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COMMENTS

OF

THE NATURAL RESOURCES DEFENSE COUNCIL, INC.

ON THE

STATE/FEDERAL NATURAL RESOURCE DAMAGE ASSESSMENT PLAN

FOR THE EXXON VALDEZ OIL SPILL

(PUBLIC REVIEW DRAFT, AUGUST 1989)

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Lane, P.A., 1989. Environmental Effects Monitoring: Pitfalls and Possibilities in Relation to Offshore Oil Development.

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INTRODUCTION

The Natural Resources Defense Council, Inc. (NRDC) submits the following comments on the Public Review Draft of the State/Federal Natural Resource Damage Assessment Plan for the Exxon Valdez Oil Spill (August 1989) (hereafter "Draft Plan" or "Draft Assessment"). NRDC has more than 120,000 members and supporters nationwide many of whom use and enjoy areas affected by the Exxon Valdez oil spill.

The overriding concern of NRDC and its members is that the environment of Prince William Sound and other areas of Alaska affected by the spill be restored to the maximum extent possible to the highly pristine, productive state that existed before the accident, and that to the extent this is not possible, replacement habitat be acquired to compensate the American public for these losses. This goal requires an adequate damage assessment plan and restoration plan; yet neither are provided here. By arbitrarily limiting the assessment plan to one year of studies, and by otherwise limiting severely the scope of the assessment plan, the Trustees may seriously underestimate the nature and extent of damage caused by the spill. Moreover, there has been almost no serious planning on ways to restore the long-term productivity of the areas affected by the spill, or to acquire replacement habitats where full restoration is not possible.

NRDC appreciates this opportunity to comment on the draft plan. The opportunity provided, however, is only of extremely limited value. NRDC and other environmental groups have distributed the plan to a large number of experts around the country qualified to comment on all aspects of the plan. The initial responses of those experts has been virtually unanimous: The Draft Plan is so vague that it is not amenable to serious review by outside experts. The Draft Plan omits important details on all of the proposed studies, making it difficult or impossible to comment intelligently on the merits of the studies.

NRDC's comments on the Draft Plan fall into two classes. Our initial comments address broad legal and policy concerns related to the Draft Assessment. In addition, we summarize some of the major points raised by our outside experts. Attached to these comments are specific critiques prepared by nine outside experts on particular aspects of the Draft Plan. Resumes are included for each of these experts. These critiques should not be considered an "appendix", but rather constitute the heart of NRDC's comments on the technical merits of the proposed assessment plan. In order to ensure that the scientists and economists conducting the studies have the benefit of these comments, we ask that all the technical critiques be circulated to each of them.

NRDC's experts focused on broad, ecosystem-wide studies proposed in the Draft Plan, such as the Coastal Resources and Air and Water Pollution Studies. Studies designed to evaluate the effects on individual species are evaluated as they relate to these broad concerns. Where we do not comment specifically on individual assessment proposals, this implies neither agreement nor disagreement with the proposal. Other environmental groups are working with experts on other specific aspects of the Draft Plan (such as birds, marine mammals and terrestrial mammals).

I. THE ASSESSMENT LACKS ADEQUATE DETAIL TO ENABLE MEANINGFUL TECHNICAL REVIEW

All the technical reviewers that NRDC consulted stated that there was not enough detail provided in the draft plan to permit adequate peer review.[1] Dr. McElroy says that: "The level of detail in the study plan, methods and analyses given and budgets presented would be completely unacceptable in any kind of peer-reviewed grant or contract application." Dr. Lane states: "Although it is clear that many of the main environmental components have been identified for study, it is not so clear that the studies are designed well enough to provide the needed information to quantify damages rigorously. In particular, there is very little information given on sampling design and methods of data analysis and interpretation during the post-collection phase." Dr. Liljestrand noted that the level of detail provided in the Draft Plan would not suffice to pass scrutiny had this plan been submitted by a private party for government agency approval. Dr. Kavanaugh and our other experts reached the same conclusion with respect to other scientific and economic studies.

We appreciate the haste with which the study plan was put together and the tremendous pressures the Trustees and their

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1 Obviously more detailed information on most of these studies could have been provided since when the Draft Plan was made available most of the studies were already underway.

staffs were under. However, we believe it is in the Trustees' interests, and ultimately in the public's interest, to ensure the most rigorous and effective study regime is adopted, particularly in light of the scrutiny to which the results will be subject in any litigation that will eventually result. Thorough scientific and technical peer review of the study plan in advance is one of the best ways to ensure that the study results are sound and stand up in court.

Ironically, we understand that at the same time that comments on this extremely vague plan are due, far more detailed research proposals are being prepared for circulation to peer review scientists around the country. If true, in essence the public is being excluded from participation in the more important and meaningful opportunities to comment on the assessment.

To this end, we urge the Trustees to provide the opportunity for further peer and public review of the studies proposed to be performed this next spring and thereafter. We formally request that the following steps be taken to ensure proper public input to this process:

1. Copies of these comments, including the specific attached comments of outside experts, should be circulated to all government scientists and economists (including contractors) who are developing and conducting the actual studies;

2. Meetings should be scheduled to allow our outside experts an opportunity to discuss their concerns directly with

the government (or contractor) scientists and economists who are actually developing and conducting those studies;

3. Information on the results of studies to date and detailed proposals for additional research should be circulated to the experts who helped NRDC and other groups review the Draft Plan at the same time they are circulated to other outside experts;[2] and

4. As explained in detail below, the public should be given an opportunity to participate formally in future decisions to continue or discontinue damage assessment studies, and in the development of the restoration plan.

II. THE RESTRICTION OF ASSESSMENT STUDIES TO ONE YEAR IS ARBITRARY AND NOT IN ACCORDANCE WITH LAW.

A. The One-Year Limitation on Assessment Studies Is a Violation of the Trustees' Duty to Recover Restoration Costs

The federal and state trustees for natural resources affected by the Exxon Valdez oil spill are under an obligation to recover costs for the restoration of damaged natural resources in and around Prince William Sound. Section 311(f)(5) of the Clean Water Act provides that designated federal and state officials "shall act on behalf of the public as trustee of the natural resources to recover for the costs of replacing or restoring such resources." 33 U.S.C. §1321(f)(5) (emphasis added). Section 107(f)(1) of CERCLA states that sums recovered be used to

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[2] In essence, we ask that our experts be incorporated in the scientific peer review process that the Trustees apparently are conducting anyway.

restore, replace or acquire the equivalent of the damaged resources. 42 U.S.C. §9607(f)(1). To recover such costs and restore the environment, the Trustees first must assess the full extent of injury. An underestimation of injury will lead to an underestimation of restoration or replacement costs, an inadequate recovery from Exxon, and an inadequate restoration of the environment.

The Trustees violate their statutory duties by arbitrarily restricting assessment studies to a period of less than one year. The Executive Summary states: "The damage assessment document is essentially a one-year plan. No further studies will be conducted after February 28, 1990, except those approved by the Trustees upon recommendation of the Trustee Council and scientific and legal review groups as being necessary to promote restoration and to support assessment of legally recoverable natural resource damages." (p. i). However, as the Draft Plan itself states the spill will have long-term effects not discernible within one year. The Draft Plan recognizes that "oil and its complex breakdown products are expected to linger in some areas for many years," (Draft Plan at 1), acknowledges the "possibility of delayed population effects in some species," id. at 15, and states with respect to at least one species that the "full effect of the spill may not become evident this year." Id. at 15.[3] As the comments of Drs. McElroy, Lane, Sanders,

3 Elsewhere, the Plan states: "Oil and its complex breakdown products will persist for a long time; the nature and degree of (continued...)

Kavanaugh, Vogel, Wright, Hayes and Button (attached) attest, a responsible damage assessment cannot be done in one year.

Due to the magnitude of the Valdez spill, the unique properties of the affected ecosystem and the virtually certain possibility of long-term and delayed biological injury, a study of at least several years duration is necessary to adequately ascertain the extent of injury and the costs of restoration. The planned termination of data analysis on February 28, 1990, requiring the termination of data gathering in September of this year, bears no rational relationship to the duration of study required to assess damages from the spill and will prevent full recovery of restoration costs.

We understand that all prior drafts of the plan were for 5 years of study and that it was only at the last minute that federal officials in Washington, D.C. ordered that the government commit to only one year of study. That decision is an arbitrary one, driven by political concerns, rather than one justified by science or the public interest.

B. <u>The One-Year Limit On Assessment Studies Is a Violation of the Trustees' Duty to Assess Long-Term Effects</u>

Subordinate to the Trustees' duty to recover restoration costs is an explicit statutory duty to assess natural resource damages. Section 107(f)(2)(A) of the Comprehensive Environmental Response and Liability Act (CERCLA), states that natural resource

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[3](...continued) toxicity of that oil will vary over time, and will require considerable study to determine its ultimate fate and effects." Id. at 237.

trustees "shall assess damages for injury to, destruction of, or loss of natural resources" for purposes of recovering restoration costs. 42 U.S.C. §9607(f)(2)(A). This provision is made expressly applicable to the oil spill liability section of the Clean Water Act. Id. The duty to assess natural resource damages is violated by the Trustees when they restrict studies in a manner that will result in a failure to ascertain long-term injury.

CERCLA specifically provides that long-term injuries are to be studied. In a section requiring the Department of Interior to draft regulations governing natural resource damage assessment, CERCLA mandates that such regulations include provisions designed to "determine the type and extent of short- and long-term injury." 42 U.S.C. §9651(c)(2). The legislative history of CERCLA demonstrates that Congress was aware of the problem of long-term injury and intended such injury to be addressed. A report by the Senate Committee on Environment and Public Works indicates that the committee received testimony that injuries of long duration do result from spills of oil and other hazardous materials. See S. Rep. No. 848, 96th Cong., 2d Sess. at 84 (1980), and acknowledges that damage assessment includes "evaluation of long-term or delayed impacts on biological systems." Id. at 87. Moreover, in addressing assessment regulations, the report reiterates that provisions governing large or "unusually damaging" spills are to contain "protocols for field assessment of the type and extent of short- and long-term damage." Id. at 86 (emphasis added).

The regulations ultimately promulgated by the Department of Interior for natural resource damage assessment reflect the statute's focus on the long-term. First, the regulations direct trustees to consider, inter alia, the "duration, frequency, season and time of the discharge or release." Natural Resource Damage Assessments, 43 C.F.R. §11.64(a)(4)(ii) (emphasis added). Second, "injury" is defined as a "measurable adverse change, either long-term or short-term, in the chemical or physical quality" of a natural resource resulting "directly or indirectly" from exposure to oil or hazardous materials. 43 C.F.R. §11.14(v). Finally, the regulations specify various methods for determining injury to biological resources that cannot be performed effectively in a data-gathering period of less than one year. The regulations recognize inter alia, "cancer," "genetic mutations" and "physiological malfunctions (including malfunctions in reproduction)" as categories of injury, §11.62(f)(1)(i). In order for injuries of this nature to be statistically observed, more than one year of study is necessary. For example, for reproductive malfunctions, a growth period of at least one reproductive cycle is essential.

The February 28 termination date for studies restricts field data gathering to a period of six months, since field studies must end before the onset of the Alaskan winter. In this period of time researchers will be unable to obtain statistical data on delayed population effects and many types of indirect injury that will occur.

As discussed in the comments of Drs. Lane, McElroy, Sanders, Vogel, Wright, Hayes and Button, there are many significant long-term impacts that will not become evident in the first year. Through processes such as bioaccumulation and biomagnification and through the successional stages in benthic infauna described by Dr. Sanders, population impacts will be felt years after the original contaminant release. Dr. Button describes the potential for long-term changes in water chemistry that will persist for long periods, referring to the decade to century life times of hydrocarbons and their products.[4]

By cutting off studies after the first year, it will also be impossible to analyze two related factors that could not possibly be addressed in the initial year. First, it is not possible to study natural resource damages caused by the various responses to the oil spill, including first year cleanup and assessment activities. Given the massive deployment of resources and the tremendous potential for environmental disruption caused by this presence, these effects may be quite dramatic. Exxon and other PRPs are liable for these impacts as well as those caused by the spill itself. Relatedly, failure to continue studies in subsequent years will render it impossible to determine the actual effectiveness of activities conducted in year one.

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[4] Drs. Vogel, Wright and Hayes agree that one-year studies cannot examine water quality phenomena that have longer time scales.

To ignore such impacts and to have decisions about which studies to continue based solely on whether there have been observed effects in the first year would lead to a serious underestimate of the spill's impacts. To cut off studies prematurely not only will preclude full recovery from Exxon in this case, but will prevent a full scientific understanding of both the short- and long-term effects of a major oil spill, an understanding which has been seriously lacking to date and which would help inform future public policy debates. By failing to provide studies to adequately assess such injuries, the Trustees violate both the statute and regulations governing natural resource damage assessment.

C. The Trustees' Violation of Their Statutory Duty To Adequately Assess Damages Is Not Cured By the Provision in the Assessment Plan Allowing for An Extension of Studies.

The need for assessment studies of longer than one year's duration is evident now. Thus while the Assessment Plan proposed by the Trustees provides for an extension of studies after February 28 if "approved by the Trustees upon recommendation of the Trustee Council and scientific and legal review groups as being necessary to promote restoration and to support assessment of legally recoverable natural resource damages," (Draft Plan at 26), this provision does not satisfy the Trustees' duty to ensure that damages are properly assessed and the full costs of restoration are recovered. This extension provision does not obligate the trustees to formally consider extension in any manner and isolates any such consideration from public notice and review. It thus gives no guarantee that necessary studies will be performed. The recovery provisions of the Clean Water Act and the assessment provisions of CERCLA mandate that the Trustees adopt a reasonable duration for assessment studies before the assessment plan is approved. Piecemeal decisions to extend a particular study here or there cannot replace the function served by a comprehensive, coordinated long-term assessment plan.

III. THE TRUSTEES MUST PROVIDE PUBLIC NOTICE AND COMMENT ON ANY DECISION TO TERMINATE OR EXTEND ASSESSMENT STUDIES AFTER FEBRUARY, 1990.

If the Trustees retain the February, 1990 deadline for assessment of natural resource damages resulting from the Exxon Valdez Oil Spill, they must provide an opportunity for public participation at the time this deadline is reviewed. The Draft Plan currently provides that the Trustees may extend studies beyond the deadline after consultation with "legal and scientific review groups" and upon a determination by the Trustees that extensions are "necessary to promote restoration and to support assessment of legally recoverable natural resource damages" (Draft Plan at 26). No opportunity for public participation is included in this review process.

However, public participation in the development and amendment of the Draft Plan is required under both the Administrative Procedure Act (APA) and the Department of Interior

(DOI) regulations governing damage assessment.[5] The APA requires federal agencies to give public notice and solicit public comment in connection with any "rule making." 5 U.S.C. §553. "Rule making" is defined as the process of "formulating, amending, or repealing any rule," 5 U.S.C. §551(4), while "rule" is broadly defined to include any "agency statement of general or particular applicability ... designed to implement, interpret, or prescribe law or policy." 5 U.S.C. §551(5) (emphasis added). The Draft Plan is a "statement of particular applicability designed to implement law" that has substantive impact on the rights and duties of affected parties and thus is subject to the APA notice and comment procedures.

The Draft Plan is subject to regulatory notice and comment procedures under 43 C.F.R. §11.32. This section of the DOI assessment regulations provides that any assessment plan or significant modification of an assessment plan must be made available for public comment for 30 days prior to the plan taking effect. 43 C.F.R. §§11.32(c), 11.32(e)(2).

Any decision to terminate or extend assessment studies beyond February 28, 1990 will constitute an amendment or significant modification of the assessment plan. The duration of studies is a critical element of the plan, directly linked to the type and extent of injury that will be detected and the amount of damages that will be assessed. The final decision with respect to termination or continuation of studies, therefore, will

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5 Sections 101(e) of the Clean Water Act and 117 of CERCLA also evidence a congressional concern for ensuring public participation in the development of plans of this type.

significantly affect the character of the plan. The public must be involved in such an important decision at the time it is made.

To provide meaningful public review, the Trustees should do three things:

1. Provide the public with information regarding the results of studies performed this past summer since those results bear upon the direction of further studies;

2. Provide greater detail on the studies proposed to be performed for upcoming seasons than does the draft plan (which, as the experts state, provides inadequate information to enable proper scientific review); and

3. Allow early enough opportunity for public input so that the public comments can be useful in the design and conduct of the studies that are performed (again in contrast to the process followed in the draft plan where the field studies were completed before there was any public comment).

IV. THE ASSESSMENT NEEDS TO HAVE MORE OF AN ECOSYSTEMS FOCUS.

One of the most serious criticisms noted by the scientists who reviewed the draft plan was the lack of an ecosystems approach to studying the effects of the spill. As Dr. Pat Lane observed in her comments:

> All natural populations exist in ecosystems and although many key populations are of interest because of their direct commercial value, studying them in isolation usually will not produce a true representation of total environmental deterioration. Many populations are predators, competitors, or prey in regard to their interactions with other species in the terrestrial and marine foodwebs that exist in and around Prince William Sound. Indirect changes will come about not only from the sublethal and life history changes in the individual populations that inhabit the ecosystems, but also from the altered ecological interactions and foodwebs. A predator population can

> decline not only from the direct effects of oiled feathers or ingested oil, but also from the lack of a critical prey species that was killed previously by the oil spill. There is no evidence that an ecosystem approach will be taken to examine and quantify foodweb effects related to the oil spill. This is exceedingly unfortunate for two reasons. First, from an ecological point of view in the final analysis it is the long-term persistence of the ecosystems of the planet that are of main concern, not just the few species that are associated with direct monetary benefits today. Secondly, focus on populations gives too narrow a definition of damage and must a priori lead to further underestimates in damage assessment.... Thus, if the guilty party were made to pay only for the number of birds or mammals directly killed by the oil spill, for example based on a carcass count, the amount of true damage could be underestimated by orders of magnitude. (emphasis supplied).

Dr. Lane recommends the use of appropriate models at both the population and ecosystem levels to predict multi-generational effects and cites to work she has done previously (copies attached) of both population and ecosystem level risk analyses.

Dr. McElroy also stated this same concern:

> The plan focuses on assessing damage to each resource as an individual unit with emphasis placed on quantification of exposure to oil components, stock size, and in some cases reproductive fitness. Very little effort has been placed on assessing impact on system wide, or interactive processes. For example, how oiling may effect productivity in a given area which in turn may affect species composition and or food resources. Investigation of each resource species as an individual component is extremely costly and may miss subtle effects caused by interactions between species. If species A is severely affected, its former prey may become more abundant which may deplete food resources of species B. In this case the two species don't interact directly, but effects on one can lead to significant effects on the other. In order to get a complete picture of damage to the ecosystem, a comprehensive damage assessment plan should focus on individual species as well as their interactions and functioning of the ecosystem as a whole.

The persistence of hydrocarbons in the sediments and the resulting alterations in benthic communities also are crucial areas of study. Dr. Howard Sanders, who did pathbreaking work on this issue in connection with the Florida barge spill off West Falmouth, comments on the importance of studying these effects and understanding the threats to fish and shellfish populations dependent on these communities. He recommends methods of study that will allow proper understanding of these effects.

Drs. Liljestrand and Button raise similar concerns regarding the effects of hydrocarbons in the air and water. For example, Dr. Liljestrand comments that the effects of air contaminants must include the dry flux of organic air pollutants onto vegetation (which may affect the plants and result in subsequent intake by plant foragers). Dr. Button notes that the studies seem to ignore long-term chemical changes induced by the hydrocarbons introduced by the spill, and their effect on global as well as regional water chemistry.

All these comments point to the need for an expanded ecosystems scope which will provide a fuller and more complete assessment of injury than the draft plan proposes.

V. EXXON SHOULD NOT PLAY A MAJOR ROLE IN THE DAMAGE ASSESSMENT AND RESTORATION PLAN DEVELOPMENT OR IMPLEMENTATION.

The Draft Assessment leaves open the question of the role of Exxon and other potentially responsible parties (PRPs) in conducting the damage assessment, and in developing and implementing the restoration plan. In particular, the Trustees "have not decided whether, or to what extent, potentially responsible parties should participate in the damage assessment." Draft Assessment at iii. We object strongly to the possibility that Exxon and other PRPs will be given a significant role in these tasks.

We do not, of course, object to any requirement that Exxon fund damage assessment and restoration efforts by the Trustees or their agents, as we believe is required by CERCLA and the Clean Water Act, so long as Exxon has no control (outside of the normal public process) over how the funds are spent and how the studies and restoration are conducted. In fact, because it is apparent that many of the problems identified in these comments relate directly to inadequate Trustee resources to conduct the assessment,[6] the Trustees should strongly consider filing a cost recovery action <u>immediately</u> against Exxon and the other PRPs as a means of financing immediate, ongoing damage assessment costs.

However, as explained below, we object on both policy and legal grounds to further involvement by Exxon in the damage assessment and restoration processes.

A. <u>It is Bad Policy to Allow Exxon to Participate in the Damage Assessment and Restoration</u>

Given the potential liability and other consequences faced by Exxon and other PRPs (and the oil industry as a whole) as a result of this oil spill, it is completely unrealistic to expect

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6 For example, we hear disturbing reports that numbers of samples may be cut back drastically due to financial constraints. This could severely undercut the validity of data and conclusions drawn from those data. Similarly, due to the high cost of fractionizing water samples, only a very small percentage of the samples is being taken for specific fractions; the rest are analyzed for total hydrocarbons. This limits severely the Trustees' ability to determine concentrations of individual hydrocarbon fractions, such as benzene, ethylbenzene, toluene, xylene and other constituents.

that these parties can participate in the assessment and restoration from an objective perspective.

Allowing PRPs to participate in the assessment process is akin to asking the fox how many chickens it ate. Because Exxon is financially liable for any natural resources destroyed or damaged due to the spill or the spill cleanup, it clearly has little incentive to document the full magnitude and severity of those damages. In fact, Exxon has a direct pecuniary incentive to minimize any proof of the damages caused by the spill.[7]

This conflict of interest is far from purely theoretical. Exxon now has been sued by a large number of parties, including NRDC and other environmental groups, commercial interests, and by at least one of the Trustees.[8] Thus, a direct adversarial interest already exists related to the specific issues that will be addressed by the damage assessment and restoration plan.[9] It is completely untenable to give Exxon direct control over matters that are likely to be contested in court between Exxon and the Trustees.

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7 Information collected by NRDC and other groups demonstrates that where PRPs participated in Superfund remedial investigations, treatment options (as opposed to containment or other less permanent remedies) were chosen only 38% of the time, compared to 61% where EPA or states took the lead in remedy selection. This demonstrates the high potential for PRP bias in this type of activity.

8 We fully expect that suits will be filed by the federal Trustees as well, if the Trustees are to fulfill their public trust responsibilities under CERCLA and the Clean Water Act.

9 This adversarial relationship was exacerbated by Exxon's recent lawsuit against the State of Alaska. Conceivably, Exxon could use information collected during the damage assessment in its case <u>against</u> one of the Trustees.

Even aside from the formal conflict of interest related to Exxon's potential financial liability, Exxon clearly has an interest in minimizing the public's awareness of the actual extent of the damages caused by the spill. From the outset, Exxon seems to have been concerned first and foremost about the public relations implications of the spill. We expect that this will continue to guide Exxon's activities. These concerns could jeopardize the objectivity and adequacy of the assessment and restoration. One major factor driving Exxon's behavior, we suspect, is the desire of the oil industry to drill in the Arctic National Wildlife Refuge and other frontier areas of Alaska and the Outer Continental Shelf. It is in the long-term interests of the industry as a whole to attempt to minimize the public's view of the damage caused by this highly visible event.

One might argue that while the concerns discussed above apply to the damage assessment process, they should have little bearing on Exxon's ability to develop and to conduct the restoration plan. Here too, however, Exxon has a direct conflict of interest that may jeopardize the conduct of an adequate restoration effort. Exxon has an interest in deciding whether or how to conduct any given portion of the restoration based purely on whether it will reduce their ultimate liability by a sufficient amount.[10] Indeed, since as confirmed by the <u>State of Ohio</u> decision restoration cost is one measure of Exxon's

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[10] Exxon's possible attitude in this regard may be anticipated based on the company's callous refusal to commit to return next summer to continue the cleanup effort.

liability, Exxon has a <u>direct incentive</u> to minimize restoration costs.

While this type of cost balancing may be appropriate for a private corporation, it is completely inappropriate for purposes of the public decision on the appropriate restoration of Prince WIlliam Sound. This critical public decision should be based entirely on biological factors. All feasible efforts should be made to restore the environment of the Sound to as close an approximation of pre-spill conditions as possible.[11]

Allowing the responsible parties to participate in the damage assessment and restoration would be particularly ironic and inappropriate in this case, where the malfeasance or nonfeasance of Exxon, Alyeska and other responsible parties was so directly responsible for the accident, the almost complete failure to contain the accident, and the extremely ineffective cleanup to date. Exxon's poor response to date, which has focused on public relations to the detriment of sound environmental response, renders them completely inappropriate for a significant role in the damage assessment and restoration.

Finally, it may be true that Exxon (and its consultants) have more personnel than the Trustees to devote to the damage assessment and restoration. This does not mean, however, that Exxon should participate directly in these efforts. As explained above, Exxon can and should be required to pay the Trustees, <u>in</u>

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[11] As discussed elsewhere in these comments, the Clean Water Act establishes a preferred hierarchy of restoration, rehabilitation and acquisition of replacement resources. While Exxon might decide that acquisition of replacement resources is cheaper than restoration, the Trustees are not free to make this choice. If restoration is feasible, it must be the preferred approach.

advance where necessary, to retain the necessary consultants and other personnel to conduct a completely independent assessment and restoration.

B. It Would Be Illegal to Allow Exxon to Participate Extensively in the Assessment Plan and Restoration

These policy arguments clearly suggest that Exxon should be given no major substantive role in the assessment and restoration. We also believe, however, that even after State of Ohio, assigning Exxon this role under these circumstances would be illegal.

The Clean Water Act imposes a specific trust duty on the Trustees to conduct the damage assessment and restoration. CWA section 311(f)(5) provides:

> The President, or the authorized representative of any State, shall act on behalf of the public as trustee of the natural resources to recover for the costs of replacing or restoring such resources. Sums recovered shall be used to restore, rehabilitate, or acquire the equivalent of such natural resources by the appropriate agencies of the Federal Government, or the State Government.

(emphasis added). This language indicates that the Trustees have the responsibility to conduct the damage assessment and restoration effort, and prohibits the delegation of this trust duty to an outside party,[12] particularly outside parties with a direct adverse interest.[13]

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[12] We do not suggest that specific portions of the assessment or restoration cannot be performed by independent outside contractors, who have no interest in the outcome, and who are under the direct supervision of the Trustees.

[13] With respect to restoration, the Conference Report on the 1977 Clean Water Act Amendments, which added sections 311(f)(4) and (5), confirms that the "measure of liability is the reasonable costs actually incurred by Federal or State authorities in replacing the resources or otherwise mitigating the damages." H. (continued...)

Similarly, section 107(f)(1) of CERCLA provides:

> The President, or the authorized representative of any State, shall act on behalf of the public as trustee of such natural resources to recover for such damages. Sums recovered by the United States Government shall be retained by the trustee ... for use only to restore, replace, or acquire the equivalent of such natural resources. Sums recovered by a State as trustee under this subsection shall be available for use only to restore, replace, or acquire the equivalent of such natural resources by the State.

(emphasis added). CERCLA section 107(f)(2)(A) and (B) proceed to elaborate that the assessment of natural resource damages must be performed by federal and state officials, respectively, designated by the President and the Governor of the affected state.

Section 104 of CERCLA does authorize the President to allow a PRP to conduct removal or remedial action, when the President determines that such action will be done properly and promptly. The definitions of "'remove' or 'removal'" and "'remedy' or 'remedial action'" (CERCLA sections 101(23) and (24)) describe cleanup tasks, as distinct from natural resource damage assessment or restoration activities. By contrast, the natural resource damage assessment and restoration provision (section 107(f), uses the terms "restore, replace, or acquire the equivalent of such natural resources." Thus, even if Congress intended to allow the PRP to conduct a cleanup, it did not intend to allow PRPs to conduct the damage assessment or restoration.

This distinction makes perfect sense. The PRP may have a direct interest in conducting a prompt and adequate cleanup, so

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[13](...continued)
Conf. Rep. 830, 95th Cong. 1st Sess. 92 (December 6, 1977) (emphasis added).

as to minimize potential liability for natural resource and other damages. But as explained above, the PRP has a direct conflict of interest with respect to the natural resource damage assessment and restoration.

Despite this statutory distinction, the State of Ohio decision (we believe incorrectly) allows the Trustees flexibility to delegate purely ministerial duties related to the damage assessment to PRPs. The Court made it clear, however, that such duties must be supervised closely by the Trustees, and only consistent with a lawfully-developed assessment plan. For the policy reasons discussed above, we do not believe that the Trustees should exercise this flexibility in this case.[14] Exxon has not proven itself sufficiently reliable and objective to serve the public interest in these tasks.

Equally important, because of the extremely vague nature of the assessment plan, implementation of all or any part of the plan by Exxon would be more than purely ministerial. The plan gives little or no guidance on such critical issues as location of sampling, size and numbers of samples, analytical techniques, data preservation methods, quality control procedures, and other issues which severely affect the results of the studies. To delegate such decisions to Exxon would seriously compromise the study effort and give them major rather than ministerial responsibilities in conducting the assessment. Given the magnitude and complexity of this damage assessment, we doubt

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14 The Trustees note repeatedly that no decisions have been made on whether to follow the Interior Department assessment rules, in whole or in part.

whether sufficient guidance can be provided to render Exxon's role purely ministerial.

Also because of the extremely vague nature of this assessment plan, allowing Exxon or other PRPs to participate directly in the damage assessment and restoration would violate the due process and public participation rights of NRDC and other parties who have a strong interest in the adequacy of these processes. The Trustees' decisions on appropriate remedial action, the monetary value of the resources lost or damaged due to the accident, and on the appropriate restoration, replacement or acquisition actions, are formal administrative decisions subject to the Administrative Procedure Act, section 101(e) of the Clean Water Act, section 117 of CERCLA, and relevant provisions of state law. Particularly if the plan remains as vague as it is now, the parties who actually conduct the assessment and restoration will end up making important decisions, without public input, on how the assessment and restoration will be conducted. Allowing Exxon or other PRPs such a direct role in decisions related to the conduct of the damage assessment and restoration gives one set of interested parties a clear preference and advantage in this public process. This would violate fundamental tenets of due process and public participation in agency decisions.

VI. THE TRUSTEES SHOULD PROCEED QUICKLY WITH THE DEVELOPMENT OF A COMPLETE RESTORATION PLAN.

Although the cover letter to the draft plan indicates that the document includes both a draft natural resource damage assessment plan and a draft restoration strategy, no actual proposed restoration strategy is included in the document.[15] Instead, the document includes only an extremely brief discussion of how the proposed restoration plan will be developed in the future. This brief discussion provides no information on the direction the Trustee Council is considering for a restoration plan, or even possible options. Nor does the discussion even include a precise schedule for the development of such a plan.

The draft plan should have included a far more detailed discussion of this issue. In particular, as required by the State of Ohio decision, the total damages assessed against Exxon must include the cost of restoration or replacement, to the extent possible, and to the extent restoration or replacement is not possible, the cost of acquiring replacement resources or habitat. Thus, the restoration plan has a direct relationship to, and therefore should be prepared as a part of, the natural resource damage assessment plan.

But given that the plan announces an intent to seek substantial additional public comment as it proceeds with the development of a restoration plan (we agree this additional opportunity for comment is legally necessary), we urge the Trustees to proceed with the development of the restoration plan as quickly as possible. While we recognize that some elements of the restoration plan require a more detailed assessment of what resources were lost or damaged due to the spill, development of

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[15] We use the term "restoration" to include restoration, replacement, and acquisition of replacement resources and habitat. As discussed extensively below, the Trustees should ensure similar inclusive terminology.

the restoration plan does not have to be put completely on hold while this information is collected. With respect to some types of resources, sufficient information is available now to prepare at least an initial draft of a restoration plan. This plan can be revised as more complete information becomes available.[16]

Moreover, given that an entire year of data collection has already occurred for most of the studies included in the draft restoration plan, it is unclear why certain aspects of the restoration cannot begin next summer. We recognize that the Trustees must balance the goals of conducting a detailed damage assessment and conducting restoration activities that may obscure the damage assessment process. We also understand that, in some cases, initiation of restoration work may have to await additional information on the nature and extent of damage.

The overriding objective, however, must be to restore the affected environment as quickly and completely as possible. Therefore, well-considered restoration work should begin next year wherever possible, particularly where success will be improved if restoration begins more quickly.[17] As a corollary, since the public must have a fair opportunity to comment on proposed restoration activities, a proposed restoration plan must

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[16] With respect to resources for which even less information is available, the Trustees could at least scope out the components of the restoration plan that need to be developed.

[17] This is not to say that the Trustees should rush to implement restoration procedures that may be ineffective or counterproductive. See comment 4 below.

be prepared this winter, at least with respect to those activities that may begin next year.[18]

When the restoration plan is developed, it should incorporate the following concepts, at a minimum:

1. The restoration plan must include full consideration of restoration, replacement, and acquisition of replacement resources and habitat. Currently, for example, the draft plan includes no reference to acquisition of replacement resources or habitat. See Draft Plan at 27-28.[19]

Proper consideration of all of these strategies is essential for a number of reasons. First, as noted by many of the experts who commented on the draft plan, complete restoration of the environment of Southcentral Alaska is not possible. Therefore, replacement or acquisition will be necessary to compensate the American public and the environment fully for the damage caused by the spill.

Second, currently the studies identified in the damage assessment plan do not focus on the full range of restoration, replacement or acquisition strategies. For example, no study specifically aims to identify the types of habitat that may be priorities for additional acquisition, and to identify potential

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[18] Our concern that an opportunity to comment might postdate the actual work is well-founded, since this is precisely what occurred with respect to the first year of field data collection on the damage assessment studies.

[19] As discussed above, cleanup, which involves removal of oil and other contaminants, should not be confused with restoration, which focuses on the biological functioning of the affected environment. Thus, "bioremediation" techniques, while potentially desirable cleanup methods, do not constitute restoration.

target acquisition areas not currently under public ownership, or that are not currently protected. Similarly, no studies address specifically such issues as the feasibility of restocking populations, or the feasibility of restoring polluted benthic habitat. The draft restoration plan must address these issues.

Third, the restoration plan should identify replacement and, in particular, acquisition opportunities that might be time-limited. For example, the Trustees may elect to protect additional habitat in Prince William Sound by repurchasing timber leases or by cancelling pending timber sales in the Chugach National Forest, and by recommending more areas of the forest with important fish and wildlife habitat for wilderness designation.[20]

Similarly, should the Trustees decide that additional marine habitat should be protected to compensate for habitat lost due to the spill, opportunities for acquisition must be identified quickly. Viable opportunities include repurchasing existing oil and gas leases in Bristol Bay or other areas of Alaska, which would protect critical habitat for many of the species affected by the spill, or the creation of a Prince William Sound Memorial Marine Sanctuary in areas that are currently subject to logging, oil and gas or other development pressures.

2. The restoration plan must consider all aspects of the environment of the affected area, and not just commercially important or other commonly-recognized species. Instead, the

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[20] Decisions on some pending timber sales have been postponed due to the spill. Obviously, these sales must be reconsidered in any event to account for the major new biological stresses caused by the spill.

restoration plan must be designed to restore, replace, or acquire replacement habitat for all affected species, and all affected environmental qualities. In short, the goal is restoration or replacement of the total environment, and the environmental productivity and diversity that existed before the spill.

3. The restoration plan should focus on qualitative as well as quantitative environmental measures. For example, a restoration plan that focuses only on numbers of species and numbers of organisms might supplant the affected environment with a somewhat modified ecosystem, in lieu of true restoration. Thus, the plan should consider not only numbers of species, but the specific types and distributions of species in the region before the spill. Similarly, the plan should focus not only on population size, but also on the relative size of various populations that interact in the environment. This will ensure that the affected environment is returned to as close a condition as possible as existed before the spill.

In addition, the restoration must focus on wilderness and other aesthetic values, in addition to purely biological factors. Prince William Sound, Kenai Fiords National Park, Katmai National Park and Preserve, Kodiak National Wildlife Refuge and other affected areas are recreational resources for thousands of people, and were intended to be preserved in their pristine, natural state for future generations. National parks and other conservation system units in particular were created by law specifically for wilderness and other recreational purposes.[21] These purposes, as set forth in relevant organic legislation, land use and conservation plans, and other documents should be reviewed as part of the restoration planning process. For example, to the extent that the full wilderness values of an affected national park cannot be "restored", these values should be replaced through acquisition of other areas.[22]

4. Extreme care should be taken with artificial "restoration" and "rehabilitation" techniques.[23] While we encourage the Trustees to consider the full range of restoration and replacement options, and to employ options that are promising, some "restoration" techniques may do more harm than good, depending on the circumstances, location, and intensity of use. For example, salmon hatcheries may increase the local salmon population and harvest, at the expense of the integrity of wild salmon stock. Other efforts, such as restocking of wild populations, may require considerable time and resources, with limited success. The same resources may be spent more effectively by acquiring replacement habitat to support remaining local populations while the affected regions recover naturally. While we do not intend to choose particular options at this time,

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[21] For example, the entire coast of Katmai National Park, much of which was affected by the spill, is designated wilderness.

[22] Obviously, this determination is relevant to the final damage assessment to the extent that funds are needed to acquire additional land resources.

[23] We do not consider techniques such as "bioremediation", which uses nutrients to encourage bacteria growth as a means of removing oil, to constitute "restoration". These techniques are properly considered cleanup activities.

we urge the Trustees to consider the full costs and effects of all possible restoration strategies before particular strategies are selected.

5. As with the damage assessment, the restoration plan must provide, to the maximum extent possible, for the renewal of the long-term productivity and diversity of the affected environment, and not just for the elimination of short-term, chronic effects. For example, it is not sufficient simply to eliminate acute toxicity in the environment and to replace the most obvious species to their original numbers. Efforts must be made to ensure that the structure, function and productivity of the food chain and other aspects of ecosystem function are restored to the greatest extent possible. Similarly, attention must be given to sublethal effects, such as the reproductive success, growth potential, and overall health of individuals, as well as direct mortality.

6. The restoration plan must address damages caused by the cleanup and other response activities conducted this summer, as well as damage caused by the spill itself.

VII. THE TRUSTEES MUST DECIDE WHAT ASSESSMENT STANDARDS AND PROCEDURES WILL BE USED IN THE ASSESSMENT, AND ALLOW PUBLIC INPUT INTO THOSE DECISIONS.

The Draft Assessment repeatedly notes that no decisions have been made on such critical decisions as whether the Interior Department damage assessment rules will be used, in whole or in part, and what measures of damage will be used in the process.

These statements ignore two critical factors. First, the State of Ohio decision set forth critical guidance on what aspects of the rules may or may not be used, and on what basic economic valuation principles _must_ be used in the assessment process.[24] For example, the decision makes clear that the Trustees _may not_ employ the "lesser of" concept in Interior's rules, or any variant on that principle. Rather, restoration cost must be considered the preferred approach unless restoration is technically impossible or grossly disproportionate to the value of the resources. Conversely, the decision makes clear that the measure of damages must _exceed_ restoration costs; the lost use and nonuse values also must be assessed in order to make the public and the environment whole. In such cases, the Court explained that additional damages should be used to acquire replacement resources or habitat. Finally, the Court noted that lost use values should not be based exclusively on "market factors." All reliable means of calculating the value of the resource must be employed.[25]

The draft assessment must be revised in light of the decision in _State of Ohio_ to expand the economic studies to evaluate the costs of restoring, replacing or, where neither is possible, acquiring equivalent resources elsewhere. The economic studies described in the draft plan, however, emphasize lost use values to the exclusion of restoration. The comments of economist Mike Kavanaugh (attached) make clear the need to expand

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[24] Economic issues are addressed in greater detail in the attached comments of Michael Kavanaugh.

[25] The Draft Assessment continues to obfuscate this issue by indicating that lost use values will be considered in the assessment, without defining the types of uses that will be considered and the methods of valuing those uses.

the scope of analysis; in addition, he suggests ways to improve the proposed studies assessing lost use values.

Second, the standards and procedures that will be used in the damage assessment will have a critical effect on the results of the analysis. As such, the public has an absolute right to comment on these decisions. Moreover, since the procedures and economic methods that will be used to value the resources lost or damaged due to the spill may affect the types of scientific studies that are conducted, or vice versa, it is not sufficient to allow public participation on this issue after all of the scientific studies are completed. Public input into these decisions should be allowed, therefore, as soon as possible.

VIII. THE TRUSTEES SHOULD INCORPORATE THE VIEWS OF A BROADER SCOPE OF EXPERTS AND RESEARCHERS.

As noted above, we request that NRDC's experts play a role in the formal peer review process being used by the Trustees. We also believe, however, that other legitimate views may be excluded from the ongoing damage assessment process.

For example, the role of the National Park Service is not spelled out in the Draft Plan, leaving it unclear whether their views are properly being considered. Extremely important national park lands were affected by the spill, yet only the U.S. Fish and Wildlife Service (FWS) is listed as the Interior Department's Trustee representative. This role should be shared between FWS and NPS, to ensure that the interests of valuable park lands are protected, and to take full advantage of the data collected by NPS during and after the accident.

Similarly, the Draft Plan appears to ignore entirely the fact that much independent research and information collection is being conducted in the areas affected by the spill. This ranges from formal scientific research by independent scientists, to coordinated or anecdotal efforts by citizens to identify carcasses, oiled beaches and other readily-identified effects of the spill. The assessment plan should discuss a formal effort to collect and use, as appropriate, this information collected by outside sources.

CONCLUSION

The Draft Assessment Plan fails to provide sufficient detail to allow serious public comment on the conduct of the Exxon Valdez damage assessment and restoration planning processes.

Nevertheless, it is apparent from the information provided that the plan contains serious flaws that may jeopardize both the damage assessment and the restoration plan. Most notably, the general proposal to limit the plan to one year of studies will seriously underestimate the natural resource damages caused by the spill. Moreover, the Trustees' failure to initiate serious restoration planning calls into question their commitment to a comprehensive, long-term restoration of the affected environment, or to purchase replacement resources and habitat where full restoration is not possible.

We urge the Trustees to correct the violation of our public comment rights by allowing additional opportunities to comment on all future key decisions related to the damage assessment and restoration. More important, the Trustees should broaden the scope and duration of the damage assessment plan, and initiate careful restoration planning immediately, consistent with these comments and the attached comments of our experts.

ATTACHMENTS - COMMENTS OF EXPERT REVIEWERS

Comments of Dr. Anne McElroy

Comments of Dr. Patricia A. Lane

Comments of Dr. Howard L. Sanders

Comments of Dr. Michael Kavanaugh

Comments of Dr. Howard Liljestrand

Comments of Dr. D.K. Button

Comments of Drs. Steven Wright, Kim Hayes and Timothy Vogel

APPENDIX (Studies referred to in the comments of Dr. Patricia A. Lane)

Crowell, M.J. and P.A. Lane. The Effects of Crude Oil and the Dispersant COREXIT 9527 on the Vegetation of a Nova Scotia Saltmarsh: Impacts After Two Growing Seasons.

Lane, P.A., 1989. Environmental Effects Monitoring: Pitfalls and Possibilities in Relation to Offshore Oil Development.

Lane, P.A., 1989. Synopsis for Environmental Effects Monitoring: Pitfalls and Possibilities in Relation to Offshore Oil Development.

Lane, P.A., 1988. Reference Guide to Cumulative Effects Assessment in Canada, vol. I.

Lane, P.A., M.J. Crowell, D.G. Patriquin and I. Buist, 1987. Use of chemical dispersants in salt marshes. Environmental Studies Research Funds Report No. 070. Ottawa. 100 p.

Lane, P.A., 1985. Ecological Risk Analysis in Regard to Offshore Oil Development at Hibernia.

COMMENTS AND RESUME

OF

ANNE McELROY, PhD

COMMENTS ON THE DRAFT STATE/FEDERAL NATURAL RESOURCE DAMAGE ASSESSMENT PLAN FOR THE EXXON VALDEZ OIL SPILL RELEASED IN AUGUST 1989, PREPARED SEPTEMBER, 1989

Anne McElroy
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University of Massachusetts-Boston

Scope of Review:

As stated in the Federal Register, public comments are being requested to ensure that:

1) important resource concerns are not omitted,
2) the methodologies receive independent review,
3) that appropriate methodologies are chosen for assessment, and
4) that the costs of the assessment are reasonable.

The Register notice also states that additional work will only be done if such study is required to support legal recovery of damages for harm to natural resources if such studies are justified scientifically and are consistent with the objective of restoration of the ecology of the effected area.

As noted in the Register, to expedite damage assessment, all studies were begun prior to publication of the Assessment Plan. Indeed, according to the plan all data collection should be finished by mid September 1989, prior to the receipt date for comments. Data analysis will continue until February 28, 1989. Comments at this point can only serve to criticize the Draft Plan and make suggestions for additional work in the future. Without any preliminary data, suggestions will be speculative. Considering the huge expenditure of funds (35 million) committed to this plan, independent review prior to commencement of study should have been obtained.

To purpose of the plan is to determine the extent and magnitude of injury to natural resources of Prince William Sound and the adjacent Gulf of Alaska in support of the development of a restoration plan to promote the long-term recovery of natural resources and to support damages to be claimed for the loss of services.

The plan focusses on assessing damage to each resource as an individual unit with emphasis placed on quantification of exposure to oil components, stock size, and in some cases reproductive fitness. Very little effort has been placed on assessing impact on system wide, or interactive processes. For example, how oiling may effect productivity in a given area which in tern may affect species composition and or food resources. Investigation of each resource species as an individual component is extremely costly and may miss subtle effects caused by interactions between species. If species A is severely affected, its former prey may become more abundant which may deplete the food resources of species B. In this case the two species don't interact directly, but effects on one can lead to significant affects on the other. In order to get a complete picture of damage to the ecosystem, a comprehensive damage assessment plan should focus on individual species as well as their interactions and functioning of the ecosystem as a whole.

The goals of the major sections of the plan are summarized below:

Part I: Injury Determination/Quantification:

Coastal Habitat: to measure spill-related changes in supra-, inter- and subtidal zones.

Air/Water: to determine the distribution and composition of petroleum hydrocarbons in water, sediments, and living resources (ie. determine the dose).

Fish/Shellfish: to quantify numbers and effects in major fisheries species.

Marine Mammals: quantify deaths, pathology and toxicology as well as number and distribution.

Terrestrial Mammals: quantify damage to coastal species which would consume contaminated aquatic species and run laboratory experiments to assess effects on mink as a model.

Migratory birds: quantify mortality, population census, reproductive success.

Technical Services: Provide the expertise and coordination to ensure accurate and verifiable measurements of hydrocarbons in all samples, histopathological measurements in tissue samples, and mapping of results obtained.

Part II: Development of the Restoration Plan and Implementation Plan:

Part III; Damage Determination: Economic Value of Resource Use

In the summary statement at the beginning of the plan, the following criteria were given for choice of the studies included into the plan:

1) likely validity of impact hypothesis,
2) soundness of scientific approach,
3) cost-effectiveness, and
4) coordination with related work.

From the information presented in the plan, it is very difficult to assess how well each study met these criteria. Considering the extent of the spill, it is likely that all of the resources under investigation would be affected in some way. Therefore the hypothesis of impact is a moot point. The individual studies only justified the importance of the specific resource under investigation, not the soundness of the scientific approach. In many cases an adequate description of what will actually be measured is absent. Details of sampling and analysis are also sparse, making analysis of the approach and particularly the cost-effectiveness impossible.

I have gone through the details of the Coastal Habitat, Air/Water, Fish/Shellfish, and Technical Services portions of the proposal, have made specific comments on each, and prepared a brief overall summary statement.

GENERAL COMMENTS ON THE PORTIONS OF THE PLAN REVIEWED

In all cases it is impossible to tell if the budgets are appropriate because no details are given on sample size, number of man-hours needed, specific equipment, or anything else. The level of detail in the study plan, methods and analyses given and budgets presented would be completely unacceptable in any kind of peer-reviewed grant or contract application.

In most of these studies, it is also impossible to tell if the methods to be used are appropriate, again due to lack of information presented. The QA/QC plans given in Appendix A and B for chemical analysis and histopathology analysis indicate field sample collectors and analysts will all be properly trained and that appropriate blanks and standards will be run, and that periodic inspection and intercalibrations will be conducted. No similar description of QA/QC is given for the other measurements described in the plan. A large concern is the speed at which this study was undertaken, and the early date at which it is to be completed (2/28/90). Judging by the dates attached to the signatures on the QA/AC plans, much of this work was already in progress before this document, or standard analytical procedures were agreed upon.

Considering the magnitude of the task, it is impossible to believe that these analyses will be completed by March, 1990. If not, when will the information be available. No time-lines for interim reports or data coordination are given. This will be essential to damage assessment and making informed decision on what portions of this study, or addition work may need to be done in subsequent years. Almost no information is given about coordination, specifically when each of these studies will be done, if different portions will be coordinated temporally, who will be responsible for coordinating sampling, analysis, and data transfer. Formation of the Analytical Chemistry Group and the Histology Technical Group to oversee all QA/QC, and I hope coordinate data evaluation, is a step in the right direction. Similar coordination and oversight groups should be developed for the other types of data to be generated.

The studies as presented appear to be mostly descriptive, in some cases grossly over-sampling specific habitats or species. There is a tremendous amount of information available about the effects of oil on organisms (NRC, 1985). Information obtained from other similar spills should also be utilized (e.g. the Amoco Cadiz which grounded near a rocky coast in temperate waters). This work should not be repeated, rather the information from these studies should be utilized. Short-term efforts should be focused on clearly documenting the extent of oiling and effects on key resource species. This is adequately, and in some cases excessively covered in the plan. However, additional study should focus and measuring and predicting the reservoirs, movement and availability of oil which remains in the system, and in quantifying long-term effects on resource populations and community function and structure. Possibly monetary damages could be assessed in two phases, immediate and continuing.

Assessment of short-term effects on these species will generate data needed to calculate immediate monetary damages. In addition, provisions must be made to assess the economic values of long-term, more subtle damages. For example, persistent changes in benthic community structure or productivity might represent a significant enough change in food resources to cease to support a given commercial species in a given area. If the coupling between community productivity and decomposition is significantly disturbed, anoxic conditions could develope which would render the area unsuitable for many species. Determination of the movement, persistance and availability of oil in the benthos is essential to the prediction of long-term effects. Information of this type will be more useful to understand the fates and effects of oil in this system and predict future fates and effects of the oil from the Exxon Valdez as well as other spills which will undoubtedly occur in the area.

Ecosystem function parameters have been largely left out of this study. Community structure will be evaluated in the Coastal Habitat Study, and in some of the fish studies the age/size distribution of individual species will be documented, but little effort has been made to access the functioning of the ecosystem. Particulary in the near-shore estuarine habitats primary and secondary productivity as well as system respiration and organic mater decomposition should be assessed in selected areas. In the Amoco Cadiz petroleum degradation by microbes was significant, and researchers felt that the relative decrease in abundance of hydrocarbon metabolizing bacteria with time was a good indicator of recovery. Investigation of oil degrading microbes is absent from the plan of study. Similarly, structural and functional analysis of micro and macro plant and algal communities appears to be left out of the study plan. Coastal and submerged plants and algae should be included in the study, as these species can be important habitat in themselves and form the basis of the food chain.

Another aspect that could be better addressed concerns the fate of persistent oil components. Analysis of hydrocarbons in the sediment and pore waters should be documented for years. Twenty years after the oil spill near West Falmouth in Buzzards Bay, MA, oil was found in marsh sediments (John Farrington, pers. comm.). In the Amoco Cadiz spill oil migrated down through beach sands and cobble to the beach/water table interface. Movement through subsurface waters has not been addressed here. Oil buried in beach sediments may be quite persistent and would be re-released during winter storm events. The magnitude of this annual re-infusion of relatively unweathered oil should be assessed. As mentioned above, the air-sea interface also seems to have been neglected.

Study of the Amoco Cadiz oil spill for 20 months demonstrated the persistance of oil in nearshore sediments, and the persistance of alterations in benthic community and coastal marsh habitats. Indeed these later two parameters should little evidence of recovery during this period. Considering the colder waters of the arctic, recovery may be much slower. Clearly portions of these studies must be continued for at least several years, with some analyses continued even longer. The damage assessment plan presented, if conducted properly, should be able to support calculation of the immediate monetary damages associated with the Exxon Valdez spill, but some provisions must be made for careful study to assess long-term damages.

COASTAL HABITAT INJURY ASSESSMENT

Overall goals are to determine:

1) abundance of intertidal and subtidal organisms used as food by resource species,
2) contamination of these food resources by oil,
3) quantification of injury over the entire 600 mile affected area, and
4) recovery of various habitat types after clean-up treatments.

Although not specifically stated in goals, attempts will also be made to assess potential impacts of clean-up efforts on the above. This portion is mostly aimed at looking at food chain effects, both for lack to food items and food chain transfer of oil.

Study 1: Comprehensive Assessment of Injury to Coastal Habitats

Description:

Phase 1: categorize coastline into 5 representative coastal habitat types, with representatives of each with low, med, and high oiling. Selection of sites will be "statistically valid" and ground-truthed through a reconnaissance survey. Study design will allow extrapolation to entire 600 mile affected area. Initial selection will be based on exiting coastal morphology scheme and shoreline impact survey maps prepared by Technical Services Study 3#. Ground-truthing will establish approx. 150 study sites.

Phase 2: assess changes in critical trophic levels and interactions, and assess changes in terms of quantity (biomass, productivity) and quality (vigor and utility to other trophic levels) and composition (community composition, diversity and standing crop of key species).

These data will be used to:

1) assess injury to beach sediment and soils,
2) establish response of these parameters to oiling and clean-up,
3) estimate rate of recovery and potential for restoration, and
4) provide linkages to other studies.

Methods:

Phase 1: using GIS pick 3 rep. sites, for each of 45 categories (3 regions x 5 habitat types x 3 degrees of oiling) plus extras = 150. Visit to check and photograph sites, establish boundaries, and describe sites.

Phase 2: study 4 vertical transects through all 3 tidal zones at each site. Chemical analysis of sediment will include hydrocarbon composition as well as determination of volatile organic compounds. The percent of sediment covered with oil, depth of oiled sediment, salinity and soil/sediment texture will also be determined. Biological analyses will include community composition, cover, and standing stock for each trophic level measured. Dominant producing and prey organisms will be designated as key species and estimates of quantity and quality made to assess their contribution to energy flow in the habitat. Amphipod LC50 bioassays will be done to assess sediment toxicity. Samples of key species will be analyzed for hydrocarbon content. Additional species may be investigated to support other projects. It appears that some of these parameters will be followed over time, as changes over time are mentioned.

Comments:

As described, this study could provide extremely valuable information as to the effect of oil on benthic community structure, the extent of contamination by various oil components in the coastal zone of the entire effected area, and some estimate of how the oiling of benthic communities may affect species feeding on these organisms either due to lack to food (due to death of prey organisms) or food chain transfer of hydrocarbon contaminants (based on the hydrocarbon content in key prey items observed).

It is impossible to tell from the information given how well these objectives will be realized. Measurements will be made along 4 transects at each of 150 sites. No information is given about how many of each type of measurement will be made along these transects, or what methods will be used. No mention of the time scale for sampling is given. Will some of these be visited just post spill, and others only at the end of the summer? The only way to really assess damage to these habitats and predict recovery or plan recovery strategies would be to revisit a representative number of sites on an annual basis for at least several years, with less frequent sampling at multi-year intervals for a least a decade. On the recent 20 year anniversary of the West Falmouth oil spill in MA signs of oil were still present in subsurface sediments.

Although alluded to, no specifics are given on how the success of the beach steam cleaning operations will be assessed. Paired measurements between beaches that were manually cleaned and those which were left alone could determine whether or not these efforts had any long-term effect on the removal of oil and toxicity to organisms. It is quite likely, in my opinion, that steam cleaning may have done more harm than good. This would be a perfect opportunity to assess this before any more "steaming" is done next year.

In principle this study, if adequately carried out and scaled down to a manageable number of sites, would be a good start to assess coastal habitat damage. In addition to the chemical analysis of sediment and biota, species abundance and composition analysis, and sediment toxicity bioassays proposed, plants and algae should be included in the abundance censuses and be analyzed for hydrocarbon content. As the basis of the food web and important habitats in themselves, the effects of oil on these species should definitely be quantified.

It would be helpful to get an estimate of community function in coastal habitats. Primary and secondary productivity should be assessed in the intertidal and nearshore water column and benthos. This will mean analysis of phytoplankton, submerged vegetation and macroalgae as well as determination of organic carbon and hydrocarbon turnover by microbes. Benthic community respiration rates might also yield useful relative information about impacted and control habitat function.

AIR/WATER RESOURCES INJURY ASSESSMENT

WATER RESOURCES

Overall goals are to:

1) map the extent and persistance of floating oil (slick, mouse, tar balls) over the study area, and verify that this material came from the Exxon Valdez,
2) quantify the geographic and temporal distribution of dissolved and particulate oil in the water column, and
3) document levels of petroleum hydrocarbons in subtidal and deep water sediments and biota

Study #1: Geographical Extent and Temporal Persistence of Floating Oil from the Exxon Valdez

Summary: This is primarily a mapping project which will utilize exiting aerial photographs following the progression of the spill, and apply mathematical models to predict coastal impact, and amount of floating oil. Satellite imagery will also be employed. Samples of floating oil will be analyzed for hydrocarbon content and distribution to "fingerprint" the oil in the hope of assigning it to that carried by the Exxon Valdez.

Comments: Use of aerial and satellite images over time should be very useful to map surface oil movement, and document all shore areas impacted. Fingerprinting the oil (particularly before had weathered significantly should help to implicate the Exxon Valdez).

Study #2: Petroleum Hydrocarbon-Induced Injury to Subtidal Marine Sediment Resources

Summary: This study will analyze total petroleum hydrocarbons (TPH) by gas chromatography (GC) and polycyclic aromatic hydrocarbons (PNA) by GC-mass spectrometry with selective ion monitoring (SIM) in subtidal and deep sediments as well as sediment grain size and organic carbon content in offshore areas known or expected to have been oiled and nearshore sites in coordination with the intertidal sampling sites established by the Coastal Habitat study. Site selection will be based on areas likely to have received oil, sensitive areas (hatcheries and estuaries), and areas near to oiled coastal habitats. Sampling will be done in Prince William Sound, Kenai Fiords, the Kodiak Island area and additional locations extending to the Aleutian Chain. In Prince William Sound a manned submersible will be used to visually check areas for the presence of oil. Hydrocarbon analysis will be done on the top 2 cm of the sediment. If preliminary screening indicates the absence of oil, GC-MS will be omitted.

Comments: This study should give an accurate picture of how much and what components of the oil are contaminating surface sediments in deep and nearshore areas. The analytical methods should be appropriate, but again, no indication is given of exactly how many samples will be analyzed. If these data are to support the coastal habitat study, the same sampling and chemical methods must be used. Since hydrocarbon concentrations in the sediments of some of these areas should be high, it would be very useful to also measure these compounds in pore waters, as this will allow better estimates of what may be available to biota, and what may be easily remobilized from the sediment. Another informative exercise would be to bring representative samples of these sediments into the laboratory. Relatively simple microcosm experiments would generate data on the actual flux of hydrocarbons out of the sediment and its bioavailability to marine organisms. This information would greatly assist modeling the long-term fate of these compounds in subtidal sediments.

Study #3: Geographic and Temporal Distribution of Dissolved and Particulate Petroleum Hydrocarbons in the Water Column

Summary: This project will analyze volatile aromatic hydrocarbons, TPH by GC and PNA by SIM in water samples already collected at 1,3,5, and 9 depths by a number of groups at "numerous" stations in Prince William Sound, Kenai Fiords and Katmai National Parks. In addition, mussel cages will be deployed at 12 sites in the sound and 18 sites outside the sound to serve as sentinels of water column concentrations of these compounds. Tissue burdens of petroleum compounds will be analyzed in mussels. Additional water samples (including bottom water) will be collected and analyzed as described above at a selected number of sites.

Comments: These parameters need to be measured in water column samples. However, no mention is given in the methods of how or what size of water samples were collected. Due to the low concentrations which would be found in most samples except those taken in the immediate vicinity of the slick, these measurements are very difficult. In order to get really accurate numbers (ie. detectable levels), extremely large volumes (up to many gallons) of water must be collected using clean techniques. In the summary, they speak of determining dissolved and particulate concentrations, yet no mention of this is given in the methods. Due to the high partition coefficients of some of these compounds, it is very important to analyze dissolved and particulate fractions separately. Unless it was clearly specified that all groups had collected water samples in exactly the same way, I would also worry about results being comparable.

Another portion of the water column which seems to have been ignored is the sea surface microlayer. This interface is well known to be a location for locally high concentrations of hydrocarbons. It is also the home of floating eggs and larvae, and a location of photochemical reactions which are likely to alter the chemistry and toxicity of petroleum compounds in this layer.

Use of caged mussels as sentinel organisms is a good idea, but again, evaluation of this portion of the project is hampered by lack of information. How long will the cages be deployed, and at what depths? Hydrocarbon concentrations in mussel tissues tend to be lowest in the late summer just after spawning. Will the same compounds be quantified and mussel tissue and water column samples? How many replicate mussels per cage, and cages per area? There is a large amount of data in the literature on accumulation and depuration of hydrocarbons from caged mussels. Placing caged mussels at so many stations may be unnecessary.

Project #4: Injury to Deep Water (>20 meters) Benthic Infaunal Resources from Petroleum Hydrocarbons

Summary: This study plans to collect benthic samples by Van Veen grab for analysis of community structure at sites (and at the same time) of deep water sediment sampling. Samples will be archived waiting results of sediment analyses, and some undetermined subset would eventually ba analyzed for infaunal species composition, abundance, and biomass. Sediments will also be analyzed using "microbial techniques."

Comments: This study stands out for the lack of information presented. No specifics are given as to the number of grabs per station, nor the level of enumeration to be achieved. The statement about "microbial techniques" is meaningless by itself. Since no information is given about the frequency of sampling it is impossible to say how the results of this study would determine the persistence of injury to benthic resources studied. One of the justifications for this study is that is these species serve as food sources to resource species, and that this study will quantify the extent of contamination of these food resources. Monitoring species composition and biomass will determine if these dietary resources have been destroyed, but unless samples of these organisms are evaluated for hydrocarbon content, it will not be possible to determine the potential for food chain transfer of hydrocarbons from benthic infauna to marine resources.

Once water column concentrations of oil have dissipated. The sediments and infaunal organisms will serve as the long-term source of hydrocarbons to the water column and species resident or migrating through the entire area. Investigation of these processes should not be omitted.

Study #5: Injury to the Air Resource from the Release of Oil-Generated Volatile Organic Compounds

Summary: This study will measure the volatile organic compounds (VOC) concentrations coming off fresh and weathered oil, and model these data into existing air dispersion models and wind vector data to predict what concentrations of VOC would have been over time and space and model toxic exposure probabilities to organisms encountering contaminated air.

Comments: I don't know much about this area, but if the models are accurate they could predict the extent of toxic concentrations in the atmosphere which may have caused injury to any birds and marine mammals which were there at the time. The need for this study to access resource damage does not seem compelling to me. This study would have more utility in predicting atmospheric toxic exposures from future events.

Overall Comments Coastal Habitat Assessment:

Despite the lack of detail in the study descriptions, components of all of these studies are essential to document the extent of oil in the water column and benthos (sediment and organisms) and any immediate changes in populations observed. I would strongly suggest that the number of sites visited could be reduced in favor of more detailed analyses at some of the sites. Continuation of sampling in subsequent years will be essential to determine the long-term impacts, plan remediation strategies, and document recovery. In my opinion, the additional measurements and experiments suggested would help to better document effects of oil on the habitats and provide information that could be used to model and predict the fate and effects of oil in these areas.

FISH/SHELLFISH INJURY ASSESSMENT

Overall goals:

Each species was evaluated as a separate resource with species selection based on value as an indicator organism or role in major fisheries. For each resource evaluated, abundance and mortality of larvae, juveniles, and adults in oiled and non-oiled areas was assessed. Through the use of the Technical Services Program, tissue concentrations of petroleum hydrocarbons in resource species in some of these studies will also be evaluated.

These studies will be reviewed in groups containing all studies related to a particular species, or studies related to similar species. Each study in the group will be briefly described, followed by comments on the entire group.

Study #1: Injury to Salmon Spawning Areas in Prince William Sound

This portion will visually inspect all known spawning streams in the Sound directly affected by oil, photograph each area and document the extent of oiling including penetration of oil into the substrate. Approximately 100 streams will be surveyed by counting numbers of live and dead salmon by species, location in river, stage of spawning, evidence of prespawning mortality, tide stage and visibility.

Study #2: Injury to Salmon Eggs and Preemergent Fry in Prince William Sound

Forty-six of the streams studied in #1 will be selected for preemergent fry studies. Historical data is available on approximately half of these streams. In each stream 4 zones upstream will be samples for numbers of live and dead eggs and live and dead preemergent fry by species. This will be done 2 times in April and once in autumn.

Study #3: Salmon Coded-Wire Tag Studies in Prince William Sound

Salmon fry or smolt will be tagged prior to release from five hatcheries in the Sound. Two of which received heavy oiling. Marine abundance, survival and harvest of tagged fish will be assessed, as well as the extent of straying of returning salmon into outlying areas.

Study #4: Early Marine Salmon Injury Assessment in Prince William Sound

This study will evaluate some of the tagged fish from Study #3 collected at various points as they migrate through oiled areas for tissue hydrocarbon content and histopathology. Abundance, growth, feeding habits, and behavior of juvenile salmon from both oiled and un-oiled areas will also be assessed. Any fish kills observed will be documented. Pairwise comparison between oiled and control areas will be made for all parameters measured.

Study #7:Injury to Pink/Chum Salmon Spawning Areas Outside Prince William Sound

Numbers and locations and species of live and dead spawning salmon will be determined in at least 4 locations in 109 streams outside Prince William Sound where historical information on fry density is available.

Study #8: Injury to Pink and Chum Salmon Egg and Preemergent Fry in Areas Outside Prince William Sound

Preemergent fry and egg sampling will be done in the fall and spring (Spring, 1990?). Counts of live and dead eggs and fry by species will be done at each of 10 digs at 4 locations in each stream studied. All 109 streams will be assessed for preemergent fry and approximately 80 steams examined for eggs.

Study #9: Early Marine Salmon Injury Assessment for the Kenai Peninsula and Kodiak/Shelikof Strait

This study will repeat many of the measurements made in Study 4 on juvenile salmon in locations more distant from the site of the oil spill, but which were impacted by the slick at a later date.

Comments Studies #1-4:

Together these studies will generate a picture of the how badly the salmon spawning habitat was affected by oil, the impact on eggs and fry, and the success and relative health of this year's crop of released fry and smolt as well as their exposure to petroleum hydrocarbons. Portions of the study should be continued to document re-capture of tagged fish returning from the ocean in subsequent years to quantify any long-term effects of the spill on these species. Again, the number of sites to be studied seems excessive. Certainly a good picture of the effect of oil on spawning salmon and their eggs and fry could be documented with many fewer sites.

Comments Studies #7-9:

These studies repeat in lesser detail some of the work done on salmon species within Prince William Sound. As these fisheries probably were exposed to oil of different concentration and composition from that experienced in the Sound, their study seems justified in the complete assessment of the effects of the spill to fisheries in the area. Once again, the number of sites seems excessive, and to really document effects on these fisheries, some areas should be revisited in subsequent years.

Study #5: Injury to Dolly Varden Char and Cutthroat Trout in Prince William Sound

This study will investigate the effects of the spill on two recreational fisheries species with fairly narrow habitat ranges utilizing streams and lakes which communicate with the Sound. These species migrate annually in and out of overwintering lakes down streams into the estuary to feed, and then migrate back again. Weirs will be placed on four streams to catch and tag individuals from the spring emigration. All fish caught will be counted. Weirs will be placed on two additional oiled and un-oiled rivers to count all smolting, overwintering and spawning Dolly Varden char and cutthroat trout. Two of these streams have oiled estuaries, two do not. Survival of the tagged fish will be assessed through the capture of tagged fish in the recreational fishery described in Study #6 and recapture in this study (no date given).

Study #10:Injury to Dolly Varden Char and Sockeye Salmon in the Lower Kenai Peninsula

This study basically expands the work done on Dolly Varden char in the Sound as part of Study #5 to four areas in the Lower Kenai Peninsula (2 oiled and 2 control). Sockeye salmon are also found at two of these sites.

Comments: Compared to the salmon studies, this one seems much more manageable. Pairwise comparisons will be made between replicate oiled and un-oiled stream/estuary systems. Although the fate of some of the tagged fish will be assessed as part of the Sport Fishery Harvest Effort (Study #6), it would also make sense to place weirs on the river to document the number of fish (both tagged and untagged) returning to the lakes to overwinter. These fish will have spent the summer feeding in areas impacted by oil, and therefore should best demonstrate any effects. Samples of fish on both the downstream and upstream migration would be taken for hydrocarbon analysis and histopathology. Measurements should also be taken of length and weight to document any sublethal effects of oil on growth during the summer feeding period.

Study #6: Prince William Sound and Gulf of Alaska Sport Fishery Harvest and Effort

This study will survey the sport fishery harvest of salmon, rockfish, halibut, cutthroat trout, and Dolly Varden char by interviewing anglers from 7 locations from May 1 through September 15. Information on the sport catch from anglers using sea planes will be obtained through logbooks maintained by fishing guides. Some fish caught will be examined for (visual I presume) signs of oil contamination. Although not stated, I would assume the study would document the location of capture of tagged fish.

Comments: By comparison with historical data on the sport fishery catch, this information should determine whether or not in the first season post spill sport fisheries have been affected. This project should generate information directly applicable to the impact of the spill on sport fisheries, should relatively cheaply gather information on fish abundance independent to that collected directly as part of this study, and by involving the sport fishing populace should generate public enthusiasm for the restoration efforts.

Study #11: Injury to Prince William Sound Herring

Spawn deposition surveys will be conducted in up to 160 randomly selected transects through areas of herring spawn by divers and non-size selective harvesting of spawning adults. This information will be used to estimate herring abundance, egg densities, spawning bed dimensions and fecundity. The ratio of live to dead herring eggs in oiled and non-oiled areas will be assessed every four days until hatching. Eggs will be collected for hydrocarbon analysis. 180 batches of spawn collected from oiled and non-oiled areas will be reared in the laboratory where survival of eggs, larvae, size, weight and presence of visible abnormalities will be assessed. Data will be compared with historical information.

Study #12: Injury Assessment to Kodiak and Alaska Peninsula Herring

This study appears to repeat some of the work done in Study #12 in two other areas. Laboratory exposures will be conducted to experimentally determine the lethal and sublethal effects of oil on herring eggs, larvae and adults. Data collected from the field will be compared with historical information.

Comments on Studies #11 & 12: Studies #11 & 12 are aimed primarily at determining the effect of oil on fecundity and survival of herring in and outside of the Sound. Study #11 appears to be a comprehensive approach to assessing abundance and reproductive success in this species. 160 transects seems excessive, but no information is given on the size of the area to be surveyed. Study #12 is extremely vague about what will actually be done, but it appears that different kinds of laboratory investigations will be conducted in these two studies. Better integration is clearly warranted. The effects of water soluble fractions of oil on fish larvae have been well studied by others. Repeating these as part of this study does not seem appropriate.

Study #17: Injury to Prince William Sound Rockfish

This study will assess rockfish populations at 10 reefs in the Sound (6 oiled, 4 non-oiled). Fish will be collected with long-line gear in May and again in August and tissues from fish collected for hydrocarbon analysis. Live fish collected with hook and line. Dead fish on the surface will also be collected. Dead fish will be necropsied, and live fish sampled for hydrocarbon content. The number and distribution of rockfish collected will be compared with historical surveys.

Study #23: Injury to Rockfish, Halibut, and Lingcod Along the Lower Kenai Peninsula

This study will essentially repeat that described in study #17 at several locations in oiled and non-oiled water in and near Resurrection Bay. The species list investigated will be expanded to include halibut and lingcod. Sites selection will be based on areas known to have supported sport fisheries in these species in 1988.

Comments Studies #17 & 23: These fish occupy a habitat not previously well studied, so their examination is justified. Although not specified, I would assume numbers caught during a standardized fishing effort as well as size and size will be quantified. Fish should also be examined for parasites, oiled stomach contents, and general condition. Efforts should be made to determine the age of the fish caught (otolith analysis). This will determine what proportion of the population is being counted and demonstrate if any age-dependant effects are being observed. Organoleptic testing (taste tests for tainting) for hydrocarbons is proposed in this study. This makes sense as these fish are consumed by humans, and oily taste would lessen their value. Why has organoleptic testing been omitted from the other studies? Regardless, standard hydrocarbon analysis should also be done on these fish. Hydrocarbon analysis methods used on tissues taken in any of these studies should be comparable.

Study #13: Injury to Prince William Sound Clams

This study will assess populations of clams (cockle, littleneck, clam, and butter clam) at three sites each which received no, moderate and heavy oil contamination. At each site three transects will be set up and clams sampled at seven tidal heights along each transect. Live and recently dead specimens will be collected, identified and counted. At each site an additional transect will be set up to determine numbers of dead shells deposited on the shore. For each species three samples will be collected per transect for hydrocarbon analysis and histopathology. Growth and age estimations will be made on 100 littlenecks collected from each transect at each site. One of the heavily oiled sites will be monitored biweekly from May through September. If sudden changes in the proportion of dead clams appear, all other sites will be revisited at that time. If this does not occur, all sites will be revisited once during the fall. The repeat sampling will be used to monitor growth and relative abundance in young-of-the-year clams.

Study #21: Injury to Clams Outside Prince William Sound

This study repeats the analyses in Study #13 at ten locations in Resurrection Bay, lower Cook Inlet, Kodiak Island/Shelikof Strait, and the Alaska Peninsula. At each location an oiled and a nearby non-oiled beach will be selected. In addition to the species enumerated above, the razor clam will also be investigated. Five of the locations (which ones is not clear) will be revisited to document changes in growth rates and recruitment between oiled and non-oiled beaches.

Study #16: Prince William Sound Oysters

Mortality, growth, condition and hydrocarbon content will be followed monthly from April-September in marked individuals from three oyster farms in the Sound. One was in the spill, one near it, and I presume one was relatively unaffected. Parameters measured will be evaluated with respect to degree of oiling received and historical data from pre-spill years.

Study #25: Injury to Scallop Resources in Kodiak Waters

Mortality, growth, and condition factors of wild pink, spiny, and weathervane scallops at one oiled and one non-oiled site in the Kodiak area will be monitored monthly. Tissue samples for hydrocarbon analysis will be collected every over month following the spill through October.

Comments on Studies #13,21,16,25: The clam studies (#13 & 21) appear to be well designed and should unambiguously document the short-term effects of oil on mortality and growth in 4 different bivalve populations. However, it is not clear from the project description how growth will be documented, nor how examination of growth parameters and the abundance of bivalves two to four years old will give information about temporal changes in growth rates and recruitment between oiled and non-oiled beaches. Condition (although not stated I assume they are referring to a body condition index(volume of soft tissue to total volume of organism)) should also be measured on a subset of individuals from the clam studies to provide information comparable to that obtained in the other bivalve studies.

Will the bivalves be allowed to depurate (void) their gut contents prior to analysis for hydrocarbons? The presence of hydrocarbons in material in the gut can dramatically alter whole body levels analyzed. There are good arguments for and against depuration. However, the same approach should be used in all studies if comparable information is to be obtained.

Using marked individual the oyster study (#16) should give better information about growth and age dependent mortality. However, care should be taken to adequately assess effects on oysters of different ages (younger ones may be more sensitive). The scallop study (#25) is very poorly defined. One of the justifications for conducting this work is the cooperative mariculture feasibility and demonstration project at Kodiak, yet no further mention is given of assessing scallops from the projects. Following only one oiled and non-oiled site monthly over time seems insufficient. A better design would utilize multiple oiled and non-oiled sites visited less frequently if necessary. Also no mention is given as to how the scallops will be sampled to ensure adequate representation of the area. How will age-dependent mortality be assessed? Considering the relatively large budget assigned to this particular project ($2.2 million), a better study design is certainly warranted.

Study #14: Injury to Prince William Sound Crabs

Levels of hydrocarbons will be measured in Dungeness crab samples collected immediately after the spill and again in the autumn prior to egg hatch at eight sites (4 each oiled and control). Fecundity and egg condition will be determined from examination of the adults. Ovigerous crabs will be held in the laboratory until larval release for estimation of larval production. Similar measurements will be made on brown king crab collected in August. Samples of both species will also be taken for histopathology. Observations will be correlated with leveled of hydrocarbons in the sediments at the location of crab collection as determined in the air-water studies. Incidence of leg loss and abnormalities in shells of newly molted crabs will also be assessed.

Study #22: Injury to Crabs Outside Prince William Sound

This study will repeat the fall sampling on Dungeness crab described in Study #14 at some number of oiled and non-oiled sites in Cook Inlet and near Kodiak Island.

Comments on Studies #14 & 22: Study #14 is very well designed. Comparing hydrocarbon levels in these crabs just post-spill and just prior to spawning will give information about speed of depuration from this species as well as short term effects on the adult and on reproductive success. Since female crabs carry eggs on their pleiopods, adults, eggs and larvae can be examined relatively easily in this species. I would suggest that hydrocarbon content of eggs and larvae also be determined. At relatively little additional cost, this will provide useful information to estimate impacts on larvae (the effects of oil on a number of crab larvae have been well documented) as well as provide more information on potential food chain transfer of hydrocarbons.

Study #22 is very poorly described. Although investigating effects on crab outside the Sound is important, from the description provided in study #22 it's impossible to tell what they are going to do. Since crabs live in intimate content with the sediment and scavenge for food, they should be good long-term indicators of oil remaining in the sediments of these areas. Components of this study should definitely be continued in subsequent years.

Study #15: Injury to Prince William Sound Spot Shrimp

Spot shrimp will be collected from oiled (Unakwik Inlet, Port Wells, Culross Passage) and non-oiled (adjacent to Eleanor, Knight, and Green Island) areas. Catch (in up to 264 pots) will be enumerated by number, weight, size, sexual stage, and fecundity for each species. Samples will be taken for hydrocarbon analysis. A stratified sampling plan by depth and location within oiled areas will allow statistical comparisons between relative abundance, fecundity, stage of egg development, size frequency distribution, sex ratios, species catch composition, and hydrocarbon content to be made.

Comments: This study appears to be well designed. From the information given it's impossible to tell if the sample size is appropriate. If possible, egg hydrocarbon content and survival should be assessed.

Study #18: Prince William Sound Trawl Assessment

This study will assess the bottom fishery within the Sound. Surveys will be conducted from Mid-May to mid-June and again in August enumerating species abundance and collecting otoliths for age determination in primary groundfish species. These surveys will document the abundance of all species of groundfish caught and age class composition for primary species. At eight locations (4 oiled, 4 clean), tissue and organ samples of fish and shellfish will be collected for hydrocarbon analysis and physical injuries, and stomach analysis for tar balls in ground fish.

Study #24: Shellfish and Groundfish Trawl Assessment Outside Prince William Sound

This study will conduct parallel surveys to those conducted in Study #18 in June and August in lower Cook Inlet (Kachemak and Kamishak Bays), bays along the Alaska Peninsula, and coastal waters of the Aleutian Islands. Species abundance and age composition will be determined as described above. Stomach, muscle, liver, and bile samples will be collected and analyzed for indication of exposure to oil and potential reproductive damage.

Comments on Studies #18 & 24: The post-spill survey should determine any immediate impacts of oil on the fisheries of all these species. The fall survey should provide information on missing year classes, and provide a baseline for future impairment of these stocks due to longer-termed effects of the oil. Hydrocarbon levels in tissue would indicate any human risk from consuming these species. There appears to be some discrepancies between the methodology to be used between the two studies. Stomach contents will be analyzed in #18, but not in #24. Study 24 states that it will analyze bile for the presence of PAH metabolites. This is an excellent idea because these species can rapidly metabolize petroleum hydrocarbons. Therefore tissue levels of unmetabolized PNA would not be appreciable unless the fish were still being exposed to hydrocarbons. No mention of bile analysis is given in study #18. "Biochemical analyses" will be used to assess reproductive damage in the fish caught in study #24. These methods should be clarified. Due to my knowledge there are no "standard" biochemical analyses to assess reproductive damage. Regardless, the same methodologies should be utilized in all fish studies.

Study #19: Injury to Larval Fish in Prince William Sound

Potential damage to larvae in the water column will be assessed in this study. According the draft report, there is virtually no historical data on larval distribution or abundance in Prince William Sound. Larvae will be collected using Tucker trawl nets with 0.5 and 1.0 mm mesh sizes and the MOCKNESS multiple open and closing net system once per month from March through October. Larval densities will be recorded. Although not explicitly mentioned, it appears that for some species, larval size and weight will be recorded.

Comments: This study should generate very useful information about larval resources in the Sound. However, several important factors were either not mentioned or were left out. No specifics are given as to the number of trawls in oil and un-oiled areas or the depths at which larval collections will be made. Abundant or important larvae should be examined for physical deformities, and hydrocarbon content. Nowhere in the entire plan of study have I seen any reference to enumeration of phytoplankton or zooplankton abundance or species distribution. In addition to fish larvae, zooplankton caught in these nets should be enumerated. These species serve are food for many of the larvae, and have been shown to be sensitive to oil. Running small meshed next behind the nets already being towed in this study would also allow enumeration of phytoplankton. Again, for little additional cost another component of the food chain could be assessed in this study.

Study #20: Undersea Observations

Remotely operated vehicles (ROVs) will be used to visually assess the extent of submerged sediment oiling in up to 1,500 m depth in Prince William Sound and the northwestern Gulf of Alaska. These observations will support designation of paired oiled and un-oiled areas for the trawl surveys.

Comments: The utility of using ROVs to locate oiled and un-oiled deep water sites in support of the fisheries surveys is well justified. Actual proof of oiled sediments will be based on the sediment surveys conducted in other sections. Sixty days of ROV time are requested. This seems excessive if they are really being used primarily to support these other studies and not merely to photograph the entire seafloor in Prince William Sound and the northwestern Gulf of Alaska. Documentation of how ROV use will be coordinated with the other studies it is to support should be presented.

Study #26: Injury to Impacts on Sea Urchins off Kodiak Island

Urchins from four oiled and four non-oiled areas off Kodiak Island will be examined. At each site five transects will be surveyed at high tide in September and November during the egg maturation period. Transects will be picked so that at least three traverse kelp beds (prime urchin habitat). At one meter intervals from mean high water to a depth of 20 m and out to a distance of 3 m of either side of the transect, data will be collected on the numbers of live vs. dead and oiled vs non-oiled kelp. Every urchin encountered will be assessed for viability, sex, diameter and position. Along each transect a random sample of ten mature females will be assessed for roe weight as a proportion of total weight and size. At each sample location, roe from ten random individuals will be taken for histological examination and three random composite samples of ovaries collected for hydrocarbon analysis. In addition, twenty live urchins will be shipped to the laboratory for bioassay of toxicity of oil to urchin larvae.

Comments: Compared to most others, this study was very clearly described. The data collected should give valuable information on direct mortality of adults, reproductive effects on adults, eggs pathology, viability of larvae, and success of young of the year urchins. The hydrocarbon analysis of roe will also help to quantify exposure and help to assess risk of human consumption. Noting the presence of alive and dead and oil and un-oiled kelp will not along help to assess exposure to the urchins, but document direct impact on another important resource, the kelp itself. Assessment of effects on coastal and submerged vegetation and micro- and macroalgae is largely absent from the study plan. In addition to visually noting the presence of oil, samples of kelp should be taken for hydrocarbon analysis.

TECHNICAL SERVICES

Study #1: Hydrocarbon Analytical Support Services and Analysis of Distribution and Weathering of Spilled Oil

This section and the details presented in Appendix A describe the framework under which hydrocarbon analysis will be conducted.

Comments: This component is the most critical of the entire study, as accurate and comparable determination of the quantity and composition of petroleum hydrocarbons in all samples is essential to tying any effects measured to the spill, predicting future effects on biota, and monitoring restoration of the environment through either natural processes or human intervention. This section and the supporting documents in Appendix A indicate that the hydrocarbon analysis will be conducted in an appropriate manner. However, since the QA/QC plan was signed in many cases after many of the samples were collected for this study, one has to wonder whether or not all the steps to ensure the quality and comparability of the analytical measurements will or has been adequately carried out. Results from intercalibration exercises and data on field and analytical blanks should be reported in the documents resulting from this study. The formation of the Analytical Chemistry Group to oversee all these efforts is an excellent idea.

Chemical analysis should be comparable between the different studies. Some studies neglected to mention what chemistry would be done, some indicated analyses not mentioned in others. Only in one investigation was the analysis of PNA metabolites discussed. Metabolites should be assessed in all fish sampled for routine hydrocarbon analyses. In the Amoco Cadiz oil spill dibenzothiophenes (sulfur containing aromatic hydrocarbons) were found to be a persistent indicator of oil contamination whereas levels of PNAs were sometimes high even in control samples due to the widespread distribution of these compounds in the biosphere. Analysis for dibenzothiophenes should be included in the study plan.

Study #2: Histopathology: Examination of Abnormalities in Tissues from Birds, Mammals, Finfish, and Shellfish Exposed to the Spilled Oil

This section and the details presented in Appendix B describe the framework under which examine of tissue samples for histopathology will be conducted.

Comments: Histopathological analysis can give very clear and comparable evidence of the effects of oil on aquatic organisms. The description of the methods and the QA/AC plans sounds adequate, although this is not my area of expertise. However, no mention of exactly how preserved tissues will be sampled is given. More effort should be placed on documenting histopathological responses which may lead to long-term affects such as genetic abnormalities. I would like to note that lack to overt histopathology should not necessarily be taken to mean that the organisms were unaffected.

Study #3: Mapping of Damage Assessment Data and Information

All data will be computerized and maps will be prepared to document the extent of oiling in the area, upon which effects noted can be superimposed.

Comments: The initial maps documenting the extent of oiling of water and shoreline over the entire region will be prepared by June 19, 1989. These will be useful to in development of the Coastal Habitat, and fish and Shellfish assessment studies. Adapting a computerized format to collate and display the information generated by this study is critical to proper evaluation of results and the early identification of trends and areas which will require further study. The initial maps should have been included in the Study Plan. Furthermore, a time-table for generation of subsequent maps and their distribution should be included in the plan.

PART II DEVELOPMENT OF THE RESTORATION PLANS

Comments: Basically all this section says is that a restoration plan will be developed for $500,000. No information is given about the types of strategies which may be considered. It appears that little though has been given to how to approach restoration.

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COMMENTS AND RESUME

OF

PATRICIA A. LANE, PhD

STATE/FEDERAL NATURAL RESOURCE DAMAGE ASSESSMENT PLAN FOR THE EXXON VALDEZ OIL SPILL AUGUST 1989-PUBLIC REVIEW DRAFT

PLA RESPONSE TO FOUR MAIN POINTS
October 13, 1989

1) IS THERE ENOUGH INFORMATION PRESENTED TO EVALUATE THE PROPOSED STUDIES PROPERLY?

Generally, only brief overviews of each study or sub-study are given. Although it is clear that many of the main environmental components have been identified for study, it is not so clear that the studies are designed well enough to provide the needed information to quantify damages rigorously. In particular, there is very little information given on sampling design and methods of data analysis and interpretation during the post-data collection phase. In most studies in which the quantitative details are not well specified in advance for both pre- and post-data collection study phases, there is a loss of usable information and a waste of time and resources. In PLA's report on environmental effects monitoring (1989a,b), we point out many of these pitfalls and show through an examination of world wide impacts of oil on environmental components, how poor field sampling designs have greatly contributed to the failure to document environmental effects attributable to a wide variety of oil production activities, including spills. These effects were undoubtedly far more significant than those quantified and documented.

The text of the Damage Assessment Plan does not read as if it were written by authors knowledgeable in these areas. This comment applies to both pre- and post-sampling and statistical data analysis, as well as modelling on the population and ecosystem levels. A few sentences are interspersed concerning statistical analyses and modelling but few details are given as to what types of data analyses and ecological models will be used and with what expected results (prediction time frame, accuracy, confidence level, uncertainty level etc.). The fact that the quantification aspects of the assessment were not given more initial attention is extremely worrisome and is expected to affect the final results.

A few general comments:

a) It might be wiser to concentrate on fewer components and use particular species as indicators of damage for a broader group of species than to try to measure everything at such a gross level that all results are poor. At the very least, quantification efforts have to be detailed and rigorous for selected species representative of classes of damage. The existing baseline data for each component were not specified. Had this information been fully specified, it would have been clearer which components would be more useful than others to quantify at the various possible levels of detail. It was unclear if the authors themselves were fully cognizant of the state of the background data sets.

b) There was almost no information on how the assessors were going to translate environmental effects (even if well measured) into economic damages. This is part of the quantification problem but also the complete lack of an appropriate logic bridge from the ecological to economic areas of concern, as well as the lack of associated field and paper data collection exercises. Logic bridge refers to a set of steps that outline how one proceeds from the environmental measures in the field to estimating loss to a population or habitat. This estimate must take into account not only the short term acute event (such as the death of X number of individuals) but also the damage to the success (size) of the future population because of the loss of reproductive contribution of these individuals (and logically of their lost offspring) to future generations. The logic bridge must then proceed to link the environmental loss to its economic value. The assessment plan does not present a convincing logic bridge, which indicates that the priority was given to obtaining field measurements. Too little attention was paid to whether or not the data would be solid and maximally useful and whether the logic underlying the final damage estimates would be convincing in a legal milieu.

c) Although the use of a Geographic Information System (GIS) to represent the spatially-referenced impacts is commendable, it is only described as a tool to map the valued resources and oiled areas. A GIS is designed to store and manage large spatial data sets and to produce appropriate maps of these data. These functions, however, represent only part of the usefulness of this type of tool. In many cases, these functions may not be cost effective for a particular application. More importantly, if the GIS is "intelligent", that is, can take the spatially-referenced information and subject it to damage assessment functions, including ecological risk analysis, then the GIS can be made into an invaluable tool for achieving the damage assessment objectives. There was no evidence in the Damage Assessment Plan that the GIS would be "intelligent" and fully utilized with state of the art assessment methods. "Intelligence" here is used in the sense of providing more than a map of existing conditions either by 1) incorporating dynamic models of future conditions or by 2) integrating different types of existing information into new types of information and their habitats. For example, if bird populations were mapped in with a GIS, it would be possible to model these populations over time to produce "future maps" of the distribution and abundance of the species of interest and then to estimate longer term damage by calculating change with and without the oil spill to estimate longer term damage. In 2, other types of information (toxicity, physiology, behaviour) could be added to that of direct mortality of a species to illustrate future population size, or habitat damage could be modelled with recovery functions to illustrate how the mapped habitat would change over time.

Essentially, an "intelligent" GIS uses additional models to develop more useful types of information or to link future states to present states. The logic bridge discussed above can also be at least partially, if not wholly, incorporated into the analysis. This type of GIS is costly but would become cost effective in the context of a long term damage assessment plan. For the particular type of damage in Prince William Sound, a long term damage assessment capability is definitely needed.

d) The virtual lack of any detail on the restoration part of the plan also did not inspire confidence. There should have been at least preliminary categories of restoration activities and planning so that when the field and laboratory studies were conducted, preliminary evaluations of feasibility and priority could have been undertaken.

e) The problems identified above indicate to us the haste with which the Damage Assessment Plan was probably assembled and the inherent difficulties in coordinating such a large set of activities under less than ideal conditions. While these comments cannot influence the data collection to date, there are still some things that can be done to insure that the data collected will be analyzed as appropriately as possible in the remaining time before results are generated. These "things" include taking stock of the overall objectives of the program and the array of quantitative techniques that are available to facilitate data analysis and interpretation, including the development of appropriate models where none presently exist. For example, if samples are pooled in particular ways during laboratory analysis, this will preclude some types of statistical analysis. Or if certain measurements are not taken, this lack of information may produce a logic bridge with a few key piers missing. As much as possible, any part of ongoing procedures should be improved to maximize the usefulness and reliability of the results to develop the long term damage assessment capability. Specifically, it would be desirable for all data to be placed in a central data analysis centre which could be accessed by computer network (normal phone lines) by interested parties. There should be a coordinated effort of the "data analysts" to standardize their "logic bridge or bridges" and formats of data collection, analysis and reporting.

Available software (models, statistical methods, etc.) should be assembled with one or more individuals to assist in their application and interpretation of results. In summary, it is important to coordinate and share resources and to communicate and integrate results among the assessors, as was done during the spill. The degree this coordination is possible and practical, gives a good indication as to how feasible it is to measure community ecosystem response and cumulative effects.

f) Figure 7 in the Damage Assessment Plan lists the use of "Impact Hypotheses" as one of the key steps in the logic bridge. Hypothesis is a word that is frequently used in science but it can have quite a different meaning when employed in impact assessment. Often it is not possible to "test hypotheses" in an impact assessment context, whereas this is possible in a controlled laboratory experiment. It is important to understand the differences and not to promote hypothesis testing when in fact that is not possible. (See P. Lane and Associates Limited 1989a, b).

In summary, we do not believe that the studies are detailed sufficiently. More worrisome than the actual description, which can best be portrayed as a fairly superficial "measure everything" approach, is the lack of evidence as to how the data will be integrated and analyzed in a rigorous, quantitative way to provide definite estimates of damage regardless of whether or not a GIS is used. Most of the environmental studies are organized on a per species basis. Whereas much of the damage assessment must focus on a per species basis, it will not be possible to simply add up damage caused to many populations and obtain a measure of "ecosystem damage on cumulative effects" for the Prince William Sound area.

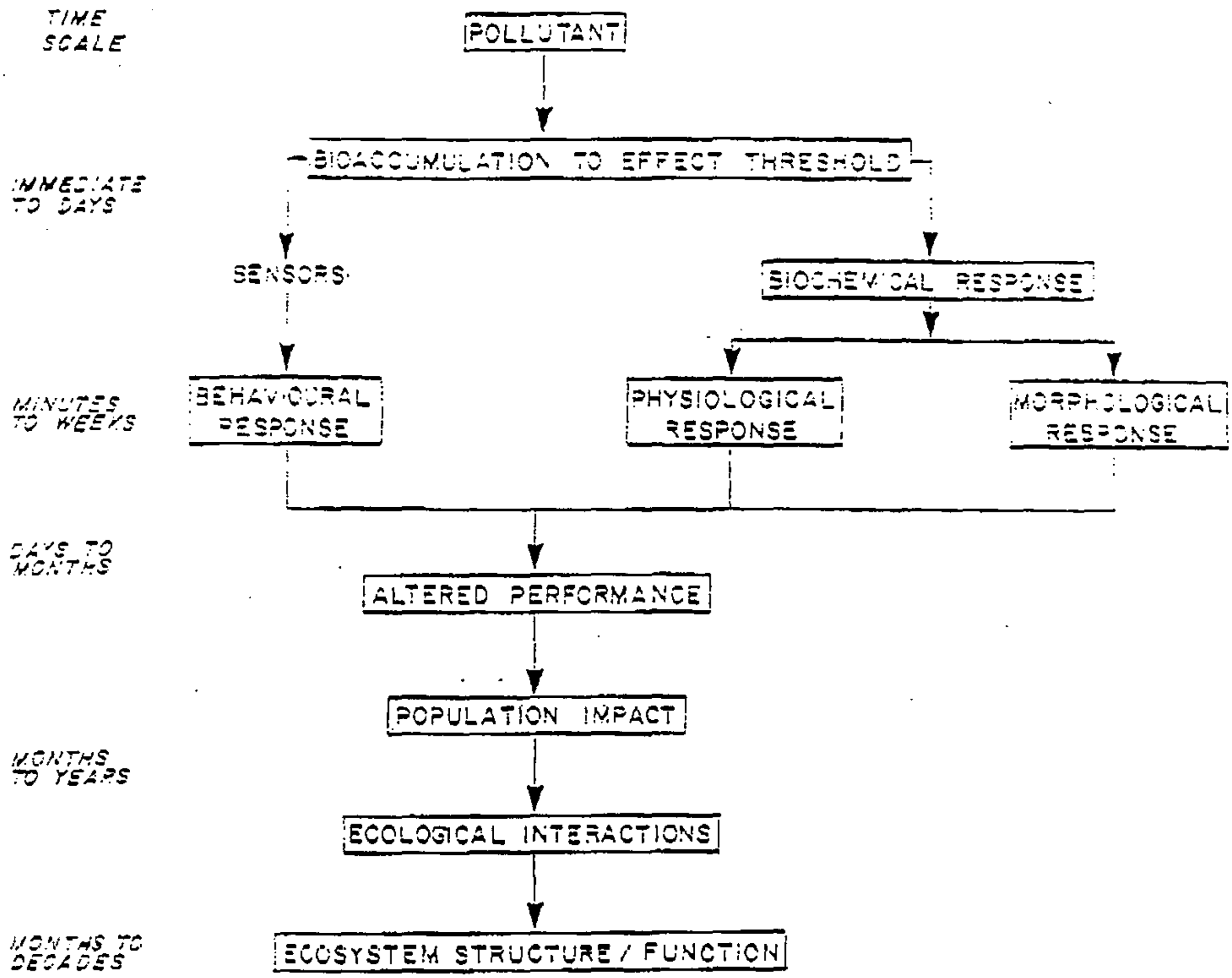
In an ecological system, a change in one component can lead to changes in other components. Analysis of single populations precludes a rigorous delineation of indirect effects and effects of foodwebs. In addition, several pathways of effect can exhibit feedback relationships to populations of interest so that damage may be multiplicative, not simply additive. For example, 8 x 10 = 80 units of damage not 8 + 10 = 18 units of damage.

Methodologies given in Lane et al. (1988) for cumulative impact analysis give an overview of methods available to form an integrated cumulative effects assessment process for extended space (longer than local ecosystem) and time scales (longer than one year). This process undoubtedly will be the framework for understanding the damage to the soil and subsequent recovery of Prince William Sound. A cumulative effects assessment and management process should be an integral part of the management of Prince William Sound for the next several years, if not the next several decades.

2) WILL THE PROPOSED STUDIES (BASED UPON A COMMITMENT TO FEBRUARY 1990) PROVIDE A BASIS FOR PREDICTING LONG-TERM EFFECTS; IF NOT, WHAT STUDIES SHOULD BE INCLUDED TO DO THIS?

As the attached Figure 1.1(PLA, 1989a) illustrates, a variety of sublethal, subpopulation effects can impact a population months to years after the original contaminant release. At the population level all of these types of changes would be reflected in altered age-specific fecundity and survivorship schedules(See P. Lane and Associates Limited, 1985). Such a release can also have immediate impact on population through direct mortality following contaminant release. This direct mortality is quantifiable depending on the species, available field data and resources etc. However, the loss of those animals may well be more important in terms of their reproductive contribution to future generations than is the immediate loss of x individuals.

To be meaningful, long term effects much include both direct and indirect causes of mortality from the death of individuals as well as from lowered fecundity and survivorship of age classes. If this is not computed correctly, mortality can be underestimated by many fold. For example, a study of direct mortality might result in the recording of the death of a single individual, whereas a study that includes measures of indirect mortality could conclude that the loss of this individual from the population would result in the loss of 5 - 100 individuals in future generations. In addition, individuals living in very small populations may have trouble finding mates or receiving appropriate behavioral cues and other learning experiences needed for reproduction and survival. Small



Source-after Gesamp (1980) and Scope (1984).

SCHEMATIC DIAGRAM OF THE EFFECTS AT DIFFERENT LEVELS OF THE BIOLOGICAL HIERARCHY AFTER INTRODUCTION OF POLLUTANT INTO THE ENVIRONMENT populations are also more vulnerable to chance events and therefore have a much higher probability of extinction.

All natural populations exist in ecosystems and although many key populations are of interest because of their direct commercial value, studying these populations in isolation usually will not produce a true representation of total environmental deterioration. Many populations are predators, competitors, or prey in regard to their interactions with other species in the terrestrial and marine foodwebs that exist in and around Prince William Sound. Indirect changes will come about not only from the sublethal and life history changes in the individual populations that inhabit the ecosystems, but also from the altered ecological interactions and foodwebs. A predator population can decline not only from the direct effects of oiled feathers or ingested oil, but also from the lack of a critical prey species that was killed previously by the oil spill. There is no evidence that an ecosystem approach will be taken to examine and quantify foodweb effects related to the oil spill. This is exceedingly unfortunate for two reasons. First, from an ecological point of view, in the final analysis it is the long-term persistence of the ecosystems of the planet that are of main concern, not just the few species that are associated with direct monetary benefits today. Secondly, focus on populations gives too narrow a definition of damage and must a priori lead to further underestimates in damage assessment. See P. Lane and Associates(1985) for an illustration of both population and ecosystem level risk analysis. Thus, if the guilty party were made to pay only for the number of birds or mammals directly killed by the oil spill, based for example upon a carcass count, the amount of true damage could be underestimated by orders of magnitude.

Long term damage is undoubtedly the most important in terms of both total amount of damage and in terms of ecosystem viability. The only way that long term damage can be assessed is through the wise use at both the population and ecosystem levels of appropriate models that would predict possible levels of effects over at least two-three generation periods of the longest-lived members of the ecosystem. Such models are described in PLA (1985) and Lane et al. (1988). Because of the uncertainty of long term predictions, the modelling tool should be able to handle various levels of uncertainty and to be corrected, based on further monitoring data. This particular oil spill will probably be visible for decades. There is no humanly possible way to assess total or long term damage based on data collected within a one year period following the spill. It is possible, however, within this time period, to develop the monitoring systems, the quantitative methodologies and other tools (GIS), the data baselines and an overall plan of damage assessment. In Lane et al. (1987) and Crowell and Lane (1988) we show how a ten minute spill of oil dispersant (Corexit 9527) and oil plus dispersant (each approximately one millimetre thick) produced environmental effects over two subsequent years. These effects included not only ecological measures such as population abundances and distribution of the dominant saltmarsh grasses, but also morphological, physiological and reproductive effects. Plans are underway to study the effects and damage of these miniature controlled spills in the fourth year of saltmarsh recovery.

It is unconscionable to terminate data collection and assessment at such a premature point (one year) when perhaps less than 10-20% of the total damage has been observable or quantifiable. There should permanent monitoring sites with a variety of data gathered; similar to the saltmarsh experiments but extended for a variety of ecosystems. A variety of measurements should be undertaken as illustrated in Lane et al. (1987) and community recovery and recolonization of selected biota should be measured on a continuing basis over a period of several years.

4) ARE THERE OTHER IMPORTANT GAPS IN THE STUDIES PROPOSED?

Several important gaps in the studies have already been mentioned:

1) Lack of Quantitative Rigor

- both short and long term calculations
- field and laboratory designs
- statistical methods and validity of assumptions
- modelling methods, especially ecological risk analysis
- turning environmental results into economic measures

2) Little Evidence of Strong Logic Bridges (necessary to document cause and effect in regard to the following):

- relationships between individuals and populations and between populations and ecosystems
- relationships between terrestrial and marine ecosystems
- relationships between laboratory data (toxicity tests) and population and ecosystem effects
- relationships between various time scales of effects in regard to generation times and time scales of other ecological events
- relationships between sublethal and lethal effects
- role and significance of habitat versus pure biological damage of an individual, population or ecosystem
- relation between environment and economy in a sustainable development context
- relationships between various spatial scales of effects in regard to the spatial patterns of the habitat types (this could be partially resolved with an intelligent GIS)

3) Cumulative Effects Assessment and Management-Sustainable Development

Cumulative effects result in large scale, regional patterns of environmental deterioration. Sometimes they come about from the "tyranny of small decisions" of many different human activities, each small in itself, over an extended ecosystem; sometimes cumulative effects arise from the multiple activities related to a large development; or in the case of Prince William Sound, cumulative effects arise from a catastrophic event. Examples of cumulative effects include global warming and climate change, acid deposition, habitat fragmentation and alienation, pollution of receiving environments, losses in soil quality and quantity, pollution of large aquifers, loss of biological diversity etc. Recently P. Lane and Associates Limited(1988) have defined and categorized cumulative effects and methodologies for assessing and managing them. If we fail to have sustainable development on this planet, it will be because we have not been able to identify, prevent and reverse cumulative effects.

The Valdez oil spill has endangered the sustainable nature of the Prince William Sound ecosystems substantially. To understand and quantify this endangerment to sustainable development a cumulative effects analysis should be undertaken. Nowhere in the Damage Assessment Plan was this suggested. Unfortunately, cumulative effects are not just additive; they may also be multiplicative. To the degree that they are multiplicative and interacting, damage may again be greatly underestimated. For this type of a cumulative effects problem, the analysis should be based upon an "intelligent" GIS with appropriate environment-economic models to predict endangerment to sustainable development indicators.

APPENDIX A:
Detailed Notes on Some of the Component Studies

Comments on each component area generally reflect (i) a lack of background information that would enable the "public" to determine if sufficient studies were planned and carried out, and (ii) the inadequacy of a one year sampling program for assessing environmental damage.

1) **COASTAL HABITATS** Study #1, Phase 1: The affected coastline is to be categorized into five "representative" habitat types. What are the different types and how were they chosen? We believe they used existing coastal morphology schemes, but no references or details were given. Up to 150 sampling sites are to be chosen:

5 habitat types X 3 geographic regions X 3 degrees of oiling X 3 replicates

+ 15 more sites that were either lightly-, or moderately to heavily-oiled.

The statistical design is supposed to allow extrapolation of collected information to the entire affected area. With so many sites and the short time period available for study, it is very unlikely the data can be extrapolated to all other locations. Large and rapid seasonal changes in physical, chemical and biological variables in the sub-Arctic place severe constraints on the sampling program. Unless the data collection is carried out in a synoptic-fashion, comparisons to other sites, and between oiled and non-oiled sites are simply not valid. Lacking pre-spill data on most of these sites, it's also unrealistic to assess oiling-damage. Since there are some data available from the Valdez area (refs not given), why not concentrate on the few (?) sites that have some "history" and do less-comprehensive studies on under-represented coastal habitat types.

Phase 2: This part of the study purports to assess changes in "critical" trophic levels and interactions. Who decides what is "critical?" Secondly, how do they expect to determine whether changes in population biomass and productivity, community diversity, vigour and utility to other trophic levels are due to oiling without seasonal, annual, or pre-spill data? Can rate of recovery of these habitats be determined for short-term data collections? They also plan to "kill more animals" by doing on-site amphipod LC_{50} bioassays - is this really necessary?

2) **AIR/WATER RESOURCES** Study #1 - Floating Oil: This study is useful in that it actually confirms that oil slicks, etc., come from the EXXON VALDEZ, and monitors the spread of floating oil over time. All the analyses will take some time to complete and consequently this delay sets back other studies waiting for this information to plan their sampling projects.

Study #2 - Oil in Subtidal Sediments: Again useful for other studies, but lacking hard data from Study #1, any models projected for oil spill movement will really be guesses. A lot of sediment samples (and analysis time) may be taken from sites where projected likelihood of oil contamination was high, but received no oil.

Study #3 - Oil in the Water Column: Necessary data, but time consuming taking all of the vertical profiles in relatively shallow (well-mixed) waters. Mussel cages deployed at 12 sites in the Sound, and 18 outside, should be useful for long-term indications of water quality. However, the mussels are transplants from control sites in southeast Alaska - unknown influence on the results?

Study #4 - Injury to Benthic Infauna: As mentioned in the report, many of the samples taken will be archived pending receipt of subtidal oil data (see Study #2 and Technical Services Study #1). Time is an important constraint here.

Study #5 - Volatile Organic Carbon Release: VOC to be measured and along with air dispersion models (wind data required) used to reconstruct ambient VOC concentrations throughout the Sound over time. Prediction of "unhealthful" conditions (to humans) may tell us if terrestrial and marine animals were in any danger. Model loss rates also to be used in mass balance calculations on the fate of spilled oil - utility ??

3) **FISH/SHELLFISH** We have reviewed the 26 Fish/Shellfish studies (p. 48-111) and, in general, cannot recommend that the Feb 28, 1990 deadline is sufficient to assess the damage caused by the Exxon Valdez oil spill.

The 26 studies proposed are generally inadequate for predicting long-term effects on fish/shellfish populations. It is our opinion that these studies are better suited for estimating the short-term and acute effects of the spill.

We would suggest as a minimum requirement to assess the long-term effects of the spill that the time period be considerably extended for numerous studies. In single species studies, the minimal time period we would recommend would be equal to the average longevity of individuals of that species. This would allow following affected age classes till their demise.

Major gaps exist in the assessment in our opinion. There is no investigation into the sublethal and long-term effects (or delayed manifestations) on individuals or the duration of the damage by the oil spill. Behavioral avoidance studies have been neglected, as have effects of early exposure to oil studies and micro-habitat studies.

Furthermore, the approach taken has been an instantaneous examination of commercially important species only. Little, if any, attention has been focused on a community response approach. It is important to examine the food web that commercially important species are part of, along with such processes as bio-accumulation and bio-retention. The proposed short time frame precludes this. Study of the fish foodweb should be undertaken backed by loop analysis, a qualitative modelling tool. Foodweb structures before and after the spill could be compared supported by toxicity and habitat studies over a period of several years. It is also possible to determine a set of stability measures using loop analysis.

Considering the vast area contaminated by oil, both in the Sound and beyond, we find the proposed study design too limited. Some studies suggest less than 10 sampling sites for the whole area. We recommend a much greater amount of testing both in the Sound and beyond, at numerous sites with varying concentrations of oil contamination (not just 'oiled' and 'non-oiled').

We also recommend that greater attention be given to statistical analyses. Samples should be collected minimally in triplicate. This would allow for estimation of variance at sites.

Many of the proposed statistical analyses are dubious due to the over use of ANOVA. Although surprisingly robust, the Analysis of Variance (ANOVA) is still limited to the analysis of monotypic data and has frequently been revealed as inappropriate for sigmoidal relationships of toxicity curves or the skewed bell shape of habitat preference curves. Other statistical analyses might perform these analyses better, such as non-parametric and multi-variate statistics.

Numerous studies make use of hydrocarbon testing. Methods suggested may result in underestimating contamination. Sampling numerous individuals (15+) representative of each age/size class would allow better regressions. Composite samples should be avoided.

Finally, we are uneasy with the use of such phrases as 'standard methods' and 'representative sample' that appear in some studies. Of even greater concern is the lack of quoting sample sizes or number of sample sites by some studies and the absence of the rationale for deciding the sample size used.

Notes on 26 Fish/Shellfish Studies

Study #1 - What are "aerially surveyed index streams?"

If they are aerially surveyed streams for salmon abundance for how long have they been surveyed? (how many years?)

Historical data must be corrected for timing climate, harvest recruitment, and water levels

Damage estimates of the loss of habitat would have to be estimated annually at least until the progeny of 1989 spawners return, which would be approximately autumn of 1994. This would help account for changes in imprinting, degradation of oil, changes in microhabitat preference and unpredicted effects.

There is no mention of microhabitat studies to determine if redd mating females avoid lightly oiled areas or are less effective in making redds in oiled areas.

Suitable control sites may not exist in the Sound as salmon are highly mobile with keen olfaction; avoidance may be for the general area.

No mention was made of sublethal effects of oil on adult spawners such as:

1) confusion of olfactory senses
   - needed for navigation to some degree
   - needed for avoidance of mammalian predators such as bears (supposedly)
2) less effective spawners because a decrease or loss of key reproductive behaviours.

Study #2

- two replicates - two does not say much, if anything

First two weeks of April and last two weeks of April - depending on seasonal timing, are not replicates when we are talking about preemergent fry

1 site/stream 4 zones/site, 1 transect/zone, 10 samples/transect

- suggest numerous sites/stream - as determined by variability of the data!
- incredible potential for bias
- should be repeated at least each and every year including the year that progeny of 1989 adults return and breed

Study #3 - loss in production - directly by exposure
- indirectly by food chain
- indirectly avoidance not just by exposure!

A. Marine survival and harvest of Pink Salmon
   - the use of only three oiled streams and two non-oiled is not adequate - inter-stream variability will be high, hence will need to use more oiled and non-oiled streams
   - should be repeated for two years (1990 and 1991) so both even-year and odd-year runs are sampled

B. Sockeye
   - proposed only two oiled and one non-oiled watersheds
   - why use streams for pink salmon and watersheds for sockeye?
   - sockeye generally live for four years and migrate considerable distances. Examination of available fish during one year is not a good estimate for other 3 age groups.

C. Hatcheries
   - as in natural studies such a short time frame will not adequately predict the actions of unsampled age groups

D. Smolts
   - should be repeated for each age class (0+, 1+, (2+))

E. Straying
   - why only in outlying areas?

This is a multi year study - tagged as fry, recovered as adults - clearly beyond Feb, 1990. Are all fishery projects exempt from this deadline?

Study #4

- may have to leave the Sound for representative samples

- hydro carbon testing study not adequately described; should comprise 15 individuals from each size category for each site

Studies 1-4 are about salmon - pink and sockeye. What about wild populations of chum, chinook and coho?

Study #5

There is no incorporation of straying between streams. Increased amounts of straying will bias results.

No estimate of reduced fecundity or viability due to oil exposure.

Are the trout in the area breeding after one sea summer? In some places they breed after 2-3 summers in the sea. I do not know about these popins.

2 oiled weir sites - statistically minimum number should be 3 per condition
2 non oiled weir sites

Study #6

There is no attempt outlined to determine pre-spill harvest, effort, distribution, etc. (except opening statement).

Angler `perception' may be more important than accounted for.

Study #7

Object to produce catalog - no analysis
Data base for other studies

Study #8 - Repeat of Study #2 but outside Sound - does this study also use oil and non oiled areas

Study #9 - Repeat of study #4 but outside Sound

Study #10 - Repeat of Study #5 but outside Sound - 1 oiled weir site and 1 control weir site only! should be at least 3 and 3

Study #11

There are no studies on what effect exposure to oil at an early age has on later development, fecundity, etc.

This study should be repeated each year until 1989 spawn has an insignificant contribution to the population (6-8 years?)

Study #12 - Same comments as #11
Laboratory work should be validated with a field study

Study #13

Cockle, Littleneck and Butter Clam

Number of quadrants should be determined by variability (currently 7/transect)

Hydrocarbon analysis

"3 samples of specimens" - how many individuals?

Test individual! not as a composite.
Should test numerous individuals size per age class

Growth and Age - why only littleneck?
- monitoring of all sites should be done more often than once in the spring and once in the fall - perhaps monthly
- should also include estimates of growth potential on temperature and contrast with real growth
- what happened to razor clams?
- ANOVA not appropriate unless it can be demonstrated that the relationships are at least monotypic and not either the typical bell shape, or sigmoid that would be expected from these studies!

Study #14 - CRABS
- misuse of ANOVA again
- no mention of long-term effects of exposure on young crabs

Study #15 - SHRIMP
- same comments as #14

Study #16 - OYSTERS
- Hydro-carbon testing and all other aspects of the study should continue for much longer than the six months proposed, especially if oysters are the indicator species as eluded to in the study!! (perhaps 7 years)

Study #17 - ROCKFISH
- Would like to see an estimate of density, growth, age structure of popln - all lacking from proposed study.

Study #18 - TRAWL
- should include growth
- unlikely that fish will live long if ingesting tarballs - result will be an underestimate!

- the mid-May to mid-June and the August trawl will not identify missing age groups less than recruitment age unless non-commercial gear is used
- suggest repeating the trawls yearly for ~5 years

Study #19 - LARVAL FISH
- should not be restricted just to the Sound

Study #20 - UNDERSEA OBSERVATIONS
- this is support for other studies and amounts to spot checks
- what is needed is a system or a grid that maps oil contamination and degree of such for the whole area including beyond the Sound

Study #21 - CLAMS
- similar to study #13 except outside Sound - same comments
- why change of species from littleneck clams to razor clams?
- should be the same as that chosen in 13

Study #22 - CRABS
- same as #14 except outside of Sound
- no mention of # of sites or sample sizes

Study #23 - ROCKFISH
- same as #17 except outside of Sound

Study #24 - TRAUL
- same as #18 except outside of Sound
- this study includes historical data

Study #25 - SCALLOPS
- should be long-term to monitor recovery (continual damage)

Study #26 - SEA URCHIN
- 10 females per transect - very small sample to determine abnormalities!
- no statistical confidence
- 20 sea urchins for a bioassay? - should be 20 animals/conc. plus 20 for control
- reservations about ANOVA

7) TECHNICAL SERVICES Study #1 - Hydrocarbon Analysis: With all of the samples to be analyzed (air, water, sediment, and various biota samples and tissues) by a number of laboratories, some defined protocol for sampling, preservation, labelling of the samples, analytical practises, and measures of quality control/assurance must be agreed upon and followed. Coordination by an "Analytical Chemistry Group" will speed up some work but slow down others by adding yet another layer of bureaucracy. Hence it is highly unlikely that all of the samples will be analyzed and checked for inter-lab comparability in the time frame allotted. Only time will tell if adequate precautions were taken and if there were sufficient data to enable assessment of oiling damages.

Study #2 - Histopathology: Necessary, but very time consuming. One can only hope sufficient "control" samples were taken to see the range in various attributes of normal cells and tissues.

Study #3 - Mapping: Supposedly by June 19, 1989, the first map showing oil damage and movement was to be completed. This should have been sent along with the Public Review Draft, along with locations of some of the field sites chosen for the Coastal Habitat Study #1 and Air/Water Studies, and any sites with historical data.

COMMENTS AND RESUME

OF

HOWARD L. SANDERS, PhD

October 26, 1989

COMMENTS OF DR. HOWARD SANDERS, WOODS HOLE OCEANOGRAPHIC INSTITUTE, ON THE DRAFT STATE/FEDERAL NATURAL RESOURCE DAMAGE ASSESSMENT PLAN FOR THE EXXON VALDEZ OIL SPILL (AUGUST 1989)

Sediments serve as the ultimate sinks for oil spilled or leaked into the water column. A not very extensive review of the literature revealed more than 30 citations documenting this very general phenomenon for a wide variety of crude oils and refined products. Findings from some of the more readily available papers are summarized in Attachment A. Some or all of these findings may well be germane and critically important to an understanding of the EXXON VALDEZ Oil Spill and spills generally. The incorporation of these processes into the study program offers a unique opportunity to make a highly appropriate and major contribution to the overall research program.

The relatively enclosed Prince William Sound is not a high energy, open ocean, coastal environment. The seafloor at depths of 20 or more meters in the Sound and fjords that project inland along the periphery of the coastline, to a major extent, are low energy, depositional habitats or "sinks" of fine-grained sediment composed primarily of silt- and clay-sized particles and an ample percentage of organic carbon. Under normal conditions, such depositional habitats have a lower oxygen content of water at the sediment-water interface and within the interstitial water of the upper oxidized sediment largely relative to higher energy sediment habitats. A highly probable response to the unusually large and potentially disastrous EXXON VALDEZ oil is that the "...Oil is likely to move deeper into the fjords rather than being flushed out. In general, this results in the oiling of increasingly sensitive environments, since the higher-risk, lower-energy environments are located deeper in the fjords and bays..." [See page 13, second paragraph, Public Review Draft.]

What, then, might we expect in regard to possible impacts to the Prince William Sound seafloor and its associated marine life from the massive spillage of Alaska North Slope crude oil that poured from the grounded tanker EXXON VALDEZ into Prince William Sound? Benthic infauna and epifauna living in and on the seafloor sediments are the most important accessible food resource available to commercially important stocks of demersal, bottom-dwelling fish stocks and larger invertebrate crustaceans. In Prince William Sound, this would include among others, halibut, pollack, sablefish, Pacific cod, as well as the Tanner crab, king crab, and the sidestripe shrimp that are worth several million dollars annually. [See Fish/Shellfish Study Number 18, pages 91 and 92 of the Public Draft Report.] If, indeed, large concentrations of the highly toxic North Slope crude oil reaches the seafloor, particularly those extensive areas that are composed of fine-grained, low-energy, organically rich, depositional habitats; then the deep-water benthic infauna and epifauna could well be adversely or fatally affected. [See Air/Water Study Number 4, page 44 of the Public Draft Report.] "... A manned submersible will be used in Prince William Sound during the 1989 field season to visually check for oil in bottom sediment." which is now probably over. [See Air/Water Study Number 2, page 40 of Public Draft

Report.] The resulting information that has accrued of sites or locations where North Slope crude oil has reached the Prince William Sound seafloor and entered the sediment, can then be used to establish vitally important sampling benthic stations that can monitor changes in chemical toxicity and successional benthic faunal changes over time at these oiled contaminated sites. The limited published information available on the effects of the EXXON VALDEZ spillage suggests that the Alaska North Slope crude oil may have been damaging or lethal to a significant and, possibly, a major fraction of the marine benthic fauna in the severely impacted western and southwestern areas of Prince William Sound. North Slope crude oil is highly toxic. Approximately 25 percent of the oil is composed of aromatics, "...which are generally considered the most toxic hydrocarbon components." The oil also "...contains significant quantities of toxic metals." [See Page 235, bottom paragraph of the Public Review Draft.] The massiveness of the oil spilled assures that some and, perhaps, a considerable quantity of oil may reach the seafloor and saturate the topmost centimeters of the sediment. Yet, because of the high toxicity of the North Slope crude oil and the sheer magnitude of the oil spill -- a worst case scenario of a major killoff or total eradication of the benthic invertebrates and demersal fish at the more heavily oiled bottoms and a resulting organically overloaded, contaminated, and anoxic seafloor -- may not be an unrealistic possibility. Although, information has accrued "...about the distribution of spilled oil from the EXXON VALDEZ on the water surface and in the intertidal areas of Prince William Sound and the Gulf of Alaska.... the extent, distribution, and patchiness of oil and oil byproducts on the seafloor is unknown." [See page 96 of the Public Review Draft. (emphasis added)]

It may already be too late to obtain the crucial information on the impacts of the short-lived, volatile, extremely toxic, single-ringed, aromatic hydrocarbons such as benzene and toluene on the flora and fauna in the water column and the depositional sediment habitats that cover most of the Prince William Sound seafloor and its peripheral fjords. Yet, if the pre-spill information on the concentrations of molecular oxygen present in upper oxidized sediment layer and the depth position of the Redox Potential Discontinuity Layer in the sediments are absent or unavailable, it will still be possible to effectively use a post-spill monitoring and assessment program at selected oiled, depositional, sediment stations with different degrees of oil concentrations and different benthic infaunal successional stages at any given period of time. Stations at sediment sites that were not oiled or very minimally oiled in the aftermath of the EXXON VALDEZ oil spill should serve as controls for the oil contaminated sediment stations. Indeed, it has become vitally important to initiate as soon as possible such a monitoring program over time and space with a particular emphasis on samples collected at water depths greater than 15 meters. In addition to the usual standard procedures normally used in taking bottom samples, the processing of the samples, determining the number of species present in a sample, the number of specimens that compose each species, and the percent composition that each species contributes to the total faunal density, such a program should include both measurements of oxygen content at the sediment-water interface and in the interstitial water of the sediment and determinations of the depth in centimeters of the redox discontinuity layer in the sediment that separates the upper oxygenated from the lower anoxic sulfide sediment. Since the vast majority of the fauna present at the initial stages of succession are small post-larval animals that would readily pass through the standard 1.0 mm screen apertures, screen mesh sizes of .3 mm or less should be used in the processing.

A severe kill of benthic invertebrates on and in the sediment and a lesser kill of their predators, the much larger, more mobile demersal fish associated with the seabottom by the spilt North Slope crude oil has and could bring about a significant organic enrichment in these low-energy, depositional, sedimentary habitats. The elevated concentrations of sedimented organic matter would likely be further augmented by a slowly sinking pulse of enormous numbers of dead, minute zooplankters, larvae of benthic invertebrates, and larval fish that settle onto and then are incorporated into the sediment after these organisms were poisoned in the overlying water column by the toxic crude oil. The much larger, heavier, contaminated carcasses of orders of magnitude fewer pelagic fishes would sink rapidly through the water column onto the bottom.

The organic matter in these depositional environments scavenge the available oxygen molecules from the interstitial pore water present in the upper centimeters of the sediment and at the sediment-water interface. The oxygen uptake by the organic matter provides the necessary requisite for maintaining the resultant processes of decomposition and decay. After a period of time, the interstitial water and the sediment-water interface, through excessive organic overloading, become devoid or nearly devoid of molecular oxygen. The Redox Potential Discontinuity and the underlying anoxic Sulfuric Layers move upward and the RPDL reaches the sediment surface or may even move entirely out of the sediment into the immediate overlying water.* At that stage, in the absence of molecular oxygen and animal life, the sediment goes totally anaerobic and azoic. At any given time over subsequent periods of alternating upward and downward migrations of the RPDL through the sediment, the depth position of the RPDL serves as a remarkably good indicator both of the available molecular oxygen present in the interstitial water in the uppermost aerobic layer of the sediment and the successional stage of the benthic fauna currently occupying the sediment. This insightful approach can be very effectively used for the ongoing EXXON VALDEZ Oil Spill study. Such an ongoing monitoring program would be most valuable and central to the evaluation of whether the more severely oiled areas of the seafloor have or will become long-term repositories "for hydrocarbon, contributing to chronic toxicity through mobilization of oil into the water column." (See Page 39 of Public Review Draft.)

From the now available Public Review Draft of the State/Federal Natural Resource Damage Assessment plan for the EXXON VALDEZ Oil

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* A detailed discussion of the RPDL is included in Attachment B.

Spill itself, it has become clearly evident that pollution impact will almost certainly be long-term and severely damaging. Yet, inexplicably, the Executive branch of the Federal Government has recently decided to fund for only one year the largest and potentially most damaging oil spill in the nation's history of one of the most pristine, wild, and unspoiled ecosystems in North America. Unless this unexplained dichotomy is quickly, effectively, and constructively resolved, the fundamental objectives of the EXXON VALDEZ oil spill studies may well be profoundly compromised. If, indeed, such a scenario is realized, it will confound, distress, anger and antagonize the involved professionals dedicated to the study, the environmental movement within the United States and throughout the world, and a very significant percent of the informed, concerned, and responsible citizenry here and abroad.

Attachment A

In the area of the FLORIDA spill, off West Falmouth, Massachusetts, in Buzzards Bay, the light #2 fuel oil adhered to particulate organic matter and fine sedimentary particles in the water, and rapidly settled to the bottom (Blumer and Sass 1972). There, the oil degraded very slowly, and spread over the bottom, probably in part, by resuspensions months and even years after the spill.

Crude oil from the blowout at the Santa Barbara Platform initially reached the bottom sediments by the same mechanism operative off West Falmouth, and later spread along the bottom to cover much of the floor of the Santa Barbara Basin to water depths of 500 m (Kolpack, 1971). In the aftermath of the spill of heavy Bunker Oil C oil from the ARROW into Chedabucto Bay, Nova Scotia, the petroleum hydrocarbons dispersed widely throughout the water and in the subtidal sediment (Scarratt and Zutko, 1972).

In the massive AMOCO CADIZ spill off Brittany, fine droplets of light crude oil were absorbed by suspended sedimentary particles; a large quantity of oil reached the seafloor within two weeks (Cabioch, Dauvin and Gentil, 1978). Once on the bottom, this oil travelled along the seafloor with the silt (Spooner, 1978, p. 284). Toxic effects of the oil became manifest 90 km from the wreck five days after the spill began.

In the study of the TSESIS spill in the northern Baltic Sea, off Sweden, sediment traps were placed in the water column 20 m below the surface, to measure the quantity of heave #5 fuel oil absorbed on settling organic and sedimentary particles (Johnson, 1979). The #5 fuel oil composed as much as 0.7 percent of the sedimented matter recovered from the traps in the two weeks following the spill. Indeed, further very recent sediment samples collected from muddy, intertidal, fine-grained, depositional study sites revealed the presence of residues of Number 2 fuel oil 20 years after they were heavily oiled in the immediate aftermath of the oil spillage from the barge FLORIDA.

The FLORIDA and ARROW oil spill studies continued for several years. Oil residues from both accidents were still present in some of the bottom sediments a decade after the initial spills.

Oppenheimer, Miget and Kator (GURC/OEI, 1974) found oil residues present in each of eight zooplankton samples collected in the Gulf of Mexico off Louisiana. During the ARROW spill study of Chedabucto Bay, Nova Scotia, it was observed that the zooplankton ingested small globules of oil in the water column. Conover (1971) found that their faecal pellets contained as much as 7 percent Bunker C oil. He calculated that about 20 percent of the oil was sedimented to the bottom as zooplankton feces.

Wiebe, Boyd, and Winget (1976) measured the rate of sinking of zooplankton faecal pellets that sank at an average speed of 171 meters per day at a water temperature of 22° C and 151 meters per day at 5° C.

These three bits of information strongly suggest that zooplankton faecal pellets provide a major and rapid route for transporting oil through the water column to the seafloor at depths of 200 m and shallower.

ATTACHMENT B

An anaerobic sulfide system underlies a covering of oxidized sediment in all aerobic marine subtidal soft-bottom environments [Fenchel and Riedl, 1970]. Interposed between the oxygenated and reduced layers is the narrow, transitional Redox Potential Discontinuity Layer (RPDL) where small amounts of both oxygen and reduced compounds are present. This three-tiered layering pattern is the manifestation of the one-way supply of free oxygen into the sediment at the sediment-water interface. Once in the bottom, the concentration of free oxygen present in the interstitial water of the sediment progressively diminishes with depth until it disappears. The absolute depth of this oxygenated zone is controlled by a number of physical and biological conditions. However, there are two primary conditions, the amount and rate of organic matter imported into the sediment and the concentrations of free oxygen available for degradation. A low rate of organic import and a high availability of oxygen can extend the oxygenated layer as much as 25 or more centimeters below the sediment surface. Alternatively, a high rate of organic import and a low availability of oxygen can limit the aerobic layer to the uppermost few millimeters of sediment or, together with the Redox Potential Discontinuity Layer, it might be entirely displaced as the anaerobic layer pushed upward to the sediment surface.

Other conditions that move the RPDL upward or downward to narrow or broaden, respectively, the aerobic zone include both physical factors such as temperature, particle-size composition of the sediment and storm-generated waves that reach the surficial seabed and biological factors such as intensity of bioturbation and degree of mucus secretion. Conditions that raise the RPDL towards the surface are (1) high temperature; (2) low-energy depositional sediments, with relatively high organic content and predominantly composed of fine-grained silts and clays, that reduce sediment permeability and scavenge available free oxygen; and (3) mucus secretions that bind sediment particles and form a substrate for bacteria. Conversely, conditions that move the RPDL deeper into the sediment are (1) low temperature; (2) high energy, erosional sediment environments with little organic content and largely composed of coarse-grained sands and gravel, that enhance permeability and allow penetration of free oxygen deeper into the porous substratum; (3) storm-generated waves that reach and disturb the underlying seabed and oxygenate the superficial sediments; and (4) bioturbation by benthic infauna through burrowing activity and tube-building that introduce free oxygen into the deeper sediments.

There is now an abundant documentation in regard to organic enrichment that related the depth of the Redox Potential Discontinuity Layer in the sediment to the successional stages of the benthic fauna. There is no attempt here to review the extensive relevant literature. Instead, the reader is referred to the important review article by Pearson and Rosenberg [1978] that provides an excellent synthesis of the subject and some mostly more recent papers [McCall, 1977; Rhoads, McCall, and Yingst, 1978; Yingst and Rhoads, 1980; Sanders et. al., 1980; Aller, 1980; Rhoads and Boyer, 1982; Larson and Rhoads, 1982] that have added further insightful dimensions to our understanding of this relationship. Benthic faunal succession remains remarkably similar independent of whether it is manifested along a temporal or spatial gradient. Temporal succession occurs in the aftermath of a severe disturbance or perturbation that significantly reduces or eradicates the resident benthic population. Examples include responses to a massive red tide outbreak [Dauer and Simon, 1976; Simon and Dauer, 1977], a deluge from a tropical storm that created near freshwater conditions in shallow water and deoxygenation in deeper water beneath the sharp halocline that was generated [Boesch, Diaz, and Virnstein, 1976], anaerobiosis through accumulations of drifted macroalgae and a covering of blue-green algae [Watling, 1975], dumping of dredge spoils [Rhoads et. al., 1978; Rhoads and Boyer, 1982] and an oil spill [Grassle and Grassle, 1974; Sanders, 1978; Sanders et. al., 1980]. Spatial succession is a response over distance to a chronic source of pollution. Examples, among others, are pulp mill waste [Pearson, 1975; Rosenberg, 1976] and sewage industrial waste [Reish, 1959 and 1971; Wade, Antonio, and Mahon, 1972] discharges. There are, of course, successional or regressional events that have both a temporal and spatial component such as the chronic release of petroleum at an oil rig complex from initiation of operations through the next few years [Addy, Levell, and Hartley, 1978].

The patterns that have emerged as a result of organic enrichment reveal faunal succession over time and space. At very high inputs of organic matter into the seafloor, the anaerobic layer rises to the sediment-water interface, the sediment is laminarly stratified, devoid of a benthic fauna and undisturbed in the absence of bioturbation. When the RPDL is limited within millimeters of the sediment surface, the initial successional stage is present. Its benthic fauna is usually characterized by small opportunistic polychaetes that are either tubiculous or motile and barely infaunal and are members, respectively, of the Families Spionidae and Capitellidae. The vast majority of individuals belong to one or two species (i.e., pronounced numerical dominance). The few pioneer species typically found are confined to the very narrow oxygenated surficial layer and exist under marginal and variable conditions that include low to minimal levels of free oxygen, high concentrations of sulfides and a low pH. These opportunistic species are eurytopic (i.e., wide physiological tolerances) and have broad, zoogeographic distributions. As products of the ephemeral nature of their environment, these resilient opportunistic species are small and rapidly achieve sexual maturity. Yet, this initial successional stage typically has very high numerical abundances that exceed those that appear in any of the subsequent successional stages.* Because its species are limited to and feed as deposit-feeders from the surficial sediments or as suspension-feeders from the immediately overlying water, the sediment surface becomes pronouncedly pelletized. The fecal pellets, in turn, provide surfaces for microbial activity. Although the benthic faunal biomass of this primary successional stage is small compared to the relatively long-lived, slow-growing, late-maturing and larger macrofauna present in the late successional stages, their brief life spans and the rapid turnover of multiple generations within the course of a single year are indicative of very high rates of annual organic productivity [J.F. Grassle and J.P. Grassle, 1974; McCall, 1977; and Rhoads et. al., 1978] that most likely will exceed production rates realized in later stages. Rhoads et. al. [1978] conclude that the pioneer species in Long Island Sound have individual and population growth rates that are 10 to 100 times higher than the equilibrium species that characterize the late successional stages.

Related to this phenomenon is the remarkably high colonizing potentials of these pioneer species as demonstrated with azoic sediment tray experiments carried out by J.F. Grassle and J.P. Grassle [1974] on an intertidal sediment of fine sand in the Wild Harbor River estuary of Buzzards Bay, Massachusetts and by McCall [1977] on a subtidal sandy silty sand bottom beneath 14 meters of water in Long Island Sound off Connecticut. Grassle and Grassle's study revealed that a density equivalent to more than 400,000 individuals per sq. meter of the polychaete Capitella capitata sensu lato were present after a one month interval. We now know that Capitella capitata is, in reality, a complex of very similar sibling species [J.P. Grassle and J.F. Grassle, 1976; J.F. Grassle and J.P. Grassle, 1977]. More than a single Capitella species colonized the Grassles' sediment trays. One species, Capitella type 1, grows from settlement to maturity in about 30 to 40 days, an adult female produces anywhere from one to several broods and breeding occurs at the study site throughout the year at water temperatures that range

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* Samples collected from this successional stage and then washed through a screen with 1.0 mm-mesh aperture will retain about an order of magnitude fewer specimens -- primarily mature, adult animals -- than would a screen with 0.3 mm-mesh apertures where the smaller postlarval specimens comprise the vastly greater percentage of the total fauna retained on the screen. Clearly the employment of screens having 0.3 mm-mesh apertures are decidedly more relevant and germane for the first and, to a lesser degree, the second successional stages of the benthic invertebrate infauna than for the later successional stages. Yet, 0.3 mm-meshed screen do retain nearly all the postlarvae of most of the species present in the later successional stages. The readily available postlarvae can be effectively used to measure the dynamics of growth in length and dry organic weight over time at selected stations that are sampled on a monthly basis.

from -1.5°C in winter to more than 24°C in summer. In McCall's experimental bottom samples in Long Island Sound, the azoic sediments were immediately colonized. Within ten days, densities of the spionid polychaete Streblospio benedicti and the capitellid polychaete Capitella capitata sensu lato reached 418,315 and 36,120 per sq. meter, respectively [McCall, 1977]. Rhoads et. al. [1978] estimate the Streblospio produces 3 to 4 generations per year in Long Island Sound study site.

As products of the transient nature in time and space of their pioneer stage habitat, the opportunistic species experience very high mortalities as larvae in the plankton and throughout their postlarval benthic life. Their confinement to the oxygenated surficial sediment that may be only millimeters thick deprives them of the refugium of depth. Thus, they are most susceptible to predation by fish, decapod crustaceans, and other epifaunal carnivores.

Species that appear following a severe disturbance that defaunates the benthos, and explosively increase to reach extreme abundances during the first recovery stage and then go into an equally sharp precipitous exponential decline as the initial pioneer stage terminates, are few in number. Yet, most of the benthic fauna present during the initial colonization stage are members of such species. In North America and Europe where the vast majority of the studies on benthic faunal succession have been done [see Table 1 in Pearson and Rosenberg, 1978], this small group of opportunistic species mostly belong to the polychaete families Spionidae and Capitellidae. Species that best characterize this group are Capitella capitata sensu lato, and the spionids, Polydora ligni and Streblospio benedicti along both the Atlantic and Pacific coasts of North America and Capitella capitata sensu lato and the spionids Scolelepis fulginosa and Polydora ligni [=P. ciliata] in European waters. Other species associated with these prime opportunists are present at much lower densities and do not share their 'boom and bust' life history patterns. Unlike the ephemeral opportunists, they display much less temporal variability and usually persist to become members of some of the sequential successional stages where they are often more abundant.

Spionid polychaetes are one of the key colonizers of the pioneer successional stage. They form dense thickets or mattings of closely spaced, small diameter, vertical tubes. Aller [1980] demonstrated that the toxic compounds in the ambient pore water, that diffuse into the tubes from the surrounding reduced subsurface sediment, are flushed from the tubes into the overlying water where oxygenated water from above the tubes is drawn in as replacements. By means of these outflowing and inflowing fluid bioturbating activities and the high density of closely arrayed tubes, the spionid worms collectively are able to maintain adverse solutes such as NH_4^+ or H_2S within their tubes at relatively low and constant levels. However, as a result of these pumping activities, the oxygenated water within the tubes also diffuses out into the surrounding subsurface sediment to stabilize and deepen the narrow surficial oxygenated layer and thus allow other early successional species to colonize the sediments.

The later successional stages will be dealt with herein in a more cursory and general manner. Yet, sufficient information will be conveyed to provide the necessary frame of reference. For detailed knowledge and information on the later successional stages, the reader is referred to the papers and bibliographies of Pearson and Rosenberg [1976; 1978], Rhoads, McCall and Yingst [1978]; Yingst and Rhoads [1980], Aller [1978; 1980], Aller and Yingst [1980] and Rhoads and Boyer [1982].

Along the progression from the pioneer stage through the sequences of later successional stages, certain general trends become clearly evident. The RPDL migrates deeper into the seafloor, the sedimentary depth occupied by the macrofauna similarly deepens, the feeding mode gradually shifts from surface deposit-feeders and suspension-feeders to preponderantly subsurface deposit-feeders, the maximum size of the macrofauna, the degree of both fluid and particle bioturbation and the structural and ecological complexity of the infaunal assemblage increase. All these trends are intimately interrelated, interdependent, and highly correlated. If the progression of sequential succession from pioneer to equilibrium stage is undisturbed, which may or may not occur, changes in faunal composition will be persistently gradual and nearly continuous rather than disjunct and abrupt, with intervals of arrest and retrogression.

Bioturbation activities such as irrigation by sedentary or relatively sedentary infauna living in tubes, shafts or often deep semi-permanent burrows that connect directly to the sediment surface and random burrowing by errant infauna increase the passage of free oxygen and dissolved nutrients into the sediments and the flushing of deleterious metabolites from the sediment that are orders of magnitude greater than molecular diffusion rates. The manifestations of such activities are the lowering of the RPDL and the enhancement of microbial activity, particularly at the discontinuity layer [Hylleberg, 1975; Aller, 1978; Yingst and Rhoads, 1980; Rhoads and Boyer, 1982].

Intense errant burrowing activity accelerates diffusion rates by increasing water content and homogenizing finer-grained sediments [Rhoads and Boyer, 1982]. Deposit-feeders void ingested sediments as feces in the form of organic-mineral aggregates that may form as much as 70% of the soft sediments [Johnson, 1974]. Such aggregations have two important effects. They significantly increase sediment porosity and thereby facilitate diffusion and the transfer and oxidation of reduced chemicals. Secondly, they enlarge the environmental space available for meio- and macrofauna and provide organic-rich surfaces for bacterial flora.

The deep semi-permanent feeding burrows, characteristic features of the later, mature, successional stages, are usually associated intimately with the RPDL. The rapid and immediate vertical transfer of well-oxygenated, nutrient-rich water from above the seafloor to the immediate proximity of the RPDL that lines the burrow deep into the anaerobic, sulfidic sediment is brought about by the pumping activity of the burrow occupant, usually a large invertebrate. Such a behavioral strategy bypasses the route of slow diffusion downward through the sediment and the gradual attenuation of oxygen tension with depth. One variant of this pattern is the 'conveyor-belt' deposit-feeder that feeds head down in the sediment as exemplified by maldanid polychaetes as, for example, Clymenella torquata [Rhoads and Stanley, 1965]. In this position, the polychaete progressively 'mines' deeper into the seafloor and selectively ingests the fine sediment patches which are processed in the gut and discharged as unconsolidated feces at the surface. Highly irregular, three-dimensional RPDL-lined water pockets are created by the intense feeding activities of these worms. The pockets, themselves, may protrude deep into the anaerobic zone to form localized aerobic areas. One of the ultimate results of such activities is the markedly increased microbial activity.

An essentially identical feeding pattern exists for a very different invertebrate, the infaunal holothurian echinoderm, Molpadia oolitica [Rhoads and Young, 1971]. Like Clymenella, this sea cucumber lives head down vertically and feeds deep in the underlying sediment often 20 or more centimeters beneath the surface and deposits its unconsolidated feces upward onto the seafloor. Molpadia ingests only the fine-grained particles to create highly convoluted, three-dimensional, RPDL-lined, aerobic voids or feeding pockets at depth within the surrounding unperturbed anaerobic sediment that considerably enhance microbial activity and chemosynthesis. Other feeding strategies have been utilized by deep-dwelling infauna occupying semi-permanent burrows. Hylleberg [1975] applied the term 'gardening' to describe the effects of feeding by the lugworm, Abarenicola pacifica. This polychaete, like other members of the Family Arenicolidae, lives in deep U-shaped burrows. By irrigating its tube, the worm pumps oxygen and nutrients from the overlying water into the feeding pocket. These, together with the animal's own feces, provide the stimulus for microbial growth along the RPDL lining the feeding pocket. The microbes so produced, as well as meiofauna feeding on this rapidly growing flora, serve as the primary food source for the lugworm.

Another example of 'gardening' has been demonstrated by Frey and Howard [1975] for the burrowing shrimp, Upogebia litoralis. This crustacean collects plant material on the sediment surface which it packs along the inner walls of the burrow. Then after incubation it 'harvests' or ingests the bacteria that grow on the plant detritus.

Microbiologists, for more than 32 years have know the Redox Potential Discontinuity Layer to be a site of significant microbial activity [Vishniac and Santer, 1957]. This relationship has been shown both in the water column [Sorokin, 1964; 1965; 1972] and in bottom

sediments [Hayes, 1964; Fenchel and Riedl, 1970; Sorokin, 1'
Yingst and Rhoads, 1980]. Thiobacillus bacteria [Vishniac ..
Santer, 1957], oxidizers of reduced sulfur compounds, and other chemosynthetic bacteria [Fenchel and Riedl, 1970] are especially abundant there. Rhoads and Boyer [1982] observed in the deeply oxygenated sediments of the late successional stages that both errant and sedentary components of the benthic fauna were "... concentrated at, but not limited to the RPDL. The RPDL is in fact related to the feeding depth."

The strong implication that logically flows from these observations is that wherever the RPDL is present, independent of sediment depth or successional stage, it becomes the site of chemosynthetic primary production. Thus chemosynthetic primary production must be an ever present phenomenon in the sediments of eutrophic marine environments that include the shelves and, in part, the continental slopes throughout the World Ocean except under the special conditions discussed earlier that permit the anaerobic zone to rise to the sediment-water interface and thus displace both the RPDL and the upper aerobic layer. The studies cited above that infaunal deposit-feeders concentrate and feed at the RPDL indicate that chemosynthesis, currently unevaluated, may be an important and possibly dominant food source (as compared to photosynthesis) for the infaunal benthos.

COMMENTS AND RESUME

OF

MICHAEL KAVANAUGH, PhD

October 20, 1989

To: Sarah Chasis
From: M. Kavanaugh

Re: Review of State/Federal Natural Resource Assessment Plan for the Exxon Valdez Oil Spill

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This review of the State/Federal Natural Resource Assessment Plan for the Exxon Valdez Oil Spill is limited to the restoration plan and the natural resource damage determination on pages 185 to 202 of the public review draft. The stated purposes of the studies are: (1) to support the development of restoration plans to promote the long-term recovery of the natural resources; and (2) to support the determination of damage claims presented to the responsible parties. An assessment that fulfilled these purposes could provide the trustees (and the public) with a statement of the harm done to nature by this spill and what could be done about it. Unfortunately, the purposes are unlikely to be fulfilled and an opportunity will be missed to assess the spill's damage and to evaluate responses because:

* There is a too much emphasis on studies to determine lost use value over studies to develop restoration plans. Analysis of restoring and purchasing equivalent resources elsewhere (restoration) is likely to be as important if not more important than studying lost use values. Determining how much polluters must pay for the restoration of the damaged natural resources is one of the purposes of the calculations. The calculation of use values is relevant for determining that portion of the damage claim to cover the diminution of use during the interim required to achieve restoration. If restoration is impossible, then use value studies take on added importance. But, it cannot be determined in advance that restoration is impossible.

* Neither the development of a restoration plan nor the conduct of a credible, professional assessment of the natural resource damages caused by the spill can be completed by February 28, 1990 (the deadline). The deadline may reflect lack of funding (See <u>The Exxon Valdez Oil Spill, A Report to the President</u>, Skinner, S.K. and W.K. Reilly, p.35). Nevertheless the same report calls for long-term...broad gauge, carefully structured...damage assessments (Executive Summary p. ES-2). The deadline may also reflect a desire to complete the assessment early, since the full extent of the damage will never be known

with certainty. Nevertheless, the scope and complexity of the studies plus the need to sequence the studies makes it impossible to complete all of the studies by this winter.

* The description of the process to develop a restoration plan is too brief. At a minimum, the plan should contain both restoration and replacement strategies. The restoration strategies should provide estimates of how long the resources will take to recover given alternative levels of clean-up, as well as measures to promote long-term recovery such as requiring all tanker traffic moving through the spill area during the restoration period to move only in daylight hours and be doubled-hauled or have the cargo containerized. The replacement strategies should consider replacement in-place (e.g., breed in captivity) and establishment of an environmental permanent fund to fund long-run efforts to restore the damaged resources or purchase equivalent resources (or the development rights) elsewhere (i.e., acquire and deed to the public resources such as land and shoreline outside of the spill area).

* The descriptions of the economic use studies:

- are too brief to allow a thorough review. It is unusual for the government to fund millions of dollars worth of research on the strength of descriptions like those contained in the public review draft. To complete the 9 proposed studies in 10 months means spending on the order of $14,000 per day. Surely, someone has a better idea of how sums of this magnitude are being spent then is revealed in this document.

- show no appreciation of the problems that might be encountered and the special analytical techniques needed to value natural resource losses that:

-- involve ecological losses for which existing evaluation methodologies are wanting;
-- may be irreversible;
-- may not be apparent for a year or more;
-- may be catastrophic if endangered species are threatened or if there is loss of habitat; and
-- will be subject to considerable uncertainty.

- contain no discussion of the applicability of existing literature and models. Most studies of tourism losses, for example, count these losses as transfers because there are readily available substitutes for a given polluted beach. There might not be available substitutes for an Alaskan experience and the existing literature and models may be misleading.

- are silent about the choice of a discount rate. The spill and its effects will last many years. This coupled with the potential for irreversible (or extremely long-lasting) damage implies that the spill has transferred resources from future generations to current generations. The discount rate is the analytical parameter that allows inter-temporal comparisons. There is literature suggesting fair representation of future generations requires use of a zero or near zero discount rate. (See, Schulze and Kneese, Risk Analysis, 1981 and Schulze, Brookshire and Sandler, Natural Resources Journal, 1981).

A. Economic uses studies:

1. price effects;
2. industry costs; and
3. bioeconomic models.

Taken as a group and reading between the lines, these studies have the potential to estimate the damages caused by the spill to the commercial fishing industry and their customers during the interval necessary to restore the natural resources to their pre-spill condition. The studies, however, will not measure any degradation in the quality of life suffered by the fishing communities. This degradation can take many forms including increased alcoholism and violence.

The correct measure of the loss to the commercial fishing industry and its customers is loss is the discounted present value of current and future reductions in consumers' plus producers' surplus plus the value of the resources made idle by the spill. (The discount rate should be zero or near-zero to account for the long-term impact of the spill. Surplus refers to the difference between what people are willing-to-pay for a good or service and the amount of resources they have to forego to have the good or service. Analytically, it is the area above the supply curve and beneath the demand curve. The resources made idle by the spill are represented by the area under the supply curve. Measuring surplus requires, (a) defining demand curves for the products of the commercial fisheries in terms of their elasticity of demand, [presumably this is accomplished in #1], (b) describing the supply curves [presumably #2], and (c) estimating the shift in demand and supply curves caused by the spill in current and future years [parts of #2 and #3].)

Since in the first year of the spill almost all of the catch was lost, the measure of damage is the surplus loss plus the opportunity cost of the idled fishing boats and unemployed labor. This estimate is repeated for all subsequent years the spill influences commercial fisheries. The subsequent influence of the spill may take two forms. The first is a supply side effect. The spill may reduce significantly the fish population and require more fishing effort (e.g., boats have to be cleaned more frequently, travel farther to reach fishing grounds, and stay longer to catch a load of fish). Analytically, this is an upward shift in the supply curve. The second is a demand side effect. A stigma may attach to Prince William Sound product for years to come such that wholesalers, retailers and the public will consume Prince William Sound product only if they are offered a price discount. (For example, Prince William Sound product may be relegated to low value uses such as cat food.) Analytically, this is a downward shift in the demand curve. It is likely that in subsequent years the idled boats and fishermen will be re-employed. This is taken into account by reducing the charge in future years for the opportunity cost of idled resources.

Any claim the Trustees present to Exxon will be closely examined. One concern I have is that the investigators in a rush to meet the deadline will use approximations that would not be needed if they took the time to make the estimates correctly. For example, the investigators may assume that fish are fish and not distinguish among different markets for and quality variations among fish. Not only might these shortcuts produce biased estimates of the loss, but the approximations may be so unacceptable so as to provide Exxon with the opportunity to render the estimates useless.

A second concern that I have is that the work is spread out over three studies and this may create additional problems such as:

* duplication of effort;

* gaps in research as one investigator thinks another is responsible;

* difficulty in integrating because the studies use varying regional definitions or time-frames or otherwise lack common denominators (groupings of fish, segmentation of the industry); and

* unproductive effort as information is collected without a purpose in mind.

The description of the method and analyses mention that previous studies will be reviewed. What literature do they have in mind? By what standards are the investigators going to judge the literature? Who is going to integrate the studies? How are they going to insure that the studies will be compatible?

A third concern is the spill's effects on the quality of life in commercial fishing communities is not counted by surplus and idled resource measures. There are reports that communities have had their faith in the bounty of the environment shaken and their livelihood threatened. Mental health professionals report (e.g., J. Randal, Washington Post, 9/26/89) the spill has led to increases in alcoholism and violence. The trustee should be aware that the cost of community disintegration is not considered in these studies.

A fourth concern, again, is the deadline. Even if there were off-the-shelf, current models of the fishing industry that could be identified and used, the use of the models would have to await the completion of the injury determination studies (e.g., Fish/ shellfish studies #1-5; Marine mammal studies #4 & #5; and others). Either these biological studies will be finished long before the deadline or the economic study will not be completed by the deadline.

B. Economic uses studies:
   5. Economic damages to recreation; and
   7. Study of loss of intrinsic values

These studies are likely to be the most important and expensive studies conducted. The recreation study proposes to use three methods to estimate the damage: travel-cost, contingent value, and unit day. The intrinsic value study will also use the contingent valuation method. The contingent valuation method may turn out to be the most appropriate method to estimate the value of the compensation for the damage. While the descriptions of these studies are more complete than the descriptions of the other studies, there are important topics that are not discussed. Finally, it is impossible to conduct either study by the deadline.

The travel cost method will be one of three methods used in the recreation study. It estimates demand curves (a relation between price and quantity) by using travel costs and an imputed value of time as proxies for price and recorded visits to the site (region) as a proxy for the quantity variable. This relation between price and quantity is estimated for the pre-spill and post-spill case. The difference in surplus between the two cases is estimated and used as a measure of damage. The problems the investigators face are: selecting sites (travel to Alaska may be a package and if part of the package is spoiled by the spill travel to other parts of Alaska may be forgone; in this way the effects of the spill spread to all parts of Alaska) and valuing time.

This oil spill is on-going; it is not an event. The travel-cost method uses pre-spill and post-spill data on recreation use, tourism (prices and quantities) and hunting and fishing licensees. But, post spill data cannot be collected until the spill is over. The spill is not over. Data collected for the spring and summer of 1989 is data representing recreation during the spill. This is important to know. But it is equally important to know participation in recreation in the future. There is no basis for an assumption that tourism will return to normal in 1990. Unless the investigators have a method for estimating participation in 1990 and subsequent years then the travel cost approach has a potentially serious flaw.

The unit day approach relies on expert opinion to estimate WTP. It should be used only if no other method can be used.

The third approach used in the recreation study is contingent valuation (CV). CV solicits the willingness-to-pay (WTP) for an Alaskan recreational experience. CV methods take some time to perform correctly and cannot be done correctly by the deadline.

CV methods are also used in the intrinsic study. Individuals are asked about their WTP for pristine resources or their willingness-to-accept (WTA) compensation for the damage done to their natural resources. WTA estimates how much compensation is needed to restore the well-being of citizens to the pre-spill level. Society loses when an oil spill causes sorrow, outrage, and other feelings of despair. Individuals spend valuable resources to avoid feeling such emotions. The value of the compensation required to bear such feelings will only be captured in the intrinsic value study using contingent valuation methods.

Both a WTP and a WTA approach should be used in the CV studies. Under WTP, industry is assigned a quasi-property right to the resource because industry pays the government what the public would have been willing to pay to use the resource. Under WTA, the public is assigned a quasi-property right to the resource because industry pays to the government what the public would be willing to accept to let industry use the resource. For resources with close substitutes, WTP and WTA are approximately equal (See Willig, Am Econ Rev, p.589 1976 and Hausman, Am Econ Rev, p.662 1981), but for unique resources there may be large differences between WTP and WTA (Hanemann, Am Econ Rev, forthcoming). Since it is believed that it is easier to design WTP questions than it is to design WTA questions (Carson and Navarro, Nat Res Jour, p.815, 1988) and since if the resource has close substitutes the same approximate answer results, investigators tend to favor the WTP approach. The natural resources damaged in Alaska, however, may be unique and both WTP and WTA approaches should be used.

Contingent valuation consists of using surveys to identify and quantify economic values that are contingent upon an actual market existing. In particular, markets for recreating and, separately, intrinsic Alaskan natural resource values are simulated using surveys. The survey results are susceptible to bias and questions must be designed and pre-tested to avoid bias. Often focus groups are used in the design and pre-test process.

There are two survey designs: iterative bidding formats and non-iterative formats. In both designs the amenity being valued must be described sufficiently so that the respondent knows what he is being asked. This description may include photographs, sketches, written description, videos, verbal descriptions and the like. In the iterative format the respondent is asked a series of questions to identify the value. For example, the interviewer may show the respondent a picture of a dog and then asked if he is willing to pay nickel for the dog? a dime? a dollar? with the amount increasing until the respondent indicates the highest price he would be willing to pay for the dog. In the non-iterative format the respondent is asked to either answer yes or no to a single state value ("Would you pay 50 cents for this dog?) or is asked to write down the amount he would pay (Please state on the line indicated how much you would pay for the dog.) It is generally acknowledged that the iterative interview method is more reliable.

In either format, the survey instrument will have, at least, two parts. The first to record bid information, the second to record demographic information.

Conducting a CV study requires several steps. First, the spill damage is assessed and described so that the respondent knows what he is paying to avoid or being compensated to accept. Second, questionnaires are developed and tested for biases such as anchoring and for misunderstandings. They may have to be revised. If the revisions to the questions are extensive, a second pretest may be needed. At this stage, a focus group might be given alternative descriptions of the spill to develop a robust description. The questions should have a wide scope. Individuals should be asked not only about their values for the loss of particular animals but also about how they value the loss of a pristine environment and unspoiled wilderness. Third, the population of eligible respondents is determined and sampled. For the Alaskan oil spill the eligible population to be sampled must include all U.S. citizens and possibly residents of other countries. Fourth, the questionnaires are administered. This may take considerable time if the sample is large. The final steps are tabulation, aggregation, and interpretation of the results. It is plain that there simply isn't enough time to perform a contingent value study by the deadline.

Two other issues in assessing damage and making restoration plans are the speed of recovery and uncertainty. Some of the more important estimates the biologists and other physical scientists can provide are estimates of how long it will take the environmental and natural resources to recover from the spill. This information is important not only because it sets the period for claiming diminution of use values; but also, if the damage is irreversible, catastrophic, or has long lead times economists must consider a larger set of future uses. If, for example, the damage is estimated to last for 5 years, then the future uses of the resources may be considered as known (i.e., committed). If, on the other hand, the damage is estimated to last for 50 years, committed uses may impart little information about the future and more speculative uses must be considered in the analysis.

All of the estimates of damage are going to be subject to uncertainty -- uncertainty about magnitude and duration of the resources lost and damaged; uncertainty about how much compensation citizens need to restore them to a pre-spill level of well-being. This suggests that a single-point estimate of the damages should not be relied upon as the measure. Instead the results should be reported as distributions.

C. Economic use studies:
   4. Effect on value of public land;
   6. Effect on subsistence households;
   8. Effect on research programs; and
   9. Effect on archaeological sites.

These are four studies of the impact on the spill on well-defined targets. Each has its own problems that are not addressed in the study descriptions.

* <u>Public land.</u> How are the investigators going to "project market demands for leases and sales in the area affected by the oil spill". This is the central analytical element. Are they going to use hedonic techniques? are they going to use the opinion of appraisers? both? It would seem that the results of economic study #3 "Bioeconomic models for damage assessment" would have to be completed prior to completing study #4 because there may be important effects on fishery resources that will be reflected in the value of public lands.

* <u>Research programs.</u> The tabulation may be able to be confined to a table listing project, amount, delay, and the funds put in jeopardy by the spill. The results will depend on the duration of the spill and its effects.

* <u>Archaeological study.</u> How are the investigators going to assess the economic damage to the site? will they use appraisers? CV methods? The description mentions a field survey. Unless it is already completed, then to perform the study by the deadline means doing a field study during the Alaskan winter.

* <u>Subsistence study.</u> This study looks well thought-out, but it cannot be completed by the deadline because the effects of the spill will still be occurring.

COMMENTS AND RESUME

OF

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24 October 1989

Bob Adler
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National Resources Defense Council
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Dear Bob:

The proposed Air/Water Study Number 5 of the Exxon Valdez Natural Resource Damage Assessment Plan and Restoration Strategy on air pollution was sketchy, and the response to further questions provided only a few of the additional details needed to review the adequacy of the work plan. If this study had been proposed by an industry to a governmental agency for review, it would not be accepted in its current form. The proposal is still too vague.

The crucial questions are 1) which computer algorithms will be used, 2) what input data are available, and 3) what assumptions will be required to estimate the release of volatile organics from the slick and deposition flux of gaseous organics to the receptors. These determine the accuracy of the model predictions and are needed in order to perform error propagation and error analysis.

The specific computer algorithms for release, dispersion and deposition were not identified, only that they would be USEPA approved. The various dispersion models have different capabilities, and the specific model needs to be identified in order to evaluate its inherent limitations. In particular, most of the standard models do not properly incorporate dry deposition fluxes into the mass balance. That is, dispersion models with dry deposition added frequently do not conserve the mass of the pollutant. The commonly used short-term ISC regulatory model would not be adequate. A model that 1) uses the solutions of Rao for simultaneous dispersion and deposition, 2) includes corrections specific for dispersion in overwater boundary layers, and 3) includes corrections for dispersion in complex terrain is recommended.

The main inputs to the dispersion models are the meteorological data and the source fluxes. The meteorological inputs have not been identified, other than that the National Weather Service is the primary source and measurements were made on Coast Guard vessels. From these, the wind vector and climatological history will be reconstructed. While the data is available for the determination of the wind fields, it is not apparent that the data required to determine atmospheric dispersion characteristics exists, especially over the long trajectories between the source (the oil slick) and receptor (site of deposition and impact). The types and extent of supplemental data, beyond that normally monitored by the National Weather Service, from the source and receptor areas becomes important in order to miminize approximations and uncertainties. A careful evaluation of dispersion is needed for this case of intermediate range transport.

The VOC source flux will be modeled with specific modeling of the benzene, toluene, xylene, and ethylbenzene fluxes. These species are all of the same class, monocyclic aromatics. These volatile aromatics have been singled out for the hazard assessment, because these compounds should have had concentrations which could be detected analytically. In terms of hazard assessment, the reference is not the limit of detection, but the reference contaminant level which has a biological impact. It is recommended that the list be expanded to other components of crude oil which have much lower reference contaminant levels than those of the monocyclic aromatics, and it is recommended that flux calculations for specific compounds be expanded to representative chemicals other classes. For example, while the ratio of the fluxes by evaporation to dissolution is about 6:1 for the monocyclic aromatics, it is about 20:1 for polycyclic aromatics.

The dry flux of organics to plants will be included, although the parameterization of the dry deposition velocities for the organic compounds has not been specified. This is an area of relatively large uncertainty. A careful evaluation of the range of possible of deposition velocities should be made.

The main approximation is how to couple the evaporative flux to the air pollutant concentrations. These approximations have not been identified. The simplest models assume either a constant, average flux (release rate) or a first-order removal and use Gaussian plume dispersion models. The most complex use heat balances and mass transfer coefficients which depend on the meteorology. The evaporative flux depends on the oil slick composition, either by Raoult's Law in the ideal case or with activity or fugacity corrections in the non-ideal case. A careful evaluation of the range of possible of evaporative fluxes should be made, and in general, the simple approximations should be avoided.

Finally, error propagation and error analysis should be performed on the cumulative model results.

Sincerely,

Howard M. Liljestrand

Howard M. Liljestrand
Associate Professor of Civil Engineering

COMMENTS AND RESUME

OF

D.K. BUTTON, PhD

Mr. Bob Adler
Natural Resources Defense Council
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October 23, 1989

Dear Mr. Adler

Review of the damage assessment and restoration activities associated with the *Exxon Valdez* oil spill is from the perspective of the status of the investigation at this point, and what should be done from from here out. Opinions were formed mainly from activities and results seen to date along with conversations with officials and workers in a number of areas.

1. Much focus has been on those effects which are visible and on the high end on the food chain; oil slick movement, oily and discolored beaches, and affected birds and mammals.

2. The progress of weathering, i. e. evaporation, dissolution and effects microbial oxidation of the hydrocarbon distribution within the component of beached oil, and associated fertilizer effects, all of which relate to the quantity and quality of oil persisting, appears to be becomming well documented. Mechanistic aspects of the disolution process, particularly biodegradation, appears to be rather low-tech with extensive repetition favored over complete modern, and thoughtful measurements based on sound principals of physical cemistry. A better balance between field work and the laboratory and theoretical support seems desirable in order to locate changes in the less-obvious relationships. Perhaps we can describe which components disappeared, but cannot tell to what they were converted, where they went, or why. Less obvious actors and bioconversions the process of biodegradation does not mean less important. For example half the oceans biomass is bacterial, yet measurements used are sensitive to only a fraction of a percent of these organisms. Efforts to understand biodegradation of mixed hydrocarbons in the oil phase, a key removal process in this instance, has not been attempeted. In laboratory culture, 70% bioconversion of aromatics can be to hydroxylated aromatics, compounds which account for most of the biochemical activity, carcinogenicity for example, of the parent compound, yet production of these compounds by bacterial action in the beaches remains unmeasured.
Seventy three miles of beach were treated with 40 tons of fertilizer without understanding these basic mechanisms affected. Well-controled laboratory experiments with structured mixtures of hydrocarbons, key components of which are radio-labeled as tracers are in order.

3. Documentation of the passage of particulate hydrocarbons to benthic biota appears to be progressing well.

4. Significant efforts are underway to document changes in tissue chemistry and normal biochemical components in benthic fishes and offshore fishes related to the oil spill. While effects have also been measured on inshore fishes such as salmon, these investigations are more limited. Routes of contamination which involve dissolved hydrocarbons from the water column, as opposed to collection of particulate hydrocarbons by the benthos, are not understood.

Short-term laboratory studies of isotopic hydrocarbon uptake by fishes in bacteria-free systems could help decide if the hydrocarbons in salmon, for example, come from the dissolved phase through the gills, or from particulates firtst collected by their food organisms.

5. Induced changes in water chemistry appear to have been neglected even though the solubility and dissolution rates of light hydrocarbons and aromatics are known to be great. Sensitive measurements of the type required to document these changes were not implemented. It is too late to begin these now, but the technology should be in hand. Neither have measurements of metabolic products of the type documented in fishes (3 above) been attempted, yet their formation in the water column may be even more extensive. As alkylating agents, these are the bioactive components rather than the hydrocarbons as pointed out above.

Effects of the present spill as part of an accumulating load in marine systems due to the decade-to-century life times of hydrocarbons and their products appear not to be addressed. This is seen as a problem of scope, considering the spill as a regional problem when the impact is more its contribution to global changes in water chemistry. Since these changes are slow and cumulative, it is not to late to attend to the Alaskan contribution. The main question is how an increasing load of hydrocarbons and their products affects the functionality of the ocean.

Required studies involve systems sufficiently well controlled so that effective concentrations can be sustained without losing them to bacterial activity, and thus get results over reasonable time frames.

In summary, the most significant damage impact not well addressed, in my opinion, is contribution of the spill to global change. Potential impacts are quite real. And, as in the case of egg-shell thinning from the products of DDT metabolism, careful investigations can establish cause/effect relationships. A significant fraction of the world ocean circulates through Alaska, and we add components to it that will be present for centuries. The fact that other nations may not be good world citizens does not relieve us from the responsibility of containing our discharges; someone needs to lead. The damage impact assessment seems to say that if the offending components leave Prince William Sound, which indeed they do in a few days or weeks, then they are not in fact of concern.

D. K. Button

COMMENTS AND RESUMES

OF

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October 27, 1989

Robert Adler, Esq.
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Dear Mr. Adler:

Professors Steven Wright and Kim Hayes and I have reviewed the draft of the *Exxon Valdez* Environmental Impact Assessment Plan. In general, the proposed studies are described with a lack of sufficient detail for our assessment. Without evidence of the justification for the proposed research as is typically included in academic proposals (which include references to other published research), we cannot assess the level of science proposed. However, based on the scant information provided, we are able to make a few comments regarding some of the possible shortcomings of the assessment plan.

The studies are for only one year which precludes the examination of many phenomena that have longer time scales. Forcing scientists to do one year projects of long term phenomena is not appropriate. For example, the examination of areas that are "lightly-oiled" depends upon when they are lightly oiled. Some oiling of areas will continue after initial identification of lightly oiled areas (more details on attached page). Another example of the long term effect would be the mutagenicity and carcinogenicity of the oil spills on organisms.

Measurements described in the assessment plan seem suited to the expertise of the agencies personnel and not necessarily suited to best characterize the changes in the ecosystem. For example, little discussion about the effect of the spill on the microbial ecology is provided and then just briefly when referring to the benthic microorganisms. Measurements that cannot adequately cope with the heterogeneous nature of oil distribution will also suffer.

Since no discussion of time and money limits is provided and the spill area is clearly impossible to restore completely in a year or two, discussion of how the data collected will be used for partial remediation and accounting needs to be stated explicitly.

More detailed comments are attached.

Sincerely,

Timothy M. Vogel

Timothy M. Vogel
Assistant Professor

Coastal Habitat Study Plan: In general the assessment plan seems to lack a study related to the fate and transport of oil in intertidal and supratidal zones. In the Coastal Habitat studies, a more comprehensive plan for assessing the physical/chemical interactions of the oil with the coastal sediments needs to be given. This might be done by adding two additional projects to the Air/Water study plan such as: (1) Evaluation of Petroleum Hydrocarbon persistence in Intertidal Sediments, and (2) Evaluation of Petroleum Hydrocarbon Persistence in the supratidal Sediments. In the current description of the coastal habitat studies, it appears these areas are not covered or that the research plan is not given in sufficient detail to indicate that they are to be studied.

Measurement of Petroleum Hydrocarbons. A more comprehensive plan needs to be developed and included in the report, indicating what oil components will be screened and how they will be measured analytically. The only information given in the report (p40) states that analyses to be done are TPH/GC and PNA/SIM characterization of marine sediments, TOC on selected samples and size fraction analysis on representative samples. It will be essential to perform a comprehensive analysis of the change in composition of the oil in the sediments in time by monitoring appropriate classes of hydrocarbon components of the oil. Total Petroleum Hydrocarbon (TPH) analyses will not be adequate to assess the damage or to monitor remediation efforts. It is recommended that individual components of the oil be monitored throughout the study at selected sites covering a wide range of molecular weight size classes. This will be essential for assessing the potential damage and be necessary if one is to effectively monitor temporal changes and to determine how well natural, as well as, engineered remediation efforts are working.

Coastal Habitat Study, p. 31 - Mention is made that studies will be performed on 3 degrees of oiling; none, light, and moderate to heavy. It would appear that the *light* classification may be insufficient to clearly delineate the extent of the problem. For example, a section of shoreline might have been lightly oiled within a few days of the spill or it may have been contaminated two months later. The composition of the residual oil will have significantly changed over this time frame and therefore the environmental response may well be significantly different. It seems as though a time aspect to the contact must be included as well; i.e. whether it is contacted soon after the spill or not.

Air/Water Study 1, p. 37 - Mention is made that "Oil spill models will be used . . .". Such models will probably not have sufficient accuracy or spatial resolution to provide any basis for estimates of spill extent or volumes. The oil spill models will be only as accurate as the estimates of general circulation within the system and it is not made clear how this information will be generated. Only field studies would provide the sort of information required such as detailed circulation pattern. These studies need to be performed.

Coastal Habitat Study, p. 32 - States that "four vertical transects will be established on each of the 150 sites . . .". The spatial resolution of these transects is not provided. This should be a critical issue particularly in the breaker zone. It may be visualized that in the area of active sediment transport (which is near the location of wave breaking), oil will be entrained into the sediment much more readily than elsewhere. Depending upon tidal fluctuations, this may or may not encompass a significant distance across the shoreline. No indication has been given that these physical processes have been considered and the description provided, as elsewhere in the report, is simply insufficient to know whether or not this issue will actually be resolved by the sampling procedure described. It does seem likely, however, that with 600 transects, the spatial resolution of the sampling will be limited. In order to have better understanding several sites need to be examined in greater detail.

Detailed studies regarding microbial diversity changes as a result of the oil spill is necessary. An ecology cannot be examined without studying the bottom of the food chain. Laboratory studies examining the influence of oil on microbial diversity combined with measured changes in microbial populations at the spill location will aid in determining impact. In addition, long term studies regarding the recovery of microbial populations in the spill area are needed.

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1988. McElroy, A.E. and Colarusso, P.D. Disposition of dietary benzo(a)pyrene in aquatic species: winter flounder (Pseudopleuronectes americanus) and green crab (Carcinus maenus). Mt. Desert Is. Biol. Lab. Bull. 27:45-47.

1989. McElroy, A.E., Farrington, J.W., and Teal, J.M. Bioavailability of polynuclear aromatic hydrocarbons in the aquatic environment. In: Metabolism of Polynuclear Aromatic Hydrocarbons (PAHs) in the Environment U. Varanasi ed. Chap. 1. p 1-39, CRC Press; Boca Raton, FL.

1989. Kleinow, K.M., Cahill, J.M., and McElroy, A.E. Influence of biotransformation on the dietary bioavailability of environmental carcinogens to the winter flounder (Pseudopleuronectes americanus). Mt. Desert Is. Biol. Lab. Bull. 28:122-123.

1989. McElroy, A.E. and Sisson, J.D. Trophic transfer of benzo(a)pyrene metabolites between benthic organisms. In press. Mar. Environ. Res.

Papers presented at meetings:

1979. Critz*, A.M., Obaid, A.L., and Crandall, Influence of temperature and SITS on HCO^{3-}/Cl^{-} exchange in dogfish erythrocyte suspensions, American Physiological Society, Dallas, TX.

1981. McElroy, A.E., Howes, B.L., and Teal, J.M., Seasonal variation of methane and carbon dioxide in salt marsh sediments, American Society of Limnology and Oceanography, Milwaukee, WI.

1982. McElroy, A.E., Tripp, B.W., Teal, J.M., and Farrington, J.W., The biogeochemical fate of benzanthracene and its oxygenated metabolites in recirculating benthic microcosms, American Society of Limnology and Oceanography, San Fransisco, CA.

1983. McElroy, A.E., Physiological and biochemical effects of the polycyclic aromatic hydrocarbon benz(a)anthracene on the deposit feeding polychaete worm Nereis virens, Eighteenth European Marine Biology Symposium, Oslo, Norway.

1985. McElroy, A.E., In vivo metabolism of benz(a)anthracene by the polychaete Nereis virens. Third International Symposium on Responses of Marine Organisms to Pollutants, Plymouth, UK.

1985. McElroy, A.E., The influence of source on the bioavailability of benz(a)anthracene in benthic microcosms. Sixth Annual Meeting, Society of Environmental Toxciology and Chemistry, St. Louis, MO.

1986. McElroy, A.E. and Means, J.C., Factors affecting the bioavailability of hexachlorobiphenyls to benthic organisms, Tenth Annual Aquatic Toxicology Symposium, American Society for Testing Materials, New Orleans, LA.

1986. McElroy, A.E., and Means, J.C., Uptake, metabolism, and depuration of PCBs by the polychaete Nereis virens. Toxic Chemicals and Aquatic Life: Research and Management," Symposium sponsored by NOAA, NCI, EPA, US Army, VIMS, and Battelle, Seattle, WA, Invited poster presentation.

1986. McElroy, A.E. and Means, J.C., Relative availability of spiked PCBs vs. incurred residues in contaminated sediments. Seventh Annual Meeting Society of Environmental Toxicology and Chemistry, Arlington, VA.

1987. McElroy, A.E. and Means, J.C., Bioaccumulation of PCB congeners by the deposit feeding clam Yoldia limatula: Controlling factors in sediment. Eight Annual Meetin, Society of Environmental Toxciology and Chemistry, Pensicola, FL.

1987. McElroy, A.E. Assessment of the petroleum marine pollution problem. Invited Speaker for the Symposium on Physical and Chemical Oceanography in Chile and South America, University of Concepcion, Chile.

1988. McElroy, A.E. Metabolism of benz(a)anthracene in benthic microcosms: Influence of a tubiculous polychaete and mode of introduction. Ocean Sciences Meeting, American Society of Limnology and Oceanography, New Orleans, LA.

1988. McElroy, A.E., J.W. Farrington, and J.M. Teal. Metabolism of polycyclic aromatic hydrocarbons in benthic microcosms. Symposium on Fate of Chemicals in the Ocean, American Chemical Society, Toronto, Canada.

1989. McElroy, A.E. and Sisson, J.D., Metabolism of dietary carcinogens in aquatic food chains. Society of Toxicology Meeting, Atlanta, GA.

1989. Kleinow, K.M. and McElroy, A.E., Toxicokinetics and disposition of benzo[a]pyrene (BaP) and BaP 7,8 diol in the winter flounder. Society of Toxicology, Atlanta, GA.

1989. McElroy, A.E. and Sisson, J.D., Trophic transfer of benzo(a)pyrene metaboites in and between benthic marine organisms. Fifth International Symposium on Responses of Marine Organsisms to Pollutants, Plymouth, England.

PATRICIA A. LANE, Ph.D

CURRICULUM VITAE

CURRICULUM VITAE OF PATRICIA A. LANE

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CURRICULUM VITAE OF PATRICIA A. LANE

A. Personal

Born:
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Marital Status:
Divorced

Children:
Four (Born 1963, 1967, 1969, 1975)

Residence Address:
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FAX: (902) 566-3768

Dual Citizenship:
Canadian Citizen
Social Insurance No. 155-088-296

United States Citizen
Social Security No. 132-36-9688

B. Academic Degrees

B.A., 1964, Biology, Hartwick College, Oneonta, New York.

M.A., 1966, Biology, State University of New York at Binghamton.

Ph.D., 1971, Ecology, State University of New York at Albany.

C. Training and Experience

1965 - 1966	Teaching Assistant Department of Biology State University of New York at Binghamton Binghamton, New York
1969 - 1971	NDEA Pre-doctoral Fellow Department of Biology State University of New York at Albany Albany, New York
1971 - 1973	Post-doctoral Ford Fellow Department of Biology University of Chicago Chicago, Illinois
1972 - 1973	Research Associate W. K. Kellogg Biological Station Michigan State University Hickory Corners, Michigan
1973 - 1973	Assistant Professor (summer) W. K. Kellogg Biological Station Michigan State University Hickory Corners, Michigan
1973 - 1978	Assistant Professor Department of Biology Dalhousie University Halifax, Nova Scotia
1974 - 1978	Adjunct Assistant Professor W. K. Kellogg Biological Station Michigan State University Hickory Corners, Michigan
1978 - 1984	Associate Professor Department of Biology Dalhousie University Halifax, Nova Scotia

1980 - 1982	Visiting Associate Professor Department of Population Sciences Harvard School of Public Health Harvard University Boston, Massachusetts
1982 - 1984	Visiting Associate Professor Graduate School of Oceanography University of Rhode Island Kingston, Rhode Island
1982 - present	Visiting Lecturer Department of Population Sciences Harvard School of Public Health Harvard University Boston, Massachusetts
1983 - present	President P. Lane and Associates Limited Halifax, Nova Scotia, and Charlottetown, Prince Edward Island
1983 - 1985	Director Caribbean Fisheries Research Foundation, Inc. St. Croix, U.S. Virgin Islands
1984 - 1984	Visiting Professor Graduate School of Oceanography University of Rhode Island Kingston, Rhode Island
1984 - present	Professor Department of Biology Dalhousie University Halifax, Nova Scotia
1985 - 1986	Director National Foundation for the Environment Halifax, Nova Scotia
1986 - present	Professor School of Resource and Environmental Studies Dalhousie University Halifax, Nova Scotia

D. Fellowships, Honours and Awards

1969 - 1971	Pre-doctoral Fellowship (NDEA)
1971 - 1973	Post-doctoral Fellowship (Ford Foundation Grant for Population Biology)
1971	Travel award for 18th Congress, SIL, in Leningrad, U.S.S.R., from American Society of Limnology and Oceanography, and the Ecological Society of America.
1974 - present	(invited and/or named in:) Who's Who in American Men and Women of Science Noteworthy Community Leaders in America Who's Who in Frontiers of Science and Technology Who's Who in Canadian Women The International Directory of Distinguished Leadership Personalities of the Americas World's Who Who of Women
1976	American Society of Naturalists (elected).
1984	Environmental Science and Engineering Fellowship. Sponsored by the American Association for the Advancement of Science and Environmental Protection Agency. Washington, D.C.
1985	Senior Ecologist Certification by Ecological Society of America.
1985	Named One of Top Ten Outstanding Campus Achievers, Campus Canada.
1987	Elected Fellow, The Rawson Academy of Aquatic Science
1988 - 1989	Elected Director, The Rawson Academy of Aquatic Science
1988 - 1989	Invited Member. Management Board of Environmental Choice Program. Appointed by Federal Minster of the Environment.

E. Consulting Experience

1. Main Consulting Areas

a) Development and implementation of environmental impact assessment methodologies for marine, terrestrial and freshwater environments, including ecological risk and causal network analyses.

b) Qualitative and quantitative modelling of perturbed ecosystems.

c) Evaluation of environmental effects of oil pollution, thermal pollution, mining activities, nutrient enrichment, acid deposition and physical alterations to ecosystems.

d) Design of environmental effects monitoring programs and environmental protection plans.

e) Design of field and laboratory experiments and data analysis for fates and effects of pollutants.

f) Training of environmental managers and ecologists.

2. Experience (Prior to 1983)

1974 - 1976	Served as environmental consultant to Quirk, Lawler and Matusky, Environmental Engineers, Tappan, New York on application of niche analysis to the phytoplankton, zooplankton, benthos and fish larvae impacted by power plants in the Hudson River. Also assisted in the design of monitoring programmes and critique of fish population models.
1978	Served as environmental consultant to MacLaren-Marex, Halifax, Nova Scotia on multivariate statistical approaches to phytoplankton communities in the Davis Strait (analyzed Irving Oil data set).
1980-1981	Served as advisor on Hudson River studies, Pandullo and Quirk, New Jersey.
1982	Served as environmental consultant on pollution in Kingston Harbour, Jamaica, under auspices of McGill International with travel grant awarded to Dr. B. Marcotte of McGill University from The Royal Bank of Canada. Held discussions with key personnel at Scientific Research Council; University of West Indies; Ministry of Health (Environmental Control); and Natural Resources Conservation Department.

3. Experience (After 1984)

Project manager on more than 120 company contracts. Selected current and recent projects since 1984 include:

1984 - 1985	Ecological Impacts of the Budworm-Killed Forest. Environment Canada.

1984 - 1985	Jack Lake Land Assembly - Environmental Impact Assessment of Surface and Groundwater Concerns Related to Suburban Development. Canada Mortgage and Housing Corporation and Province of Nova Scotia.
1985 -	Hibernia Environmental Impact Statement: Risk Assessment and Modelling of Sea Birds and the Pelagic Ecosystem. Critique of Mobil E.I.S. Environment Canada.
1985 - 1986	Athol Sulphuric Acid Spill. Field Assessment of Pollution Effects on Higher Vegetation and Multivariate Community Analysis. Environmental Protection Service, Environment Canada. (Sub to Lavalin.)
1985 - 1986	A Study of Water Quality Issues at Selected Prince Edward Island Causeways. P.E.I Department of Transportation and Public Works.
1985 - 1986	Snow Crab Infrastructure Study. Department of Fisheries and Oceans.
1985 - 1986	Fault Tree Analysis for the Risk of Fire in Regard to the Use of Wood in Coal Mines. Department of Energy, Mines and Resources.
1985 - 1986	Chezzetcook Salt Marsh - Environmental Impact Assessment and Baseline Data Collection for Terrestrial and Marine Ecosystems Related to Highway 107 Construction. N.S. Department of Transportation.
1986 - 1986	Caribou Risk Assessment in Regard to Power Transmission Lines. Newfoundland-Labrador Hydro.
1986 - 1986	Field Studies, Population Modelling, Resource Management and Stock Assessment of Surf Clam Populations on Banquereau Bank, Nova Scotia. Development of a New Fishery. Fishery Investments Limited.
1986 - 1986	Environmental Risk Catalogue of Non-Pesticide Toxic Chemicals on Migratory Birds in the Atlantic Provinces. Canadian Wildlife Service.
1986 - 1986	Sedimentation Study of Chezzetcook Inlet. N.S. Department of Transportation.
1986 - 1986	Review and Critique of Field Studies Concerning Oil and Dispersants. National Research Council. U.S. National Academy of Sciences.

1986 - 1986	A Review of Water Quality Standards and Marine Receiving Waters in Regard to Meat Processing Plant Effluents. P.E.I. Department of Development.
1986 - 1986	Hydrodynamic Modelling and the Socio-Economic Effects of a One Metre Rise in Sea Level at Charlottetown. Canadian Climate Program, Atmospheric Environmental Services.
1986 - 1987	Environmental Impact Assessment, Effects Monitoring and Protection Planning for Gold Tailings Reclamation and Mining. Seabright Industries. (3 projects)
1986 - 1987	Development of a Socio-economic Methodology for Assessing Impacts related to Climate Change in Atlantic Canada.
1986 - 1987	Evaluation of Holistic Marine Ecosystem Modelling As a Potential Tool in Environmental Impact Assessment. Dalhousie Institute of Resource and Environmental Studies, and Marine Ecology Laboratory, Bedford Institute of Oceanography.
1986 - 1987	Environmental Capacity Study of Western Brook Pond. Parks Canada (2 contracts).
1986 - 1988	The Effects of Oil Dispersants on Salt Marsh Vegetation. Environmental Studies Revolving Funds. Canada Oil and Gas Lands Administration. Second year Continuation, Environment Canada.
1987 - 1988	Development of a Reference Guide and Feasibility Study for Cumulative Effects Assessment. Canadian Environmental Assessment Research Council.
1987	Evaluation of the Water Resource Research Program of the Directorate of Inland Waters, Environment Canada. Rawson Academy of Aquatic Science.
1987 - 1988	Physical and Biological Oceanographic Studies of Proposed Addition to Trenton Generating Station. Nova Scotia Power Corporation (4 contracts).
1987 - 1988	Generic Initial Environmental Evaluation and Public Information Program for Northumberland Strait Fixed Crossing Project. Public Works Canada. (3 contracts).
1987 - 1988	An Ecosystem Risk Modelling and Field Studies of the Fates and Effects of PAHs in Sydney Harbour. Department of Fisheries and Oceans. (4 contracts).

1987 - 1990 Biotechnological Approach to Environmental Decontamination of Heavy Metals Using Higher Plants at an Abandoned Gold Tailings Site. Energy Mines and Resources (3 contracts).

1987 - 1988 Assessment of the Freshwater Impacts of Low Level Flying for the Goose Bay NATO Base, Labrador. Lavalin/Department of National Defense (2 contracts).

1987 - 1988 Design of a Large Environmental Rehabilitation Project Centered on Sustainable Development for the Mahaweli Watershed: Sri Lanka. Ecological and Women in Development Components. Canadian International Development Agency.

1988 - 1992 Environmental Evaluation of Proposal Call, Monitoring and Inspection Services for Northumberland Fixed Crossing Project. Delcan/Stone & Webster Joint Venture for Public Works Canada.

1988 - 1989 Evaluation of the Pitfalls and Possibilities for Marine Environmental Effects Monitoring for Offshore Oil Development. Environment Canada.

1988 Design of Environmental Effects Monitoring Program for Sydney Harbour. Acres International Limited. N.S. Department of Environment and Environment Canada.

1988 Environmental Marine Effects of St. Peters Bay Development. Morello and Associates.

1988 - 1989 Damage of Hurricane Gilbert and Sustainable Development in Jamaica. Canadian International Development in Jamaica. Canadian International Development Agency and the Institute for Research on Public Policy (2 contracts).

1988 - 1989 Terrestrial Baseline Study for the Fixed Link Crossing. Delcan/Stone & Webster Joint Venture for Public Works Canada.

1988 - 1989 Design of a Wetlands to Ameliorate Acid Mine Drainage at the Halifax International Airport. Transport Canada.

1988 - 1990 Implementation of Marine Monitoring Program for Tar Pond Clean-up. Acres International Limited. N.S. Department of Environment and Environment Canada.

1989	Ecological Risk to Cormorants of Accidental Marine Spills in Relation to the Fixed Link Crossing. Delcan/Stone & Webster Joint Venture for Public Works Canada.
1989	Expert Witness to Assist the Sieria Club Legal Defense Fund Inc., Juneau Alaska on Exxon's proposed use of Corexit 9580 as a shoreline cleaner in Prince William Sound.
1989	Expert opinion on efficacy of Natural Resource Damage Assessment Plan for Exxon Valdez Oil Spill for Natural Resources Defense Council. New York, New York and Washington, DC.
1989	Qualitative Ecosystem model to study the effects of ice on commercial fisheries in the Northumberland Strait.
1989	Comprehensive Environment Management plan for the Northumberland Strait Crossing Project. Delcan/Stone and Webster Joint Venture for Public Works Canada.
1989	Spatial Analysis of Island-wide Terrestrial Impacts related to increased traffic and tourism of the Northumberland Strait Crossing Project in a sustainable development context. Delcan/Stone and Webster Joint Venture for Public Works Canada.
1989-1990	Agratic Resource Inventory and Environmental Planning for Cape Breton Highlands National Park. Parks Canada.
1989 - 1990	Expert Witness to Assist Public Works Canada in EARP panel hearings for Northumberland Strait Crossing Project.
1989 - 1990	Study of Mechanisms Operative in Natural Freshwater Wetlands. Environment Canada.
1989 - 1991	Traning Regulators for the Implementation of the Environmental Assessment and Review Process (EARP). Federal Environmental Assessment Review Office (FEARO).

F. <u>Publications</u>

1. Theses

1966 M.A. Thesis: A study of the planktonic algae of two ponds. State University of New York at Binghamton. 120 pp.

1971 Ph.D. Thesis: A comparative study of four zooplankton communities. State University of New York at Albany. 202 pp. Diss. Abs. 72-31,784.

2. Journal Articles [Note: P. Lane is senior author on all papers except those marked with * after year.]

1969 A winter-spring study of the phytoplankton of two New York ponds. Journal of the Elisha Mitchell Science Society 85:23-31.

1970 A mathematical analysis of the niches of Lake Michigan zooplankton. In: Proceedings of the 13th Conference on Great Lakes Research, pp. 47-57 (with Donald C. McNaught).

1973 A niche analysis of the Gull Lake (Michigan, U.S.A.) zooplankton community. Verhandlungen Internationale Vereinigung für Theoretische und Angewandte Limnologie 18:144-157 (with Donald C. McNaught).

1975 The feasibility of using a holistic approach in ecosystem analysis. In: S.A. Levin (ed.), Ecosystem Analysis and Prediction; Proceedings of the Conference on Ecosystems, pp. 111-128 (with George H. Lauff and Richard Levins). Society for Industrial and Applied Mathematics.

1976 Dynamics of Aquatic Systems. I. A comparative study of the structure of four zooplankton communities. Ecological Monographs 45:307-336.

1976 Measuring invertebrate predation _in situ_ on zooplankton assemblages. Transactions of the American Microscopical Society 95(2):143-155 (with M.J. Klug and L. Louden).

1977 Dynamics of aquatic systems. II. The effects of nutrient enrichment on model plankton communities. Limnology and Oceanography 21:454-471 (with R. Levins).

1977 The evolutionary strategy of mimicry. American Biology Teacher 39:214-217.

1978 Zooplankton and the community structure controversy. Science 200:458-460.

1979 Role of invertebrate predation in structuring zooplankton communities. Verhandlungen Internationale Vereinigung für Theoretische und Angewandte Limnologie 20:480-485.

1979 Relative roles of vertebrate and invertebrate predation in structuring zooplankton communities. Nature 280:391-393.

1981 Fish versus zooplankton predation in lakes. Nature 292:780.

1982 Using qualitative analysis to understand perturbations in marine ecosystems in the field and laboratory. In: P. Archibald (ed.), Environmental Biology State of the Art Seminar, pp. 94-122. Office of Exploratory Research, U.S. Environmental Protection Agency, Washington, D.C. EPA-600/9-82-007.

1984 Peering through nature's kaleidoscope at a marine plankton community. In: P. Archibald (ed.), Environmental Biology State of the Art Seminar. Office of Exploratory Research, U.S. Environmental Protection Agency, Washington, D.C.

1984* Plankton of an acid-stressed lake (Kejimkujik National Park, Nova Scotia, Canada). Part 1. Design and water chemistry results of an enclosure experiment. Verhandlungen Internationale Vereinigung für Theoretische und Angewandte Limnologie 22:395-400 (with T. M. Collins; 2nd author).

1984 Plankton of an acid-stressed lake (Kejimkujik National Park, Nova Scotia, Canada). Part 3. Community network analysis. Verhandlungen Internationale Vereinigung für Theoretische und Angewandte Limnologie 22:406-411 (with A.C. Blouin).

1984* Comparison of plankton-water chemistry relationships in three acid-stressed lakes. Internationale Revue der Gesamten Hydrobiologie 69:819-841 (with A. C. Blouin, T. M. Collins and J. J. Kerekes; 2nd author).

1985 Qualitative analysis of the pelagic food webs of three acid-impacted lakes. Internationale Revue der Gesamten Hydrobiologie 70:203-220 (with A.C. Blouin).

1985 A food web approach to mutualism in lake communities -- Distinguishing direct, indirect and community effects. Chapter 14 in: D. Boucher (ed.), Mutualism; New Ideas About Nature, pp. 344-374. Université du Québec a Montréal. Montreal, Quebec.

1985 Food web models of a marine plankton community: an experimental approach. Journal of Experimental Marine Biology and Ecology 94:41-70 (with T.M. Collins).

1986 Symmetry, change, perturbation and observing mode in natural communities. Ecology 67:223-239.

1986 Preparing marine plankton data sets for loop analysis. Ecology. Supplementary Publication Source Document No. 8525A.

1986* The theory of loop analysis. Ecology. Supplementary Publication Source Document No. 8525B (with J.A. Wright: 2nd author).

1986 Receiving water responses to wastewater discharges to the marine environment -- Biological effects and risk analysis. Chapter to appear in: D. Waller (ed.), Wastewater Discharges to Marine Environment. Technical University of Nova Scotia Symposium. (In press)

1987 Impact of experimentally dispersed oil on vegetation in a northwestern Atlantic salt marsh -- Preliminary observations. In: J.O. Ludwigson (ed.), Proceedings of the 1987 Oil Spill Conference. Sponsored by American Petroleum Institute, Environmental Protection Agency, United States Coast Guard. API Publication 4452 (with J.H. Vandermeulen, M.J. Crowell and D.J. Patriquin).

1987 Patchwork: Mesocosm tank studies on marine plankton patchiness. In: Proceedings of a conference, The Ocean "An International Workplace". Oceans 1987, pp. 929-934 (with N. Balch, H. Price, T. Collins; 4th author).

1988* Recovery of a Nova Scotian saltmarsh during two growing seasons following experimental spills of crude oil and the dispersant Corexit 9527. Proceedings of the Eleventh Arctic and Marine Oil Spill Procurement Technical Seminar, pp. 89-128 (with M.J. Crowell; 2nd author). Environment Canada Publication (Environmental Protection Service).

1989 Heavy metal removal from gold mining and tailing effluents using indigenous aquatic macrophytes (Phase I). Proceedings of the BIOMET Annual Meeting, November 2, 1988, Calgary, Alberta, pp. 3-37 (with M. Crowell and M. Graves).

1989* Factors affecting plant biomass and tissue concentrations of arsenic and mercury and the distributions of plant communities on gold tailings in Nova Scotia, CANMET, Energy, Mines and Resources (with M.J. Crowell).

3. Selected Technical Reports (University and Consulting) [Note: P. Lane is senior author on all papers except those marked with * after year.]

1977 Response of the structure and stability of four aquatic communities in the Hudson River to thermal effluents. Dalhousie University Technical Report, 500 pp. (with J.A. Wright).

1981 Distribution and abundance of zooplankton in three lakes in Kejimkujik National Park, Nova Scotia. Dalhousie University Technical Report, 139 pp. (with A. C. Blouin and K. Cook).

1981 A comparison of three plankton communities in Kejimkujik National Park, Nova Scotia. Dalhousie University Technical Report, Volume 1, 143 pp.; Volume II, 166 pp. (with A. C. Blouin and K. Cook).

1981 Analyzing perturbations to marine ecosystems using loop analysis and time averaging. Harvard Marine Ecosystems Research Group, Harvard University Technical Report, 60 pp. (Editors: P. Lane and R. Morison).

1982 Plankton-nutrient interactions in Pebbleloggitch, Beaverskin, and Kejimkujik Lakes in 1980 and 1981. Kejimkujik National Park, Nova Scotia. Dalhousie University Technical Report, Volume I, 182 pp.; Volume II, 221 pp. (with A. C. Blouin and T. M. Collins).

1985 Possible holistic approaches to the study of biological - physical interactions in the oceans. Working Group Report. Ecosystems Theory in Relation to Biological Oceanography. SCOR/UNESCO Working Group No. 73. (6th author)

1987 Use of chemical dispersants in salt marshes. Report No. 070, Canada Oil and Gas Lands Administration, Ottawa, Ontario. Environmental Studies Research Fund. (with M. Crowell, D.G. Patriquin, and I. Buist.)

1988 A reference guide to cumulative effects assessment in Canada. Vol. I (with R.R. Wallace, R.L. Johnson and D. Bernard). Vol. II. Feasibility study in CEARC cumulative effects assessment (CEA); Wetlands of the boreal agricultural fringe of the prairie provinces (with R.R. Wallace; 2nd author). Vol. III. Overview of agencies and institutions interested in cumulative effects assessment and management (with N.C. Sonntag, R.R. Wallace, B.M. Marcotte and S.H. Janes; 2nd author). Canadian Environmental Assessment Research Council, Ottawa, Ontario.

1988 Generic initial environmental evaluation of the Northumberland Strait Crossing Project. Public Works Canada, Ottawa, Ontario. (with G. Gillis).

1988 Mahaweli environmental rehabilitation project in Sri Lanka. Volume I. Ecological Aspects; Volume II. Appendices. Canadian International Development Agency, Hull, Quebec. (with S. Derarajan, M. Jansen, S. Kotagama, R. Senanayake, G. Shea, R. Subasinghe and N. de Zoysa)

1988 Mahaweli environmental rehabilitation project in Sri Lanka. Women in development. Canadian International Development Agency, Hull, Quebec. (with P. Abewardena, G. Shea, K.M. Vitarana and A. Wickramesinghe)

1989 Jamaica 1988: Hurricane Gilbert; The relationship between environmental degradation and the severity of natural disasters. Canadian International Development Agency, Hull, Quebec. (with J.J. Harrington, G.A. Shea and J. Douglas)

1989* Evaluation of Holistic Marine Ecosystem Modelling as a Potential Tool in Environmental Impact Assessment. Biological Sciences Branch, Scotia-Fundy Region, Department of Fisheries and Oceans, Bedford Institute of Oceanography, Dartmouth, Nova Scotia, 177 pp. (with P.K. Stokoe, R.P. Cote and J.A. Wright; 2nd author)

1989 Further Studies on the Distribution and Fate of Arsenic and Mercury at a Site Contaminated by Abandoned Gold Mine Trailings. P.A. Lane, M.J. Crowell, R.J. Pett, and D.S. MacKinnon, P. Lane & Associates, Ltd., Halifax and M.C. Graves, Cuesta Research Ltd., Dartmouth.

Plus a large number of other consultant reports.

4. Abstracts

1982 Zooplankton studies. Proceedings of the Kejimkujik Calibrated Catchments Program Workshop, November 18, 1981. J.J. Kerekes (ed.), pp. 55-56 (with A.C. Blouin).

1983 Quantitative analysis of lake communities and enclosure experiments in Kejimkujik National Park. Proceedings of the Kejimkujik Calibrated Catchments Program Workshop, April 26, 1983. J.J. Kerekes (ed.), pp. 62-66 (with A.C. Blouin and T.M. Collins).

1983 Qualitative analysis of lake food webs in Kejimkujik National Park. Proceedings of the Kejimkujik Calibrated Catchments

Program Workshop, April 26, 1983. J.J. Kerekes (ed.), pp. 67-69 (with A.C. Blouin and T.M. Collins).

[Note: Several papers given at meetings listed in Section H also appeared as abstracts in conference proceedings.]

5. Papers and Abstracts Completed Under My Supervision (in addition to theses in L. 3.)

1980 Bohrer, Richard N. Experimental studies on diel vertical migration. In: W.C. Kerfoot (ed.), Evolution and Ecology of Zooplankton Communities. Special Symposium Volume 3, pp. 111-121. American Society of Limnology and Oceanography. University Press of New England, Hanover, New Hampshire.

1980 Skiver, John. Seasonal partitioning patterns of marine calanoid copepods species interactions. Journal of Experimental Marine Biology and Ecology 44 (2-3):229-246.

1983 Blouin, Anthony C., Terrence M. Collins and Joseph J. Kerekes. Plankton of an acid-stressed lake (Kejimkujik National Park, Nova Scotia, Canada). Part 2. Population dynamics of an enclosure experiment. Verhandlungen Internationale Vereinigung für Theoretische und Angewandte Limnologie 22:401-405. Also presented at the XXIInd Congress of the International Association of Theoretical and Applied Limnology. Lyon, France, by A.C. Blouin.

1983 Collins, Terrence M., and Anthony C. Blouin. Nutrient enrichment using experimental marine plankton communities. I. Dalhousie tower tank. 46th Annual Meeting American Society of Limnology and Oceanography, Memorial University, St. John's, Newfoundland. (presentation plus conference abstract)

6. Writing Commitments and Papers in Preparation

Book Under Contract

Qualitative Ecosystem Analysis. (with Richard Levins) Ecological Studies Series. Springer-Verlag Publishers, New York.

Papers in Preparation

Manipulation of ctenophore populations in experimental marine food webs. Journal of Experimental Marine Biology and Ecology. (with T.M. Collins)

Loop analysis as a useful technique for environmental impact assessment. Ecological Modelling.

Loop analysis of the nutrient enrichment experiment conducted in the MERL mesocosms. Marine Biology.

The plankton food web of Narragansett Bay. Limnology and Oceanography.

A comparison of marine and freshwater plankton foodwebs. Ecology.

Once upon a googol: The quest for biologically-reasonable networks. American Naturalist.

Connectedness in marine and freshwater food webs. Ecology. (with J.A. Wright).

G. <u>Symposia as Invited Speaker</u>

1973 First International Congress of Evolutionary Biology and Systematics. Boulder, Colorado. "Homage to the Loch Ness Monster, or Why Are There So Few Niches?".

1974 Symposium of Society of Industrial and Applied Mathematics, Alta, Utah (sponsored by the National Science Foundation). Exhibit A: The feasibility of using a holistic approach in ecosystem analysis.

1981 Symposium -- Environmental Protection Agency, Office of Innovative Research (Biology). Duluth, Minnesota. Using qualitative analysis with marine plankton communities.

1983 Symposium -- Environmental Protection Agency, Office of Innovative Research (Biology), Seattle, Washington. Peering through nature's kaleidoscope at a marine plankton community.

1985 Symposium -- Technical University of Nova Scotia, Centre for Water Resources Studies, Halifax, Nova Scotia. Discharges to the Marine Environment. Receiving water responses to wastewater discharges to the marine environment: biological effects and risk analysis.

1985 Symposium -- U.S. Environmental Protection Agency. Health and Environmental Review Division. Washington, D.C. Perspectives on Ecological Risk Assessment. Loop analysis as a tool for ecological risk assessment.

1986 Symposium -- Technical University of Nova Scotia, Centre for Water Resources Studies. Assessment of Impacts of Wastewater Discharge on Marine Environments. Talks on Biological Field Studies and Ecosystem Modelling. (Invited Speaker)

1987 Symposium -- The Institute of Electrical and Electronics Engineers, Inc. Canadian Atlantic Section's Spring Seminar 87. Talk on Ecological Risk Analysis with Energy Development. (Invited Speaker)

1989 Symposium -- Technical University of Nova Scotia. Sewage Treatment. Environment Assessment - Its Role in Plant Siting and Design. (Invited Speaker)

H. Papers Given at Meetings (in addition to Symposia) [Note: P. Lane is senior author on all papers except those marked by * after year]

1970 A mathematical analysis of the niches of Lake Michigan zooplankton. 13th Conference International Association for Great Lakes Research (with Donald C. McNaught). State University of New York, Buffalo, New York.

1971 A comparative study of the structure of zooplankton communities. 34th Annual Meeting American Society of Limnology and Oceanography (with Donald C. McNaught). Freshwater Institute, Winnipeg, Manitoba.

1971 A niche analysis of the Gull Lake (Michigan, U.S.A.) zooplankton community. XIIIth Congress International Association of Theoretical and Applied Limnology (with Donald C. McNaught). Leningrad, U.S.S.R.

1971 Understanding zooplankton community structure using niche analysis. Plankton Conference (sponsored by Ford Foundation Grant for Population Biology). University of Chicago, Chicago, Illinois.

1982 Community dynamics of the Delaware River phytoplankton in relation to sewage effluents. 35th Annual Meeting American Society of Limnology and Oceanography (with George Schumacher). Florida State University, Tallahassee, Florida.

1973 The limiting factor myth. 36th Annual Meeting American Society of Limnology and Oceanography (with Richard Levins). University of Utah, Salt Lake City, Utah.

1977 Response of the Gull Lake zooplankton community to nutrient enrichment. 40th Annual Meeting American Society of Limnology and Oceanography (with George Lauff and Richard Levins). Michigan State University, East Lansing, Michigan.

1977 A plankton parable about chitterlings. XXth Congress of the International Association of Theoretical and Applied Limnology. Copenhagen, Denmark.

1977 Response of the structure and stability of four aquatic communities in the Hudson River to thermal effluents. Savannah River Ecological Laboratory. Conference on Thermal Pollution. Athens, Georgia.

1979 Stress to marine ecosystems. Panel member for Conference on Water and Environmental Law. Dalhousie University, Halifax, Nova Scotia.

1980 Analyzing perturbations to marine ecosystems using loop analysis and time averaging. Three talks: (1) The qualitative approach and its significance for marine ecosystems, (2) Applying loop analysis to marine plankton communities, (3) Information needed: organisms, ecosystems, and parameter inputs. U.S. Environmental Protection Agency - Harvard Research Meeting. Harvard University, Boston, Massachusetts.

1980 Sexism in Biology (panel member). National Association of Biology Teachers. Boston, Massachusetts.

1983 Nutrient enrichment using experimental marine plankton communities. II. Loop analysis. 46th Annual Meeting American Society of Limnology and Oceanography. Memorial University, St. John's, Newfoundland.

1983 Peering through nature's kaleidoscope at a marine plankton community. U.S. Environmental Protection Agency -- State of the Art Seminar. Office of Innovative Research, U.S. Environmental Protection Agency, Seattle, Washington.

1983* Plankton of an acid-stressed lake (Kejimkujik National Park, Nova Scotia, Canada). Part 1. Design and water chemistry results of an enclosure experiment (presented by T.M. Collins; 2nd author). XXIInd Congress of the International Association of Theoretical and Applied Limnology. Lyon, France.

1983 Plankton of an acid-stressed lake (Kejimkujik National Park, Nova Scotia, Canada). Part 3. Community network analysis. (with A.C. Blouin). XXIInd Congress of the International Association of Theoretical and Applied Limnology. Lyon, France.

1984 Notion of core structure in marine plankton communities. Conference on Ecosystem Theory in Relation to Biological Oceanography. Sponsored by SCOR/UNESCO Working Group No. 73, National Sciences and Engineering Research Council of Canada, U.S. National Science Foundation and the U.S. Office of Naval Research. Université Laval, Quebec City, Quebec.

I. <u>Representative Workshops, Conferences, Radio-TV Presentations, Special Courses and Miscellaneous</u>

1975 Joint Panel on Ecosystem Analysis and Predicting the Effects of Changing Water Quality. Sponsored by the Institute of Ecology, U.S. National Water Commission, and U.S. National Academy of Sciences. University of Texas. Austin, Texas. (Invited Workshop Member)

1982 Adaptive Environmental Assessment with Integrated Pest Management in Corn Production Systems. U.S. Fish and Wildlife

- Environmental Protection Agency Workshop. Fort Collins, Colorado. (Invited Workshop Member)

1984 Water Resource Management in Nova Scotia - Priority Issues and Research Needs. Centre for Water Resources Studies, Technical University of Nova Scotia. (Invited Participant)

1984 Long Range Research Agenda. Environmental Biology- ecological effects subpanel. Sponsored by the Environmental Protection Agency and the Ecological Society of America. Annapolis, Maryland. (Chairperson)

1985 Rene Dubos Forum Program - Water Management. The Rene Dubos Center for Human Environments. New York City, New York. (Invited Workshop Member)

1985 Course for Environmental Managers of Indonesia. Sponsored by Canadian International Development Agency (CIDA). Institute of Resource and Environmental Studies, Dalhousie University (Instructor on ecological modelling)

1985 American Association for the Advancement of Science (AAAS)/U.S. Environmental Protection Agency. Wrote and presented a federal environmental management opinion paper in a national competition judged by 20 leading environmental managers and was awarded an environmental policy fellowship to study in Washington, D.C.

1985 Conference - Discovery and Exploitation in Human Systems: Modelling complexity in fisheries. United Nations University Global Learning Division and Department of Fisheries and Oceans. (Invited Discussant

1986 Conference - Assessment of Impacts of Wastewater Discharge on Marine Environment. Technical University of Nova Scotia. (Invited Speaker on biological field studies and ecological modelling)

1986 World Commission on Environmental and Development of the United Nations. Government of Nova Scotia and Environment Canada. (Invited Participant)

1986 Workshop - Grand Banks Modelling. Marine Ecology Laboratory, Bedford Institute of Oceanography. (Invited Participant)

1986 Workshop - Cumulative Impact Assessment. Canadian Environmental Assessment Research Council (FEARO). Montreal, Quebec. (Invited Participant)

1986	Workshop - Toxic Chemicals in the Environment. Environment Canada, Sackville, N.B. (Invited Speaker)
1986	Workshop - 13th Aquatic Toxicology Workshop, Moncton, N.B. (Invited Panel Discussant)
1987	Workshop - Use of Models in Environmental Impact Assessment. Dalhousie School for Resource and Environmental Studies - Bedford Institute of Oceanography. (Organizer and Speaker)
1987	Radio Presentation - CBC - Environmental Risk of Oil Development- Perception and Management. (Invited Speaker)
1987	Cabinet Briefing Document - Contributed to Environmental section on feasibility of constructing a 14-km bridge across the Northumberland Strait to link Prince Edward Island and New Brunswick.
1987	Workshop - Fluctuating Water Levels in the Great Lakes. Cross Support Group, International Joint Commission. (Invited Member)
1987	Conference - Science and Technology. Poster display on Environmental Risk Analysis: Integrating Science and Technology.
1988	Radio Presentation - Canadian Broadcasting Corporation - Prince Edward Island and New Brunswick. Fixed Crossing Project.
1988 - 1989	Four Board Meetings of Environmental Choice Program to establish policy and implementation procedures.
1989	Television Presentation - Shaw Cable Station - Environmental Choice Program, Canada's Domestic Initiative in Sustainable Development.
1989	Department of Fisheries and Oceans (DFO) workshop organized by the Rawson Academy, "How to Implement and Evaluate the No Net Habitat Loss Policy".
1989	Department of Fisheries and Oceans workshop. Plastic Debris in the Aquatic Environment (invited facilitator on research needs and technological development).
1989	Round Table on Sustainable Development sponsored by the Canadian International Development Agency and Institute for Research on Public Policy. Atlantic Region Consultation (invited member).

1989 Hurricane Gilbert: Jamaica 1988. A Case for Sustainable Development. Summer Science Institute, Dalhousie University (invited speaker).

1989 Workshop - Fluctuating Water Levels in the Great Lakes St. Lawrence River Basin. Review of Phase I. International Joint Commission (invited member).

1989 Building Partnership for Environmentally Sound Development in Nova Scotia. Nova Scotia Department of Environment and other groups. (Invited member for final summation panel).

1989 Seminar on Marine Outfall Design and Siting (with special reference to Halifax Harbour). Technical University of Nova Scotia (Chairperson, 2nd day).

1989 Thirty years of the Cuban Revolution: An Assessment Panel on Sustainable Development and Environment (Chairperson).

1989 Orientation Sessions (0.5 days) for Senior Managers on Environmental Assessment and Review Process Policy and Objectives. Federal Environmental Assessment Review Office (Invited participant, Ottawa training session (2.5 days) head instructor, Halifax, Charlottetown and St. John's).

1989 Initial Environmental Assessment Procedures and Practices. Federal Environmental Assessment Review Office. (Invited participant, Ottawa, head instructor, Halifax, Charlottetown and St. John's)

J. University Grants Administered

[Note: Grants and contracts awarded in U.S. dollars are indicated by an asterisk (*)]

1971 - 1972 Determination of secondary production and the relationship of community structure to productivity using tracer methodology. (with Donald C. McNaught) I.B.P. grant on Lake George to State University of New York at Albany. ($12,000*)

1972 - 1974 The structure and stability of the Gull Lake zooplankton community. Part I. (with R. Levins and G. Lauff) U.S. National Science Foundation, grant to Michigan State University. ($60,000*)

1973 - 1974 Comparisons of three zooplankton communities undergoing various environmental perturbations. National Research Council operating grant to Dalhousie University. ($3,000)

1974 - 1975 The structure and stability of the Gull Lake zooplankton community. Part II. (with R. Levins and G. Lauff) U.S. National Science Foundation grant to Michigan State University. ($37,870*)

1974 - 1975 The *in situ* measurement of the predator-prey dynamics in a neritic zooplankton community (Bedford Basin). National Research Council operating grant to Dalhousie University. ($5,000)

1974 The structure of a marine zooplankton community undergoing perturbation. Dalhousie University Research Development Fund. ($2,500)

1974 - 1975 Application of loop analysis and community matrix analysis to aquatic ecosystems. Part I. Quirk, Lawler, and Matusky Environmental Engineers. Tappan, New York. Grant to Dalhousie University. ($65,250*)

1974 The genetic responses of Gull Lake *Daphnia* spp. to selection pressures induced by eutrophication: an isozyme study. (with E. Zouros) Dalhousie University Research Development Fund. ($6,500)

1975 - 1978 The structure and stability of the Gull Lake zooplankton community. Part III. The evaluation of systems biology in response to the perturbation of eutrophication. (with R. Levins) U.S. National Science Foundation. Two-thirds of grant to Dalhousie University; one-third to Michigan State University. ($90,200*)

1975 - 1976 Application of loop analysis and community matrix analysis to aquatic ecosystems. Part II. and supplemental request plus secretarial assistance ($20,000*). Quirk, Lawler and Matusky Environmental Engineers. Tappan, New York. Grant to Dalhousie University. ($33,150*)

1975 - 1978 The structure and stability of the Bedford Basin zooplankton community. National Research Council operating grant to Dalhousie University. ($30,590)

1975 Application of loop analysis to a set of ecological communities. Dalhousie University Research Development Fund. ($2,400)

1978- 1981 Application of loop analysis to the Bedford Basin ecosystem. National Research Council operating grant to Dalhousie University. ($41,229)

1978 - 1981 The qualitative structure of marine ecosystems and their response to stress. Natural Sciences and Engineering Research

Council of Canada strategic grant to Dalhousie University. ($79,286)

1979 Effective use of the scintillation counter in biological studies. Dalhousie University Research Development Fund. ($10,000)

1980 - 1981 A zooplankton study of three lakes in Kejimkujik National Park in regard to acid precipitation. Environment Canada grant to Dalhousie University. ($8,500)

1980 - 1982 New approaches in evaluating environmental impact in marine ecosystems. (2nd author, with R. Levins and C. Puccia) U.S. Environmental Protection Agency grant to Harvard University. ($311,000*)

1981 - 1982 Cause-effect relationships in planktonic food webs of lakes undergoing acid precipitation. Environment Canada grant to Dalhousie. ($9,545 + approximately $10,000 in support services)

1981 - 1982 Cause and effect in understanding marine pollution. (with R. Levins and R. Morison) National Oceanic and Atmospheric Administration. U.S. Department of Commerce to Harvard University. ($71,000*)

1981 - 1984 Experimental validation of cause and effect relationships in polluted marine ecosystems. Natural Sciences and Engineering Research Council of Canada strategic grant to Dalhousie University. ($106,888)

1982 - 1983 Experimental and theoretical geometry of stressed marine ecosystems. Natural Sciences and Engineering Research Council of Canada operating grant to Dalhousie University. ($10,000)

1982 - 1983 An experimental approach to understanding the effects of acid precipitation, liming, and nutrient enrichment on a lake plankton community. Environment Canada grant to Dalhousie University. ($24,988; approximately $3,000 in support services)

1982 - 1983 A qualitative approach to cause and effect in evaluating marine pollution. National Oceanic and Atmospheric Administration. U.S. Department of Commerce grant to the University of Rhode Island ($164,071*), with subcontract to Dalhousie University. ($27,950*)

1982 - 1984 Qualitative environmental impact assessment: marine plankton communities. U.S. Environmental Protection Agency grant to Dalhousie University. ($93,254*)

1983 - 1984 A qualitative approach to cause and effect in evaluating marine pollution. Year IIIA. Validation of predator-prey pathways, benthic-pelagic coupling and stability criteria. National Oceanic and Atmospheric Administration. U.S. Department of Commerce grant to the University of Rhode Island. ($94,612*)

1983 - 1984 A qualitative approach to cause and effect in evaluating marine pollution. Year IIIB. Data analysis and computer studies. National Oceanic and Atmospheric Administration, U.S. Department of Commerce grant to the University of Rhode Island with the same amount subcontracted to Dalhousie University. ($63,312*)

1983 - 1984 Biogeographic survey of lake plankton in relation to pH range in Nova Scotia. Environment Canada grant to Dalhousie University. ($13,942).

1983 Funding addendum for computer equipment. U.S. Environmental Protection Agency grant to Dalhousie University. ($6,623*)

1984 - 1985 Qualitative food web analysis of lakes 223 and 227 in the Experimental Lakes Area. Natural Sciences and Engineering Research Council of Canada. ($12,000)

1984 - 1986 Qualitative environmental impact assessment: marine plankton communities (Part II). Continuation proposal to U.S. Environmental Protection Agency. ($149,949)

1985 - 1986 Testing hypotheses about vertical migration using the Dalhousie tower tank. Natural Sciences and Engineering Research Council of Canada. ($10,000)

1985 - 1986 Seasonal survey utilization of inshore fish habitats in northeast Nova Scotia. Department of Supply and Services. ($6,325)

1986 - 1987 Modelling of groundfish and pelagic fisheries off Nova Scotia. Department of Fisheries and Oceans. ($9,500)

1986 - 1988 Invertebrate predation and littoral cladoceran community structure. N.S.E.R.C. ($42,000)

1987 - 1988 Part I - Modelling of groundfish and pelagic fisheries off Nova Scotia. Department of Fisheries and Oceans. ($10,000)

1988 - 1989 Part II - Modelling of groundfish and pelagic fisheries off Nova Scotia. Department of Fisheries and Oceans. ($10,000)

1988 - 1989 Part III - Modelling of groundfish and pelagic fisheries off Nova Scotia. Department of Fisheries and Oceans. ($10,000)

1988 - 1989 Quantifying ecosystem risk for a polluted marine harbour. N.S.E.R.C. ($14,000).

Total funds received from 34 grants and contracts listed above:
$1,788,011.00 U.S.
$ 481,193.00 Canadian

K. Professional Societies and Organizations

American Naturalists Society (elected)
American Society of Limnology and Oceanography
Canadian Society for Theoretical Biology
Ecological Society of America
International Association of Theoretical and Applied Limnology
International Society for Ecological Modeling
Nova Scotia Institute of Science
Nova Scotia Society for Academic and Industrial Liaison
Rawson Academy of Aquatic Science (elected)
Society of Canadian Limnologists
Society of Canadian Zoologists
United Nations Association of Canada

[Note: Formerly a member of AAAS, AIBS, International Association for Great Lakes Research, Sigma Xi.]

L. University-Related Professional Service

1. Reviews

a) Papers:

American Midland Naturalist
American Naturalist
Canadian Journal of Botany
Canadian Journal of Fish & Aquatic Sciences
Canadian Journal of Zoology
Canadian Journal Water Research
Ecological Monographs
Ecology
Evolutionary Theory
Limnology and Oceanography
Marine Biology
Science
Water, Air, and Soil Pollution

b) Grant Proposals:

i) ad hoc reviewer for:

U.S. National Science Foundation
Canadian National Sciences and Engineering Research Council
National Oceanic and Atmospheric Administration,
U.S. Department of Commerce
NATO

ii) grant review panel member for:

1979 - 1981 CANUSA (Canadian-U.S. Department of Agriculture) spruce budworm program.

1981 - 1985 Office of Innovative Research. Environmental Biology. U.S. Environmental Protection Agency. (Attended panel meetings Seattle, Washington, April 1983; New Orleans, Louisiana, January 1984; Eugene, Oregon, September, 1984).

2. <u>University Committees, Associations and Service (members unless otherwise indicated)</u>

1973 - present Dalhousie Women's Faculty Organization

1977 - present Dalhousie Faculty Association

1977 - present Canadian Association of University Teachers

1973 - 1974 Committee on Mathematical Biology (interdepartmental group at Dalhousie formed to assist National Research Council in planning future support for this area.

1975 Organizing Committee: Dalhousie Meeting. American Society of Limnology and Oceanography.

1975 - 1977 Teaching Equipment Budget Committee, Department of Biology, Dalhousie University.

1975 - 1977 Graduate Program Committee. Department of Biology, Dalhousie University. Chairperson.

1978 Dalhousie Women's Faculty Organization, Dean Selection Subcommittee.

1979 - 1980 Acting Secretary, Departmental Committee of the Whole. Dalhousie University.

[Note: 1980 - 1982 P. Lane was away at Harvard University.]

1981 Academic Plan Workshop, sponsored by Dean, Harvard School of Public Health, Pine Manor College, Chestnut Hill, Massachusetts. (invited participant)

1983 - 1984 Curriculum Review Committee. Department of Biology, Dalhousie University.

1983 - 1985 Faculty of Arts and Science Tenure Committee. Dalhousie University.

1983 - present Research Overhead Fund Committee, Department of Biology, Dalhousie University. Treasurer. (1983 - 1984).

1984 Dalhousie Women's Faculty Organization, Dean Selection Subcommittee.

1985 Associate Deanship Search Committee. Faculty of Arts and Science. Dalhousie University.

1985 Academic Planning Committee. Department of Biology. Committee Chairperson and Editor of Academic Plan. Dalhousie University.

1985 - 1986 University Committee to Prepare Large Proposal for Diploma Programme in Ocean Studies. Submitted to International Centre for Ocean Studies. (Proposal was successful.) Dalhousie University.

1985 - 1986 Symposium Steering Committee. Assessment of Impacts on Wastewater Discharge on the Marine Environment. Technical University of Nova Scotia. (member)

1986 Search Committee for Administrative Officer. Department of Biology. Dalhousie University.

1986 Symmetry of Natural Communities. Department of Biology (Invited speaker representing departmental ecologists.) Dalhousie University.

1986 - 1987 President's Comparability Committee on the Status of Women at Dalhousie.

1986 - 1987 *Ad Hoc* User Fee Committee. Department of Biology. Dalhousie University.

1986 - 1987 Graduate Programme Committee. Department of Biology. Dalhousie University.

1986 - 1987 Review Committee of the Department of Sociology and Social Anthropology. Faculty of Arts and Science. Dalhousie University.

1986 - 1987	Promotions and Reappointments Committee. Department of Biology. Dalhousie University.
1986 - 1987	Chairperson Adjudication Committee. Faculty of Arts and Science. Dalhousie Unviversity.
1986 - 1987	Steering Committee for ICOD Diploma Program at Dalhousie. Law Faculty. Dalhousie University.
1986 - 1989	Advisory Board and Promotions Committee, School for Resource and Environmental Studies. Dalhousie University.
1987 - 1988	Selection Committee, Director, School for Resource and Environmental Studies. Dalhousie University.
1987 - 1989	Advisory Committee, Marine Affairs Program, Dalhousie University.
1988 - 1990	Chairperson, Teaching Equipment Budget Committee. Department of Biology, Dalhousie University
1989	Financial Strategy Committee. Board of Governors. Dalhousie University.
1989 - 1992	Elected Chair, University Senate, Dalhousie University.
1989	Financial Strategy Committee: Subcommittee on Operating Expenses. Board of Governors. Dalhousie University.
1989	Financial Strategy Commitee: Subcommittee on Statistics. Board of Governors. Dalhousie University.
1989	Chairperson, Joint Senate APC - FPC Subcommittee to Establish Criteria for Program Priorities.
1989 - 1992	Board of Governors. Dalhousie University.
1989 - 1992	Development Committee. Board of Governors, Dalhousie University.
1989 - 1992	Chairperson, Senate Academic Planning Committee. Dalhousie University.
1989 - 1992	Chairperson, Senate Steering Committee. Dalhousie University.
1989 - 1992	Senate Financial Planning Committee. Dalhousie University.

1989 - 1992	Senate Physical Planning Committee. Dalhousie University.
1989 - 1992	Senate Committee on Academic Administration. Dalhousie University.
1989 - 1992	President's Advisory Committee. Dalhousie University.
1989 - 1992	Chairperson, University Teaching Excellence Award Committee. Dalhousie University.
1989 - 1990	Search Committee for Director of School of Education. Dalhousie University.
1989	Meeting of Association of Atlantic Universities on Institutional Role and Planned Capacity of Maritime Universities. Liscombe Lodge, Nova Scotia.

3. <u>Seminars</u>

Acadia University
Bigelow Laboratory, Maine
Dalhousie University
  Department of Biology
  Department of Physiology and Biophysics
  Department of Oceanography
  Institute of Resource and Environmental Studies
Environmental Protection Agency
Electric Power Research Institute
Harvard University
  Center for Population Studies
  Department for Population Sciences
McGill University (3)
  Department of Biology
  Institute of Oceanography
Michigan State University (2)
  W.K. Kellogg Biological Station
Mount Allison University
Radcliffe College
State University of New York, Albany
State University of New York, Binghamton
Technical University of Nova Scotia
University of Alabama
University of British Columbia
University of Chicago
University of Georgia
University of Illinois
  Chicago Circle
University of Massachusetts

University of Michigan
  Department of Zoology
  Great Lakes Research Division
University of Rhode Island
  Department of Zoology
  Graduate School of Oceanography
University of Washington
University of Wisconsin
University of Victoria
Wayne State University
Yale University

4. Other

1969 - 1971	Intensive field work on variety of New York State lakes including Lake Ontario.
1971	Sampling in Lake Baikal, Siberia, USSR.
1972 - 1974	Participant in three field expeditions to study ant competition, community structure and island biogeography in Puerto Rico and adjacent Caribbean Islands. Sponsored by Ford Foundation, University of Chicago and University of Utah.
1972 - 1978	Principal investigator on large field study concerning eutrophication; fish, benthos, plankton, macrophyes, aquatic insects and water chemistry on two Michigan lakes. Maintained laboratories and technical staff in Michigan.
1973 - present	Conducted/managed approximately 30 cruises and field trips off of Nova Scotia coast using vessels from Bedford Institute of Oceanography.
1974	Research presentation to granting agency: U.S. National Science Foundation. Washington, D.C.
1974 - 1976	Served as environmental consultant to Quirk, Lawler and Matusky, Environmental Engineers, Tappan, New York on application to niche analysis to the phytoplankton, zooplankton, benthos and fish larvae in the Hudson River. These communities are undergoing considerable stress from thermal pollution.
1976	Designed and conducted a public survey of multiple usage of Gull Lake, Michigan. Results of questionnaire as well as other scientific results were disseminated to many lay public groups concerned about lake pollution. Gull Lake Environmental Education Project. (with J. Johnson).

1977	Global Resource Resolution Committee. XXnd Congress of the International Association of Limnology. Copenhagen, Denmark.
1978	Served as environmental consultant to MacLaren-Marex, Halifax, Nova Scotia on multivariate statistical approaches to phytoplankton communities in the Davis Strait (analyzed Irving Oil data set).
1978 - present	Principal investigator for series of large mesocosm experiments on perturbations to marine ecosystems using Dalhousie Tower Tank (Aquatron).
1980	Research presentation to granting agency: U.S. Environmental Protection Agency. Washington, D.C.
1980	Invited participant in Harvard Study Group for applying loop analysis to problems in social epidemiology. Workshop in New Hampshire.
1980- 1982	Research collaborator with Dr. Toshihiko Hasegawa of Japan (M.D., Research Fellow at Harvard). Regular meetings to discuss use of qualitative modelling techniques for medical studies.
1981 - 1985	Project manager for ten cruises on Narragansett Bay, Rhode Island using U.S. Coast Guard vessel. Maintained laboratories and technical staff in Rhode Island.
1982	Experimental validation of cause and effect relationships in polluted marine ecosystems. Joint Oceanographic Assembly (SCOR-CMG-IABO-IAMAP-IAPSO-ECOR- CNC) Poster Session. .Department of Oceanography Open House. (with T.M. Collins)
1983	Invited contributor to planning document: Long Range Research Objectives for Environmental Biology for the U.S. Environmental Protection Agency.
1984	Served as chairman of subpanel on Ecological Effects in the Environmental Protection Agency's Long Range Research Agenda Workshop in Environmental Biology. Annapolis, Maryland.
1984	Invited symposium participant. Water Resources Management in Nova Scotia - Priority Issues and Research Needs. Centre for Water Resources Studies, Technical University of Nova Scotia.

1985	Scholarship Selection Committee. International Centre for Ocean Development. (National awards for marine students from developing countries.)
1985	Research presentation on ecosystem level risk analysis. Electric Power Research Institute. Palo Alto, California. (invited speaker; with L. Ginzburg).
1985	Research Discussions - U.S. Office of Naval Research - U.S. National Science Foundation - U.S. Agency for International Development - U.S. Environmental Protection Agency - U.S. Department of Agriculture
1985 - 1986	Symposium Steering Committee. Assessment of Impacts on Wastewater Discharge on the Marine Environment. Technical University of Nova Scotia. (Member)
1986	Research presentations on environmental effects monitoring and ecological risk analysis to Mobil, Husky-BoValley, PetroCan, ESSO, Department of Development, Provincial Department of Environment, Environment Canada, Newfoundland Offshore Board and Department of Fisheries and Oceans, St. John's, Newfoundland. (Invited Speaker)
1986	Research presentation on environmental capacity concept applied to park planning. Parks Canada. Halifax, N.S.
1986	Research presentation on environmental capacity concept applied to sewage pollution in Halifax Harbor. Metropolitan Area Planning Commission. Halifax, N.S.
1987	Research presentation on cumulative effects assessment to Canadian Environmental Assessment Research Council, Ottawa, Ontario and Canadian Wildlife Service and Ducks Unlimited. Edmonton, Alberta.
1988	Advisor to the Rawson Academy for review of the Water Resources Research Programme (for approximately the last ten years) of the Inland Waters Directorate of Environment Canada involving the funding of university research and evaluating the success of the grant program.
1989	Invited guest of COMARNA. Cuban National Commission on Environment and Natural Resources, and six other agencies. Havana, Cuba.

1989 Invited member of Organizing Committee for Workshop on Marine Outfall and Siting Design. Technical University of Nova Scotia.

1989 Research presentation on constructing wetlands to ameliorate acid mine drainage and heavy metal contamination at the Halifax International Airport (Invited by Transport Canada).

M. Teaching Experience (at Dalhousie University unless otherwise noted in parentheses):

1. Courses [A = winter term (1/2 credit); B = spring term (1/2 credit); C = spring and winter terms (1/2 credit); R = spring and winter terms (1 credit); * = graduate class; ** = team taught; enrollment (X); percentage faculty responsibility given in parentheses after class title]

1973 Summer	Biol. 518* (10)	Ecology of Zooplankton (100%) (Michigan State University)
1973 - 1974	Biol. 1060B (45)	Man & His Environment** (50%)
	Biol. 2000R(450)	Diversity of Organisms**16%)
	Biol. 4062B/5062B*(10)	Advanced Ecology Seminar (50%/50%)
1974 - 1975	Biol. 2000R(500)	Diversity of Organisms** (16%)
	Biol. 3061A (60)	Structure & Function of Ecosystems** (25%)
	Biol. 4062A/5062B*(15)	Advanced Ecology Seminar** (50%/50%)
1975 - 1976	Biol. 2000R(500)	Diversity of Organisms** (25%)
	Biol. 3061A (50)	Structure & Function of Ecosystems** (25%)
1977 - 1978	Biol. 2060A/B (90/90)	Introduction to Ecology (100%/100%)
1978 - 1979	Biol. 2060A/B (70/55)	Introduction to Ecology (100%/100%)
	Biol. 5700A*/5701B*(22)	Graduate Seminar Class** (50%)
1979 - 1980	Biol. 2060B (60)	Introduction to Ecology (100%)
	Biol. 3612B/5612B*(19)	Limnology (100%)
	Biol. 4807B(1)	Special Topics: Plankton Dynamics in the Tower Tank (100%)
1980	Special Class (12)	Ecology Portions of summer class for high school teacher** (15%)

1980 - 1982	Pop. Sci. 210C*(10)	Dynamics & Management of Aquatic Systems (Harvard University) (class for medical doctors and health specialists) (100%)
1982 - 1983	Biol. 2060A (61)	Introduction to Ecology (100%)
	Biol. 5700A*(32)	Graduate Seminar Class** (50%)
	Biol.3061B/5061B*(40/2)	Communities & Ecosystems (100%)
	Biol. 5828B*(1)	Special Topics: Benthic Pelagic Coupling (100%)
	Biol. 5652C*(9)	Advanced Ecology Seminar** (10%)
1983 - 1984	Biol. 5700C*(28)	Graduate Seminar Class** (50%)
	Biol. 3061B/5061B*	Communities & Ecosystems (100%)
	Biol. 2060A (42)	Introduction to Ecology (100%)
	Biol. 4616B/5616B*	Ecosystem Analysis (100%)
	Biol.1984R(7)	A Citizen's Guide to Biological Issues** (16%)
	Biol. 5831B*(1)	Special Topics: Marine Plankton Communities (100%)
	Biol. 5652C*(12)	Advanced Ecology Seminar** (10%)
1984 - 1985	Biol. 3061B(25)	Communities and Ecosystems (100%)
	Biol. 2046R(50)	Ecology and Evolution (16%) Computer Simulation and Adaptive Environmental Assessment
	Biol. 5705C(10)	Graduate Stream Course Stream A (33%) Foodwebs
1985 - 1986	Biol. 2066B(75)	Human Ecology (85%)
	Biol. 4616B/ 5616B(6)	Ecosystem Analysis (100%)
1986 - 1987	Biol. 1000(800)	Introductory Biology (15%)
	Biol. 5652C(15)	Graduate Stream Class (12%)
	Biol. 2066B(84)	Human Ecology (100%)
	Biol. 3061B(46)	Communities and Ecosystems (100%)
1987 - 1988	On Sabbatical Leave - No Teaching	
1988 - 1989	Biol. 2066B(182)	Human Ecology (50%)
	Biol. 3061A(24)	Communities and Ecosystems (100%)
	Biol. 5616B(2)	Ecosystem Analysis (100%)
1989-1990	Biol. 2066B(120)	Human Ecology (100%)

[Note: I have also given guest lectures in a number of classes at Dalhousie and two at Harvard.]

2. Laboratory Manuals

1977	Biol.2060A/B	Laboratory Manual for Introductory Ecology. (1st edition) Dalhousie University. (with C. Knight). 139 pp.
1982	Biol. 3061B/5061B	Laboratory Manual for Communities and (1st edition) Ecosystems. Dalhousie University. (with C. Knight and C. Corkett). 120 pp.
1985	Biol. 2066B	Laboratory Manual for Human Ecology. Dalhousie University (with C. Knight and D. Gill). 136 pp.

3. Students

a) Present Students

1988 Michael Paterson. (Ph.D., expected). Predatory relationships and foodweb analysis of a chydorid community. Killam Fellow (M.Sc., Indiana University. Bloomington, Indiana)

b) Past Students

Students who have completed degree requirements under my supervision are: (degree awarded is given in parentheses after name)

1979 William Atherton (M.Sc.). An annual study of the vertical migration patterns in zooplankton of the Bedford Basin. (107 pp.) (B.A., Boston University. Woods Hole, Massachusetts)

1985 Anthony C. Blouin (Ph.D.). Comparative patterns of plankton communities under different regimes of lake acidity in Nova Scotia, Canada. (M.Sc., University of Toronto. Toronto, Ontario)

1983 Richard Bohrer (Ph.D.). Diel activity patterns in marine copepods. (358 pp.) Department of Oceanography, Dalhousie University (Killam Graduate Scholarship Student). (M.Sc., The Johns Hopkins University. Baltimore, Maryland)

1978 Raj Bhanot (Honours, B.Sc.). Digestive enzymes in *Calanus finmarchicus*. (47 pp.)

1989 Terrence M. Collins (M.Sc.). A comparative study of the vertical migration of marine plankton in the field and laboratory. (B.Sc., University of Guelph. Guelph, Ontario)

1986 Annette D'Eon (Honours B.Sc.) Comparison of feeding success in larval sand lance Ammodytes sp. in two regions of Brown's Bank.

1977 Terrence Gallivan (Honours, B.Sc.). The role of fouling organisms in oyster farming in Cape Breton. (60 pp.) (internal supervision only).

1978 Goldie Gibson (M.Sc.). The ecology and feeding biology of the pepod Temora longicornis (Mueller). (104 pp.) (B.Sc., Queen's University. Kingston, Ontario)

1979 Dian Gifford (M.Sc.). The population biology and community ecology of the marine cladocera in Bedford Basin with special reference to the feeding biology of Podon leuckarti (G.O. Sars). (151 pp.) (B.Sc., University of Massachusetts. Boston, Massachusetts)

1975 Kenneth Lee (Honours, B.Sc.). A seasonal analysis of the distribution of phytoplankton pigments in the Bedford Basin. (37 pp.) (Sarah Lawson Botany Scholarship holder).

1975 David MacDonald (Honours, B.Sc.). The effect of invertebrate predation on cyclomorphic cladocerans in Gull Lake. (119 pp)

1985 Terrence Parker (Honours, B.Sc.). Water chemistry and plankton relationships in Halifax urban watershed lakes.

1975 Paul Phinney (M.Sc.). The effects of oil pollution on the green sea urchin. (66 pp.) (B.A., U.C.L.A. at Berkeley. Berkeley, California)

1975 Joe Salter (Honours, B.Sc.). The population dynamics of the copepod Pseudocalanus using field estimators. (46 pp.)

1977 John Skiver (M.Sc.). Resource partitioning patterns of marine copepods. (73 pp.) (B.Sc., Northeastern University. Boston, Massachusetts)

1981 M. Lynne Travers (M.Sc.). A comparison of methods for environmental impact assessment. (343 pp.) (B.Sc., Queens University. Kingston, Ontario).

In 1979, she was selected as 1 of 3 students across Canada to participate in the summer Professional Development Program of the Department of Environmental and Social Affairs of Petro- Canada. Calgary, Alberta.

1985 Kelly Walker (Honours, B.Sc.). The influence of light intensity on phytoplankton settling losses within a marine mesocosm.

c) Students I have supervised who are not at Dalhousie:

1975 Alastair Barber (independent honours project, Reading University, England). The effects of eutrophication on the profundal benthic fauna of Gull Lake, Michigan. (88 pp.)

1975 Anthony Hardaway (B.Sc., Kalamazoo College). Feeding studies of the Gull Lake zooplankton using the Coulter Counter. (103 pp.)

1977 Steven Jubliano (B.Sc., Kalamazoo College). Some aspects of predation by *Chaoborus punctipennis* on crustacean zooplankton. (65 pp.)

1978 Roger Ovink (M.Sc., Michigan State University). The selective feeding of immature bluegills and brook silversides on the zooplankton of Gull Lake, Michigan. (38 pp.)

d) I have served on the supervisory committees of approximately 30 additional students at Dalhousie (one student was in the Department of Physiology and Biophysics). I have also advised one graduate student at the University of Chicago, one graduate student at the University of Rhode Island and one graduate student at Harvard University.

N. Professional and Community Activities Outside Dalhousie University

1974 - present	Give lectures to public school and scout groups concerning aquatic animals and their ecology.
1978 - 1980	Assistant Leader, Scouts Canada.
1977 - 1984	Member, Highland Park Ratepayer's Association.
1979 - present	Member, Nova Scotia Writer's Federation. (1979 - prize for children's story 1976 - present - fiction published under pseudonym)
1980	Invited Panel Member, Sexism in Biology. National Association of Biology Teachers. Boston, Massachusetts.
1981	Participant, United Nations Conference on the Status of Women. New York, New York.
1981 - 1982	Participant, Harvard Faculty Big Sisters Project for Radcliffe College undergraduates.

1982	Invited speaker, Careers for Women in Ecology. Summer Program for Women Science Students. Radcliffe College, Cambridge, Massachusetts.
1982	Invited speaker, Women in Science Program. Great Lakes Research Division, University of Michigan, Ann Arbor, Michigan.
1983 - 1985	Member, Halifax Women's Network
1984 - present	Member, Halifax Board of Trade
1985	Invited speaker, Women in Business Conference. Title: Opportunities for women in the environmental field - offshore and onshore. Atlantic Management Training Centre. Nova Scotia Department of Development, Halifax, Nova Scotia.
1986	Invited speaker, Stresses to Lake Ecosystems. Dartmouth Lakes Advisory Board.
1986	Invited speaker, two public meetings on Salt Marsh Oil-Dispersant Study. Eastern Shore Development Corporation and Lower Chezzetcook Residents.
1988	Co-host of Sir Edmund Hilary Foundation fund-raising dinner and lecture on Mt. Everest climb for Dalhousie students by Sir Edmund Hilary sponsored by P. Lane and Associates Limited at Dalhousie University.
1989 - present	Invited Member, Halifax Harbourside Rotary Club.
1989 - present	Elected Director of International Services, Halifax Harbourside Rotary Club.
1989	Presentation on Sustainable Development in Jamaica -- Impact of Natural Disasters (Hurricane Gilbert as a Case Study), Halifax Harbourside Rotary Club.

HOWARD L. SANDERS
Biologist
Senior Scientist (Emeritus)
Woods Hole Oceanographic Institution

Birth: March 17, 1921

B.A., University of British Columbia, 1949
M.S., University of Rhode Island, 1951
Ph.D., Yale University, 1955

Instructor, 1960-1968, Marine Biological Laboratory
Adjunct Professor of the Biological Sciences, 1969-1975, State University of New York at Stony Brook
Research Associate of the Smithsonian Tropical Research Institute, 1970
Associate in Invertebrate Zoology, 1969-1980, Harvard University
Research Affiliate of the Marine Sciences Research Center, State University of New York at Stony Brook, 1969-1980
Research Associate, 1955-1963; Associate Scientist, 1963-1965; Senior Scientist, 1965-1986, Woods Hole Oceanographic Institution

Correspondent du Museum National d'Histoire Naturalle, 1975 to present
Fellow of the American Association for the Advancement of Science
AAAS Council Delegate of Section G - Biological Sciences, 1980-1982
Member, National Academy of Sciences
Member, Committee on Arthropods for the Smithsonian Oceanographic Sorting Center (SOSC)
Member, Biological Methods Panel of the National Academy of Sciences Committee on Oceanography. Chairman of the Working Group on Benthic Productivity, 1970
Member, Corporation of the Marine Biological Laboratory
Member, Bermuda Biological Station for Research
Member, Review Committee of the Duke University Cooperative Research and Training Program in Biological Oceanography, 1968-1970, Chairman, 1970
Member, National Science Foundation Environmental Biology Advisory Panel, 1966-1968
Member, Advisory Panel of the National Academy of Sciences for the Central American Sea Level Canal, 1969-1970
Participant of NAS/NRC Workshop on Inputs, Fates, and Effects of Petroleum in the Marine Environment, 1973
Member, Visiting Committee of the Ecosystem Center of the Marine Biological Laboratory
Member, Selection Panel for the AAAS-Rosenstiel Award in Oceanography 1975-1976, Chairman, 1976
Participant, NAE/NRC Workshop on Assessment of Safety of Outer Continental Shelf Activities, 1980
Member, Search Committee to Select the Director of the National Museum of Natural History, Smithsonian Institution, 1985

Committee Member, 1985 NAS Gilbert Morgan Smith Medal Award for Excellence of Published Research on Marine or Freshwater Algae
Member, International Association for Biological Oceanography Working Group on "High Diversity Marine Ecosystems", 1986
Board of Supervisors, the City and County of San Francisco, Certificate of Honor, 1983

Editorial Board, Limnology and Oceanography, 1962-1964
Consulting Editor, Pacific Naturalist, 1963-1966
Board of Editors, Journal of Marine Research, 1964-1965

Societies: AAAS, Society of American Naturalists

Research Interests: Ecology as applied to marine benthic communities; crustacean phylogeny; protobranch bivalves; deep-sea biology; oil pollution biology

Author or co-author of about 64 scientific publications

PUBLICATIONS

1952 Sanders, H. L. The herring of Block Island Sound. Bull. Bingham Oceanogr. Coll. 13(3): 220-237.

1955 Sanders, H. L. The Cephalocarida, a new subclass of Crustacea from Long Island Sound. Proc. Nat. Acad. Sci. 41(1): 61-66.

1956 Sanders, H. L. Oceanography of Long Island Sound, 1952-1954. X. The biology of marine bottom communities. Bull. Bingham Oceanogr. Coll. 15: 345-414.

1957 Sanders, H. L. The Cephalocarida and crustacean phylogeny. Syst. Zool. 6(3): 112-128.

1958 Sanders, H. L. Benthic studies in Buzzards Bay. I. Animal-sediment relationships. Limnol. Oceanogr. 3(3): 245-258.

1959 Sanders, H. L. The significance of Cephalocarida in crustacean phylogeny. Proc. XVth Intern. Congr. Zool., pp. 583-584.

1959 Sanders, H. L. New light on the crustaceans. Nat. Hist. 68(2): 86-91.

1959 Sanders, H. L. Sediments and the structure of bottom communities. Intern. Oceanogr. Congr. Preprints, p. 583.

1960 Sanders, H. L. Benthic studies in Buzzards Bay. III. The structure of the soft-bottom community. Limnol. Oceanogr. 5(2): 138-153.

1961 Sanders, H. L. On the status of the Cephalocarida. Crustaceana 2(3): 251.

1961 Sanders, H. L., E. M. Goudsmit, E. L. Mills and G. R. Hampson. A study of the intertidal fauna of Barnstable Harbor, Massachusetts. Limnol. Oceanogr. 7(1): 63-79.

1962 Sanders, H. L. and R. R. Hessler. *Priapulus atlantisi* and *Priapulus profundus*, two new species of priapulids from bathyal and abyssal depths in the North Atlantic. Deep-Sea Res. 9(12): 125-130.

1963 Sanders, H. L. The Cephalocarida. Functional morphology, larval development, comparative external anatomy. Mem. Connecticut Acad. Arts & Sci. 15: 80 pp.

1963 Sanders, H. L. Phylogeny and evolution of Crustacea. Mus. Comp. Zool., Spec. Publ. XIII. Significance of the Cephalocarida, pp. 163-175.

1963 Sanders, H. L. Some observations on the benthonic fauna of the deep-sea. Proc. XVI Intern. Congr. Zool. 4: 311.

1963 Sanders, H. L. The deep-sea benthos. AIBS Bull. 13(5): 61-63.

Publications (continued):

1964 Sanders, H. L. and R. R. Hessler. The larval development of *Lightiella incisa* Gooding (Cephalocarida). Crustaceana 7(2): 81-97.

1964 Hessler, R. R. and H. L. Sanders. The discovery of Cephalocarida at a depth of 300 meters. Crustaceana 7(1): 77-78.

1964 Sanders, H. L. Oceanography of the western South Atlantic. Science 147(3654): 183-184.

1965 Sanders, H. L. Time, latitude, and structure of marine benthic communities. An. da Acad. Brasil de Ciencios 37 (Supl. Setembro de 1965): 83-86.

1965 Sanders, H. L., R. R. Hessler and G. R. Hampson. An introduction to the study of deep-sea benthic faunal assemblages along the Gay Head-Bermuda transect. Deep-Sea Res. 12: 845-867.

1965 Sanders, H. L., P. C. Mangelsdorf and G. R. Hampson. Salinity and faunal distribution in the Pocasset River, Massachusetts. Limnol. Oceanogr. (Alfred C. Redfield 75th Anniv. Vol.) 10: R216-R228.

1965 Hessler, R. R. and H. L. Sanders. Bathyal Leptostraca from the Continental Slope of northeastern United States. Crustaceana 9(1): 71-74.

1966 Sanders, H. L. and R. R. Hessler. Zonation in the benthic fauna of the deep sea. 2nd Intern. Oceanogr. Congress (Moscow). pp. 313-314.

1966 Hessler, R. R. and H. L. Sanders. The diversity of the benthic fauna in the deep-sea. 2nd Intern. Oceanogr. Congress (Moscow), pp. 157-158.

1966 Hessler, R. R. and H. L. Sanders. *Derocheilocaris typicus* Pennak and Zinn revisited. Crustaceana 11: 141-155.

1966 Allen, J. A. and H. L. Sanders. Adaptation to the abyssal life as shown by the bivalve *Abra profundorum* (Smith). Deep-Sea Res. 13: 1175-1184.

1967 Owen, D. M., H. L. Sanders and R. R. Hessler. Bottom photography as a tool for estimating benthic populations. pp. 229-234. In: Deep-Sea Photography, B. Hersey (ed.).

1967 Hessler, R. R. and H. L. Sanders. Faunal diversity in the deep sea. Deep-Sea Res. 14: 65-78.

1968 Sanders, H. L. Marine benthic diversity: a comparative study. Amer. Nat. 102: 243-282.

Publications (continued):

1968 Hessler, R. R. and H. L. Sanders. Life on the floor of the deep-sea (in Romanian). Scinteia 38(7829): 6.

1968 Hessler, R. R. and H. L. Sanders. Faunenmannigfeltigkeit in Tiefseebodengemeinschaften. Umschau. 69 Jahrgang, p. 87.

1969 Allen, J. A. and H. L. Sanders. *Nucinella serrei* Lamy (Bivalvia: Protobranchia) a monomyarian solemyid and possible living actinodont. Malacolgia 7: 381-396.

1969 Sanders, H. L. Benthic marine diversity and the stability-time hypothesis. Brookhaven Symposia in Biology 22: 71-81.

1969 Sanders H. L. and R. R. Hessler. The ecology of the deep-sea benthos. Science 163: 1419-1424.

1969 Sanders, H. L. and R. R. Hessler. Diversity and composition of the abyssal benthos. Science 166: 1034.

1969 Slobodkin, L. B. and H. L. Sanders. On the contribution of environmental predictability to species diversity. Brookhaven Symposia in Biology 22: 82-95.

1969 Hampson, G. R. and H. L. Sanders. Local oil spill. Oceanus 15: 8-11.

1970 Hessler, A. Y., R. R. Hessler and H. L. Sanders. Reproductive system of *Hutchinsoniella macracantha*. Science 168: 1464.

1971 Blumer, M., H. L. Sanders, J. F. Grassle and G. R. Hampson. A small oil spill. Environment 13: 1-12.

1971 Sanders, H. L. and J. F. Grassle. The interrelationships of diversity distribution, and mode of reproduction among major groupings of the deep-sea benthos. Proc. Joint Oceanogr. Assembly (Tokyo, 1970): 260-262.

1972 Jones, N. S. and H. L. Sanders. The distribution of Cumacea in the deep Atlantic. Deep-Sea Res. 19: 737-745.

1973 Sanders, H. L. and J. A. Allen. Studies on deep-sea Protobranchia. Prologue and the Pristiglomidae. Bull. Mus. Comp. Zool. 145: 237-261.

1973 Allen, J. A. and H. L. Sanders. Studies on deep-sea Protobranchia. The families Siliculidae and Lametilidae. Bull. Mus. Comp. Zool. 145: 263-309.

1973 Hessler, R. R. and H. L. Sanders. Two new species of *Sandersiella* (Cephalocarida), including one from the deep sea. Crustaceana 24: 181-196.

1973 Grassle, J. F. and H. L. Sanders. Life histories and the role of disturbance. Deep-Sea Res. 20: 643-659.

Publications (continued):

1974 Sanders, H. L. The West Falmouth Oil Spill Saga. New Engineer 3(5): 32-41.

1975 Grassle, J. F., H. L. Sanders, R. R. Hessler, G. T. Rowe and T. McLellan. Pattern and zonation: a study of the bathyal megafauna using the research submersible ALVIN. Deep-Sea Res. 22: 457-481.

1975 Turekian, K. K., J. K. Cochran, D. P. Kharkar, R. M. Cerrato, H. L. Sanders, J. F. Grassle and J. A. Allen. Slow growth rate of a deep-sea clam determined by ^{228}Ra chronology. Proc. Nat. Acad. Sci. 72(7): 2829-2832.

1977 Sanders, H. L. and J. A. Allen. Studies on deep-sea Protobranchia (Bivalvia); the family Tindariidae and genus *Pseudotindaria*. Bull. Mus. Comp. Zool. 148(2): 23-59.

1977 Sanders, H. L. The West Falmouth Spill - FLORIDA, 1969. Oceanus 20(4): 15-24.

1977 Sanders, H. L. Evolutionary ecology and the deep-sea benthos. In: The Changing Scenes in Natural Sciences, 1776-1976. C. E. Goulden (ed.). Academy of Natural Sciences Spec. Publ. Philadelphia, pp. 223-243.

1978 Sanders, H. L. FLORIDA oil spill impact on the Buzzards Bay benthic fauna: West Falmouth. Jour. Fish. Res. Bd. Canada 35(5): 717-730.

1979 Grassle, J. F., H. L. Sanders and W. K. Smith. Faunal changes with depth in the deep-sea benthos. Deep Sea - Ecology and Exploitation. Ambio Special Report No. 6: 47-50.

1979 Grassle, J. F., C. J. Berg, J. J. Childress, J. P. Grassle, R. R. Hessler, H. W. Jannasch, D. M. Karl, R. A. Lutz, T. J. Michel, D. C. Rhoads, H. L. Sanders, K. L. Smith, G. N. Somero, R. D. Turner, J. H. Tuttle, P. J. Walsh and A. J. Williams. Galapagos '79: Initial findings of a deep-sea biological quest. Oceanus 22(2): 1-10.

1979 Sanders, H. L. Evolutionary ecology and life-history patterns in the deep sea. Sarsia 64: 1-7.

1980 Sanders, H. L., Grassle, J. F., G. R. Hampson, L. S. Morse, S. Garner-Price and C. C. Jones. Anatomy of an oil spill: long-term effects from the grounding of the barge FLORIDA off West Falmouth, Massachusetts. Jour. Mar. Res. 38(2): 265-380.

1981 Sanders, H. L. Environmental effects of oil in the marine environment, pp. 117-146. In: Safety and Offshore Oil: Background Papers of the Committee on Assessment of Safety of OCS Activities. Marine Board, Assembly of Engineering, National Research Council, National Academy Press, Washington, D.C.

MICHAEL KAVANAUGH
4015 Benton Street NW #4
Washington, D.C. 20007
(202) 965-3455

EDUCATION

1975	Ph.D., Economics, University of Cincinnati
1970	B.A., Economics, Xavier University

EXPERIENCE

Dr. Kavanaugh is an independent consulting economist in Washington, D.C. From 1983 to 1985, he was a senior economist at ICF Incorporated. From 1976 to 1983, he was a senior economist and director of research at the Public Interest Economics Center in San Francisco and in Washington D.C. From 1971 to 1976, Dr. Kavanaugh taught economics at the University of Cincinnati and at Northern Kentucky University.

Dr. Kavanaugh's technical expertise is in applied microeconomics, primarily natural resource and environmental economics. He has qualified as an expert witness in state and Federal courts-of-law, and has testified before committees of the U.S. Senate and U.S House of Representatives. His experience includes the following.

1. Environmental Economics

-- Forecasted global and regional emissions of CO, N_2O, and NO_x. The estimates were made by forecasting global energy use and combustion technology by fuel, sector, region, and year. The estimates were used in developing the EPA's Stratospheric Ozone Protection Plan and used by members of the scientific community to predict future atmospheres.

-- Analyzed the economic benefits to society of the substitution of hydrocarbon propellants for CFC propellants in aerosol products. The substitutions resulted, in part, from regulations designed to protect stratospheric ozone.

-- Forecasted current and future NO_x emissions from airplanes. The work involved estimating the size and composition of the world aircraft fleet, likely jet engine technology, and flight patterns.

-- Designed alternative tax systems for funding Superfund. The work was part of the EPA's efforts to win reauthorization of legislation.

-- Calculated the amount of the civil penalty for violating effluent standards promulgated under the Clean Water Act. A computerized after-tax cash-flow model was built.

2. Resource Economics - Water

-- Directed the preparation of estimates of expected and realized benefits and costs of ten irrigation projects.

-- Developed and applied a method to determine the effects of water quality policies on agricultural output, employment and income in central California.

-- Designed and executed a research project to estimate the benefits of preserving groundwater quality in several counties in the Southwest. The work influenced the development of the EPA's Groundwater Protection Plan.

3. Resource Economics - Oil and Gas

-- Estimated the size of the coastal segment of the oil and gas industry for the U.S. Environmental Protection Agency (EPA). The work involved building and manipulating a computerized data base.

-- Analyzed the costs of EPA's proposed effluent guidelines and standards for the offshore segment of the oil and gas industry. The work included reviewing and synthesizing technical literature on production costs and forecasts of recoverable reserves.

-- Updated a U.S. Department of Interior proprietary computer model used to evaluate OCS bonus bids. The effort involved working with specialists from other disciplines to estimate in a monte-carlo framework the probable after-tax cash flows from any OCS tract.

-- Conducted an analysis of the regional effects of OCS Lease Sale #35 (Santa Barbara, Ventura, and Los Angeles counties) for the Governor's Office of Planning and Research (California). Estimates of resource recovery over time were prepared and expressed in terms of regional income and employment. The work was extended to include Lease Sale #53 (Monterey county).

-- Advised and submitted affidavits supporting the State of Alaska's position in a court case involving oil and gas leasing in the North Aleutian Basin. A computerized after-tax cash-flow model for Alaskan oil fields was constructed as part of this effort.

-- Critiqued and prepared comments on the Secretarial Issue Documents for the 5-Year OCS Leasing schedules issued in 1979, 1982, and 1986.

-- Testified before the House Committee on Merchant Marine and Fisheries (April 1983, May 1985) on how pricing and production changes in the world oil industry would influence the location, timing, and pace of OCS leasing.

-- Testified before the Energy and Environment Conference Committee in opposition to the 1982 5-Year OCS Leasing Program.

-- Calculated the loss to the Federal Treasury from an expanded and accelerated OCS leasing schedule.

4. Transportation

-- Qualified as an expert witness and submitted verified statements for the Interstate Commerce Commission's Office of Special Counsel in the following mergers: Union Pacific/ Missouri Pacific/Western Pacific and; Southern Railway/Norfolk & Western.

-- Prepared comments on ICC rulemakings involving boxcar deregulation and pricing of car hire charges.

-- Directed and conducted a prospective analysis of the effects on rail rates, coal markets, the freight car fleet, and local economies of deregulating the railroad industry.

-- Prepared portions of a brief challenging a Civil Aeronautics Board ruling involving an international air carrier.

-- Testified before committees of the U.S. House of Representatives on the economic consequences of enacting cargo preference legislation for the transportation of dry bulk commodities.

-- Investigated the influences on the market share of diesel automobiles and light trucks.

-- Forecasted the market for asbestos brake linings used by automobiles and light trucks.

5. Other

-- Testified in Federal and Superior courts-of-law to the economic losses suffered by victims of discrimination, wrongful imprisonment, and malpractice.

-- Testified before committees of the U.S. Senate and House of Representatives on the economic consequences of permitting the beer industry to establish exclusive territorial distributorships.

SELECTED PUBLICATIONS

Estimates of future CO, N_2O and NO_x emissions from energy combustion, Atmospheric Environment, March 1987.

Tropospheric $CH_4/CO/NO_x$: The next 50 years. coauthor with Anne M. Thompson. Presented at UNEP/USEPA International Ozone Conference, 1986.

Future concentrations of atmospheric methane based on assumed fluxes of CH_4, CO, and NO_x. coauthor with Anne M. Thompson. Presented at 1986 AGU Spring Meeting, Baltimore 1986.

Eliminating CFCs from aerosol uses: the U.S. experience and its applicability to other nations. U.S. Environmental Protection Agency, Washington, February 1986.

Efficient strategies for preserving groundwater quality, with Rob Wolcott. U.S. Environmental Protection Agency, May 1982.

The effect of OCS leasing schedules and procedures on fair market value. Paper presented to the Western Economic Association, Seattle July 1983.

Regional economic impacts of OCS oil and gas development. with Susan Little and Rob Wolcott. Governor's Office of Planning and Research, California, November 1976.

Exclusive territorial distributorships and consumer welfare: the case of beer. Food Marketing Institute, Washington D.C. June 1982.

The Great Giveaway, with others, Sierra Club, October 1982.

Summary: Public Interest Economics' research findings on railroad deregulation, with Allen Ferguson and Steve Buchanan. Prepared for the Federal Railroad Administration, Washington, June 1980.

Summary: eight case histories of water claimation projects. U.S. Department of Interior, January 1982.

The public benefits of the proposed Union Pacific, Missouri Pacific, Western Pacific Consolidation. Interstate Commerce Commission, August 1981

The 1983 world oil surplus: some implications for OCS leasing. Prepared for the U.S. House Subcommittee on the Panama Canal/OCS Washington April 1983.

ABBREVIATED VITA

HOWARD M. LILJESTRAND
Associate Professor
Raymond F. Dawson Centennial Fellow

THE UNIVERSITY OF TEXAS AT AUSTIN
Environmental and Water Resources Engineering Group
ECJ 8.214, Austin, TX 78712-1076
(512) 471-4604

EDUCATION AND PROFESSIONAL EXPERIENCE

1971-1974	B.A., Rice University, Environmental Science and Engineering, Minor in Biochemistry
1974-1980	Ph.D., California Institute of Technology, Environmental Engineering Science, Minor in Chemistry
1979-1980	Assistant Professor of Civil Engineering., California State University at Los Angeles
1980-1985	Assistant Professor of Civil Engineering, University of Texas at Austin
1985-	Associate Professor of Civil Engineering, University of Texas at Austin

PROFESSIONAL AFFILIATIONS

Air Pollution Control Association, Source-Receptor Modeling Committee
American Association for the Advancement of Science
American Chemical Society, Environmental Chemistry Division
American Society of Civil Engineers
Sigma Xi
Tau Beta Pi

REFEREED PUBLICATIONS

Liljestrand, H. M., Morgan, J. J. (1978) "Chemical Composition of Acid Precipitation in Pasadena, CA," Environmental Science and Technology, 12, 1271-3.

Liljestrand, H. M., Morgan, J. J. (1979) "Error Analysis Applied to Indirect Methods for Precipitation Acidity," Tellus, 31, 421-431.

Barcelona, M. J., Liljestrand, H. M., Morgan, J. J. (1980) "Determination of Low Molecular Weight Volatile Fatty Acids in Aqueous Samples," Analytical Chemistry, 52, 321-325.

Liljestrand, H. M., Morgan, J. J. (1980) "Modeling the Chemical Composition of Acid Rain in Southern California," Environmental Science Research, 17, 109-122.

Liljestrand, H. M., Morgan, J. J. (1981) "Spatial Variations of Acid Precipitation in Southern California," Environmental Science and Technology, 15, 333-8.

Liljestrand, H. M., Morgan, J. J. (1982) "Chemical Source, Equilibrium and Kinetic Models of Acid Precipitation in Southern California," in Energy and Environmental Chemistry, L. H. Keith, ed., Ann Arbor Science, 2, 103-122.

Stafford, M. A., Liljestrand, H. M. (1982) "Ambient Particulate Matter Contributions to Acidic Precipitation," in Receptor Models Applied to Contemporary Problems, Air Pollution Control Association, Special Publication 48, 200-211.

Liljestrand, H. M. (1982) "Acidic Precipitation Source Identification by Chemical Mass Balance Methods Employing Fractionation Factors," in Receptor Models Applied to Contemporary Problems, APCA, SP-48, 212-223.

Feeley, J. A., Liljestrand, H. M. (1983) "Source Contributions to Acid Precipitation in Texas," Atmospheric Environment, 17, 807-814.

Liljestrand, H. M. (1985) "Average Rainwater pH, Concepts of Atmospheric Acidity, and Buffering in Open Systems," Atmospheric Environment, 19, 487-499.

Bowders, J. J., Daniel, D. E., Broderick, G. P., Liljestrand, H. M. (1986) "Methods for Testing the Compatibility of Clay Liners with Landfill Leachate," in Hazardous and Industrial Solid Waste Testing: Fourth Symposium, ASTM, J. K. Petros, Jr., W. J. Lacy, and R. A. Conway, eds., ASTM, STP 886, 233-250.

Liljestrand, H. M., Mohr, J. D., Stafford, M. A. (1986) "Methods for the Validation of Precipitation pH: Applications to Texas Data," Journal of Environmental Science and Health Part A - Environmental Science and Engineering, 21(2), 121-146.

Stafford, M. A., Lilje-trand, H. M. (1988) "The Use of Fractionated Coarse and Fine Fingerprints for the Source Apportionment of PM-10," in Receptor Models in Air Resources Management, APCA, SP-66, 180-191.

Daniel, D. E., Liljestrand, H. M., Broderick, G. P., Bowders, J. J. (1988) "Interaction of Earthen Liner Materials with Industrial Waste Leachate," Hazardous Waste and Hazardous Materials, 5(2), 93-108.

Shackelford, C. D., Daniel, D. E., Liljestrand, H. M. (1989) "Diffusion of Inorganic Wast Constituents in Compacted Clay," Journal of Contaminant Hydrology, in press.

OTHER PUBLICATIONS

Charbeneau, R. J., Liljestrand, H. M. (1983) "Vertical Migration of Organic Pollutants During Infiltration," in Frontiers in Hydraulic Engineering, H. T. Shen, ed., ASCE, 48-53.

INVITED PRESENTATIONS

June 1983 "Precipitation Scavenging, " speaker at the Gordon Research Conference Environmental Sciences - Air, "Biogeochemical Cycles and the Atmosphere."

PREVIOUS REVIEWS OF ACID DEPOSITION

University Corporation for Atmospheric Research review of NAPAP Task Groups A, I C, and D, leader of review of Task Group D (Deposition Monitoring), Boston MA, August, 1983.

Research and Evaluation Associates, Inc. review of USEPA-ASRL activities in NAP/ Task Groups D and G, dry deposition and material effects, member of review, Raleigh, NC, April, 1985.

North Carolina State University review of NAPAP Task Groups A, B, C, and D, mem of Task Group D review, Boulder Colorado, September, 1985.

Peer Consultants, Inc., review of USEPA-EMSL dry deposition monitoring network, leader of review, Raleigh, NC, February, 1987.

Acid Deposition, member of Science Advisory Board, Calgary, Alberta.

Peer Consultants, Inc., review of NAPAP Task Groups D, leader of review, Austin, Texas, April, 1988.

Biographical Sketch of

Don K. Button

Education: University of Wisconsin, Ph.D., 1964, Biochemistry. University of Wisconsin, M.S., 1961, Biochemistry. University of Wisconsin, Superior, B.S., 1955, Chemistry, Physics

Professional: American Association for Biochemistry and Molecular Biology. Society for Analytical Cytology. American Chemical Society. American Society for Microbiology. American Society for Limnology and Oceanography. American Association for the Advancement of Science. Sigma Xi. Phycological Society of America. Society for Analytical Cytology.

Activities: Current commercial land and sea plane pilot. Civil Air Patrol. Editorial Board of Applied and Environmental Microbiology, regular referee for several journals.

Positions: Professor of Marine Science and Biochemistry, Institute of Marine Science, Department of Chemistry, University of Alaska Fairbanks, 1964 to present. Associate - University of Groningen, Holland, 1982. Visiting Scientist - Scripps Institution of Oceanography, 1978. Visiting Professor of Chemistry - University of Notre Dame, 1977. University of Colorado, Medical School, Department of Biophysics, 1969.

Publications

Button, D. K. and B. R. Robertson. 1989. Kinetics of bacterial processes in natural aquatic systems based on biomass as determined by high-resolution flow cytometry. Cytometry, 10:558-563.

Druehl, L. D., B. R. Robertson, and D. K. Button. 1989. Characterizing and sexing laminarialean meiospores by flow cytometry. Marine Biology, 101:451-456.

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Button, D. K. and F. Jüttner. 1987 Pollution-damaged trees, how northern air isn't so pure. Most Alaskan daily newspapers.

Robertson, B. R. and D. K. Button. 1979. The phosphate-limited continuous culture of *Rhodotorula rubra:* kinetics of transport, leakage and growth. J. Bacteriol. 138: 884-895.

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Brown, E. J. and D. K. Button. 1979. A simple method for arsenic speciation. Bull. Environ. Contam. Toxicol. 21: 37-42.

Arhelger, S. D., B. R. Robertson, and D. K. Button. 1977. Arctic hydrocarbon biodegradation, pp. 270-275. In D. A. Wolfe (ed.), Fate and effects of petroleum hydrocarbons in marine organisms and ecosystems. Pergamon.

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Brown, E. J., P. B. Reichardt, and D. K. Button. 1976. Low level chlorinated hydrocarbon effects on aquatic micro-organisms, pp. 344-356. In D. W. Norton (ed.), Science in Alaska II. AAAS.

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Button, D. K. 1976. The influence of clay and bacteria on the concentration of dissolved hydrocarbon in saline solution. Geochim. Cosmochim. Acta 40: 435-440.

Button, D. K. and others. 1975. *In* Petroleum in the marine environment. National Academy of Sciences, Washington. 107 pp.

Button, D. K., J. Barry Egan, W. Hengstenberg, and M. L. Morse. 1973. Carbohydrate transport in *Staphylococcus aureus* IV. Maltose accumulation and metabolism. Biochem. Biophys. Res. Commun. 52: 850-855.

Button, D. K. 1973. Hydrocarbon biodegradation kinetics, pp. 603-618. In Proceedings, National Academy of Sciences Workshop on inputs, fates and effects of petroleum in the marine environment, Arlie, Va.

Robertson, B., S. Arhelger, P. J. Kinney, and D. K. Button. 1973. Hydrocarbon biodegradation in Alaskan waters, pp. 171-184. In D. G. Ahearn and S. P. Meyers (eds.), Microbial degradation of oil pollutants. Center for Wetland Resources, Louisiana State University.

Button, D. K., S. S. Dunker, and M. L. Morse. 1973. Continuous culture of *Rhodotorula rubra.* Kinetics of phosphate-arsenate uptake, inhibition and phosphate limited growth. J. Bacteriol. 113: 599-611.

CURRICULUM VITAE

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PERSONAL INFORMATION

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Social Security Number: 533-54-0273
Birthdate: June 23, 1949

EDUCATION

Washington State University
- B.S. (Agricultural Engineering) 1971
- M.S. (Hydraulic Engineering) 1973

California Institute of Technology
- Ph.D. (Civil Engineering) 1977

PROFESSIONAL EXPERIENCE

U.S. Geological Survey, Water Resources Division: Summer Employment 1970

Washington State University
- Research Assistant: Numerical Modeling of Irrigation Advance 1970-1971
- Research Assistant: Prediction of Turbulent Flow in Rough Conduits 1971-1973

California Institute of Technology
- Research Assistant: Propagation of Tsunami Waves 197
- Research Assistant: Buoyant Jets and Plumes in Stratified Crossflows 1973-1977
- Research Engineer: San Francisco Outfall Model Study 1977

University of Michigan
- Assistant Professor 1977-1983
- Associate Professor 1983-present

TEACHING AND RESEARCH ACTIVITIES

Graduate Courses Taught

- Open Channel Hydraulics
- Coastal Hydraulics
- Groundwater Hydraulics
- Turbulent Mixing Processes
- Design of Hydraulic Systems

Short course on "Advanced Groundwater Hydraulics" with Jacob Bear, 1980

PUBLICATIONS

Book:

"Essentials of Engineering Fluid Mechanics," 5th edition, R. M. Olson and S. J. Wright, Harper and Row, Publishers

Refereed Publications:

"Submerged Turbulent Jets in Linearly Stratified Fluids," (with D.R. Wong) Journal of Hydraulic Research, Vol. 26, No. 2, 1988, pp. 199-223.

"Application of Variably Saturated Flow Theory to Clay Cover Liners", (with C.J. Miller) ASCE, Journal of Hydraulic Engineering, Vol. 114, No. 10, 1988, pp. 1283-1300.

Discussion of "Wastewater Field Thickness and Initial Dilution", Journal of Hydraulic Engineering, Vol. 111, 5, 1985, pp. 891-896.

"Field Application and Comparison of Three Mass Transport Models", (with D.A. Hamilton and D.C. Wiggert), ASCE Journal of Hydraulic Engineering, Vol. 111, 1985, pp. 1-11.

"Spreading Layer of a Two-Dimensional Buoyant Jet", (with R.B. Wallace), ASCE Journal of Hydraulic Engineering, Vol. 110, 6, pp. 813-828, 1984.

"Buoyant Jets in a Density-Stratified Crossflow", Journal of Hydraulic Engineering, Vol 110, 5, pp. 643-656, 1984.

"Preliminary Study: The Diversion of 282 m^3/sec (10,000 cfs) from Lake Superior to the Missouri River Basin", (with J.W. Bulkley and D. Wright), Journal of Hydrology, Vol. 68, pp. 461-472, 1984.

"Optimal Cost Control Strategies for Attached Algae", (with R.P. Canale, M.T. Auer, Y. Matsuoka, and T.M. Heidtke), ASCE Journal of Environmental Engineering, Vol. 109, pp. 1225-1242, 1983.

"Matched Impedance to Control Fluid Transients", (with E.B. Wylie and L.B. Taplin), ASME Journal of Fluids Engineering, Vol. 105, pp. 219-224, 1983.

Discussion to "Vertical Round Buoyant Jet in Shallow Water" (with P.J.W. Roberts), ASCE Journal of Hydraulic Engineering, Vol. 109, 3, pp. 490-494, 1983.

"Outfall Diffuser Behavior in Stratified Ambient Fluid", (with R.B. Wallace, D.R. Wong and K.E. Zimmerman), Journal of the Hydraulics Division, ASCE, Vol. 108, pp. 483-501, 1983.

Discussion of "Forced Plume in Stratified Reservoir", Journal of the Hydraulics Division, ASCE, Vol. 105, pp. 281-283, 1979.

Conference Proceedings

"An Alternate Theory of Density Current Propagation," (with Y. Kim and J. Bühler), Proceedings, National Conference on Hydraulic Engineering, Colorado Springs, Colorado, 1988, pp. 183-188.

"Outfall Plume Dilution in Stratified Fluids: A Comparison Between Field and Laboratory Data", (with P.A. Mangarella and J.M. Colonell," Proceedings, International Symposium on Model-prototype Comparison of Hydraulic Structures, Colorado Springs, Colorado, 1988

"A Revised Theory of Density Current Propagation," (with Y. Kim), Proceedings, First National Fluid Dynamics Conference, Cincinnati, Ohio, 1988, Vol. 3, pp. 2020-2027.

"Dilution of Submerged Round Buoyant Jets in Shallow Water," (with Z. Yan) Proceedings Engineering Mechanics Division Specialty Conference, Buffalo, New York, 1987.

"Wave Energy Absorbing Honeycomb Structures," (with C. N. Papadakis) Proceedings 2nd International Conference on Coastal and Port Engineering in Developing Countries, Beijing, China, 1987

"Controls of Density Current Propagation" (with J. Bühler and Y. Kim) Proceedings of 3rd IAHR Symposium on Stratified Flows, Los Angeles, California, 1987, pp.

"Control of Buoyant Jet Mixing by Far Field Spreading", (with J. Bühler) Proceedings of Symposium on Advancements in Aeronautics, Fluid Mechanics, and Hydraulics, Minneapolis, Minnesota, 1986, pp. 736-743.

"Submerged Turbulent Buoyant Jets in Stratified Fluids", (with D.R. Wong) Proceedings ASME International Symposium on Jet and Wake Flows, Miami, Florida, 1985, pp. 141-152.

"Global Constraints on Buoyant Jet Mixing in Confined Environments" Proceedings International Symposium on Refined Flow Modeling and Turbulence Measurements, Iowa City, Iowa, 1985, Chapter A13

"Modeling Contaminant Migration Under the Influence of a Series of Pumping Wells", Proceedings Conference on Practical Applications of Groundwater Models, Columbus, Ohio, 1984.

"Predicting Leakage Through Clay Landfill Covers", (with C.P. Miller) Proceedings ASCE National Conference on Environmental Engineering, Los Angeles, California, pp. 708-710, 1984.

"Analysis of Low Discharge Velocity Outfall Diffuser", (with S.W. Verhoff and Tang Chun Xi) Proceedings ASCE National Conference on Environmental Engineering, Los Angeles, California, pp. 644-649, 1984.

"An Entrainment Model for Buoyant Jet Discharges", Proceedings, Heat Transfer and Fluid Mechanics Conference, Pullman, Washington, pp. 313-329, 1978.

"Effects of Ambient Current and Density Stratification on Buoyant Jets", Proceedings of the ASCE Hydraulics Division Specialty Conference, College Station, Texas, pp. 336-343, 1977.

"Analysis of Flow in Channels with Gravel Beds", (with J.A. Roberson), Proceedings of the ASCE Hydraulics Division Specialty Conference, Bozeman, Montana, pp. 63-72, 1973.

with 600 transects, the spatial resolution of the sampling will be limited. In order to have better understanding several sites need to be examined in greater detail.

Detailed studies regarding microbial diversity changes as a result of the oil spill is necessary. An ecology cannot be examined without studying the bottom of the food chain. Laboratory studies examining the influence of oil on microbial diversity combined with measured changes in microbial populations at the spill location will aid in determining impact. In addition, long term studies regarding the recovery of microbial populations in the spill area are needed.

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EDUCATION:

Ph.D. Environmental Engineering and Science, Stanford University, 1987.
M.S. Chemical Engineering, Stanford University, 1982.
M.S. Environmental Engineering and Science, Stanford University, 1980.
B.S. Chemistry, Stanford University, 1980.

PROFESSIONAL EXPERIENCE:

Assistant Professor, Environmental and Water Resources Engineering, The University of Michigan, May, 1988 to present.

RESEARCH INTERESTS:

My primary research interests are focused on the effects that mineral surfaces and interfacial properties have on transport and transformation processes of environmental contaminants. Topics of interest include: physical/chemical processes for the removal of hazardous contaminants from water, wastewater, and groundwater environments; modeling the transport, removal, and fate of hazardous pollutants in natural and engineered aquatic environments; mechanism of reactions at the mineral/aqueous interfaces including adsorption, dissolution/precipitation, oxidation/reduction, and surface catalysis; relaxation kinetics of ion adsorption at the mineral/water interface; the influence of interfacial properties on two-phase liquid flow of organic contaminants in groundwater;; surface spectroscopic investigations of interfacial reactions; and investigations of the physico-chemical processes which control the extent and rate of sorption/desorption of inorganic contaminants.

SOCIETY MEMBERSHIPS:

Association of Environmental Engineering Professors
American Chemical Society
American Institute of Chemical Engineers
American Geophysical Union
Member of Society Sigma Xi

ACADEMIC HONORS:

NSF (National Science Foundation) Presidential Young Investigator Award Recipient 1989.
USAF (United States Air Force) Summer Faculty Research Program Award Recipient, 1989.
Edward Francis Jones Memorial Scholarship, Stanford University, 1986.
Charles D. Marx and H.S. Moreno Memorial Fellowship, Stanford University, 1985-86.
Leon Benedict Reynolds Scholar, Stanford University, 1984-1985.
Japanese Monbusho Scholarship Recipient, Department of Chemistry, Hiroshima University, Japan, 1983-1984.

PUBLICATIONS

a. Refereed Journals, Books and Symposium Proceedings:

K.F. Hayes and W.E. Kaskan, "Inhibition of CH4/Air Flames Stabilized on a Porous Bomer with CH3Br," Combustion and Flame, 24, 405-407, 1975.

M.M. Benjamin, K.F. Hayes, and J.O. Leckie, "Removal of Toxic Trace Elements from Power Plant Generation Wastestreams by Adsorption and Coprecipitation," J. Water Poll. Control Fed., 54, 1472-1481, 1982.

N. Mikami, M. Sasaki, T. Yasunaga, and K.F. Hayes, "Kinetic Studies on the Intercalation-Deintercalation of Alkali Metal Ions in γ-Zirconium Phosphate Using the Pressure-Jump Technique," J. Phys. Chem., 88, 3229, 1984.

H. Negishi, M. Sasaki, T. Iwaki, K.F. Hayes, and T. Yasunage, "Kinetic Study of Adsorption-Desorption of Methanol on H-ZSM-5 Using a New 'Gas Concentration Jump' Technique," J. Phys. Chem., 88, 5564-5569, 1984.

N. Mikami, M. Sasaki, N. Kawamura, K.F. Hayes, and T. Yasunaga, "Intercalation Kinetics of Alkali-Metal Ions into α-Zirconium Phosphate Using the Pressure-Jump Technique," J. Phys. Chem., **90**, 2757-2761, 1986.

K.F. Hayes and J.O. Leckie, "Mechanism of Lead Ion Adsorption at the Goethite/Water Interface," in "Geochemical Processes at Mineral Surfaces," ACS symposium Series no. 323, Chapter 7, 1986.

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K.F. Hayes and J.O. Leckie, "Modeling Ionic Strength Effects on Cation Adsorption at Hydrous Oxide/Solution Interfaces," J. Coll. Interf. Sci., **115**, 564-572, 1987.

K.F. Hayes, L.A. Roe, G.E. Brown, Jr., K.O. Hodgson, J.O. Leckie, and G.A. Parks, "In-Situ X-Ray Absorption Study of Surface Complexes at Oxide/Water Interfaces: Selenium Oxyanions on α-FeOOH," Science, **238**, 783-786, 1987.

K.F. Hayes, L. Papelis, and J.O. Leckie, "Modeling Ionic Strength Effects on Anion Adsorption at Hydrous Oxide/Solution Interfaces," J. Coll. Interf. Sci., **125**, 717-726, 1988.

C. Chisholm-Brause, A.L. Roe, K.F. Hayes, G.E. Brown, Jr., G.A. Parks, and J.O.Leckie, "XANES and EXAFS Study of Aqueous Pb(II) Adsorption, Physica B, in press, 1989.

C. Chisholm-Brause, K.F. Hayes, A.L. Roe, G.E. Brown, Jr., G.A. Parks, and J.O. Leckie, Structure of Pb(II) Complexes at the γ-Al_2O_3/Water Interface, Submitted to Geochimica et Cosmochimica Acta.

L.A. Roe, K.F. Hayes, C. Chisholm, G.E. Brown, K.O. Hodgson, G.A. Parks, and J.O. Leckie, "In-Situ X-Ray Absorption Study of Lead Ion Surface Complexes," submitted for publication to Langmuir.

K.F. Hayes, G. Redden, W. Ela, and J.O. Leckie, "Surface Complexation Models. I. An Evaluation of Model Parameter Estimation Using FITEQL and Oxide Mineral Titration Data," submitted for publication to J. Coll. Interf. Sci., 1989.

TECHNICAL REPORTS:

F.B. DeWalle, T. Zeisig, J. Sung, D. Norman, J. Hatlen, D. Sanning, E. Chain, M. Bissel, and K.F. Hayes, "Analytical Methods Evaluation for Applicability in Leachate Analysis," Final Report, EPA-600/2-81-046, March 1981.

J.O. Leckie, M.M. Benjamin, K.F. Hayes, G. Kaufaman, and S. Altmann, "Adsorption/Coprecipita- tion of Trace Elements from Water with Iron Oxyhydroxide," Final Report, EPRI Research Project 910-1, March 1979.

J.O. Leckie, A.R. Appleton, Jr., N.B. Ball, K.F. Hayes, and B.D. Honeyman, "Adsorptive Removal of Trace Elements from Fly-Ash Pond Effluent onto Iron Oxyhydroxide," EPRI-RP-910-1, Final Report, 1983.

B.D. Honeyman, K.F. Hayes, and J.O. Leckie, "Speciation of Trace Elements in Fly-Ash Wastewater," EPRI Special Publication, 1984.

A.L. Roe, K.F. Hayes, C.J. Chisholm, G.E. Brown, Jr., K.O. Hodgson, G.A. Parks, and J.O. Leckie. "XAS Study of Ion Adsorption at Aqueous/Oxide Interfaces," Stanford Synchrotron Radiation Laboratory Report 87-01, 1987.

C. Papelis, K.F. Hayes, and J.O. Leckie. "HYDRAQL: A Program for the Computation of the Chemical Equilibrium Composition of Aqueous Batch Systems Including Surface-Complexation Modeling of Ion Adsorption at the Oxide/Solution Interface," Technical Report No. 306, Department of Civil Engineering, Stanford University, September, 1988, 130pp.

G.E. Brown, Jr., C.J. Chisholm, K.F. Hayes, A.L. Roe, G.A. Parks, K.O.Hodgson, and J.O. Leckie. "In Situ X-ray Absorption Study of Pb(II) and Co(II) Sorption Complexes at the γ-Al_2O_3/Water Interface," Stanford Synchrotron Radiation Laboratory Report 88-01, 1988.

K.F. Hayes, G. Redden, W. Ela, J.O.Leckie. "Application of Surface Complexation Models to Radionuclide Adsorption: Sensitivity Analysis of Model Input Parameters," Final Report, Battelle Memorial Research Laboratory, Contract B-N3975-A-E, Battelle Pacific Northwest Laboratory, Richland, WA, 1989, 75pp.

PRESENTATIONS:

Oral Presentation, "Surface Complexation Models: An Evaluation of Model Parameter Estimation Using FITEQL and Titration Data," presented at the 196th National ACS Meeting in a special Symposium on Chemical Modeling in Aqueous Systems II, sponsored by Geochemistry Division, Los Angeles, CA, September 25-29, 1988.

Invited Speaker, "The Kinetics of Surface Complexation," presented at the 1988 Gordon Research Conference in Environmental Sciences, New Hampton School, NH, June 20-24, 1988.

Oral Presentation, "In Situ X-Ray Absorption Study of Surface Complexes: Selenium Oxyanions on α-FeOOH," presented at the 62nd Colloid and Surface Science Symposium sponsored by the Colloid and Interface Science Division of ACS, Penn State University, State College, PA, June 19 - 22, 1988.

Oral Presentation, "Pressure-Jump Kinetic Studies of Lead Ion Adsorption at the Goethite-Aqueous Interface" presented at 193rd ACS National Meeting in a special symposium on Colloid Controlled Migration of Pollutants sponsored by the Environmental Chemistry Division of ACS, Denver, CO, April 5-10, 1987.

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EDUCATION:
Ph.D. Environmental Engineering, 1988, Stanford University
M.S. Environmental Engineering, 1983, Stanford University
B.S. Geology, 1979, University of Washington, Seattle.
B.S. Oceanography, 1979, University of Washington, Seattle.

RESEARCH INTERESTS:
Current research examines biotransformation and mineralization of organic compounds under aerobic and anaerobic conditions. Compounds presently under study are aromatics (e.g., benzene), halogenated aliphatics (e.g., trichloroethene), and halogenated aromatics (e.g., polychlorinated biphenyls). The implications and applications of this research on the possible fate of halogenated compounds in groundwater aquifers and bioreactors is also under study.

EMPLOYMENT:
Assistant Professor, 1988-, The University of Michigan.
Assistant Professor, 1987-1988, Michigan State University.
Acting Instructor, Fall 1985, Stanford University.
Research Assistant, 1981-1987, Stanford University.
Organic Geochemist, 1979-1982, U.S. Geological Survey.

PROFESSIONAL ACTIVITIES:
Environmental Consultant: 1982-1984, Stanford University:1983-1985, Canonie Engineers: 1986, EMCON Associates: 1987, State of Michigan Representative Dodak, House Floor Leader: 1987-1988, Community Assistance Program for Environmental Toxicology: 1987-1989. Other industrial consulting: 1986-1989.

AWARDS:
Harvey Mudd College Academic Scholarship
Michigan Biotechnology Institute Faculty Development Award.
Herrick Foundation Award for PCB Research

INVITED LECTURES:
Agronomy Society of America, Annual Meeting, Symposium on Soil Remediation, Las Vegas, October, 1989
Gray Freshwater Biological Institute, Symposium on Microbial Ecology and Biodegradation, Navarre, Minnesota, July, 1989
Department of Civil and Mineral Engineering, University of Minnesota, Minneapolis, May,1989
New York University Medical Center, New York, March, 1989
American Geophysical Union, Annual Meeting, San Francisco, December, 1988.
American Water Works Association, Annual Meeting, Orlando, June, 1988
American Society for Microbiology, Annual Meeting, Miami Beach, May, 1988.

Vogel, T.M. and McCarty, P.L. 1987. Abiotic and biotic transformations of 1,1,1-trichloroethane under methanogenic conditions. Environmental Science and Technology, 21:1208-1213

Vogel, T.M. and McCarty, P.L. Relative rates of reductive dehalogenation of 1,1,1-trichloroethane, trichloroethylene, and their products, and acetate utilization under methanogenic conditions. Submitted.

Selig, H. and Vogel, T.M. Degradation of methylene-chloride-containing pharmaceutical waste in an anaerobic biofilm. In prep.

Fathepure, B.Z. and Vogel, T.M. Simultaneous reductive dechlorination of chlorinated aromatic and aliphatic compounds under methanogenic conditions. In Prep.

Selig, H. and Vogel, T.M. Chemical considerations in media for microbial growth. In Prep.

Shreve, G. and Vogel, T.M. Comparison of solid supports for development of biofilms. In prep.

Nies, L. and Vogel, T.M. Influence of substrate on anaerobic degradation of PCBs. In Prep.

PROCEEDING
AND REPORTS:

Vogel, T.M. and Kvenvolden, K.A. 1981. Hydrocarbon gases in Navarin Basin Province sediments. In: Geologic Hazards in Navarin Basin Province, Carlson, P. and Karl, H. (eds) U.S. Geologic Survey Open File Report.

Vogel, T.M. 1988. Chemical and biological transformations of hazardous wastes - Halogenated Aliphatic Compounds. In: Proceedings of American Water Works Association, June, 1988.

Vogel, T.M., Nies, L., and Anid, P., 1989. Long Term Anaerobic-aerobic degradation of PCBs, In: Research and Development Program for the Destruction of PCBs, Published by General Electric Company, Corporate Research and Development, June, 1989.

ABSTRACTS
AND
PRESENTATIONS:

Vogel, T.M., Kvenvolden, K.A., and Oremland, R.S., 1980. Hydrocarbon gases in surface sediments for San Francisco Bay, California. Pacific Division of the American Association for the Advancement of Science. Annual Meeting, Davis, CA. Abstract; p. 33.

Vogel, T.M., Kvenvolden, K.A., Carlson, P.R., and Karl, H.A. 1981. Geochemical prospecting for hydrocarbons in the Navarin Basin Province. American Association of Petroleum Geologists. Annual Meeting, San Francisco, CA. Abstract.

Vogel, T.M. and Reinhard, M. 1983. Kinetics of alkyl bromide hydrolysis. American Chemical Society. Annual Meeting, Sept., Washington, D.C. Div. Environ. Chem. 23:2. Extended Abstract; pp. 357-358.

CURRENT
FUNDING SOURCES:

National Science Foundation Science and Technology Center for Microbial Ecology
U.S. Environmental Protection Agency
National Institutes of Environmental Health Sciences
Michigan Oil and Gas Association
General Electric
Dow Chemical Company
Michigan Biotechnology Institute
U.S. Environmental Protection Agency - Hazardous Substance Research Center

APPENDIX

(Studies Referred To in the Comments of

Patricia A. Lane, PhD on the Draft Plan)

THE EFFECTS OF CRUDE OIL AND THE DISPERSANT COREXIT 9527 ON THE VEGETATION OF A NOVA SCOTIA SALTMARSH: IMPACTS AFTER TWO GROWING SEASONS

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THE EFFECTS OF CRUDE OIL AND THE DISPERSANT COREXIT 9527 ON THE VEGETATION OF A NOVA SCOTIAN SALTMARSH: IMPACTS AFTER TWO GROWING SEASONS

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ABSTRACT

This study documented the effects of experimental applications of Alberta sweet blend crude oil on the creek edge, midmarsh and high marsh zones of a Nova Scotia salt marsh over the course of two growing seasons. It also investigated the impact of the dispersant Corexit 9527 on the creek edge vegetation zone. The effects of the oil and dispersant applications were monitored using a number of parameters, including; plant height growth, stem density, biomass, species cover, plant fluorescence induction measurements, anatomical differences and soil profile changes. These data revealed that there was considerable variation in the sensitivity of the three vegetation zones to the oil treatment. The oil treatment had little effect on the creek edge zone (dominated by tall Spartina alterniflora) during the 1986 growing season and no residual effects were noted in 1987. The midmarsh zone (dominated by dwarf S. alterniflora) by contrast was severely impacted by the oil in 1986 and displayed relatively little recovery during the 1987 growing season. The large differences in toxicity between the creek edge and midmarsh zones appeared to be related to the inability of S. alterniflora growing in the physiologically stressful mid marsh zone to tolerate the additional stress of oil toxicity. Oil impacts in the high marsh zone (dominated by S. patens) were intermediate between those of the creek edge and midmarsh zones. Significant negative impacts were noted for most of the study parameters in 1986, however, the heavy mortality observed in the midmarsh zone was not found there. Data from the 1987 growing season revealed relatively little recovery. The creek edge dispersant treatment had severe negative effects on this community in 1986, however, rapid recovery was observed in 1987.

Biomass and species cover data for 1986 and 1987 revealed similar successional trends for the three vegetation zones following the application of oil or dispersant. Annual species, the most abundant of which were Salicornia europaea and Suaeda maritima, increased in abundance in plots where interspecific competition had been reduced by oil or dispersant induced mortality of Spartina. Based on current rates of recovery, the creek edge zone recovered from oiling within one year of treatment and will probably recover from the dispersant treatment within two years. The high marsh zone will probably require three to four years for full recovery, while the midmarsh zone will probably require at least five years.

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ACKNOWLEDGEMENTS

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INTRODUCTION

Salt marshes are highly productive ecosystems which are of great ecological and economic importance. Salt marshes fix large quantities of carbon, a large proportion of which is exported to estuarine and coastal waters where it fuels marine food webs. Many species of invertebrates, fish and birds utilize salt marshes as feeding, breeding and resting areas. Most of the salt marshes along the Atlantic coast of North America are dominated by the salt marsh cord grass (Spartina alterniflora Loisel). This species is tolerant of high salinity and anoxic conditions in the sediment, yet is capable of very high rates of primary productivity.

Salt marshes are highly susceptable to oil spills since they are regularly inundated by seawater and have low self cleaning potential as a result of the low energy nature of the areas in which they develop. Much variation has been found in the sensitivity of salt marshes to oil spills. Oil toxicity depends on a number of factors including type of oil, the degree of oil weathering, amount spilled, frequency of multiple spill events, time of the year in which the spill occurred, the types of organisms exposed to the oil and the amount of stress experienced by these organisms prior to the oil spill. These factors make it difficult to implement proper mitigative measures when salt marshes are threatened by oil spills. This situation is further complicated by the fact that most salt marsh clean up techniques are ineffective or cause as much if not more damage than the oil (Vandermeulen and Jotcham, 1986). No intervention may be a valid option provided the impact of the oil spill is less than that of the potential clean up option. Evaluation of this option requires the development of oil spill impact studies in a variety of salt marsh communities using different types and amounts of oil applied at different times of the year and monitored over a number of years. This is beyond the scope of most investigations, however, useful information can be derived from a variety of smaller studies.

The dispersal of incoming slicks offers a means of reducing the amount of oil entering the marsh. Generally the use of dispersants in shallow near shore waters is not recommended but may be attempted if it will reduce the amount of oil stranding in the marsh (API, 1985). Near shore applications of dispersant increase the likelihood of dispersant contamination of salt marsh vegetation. Few studies have investigated the impacts of dispersants on salt marsh plant communities (Baker et al, 1984; Delaune et al., 1984 and Smith et al, 1984). These studies have demonstrated that the phytotoxicity of various dispersant formulations varies considerably. It is therefore important to document the toxicity of a variety of dispersants in order to determine which may be safely used in close proximity to salt marsh vegetation.

In this study, the impacts of Alberta sweet blend crude oil and the dispersant Corexit 9527 were studied in a Nova Scotia salt marsh over the course of two growing seasons. The impacts of experimental crude oil spills were investigated in creek edge, midmarsh and high marsh vegetation zones while dispersant impacts were studied only in the creek edge zone. Oil and dispersant impacts were studied at the community, species and cellular levels of biological organization in order to provide a comprehensive approach to evaluation of the biological effects of the treatments.

This is a continuation of a study initiated in 1986 (Lane et al., 1987) and presents data collected during both the 1986 and 1987 growing seasons following the oil and dispersant applications in 1986. More detailed descriptions of treatment impacts on vascular plant parameters during the 1986 growing season and effects of oil and dispersants on salt marsh algal and bacterial communities are available in that report. In this study, attention was focused on parameters from the 1986 study in which recovery was not evident at the end of the 1986 growing season.

MATERIALS AND METHODS

DESCRIPTION OF STUDY SITE

The field study site was located at Conrods Beach on Petpeswick Inlet ($44^{o}42'$N, $63^{o}11'$W) (Figure 1). The Conrods Beach salt marsh has developed behind a barrier dune system, and is drained by a single channel which penetrates the dune system. The vegetation of the salt marsh is divisible into three distinct zones, which will be referred to as creek edge, midmarsh, and high marsh zones.

The creek edge zone was dominated by a lush growth of *Spartina alterniflora*. Small quantities of *Salicornia europaea*, *Plantago juncoides*, *Suaeda maritima*, and *Atriplex patula* were also present in this zone. The creek edge zone was usually restricted to within two metres of drainage channels in the marsh. The lush growth of *Spartina alterniflora* was attributable to the relatively well drained sediments of this zone.

The midmarsh zone was dominated by short *Spartina alterniflora*, with lower abundances of *Spartina patens*, *Salicornia europaea*, *Suaeda maritima*, *Triglochin elata*, *Limonium nashii*, and *Plantago juncoides*. This was the most extensive of the three zones in the Conrods Beach salt marsh and was generally found in poorly drained areas in the marsh interior. The stunted growth of *Spartina alterniflora* in the midmarsh zone is generally associated with extremely low redox potential of the sediments and high salinity of the interstitial water of the sediments of this zone.

Spartina patens was the dominant species of the high marsh zone. Small quantities of *Spartina alterniflora*, *Salicornia europaea*, *Triglochin elata*, *Suaeda maritima*, and *Glaux maritima* were also found in association with *S. patens*. The high marsh zone was located on slightly elevated, better drained and aerated soils of the marsh.

EXPERIMENTAL DESIGN

A total of twenty-one 0.5 m x 4.0 m ($2.m^{-2}$) plots were established at random locations in the salt marsh. Nine plots were positioned in the creek edge zone, with three replicate plots assigned to each of three treatments (control, oil and dispersant). In the midmarsh and high marsh zones, only control and oil treatments were assigned for a total of six plots per zone. Each plot was separated from other plots by a 10 m buffer zone to prevent or reduce cross contamination by either oil or dispersant from other plots. Nondestructive sampling was conducted within the interior of the plots

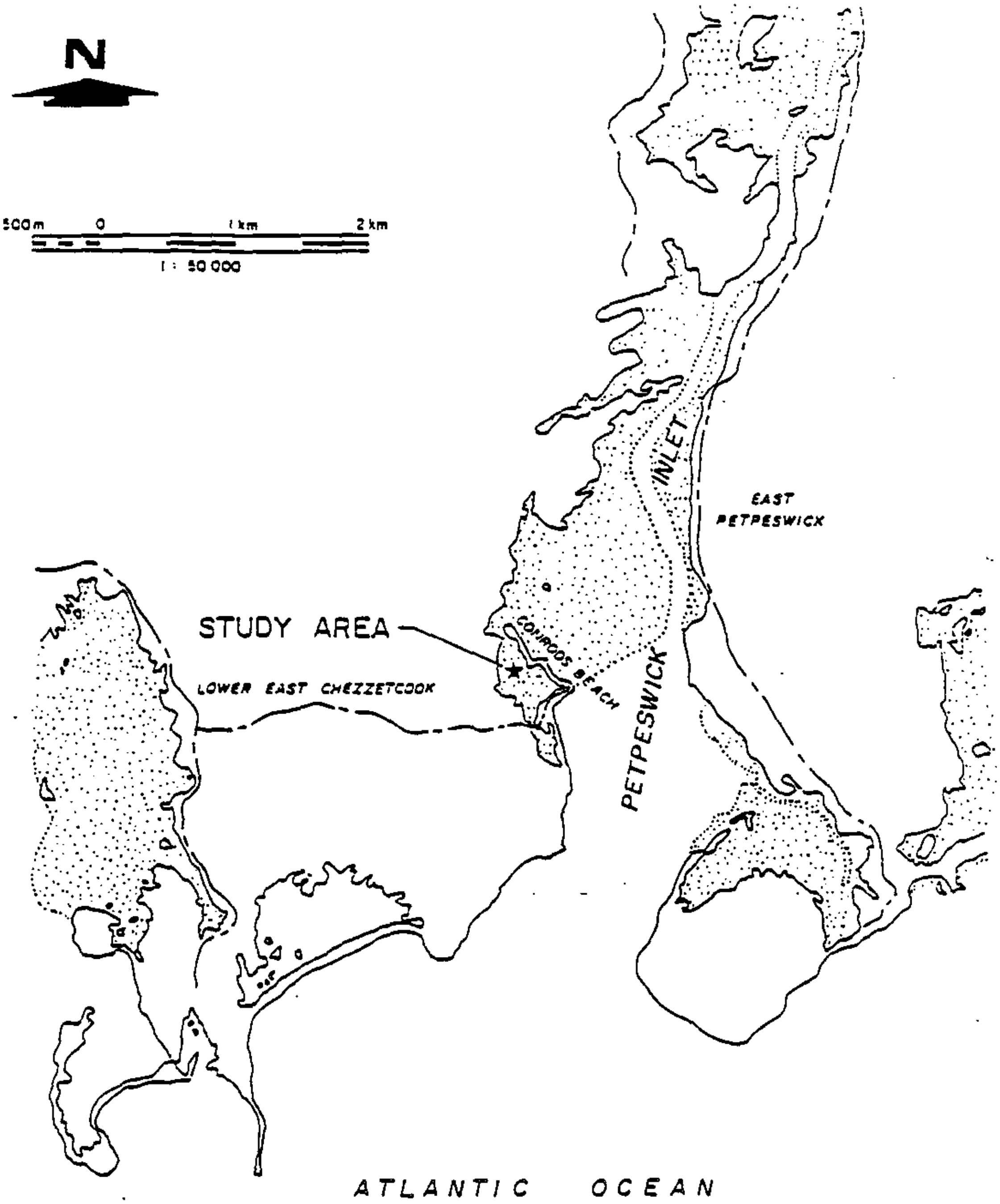


Figure 1: Map showing the location of Petpeswick Inlet and the Conrods Beach salt marsh.

while destructive sampling was done in a 0.25m wide strip surrounding each plot which received the same treatment as the plot interior. Each quadrat was surrounded by a wall of oil sorbent material to prevent the escape of oil from the quadrat. Quadrats were also covered with garden netting to exclude wildlife. Field measurements commenced on May 9 (day 1) and treatments were applied on July 7 (day 60) in 1986.

In the 1986 study three treatments were applied to each of the three vegetation zones. These included oil alone, dispersant alone and oil and dispersent applied to the same plot. Funding constraints in 1987 resulted in a reduction in the number of plots monitored during the 1987 field reason. Only the control and oiled plots were monitored in all vegetation zones along with dispersant treated plots in the creek edge zone.

OIL AND DISPERSANT APPLICATIONS

Alberta sweet blend crude oil, weathered by evaporation and stirring for 24 hours to 15-25% loss by weight, was used for all experiments. In the field experiments, 2.25 liters of weathered oil per plot were applied from a back-pack sprayer approximately two hours after the onset of the ebb period yielding a nominal 0.5 mm oil slick. The tide did not rise high enough to cover the marsh surface with water on the day of treatment applications, therefore, each plot was sprayed with seawater prior to treatment. The oil spray application was done so that the spray was held near the marsh sediment surface, at about half of the mean plant height, thereby simulating contamination by a surface oil slick.

For the dispersant treatment, ethylene glycol-based Corexit 9527 was mixed with water in a ratio of 1 part dispersant to 10 parts seawater. A total of 2.25 liters of the dispersant:seawater mixture was applied to each plot from a back-pack sprayer. Application differed from that of the oil application, in that the dispersant spray was directed at the vegetation from 50 cm above the sediment surface. This application was intended to mimic a near shore application of dispersant on an incoming tide.

PHYSICAL AND CHEMICAL PARAMETERS

Soil Profile Descriptions

Soil profile descriptions were recorded for all cores taken for chemical analysis. On each sampling date, in each vegetation zone, one core was taken from each of the 3 replicate oil plots. During the 1986 field season only one core was taken from each of the control plots, however, during the 1987 field season cores were taken from all control replicates. At each sampling site, a core 6 cm wide by 15 cm long was removed with a modified bulb planter. Each core was split longitudinally and the thicknesses of distinctive sediment layers and presence of oxidizing and reducing zones were recorded on a standard core diagram. The presence of bacterial zones, algal mat communities, the colour of roots, and the degree of root mat development were also recorded for each core. In 1986, cores were taken on five dates between early July and early September, while in 1987, cores were taken on three dates between late June and late August.

Soil Chemistry

Using the cores collected for soil profile descriptions, a 50 g sample was removed from each core and was extracted 3 times with 20 ml of methylene chloride. The resultant solution was dried, taken up in hexane and cleaned up. Samples were cleaned by pouring them through a mini-column containing sodium sulfate, copper and activated florisil. Total oil and grease values were determined with UV fluorescence analysis, scanning from 200 to 300 nm. The data were expressed as ppm of chrysene equivalents (UV fluorescence at 256 nm).

Selected sample extracts were analysed by glass capillary gas chromatography using a flame ionization detector. Relative concentrations of the n-alkanes were determined from the chromatograms. Identifications of the peaks were made using glass capillary gas chromatography mass spectrometry. Procedures followed those of Geiger and Schaffner (1978).

VASCULAR PLANT PARAMETERS

Plant Height

Within each plot, 40 *Spartina* shoots were systematically selected at 10 cm intervals and their heights were measured. Plant height was measured as the distance from the tallest point of the plant to ground level. Measurements were taken on eight occasions during the growing season in 1986 and on five occasions during the 1987 growing season.

Stem Density

Within each plot, 12 miniquadrats were systematically positioned at 30 cm intervals. In *Spartina alterniflora* dominated marsh zones (creek edge and midmarsh zones), $0.01 \cdot m^{-2}$ quadrats were used while in the *S. patens* dominated zone (high marsh zone), $0.006 \cdot m^{-2}$ quadrats were used. All shoots in each quadrat and all flowering shoots in each plot were counted and means and standard deviations were calculated for each treatment in each vegetation zone on each sampling date. Measurements were taken on four occasions during the 1986 growing season and on five occasions during the 1987 growing season.

Biomass

Biomass harvesting was conducted in the first week of September in both 1986 and 1987. A 0.09·m^{-2} quadrat was systematically positioned in one end of each plot and all aboveground living biomass in the quadrat was harvested, sorted by species, dried at 80° C in a convection oven and weighed on an analytical balance. Standing dead biomass was harvested, dried and weighed but was not sorted by species. All flowering stems in each plot were harvested. Reproductive portions were removed from vegetative portions and weighed separately. The mean Spartina shoot weight was calculated by dividing the biomass of Spartina alterniflora (creek edge and mid marsh) or Spartina patens (high marsh) in the plot by the mean stem density of the plot recorded on the day that the biomass was harvested. Mean above-ground standing crops for living plants, standing dead, reproductive tissues and mean shoot weight were calculated for each treatment in each vegetation zone for each year.

Species Cover

Percent cover for each species of vascular plant was estimated in each plot. Cover values were estimated relative to soil surface area rather than to other species in the quadrat; therefore, total cover could be higher than 100% when species overlapped. Mean cover values were calculated for each species in each treatment in all vegetation zones for three sampling dates in 1986 and five sampling dates in 1987.

Fluorometry

An explanation of the principle of plant fluorescence induction measurements is presented in Appendix 1. Three plants were randomly selected from each plot for fluorometric analysis. The upper-most fully expanded leaf was removed. All of the leaves from a particular plot were placed in a plastic bag into which distilled water was sprayed. The samples were then placed in a light proof box for transport to the laboratory. Harvesting and preparation of the leaves required approximately 0.5 hours. During transport the leaves were allowed to equilibrate in the dark for 1.5 hours. Working illumination in the laboratory was provided by a 6 volt lantern fitted with a green filter. Fluorometric measurements were made with a Brancker Research Ltd. (Ottawa) model SF-20 portable fluorometer. The fluorescence induction curve was monitored for 100 seconds. Initial, peak, transient peak, and final readings were recorded (Figure 2). Values used in analysis included the peak variable fluorescence (peak reading minus initial reading) and the 100 second difference value (value at 100 seconds minus initial value).

Leaf Anatomy

In mid-July in 1986 and 1987, two leaves were randomly selected from each plot. These leaves were pooled by treatment within each zone and three were randomly chosen from each treatment for observation. Radial cross-sections were taken from areas on each leaf exhibiting different symptoms of the treatments, and were examined under a microscope at 200x. Observations included the abundance, relative sizes, and coloration of chloroplasts, measurements of cuticle thickness and the presence or absence of plasmolysis.

STATISTICAL ANALYSIS

Statistical analyses were conducted on plant height, stem density, above ground biomass for several species, reproductive and mean shoot biomass, cover, fluorometry parameters, reducing zone thicknesses and total oil and grease concentrations. In most cases, both 1986 and 1987 data were analysed. Transformations as determined by tests for normality and homoscedasticity in 1986 were continued. Data analysis was conducted using the SPSS/PC+ V2.0 statistical package (Norusis, 1988a, 1988b). Graphs were produced with SPSS/U.C.+ Graphics (SPSS Inc., 1986).

Preliminary analysis consisted of both general descriptive statistics and analysis of variance to test whether replication was a factor. Subsequent analysis investigated the effects of treatments and time (year, and where appropriate, visit). The principle investigative technique was analysis of variance. The number of levels and the interactions tested varied with the particular data set.

Height data was transformed as follows:

$$y = \ln((x/14) + 1).$$

where 14 was the overall median height for the 1986 data.

Density was also ln transformed:

$$y = \ln(x + 1).$$

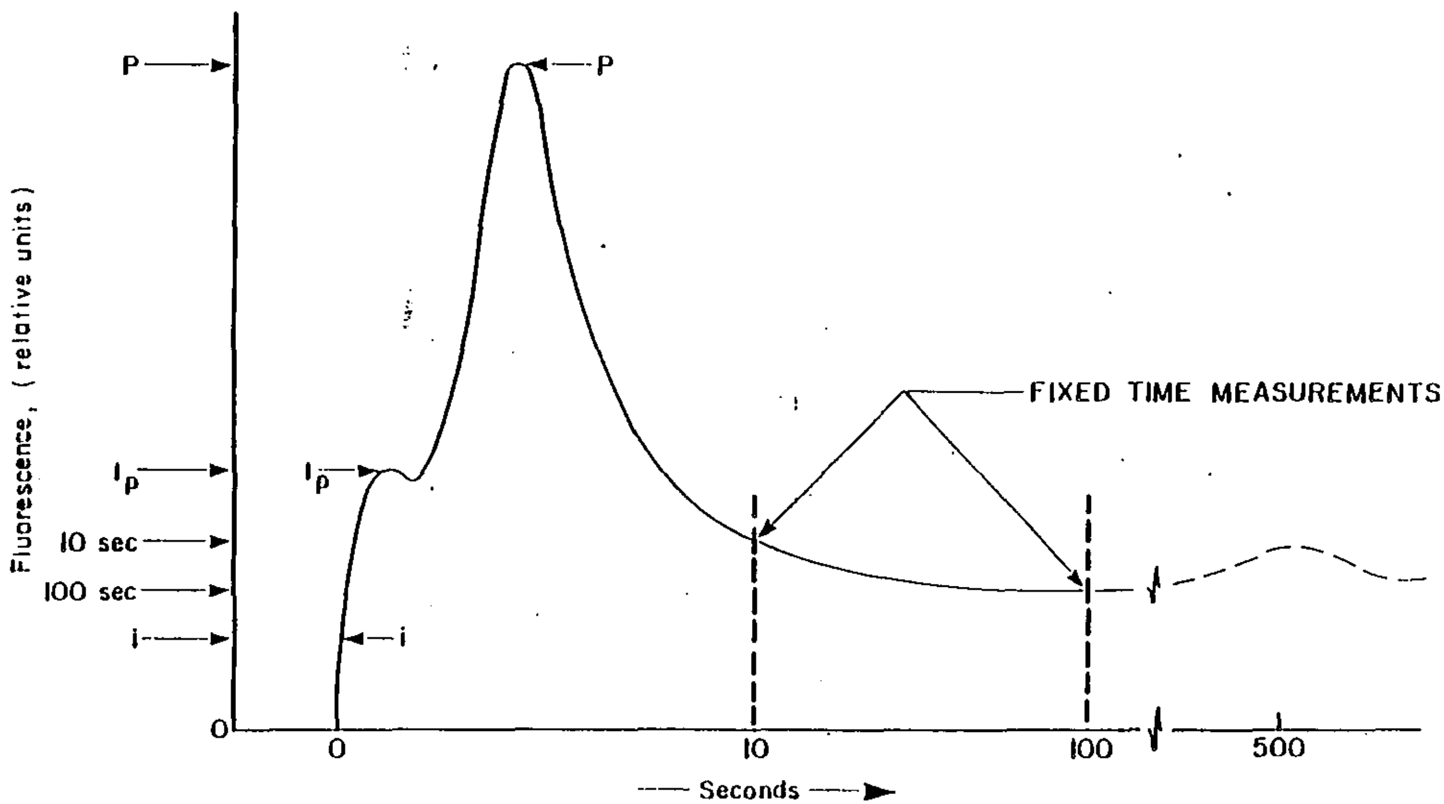


Figure 2: Diagramatic representation of the fluorescence induction curve for Spartina alterniflora. Arrows indicate recorded fluorescence values. The initial value (i) is the "fixed fluorescence". Fluorescence above this level is "variable fluorescence" which is sensitive to the physiological status of the photosynthetic system. We refer to (p-i) as "peak variable fluorescence" and 100 second values minus initial value as the "100 second differences values". tp refers to a t( ) nt peak.

Square root transformations were used on both cover and biomass data. Statistical analysis of the biomass data reported here was restricted to the two *Spartina* spp., *Salicornia europaea*, *Suaeda maritima*, total above ground living biomass and standing dead biomass. Several subsets of the dominant *Spartina* species were also investigated, including flower weight and weight per shoot.

Cover data for the creek edge, midmarsh, and high marsh were entered into discriminant analyses. The results of 4 estimates for each plot on each day were incorporated. The estimates were divided into groups according to treatment. All cover estimates from the first sampling date in 1986 were coded as controls since they preceeded treatment applications. Separate ordinations were conducted including and excluding standing dead biomass.

RESULTS AND DISCUSSION

PHYSICAL AND CHEMICAL EFFECTS

Soil Profile Descriptions

Sulfate reduction activity is the major determinant of soil profile patterns in salt marshes. Water logging of the sediments combined with microbial respiration create anoxic conditions under which sulfate reducing bacteria may proliferate. These bacteria utilize sulfate as an electron acceptor in the anaerobic respiration of small molecular weight organic compounds. It is generally believed that the carbon sources utilized by sulfate reducing bacteria are waste products of the fermentation of detritus. The reduction of sulfate produces hydrogen sulfide which is stable under anaerobic conditions. Hydrogen sulfide may also react with iron to form ferrous sulfide and eventually pyrite (Weibe et al., 1981). Deposition of the black iron sulfides produces a grey or black colour in the sediments. In zones where the sediments are oxidized, the sediment color is brown as a result of the oxidized state of the iron compounds. The transition zone between brown and grey sediments is characterized by a decline in redox potential from positive to negative values (Jorgensen, 1983). Sediment colour may, therefore, serve as an indirect indicator of sulfate reduction activity which in turn indicates the presence of anaerobic conditions.

Soil profile descriptions were performed during both the 1986 and 1987 field reasons, however, during 1986 only a single control plot was sampled on each sampling date. Consequently, only data from 1987 was suitable for statistical analysis. No data were collected for dispersant treated plots. Figure 3 presents the mean thickness of reducing zones in control and oiled plots in each of the vegetation zones in 1987. All three zones exhibited similar trends over the course of the growing season. Reducing zone thickness in control plots declined over the course of the growing season while that of oil treated plots increased. Reducing zone thickness in the oiled plots was initially lower than controls at the beginning of the growing season (Day 45) but increased to control levels by the end of the growing season (Day 110). In the creek edge plots on day 45, reducing zones were only 61% as thick as in control plots, however, this difference was not statistically significant. by day 75, reducing zones in the oiled plots had thicknesses similar to those of the control plots.

In the midmarsh zone mean reducing zone thickness in oiled plots was 53% of control plot values on day 45 and 51% of control values on day 75. These

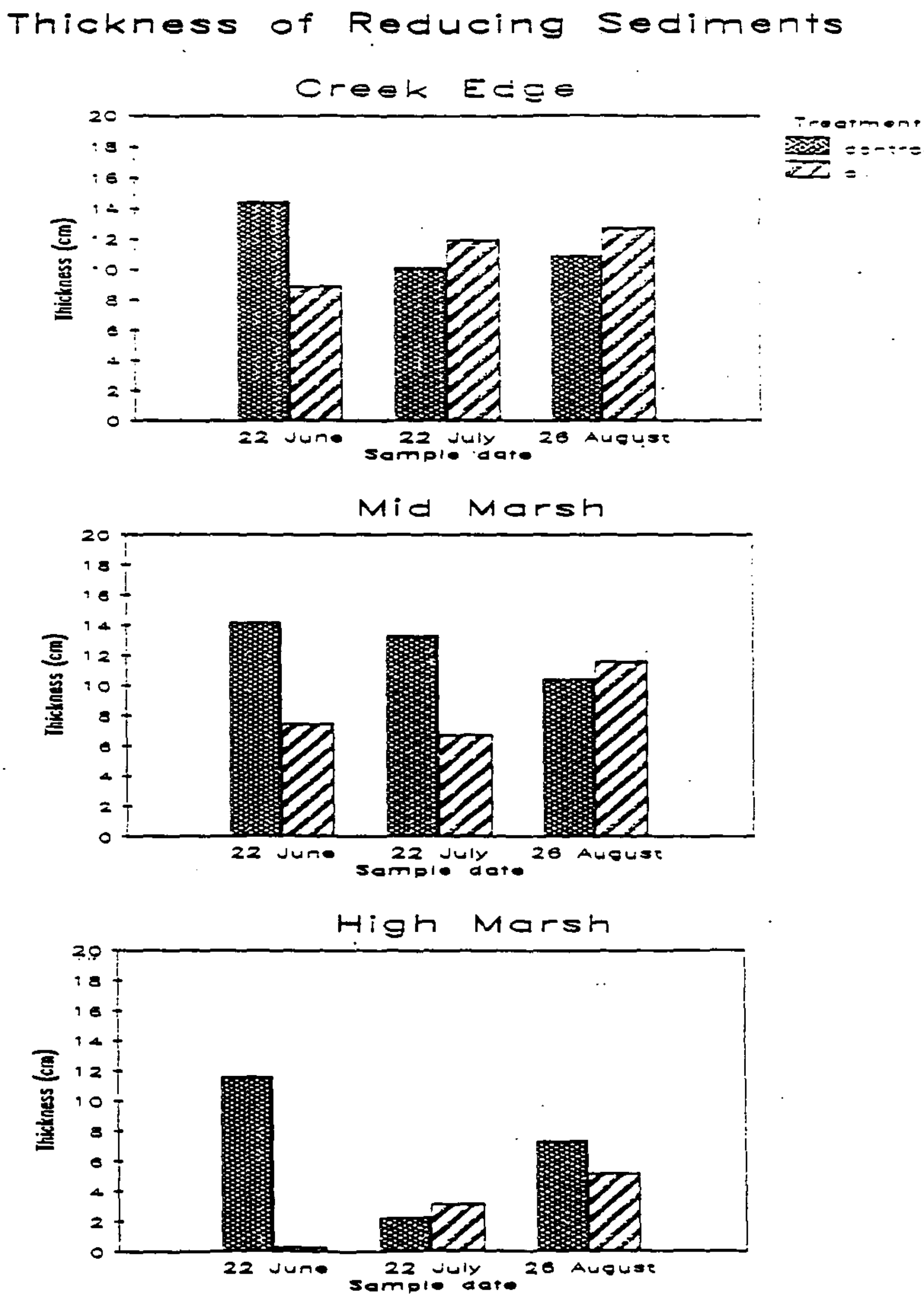


Figure 3: Histograms of mean reducing zone thickness in the creek edge, midmarsh and high marsh zones in 1987. Oil was applied on day 60.

differences, however, were not significant on either sampling date. Reducing zone thickness for oiled and control plots were similar on day 110.

Reducing zone thickness in oiled high marsh plots was significantly lower than control plots on day 45 (p 0.001, ANOVA) but returned to control values by day 75.

Contamination of salt marsh sediments by crude oil could affect reducing zone thickness in several ways:

1) An oil layer on the sediment surface or high concentrations in the sediment could provide a barrier to diffusion of oxygen into the sediments resulting in an increase in reducing zone thickness in oiled plots.

2) Oil induced mortality of Spartina plants could reduce the degree of sediment oxidation. Howes et al (1981) have demonstrated that growth of Spartina alterniflora was associated with increases in sediment redox potential. Spartina plants supply oxygen to the rhizosphere by means of passive diffusion of air through continuous gas spaces from shoots to rhizomes and roots and possibly by means of the exudation metabolically produced oxidants such as hydrogen peroxide into the rhizosphere. Mortality of the Spartina sward might be expected to be associated with an increase in reducing zone thickness in the oiled plots.

3) The crude oil could serve as a substrate for oil degrading bacteria. Respiration by these bacteria could decrease the depth to which oxygen can penetrate the sediments, resulting in an increase in reducing zone thickness in the oiled plots.

4) The crude oil could poison populations of heterotrophic bacteria in the sediment causing a reduction in bacterial respiration, increasing the depth to which oxygen could penetrate the sediments. This could cause a decrease in the thickness of reducing zones in the oiled plots.

The evidence presented in figure 3 suggests that the oil treatments were responsible for a long term (approximately one year) increase in soil oxidation, possibly as a result of a reduction in microbial respiration rates caused by hydrocarbon toxicity. Unfortunately, no estimates of microbial respiration were available for the field experiment, so there is no direct evidence to support this hypothesis. There are, however, several pieces of circumstantial evidence which support this hypothesis. Laboratory experiments in 1986 (Lane et al, 1987) using midmarsh sediment from the study area showed that Alberta Sweet Blend crude oil significantly reduced sediment respiration, although only for a period of ten days. The effects may have been more persistent under the harsher conditions experienced in the field (cooler temperatures and constant waterlogging. Standing dead biomass data for 1986 (see page) indicated that decomposition rates had been substantially reduced by the oil treatment. Rates of decomposition appeared to have returned to normal by the end of the 1987 growing season.

Other aspects of the sediment profiles did not change as a result of oil applications. Root development differed between vegetation zones but was similar between treatments within zones. The high marsh zone (dominated by Spartina patens) and midmarsh zone (dominated by S. alterniflora) had well developed mats of fine roots which were largely concentrated near the sediment surface, presumably to avoid high concentrations of toxic hydrogen sulfide and other physiological constraints associated with the anaerobic sediments in these zones. In the creek edge zone (dominated by S. alterniflora) there were fewer fine roots and more large rhizomes which extended into the sediments somewhat deeper than in the previous two vegetation zones. Frequent exchange of interstitial water in this zone would reduce the concentrations of toxic hydrogen sulfide, allowing deeper penetration of root systems.

Sediments in contact with the fine root mats of the midmarsh and high marsh plots were generally oxidized, however, oxidized zones were absent in the creek edge quadrats where fine roots were relatively scarce. No apparent declines in the extent of these zones were associated with the oil treatments in either 1986 or 1987.

Soil Chemistry

Figures 4 - 6 present hydrocarbon concentrations in oil treated and control plots in the three vegetation zones in 1986 and 1987. There was considerable variation between replicates on the various sampling dates. This could be caused by several factors. Initial distribution of the oil within the plots may have been uneven resulting in zones of higher or lower hydrocarbon concentrations. Lipophobic conditions in the water saturated sediment may have led to the concentration of oil in low areas within the plots. Oil draining down grass shoots may have penetrated into the sediment as a film around plant roots and rhizomes causing localized concentrations of oil in the sediment.

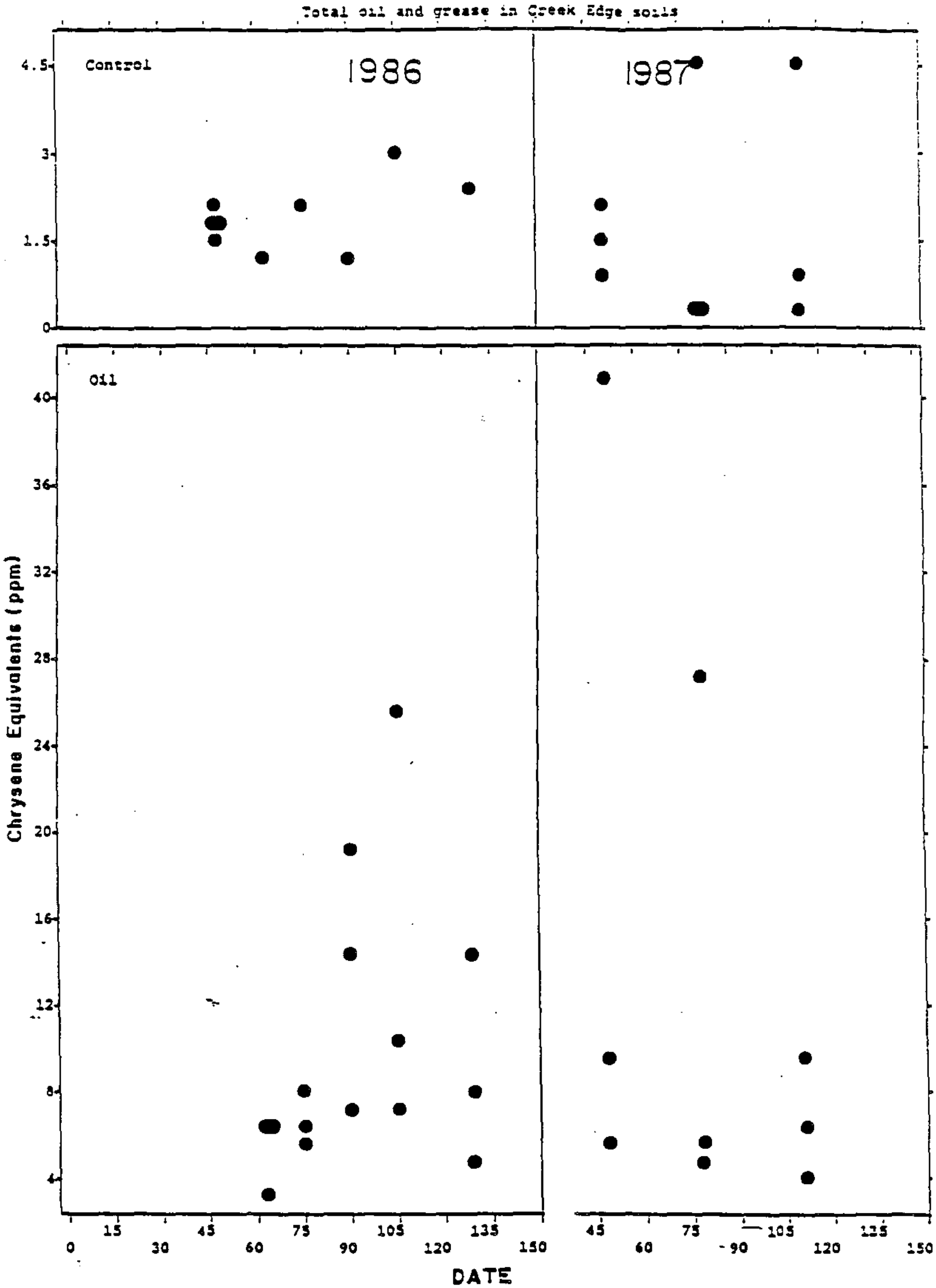


Figure 4: Scatter plot of total oil and grease concentrations in control and oil treated plots in the creek edge zone in 1986 and 1987. Oil was applied on day 60 , 1986.

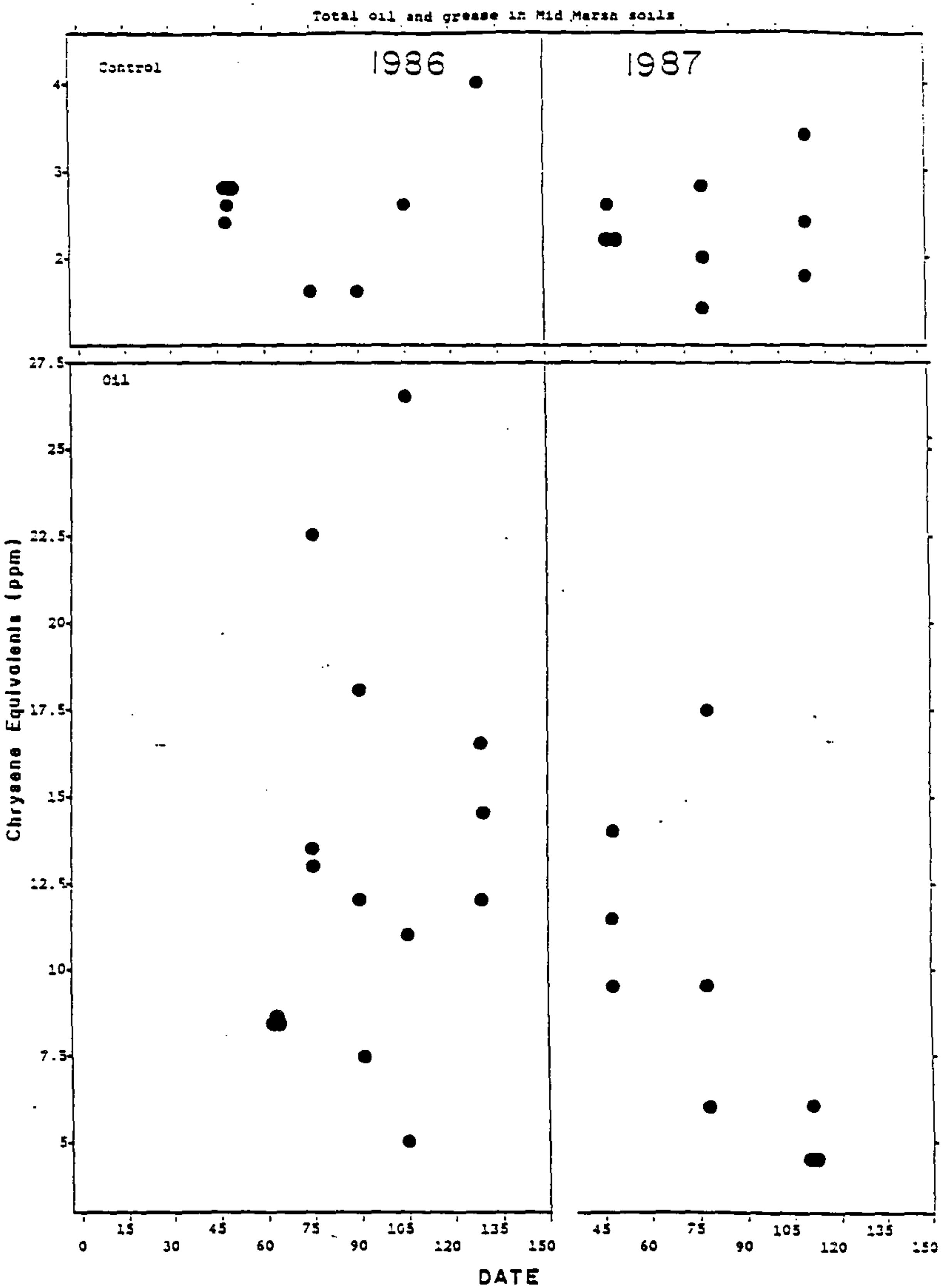


Figure 5: Scatter plots of total oil and grease concentrations in control and oil treated plots in the midmarsh zone in 1986 and 1987. Oil was applied on day 60, 1986.

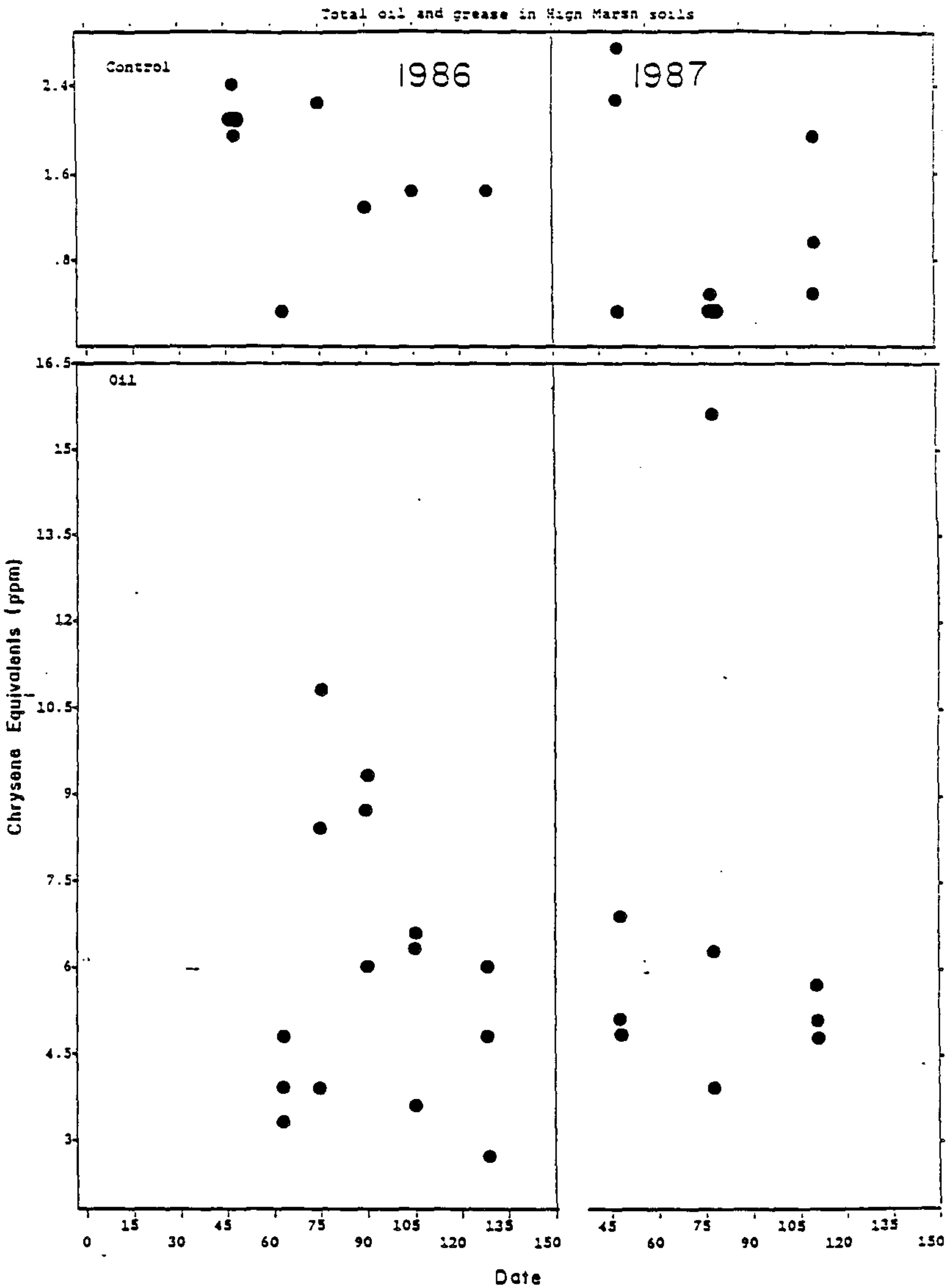


Figure 6: Scatter plots of total oil and grease concentrations in control and oil treated plots in the high marsh zone in 1986 and 1987. Oil was applied on day 60 , 1986.

The data are too variable to draw definite conclusions about the fate of the oil in the various vegetation zones other than to demonstrate that there were substantially more hydrocarbons in the oiled plots than in the control plots during both the 1986 and 1987 growing seasons. There were, however, some general trends in the data. In all zones hydrocarbon concentrations were initially low two days after oil applications but reached maximum concentrations within 30 days of application after which concentrations appeared to gradually decline. The initial increase in hydrocarbon concentrations was probably attributable to several factors:

1) Oil deposited on leaves may have flowed down the stems and onto the sediment over the course of several days.

2) Tidal inundation may have lifted oil off of plants and deposited it on the sediment surface.

3) Oil killed plants or oiled detritus laying on the surface of the sediment may have been incorporated into the sediment.

Hydrocarbon concentrations in the sediment were generally high in the creek edge and midmarsh zones and low in the high marsh zone. Low oil concentrations in the high marsh zone were almost certainly attributable to interception of the sprayed oil by the large standing crop of dead biomass in this zone. In many plots standing dead biomass was up to twice as high as the living biomass, suggesting that Spartina patens was highly resistant to decay. During the 1987 field season oil stained dead stems were still common in the oiled plots. Oil absorbed by the standing dead biomass would not be available for incorporation into the sediment for many months. In addition, this oil would be expected to weather much faster than oil incorporated into the sediments. Maintenance of a high standing crop of dead biomass may have been a factor limiting the impact of oil in the high marsh zone.

Gas chromatography of oiled marsh sediment samples revealed that the rate of weathering of the oil in the sediments was highly variable. By the end of the 1986 field season oil in the sediments on average had weathered to the point where all hydrocarbons under C-10 had been lost. This corresponded to a volume loss of 33% in an oil evaporation experiment conducted in the laboratory. The evaporation experiment determined that evaporative loss of the oil stabilized at 36% after two months of weathering (Table 1), suggesting that evaporative losses were nearly complete in the field. Further losses would be attributable to flushing of oil from the sediments and microbial degradation. By the end of the 1987 growing season hydrocarbons below C-14 had been weathered from the oil and

Table 1. Oil evaporation experiment: Percent of original oil remaining at specified times. Ten grams of oil were weathered in an open container (6 cm wide by 1 cm deep) at 20°C.

TIME (HOURS)	PERCENT OF ORIGINAL OIL WEIGHT
0	100
18	81
72	75
187	72
505	67
1,053	65
1,344	64

in two of nine gas chromatography analyses no oil was detectable.

Penetration of oil into the sediments was found to be generally restricted to the upper 15 cm (Table 2). The highest concentrations were found in the 0-5 cm range. Oil penetration was lowest in the midmarsh and high marsh zones where 77 and 76% of the oil in the upper 15 cm of the sediment was found in the upper 5 cm of the sediments. Penetration was somewhat deeper in the creek edge zone with only 61% of the oil contained in the upper 5 cm of the sediments. The deeper oil penetration in the creek edge zone was probably caused by the lower water table in this zone which would permit oil to percolate deeper into the sediments. The lack of a dense root mat in this zone may also have permitted deeper penetration of oil into the creek edge sediments. Hydrocarbon concentrations in the 5-10 cm depth range tended to be slightly elevated above control surface concentrations in the midmarsh and high marsh zones and were up to four times higher than control values in the creek edge zone. Concentrations in the 10-15 cm depth range were comparable to control values at 0-5 cm in all vegetation zones. This corresponds well to the distribution of hydrocarbons in marsh sediment noted by Hershner and Lake (1980). They found no oil below 20 cm five months after multiple dosings of No. 2 fuel oil. Over 90% of the oil was restricted to the upper 10 cm of the sediment. Other studies have found much deeper penetration. Lytle (1975) found oil to a depth of 42 cm in an experimental oil spill and Burns and Teal (1971) found oil to a depth of 70 cm after the West Falmouth oil spill.

Table 2. Mean Sediment Hydrocarbon concentrations at 5 cm depth intervals. Values for 10-15 cm are based on one sample. No data were available for high marsh hydrocarbon concentrations at 10-15 cm.

Total Oil and Grease
(ppm Chrysene equivalents (1 standard deviation))

Treatment	Depth (cm)	Creek Edge	Mid Marsh	High Marsh
Oil	0-5	48.0 (34.9)	24.7 (11.2)	27.6 (4.2)
	5-10	22.2 (28.4)	6.7 (3.9)	8.6 (7.8)
	10-15	8.6	0.6	-
Control	0-5	5.6 (8.8)	5.6 (2.8)	1.8 (2.6)

IMPACTS ON VASCULAR PLANTS

Plant Height

In the creek edge zone in 1986, significant reductions in plant height were noted on all post treatment days for dispersant treated plots (Figure 7 ($p<0.001$, ANOVA)). Plant heights in dispersant treated plots increased substantially between days 102 and 123. This trend was probably caused by selective mortality of short plants which would increase mean plant height, although growth rates of surviving plants probably did not increase. Short plants would be at a disadvantage in competition for light and would, therefore, suffer more stress than the dominant plants. Higher mortality rates would, therefore, be expected for smaller plants. The oil treatment had relatively little impact on plant height in 1986, although oiled plants were significantly shorter than controls on days 89 ($p=0.043$, ANOVA) and 123 ($p=0.034$, ANOVA).

In 1987, there was little or no evidence of oil or dispersant impacts on height growth. Early in the growing season (days 26 and 48), oil and dispersant treated plants were slightly, although significantly, taller than control plants ($p<0.001$, $p=0.021$, ANOVA). This may be attributable to reductions in stem density associated with these treatments which would reduce competition and allow more rapid growth early in the growing season. No significant reductions in plant height were noted for any of the treatments later in the growing season (Appendix 3), with the exception of oiled plants on the last sampling date (day 115) ($p=0.034$, ANOVA).

These data suggest that there was a rapid recovery of plant height growth associated with the dispersant treatment. This is not unexpected since the water miscible dispersant would be rapidly dissipated by tidal action. Data for oiled plots indicated little change in height growth between 1986 and 1987. This suggests that the oil treatment had no short term or long term effects on height growth.

In the midmarsh zone in 1986, oil did not significantly reduce plant height growth (Figure 8, Appendix 3). This was unexpected since heavy mortality was noted in oiled plots. Rapid reduction in stem density of small plants may have maintained mean plant height at an artifically high level during this period. This is supported by the fact that plant heights in oiled plots were significantly shorter than controls throughout 1987 (Appendix 3). It is difficult to determine whether there was any recovery of plant growth between 1986 and 1987 since trends for 1986 were masked by selective mortality of small plants making direct comparsions impossible. Data for

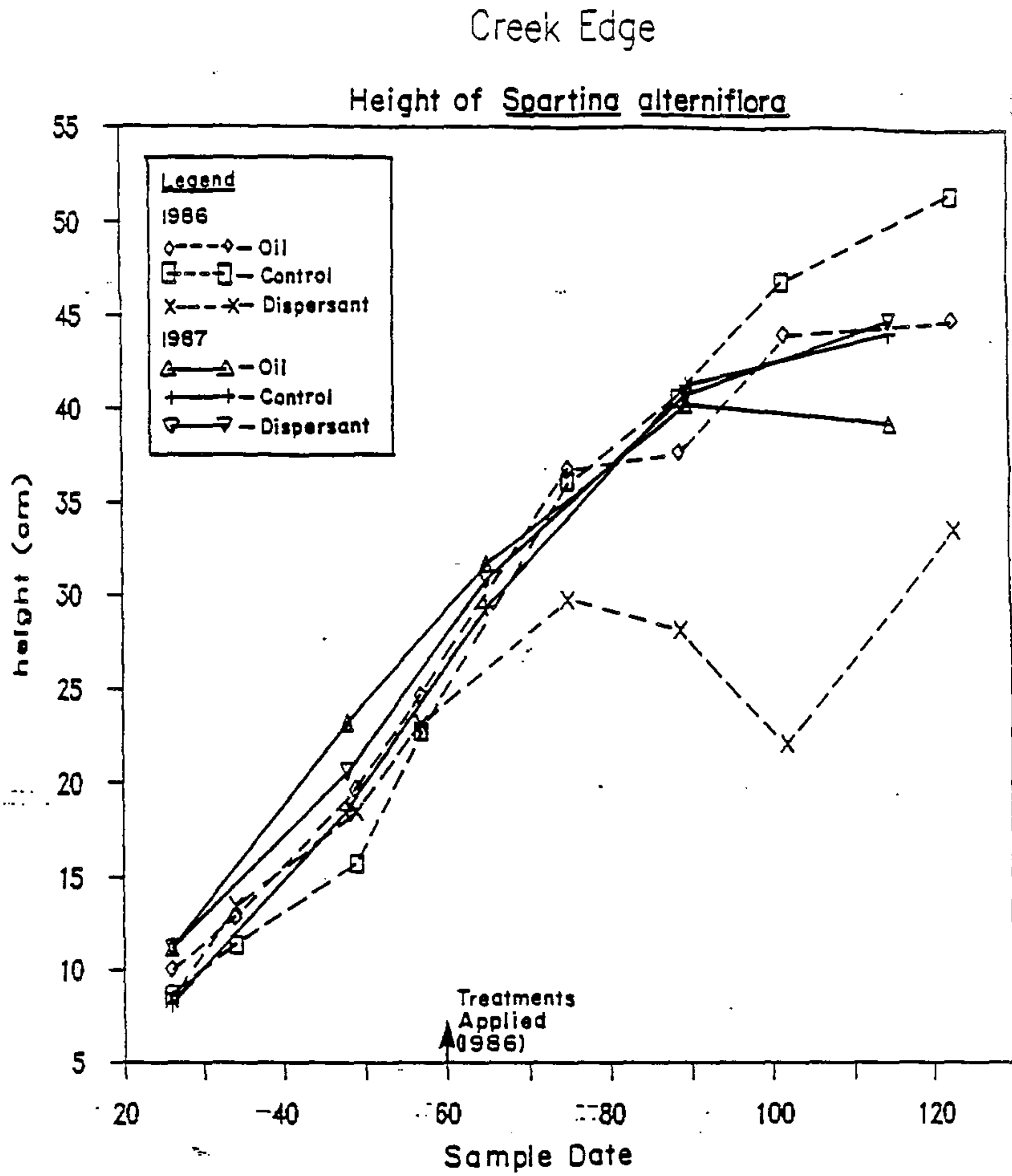


Figure 7: Plot of mean *Spartina alterniflora* height for the creek edge zone versus time.

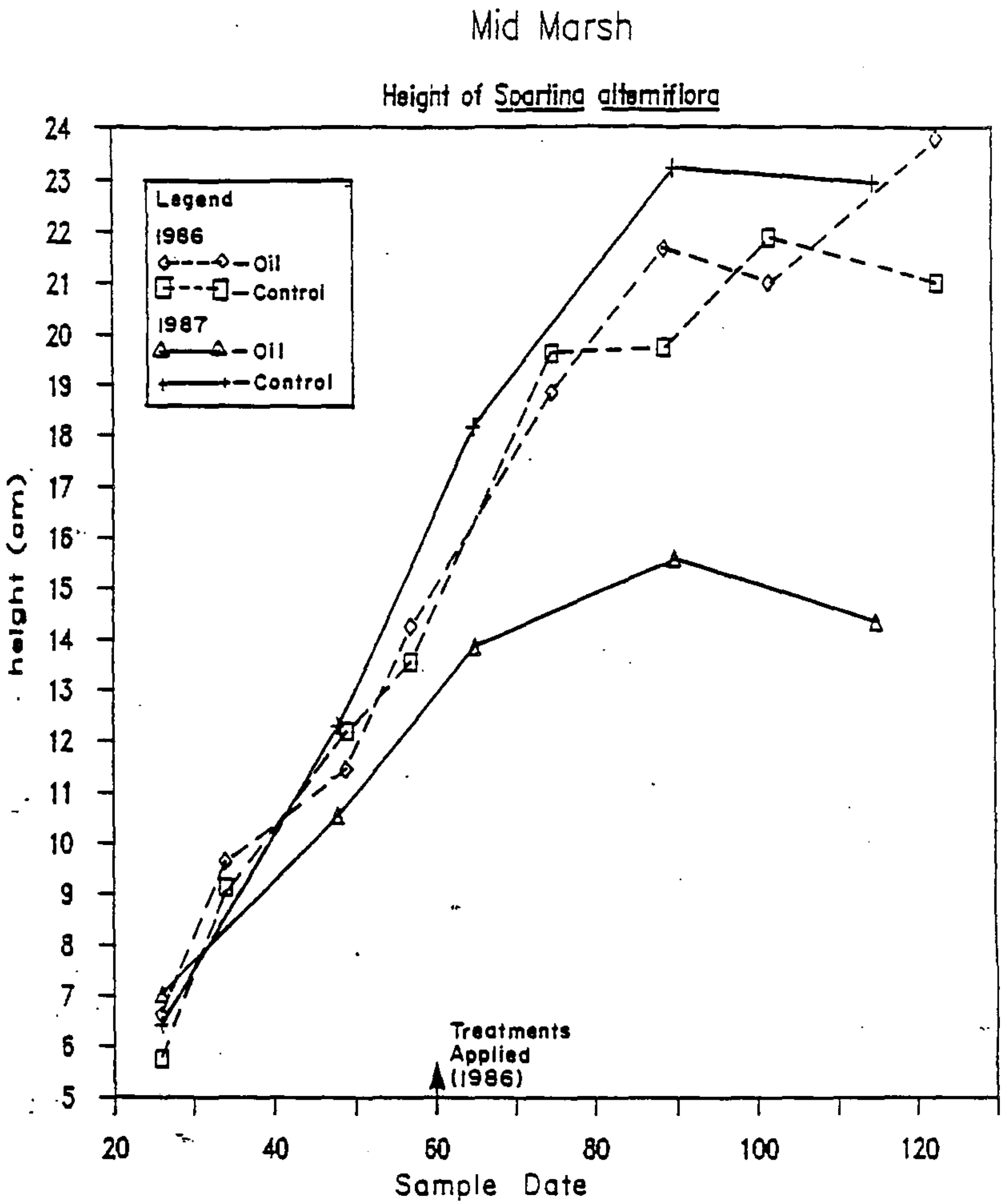


Figure 8: Plot of mean Spartina alterniflora height for the midmarsh zone versus time.

1987, however, indicate that plant height growth was still significantly affected by the oil treatment.

The larger reductions in Spartina alterniflora height in oiled midmarsh plots relative to similarly treated S. alterniflora in the creek edge zone were probably attributable to differences in sediment oxidation status (Eh) between the midmarsh and creek edge zones. Sediment oxidation status is generally lower in the midmarsh zone than in the creek edge zone (Howes et al., 1986) making it a more hostile environment for plants. Low oxygen concentrations lead to decreased ability to take up nitrogen from the sediment (Morris and Dacey, 1984), increased root respiration rates (Mendelssohn et al., 1981) and increased production of hydrogen sulfide which is toxic to root metabolism (Allam and Hollis, 1972). Untreated S. alterniflora growing in the midmarsh zone were shorter than creek edge plants, indicating the stressful nature of the midmarsh zone. The additional stress of oil toxicity was enough to alter the carbon balance of the midmarsh plants (i.e. increased respiration decreased photosynthesis) to the point where height growth was slowed. In the creek edge zone the oil would alter the carbon balance in the same way, however, activities such as flowering which are relatively unimportant to rhizomatous plants such as Spartina would be sacrificed rather than height growth. In the midmarsh zone, existing stressful conditions would have already reduced the proportion of photosynthates available for flowering so that additional stress would deplete carbon stores normally devoted to height growth.

In the high marsh zone in 1986 (Figure 9), height growth of Spartina patens in oiled plots was significantly lower than the heights of control plants after treatment applications ($p<0.001$, ANOVA). Height growth in 1987 was very similar to that noted in 1986 and was significantly lower than control heights from day 67 to the end of the sampling period ($p<0.001$, ANOVA). These data suggest that there was virtually no recovery of height growth in the high marsh zone one year after the oil treatment. On the first sampling date in 1987 (Day 26), oiled plants were significantly taller than control plants. This trend was observed in all vegetation zones although it was significant only in the creek edge and high marsh zones. Reductions in stem density associated with the oil treatments may have reduced competition allowing more rapid growth early in the growing season.

Stem Density

Stem density data for the creek edge zone in 1986 and 1987 are presented in Figure 10. The oil treatment was associated with significant reductions in stem density on all sampling dates following treatment application (Appendix 4). Data from 1987 demonstrate an increase in stem density. No

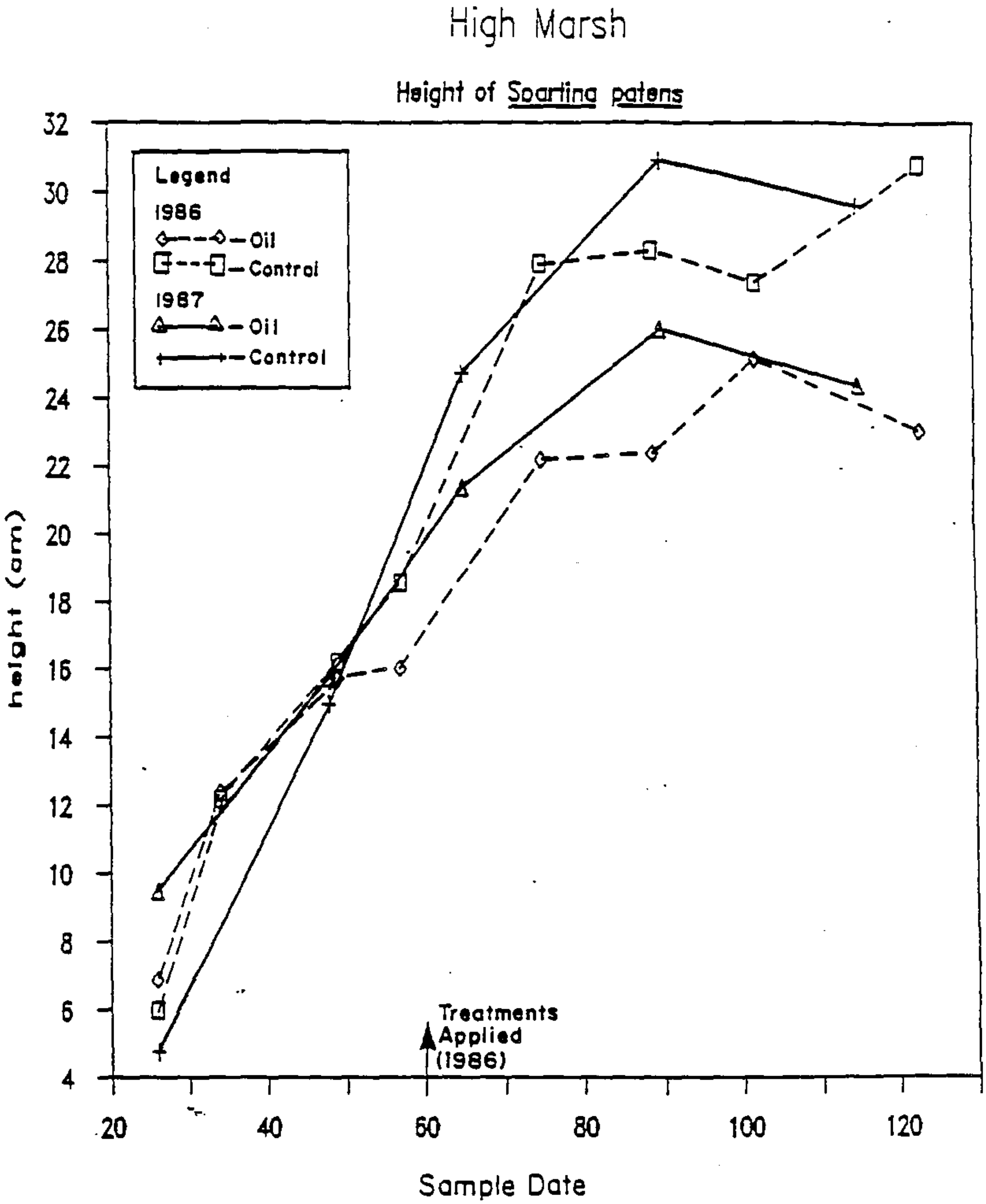


Figure 9: Plot of mean Spartina patens height for the high marsh zone versus time.

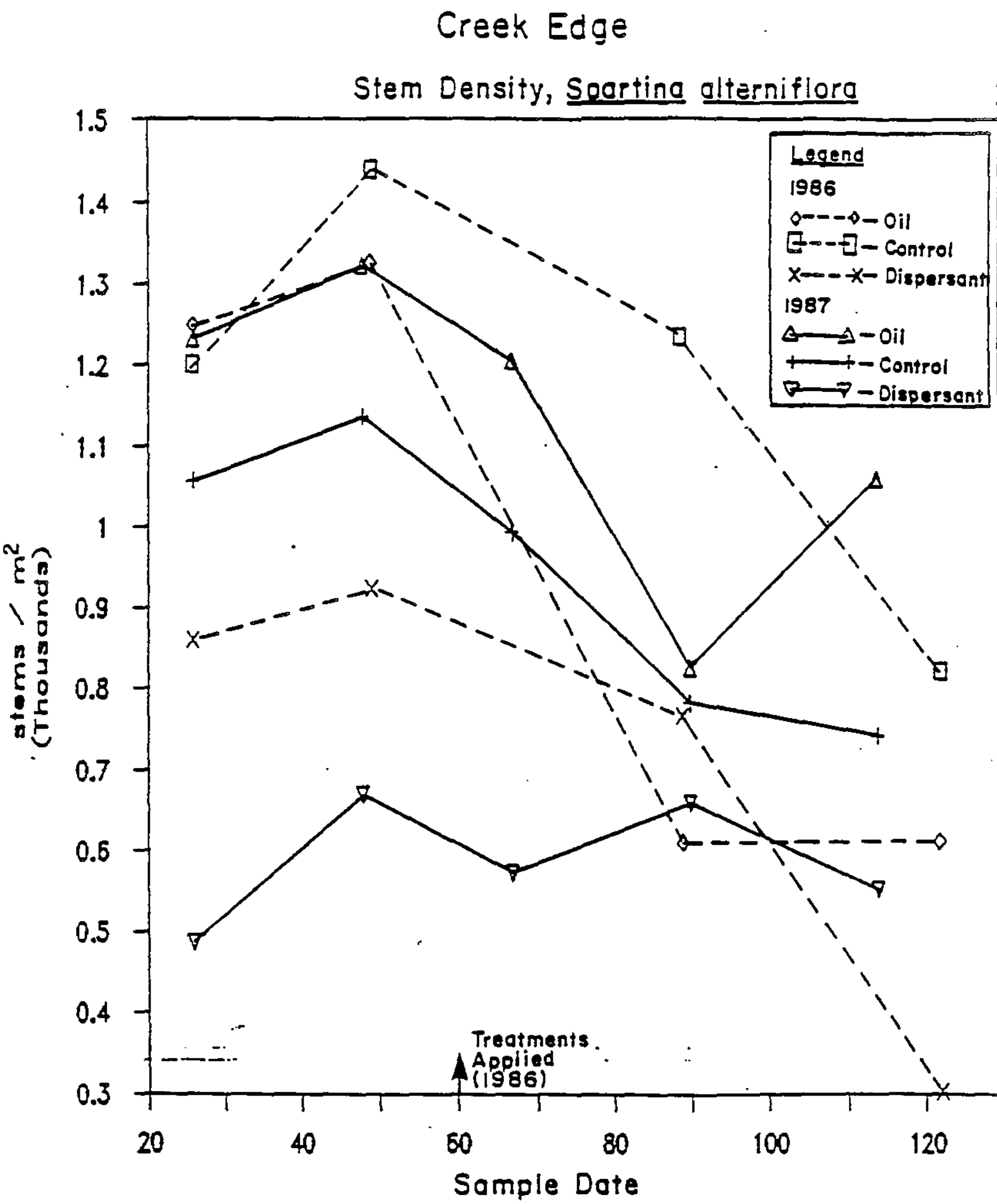


Figure 10: Plot of mean Spartina alterniflora stem density for the creek edge zone versus time.

significant differences were found between control and oiled plots in 1987 (Appendix 4). On all dates oiled plots had higher stem densities than control plots. This situation appeared to be attributable more to large reductions in control stem density rather than to substantial improvements in oiled plot stem density. Nevertheless, the data does indicate a recovery of stem density in oiled plots. No clear reasons for reductions in control stem density were evident. Small reductions in stem density were also noted in all high marsh control quadrats and two out of three midmarsh control quadrats. Trampling damage to the periphery of the quadrats may have stressed plants within the quadrats resulting in reduced stem density or yearly variations in growing conditions might also be responsible. Summer rainfall was very heavy in 1986 and light in 1987. Drought conditions might be expected to increase osmotic stress in salt marsh plants resulting in stem density reductions.

The stem density of dispersant treated plots was significantly lower than control plots on all sampling dates in 1986 including pretreatment dates ($p<0.001$, ANOVA). This indicated that control and dispersant treated plots were not directly comparable. Determination of dispersant impacts, therefore, was best determined by comparing data from 1986 and 1987 for the dispersant treated plots and comparing stem density trends for the control and dispersant treated plots. In 1986, stem density was reduced to a mean of 300 stems /m^2 by the end of the growing season (Day 123) from a maximum of 930 stems/m^2 (day 49). During 1987 stem density remained relatively stable during the growing season with 550 stems/m^2 at the end of the growing season (Day 118) and a maximum of 670 stems/m^2 (Day 48). This data suggests a moderate recovery of stem density during the 1987 growing season. At the current rate of recovery stem density in the dispersant treated plots should return to pretreatment levels within two years of dispersant applications. Stem density in control plots in both 1986 and 1987 declined gradually from a peak early in the growing season (Day 48 or 49) to minimum density at the end of the growing season (Day 115 or 123). This decline was probably attributable to mortality of shoots induced by intraspecific competition. In dispersant-treated plots in 1987 stem density remained stable and plants were generally well spaced in the quadrats. This suggests that intraspecific competition was probably reduced in these quadrats resulting in less mortality. On the last two sampling dates in 1987, the stem densities of dispersant treated plots were not significantly different from control stem densities (Appendix 4).

In the midmarsh zone (Figure 11) the oil treatment was associated with significant reductions of stem density ($p<0.001$, ANOVA (89% reduction in stem density by the end of the growing season)). Stem densities of oil treated plots remained significantly lower than controls throughout the

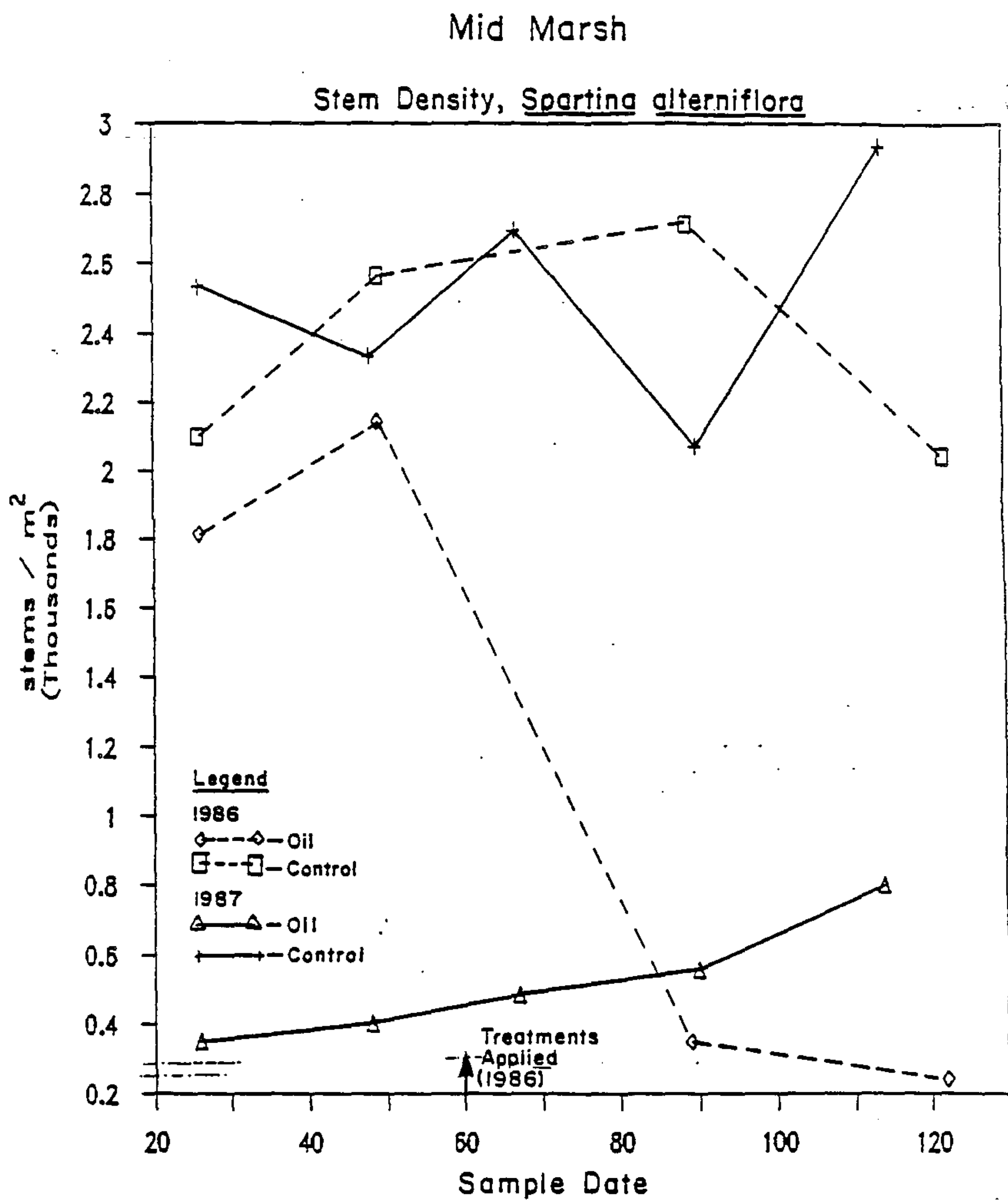


Figure 11: Plot of mean Spartina alterniflora stem density for the midmarsh zone versus time.

1987 growing season ($p<0.001$, ANOVA). Stem density early in the 1987 growing season (day 26) was 350 stems/m^2 which was similar to that noted at the end of the 1986 growing season (230 stems/m^2). Over the course of the 1987 growing season Spartina alterniflora stem density increased slowly to 800 stems/m^2. This appears to indicate that stem density recovered slightly during the 1987 growing season, however, at the end of the sampling period, the mean stem density of the control plots was still 73% higher than that of oiled plots. Complete revegetation of the midmarsh zone will probably take at least five years assuming that the current recovery rate is maintained.

Oil treatments in the high marsh zone (Figure 12) were associated with significant reductions in stem density in 1986. In 1987, oil treated quadrats had significantly lower mean stem densities on all but the first sampling date. Some recovery of stem density was evident in the data. At the end of the 1986 growing season mean stem density of oil treated plots was 48% lower than that of control plots. Stem density of oiled plots at the end of the 1987 growing season was only 32% lower than that of control plots indicating that some recovery had occurred. Complete revegetation of the high marsh might be expected to occur within three to four years of treatment application assuming the current rates of recovery are maintained.

The stem density of flowering Spartina plants varied greatly from year to year (Figure 13), however, within years the trends for the various treatments were consistent. In 1986, oil or dispersant treatments caused large declines in flowering shoot density although none of the reductions were significant (Appendix 5). For the oil treatments, the largest reduction in density was noted in the creek edge zone (99% reduction) and the smallest in the high marsh zone (64% reduction). Flowering shoot stem density in the midmarsh zone was reduced by 86%. Dispersant treated plots in the creek edge zone exhibited a 95% reduction in density. Similarly, Baker (1971) noted that oiling of Spartina x townsendii in the early summer resulted in reduced flowering. This was attributed to oil induced mortality of flower buds or primordia. Alternatively, Jefferies and Perkins (1977), suggest that under environmental conditions which require large allocations of nitrogen and carbon for maintenance (as would be expected as a result of oil toxicity) sexual reproduction may fail to occur or the development of seeds may be aborted. In 1987, the trend for flowering stem density in 1986 was reversed. Flowering shoot densities for oil and dispersant treated plots in 1987 were equal to or in most instances, higher than control densities from 1986 or 1987. In the creek edge zone, dispersant treated plots had the highest density of flowering shoots, followed by oiled plots then control plots at a ratio of 14:6:1.

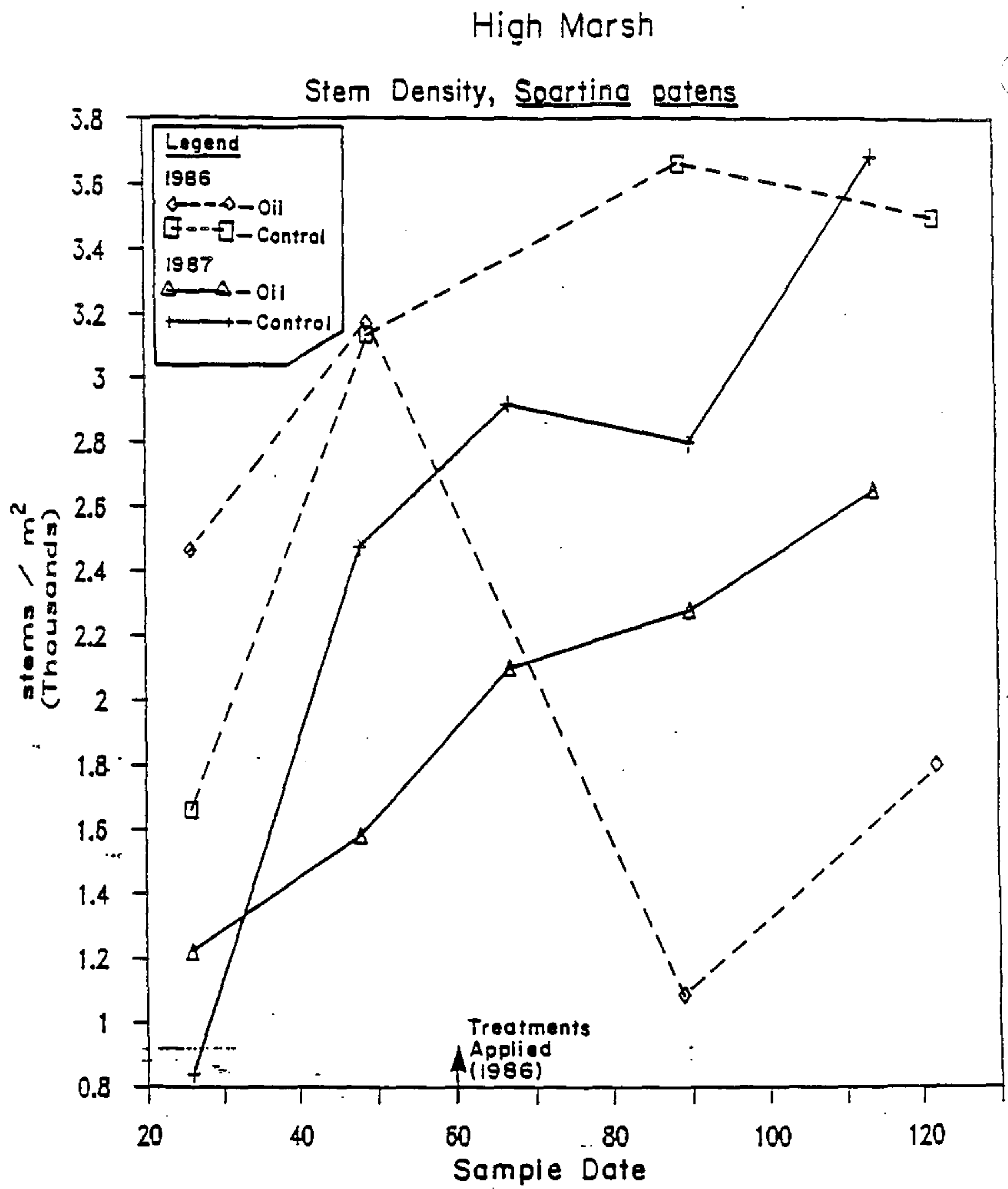


Figure 12: Plot of mean *Spartina patens* stem density for the high marsh zone versus time.

misleading since Salicornia cover was consistently higher in the oiled plots than in control plots both before and after treatment applications. In 1986, Salicornia cover in oiled plots was significantly higher than in control plots on days 35 ($p=0.014$, ANOVA) and 102 ($p=0.001$, ANOVA). There was a very strong negative relationship between Spartina patens cover and Salicornia cover ($r=-0.942$) suggesting that increases in Salicornia cover were related to reductions in S. patens competition.

Suaeda cover responded to the oil and dispersant treatments similarly to Salicornia (Figure 21). In 1986, Suaeda was present in only one dispersant plot on day 35. It disappeared from the creek edge zone following the dispersant treatment application. In 1987 Suaeda occurred sporadically in the control plots, remaining at low levels throughout the growing season. In the oiled plots Suaeda was more common, however, its cover remained stable throughout the growing season. Suaeda cover in the oiled plots was significantly higher than control plots on day 56 ($p=0.030$, ANOVA). Few Suaeda shoots grew larger than 5 cm under the well developed Spartina canopy in the oiled plots. Suaeda cover was highest in the dispersant treated plots. Cover increased throughout the growing season, reaching a peak of 6.50%. Suaeda cover in dispersant treated plots was significantly higher than that of control plots on all sampling dates in 1987 ($p<0.001$, ANOVA). There was a strong negative correlation ($r=-0.825$) between the square root of Suaeda cover and the square root of Spartina alterniflora cover suggesting that this species was responding to the removal of the dense Spartina canopy. As was noted for Salicornia, Spartina cover reductions of at least 50% were required to evoke a large increase in Suaeda cover.

In the mid marsh zone Suaeda was noted in only one control plot during the 1986 growing season (Figure 22). In 1987, Suaeda was absent in control and oiled plots on day 43 but appeared in both treatments by day 56. Suaeda cover in the oiled plots increased throughout the growing season while cover in the control plots stabilized after day 56. Suaeda cover in the oiled plots was significantly higher than in the control plots on days 70 ($p=0.044$, ANOVA) and 110 ($p=0.011$, ANOVA). Suaeda cover in the midmarsh oiled plots was equivalent to that found in oiled plots in the creek edge zone. A larger amount of cover would be expected in the midmarsh zone since Spartina mortality was much higher there. The coefficient of correlation between the square root of Spartina cover and the square root of Suaeda cover in this zone was only -0.717 as opposed to -0.825 in the creek edge zone. The combination of a normally hostile environment for plants combined with residual oil toxicity (as outlined for Salicornia) may have restricted the establishment and growth of Suaeda in the midmarsh oiled plots.

In the high marsh zone, Suaeda was present only in the oiled plots in 1986 (Figure 23). Suaeda cover in the oiled plots declined after oil application and had dissappeared from the plots by the last sampling date. This data suggests that Suaeda was sensitive to the oil treatment. Baker (1971) noted that oil treatments applied during the growing season caused severe reductions in Suaeda maritima cover. In 1987,Suaeda cover increased in both the control and oiled plots with the highest cover values noted in the oiled plots. These differences were not significant. There was a moderately strong negative relationship between Suaeda cover in the high marsh zone and Spartina patens cover (r=-0.769).

Another annual species, Atriplex patula was found sporadically in the creek edge zone in all treatments. Trends for Atriplex abundance were similar to those of Salicornia and Suaeda except that Atriplex cover declined markedly between days 90 and 100 in 1987 (Figure 24). No reason for this decline was evident.

Atriplex patula was not found in any plots in the midmarsh zone in 1986, however, it was found in some plots in 1987 (Figure 25). On days 45 and 56 Atriplex was restricted to the oiled plots, however, it became established in one of the control plots by day 70. Maximum Atriplex cover was noted between days 45 and 56 in the oiled plots. Atriplex cover in the oiled plots declined to a minimum by day 90 then increased somewhat by day 110. This cover reduction may have been caused by hypersaline conditions induced by drought conditions experienced in 1987. The increase in cover in the control plots may have been the result of increased illumination of the sediment surface caused by sampling disturbance to the edges of the control plots.

Atriplex patula cover in the high marsh zone responded similarly to Suaeda (Figure 26). In 1986 there was a decline in Atriplex cover associated with the oil treatment, however, cover returned to pretreatment levels by the end of the growing season. Increased Atriplex cover values were noted in both the control and oil-treated plots in 1987 with the largest increases associated with the oiled plots. The coefficient of correlation between Spartina patens cover and Artriplex cover was -0.758.

Plantago juncoides was found in one dispersant plot in the creek edge zone. This species was absent or overlooked on the pretreatment sampling date in 1986 (Figure 24). Plantago cover increased throughout the 1986 growing season and continued to increase at a slower rate through the 1987 growing season. This data suggests that Plantago juncoides was tolerant of the dispersant application. The dominant Spartina alterniflora was sensitive to the dispersant treatment and while its cover declined during 1986, Creek Edge Cover

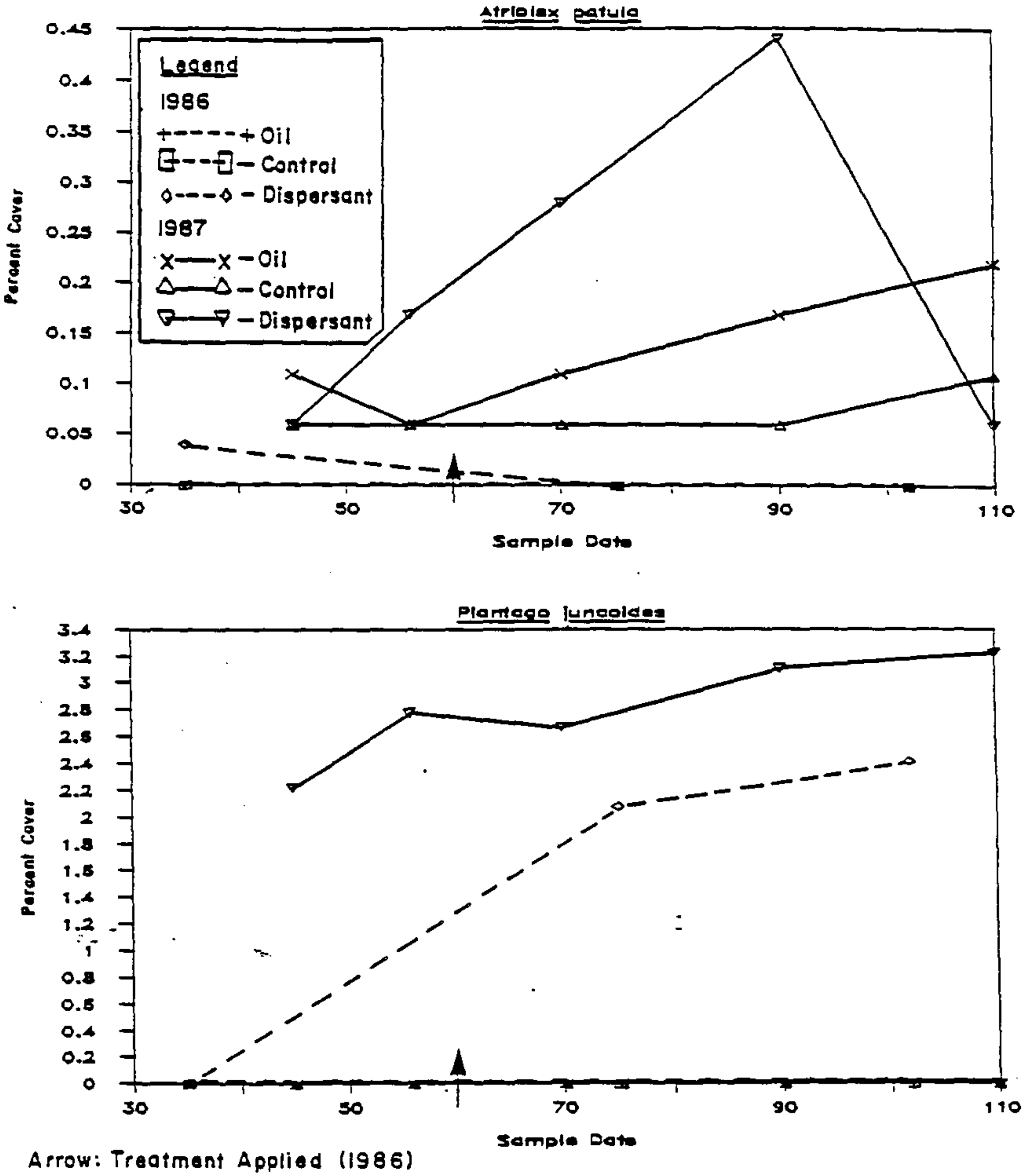


Figure 24: Plots of mean *Atriplex patula* and *Plantago juncoides* cover in the creek edge zone versus time.

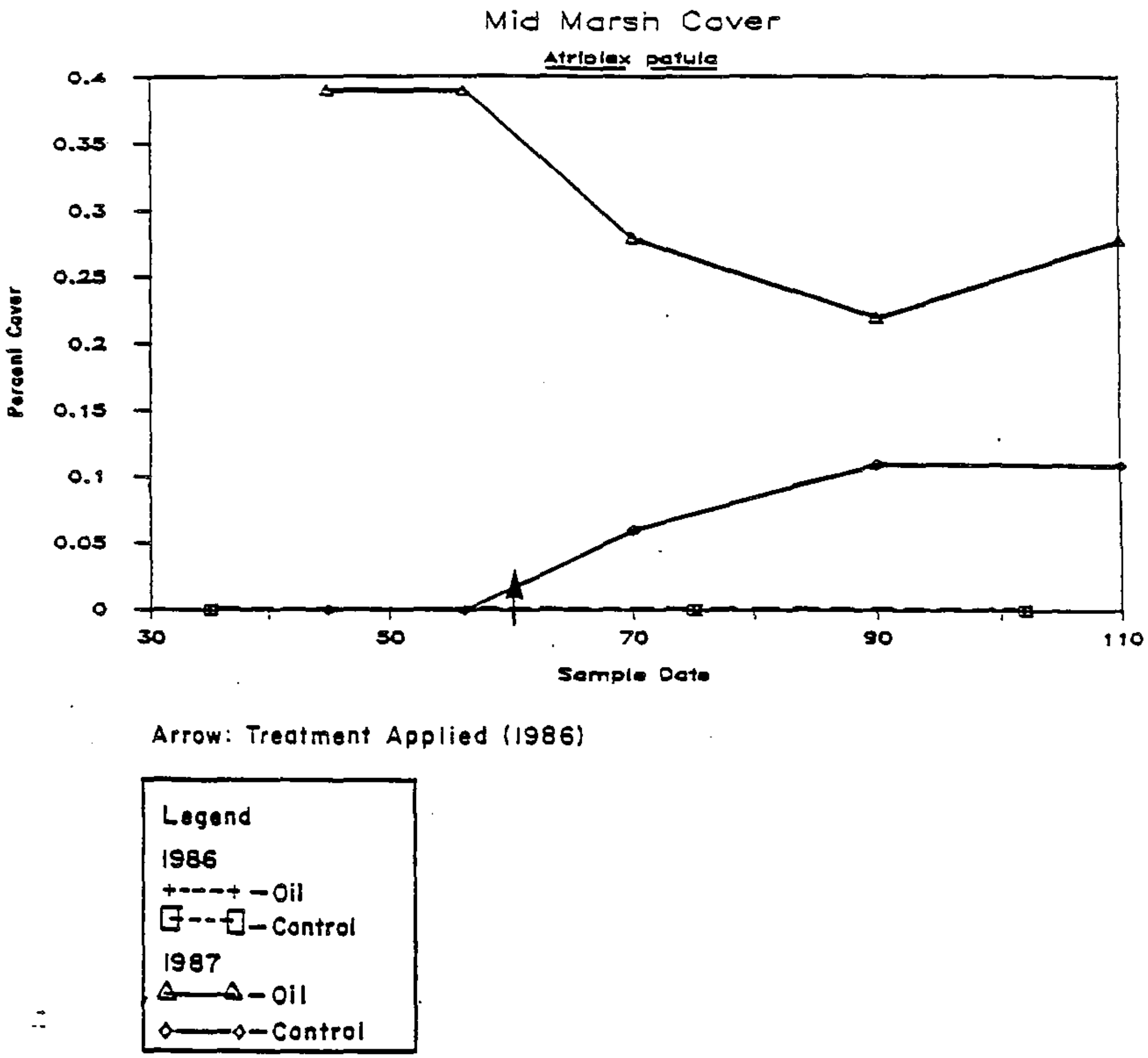


Figure 25:: Plot of mean Atriplex patula cover in the midmarsh zone versus time.

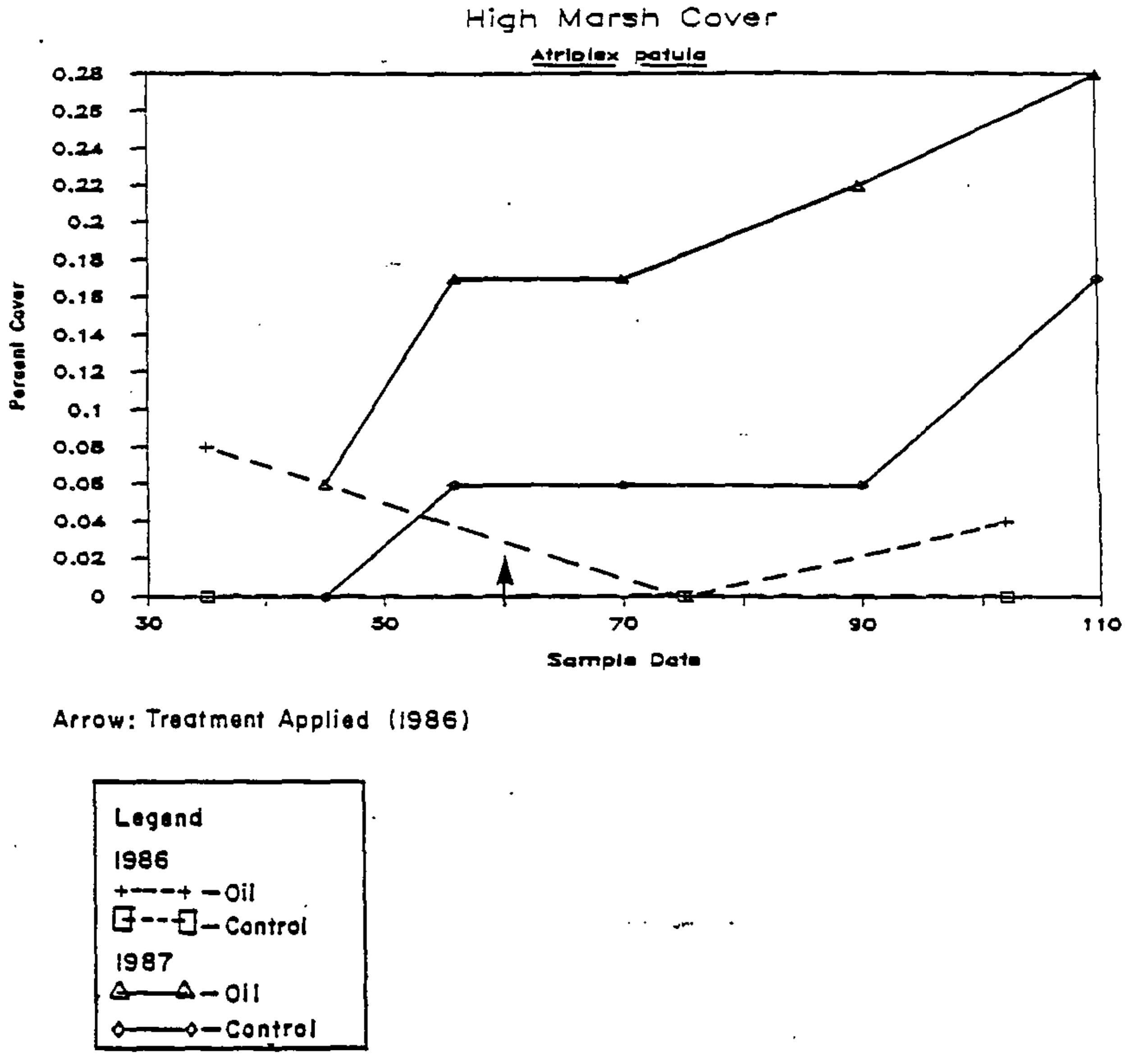


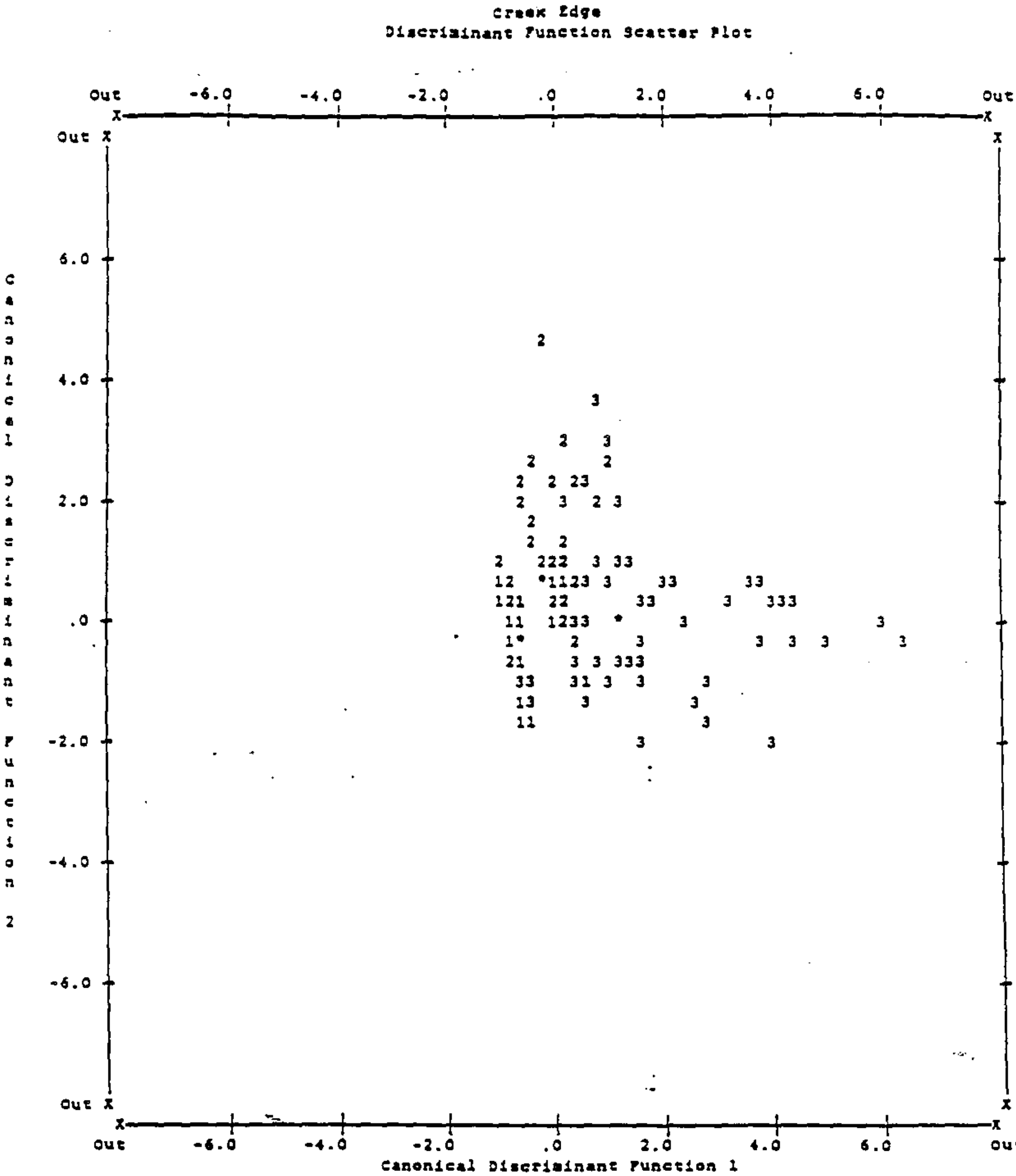
Figure 26: Plot of mean <u>Atriplex patula</u> cover in the high marsh zone versus time.

Plantago was able to quickly occupy the available space. Slow expansion of Plantago cover in 1987 probably reflects increased competition from the recovering S. alterniflora sward.

Discriminant analyses were conducted on the cover data collected in each vegetation zone. The analysis for the Creek edge zone included control, oil and dispersant treatments, therefore, the results were presented in two dimensions. Figure 27 presents a scatter plot for all samples with detritus excluded. The first axis separated dispersant treated plots (representd by 3's) from oiled plots (2's) and control plots (1's). The second function separated oiled plots from control and dispersant plots. Separation was highly significant along both axes (Wilks' lambda. $p<0.00005$). The first axis accounted for 72% of the variance explained, while the second accounted for 28%. Table 4 presents the coefficients of the standardized canonical discriminant function and the correlation of each species with each function. The asterisks with each correlation indicate which axis the species is most closely associated. For function 1 which separated dispersant treated plots from other treatments, Suaeda maritima, Plantago juncoides and Salicornia europaea were most important. Separation of the control and oil treated plots was most strongly determined by Spartina alterniflora and S. patens. For each point the probability of belonging to each treatment can be assessed. Each data point can be assessed as to whether it matches its treatment, or is more similar to another treatment. Counting the number that are assessed as misclassified provides an impression of the separation (or overlap) of the ranges resulting from treatment. For the creek edge zone, without standing dead cover incorporated, 97 of the 255 plots were considered misclassified.

The analysis which included standing dead yielded similar results. Both axes were highly significant with detritus associated with the second (control-oil) axis. The inclusion of standing dead cover in the analysis increased both the total variance and the proportion explained by axis 2.

These results indicate that the dispersant treatment was responsible for the largest floristic changes in the creek edge zone. These floristic changes were produced by the proliferation of annual species such as Salicornia and Suaeda after severe damage to the Spartina sward. The small degree of variance accounted for by the oil treatment (28%), indicated how little impact the oil treatment had on the creek edge zone. The results of the analysis suggest that the oil treatment had relatively little effect on species composition since the species most correlated with this function were the dominant Spartina species.



Symbols used in Plots

Symbol	Label
1	Control
2	Oil
3	Dispersant
*	Group Centroids

Figure 27: Scatter plot of discriminant analysis scores for plot visits in the creek edge zone. Species cover data was used in the analysis.

The high marsh and midmarsh zones involved only two treatments (control and oil), consequently, only one function can be generated to separate them. In the analysis for the midmarsh zone, separation was highly significant (Wilks'Lambda,$P < 0.00005$) with S. alterniflora having the only strong correlation (Table 4). Figure 28 clearly indicates the degree of separation obtained. A total of 19 out of 162 sampling units were flagged as misclassified. The results for the analysis incorporating standing dead cover were similar. Standing dead cover was negatively correlated with the function.

The high degree of separation for the midmarsh data indicates the severity of oil toxicity in this zone. High correlation with only S. alterniflora indicated both the high degree of oil induced mortality associated with this species and the relatively poor performance of Salicornia and Suaeda in this zone.

The results for the high marsh zone were also highly significant (Wilks' Lambda, P 0.00005), but showed more overlap (Figure 28) as indicated by the higher proportion of misclassifications (48 of 162). Salicornia europaea was highly correlated with the function, while Atriplex patula had a moderate positive correlation and Spartina alterniflora had a moderate negative correlation. Spartina patens showed little correlation with the function (Table 4). When standing dead cover was included in the analysis the number of misclassifications was reduced to 29 out of 162. The resultant function was less strongly correlated with Salicornia europea (0.65) and the correlation with standing dead was 0.44.

The high degree of misclassification for this zone suggested that the oil treatment had less impact on the floristic composition of this zone than did the oil treatment in the midmarsh zone or the dispersant treatment in the creek edge zone. High correlation of Salicornia with the function indicates that the oil treatment caused enough damage to the S. patens sward to permit a substantial increase in the abundance of Salicornia.

Fluorometry

The 1986 study (Lane et al., 1987) consisted of a field study and a parallel greenhouse study. Fluorescence induction measurements were made only for plants from the greenhouse study as a result of logistic constraints. Fluorometric analysis proved to be a sensitive technique for the detection of physiological stress in Spartina. It was decided to use this technique in the 1987 field study to determine whether plants were still stressed by the treatments one year after their application.

Table 4. Standardized canonical discriminant function coefficients (SCDFC) and pooled-within-groups correlations between species and canonical discriminant functions (CORR). Species cover values were used in the analyses for the three vegetation zones.

CREEK EDGE

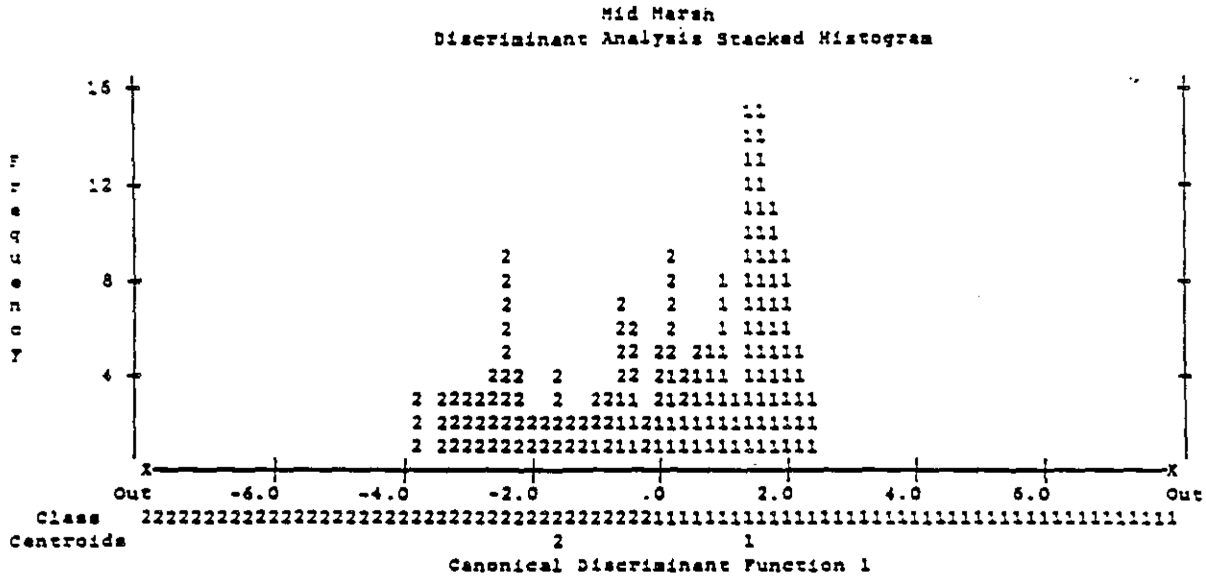
Species	SCDFC Function 1	SCDFC Function 2	CORR Function 1	CORR Function 2
Spartina alterniflora	-0.108	0.659	-0.197	0.659*
Spartina patens	0.153	0.684	0.052	0.690*
Salicornia europaea	-0.190	0.259	0.605*	0.247
Atriplex patula	-0.006	0.086	0.254	0.189
Suaeda maritima	0.918	-0.019	0.885*	0.084
Plantago juncoides	0.437	-0.114	0.637*	-0.146
Glaux maritima	-0.020	0.028	0.193	-0.044

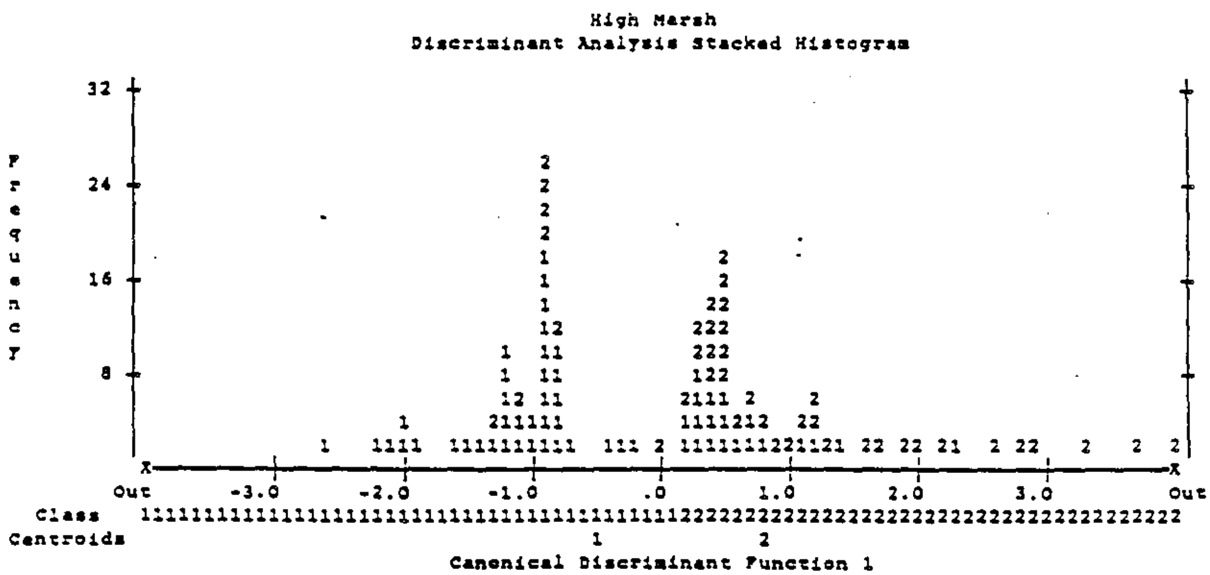
MIDMARSH

Species	SCDFC Function 1	CORR Function 2
Spartina alterniflora	0.999	0.867
Spartina patens	0.432	0.115
Salicornia europaea	0.129	-0.141
Atriplex patula	-0.162	-0.287
Suaeda maritima	-0.205	-0.191
Triglochin elata	0.106	0.123
Limonium nashii	-0.061	-0.063

HIGH MARSH

Species	SCDFC Function 1	CORR Function 2
Spartina alterniflora	-0.280	-0.307
Spartina patens	0.151	0.001
Salicornia europaea	0.903	0.886
Atriplex patula	0.152	0.343
Suaeda maritima	-0.109	0.102
Triglochin elata	-0.053	0.058
Festuca rubra	0.148	0.147
Glaux maritima	0.198	0.242





Symbols used in Plots

Symbol	Label
1	Control
2	Oil

Figure 28: Stacked histograms of discriminant analysis scores for plot visits in the midmarsh zones and the high marsh zone. Species cover data were used in the analyses.

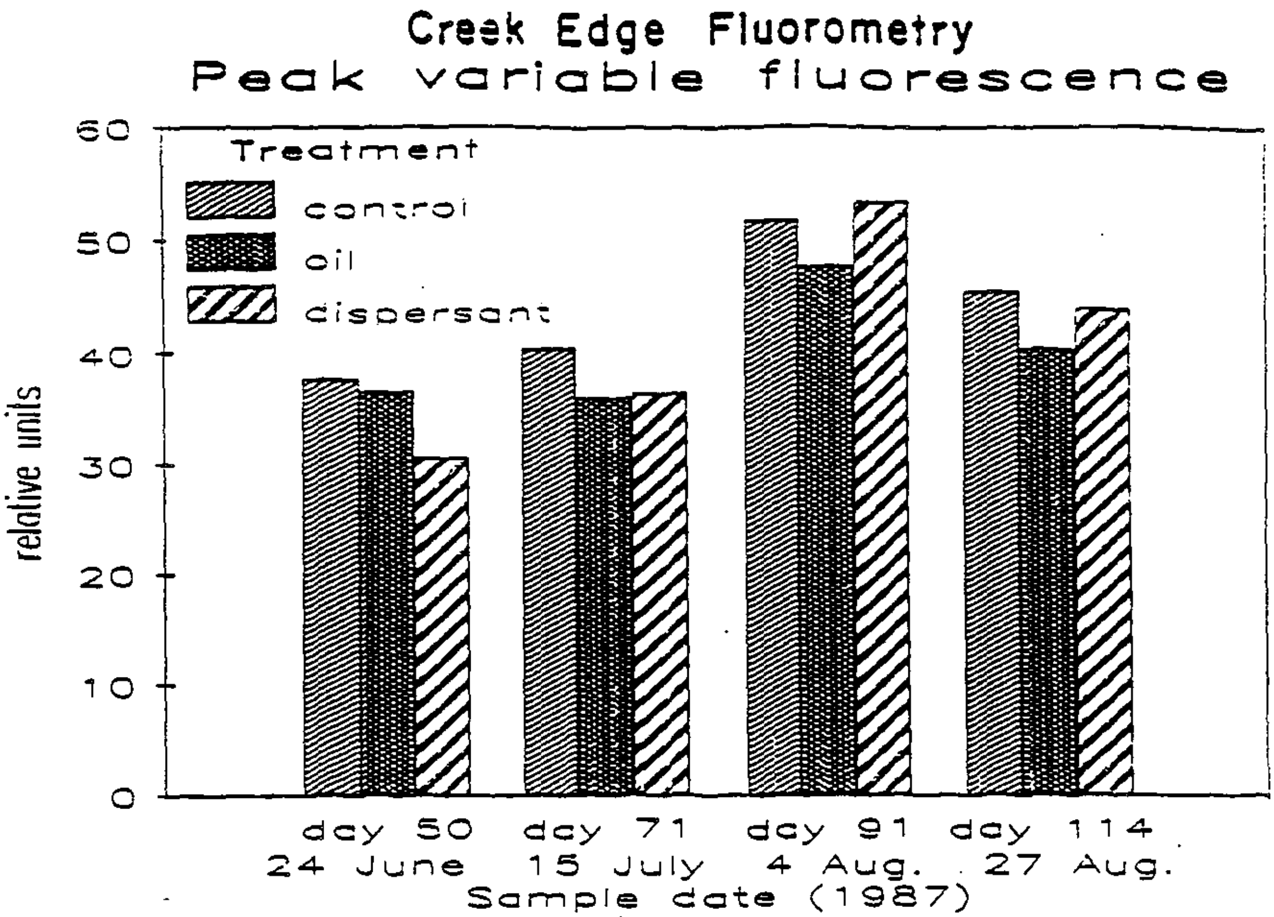
Data from the greenhouse study, unfortunately, are not directly comparable to field fluormetry results from 1987 since the microcosm culture system and modifications in sampling techniques may have altered the response of the plants during the fluorescence induction testing. Comparison of the fluorometry results with the impacts of the oil and dispersant treatments on other parameters which were monitored in both the field and greenhouse experiments in 1986 (height, stem density, biomass and leaf anatomy), suggest that treatment impacts were similar in both systems. We believe, therefore, that the general trends noted for the impacts of these treatments as detected by the fluorometric techniques employed in the 1986 greenhouse study, may be indicative of the conditions which would have been encountered in the field during the 1986 growing season.

Results from the 1986 greenhouse study (Lane et al., 1987) provided evidence of damage to the photosynthetic systems of Spartina alterniflora and S. patens in all three vegetation zones. Oil treatments caused little damage in the creek edge and high marsh zones but had significant impacts in the midmarsh zone. The creek edge dispersant treatment was responsible for significant damage to Spartina alterniflora. The impacts of the oil treatment in the midmarsh zone and dispersant treatment in the creek edge zone lasted throughout the 1986 growing season.

Of the two fluorometric measures utilized in the 1986 study, the 100 second difference values (fluorescence at 100 seconds - initial fluorescence) proved to be the most sensitive measure, indicating plant stress within one day of treatment application. Peak fluorescence (Peak fluorescence - Initial fluorescence) was much less sensitive, reliably indicating plant stress only near the time of death when other symptoms (such as chlorosis) were already evident.

The fluorescence effects observed consisted of reduced peak fluorescence and a faster return to initial values. These symptoms were suggestive of a disruption of the light receptor system of the plants.

In 1987, oiled plants from the creek edge zone (Figure 29) tended to have reduced peak variable fluorescence on all sampling dates with values for oiled plants ranging between 89 and 97% of control values. None of these reductions were significant on any of the sampling dates. Peak variable fluorescence in dispersant treated plots was low on day 50 but increased to control levels by day 91. No significant differences were noted on any sampling date. One hundred second difference values for oiled plants were significantly lower than controls on day 71 ($p=0.041$, ANOVA), but were not significantly different on any other sampling date. One hundred second difference values for dispersant treated plants were significantly higher



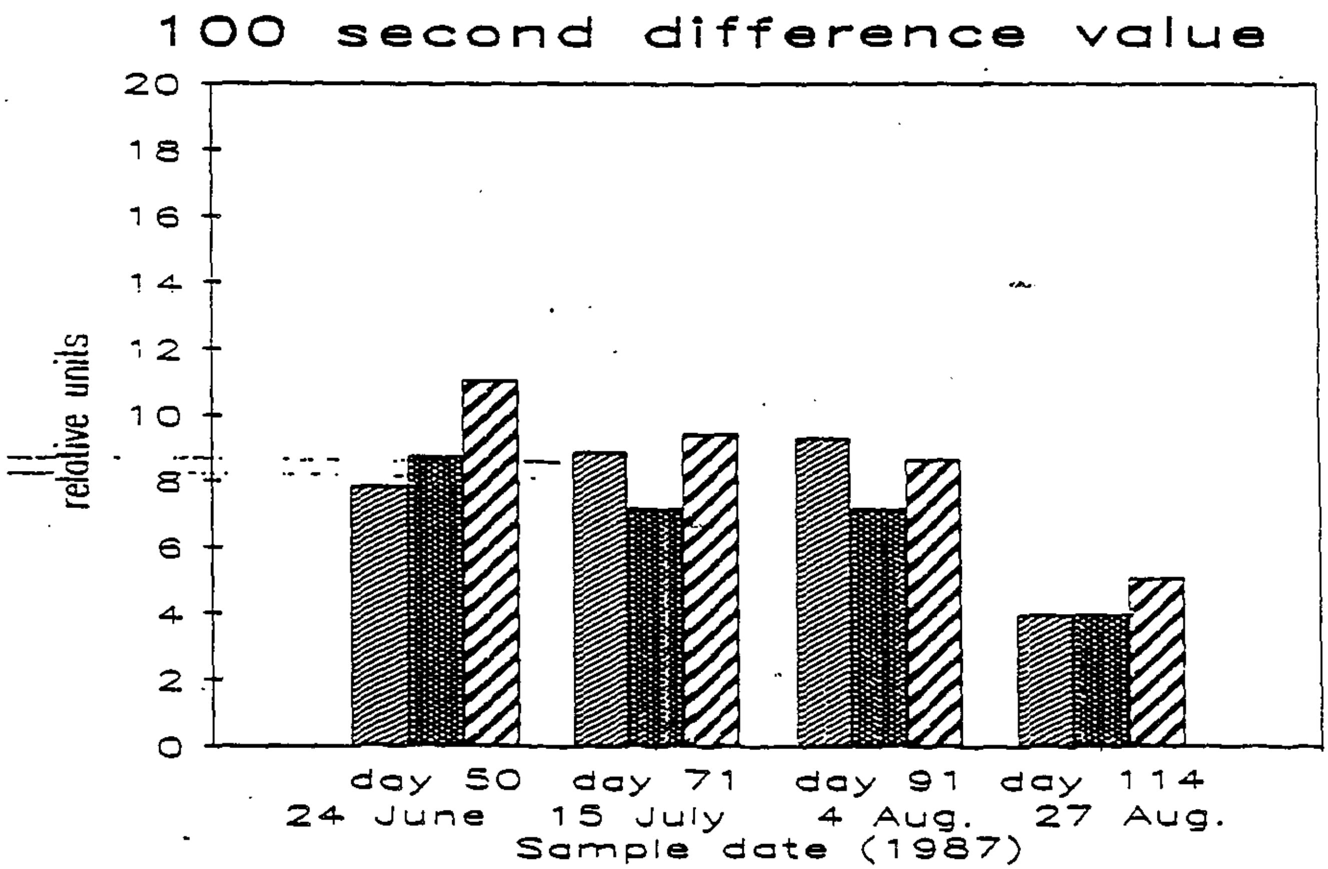


Figure 29: Histograms of peak variable fluorescence and 100 second difference values for plants from the creek edge zone on four sampling dates in 1987.

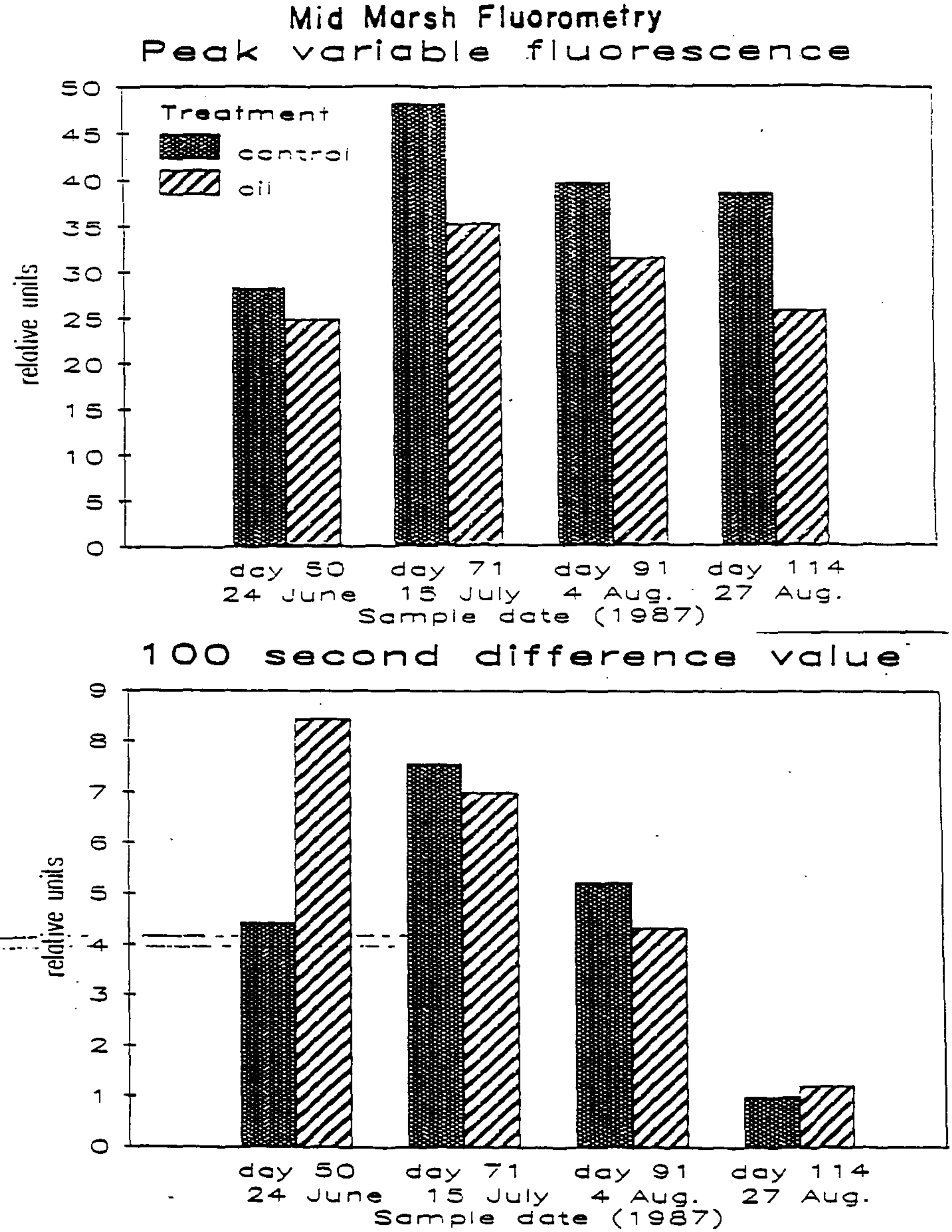


Figure 30: Histograms of peak variable fluorescence and 100 second difference values for plants from the midmarsh zone on four sampling dates in 1987.

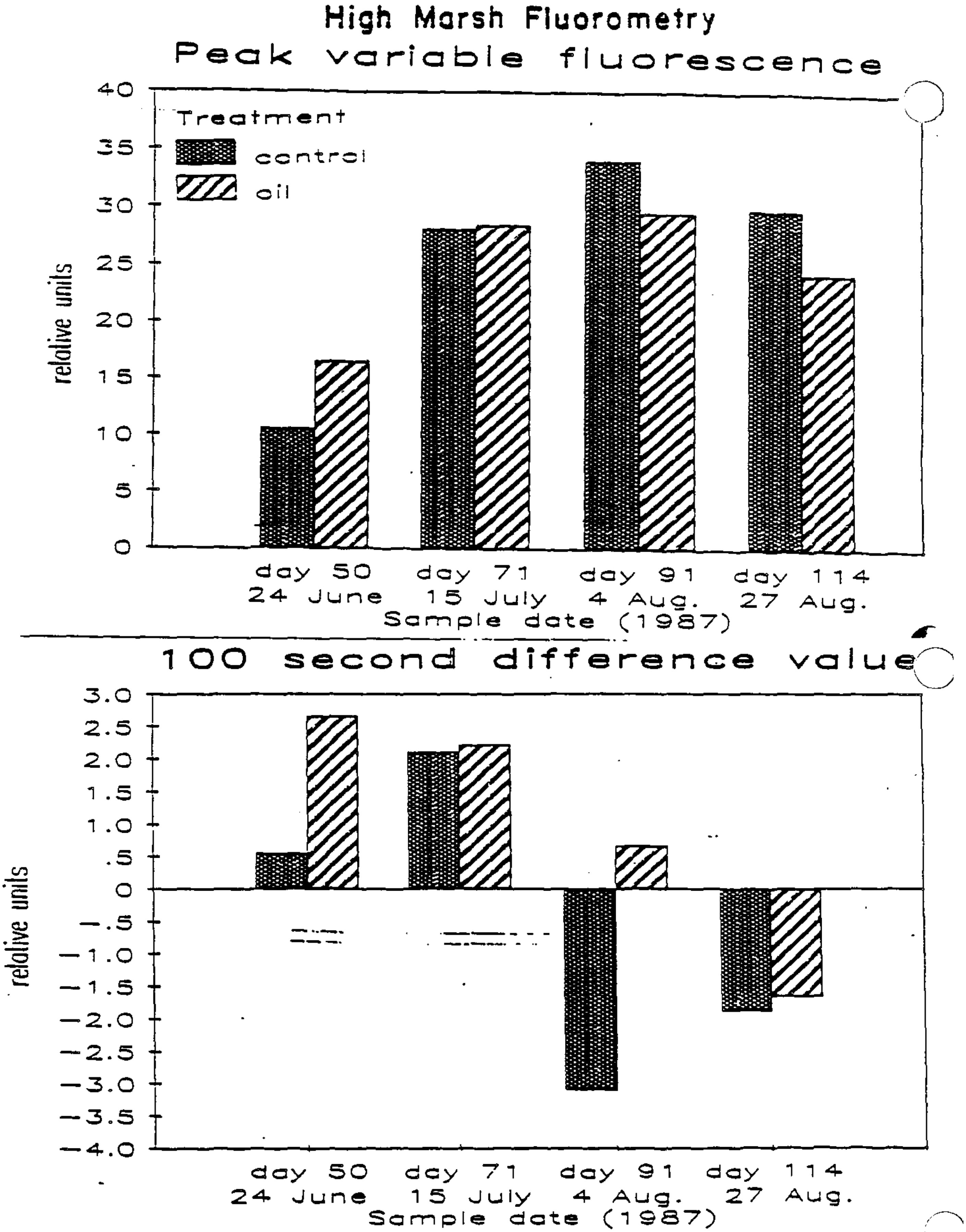


Figure 31: Histograms of peak variable fluorescence and 100 second difference values for plants from the high marsh zone for sampling dates in 1987.

than for control plants on day 50 (p=0.015, ANOVA), however, values for all other samping dates were not significantly different from the controls. These data suggest that there was little if any residual toxicity associated with the treated plots in the creek edge zone one year after treatment applications.

In the midmarsh zone (Figure 30) oiled plants tended to have reduced peak variable fluorescence values as was noted for the creek edge zone. These reductions, however, tended to be larger than in the creek edge zone with values for oiled plants ranging between 67 and 87% of control values. Peak variable fluorescence values of oiled plants were significantly lower than values for control plants on days 71 (p=0.021, ANOVA) and 114 (p=0.004, ANOVA). The trend for the 100 second difference values was also similar to that noted in the creek edge zone. Oiled plot values were lower than control plot values on days 71 and 91 but were higher than the controls on days 50 and 114. No significant differences in 100 second difference values were noted on any of the sampling dates. The significant reductions in peak variable fluorescence indicate that residual oil may have produced some plant stress.

In the high marsh zone (Figure 31) peak variable fluorescence of oiled plants was lower than the controls on the last two sampling dates, however, no significant differences were noted on any sampling date (Appendix 8). One hundred second difference values for high marsh plants displayed a trend which was common to all vegetation zones. Oiled plants had higher values than controls on day 50 but returned to control levels on all other sampling dates. The increase on day 50 was significant (p=0.031, ANOVA). Values on all other sampling dates were not significantly different from the controls. The data suggest that there was little or no residual oil toxicity in the high marsh plots one year after treatment applications.

Fluorometric analysis suggested that oil applied to the creek edge and high marsh areas had weathered sufficiently by 1987 to eliminate oil as a source of plant stress. Similarly, the dispersant applied to the creek edge zone in 1986 caused no plant stress in 1987. The dispersant was probably removed from the study plots by tidal inundation within a month of application. Data for the midmarsh zone suggested that residual oil may have stressed the plants in that zone. Sediment oil data for 1987 were too variable to determine whether more oil was present in the midmarsh zone than in the other zones. Gas chromatography data suggested that oil in all of the zones was extensively weathered by 1987. Long term toxicity in the oiled midmarsh plots may have been attributable to the stressful nature of the midmarsh environment. Physiological stresses associated with the midmarsh, such as reduced nitrogen uptake, high root respiration and hydrogen sulfide toxicity may have reduced the tolerance of midmarsh plants to oil residues which had little or no effect on creek edge or high marsh plants.

Peak variable fluorescence was the only fluorometric parameter which was consistently altered by the oil treatments. Reduction of peak variable fluorescence would suggest damage to the light receptor system of the midmarsh plants. Lower concentrations of photosynthetic pigments would reduce the proportion of the incoming light which was absorbed by these pigments and thus available for fluorescence. Chlorosis might be expected under these conditions, however, no differences in plant coloration were noted during the field observatons nor were noticeable reductions in chloroplast density observed in the leaf anatomy study. The fluorometric technique may have been sensitive enough to indicate stress before symptoms became visible or the mechanism of light receptor damage may not have involved the physical destruction of chloroplasts.

Leaf Anatomy

Anatomical data from 1986 (Lane et al., 1987), demonstrated that microscopic symptoms were identical for both oil and dispersant treated plants. Microscopic symptoms consisted of a gradual reduction in chloroplast density in conjunction with progressive chlorosis at the macroscopic level. The data suggested that both treatments had probably caused disruption of cell membranes leading to the destruction of chloroplasts and the eventual death of the cells. Additional macroscopic symptoms included oil induced stem and leaf deformities of Spartina patens which affected approximately 10% of oiled plants.

Results from the 1987 study revealed no microscopic or macroscopic differences between the control and oil or dispersant treated plants. These data suggest that the constituents of the oil responsible for the symptoms observed in 1986 had been weathered or consumed by microbes before the 1987 growing season. Any residual toxicity might be expected to produce more subtle changes in plant morphology such as reductions in growth rate or alterations in reproduction. These have been dealt with elsewhere in the text.

CONCLUSIONS

The oil treatment appeared to have been responsible for a reduction in the thickness of anaerobic reducing zones in all three vegetation zones. Significant reductions were noted only in the high marsh zone. Declines in reducing zone thickness may have been caused by oil induced decreases in heterotrophic activity which permitted the downward migration of the aerobic zone.

Hydrocarbon concentrations in the salt marsh sediments were highly variable, however, temporal trends in concentrations were apparent. Hydrocarbon concentrations in all zones initially increased over a period of approximately 30 days as oil was removed from vegetation and deposited on the sediment. In the creek edge and high marsh zones, concentrations peaked then declined within 1986 as a result of weathering and possibly flushing of oil from the sediments. Concentrations in the midmarsh zone remained high throughout 1986. In 1987, concentrations in the creek edge and high marsh zones declined relatively little and were similar to or slightly lower than end of growing season concentrations in 1986. Hydrocarbon concentrations in the midmarsh zone declined substantially during the 1987 growing season. Most hydrocarbons under C-10 had been lost from the sediments by the end of 1986. At the end of the 1987 growing season, hydrocarbons under C-14 were absent from the sediments. Oil penetration was mostly restricted to the upper 5 cm of the sediment although slightly elevated concentrations were found between 5 and 10 cm.

Plant height data indicated that Spartina height growth in the creek edge zone was relatively unaffected by the oil treatments in both 1986 and 1987 while height growth in the midmarsh and high marsh zones were significantly reduced in 1986. The midmarsh zone was more severely affected by the oil treatments than the high marsh zone. Neither zone appeared to recover during the second growing season. Height growth in the dispersant treated plots in the creek edge zone was significantly reduced during the 1986 growing season but recovered to control levels by the 1987 growing season.

Oil impacts on stem density were still evident in the midmarsh and highmarsh zones in 1987. The largest impacts were associated with the midmarsh zone in both 1986 and 1987. The larger reductions in midmarsh stem density as compared to the creek edge zone were probably attributable to the naturally higher levels of plant stress associated with the midmarsh zone. The additional stress of the oil spill probably taxed the metabolism of the midmarsh plants to the point where most individual stems died. It was difficult to determine the degree of recovery in the creek edge zone since increases in stem density of oiled plots in 1987 were accompanied by large reductions in control stem density. Nevertheless, it appeared that recovery of stem density was most advanced in this zone. The dispersant treatment caused a large reduction of stem density in the creek edge zone in 1986. A moderate increase in stem density was noted for this treatment in 1987.

The density of flowering shoots was substantially reduced (although not significantly) in 1986 by both the oil and dispersant treatments in all zones. In 1987, flowering shoot densities were high in the treated plots, particularly those in which heavy mortality in 1986 was followed by substantial vegetative recovery in 1987. This response was probably the result of a reduction of intraspecific competion which increased the proportion of resources available for flowering. Flowering shoot densities in the creek edge and midmarsh control plots declined in 1987, probably in response to drought conditions experienced during the 1987 growing season.

Total above-ground living biomass data for 1986 indicated that the midmarsh zone was severely affected by the oil treatments while the creek edge zone was virtually unaffected. Total above-ground living biomass in the high marsh zone was moderately reduced. Data for 1987 revealed full recovery for the creek edge zone. Total above-ground living biomass in the midmarsh zone increased significantly while recovery in the high marsh zone was rather poor. Total above-ground living biomass in the dispersant treated creek edge plots was significantly reduced in 1986 but returned to control levels by the end of the 1987 growing season.

Standing dead biomass data collected in 1986 generally reflected the degree of mortality associated with the various treatments and zones; however, it appeared that standing dead biomass values in the oiled creek edge and midmarsh zones were larger than expected from the observed stem density reductions. These data suggested that decomposition had been retarded by the oil treatments. The data revealed that the high marsh zone naturally maintained a very high standing crop of dead stems (up to 2 times higher than total above-ground living biomass). Standing dead biomass returned to expected values in all oiled plots in 1987. In the creek edge dispersant plots in 1987 standing dead biomass was lower than expected as a result of unusually low stem mortality during the 1987 growing season.

Two annual species, Salicornia europaea and Suaeda maritima, increased their biomass in response to mortality of the dominant Spartina species in all three vegetation zones. These increases did not occur until the 1987 growing season either as a result of a lack of seed following the period of high Spartina mortality or inhibition of Salicornia and Suaeda seed germination and/or seedling development by the oil during the 1986 growing season.

Flower biomass was reduced by both the oil and dispersant treatments in 1986, however, in 1987 flower biomass in the treated plots increased greatly with the largest increases associated with the creek edge dispersant plots where mortality had been high in 1986 but recovery had been rapid in 1987. This response was probably attributable to increased availability of resources caused by decreased intraspecific competition in plots where stem density reductions had occurred in 1986. Flower biomass in the creek edge and midmarsh control plots declined in 1987 possibly as a result of drought conditions.

Mean weight of individual Spartina shoots was not affected by the oil treatments in the creek edge zone in 1986, however, it increased relative to control plants in the midmarsh and high marsh zones as a result of selective mortality of small plants. Dispersant treated plants in the creek edge zone in 1986 weighed only half as much as control plants. In 1987, they were heavier than the control plants probably as a result of reduced intraspecific competition. The mean weights of oiled creek edge and high marsh plants were similar to their respective controls in 1987 indicating little residual toxicity. Midmarsh plants were twice as heavy as control plants in 1987 but were significantly shorter. It is believed that morphological changes may have been induced by the oil treatment.

Cover data collected during the 1986 growing season indicated little oil induced mortality in the creek edge zone, moderate mortality in the high marsh zone and severe mortality in the midmarsh zone. The dispersant treatment caused moderate mortality in the creek edge zone. Data from 1987 indicated little expansion of the Spartina sward in any of the zones. It was difficult to determine the degree of recovery in the creek edge zone since there was a considerable reduction in the cover of control plots between 1986 and 1987. It was impossible to determine whether the factor of factors responsible for the decline of the control cover would also act upon the treated plots. Drought conditions experienced in 1987 may have been responsible for the decline in control cover. Stress induced by the treatments may have been reduced during the 1987 growing season but was replaced by drought stress resulting in the lack of recovery noted in this zone.

Annual halophytes such as Salicornia europaea, Suaeda maritima and Atriplex patula were rather rare in 1986. Oil and dispersant treatments generally resulted in reductions in their abundance during 1986. In 1987, large increases in the cover of these species were noted in the oil and dispersant treated plots. High negative correlation coefficients between the cover of the dominant Spartina species in each zone and the cover of these annual species suggested that these species were rapidly colonizing areas where Spartina had been eliminated. Colonization was rapid in the creek edge zone but was relatively slow in the midmarsh and high marsh zones. In the midmarsh zone poor soil aeration and the physiological problems associated with it may have reduced the rate of colonization while in the high marsh zone the presence of a large standing crop of standing dead shoots may have reduced the rate of colonization of annuals through the shading of shade intolerant seedlings.

Fluorometry data indicated that plant stress levels were similar for control and oil or dispersant treated plots in the creek edge and high marsh zones, suggesting that there was no residual toxicity associated with these treatments in 1987. In the midmarsh zone there appeared to be evidence of some residual oil toxicity in 1987. The fluorescence response of these plants was indicative of damage to the light receptor system.

Leaf anatomy results from 1986 revealed a progressive reduction in the density of chloroplasts in the outer bundle sheath and mesophyll cells in both oil and dispersant treated Spartina alterniflora and S. patens which was accompanied by the development of chlorosis at the macroscopic level. Leaf and stem deformities were also noted for Spartina patens. In 1987, no microscopic or macroscopic differences were found between control and treated plants. These results suggest that there was little residual toxicity associated with the oil or dispersant treated plots in 1987.

This study has demonstrated that sensitivity to crude oil varies considerably among the various plant communities in the salt marsh. The creek edge zone, dominated by tall Spartina alterniflora was quite tolerant of the crude oil treatment. Results from 1986 reveal only small reductions in height, stem density, biomass and cover and by 1987 no evidence of toxic effects were apparant. Similar results have been found in several other studies (Delaune et al, 1979; Webb et al., 1981; Ferrel et al., 1984; and Webb and Alexander, 1985). The short Spartina alterniflora of the mid marsh zones, however, was very susceptable to the oil treatment. In 1986 all parameters investigated were negatively affected by the oil. In 1987 only limited recovery of this zone was noted. The stressful nature of the midmarsh zone predispose it to severe impacts from additional perturbations such as oil toxicity. In addition, the poor drainage of the zone reduces the rate at which the oil is flushed from the sediments or metabolized by microbes further contributing to the persistence of toxic effects in this zone. The impacts reported for the midmarsh zone illustrate the degree to which existing environmental stresses can affect the ability of a species

Flower Density

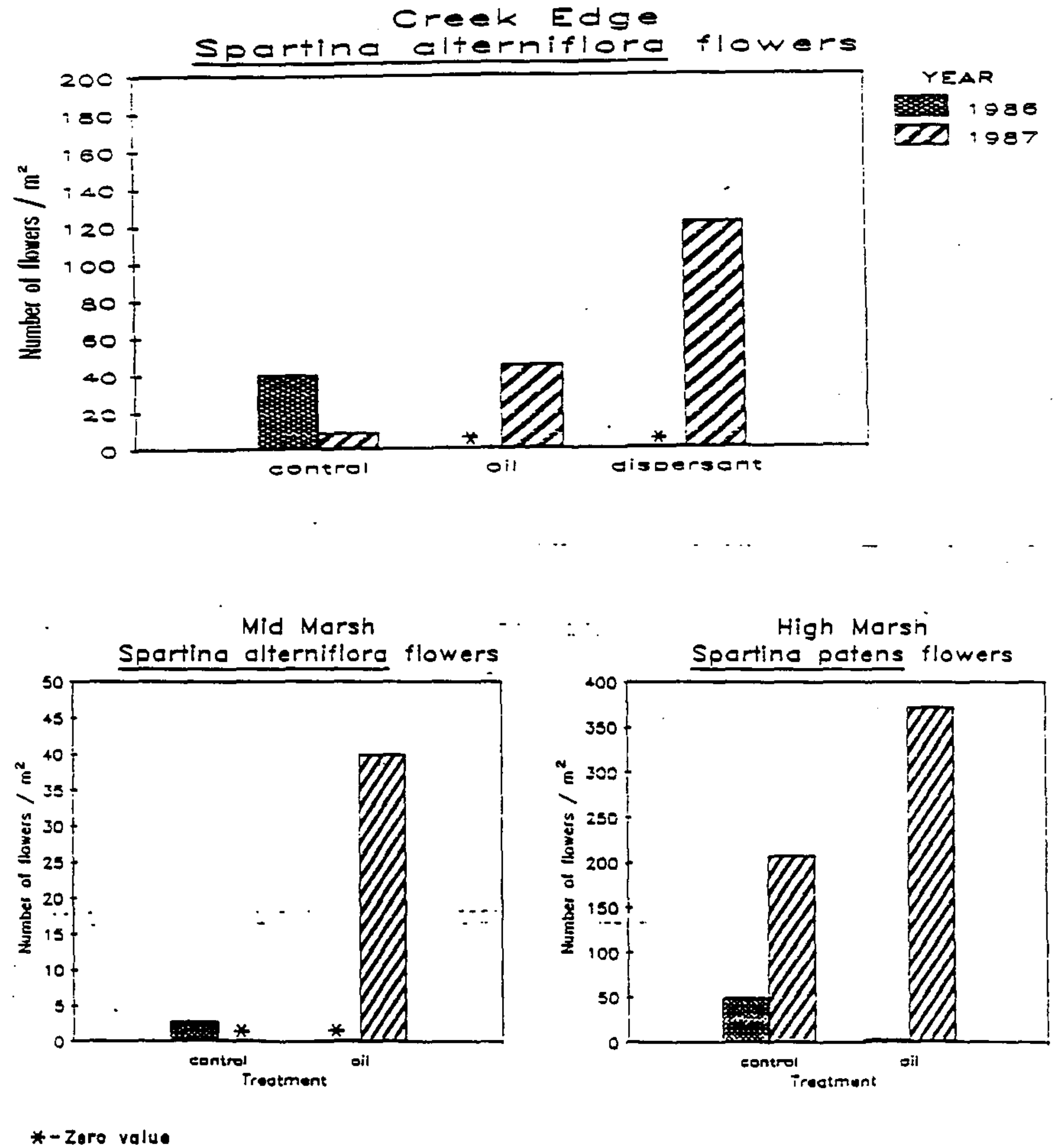


Figure 13: Histograms of mean flowering shoot density in the creek edge, midmarsh and high marsh zones.

Flowering shoot densities were significantly higher in the dispersant treated plots (p=0.004, ANOVA) but not in the oiled plots (Appendix 5). In the midmarsh zone oiled plots had 45 times more flowering shoots than control plots, however, this difference was not significant. Flowering shoot density in the high marsh zone was 1.5 times higher in the oiled plots than in the control plots but was not significantly different from the control plots. In all vegetation zones, oil treatments induced considerable, although not statistically significant, increases in flowering stem density in 1987. Lack of significance was attributable to the low number of replicates and variability of replicates within treatments. Increases in flowering shoot density appeared to be related to reductions in stem densities noted for the oil and dispersants in 1986. Stem density reductions would decrease the degree of intraspecific competition allowing more resources to be channeled into reproductive organs. Similar increases in flowering shoot density have been noted in *Spartina anglica* stands in Britain following cutting or trampling damage (Hubbard, 1970).

Biomass

Total above-ground living biomass data from the creek edge zone (Figure 14), indicated that the oil treatment had no significant effect on total above-ground living biomass in either 1986 or 1987 (Appendix 6). Plots treated with dispersant had significantly less biomass in 1986 (p=0.017, ANOVA) but recovered to control levels by the end of the 1987 growing season. In the midmarsh zone in 1986 (Figure 15), total above-ground living biomass in oiled plots was reduced to 15% of control plot biomass (significant p=0.003, ANOVA). In 1987 oiled plots had recovered to 58% of control biomass values and were not significantly different from the control plots (Appendix 6). Total above-ground living biomass for oiled plots in the high marsh zone (Figure 16) was reduced to 69% of control values in 1986. This reduction was not significant. Total above-ground living biomass in the oiled plots increased in 1987, however, control values also increased so that the relative amount of biomass in the oiled plots remained stable at 69% of control plot values. The variance of both control and oil treated plots declined substantially in 1987 resulting in a significant difference between the treatments (p=0.011, ANOVA).

These data suggest that the oil treatments had little impact on biomass production in the creek edge zone. In the more stressful midmarsh zone the oil treatment had severe impacts in 1986 but appeared to recover rapidly in 1987. Data from the high marsh zone suggests a moderate impact in 1986 but with relatively little recovery in 1987. The creek edge dispersant treatment was responsible for a major reduction in total above-ground

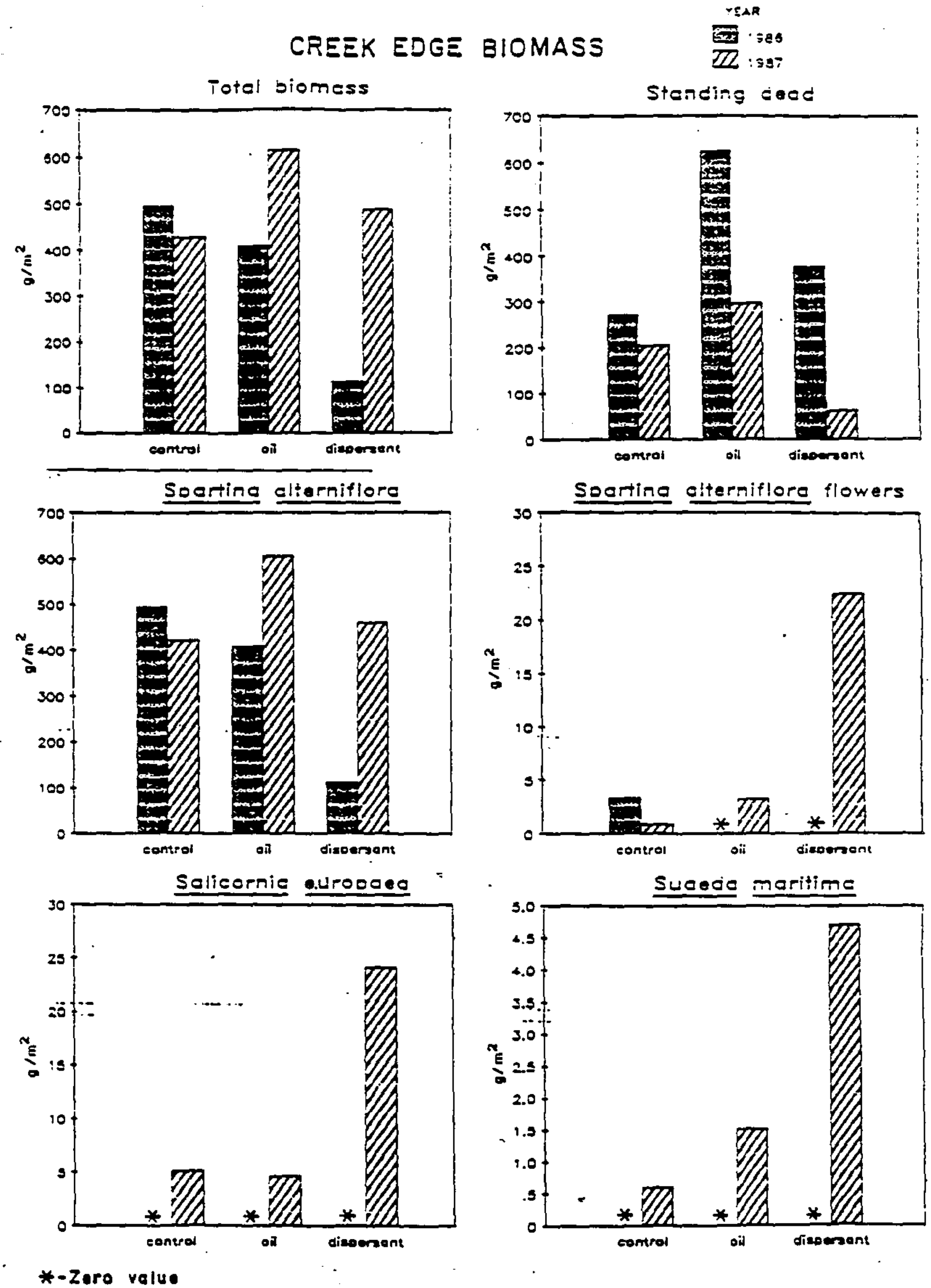


Figure 14: Histograms of mean total above-ground living biomass, standing dead biomass, Spartina alterniflora biomass, Spartina alterniflora flower biomass and Suaeda maritima biomass in the creek edge zone.

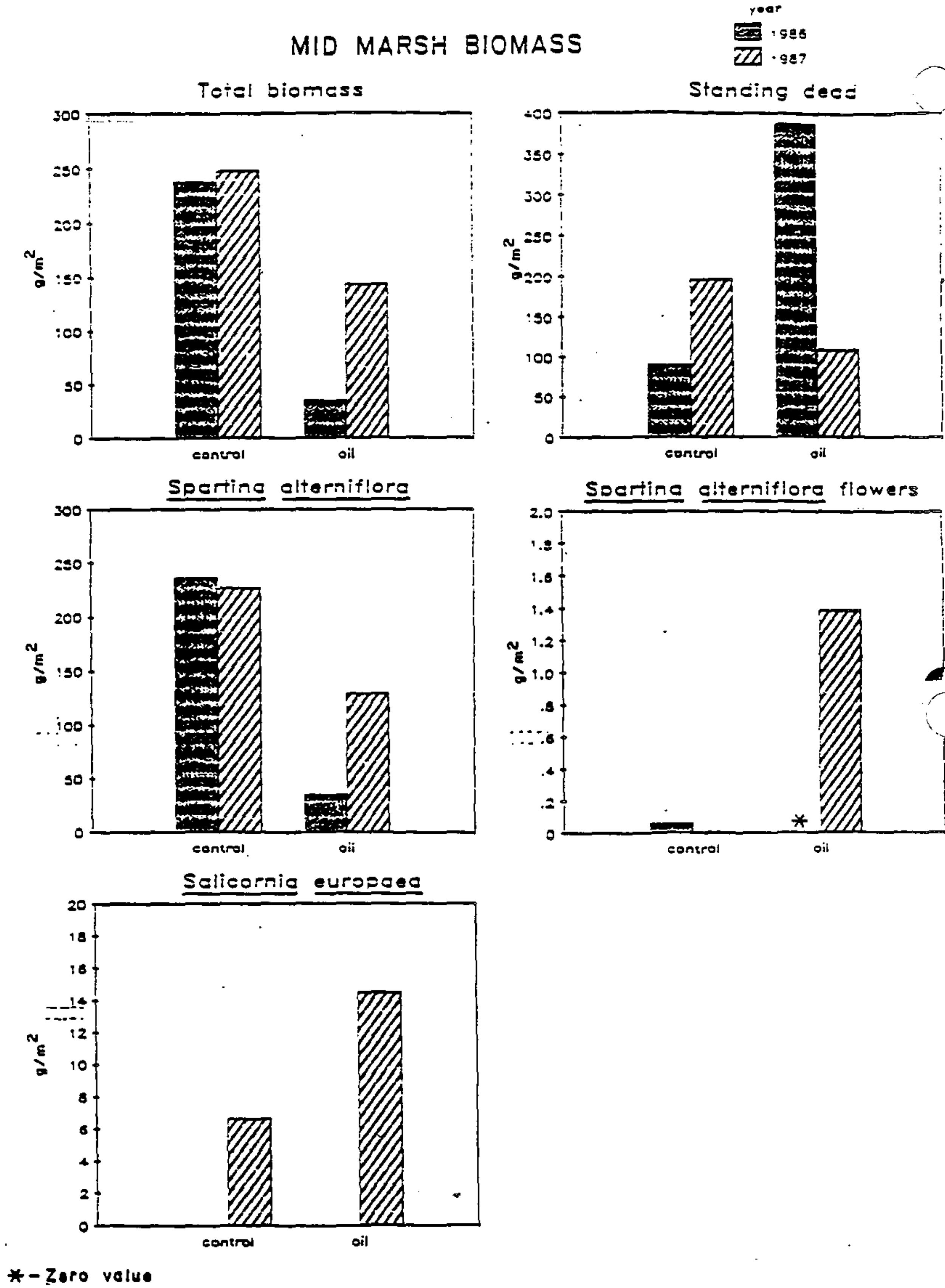


Figure 15: Histograms of mean total above-ground biomass, standing dead biomass, Spartina alterniflora biomass, Spartina alterniflora flower biomass, and Salicornia europaea biomass in the midmarsh zone.

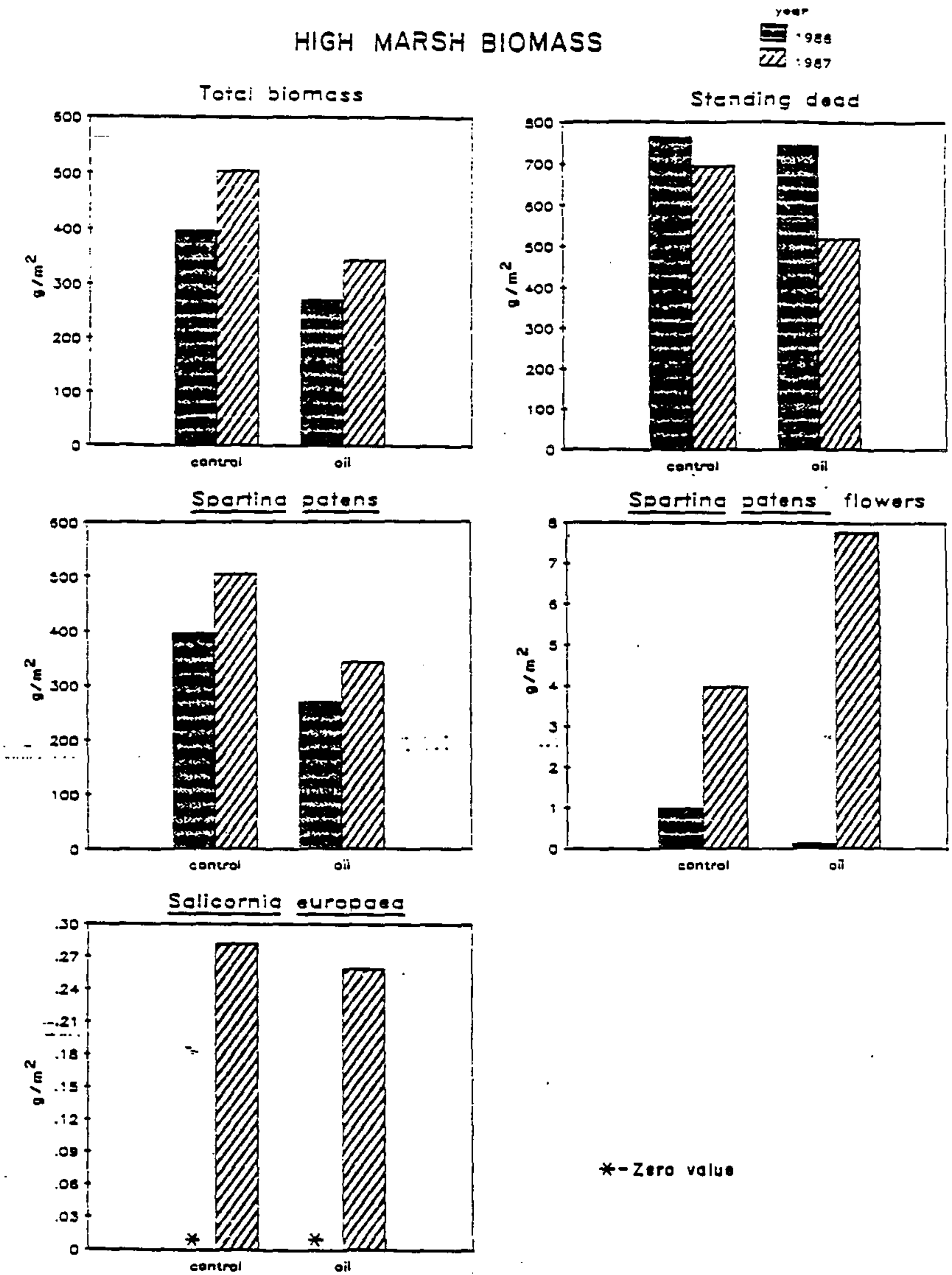


Figure 16: Histograms of mean total above-ground living biomass, standing dead biomass, *Spartina patens* biomass, *Spartina patens* flower biomass and *Salicornia europaea* biomass in the high marsh zone.

living biomass in 1986, however, it recovered rapidly to control levels by the end of the 1987 growing season.

Standing dead biomass in oiled creek edge plots (Figure 14) was 2.3 times higher (significant p=0.022, ANOVA) than that of the control plots in 1986. In 1987 standing dead biomass in the oiled plots was 1.5 times larger than that of the control and no longer significantly different from the controls. Standing dead biomass in dispersant treated plots was 1.4 times higher than control levels in 1986. This difference was not statistically significant. In 1987 the trend was reversed and standing dead biomass for the dispersant treated plots was only 31% of the mean value for control plots. In the midmarsh zone (Figure 15) in 1986, standing dead biomass increased by a factor of 4.2 (significant p=0.009, ANOVA) relative to control values following the application of oil. This large increase was countered by a large but insignificant reduction of standing dead biomass during the 1987 growing season. Standing dead biomass at this time was 56% of control standing dead biomass. In the high marsh zone (Figure 16) mean standing dead biomass in the oil and control plots were almost identical (no significant difference). In 1987 standing dead biomass in the oiled plots declined to 75% of control values. This decline was not significant.

Table 3 presents the proportion of total above-ground biomass (total above-ground living biomass + standing dead biomass) composed of standing dead biomass. Large increases in percent standing dead biomass were noted for the oil and dispersant treatments in the creek edge zone and the oil treatment in the midmarsh zone. This was to be expected since increased plant mortality would increase standing dead biomass. Comparison of standing dead biomass from the various treatments with plant mortality (as indicated by changes in stem density) associated with these treatments indicated that 1986 standing dead biomass values were higher than expected in the oiled plots from the creek edge and midmarsh zones. In the creek edge zone standing dead biomass was roughly equivalent to the combined total above-ground living biomass and standing dead biomass of the control plots yet stem density was reduced only 25% by the oil treatment. Similarly, standing dead biomass in oiled midmarsh plots exceeded the combined total above-ground living biomass and standing dead biomass of the controls although in this instance stem density reductions were more severe (88%). These results suggest that the oil treatment inhibited the decomposition of standing dead biomass. De La Cruz, Hackney and Rajanna (1981), have noted that oil treatments reduced decomposition of Juncus roemerianus standing dead biomass by 52%. In 1987 percent standing dead biomass for the oiled plots in all zones were identical to control values, suggesting that the rates of mortality and decomposition in the oiled plots had returned to control levels. Percent standing dead biomass for the

Table 3. Standing dead biomass (SDB), total above-ground biomass (TAB) and the percentage of total above-ground biomass composed of standing dead biomass (percent SDB) for various treatments in three vegetation zones in 1986 and 1987.

		1986			1987		
Zone	Treatment	SDB(g/m^2)	TAB (g/m^2)	Percent SDB	SDB(g/m^2)	TAB (g/m^2)	Percent SDB
Creek Edge							
	Control	272	769	35.4	206	636	32.4
	Oil	626	1040	60.4	298	913	32.7
	Dispersant	377	492	76.6	64	555	11.5
Mid Marsh							
	Control	92	330	27.8	197	446	44.3
	Oil	388	424	91.6	111	255	43.4
High Marsh							
	Control	765	1160	65.9	696	1200	57.9
	oil	746	1020	73.2	520	864	60.2

dispersant treated creek edge plots was much lower than that of the control plots in 1987. This was to be expected since total aboveground living biomass increased by a factor of 4 between 1986 and 1987. Stem density data for these plots indicated very little mortality during the 1987 growing season, therefore, inputs into the standing dead biomass would have been very low.

Trends for Spartina alterniflora biomass in the creek edge and midmarsh zones and S. patens in the high marsh zone (Figures 14 - 16) were identical to those of total above-ground living biomass in these zones since these species constituted 90 to 100% of the total above-ground living biomass. The reader is, therefore, referred to the text regarding total above-ground living biomass for details regarding the dynamics of these species.

Two annual species, Salicornia europaea and Suaeda maritima were the only other species which occurred regularly during the biomass sampling. Neither species was very common in 1986 in any of the vegetation zones (Figures 14 - 16). In 1987 biomass values for both species increased substantially although not significantly (Appendix 6) in all treatments and in all zones with the exception of the high marsh zone where small increases in Salicornia were noted and Suaeda was absent in both 1986 and 1987.

Salicornia and Suaeda typically colonize areas of bare sediment following disturbance (Ranwell, 1972; Hampson and Moul, 1978; Bertness and Ellison, 1987). In this study, Salicornia and Suaeda plants tended to be more numerous and larger in areas where the Spartina canopy had been opened up by oil or dispersant induced mortality. In control plots these species tended to persist as small scattered individuals.

In the creek edge zone (Figure 14) Salicornia biomass increased by the same amount in the control and oil plots between 1986 and 1987. There was little mortality of Spartina in the oiled creek edge plots, therefore, there was relatively little open space in which Salicornia could become established. In dispersant treated plots, where Spartina mortality was high, Salicornia biomass was 4.7 times higher than in control plots although high variability of the data rendered this difference insignificant. In the midmarsh zone (Figure 15) a substantial increase in Salicornia biomass was noted in both the control and oil treated plots between 1986 and 1987. Salicornia biomass was 2.2 times higher in the oiled plots (high Spartina mortality) than in the control plots, however, this difference was not statistically significant.

Suaeda biomass in the creek edge zone (Figure 14) increased in all treatments in 1987. The largest increase was noted in the dispersant treated plots (7.6 times higher than controls) followed by the oil treated plots (2.5 times higher than controls), however, these differences were not statistically significant.

The relatively large increases in Salicornia and Suaeda biomass noted in the creek edge and midmarsh control plots between 1986 and 1987, were probably related to reductions in Spartina alterniflora biomass in these plots. Reductions of S. alterniflora biomass were probably attributable to a combination of drought conditions in 1987 and sampling disturbance during both years. Salicornia is very tolerant of high salinities (Brereton, 1971). Hypersaline conditions experienced during the very dry 1987 growing season may have reduced Spartina density allowing the more salt tolerant Salicornia to proliferate.

Reproductive biomass varied considerably between 1986 and 1987 (Figures 14 - 16). In the creek edge and midmarsh zones Spartina alterniflora flower biomass in control plots declined in 1987 while in the high marsh zone S. patens flower biomass increased. In the midmarsh and high marsh zones these differences between years were significant (midmarsh $p=0.020$, high marsh $p<0.001$, ANOVA). There are no clear reasons for these declines. Drought conditions during the 1987 growing season may have reduced the incidence of flowering. Within years distinctive trends were noted. In 1986 oil and dispersant treatments caused large reductions in flower biomass in all zones. These reductions, however, were not significant as a result of high variability of the data and the low number of replicates. In 1987, the opposite trend was noted. Increases in flower biomass were noted in treated plots. Increases associated with the oil treatments were not significant as a result of low replicate number and high variability of the data. The dispersant treatment in the creek edge zone was associated with a very large increase in flower biomass which was significant ($p=0.006$, ANOVA). These increases appeared to be related to the intensity of disturbance. Plots in which mortality was high in 1986 and had displayed vigorous recovery in 1987 tended to have the highest flower biomass. Reduction of stem density would decrease intraspecific competition, thereby, increasing the availability of resources required for flowering.

No significant differences in mean plant weight were found between any of the treatments in the creek edge, midmarsh on high marsh zones in either 1986 or 1987 (Appendix 6), however, some general trends were observed in the data. In the creek edge zone mean plant weights for control and oiled plants were similar in both 1986 and 1987 suggesting no short term or long term effects of the oil treatment on plant growth (Figure 17). A reduction in mean plant weight was noted in both the control and oiled plants between 1986 and 1987, possibly as a result of drought conditions during the 1987 growing season. Dispersant treated plants averaged half as heavy as control plants in 1986 indicating a substantial reduction in growth. In 1987 dispersant treated plants were 1.4 times heavier than control plants. Stem density was low and plants were well spaced in the dispersant treated plots. Interspecific competition would have been low in these plots allowing greater growth. These data also suggest that the toxic effects of the dispersant had probably disappeared by 1987. This would be expected since the dispersant is miscible in water and would be easily flushed from the plots.

In the midmarsh zone oiled plants were 1.3 times heavier than control plants in 1986. This was probably caused by selective mortality of short plants. Short plants would have a larger proportion of their surface area covered by the oil and would be expected to suffer higher mortality. In 1987 the oiled plants were 2.0 times larger than the controls. Reductions of stem densities in the plots may have alleviated intraspecific competition allowing greater growth of plants in the oiled plots, however, plant height data indicated that these plants were significantly shorter than controls and fluorometry data indicated some residual oil toxicity. This would indicate that large changes in plant morphology had occurred, specifically that small but robust tillers were produced in response to the oil treatment. Hershner and Lake (1980) also found changes in plant morphology in response to oiling. Contrary to our findings, they observed that oiled plants were generally the same height as control plants but more slender. There was a marked reduction in the mean weight of control plants between 1986 and 1987 as was observed in the creek edge zone. This was probably attributable to drought conditions in 1987.

In the high marsh zone the mean weight of oil treated plants was 1.5 times higher than that of control plants in 1986. This increase was probably caused by selective mortality of small plants in 1986. In 1987 the mean weights of control and oiled plants were similar indicating the oil had little effect on plant growth. Between year differences in the controls were small suggesting that drought conditions had little effect on this species.

MEAN SHOOT WEIGHT

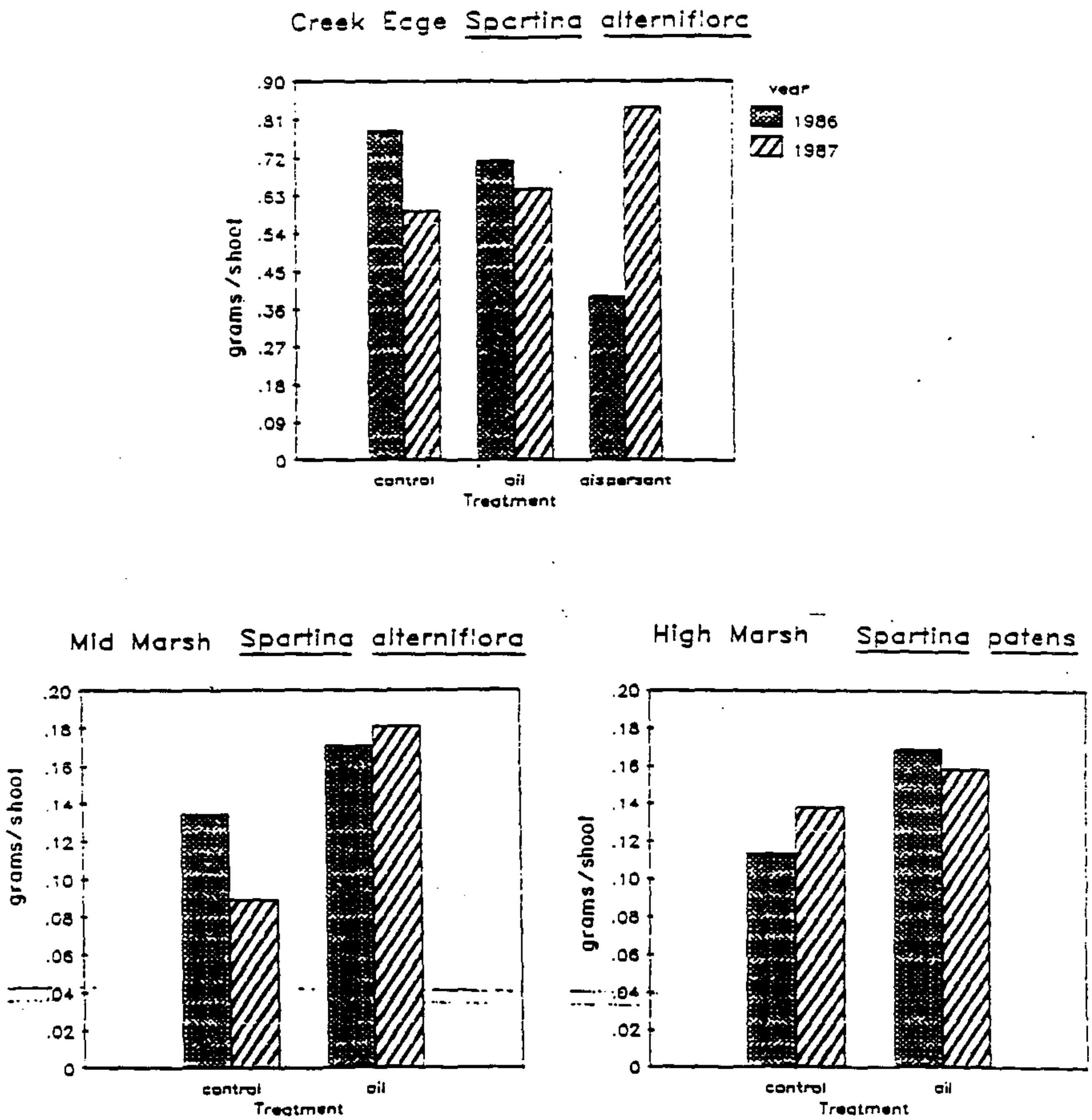


Figure 17: Histograms of mean weight of individual Spartina shoots in the creek edge, midmarsh and high marsh zones.

Species Cover

Spartina alterniflora cover in the creek edge zone was significantly reduced by the oil treatment in 1986 (Figure 18; Appendix 7). In 1987, S. alterniflora cover in the oiled plots was not significantly different from the control values, however, this apparent recovery was attributable more to a reduction in control cover in 1987 than to an increase in the cover of oiled plots in 1987. A similar trend was noted for S. alterniflora cover in dispersant treated plots. Cover reductions were significant throughout the 1986 growing season. Cover values noted during the 1987 growing season were similar to those recorded in 1986, however, on days 70 and 90 these values were not significantly different from the 1987 control values as a result of the reduction of control cover values in 1987. There is no clear reason why control cover declined in 1987. Drought conditions during the 1987 growing season may have contributed to this decline. If drought was a factor affecting the growth of controls, it would also be expected to affect growth in the treated plots. The apparent lack of recovery in these plots may be the result of an overall growth reduction caused by the drought.

In the midmarsh zone in 1986 the oil treatment was associated with significant reductions in the cover of Spartina alterniflora (Figure 19) on days 75 ($p<0.001$, ANOVA) and 102 ($p<0.001$, ANOVA). Mortality tended to occur in patches with areas of complete mortality bordering areas where mortality was very light. During the 1987 growing season no apparent expansion of surviving Spartina patches was noted, nor were new patches established, consequently, the cover noted at the end of the 1987 growing season was similar to that noted at the end of the 1986 growing season. A small increase in stem density was noted during the 1987 growing season (Figure 11). This increase was probably restricted to the interior and periphery of existing patches accounting for the lack of patch expansion noted in the cover data. During the 1987 growing season Spartina alterniflora cover in the oiled plots was significantly lower than in control plots on all sampling dates ($p<0.001$, ANOVA). The large reduction of S. alterniflora cover in the midmarsh zone relative to the creek edge zone was probably attributable to the higher physiological stress levels encountered in the midmarsh zone. S. alterniflora in this zone was unable to tolerate the additional stress associated with the oil treatment.

In the high marsh zone Spartina patens cover in the control and oil treated plots displayed little change between 1986 and 1987 (Figure 20). In 1986, the oil treated plots had significantly higher cover than control plots on day 35 (pretreatment, $p=0.048$, ANOVA), however, within fifteen days of oil application, cover in the oiled plots had declined to 90% of control

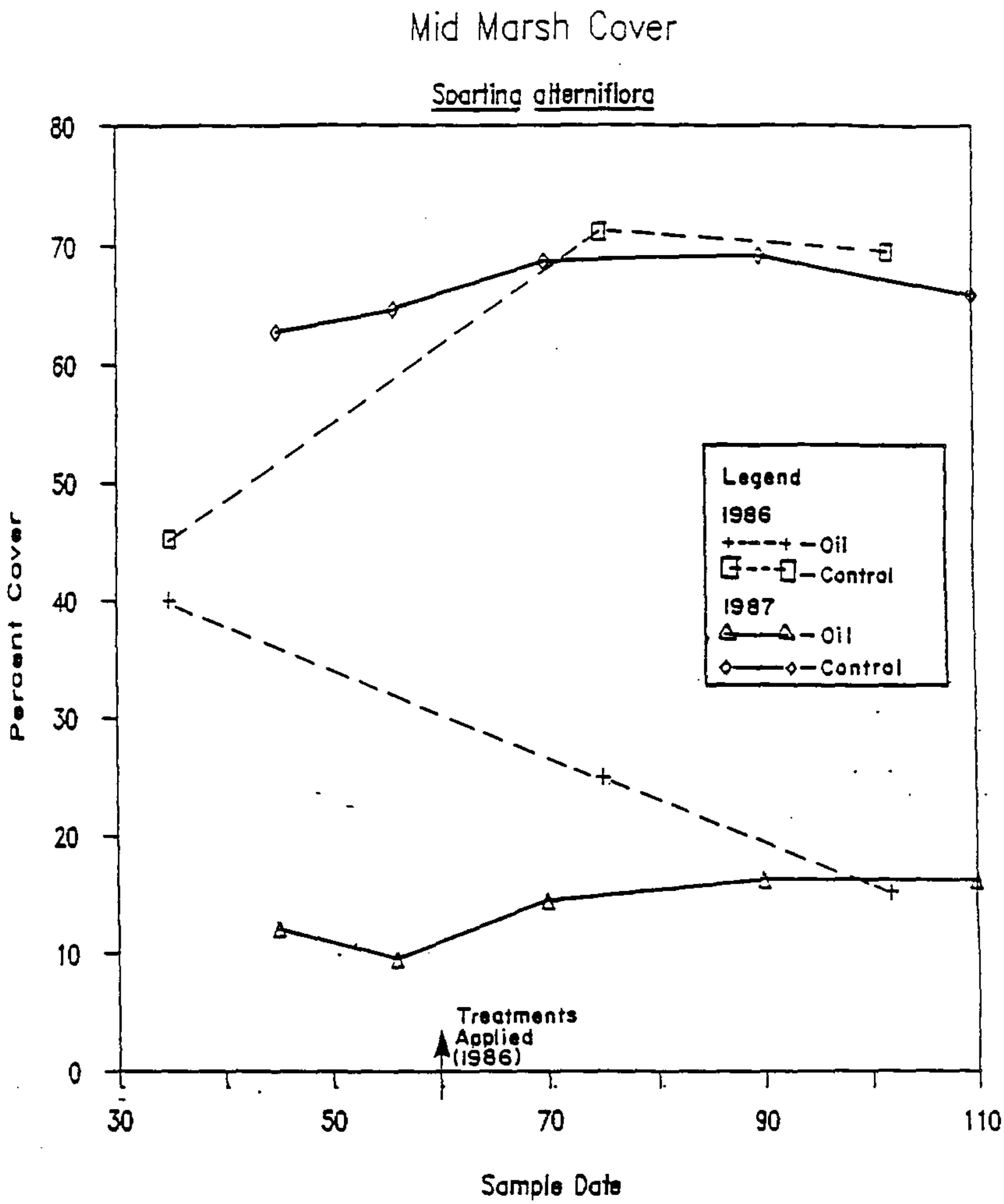


Figure 19: Plot of mean Spartina alterniflora cover in the midmarsh zone versus time.

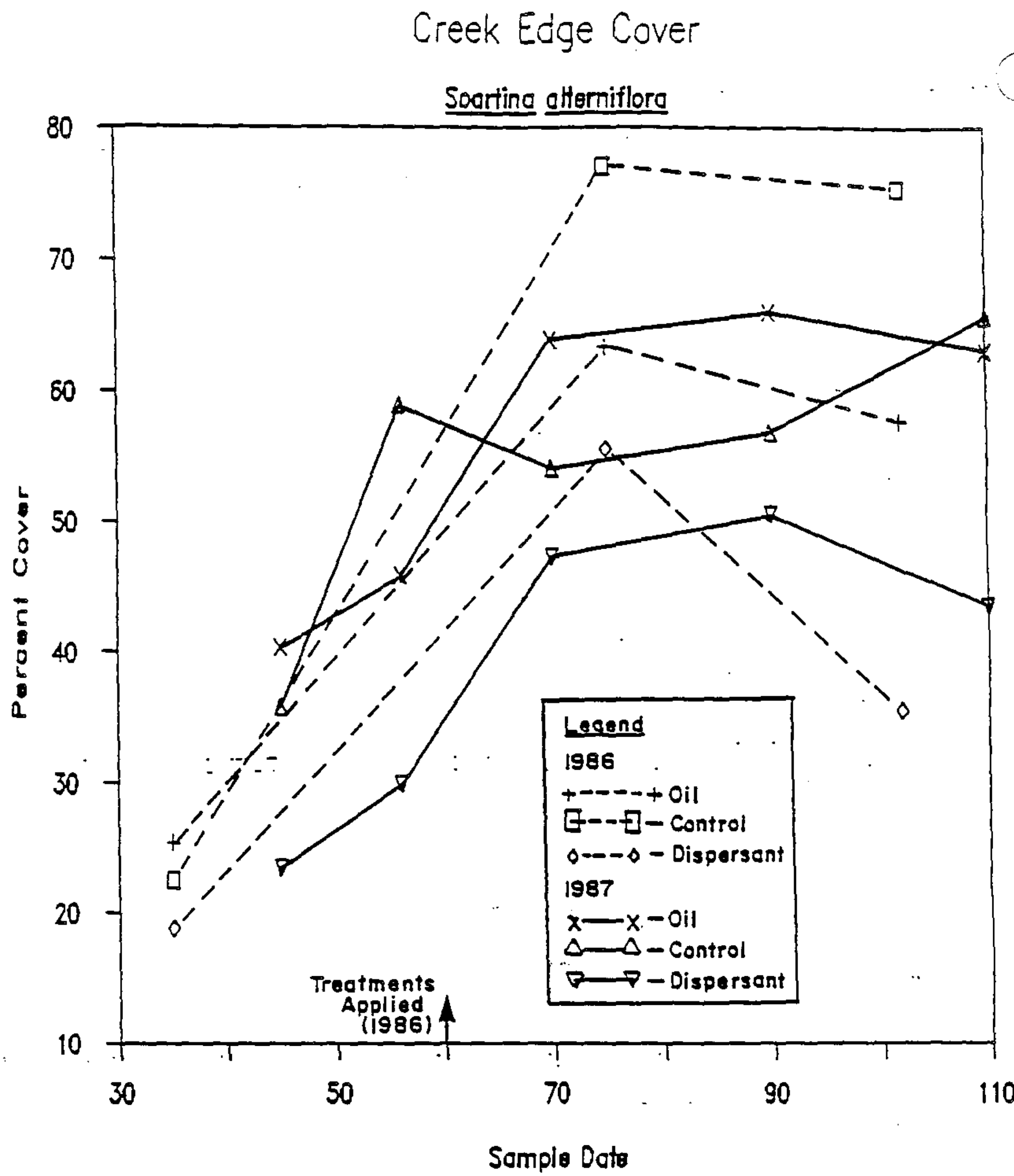


Figure 18: Plots of mean Spartina alterniflora cover in the creek edge zone versus time.

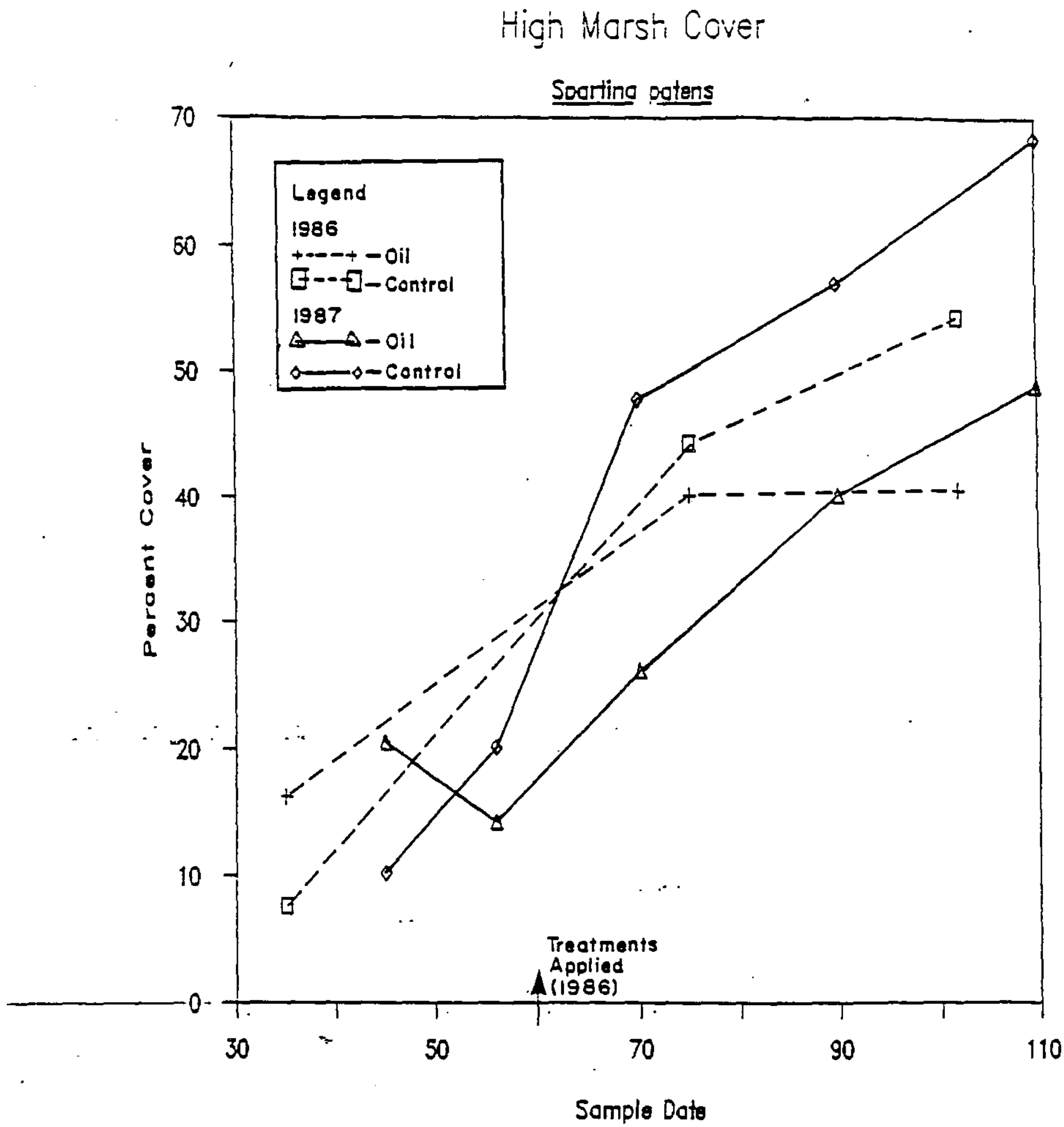


Figure 20: Plot of mean *Spartina patens* cover in the high marsh zone versus time.

values. S. patens cover was significantly lower than control values ($p=0.005$, ANOVA) on day 102. A similar trend was observed in 1987. S. patens cover in the oiled plots was significantly higher than in control plots ($p=0.011$, ANOVA) at the beginning of the growing season. It declined briefly on day 56 but recovered to 1986 oiled plot values by day 90. S. patens cover in oiled plots was significantly lower than in control plots on days 70 ($p=0.001$, ANOVA) and 110 ($p=0.031$, ANOVA).

This evidence suggests that there was no recovery of S. patens in the high marsh oiled plots. Reinvasion of bare patches by S. patens tillers is slow (Bertness and Ellison, 1987) and this species generally has very poor seed set as a result of seed predation by insects (Bertness et al., 1987). S. patens stands also maintain high detritus cover (up to twice the cover of living plants) which can interfere with the recolonization of bare patches by shading of seedlings. Removal of this detritus has been demonstrated to increase stem density by a factor of 4 (Lane et al., 1987). The detritus layer in the oiled plots remained intact throughout 1986 and 1987.

Salicornia europaea and Suaeda maritima were the most common species in the creek edge study plots other than the two Spartina species. Generally, they accounted for less than 10% of the total cover of the plots. During the 1986 growing season these annual species were uncommon in the creek edge zone (Figure 21). In 1986, Salicornia was eliminated by the oil treatment but appeared to be unaffected by the dispersant treatment. Cover values remained low and variable throughout the 1986 growing season, consequently none of these changes were statistically significant. In 1987, Salicornia cover increased in all treatments. Cover in control plots in 1987 was on average twice as high as control cover in 1986. This increase may have been attributable to sampling disturbance at the edges of the plots. It may also have been related to the drought induced reductions in Spartina cover mentioned above. Salicornia is an early successional species which is very tolerant of high salinity (Brereton, 1971). Drought conditions may have increased salinity to a point where it was stressful to Spartina but within the tolerance range of Salicornia. Salicornia cover in the oil and dispersant treated plots displayed similar trends during the 1987 growing season. Cover remained stable between days 45 and 56 after which it began to increase rapidly. In the oiled plots, cover increased until day 90 after which it stabilized. End of season cover was 3.0 times higher than control values. Cover in the oiled plots was significantly higher than controls on days 70 ($p=0.044$, ANOVA) and 90 ($p=0.023$, ANOVA). In the dispersant treated plots, Salicornia cover increased until the end of the sampling period. End of season cover in the dispersant treated plots was 9.5 times higher than control plots and 3.2 times higher than oil treated plots. Cover in dispersant treated plots was significantly higher

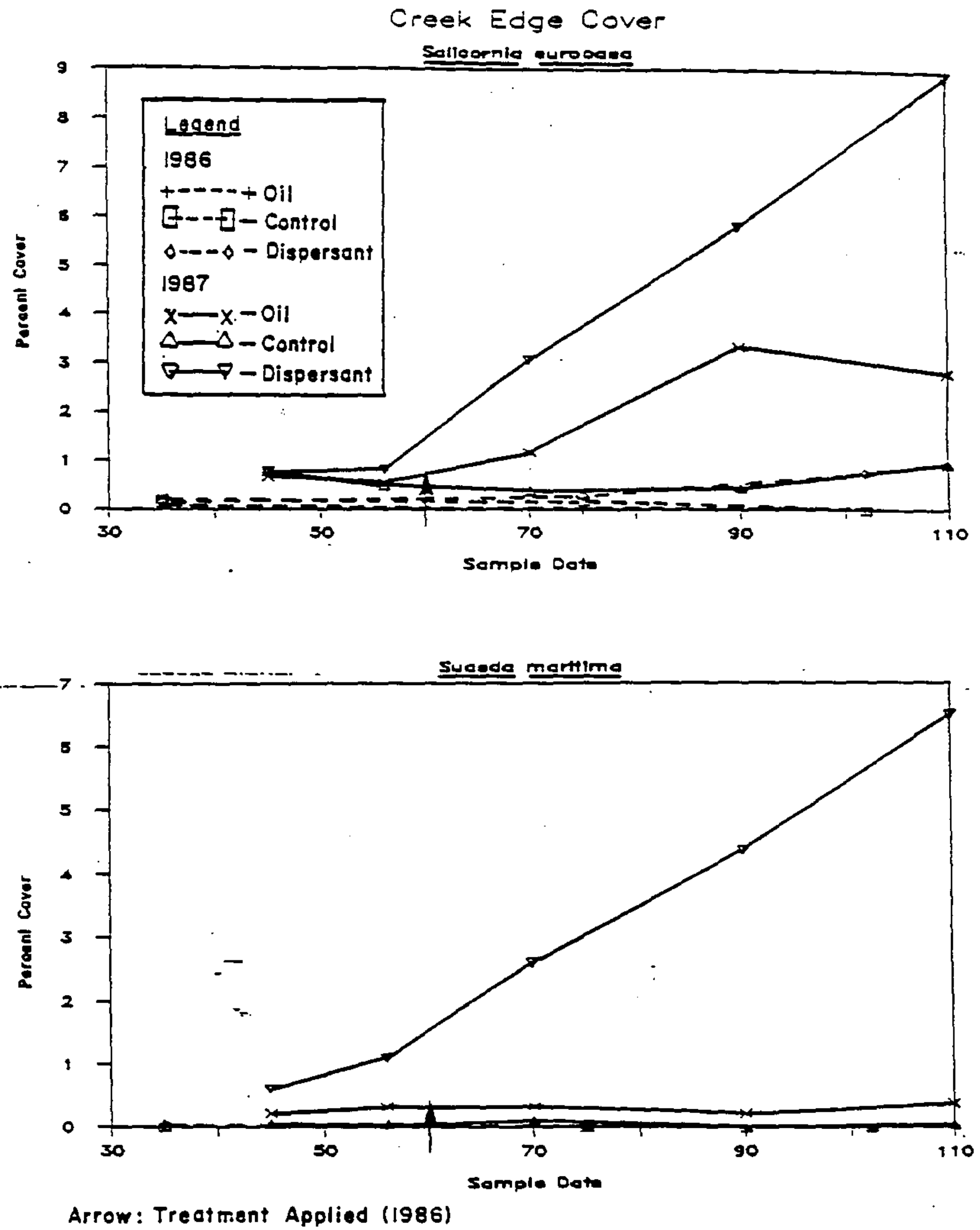


Figure 21: Plots of mean Salicornia europaea and Suaeda maritima cover in the creek edge zone versus time.

than in control plots on days 70 ($p<0.001$, ANOVA), 90 ($p<0.001$, ANOVA) and 110 ($p<0.001$, ANOVA).

The abundance of Salicornia was inversely related to the cover of Spartina alterniflora. A correlation coefficient of -0.815 was noted between the square root of Spartina alterniflora cover and the square root of Salicornia cover. Salicornia normally grows on open mudflats or in areas where stranded debris has eliminated the dominant vegetation (Bertness and Ellison, 1987). Mortality of Spartina shoots associated with the oil and dispersant treatments would open up the canopy enough to allow the establishment and maximum growth of this species. There was a curvilinear relationship between the cover of Salicornia and S. alterniflora cover. Salicornia cover was affected relatively little by reduction of S. alterniflora cover to a minimum of 50%. Below 50% cover, Salicornia cover increased rapidly.

Salicornia cover in the midmarsh zone did not respond to destruction of the Spartina alterniflora sward as vigorously as noted in the creek edge zone (Figure 22). Spartina cover in the midmarsh zone was reduced to 22% of control values by the oil treatment while the dispersant treatment in the creek edge zone reduced Spartina cover to 47% of control values, yet Salicornia cover was similar in both treatments. The strong negative correlation of Spartina cover and Salicornia cover noted in the creek edge zone was not noted in the midmarsh zone ($r=-0.656$). High physiological stress associated with the midmarsh zone accompanied by residual oil toxicity, may have contributed to the relatively poor growth of Salicornia in the midmarsh zone. This is confirmed by Brereton (1971) who found that Salicornia grew poorly in soils with low redox potential. A relatively large increase in Salicornia cover was noted in the control plots. The seasonal trend for Salicornia cover in the control plots was similar to that of the oiled plots but averaged 65% as high. This prevented the increase in cover in the oiled plots in 1987 from being statistically significant (Appendix 7). Increased Salicornia cover in the control plots was attributable to sampling disturbance which permitted the establishment of Salicornia along the edges of the plot and/or drought conditions which reduced the cover of the Spartina sward.

Salicornia cover in the high marsh zone demonstrated little yearly variation in the control plots (Figure 23). In the oiled plots the seasonal trend for Salicornia cover in 1986, was very similar to that of the control plots suggesting little oil induced mortality. In 1987, an increase in Salicornia cover was noted in the oiled plots. Salicornia cover was significantly higher in the oiled plots than in the control plots on all sampling dates ($p = 0.01$, ANOVA) except day 56. This is somewhat

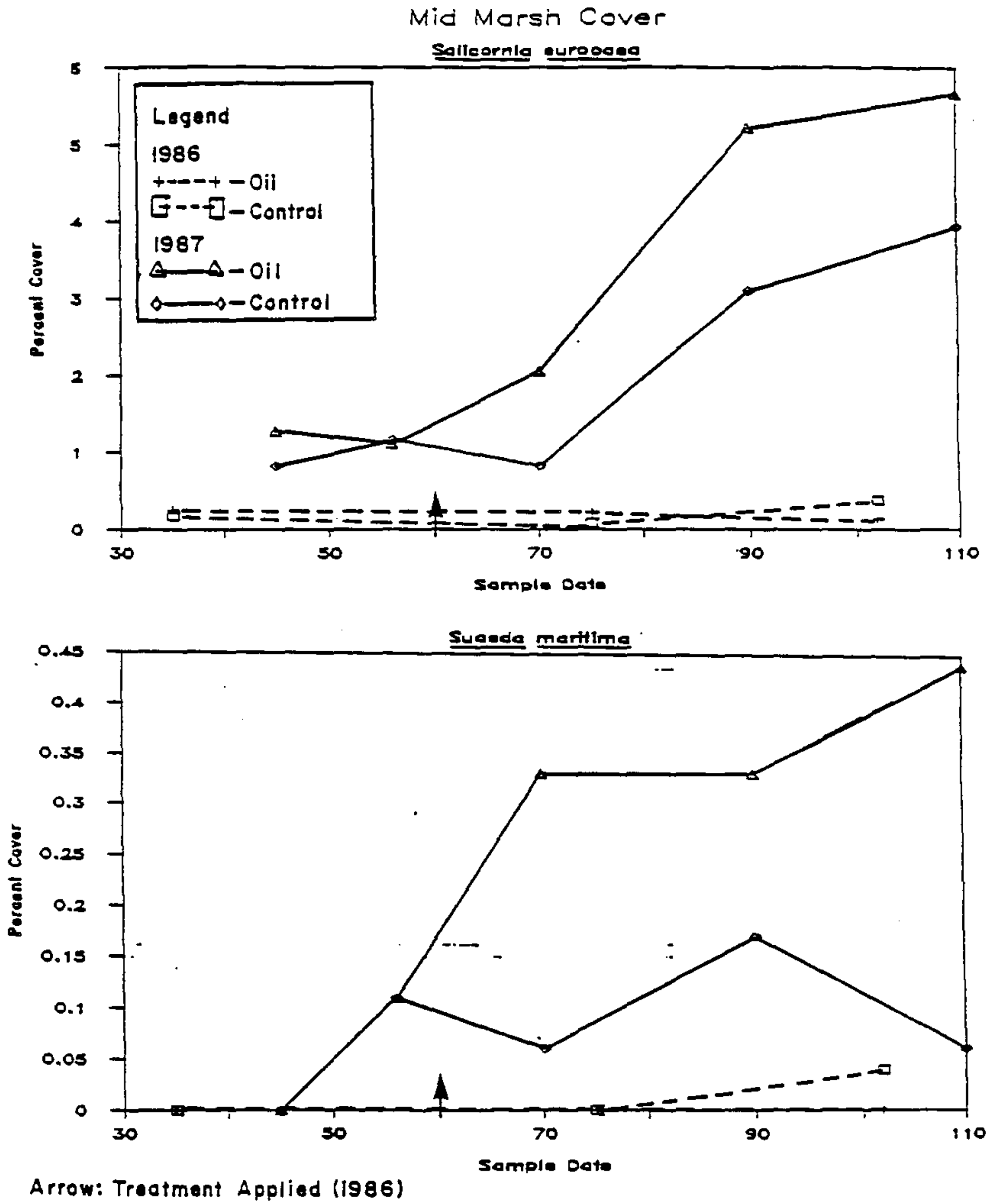


Figure 22: Plots of mean Salicornia europaea and Suaeda maritima cover in the mid marsh zone versus time.

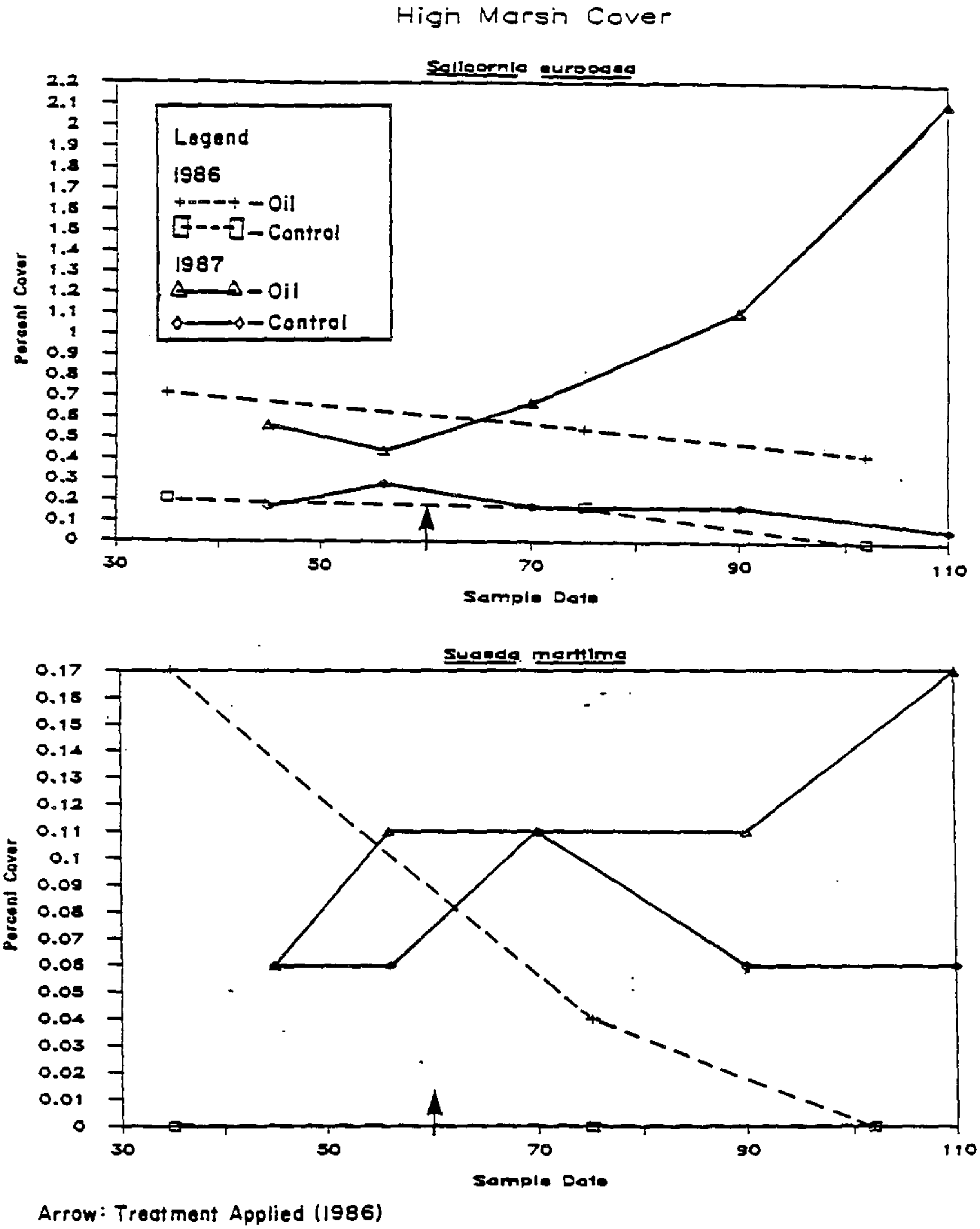


Figure 23: Plots of mean Salicornia europaea and Suaeda maritima cover in the high marsh zone versus time.

or community to cope with pollutants.

The high marsh zone was intermediate in its response to the oil treatments. Most parameters demonstrated significant impacts in 1986, however, these impacts were not as catastrophic as observed in the midmarsh zone. Relatively little recovery was noted in the various parameters in 1987. This lack of recovery may be at least partially the result of the slow vegetative colonization of open patches and poor seed set which are normally associated with this species.

Exposure of the creek edge zone to the disperant resulted in considerably more damage than the crude oil. The toxic effects, however, were short lived and most parameters investigated in this study had returned to normal or were rapidly recovering one year after the disperant was applied. These results indicate that Corexit 9527 should not be used in close proximity to salt marshes.

All three vegetation zones demonstrated similar successional trends after exposure to crude oil . Annual species of Chenopodiaceae invaded the treated plots two years after oiling. Salicornia europaea and Suaeda maritima were the most important species. Their abundance was inversely correlated with Spartina cover. We anticipate that the cover of these species will probably increase for two years following treatment, then decline as Spartina develops a dense sward. Based on current rates of recovery, the creek edge zone recovered from oiling within one year of treatment and will probably recover from the dispersant treatment within two years. The high marsh zone will probably require three to four years for full recovery, while the mid marsh zone will probably require at least five years.

The results suggest that lightly oiled marshes can recover relatively quickly. Natural cleaning may be ecologically preferred if oil contamination is low and/or when the oil enters only the creek edge zone. The use of relatively non-destructive clean up techniques such as low pressure flushing of the marsh surfaces may be justifiable if substantial portions of the midmarsh zone were oiled, provided trampling damage associated with the clean up technique was minimal. Oil induced damage to the high marsh zone, although significant, probably does not warrant the implementation of clean up techniques. The productivity of this zone was significantly reduced by exposure to the crude oil, however, the community structure of this zone remained intact and productivity can probably be expected to return to normal in a few years.

APPENDIX I: PRINCIPLES OF FLUORESCENCE INDUCTION MEASUREMENTS

Light absorbed by the chloropyll-a reaction center of photosystem II (the oxygen evolving part of the photosynthetic system) excites ground state electrons in the chlorophyll molecule. An excited electron very quickly (within ca 10^{-10} milliseconds) loses some of its excitation energy, which is dissipated as heat. This less excited, lower energy state may then jump to a primary electron acceptor, or it may return to its ground state. When it does the latter, its energy is dissipated as fluorescent light reemitted from the molecule, or as heat. If the electron is passed to the primary electron acceptor, the lost electron is replaced by an electron taken from water (with concommittant release of free oxygen). The primary electron acceptor in the meantime loses the electron to an electron carrier which loses it to another carrier and so on through photosystem I, until finally an electron is passed to NADP. The electron carrying-NADP then moves out of the internal membranes of the choroplast where the chlorophyll and carriers are located, into the stroma where it participates in the reactions which convert carbon dioxide to sugar.

Because some of the excited electron energy is always lost as heat, and because there is an inverse relationship between the wavelength of light and its energy, the wavelength of light reemitted as fluorescence is longer than that of the light that was absorbed. The fluorescence wavelength is characteristic of the molecule; for chlorophyll-a under physiological conditions, there is a main band maximum at 685 nm. To measure fluorescence, the sample is subjected to light of lower light intensities, and light emission at 685 nm is monitored.

What is termed "variable fluorescence" can be thought of as an overflow phenomenon; when there is more light absorbed than can be immediately processed via the chemical route, part or most of the excited electron energy is dissipated as fluorescence.

When the plant is first exposed to light, the initial electron acceptor and the downstream carriers are empty handed and can readily receive electrons from chlorophyll. As they become saturated with electrons, their ability to process more electrons decreases, the chlorophyll reaction center cannot pass on its excited electrons, the excited electrons drop back to their unexcited ground state and fluorescence rises. It reaches a peak value within about 3 seconds of the light being turned on. During this period, the rest of the electron carrier system and the Calvin cycle become activated and begin to accept electrons from the upstream carriers and the primary electron acceptor. More electrons can be processed, therefore,