venezuelan oil companies for hosting the meeting at which this was presented.

Anderson, J. W., McQuerry, D. L., & Kiesser, S. L. (1985). Laboratory evaluation of chemical dispersants for use on oil spills at sea. *Envir. Sci. and Tech.* **19**, 454–457.

Getter, C. D. (1986). The tropics experiment, designed to give answers for managing tropical oil spills. International Petroleum Environmental Conservation Association (IPIECA) Symposium on Oil Spills Research in Tropical Environments and Contingency Planning in the Wider Caribbean. January, 1986. Caracas, Venezuela.

Knap, A. H., Wyers, S. C., Dodge, R. E., Sleeter, T. D., Frith, H. R., Smith, S. R. & Cook, C. B. (1985). The effects of chemically and physically dispersed oil on the brain coral *Diploria strigosa* (Dana)—a summary review. Proc. 1985 Oil Spill Conference, pp. 547–551. API, Washington, D.C.

Le Gore, R. S., Marszalek, D. S., Hofmann, J. E. & Cuddeback, J. E. (1983). A field experiment to assess the impact of chemically dispersed oil on Arabian Gulf corals. Soc. Petrol. Engineers, SPE 11444, pp. 51–60.

McLaughlin, P. A., Treat, S. F., Thorhaug, A. & Lemaitre, R. L. (1983). A restored seagrass (*Thalassia*) bed and its animal community. *Envir. Conserv.* **10**, 247–254.

Roessler, M. A., Beardsley, G. L., Rehrer, R. & Garcia, J. (1975). Effects of thermal effluents on the fishes and benthic invertebrates of Biscayne Bay, Card Sound, Florida. Tech. Report UM-RSMAS 75027, 214 pp.

Teas, H. (1986). Mangrove ecosystems and recent research into the effects of dispersed and non-dispersed oil. International Petroleum Environmental Conservation Association (IPIECA) Symposium on Oil Spills Research in Tropical Environments and Contingency Planning in the Wider Caribbean. January, 1986. Caracas, Venezuela.

Thorhaug, A. (1981). Seagrasses in the Gulf of Mexico, Florida and Caribbean including restoration and mitigation of seagrasses. R. C. Carey, P. S. Markovits & J. B. Kirkwood, eds. Proc. U.S. Fish and Wildlife Service Workshop on Coastal Ecosystems of the Southeastern United States, pp. 161–178. U.S. Fish and Wildlife Services, Office of Biological Services, Washington, D.C. FWS/OBS-80/59.

Thorhaug, A. (in press). Tropical and subtropical thermal pollution *Thalassia Yugoslavica*.

Thorhaug, A. & Marcus, J. (1985). Effects of dispersant and oil on subtropical and tropical seagrasses. Proc. 1985 Oil Spill Conference, pp. 497–501. API, Washington, D.C.

Thorhaug, A., Roessler, M. & Segar, D. (1973). Impact of a power plant on a subtropical estuarine environment. *Mar. Pollut. Bull.* **7**, 166–169.

Thorhaug, A., Blake, N. & Schroeder, P. (1978). The effect of heated effluents from power plants on seagrass (*Thalassia*) communities quantitatively comparing estuaries in the subtropics to the tropics. *Mar. Pollut. Bull.* **9**, 181–187.

Thorhaug, A., Miller, B., Jupp, B. & Booker, F. (1985). Effects of a variety of impacts on seagrass restoration in Jamaica. *Mar. Pollut. Bull.* **16**, 355–360.

Thorhaug, A., Marcus, J. & Booker, F. (1986). Oil and dispersed oil on subtropical and tropical seagrasses in laboratory studies. *Mar. Pollut. Bull.* **17**, 357–361.

SCANTEXT 1000 0067 20611 25833
JOB: mpb 879 03 0004
COMM.: Cotswold type

NR NR 18.03.85

mpb 879 galley 4

TABLE 1

Results of hydrocarbon analyses of water samples. The values for the quantitative data are given in ppm for the aliphatic and aromatic fractions of hydrocarbons in the sample. The values for "total HC" are the sum of the corresponding aliphatics and aromatics. The TR (toxicity ratio) values are the concentration ratios of the [mono, di and tri methylnapthalenes] to the [mono, di, and trimethlydibenzothiophenes] from the gas chromatographic data, normalized to the same ratio for the whole oil sample. The TR ratio reflects the loss of lower molecule weight (more toxic) aromatic components in the oil. It is a measure of how closely the aromatic hydrocarbons in the water sample resemble the aromatic hydrocarbons in the original crude oil.

The WR (weathering ratio) values are the whole oil normalized ratio of the normal alkanes; n-C14/n-C20. It primarily reflects oil weathering by evaporation and dissolution. It is a measure of how closely the aliphatic fraction of hydrocarbons in the water sample resembles that of the whole crude oil.

Dosage oil concentration (ml in 100 l seater)	Dosage dispersant concentration (ml in 100 l. seawater)	Inactive aliphatic WR (ppm)	Inactive aromatic TR (ppm)	Total HC (ppm)
125	0	7.0	1.7	10.4
125	12.5	324	77	429
0	12.5	0.1	0.2	0.3
500	0	3.8	1.0	5.6
500	50	130	459	6.34
0	0	below detection		
0	50	0.05	0.1	0.15
0	0	below detection		

Murban Crude: C14/C20 = 1.73 napthalenes/dibenzothiphenes = 2.78

Procedural blanks: B1 0.02 mg 0mg
B2 0.03 mg 0 mg

Biscayne Bay: A Decade of Restoration Progress

Anitra Thorhaug, Eugene Man, and Harvey Ruvin

Abstract: *A major multijurisdictional restoration program for Biscayne Bay, Florida is described.*

Key words: *estuarine restoration, Biscayne Bay.*

Introduction

A rapidly growing population of about 2.5 million persons—with tens of millions of tourists visiting each year—occupies Dade County, Florida. A major Florida estuary, Biscayne Bay, occurs throughout the center of this community.

The shallow subtropical/tropical estuary is 61 km long and 18 km wide at its broadest. It drains the Everglades and farmlands through several rivers and a flood canal system. The Atlantic Ocean has a marked tidal effect through a chain of barrier islands to the east. The bay is shallow; the shores and bottom were previously heavily vegetated, sustaining fish nurseries.

About half of the population lives within 1 km of the bay. Most tourists choose to stay around the bay. It is heavily used for commercial and sports fishing, sailing, windsurfing, hobycatting, bathing, snorkeling, scuba diving, motor boating, jet ski and parasailing, beaches, and wading. The upper half is occupied by a large number of residential water front homes, apartments and condominiums. The Port of Miami, the largest cruise-ship port in the world and a major world cargo port, is in the mid-bay. The lower bay area includes a large federal preserve: Biscayne Monument, one of the nation's first federal estuarine preserves, regulated by the Department of Interior. Eleven municipalities have various jurisdiction around the shoreline. The State of Florida has declared a portion of the north bay an aquatic preserve.

Restoration Efforts

In 1974 the University of Miami Research Council (Dr. Eugene Man, chair) formed a Biscayne Bay Committee to focus the community for the first time

114

on the problems of the bay as a whole. Prior to this, activities had been piecemeal. The Biscayne Bay Committee, Anita Thornhaug, chair, organized a symposium on Biscayne Bay in October 1[illegible] to review how the Bay originally functioned, what impacts had occurred, and what was feasible in the future. The proceedings were published. Further, [illegible] included citizens, environmentalists, waterway groups, industry, public officials (local, state, federal), utilities, government decision-makers and managers (local, state, federal), scientists (natural and social), urban planners, lawyers, engineers, and media. Information on what was in and around the bay, how it originally functioned, and what has impacted it was presented. All sectors presented "where should we go from here" ideas. Heated discussion between various interests and positive recommendations occurred. The [illegible] bay, the central and north bay section, and future action for increasing [illegible] were discussed.

A second workshop, based on the symposium assembly organizational [illegible] held with few selected [illegible] from all the above sectors participating. The group divided [illegible] five working groups who met [illegible] to consensus on a [illegible] items. The leaders of the group report and a total [illegible] reached. In three days one [illegible] twenty-five persons [illegible] that the north and central portion, previously considered hopeless to restore, could be restored given the technologies available but that a [illegible] integrated effort would be necessary. Dade County Commissioner [illegible] made it known he would [illegible] commit himself to such a program. The appropriate body to manage the bay was considered on the [illegible] Dade County. The combined efforts of [illegible] industry, government [illegible] citizens would be necessary. [illegible] media coverage [illegible] The National Oceanic and Atmospheric Administration [illegible] Grant Program sponsored this [illegible] many individuals [illegible] in [illegible] this vision of where to proceed.

The University Biscayne [illegible] Thornhaug, Dr. Man, and other [illegible] proceeded immediately [illegible] state senator Robert McKnight [illegible] state sponsorship [illegible] federal sources of funds and [illegible] for ameliorating conditions [illegible] as well as private participation [illegible]

[illegible] Dade County "Biscayne Bay Committee" [illegible] and scientists who began to prepare county programs.

A second symposium [illegible] the Bay [illegible] in 197[illegible] to review progress [illegible] plans [illegible] group, [illegible] and implementation [illegible] and other topics.

[illegible] the [illegible] and tourist [illegible] industry [illegible] in [illegible] the region [illegible] world's such [illegible] and other facilities, [illegible] the Bay.

BEST AVAILABLE COPY

During this same period, federal, state, and local regulation of discharges helped eliminate many of the pollution sources to Biscayne Bay, such as sewage, industrial effluents, and municipal waste elimination, which declined. Consequently, when dredging was done, [illegible] turbidity occurred.

The Dade County Environmental Regulation Department and Dade County Planning Department commenced a series of [illegible] activities, which included:

1. Riprapping vertical seawalls using private funds through permit procedures;
2. Enhancing causeways with parking and beach access wherever possible for citizen use;
3. Creating "user" areas for zoned nonconflicting bay and shoreline uses such as bathing, boating, commercial activities, and marina access;
4. Providing facilities, such as bike paths, walkways, parking, picnic tables, and toilets;
5. Making a master map of bay resources;
6. Monitoring bay water and biota for a baseline;
7. Scientific studies of water circulation patterns, bottom sediments, fisheries, and functional ecosystems;
8. Construction of artificial reefs.

A completely unexpected event that greatly enhanced the community's global image of the bay resulted from the New World Art Festival. The Bulgarian artist Christo chose Biscayne Bay for an art event, "The Surrounded Islands." This event took three years of preparation, employed hundreds in construction, and resulted in a film and exhibit on [illegible] and a book. [illegible] this drew the attention of global media, and millions of visitors who had not appreciated the northern bay were introduced to its [illegible].

State government participated in the bay [illegible] 1976 [illegible] by a multimillion dollar funding program [illegible] landscaping cooperation of the Department of Transportation [illegible] causeways by water management districts [illegible] in canals and rivers, by direct road-fill permits and [illegible] run-off restrictions. A joint co-intrastate effort to [illegible] was launched during [illegible] bay [illegible] Dade County and its citizens.

A third marine improvement [illegible] held in October 1987 to review a decade of progress [illegible] and environmental groups participated in discussions [illegible] the restoration effort for the next decade. There was support [illegible] and intensifying ecosystem [illegible] water pollution control [illegible] nonconflicting [illegible] recreational boating activities, [illegible] and public [illegible] about the bay through the schools [illegible] of fishermen for monitoring [illegible] release programs [illegible] and private partnerships [illegible]

BEST AVAILABLE COPY

116

Other estuaries in Florida that used our restoration model included Tampa Bay and Indian River Lagoon.

A major symposium reviewing all Florida's efforts at estuarine restoration, as well as those on Chesapeake Bay, was held in conjunction with the Decade of Progress symposium in October 1986.

Conclusion

Conflicts still remain between various participants. About 14 million dollars of state, county, and private money has contributed to this implementation thus far. At least $1[illegible] million more is needed to complete the restoration.

Our present goal is to restore water quality and circulation, and abundant biota while preserving use for citizens and tourists. This means partially, not completely, restoring the bay to its original condition. The amount of dredging and filling for land and the use patterns of the causeway, shoreline reconstruction, artificial islands, residence and port would not allow complete restoration. Conflicts between environmental interests and developers, especially concerning marina, remains intense in this estuary. Use has improved in quality and quantity due to improved biota and water quality.

Anita Tarnopolsky, Dade County Cultural Affairs Council, Science Committee, and Research Institute of Biological Sciences, Florida International University, 1565 NE 145th St., North Miami, FL 33132. Eugene Mann, University of Miami and Dade County Cultural Affairs Council, Science Committee. Harvey Ruvin, Commissioner, Dade County.

BEST AVAILABLE COPY

Advertisement

In Miami, one woman helps restore ocean ecology

LOCAL HEROES

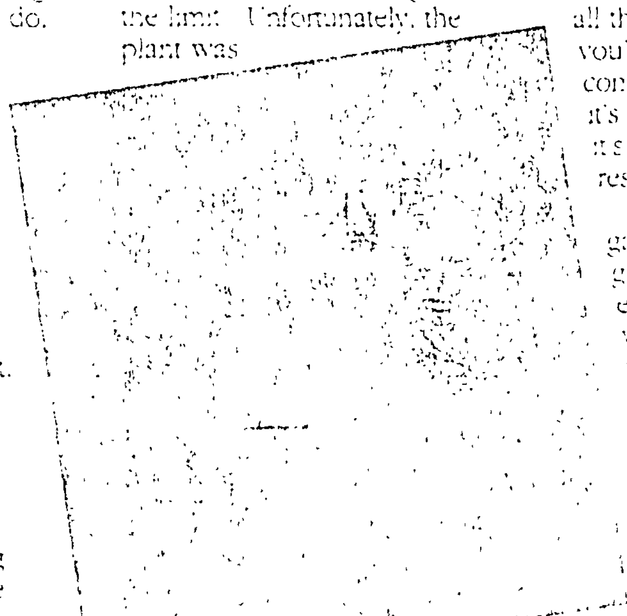
Amway

Few scientists understand tropical and marine ecology as well as [illegible] marine biologist Anitra Thorhaug, who received the United Nations Global 500 Award for her work in restoring [illegible]. As Anitra [illegible] something she was [illegible] to do.

[illegible] raised near Lake [illegible] Michigan and our family took vacations to Florida every winter. [illegible] the water when we were near the beach, my parents couldn't keep me out. [illegible] I moved [illegible] marine [illegible]. That was [illegible]. Even in the [illegible] and in Miami's [illegible] increased [illegible] the bays [illegible] been [illegible].

The [illegible] Florida [illegible] [illegible] environment. There are [illegible] habitats [illegible] from the [illegible] [illegible]

In 1967, scientists who didn't understand the southern climate claimed that a new power plant could raise bay temperatures 10 degrees without damaging the ecosystem. A colleague of mine and I said that an increase of one or two degrees was the limit. Unfortunately, the plant was



[illegible] built, and we were proven right. [illegible] acres of sea grass were killed.

[illegible] with [illegible]. We've [illegible] a lot [illegible] what the [illegible] should [illegible]. What we find [illegible] [illegible]

the Virgin Islands, the Middle East, Thailand and India.

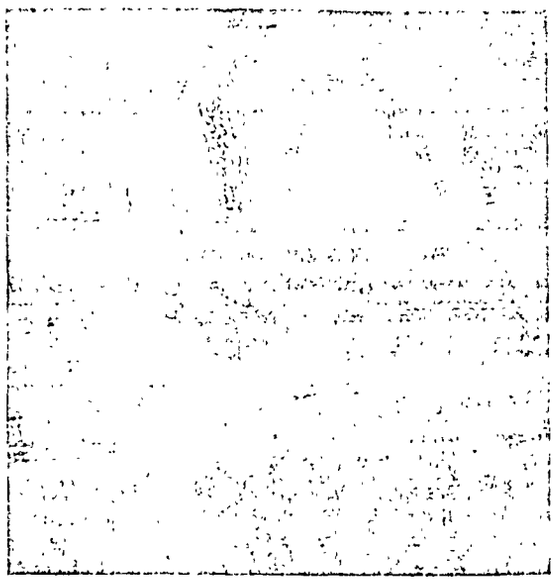
I began [illegible] underwater [illegible] fisheries in 1973. It had never been done. We planted sea grass seeds and within hours fish came back. Within three years, all the plants and animals you'd expect in a sea grass community were thriving. If it's pristine, protect it, but if it's been degraded, you can restore it.

Several years ago, I organized a conference with government, industry, scientists and [illegible] environmental leaders where we decided to restore Biscayne Bay. We've stopped [illegible] from [illegible] much of the effluent and [illegible] planted [illegible] 250 acres of sea grass [illegible] all over Florida [illegible] the same [illegible] Tampa Bay [illegible] Apalachicola Bay and [illegible].

It's a form of community [illegible] you put your [illegible] who you are.

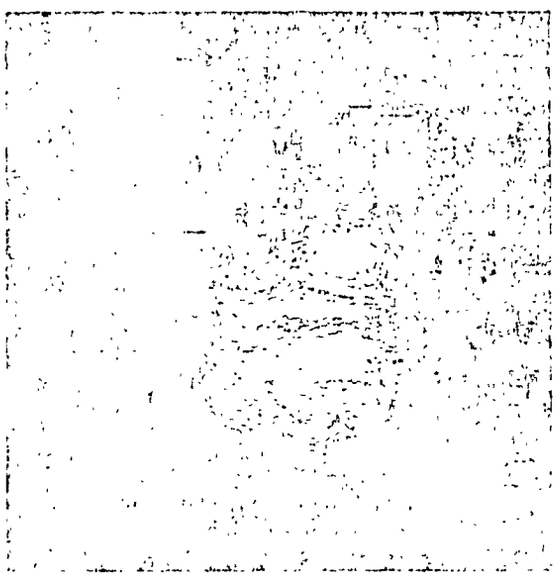
BEST AVAILABLE COPY

115



THE HOMEOWNERS

Older families hit hard by financial and real-estate losses can tap other assets for the kids' college tuition, safeguard what's survived with government notes, then revamp portfolios for their own upcoming retirement.



THE RETIREES

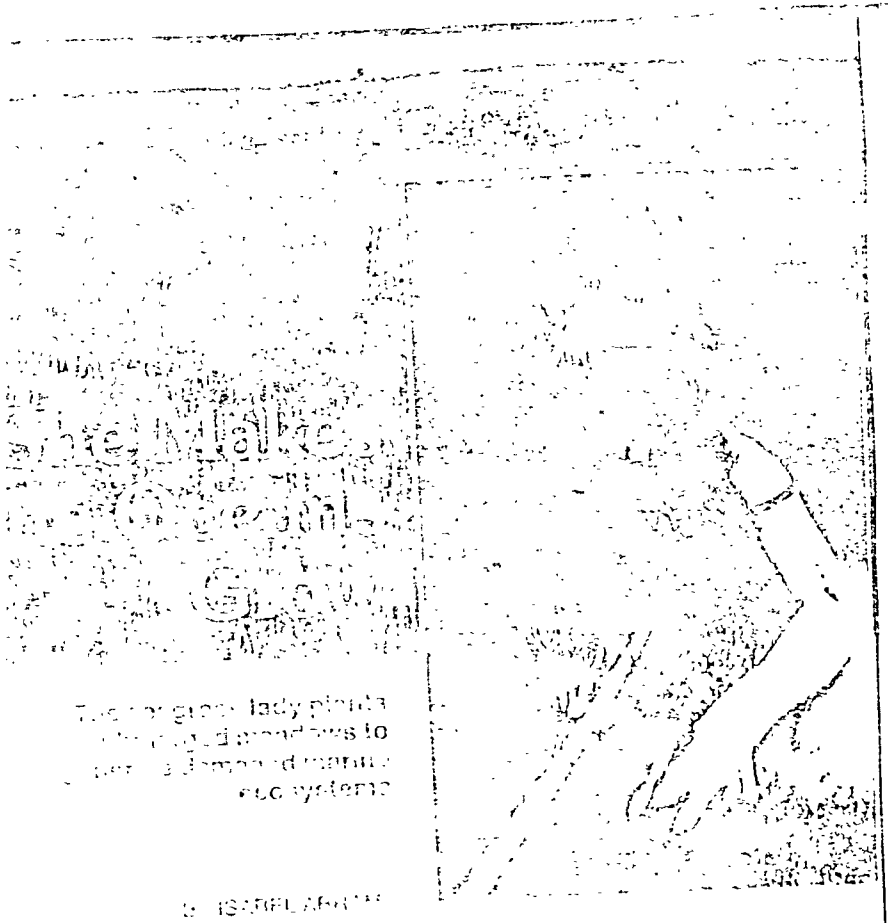
■ The Retirees. [illegible] ings [illegible] home. [illegible] between junk bonds (20 percent), CD's (10 percent), [illegible] stock [illegible]

[illegible] First, they [illegible] with those worst-case junk bonds. Some experts maintain that the market has turned junk into bargains that investors should snap up. But Greg Schultz, a money manager at Asset Allocation Advisors, Inc., in Walnut Creek, Calif., says retirees should jettison the junk and stick with high-quality, short-term bonds. Investors can capture 90 percent of the income generated by a long-term bond with one third the volatility. Two bond funds he recommends are Vanguard's Short-Term Corporate and Short-Term Government funds. The former is yielding 8.5 percent vs. just 9.7 percent for Vanguard's long-term investment-grade corporate-bond fund, but assumes less interest-rate risk.

The Retirees have too much of their savings in fixed-income investments, a common mistake for seniors, with longer life expectancy now stretching retirement for two or more decades, seniors need nearly half their capital in growth investments, usually stocks, says Gibson. Not until the mid-70s and beyond does he advise a shift to 25 percent cash, 30 percent stocks and 45 percent bonds.

Pensioners can satisfy growth *and* income needs by buying stock with generous dividends. Schultz likes American Water Works, a utility recently yielding 5.[illegible] percent; consumer-product company American Home Products Corporation yielding 4.1 percent and Dominion Resources, an energy concern, yielding 7.1 percent. [illegible] mutual funds, Schultz likes Evergreen Total Return Fund yielding 6.5 percent. Retirees can [illegible] their favorite growth mutual fund into an income-producing investment [illegible] Fidelity [illegible] Growth [illegible] [illegible] dollar amount [illegible] percentage [illegible] [illegible] of the market [illegible] prices [illegible]

BEST AVAILABLE COPY



[illegible] lady plants [illegible] meadows to [illegible] submerged marine ecosystems

By ISABEL [illegible]

[illegible] put on [illegible] Florida capital. Then [illegible] of [illegible] expressed in [illegible] [illegible] play of [illegible] [illegible] water. So [illegible] dive a [illegible] the dive a small [illegible] of [illegible] then anchored the [illegible]

[illegible] and feeding out a [illegible] could know where she [illegible] She were a wet suit as protection against the pollution and sewage and kicked her fins as little as possible to avoid disturbing toxic sediments. *This is like diving by braille*, she thought.

[illegible] local fishermen worked [illegible] Anitra, spacing the plugs of pollution-tolerant seagrass a foot [illegible] By the end of the [illegible] hour [illegible] found [illegible] under water acre.

As soon as one underwater [illegible] was [illegible] she washed the debris off their weapons and used [illegible] to fill [illegible] [illegible] on the [illegible] [illegible] Chemical [illegible] and [illegible] improvements [illegible] [illegible] and dangerous work, but they were satisfied. Anitra hoped that within weeks the area of seagrass would become a submerged meadow where shrimp and fish could graze again.

Anitra Thorhaug dives the world's harbours to transform barren coastal areas into submerged meadows. Where power plants, harbour facilities or sewage treatment plants have polluted coastlines and killed marine life—even where chemical pollutants poison the water—she tries to repair coastal ecosystems with seagrass and sometimes mangrove trees.

As a result of her work, more than 1,000 new acres of submerged meadows grow in several places in the world.

In the Philippines, near Manila and Bataan and off the south coast of Luzon—she has sown more than 25 acres of seagrass that have begun to reverse pollution and dredging damage, allowing fishing areas to be re-established. "And we need fish," Anitra says, "because we are running out of farmland."

Anitra, a research professor at Miami's Florida International University, has improved more than 80 acres at 20 different sites in Jamaica, including Kingston Harbour. Other [illegible] and [illegible]. She has demonstrated that Kingston Harbour can be reclaimed, says Thomas Brezhnev, provost of the university. In the Bahamas, her plan for seagrass farms [illegible] Nassau and Andros Island [illegible] return there in [illegible]. She has repaired [illegible] along the Florida coast and attempted the restoration of Biscayne Bay.

Network. In 1987 Anitra was asked to help with a major fisheries project in the southern river delta of Thailand, where most of the country's fish are harvested. In the river south of Bangkok, she found no signs of plant life. She inspected chemical contamination and took water samples to identify the pollution. She also inveigled the shoreline upriver and along the delta coast.

Her diagnosis: poor soil management and the tipping of hazardous chemicals had polluted the river, killing the natural seagrass that fed its ecosystem. Anitra found a seagrass that would tolerate the poisons and provide food and habitat for small clams, fish and other aquatic organisms.

In another section of the delta, sea-water ponds, built along much of the shoreline, were too infertile for shrimp. Anitra learned that mangroves had been cut to build the ponds. These trees are essential to the ecosystem because their decaying leaves enrich the soil and water, and their roots trap soil, providing a landing place for algae that serve as food for shrimp. Anitra restored the pond by planting mangroves

BEST AVAILABLE COPY

[illegible]

[illegible] to plant the disturbed area."

Like prairie grass, seagrass has a [illegible] root system that reaches [illegible] four or five feet. This, plus the [illegible] to spread laterally, allows the [illegible] to dominate other [illegible].

[illegible] of seagrass [illegible] the Caribbean and [illegible] South Pacific. Before [illegible], Anitra determines [illegible] ecosystem before it [illegible]. Then she asks herself [illegible] *would make the* [illegible]? When the area has [illegible] pollution problem, she plants a [illegible] that will withstand that pollution.

Usually she plants test plots with 50 of each species. After several [illegible], she returns to see which are still thriving and selects one or two [illegible] the entire area. If the [illegible], Anitra plants either [illegible] with four or five [illegible]. If it contains peat, she [illegible] square pieces of [illegible] because they won't fall apart on [illegible].

[illegible] Anitra [illegible] to [illegible] restora- [illegible] 250 [illegible], funded [illegible] Agency for International Development [illegible], the [illegible] $100 and $125 per [illegible] United Nations [illegible] Agriculture Organization [illegible] fishermen in both [illegible].

In her quest for new seagrass

species, Anitra sometimes encounters the unexpected. In 1980 she and a group of colleagues went diving off the northern coast of New Guinea, in coral reefs that feature more species of seagrass than anywhere else in the world. To the local inhabitants, the scientists were exotic visitors. The king of a near-by island saw their boat and beckoned them ashore, where he gave them a lavish dinner.

When Anitra took off her straw hat and her sunglasses, the king became agitated. He gave her a carved statue of an animal and she responded by taking a red bandana from her neck and tying it around the king's. The exchanges between the two continued until the king had given his guest four statues, a necklace, an amulet and three armpieces. Then an anthropologist with the group told Anitra it was time to stop because half the wealth of the village was now hers. "Will you marry me?" the king finally asked Anitra.

When she declined, he walked her to the shore with great dignity and waved goodbye with tears in his eyes as she swam back to her boat. "He had never seen anyone with green eyes and blonde hair," says Anitra "Besides, I could dive and catch fish. What more could he want?"

In the future Anitra plans to plant seagrass test plots off the coasts of Brunei, Indonesia, Malaysia, Singapore and Thailand. She is investigating how seagrass is damaged by oil spills and testing oil dispersants—chemicals that break up spilled oil so it washes away with the tide—to save shallow marine ecosystems.

Anitra's work has won wide international recognition. In 1987 she was selected for the United Nations Environment Programme (UNEP) Global 500 award.

"She is passionately committed to the care of the oceans," says Noel Brown, director of UNEP. "She is a remarkable scientist and generously devotes much of her time to training young divers and scientists to understand the dynamics of the ocean and to become involved in its protection."

The "seagrass lady" simply says, "I feel I am helping to heal the earth."

PHOTOGRAPHS: ANITRA THORHAUG

Humble Servants

When Cardinal Hume moved into the Archbishop's house in Westminster he used the furnishings of his predecessor, Cardinal Heenan. On his desk was an old fashioned telephone with buttons for various extensions including one marked "HE."

What "HE" referred to was a continuous mystery to him for weeks and eventually he could contain his curiosity no longer and asked one of the staff. The letters stood for "His Eminence," which meant *him*. It had never crossed his mind.

Tony Castle, *Basil Hume*: *A Portrait* (Collins)

BEST AVAILABLE COPY

Proceedings of the 6th International Coral Reef Symposium, Australia, 1988, Vol. 2

SEAGRASS [illegible]

[illegible]

[1] [illegible] International, [illegible]
P.O. Box [illegible], [illegible]
[2] Philippine National Environmental Protection Council
[illegible] Heart [illegible], [illegible] City, Philippines

For the first time in the tropical [illegible] or tropical Southeast Asia and [illegible] Ocean Basins, the major tropical Indo-Pacific species of sea-grasses were restored to a variety of [illegible] [illegible] thermal [illegible] [illegible] associated [illegible] communities.

[illegible]

The Philippines have 18,417 km. of coastline with extensive [illegible] the seagrass [illegible] conservative estimate [illegible] [illegible] per year [illegible].

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

tracted areas chosen from a much larger list and then prioritized by the National Environmental Protection Agency. A large variety of field sites throughout the islands was reviewed before a [illegible] sites are seen in Figure 1; [illegible] sites in Table 1.

[illegible] constructed. [illegible] were planted. [illegible] thermal [illegible] set up.

Collection of [illegible] tained [illegible] from donor [illegible] and transported [illegible] [illegible]

[illegible]

[illegible]

[illegible]

[illegible]

BEST AVAILABLE COPY

the open ocean was used as [illegible] control measurements for [illegible]. These other sites at Lagao, Bataan, [illegible] were [illegible] and served as controls.

The environmental [illegible] the [illegible] shall on a [illegible] from January to December [illegible] are seen in [illegible]. Plant transplantation [illegible] at the [illegible] site. [illegible] showed prominent seasonal [illegible]. [illegible] ranges from 12 to 27 oc oc, at the [illegible] where the whole valley in which Manila [illegible] the [illegible] and other water [illegible] point sources in the bay. [illegible] at the outer coastal [illegible] [illegible] associated salinities of [illegible] oc oc [illegible] 35 o oc. Temperature was relatively constant and high, as might be expected. The power plant site was hammer by a [illegible] than other sites [illegible] the unaffected sites within half a mile from it. Sediment depth was all sufficient for planting. Water depth at high tide ranged from [illegible]. Tides were about 0.75 m during most of the year at most sites.

Various species tested displayed differential to the pollutants. Table [illegible] listed were [illegible] of recovering sites of [illegible] structures. Sediment stabilization and [illegible] recolonization occurred. In [illegible] current induced by the causeway construction, center [illegible] a channel in which was found a rather [illegible] natural tidal flow, only Enhalus could survive. At the fertilizer factory, with clear indications of [illegible] still evident in the sediment, only [illegible] survived. The urban outfall for the city of Manila [illegible] domestic waste, Thalassia and Syringodium occurred in far higher [illegible] than [illegible] which is the most thermally [illegible] of the Atlantic. The [illegible] had highest survival for Thalassia, moderate for [illegible], [illegible] and [illegible]. Trench and fill with [illegible] Enhalus, Thalassia, [illegible] survival. It should be noted that [illegible] trenches were in August and [illegible] structure to [illegible] to do so, the Enhalus [illegible]. [illegible] oc, it had survived.

All five [illegible] tested [illegible] fully restored [illegible] areas. The best [illegible] variety of sites and pollutant types was [illegible]. Seeds of Thalassia did not work as [illegible] transplants. In the second [illegible], [illegible] Syringodium [illegible] Thalassia. Both plants and [illegible] survival [illegible] appear to [illegible].

Lateral growth [illegible] Syringodium [illegible] Thalassia [illegible] Manila Bay. [illegible] Thalassia [illegible] Syringodium [illegible] coastal [illegible] in [illegible] than [illegible].

Natural [illegible] in [illegible]

areas. For Manila Bay, control was [illegible] Bataan, [illegible] Mariveles, for Mariveles [illegible] the area [illegible] Bataan, for [illegible] control sites.

Control sites of Enhalus were [illegible] mature individuals [illegible] fish and invertebrates were evident in [illegible] Enhalus [illegible] Thalassia [illegible] while fish used it as habitat [illegible] Thalassia [illegible] from the first month [illegible] natural, recovering Thalassia and Syringodium [illegible] rich array of animal habitats.

The responses of the performance of three [illegible] main seagrass genera in a range of natural [illegible] potential impacts may be summarized:

1. Sediment stabilization: Sediment [illegible] stabilized by any of seagrasses. Enhalus, Halophila, and Syringodium appear best for [illegible] the Manila site.

2. Trench and fill. All the [illegible] to recolonize areas filled with [illegible] with heavy urban pollutant load [illegible] basis by National Environmental Protection [illegible] of high energy. Halophila and Syringodium [illegible] fill the meter square within twelve [illegible]. [illegible] exhibit high vertical growth [illegible] but not lateral growth. Thalassia [illegible] lateral expansion at the S Fishbowl [illegible].

3. Heated waste effluents. Heat [illegible] Enhalus acoroides, Syringodium [illegible] Halophila [illegible] the [illegible].

4. Sewage wastes. [illegible] Halophila and Halodule, [illegible] caused by [illegible] outfall [illegible] pollution [illegible] within a [illegible] flood control [illegible] several typhoons [illegible] water [illegible] rooted seagrass [illegible].

[illegible] Thalassia [illegible] Halophila [illegible] Thalassia [illegible] marine.

[illegible] fertilizer factory [illegible] presence of [illegible] if that [illegible] returned, [illegible] stabilize [illegible] Halophila [illegible] Syringodium [illegible].

[illegible]

BEST AVAILABLE COPY

TABLE 1.

Site Name	Major Impact	Minor Impact	Depth (m)	Basic Energy Regime	Weather Events	Sediment Type	Year of Impact	Seagrass Colonization Since Impact	Seagrass Prior to Impact	Type of Location [illegible]
[illegible] West	Dredge & fill for causeway	Mine tailings	1.0	Medium to low	None effective	Fine silt	Major 1975 Minor Since 1975	None	[illegible]	[illegible]
East	Dredge & fill	Mine pipeline spills	1.0	Medium to high	Winter storms & typhoons	Coarse sand (ripple marks)	Major 1975 Minor 1975	Light Halodule, far inner part	Halodule [illegible] mixed [illegible]	[illegible] part of mail estuary
Tip	Induced current	Hydraulic dredge & fill Mill tailings	1.0 to 2.0	High tidal current	None effective	Coarse sand (ripple marks)	1975	None	Mixed Thal, Hal Cym	Inner part of [illegible]
[illegible]la Bay	Dredge & fill	Urban sewage & run-off	1.5 - 2.5	Low	Typhoons (salinity reduction)	Fine silt	Since 1975	None	Em, Thal, Cym, Hal	Estuary (inner shore)
[illegible]an [illegible] [illegible]tary & [illegible]tuary	Dredge & fill	Urban, [illegible] & oil	N/A	High	N/A	Coarse sand overlaid by corroded fuest. calcite ripples	Major 1969 Minor Since 1968	None	Mixed Cym, Cym, Hal, [illegible]	Coastal tip of large estuary
[illegible]er Plant	Heated effluent	Industrial run-off including oil	N/A	High	N/A	Coarse sand	Major 1975, continuing since then	None	Mixed Cym, Sym, [illegible], [illegible]	Coastal tip of large estuary

Site Name	Fishing Activity	Number of Fishermen	Recolonization of natural seagrass by animals	Recolonization of restored seagrass by animals
[illegible]arundupe West	[illegible] in estuary and reef	9,582	[illegible]	Medium
East	was high in estuary	9,582	High	High
[illegible] Bay	Heavy, especially in sediment	10,589	No seagrass	High
[illegible] [illegible] [illegible] & [illegible]	High, offshore	10,000 (approx.)	No seagrass	High
[illegible]er Plant		10,000	No seagrass	No data

BEST AVAILABLE COPY

104

TABLE [illegible]

Parameter / Site	Light % transmission	Dissolved Oxygen (mg/l) hi tide	Dissolved Oxygen (mg/l) low tide	Salinity (‰) hi tide	Salinity (‰) low tide	Temperature (°C) hi tide	Temperature (°C) low tide	[illegible]	[illegible]
Manila Bay									
Surface	-	5.9 (3.4-[illegible])	[illegible] (1.6-9.2)	32.5 (4.0-40.0)	28.5 (11.0-32.0)	[illegible] (16-36)	28.5 (15.0-32.5)	-	-
Bottom	-					28.5 [illegible]	28.2 (24.5-32.0)	32.3 (3.0-35.0)	hi [illegible] (28.[illegible]-[illegible]) low [illegible] (30.[illegible]-[illegible])
% trans	57.3								
Navotas									
West: Surface	-	5.5 (5.1-5.8)	-	35.5 (32-37)	-	29.9 (28.5-32)	-	-	hi 311.0 ([illegible])
Bottom	-	5.4 (4.4-5.8)	-	35.2 (32-37)	-	29.5 (28.5-37.0)	-	20.5	low -
% trans	55.4								
East: Surface	-	5.5 (5.0-6.0)	-	33.0 (29.0-37.0)	35.8 (27-35)	31.8 (29.5-32.0)	30.6 (30.0-32.0)		hi 192.1 ([illegible])
Bottom	-	5.2 (4.7-5.9)	-	33.7 (29-36)	35.6 (35-36)	31.1 (29.0-31.0	30.5 (29.5-32)	30.2 (2.3-32.5)	low 122.9 ([illegible])
% trans	56.0								
Bataan Chemical Factory:									
Surface	-	5.5 (3.3-7.0)	-	32.5 (22-35)	34.0	29.0 (24-30)	-	-	-
Bottom	-	n.d	-	n.d	n.d	n.d	-	-	-
% trans	n.d								
Power Plant:									
Surface	-	5.2 (2.9-6.1)	5.8 (4.2-6.4)	24.8 (10.0-35.0)	20.5 (9.0-35.0)	31.8 (28.0-33.0)	31.9 (30.0-35.0)		hi 174.5 ([illegible])
Bottom	-	5.4 (4.0-6.1)	5.2 (3.2-6.5)	29.2 (10.0-35.0)	24.2 (15.0-35.0)	31.2 (29.5-32.0)	31.6 (29.5-3[illegible].0)	8.5	low 109.6 ([illegible])
% trans	56.8								

TABLE [illegible]

Survival (in percentage) and growth as shown in [illegible] of five species of seagrass grown in pollutant type in Manila Bay test plots. Survival & [illegible] after 6 months and 12 months

Spring and Fall planting

Pollutant type and Site	Halodule (Spring)	Halodule (Fall)	Thalassia (Spring)	Thalassia (Fall)	Halophila (Spring)	Halophila (Fall)	Syringodium (Spring)	Syringodium (Fall)	Cymodocea (Spring)	Cymodocea (Fall)
Sewage & fill										
Navotas	78(1.9)	8[illegible](1.7	79(1.4)	28(4.3)	3[illegible](10.5)	[illegible]	30(6.1)	27(3.8)	7[illegible](6.7)	78(8.7)
Manila Bay	[illegible](1.4)	[illegible]	8[illegible](1.8	79(6.2)	[illegible]	[illegible](12.2	n.d	n.d	[illegible]	[illegible](4.2)
Farm Runoff										
Manila Bay	3[illegible](1.9)	n.d	0	0	0	0	n.d	n.d	0	0
Pure tailings										
Navotas										
East (low energy)	6[illegible](1.7	8(1.0	n.d.	8[illegible](2.9)	1[illegible](11.8)	[illegible]	n.d	n.d	4[illegible](1.9)	[illegible]
West (low energy)	8[illegible](1.2)	9[illegible](1.2	84(2.4)	13[illegible](14.4)	84(12.5)	[illegible](14.6)	24(14.2)	4[illegible](5.2)	4[illegible](1.0)	4[illegible](4.4)
Chemical Factory										
Ammonium fertilizer	0	[illegible]	0	0	4(3.5)	0	0	0	0	0
Power Plant										
Bataan	[illegible](1.2	n.d.	[illegible]	[illegible]	[illegible]	[illegible]	0		[illegible]	[illegible]
[illegible]										
[illegible]	[illegible]	n.d	n.d	[illegible]	[illegible]		n.d	n.d	[illegible]	[illegible]

[illegible]

[illegible]

BEST AVAILABLE COPY

125